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Soil Mapping and Advisory Services

Botswana

LAND EVALUATION FOR IRRIGATION - A CASE STUDY : THE MAUNATLALA AREA

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Land evaluation for irrigation; a case study : the Maunatlala area

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The conclusions given in this report are those considered appropriate at the time of its preparation.
They may be modified in the light of further knowledge gained at subsequent stages of this project.

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1 INTRODUCTION

In the harsh semi-arid climate of Botswana, where rainfall is erratic and highly variable in time, irrigation can be an effective way to assure reliable crop production, provided it is economically viable.

At present approximately only 2 000 ha of land in Botswana are irrigated. Plans to extend this area to between 20 000 ha and 30 000 ha in the near future should have a large impact on self-sufficiency for grain crops and vegetables. However, irrigation entails high inputs in terms of infrastructure, management and technical expertise and it is important that irrigation is applied to the land with the most productive potential, so as to maximise the return on investments.

An objective estimation of the physical capability of lands for irrigation is important as a basis for subsequent economic analysis and development of marketing policy.

This report describes the physical land evaluation for sprinkler and centre pivot irrigation in the Maunatlala area which was carried out at the request of the Government of Botswana. Section 2 gives a general description of the considered area. In Section 3, the main occurring soil units, based on a semi-detailed 1/50 000 soil survey, executed during late 1988, are described. Section 4 explains the methodology used to evaluate land suitability for irrigation and presents the results of the evaluation in terms of crop specific land indices, indicating the physical suitability of a tract of land for the irrigation systems considered. Through a comparison of the land indices of different land units the most suitable land can be selected for either a centre pivot or sprinkler based irrigation scheme.

The paper should be considered as a first example of quantitative land evaluation for irrigation in Botswana and may serve as a guideline for similar investigations in the future. Evaluation of land suitability should be an essential prerequisite to any future irrigation development in Botswana.

2 GENERAL DESCRIPTION OF THE AREA

2.1 Location, Population and Infrastructure

Maunatlala village is located at about 50km east of Palapye, between the Tswapong Hills in the south and Lotsane River in the north. The survey area is within the coordinates 22°31' - 22°37' south and 27°34' - 27°46' east. (see map). The total surveyed area astride the Lotsane River is 125 km^2, or 12 500 hectares.

Maunatlala had a population of 1470 according to the 1981 population census. However according to the 1987 de-facto population projections report by the Ministry of Finance and Development Planning, the population in 1986 should have been around 2101 and in 1991 it is expected to be around 2847. This trend shows that at present (1989), the population of Maunatlala village could be around 2500.

The village has most of the necessary amenities for its size. There are two relatively bigger shops and two smaller ones, normally referred to as small general dealers. There is also another shop owned by the Cooperative Society of the village. These shops stock everything including hardware, clothing and groceries. There is also a bar, a bottle store and a butchery. As for education facilities, a primary and a community junior secondary school are available. In addition, there is a clinic with maternity facilities, a post office with solar powered automatic telephone system, tribal administration offices and sub landboard office. A community hall is also available as a meeting or conference and entertainment facility.

The village is connected to Palapye via Kgagodi and Tamasane by a good gravel road which joins the Palapye - Francistown road at Dikabeya, about 20 km north of Palapye. As the village access road is winding, the Palapye - Maunatlala distance is 90 km as compared to a distance of 50 km as the crow flies.

2.2 Climate

The climate of Maunatlala is semi arid with winter drought. The mean annual rainfall is 396 mm which is about 69mm less than in the Mahalapye area. The potential evapotranspiration, as elsewhere in Botswana, far exceeds precipitation in all the months of the year. The nearest synoptic station to Maunatlala is Mahalapye which has a rainy season between November and mid March.

Maunatlala village is located within the agro-climatic zone 3b4 (Dambe, 1987). This means that in 75 - 100 % of years, the length of the growing season will be 61-80 days. There will also be 11-20 dry days within the seasons. The growing period is the period when the amount of precipitation exceeds half the value of potential evapotranspiration. Dry days are those during the growing season when no soil moisture is available and rainfall is less than half the potential evapotranspiration. The humid period is that when precipitation exceeds full potential evapotranspiration. There are 20 - 40 days of humid period with less than 25% chances of occurrence in this area.

The soil moisture regime is aridic to ustic. The aridic regime occurs mainly on watershedding landform positions whereas the ustic occurs on water receiving positions.

Temperature values of this area can be inferred from those obtained for Mahalapye synoptic station which lies about 100 km to the south west, of (Table 1).

Temperature changes occur rapidly and frequently during all seasons resulting in considerable deviations from the mean temperature (Remmelzwaal, 1989) Absolute maximum recorded at Mahalapye is 41°C and minimum is -6°C.

Table 1

Summary of climatic data for Mahalapye

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
P mean (mm)	89	81	67	25	10	3	2	3	8	30	68	79	465
Variability P (%)	75	87	81	-	-	-	-	-	-	-	65	73	35
T mean (°C)	25.0	25.1	22.6	19.9	16.3	13.5	13.1	16.1	20.9	22.7	24.2	24.8	20.3
T mean max (°C)	30.9	30.9	28.6	26.5	24.4	22.1	22.3	25.1	29.2	29.8	30.4	30.6	27.5
T mean min (°C)	19.1	19.2	16.6	13.2	8.1	4.9	3.9	7.1	12.6	15.6	18.0	19.0	13.1
Relative humidity mean (%)	52.5	59.0	61.0	54.0	48.5	53.0	43.5	43.0	40.0	45.0	53.5	52.0	50.5
wind speed (m/s)	1.5	1.3	1.2	1.1	0.9	1.1	1.0	1.3	1.6	1.9	1.6	1.6	1.3
PET 1/ (mm)	142	120	112	83	61	44	48	76	113	137	138	153	1227
PET 2/ (mm)	173	147	138	109	88	69	78	104	137	161	163	183	1550

1/ Pike, 1971

2/ SMEC, 1987

2.3 Geology

The survey area comprises of predominantly granitoid rocks of Precambrian and Archean age mostly to the east and north of Maunatlala village. The village itself sits on brecciated, pink, felsic quartz monzonite with associated epidote or chlorite veins. A zone of undifferentiated grey gneiss extends from about 15km south east of Maunatlala and narrows northwards across the Koba river between two major zones of foliated adamellite.

The Palapye group lies south of the village as the arenaceous Tswapong formation and westwards as the argillaceous Lotsane formation. The Tswapong hills belong to the former and are composed of massive, medium to coarse grained, purple to red, ferruginous quartzites with pisolitic haematite quartzites near the base. The lithology of the Lotsane formation is purple to red flagstones, siltstone and sandy shales.

The most impressive Quaternary to recent deposits are the sand hills north west of Maunatlala. These sand deposits are more than ten meters deep and are probably derived from weathered Palapye group outliers. Other deposits are alluvial sandy soils around the bases of the scarps of the Palapye group hills. Small deposits of gravel and coarse sand are found in the Lotsane river.

The survey area is poorly supplied with perennial surface water. However there are numerous springs from the Palapye Group hills, some of which used to be the main sources of water for some villages in the vicinity of Maunatlala such as Mokoakoane which is about six kilometers to the south. The groundwater in the area is exploited either by wells or boreholes.

2.4 Geomorphology

The survey area comprises three main geomorphological units namely the hilly landscape of the Tswapong hills, the granitoid rocks, pediments and peneplains as well as the fluvial system of the Lotsane river and its tributaries.

The summit levels of the Tswapong hills are regarded as outliers of the African or early Tertiary cycle. Evidence of an earlier cycle is given by the elevated metamorphic rock outcrop on the scarp slopes of the Palapye Group hills and by the constant height of the granitoid kopjes.

The featureless plain which extends east and north of Maunatlala is part of the extensive Late Tertiary peneplain of eastern Botswana. Much of this plain is almost flat to gently undulating. A polycyclic Quaternary phase is confined to the watercourses such as the Lotsane river and its tributaries.

The Lotsane river has deeply incised the plain with a result that it rarely overflows its banks. Consequently, it has a narrow floodplain or none at all. Furthermore, such a limited floodplain is subjected to severe gully erosion perpetuated by the steep break in slope between the plain and the erosion base level (river-bed).

2.5 Vegetation

The vast featureless plain which occurs particularly to the east of the village is characterized by normal to dense savanna vegetation structure. The dominant species is *Colophospermum mopane* with *Acacia nigrescens*, *Combretum apiculatum*, *Sclerocarya caffra*, *Lonchocarpus capassa* and *Terminalia sericea* as associates. On relatively shallow areas, *Combretum apiculatum* tends to dominate. *Terminalia sericea* dominates on slightly acid sandy spots.

West of the village across the Lotsane River is a dissected plain with shallow soils (Regosols) and frequent rock outcrops. The dominant species in this area are *Colosphospermum mopane* and *Combretum apiculatum*. *Terminalia prunoides* is predominent close to the river on shallow soils over calcrete. The sandy ridge, north west of the village has dense savanna vegetation structure with *Terminalia sericea* as the dominant species. *Dichrostachys cinerea* and *Combretum apiculatum* are prevalent on the slopes of this ridge.

The occurrence of some of the more poisonous plants like *Dichapetalum cynosum* (mogau) has been reported especially on the sand ridge, north west of the village. Some precautions have been taken to protect animals against this plant by fencing in part of the ridge where it occurs most.

The third major vegetation zone of this area is the riverine woodland along the Lotsane river and its tributaries. The main species in this unit are *Acacia Karoo*, *Ziziphus mucronata*, and *Diospyros lycioides*. *Dichrostachys cineria* and *Acacia tortilis* also occur along the watercourses as well as in disturbed areas such as villages, cattle posts, watering points and fields.

2.6 Land Use

The tribal or communal tenure system is practised in the survey area. Land is essentially used for pastoral and arable farming. Tribal or communal areas are those owned by the community on which no individual has exclusive control on their use.
The major land use types of this area are the tribal traditional dryland farming and communal grazing. Major crops grown are sorghum, maize, melons and beans. The reliability of yields depends very much on the rainfall distribution within the growing season.

3 SOILS

This chapter gives a short description of the survey and laboratory methods as well as a systematic description of the soils, their classification and the soil units presented on the map.

3.1 Methods

3.1.1 Soil Survey Methods

Prior to field work, a physiographic aerial photo interpretation was carried out on the following black and white photographs;

Motloutse Block	Mot B
Contract	1/81
Photo Numbers	143 - 147
Scale	1; 50 000
Date	22nd July 1982

Different units were delineated on the basis of their topography and vegetation reflectance patterns. These units were then checked in the field by digging and describing some soil profiles on representative sites. Further checks were done by short stop augerings to confirm, eliminate and/or establish some boundaries.

The siting of profiles was done with the help of the aerial photographs. These sites were then transferred to the corresponding topographic map sheet number 2227 D, from which their grid reference, geographic locations and elevations were read.

The soil profiles were described following the "Botswana Soil Database Guidelines for Soil Profile Description" (Remmelzwaal and Van Waveren, 1988). This system is based on the FAO Guidelines for Soil Profile Description (FAO, 1977) with some amendments to suit Botswana conditions. Recordings at the Soil profile site are done in a coded soil profile format. These codes are then entered into the computer after field work.

Soil colours are described with the help of Munsell soil colour charts (Munsell Color Co., 1975).

In each profile, soil samples were taken from the most representative part of the horizon, that is, the middle 20cm or the whole horizon if it is thinner than 20cm. In very thick horizons however, it is necessary to take more than one sample per horizon to avoid missing some important diagnostic depths for soil classification purposes.

3.1.2 Soils Laboratory Methods

Reference is made to the report "Soil Testing Procedures for Soil Survey" (Breitbart, 1988) for the details in Soil analysis procedures.

The following is a list of soil chemical determinations and calculations done by the soil survey laboratory at Sebele, 10km north of Gaborone.

- Soil Reaction (pH determination)
- Electrical conductivity in saline and/or alkaline soils
- Cation exchange capacity and exchangeable cations
  CEC of clay, base saturation percentage, exchangeable sodium percentage (ESP).
- Organic matter
- Phosphorus
- Particle size
- Calculated parameters

All the above determinations were done in all the soil samples from the survey area and the results are given in Appendix 1.

3.2 Soil Classification

Soils of this area, as elsewhere in Botswana are classified according to the legend of the Soil Map of the World (FAO/Unesco, 1974). The soil Taxonomy (Soil Survey Staff, 1987 and 1975) is used as a second classification system. Some correlation with the revised legend of the soil map of the world (FAO/UNESCO/ISRIC, 1988) is also undertaken.

A full description of the soils of Botswana and correlation between the above mentioned systems is available in the General Soil Legend of Botswana (Remmelzwaal, 1988). In this legend, some new soil units and modifications of the FAO system have been introduced. Modifications which have an effect on the soils classification of this area will be discussed below.

3.2.1 Diagnostic Horizons

Ochric Horizon

The concept of "weak and very weak horizons" is never applied.

Argillic Horizon

Difficulties with the recognition of argillic horizons are usually related to the lack of clear evidence of clay translocation such as occurrence of cutans or clay bridges in weakly structured or coarse textured soils. Recognition is therefore entirely based on the measured clay increase.

3.2.2 Diagnostic Properties

Ferralic and Ferric Properties

For classification purposes in Botswana, the calculated CEC clay is corrected for organic carbon (400 meq per 100g C). In sandy soils the corrected CEC clay values are usually too high due to the low clay percentages and are therefore not used as a diagnostic property. The CEC of 4 meq/100g of soil is instead adopted as the boundary for ferralic properties. The petroferric horizon is considered as an advanced stage of nodular development and therefore, soils having a petroferric horizon are classified ferric, if applicable.

3.2.3 Phases

The petric phase originally implied layers consisting of 40% or more of oxidic concretions or hardened plinthic nodules, but this phase is also applied when other coarse fragments, including weathered and fragmented rock of at least 25cm diameter occur within 100cm of the surface. If such a layer occurs within 50cm of the surface, it is indicated as a shallow petric phase.

The petroferric phase marks soils in which the upper part of the petroferric horizon occurs within 100cm of the surface, it is indicated as a shallow petroferric phase if the petroferric horizon occurs within 50cm.

3.3 Soil Legend

3.3.1 Main Units

The first entry into the Botswana soil legend is the material from which the soil is formed, the parent material, followed by the soil unit in which the soil depth, drainage, soil colour and soil texture are described.

The key to the main units reads as follows:

A - Soils on Alluvial Deposits
B - Soils on Basic Igneous and Metamorphic Rocks
C - Soils on highly Calcareous Rocks and Materials
D - Soils on fine grained Sedimentary Rocks
G - Soils on Acid Igneous and Metamorphic Rocks
L - Soils on Lacustrine Deposits
R - Very shallow soils on Steep hills, Ridges and Escarpments
S - Soils on coarse-grained Sedimentary Rocks

The following main units occur in the survey area;

A, C, G, R and S. Soils associated with some of these parent materials will be described below.

3.3.2 Soil Units

The soil units are defined according to a standard format which contains the following elements:

- **Soil unit number**.

- **Soil depth**. The range is indicated using soil depth classes:

0 - 25 cm	very shallow
25 - 50 cm	shallow
50 - 100 cm	moderately deep
100 - 150 cm	deep
> 150 cm	very deep.

The lower limit indicated is the depth to which roots of grasses and annual crops can penetrate. The depth is normally limited by the occurence of slightly weathered or unweathered hard rock or cemented layers.

- **Drainage**. The classes follow the standard FAO/SSM classification. Normally the range is one or two classes, occasionally three.

- **Colour**. The colours are described according to the Munsell Soil Color Charts (Munsell, 1975). The range is indicated from one value/chroma to limit diagonally over one or more hues to the other value/chroma limit. The colours refer to the colours of the B horizon (or C horizon if there is no B horizon) in the moist state.

- **Texture**. Textural classes are described following the revised subdivision by Remmelzwaal and Waveren (1988). The texture generally refers to the texture at a depth of 100 cm (or immediately above a lithic or paralithic contact or cemented horizon) and occasionally to a depth of 125-150 cm if this influences the soil classification, as for some sandy soils. Normally the textural range is restricted to two or three classes.

- **Classification**. The soil classification system is the Legend of the Soil Map of the World (FAO/UNESCO, 1974), with modifications (see section 3.1.).

- **Phases**. Phases used are derived from the Legend of the Soil Map of the World (FAO/UNESCO, 1974), with amendments (see section 3.1.3), The full phase occurs in 70 percent or more of the soil unit, and a 'partly' phase in about 30-70 percent of the soil unit. Lesser occurence of phases is normally not indicated.

- **Topography**. A general indication of the topography of the unit is given with sometimes a description of the physiography added.

- **Site characteristics**. A characterisation of the site in general hydrological terms is given, as this is essential for land evaluation. One defined soil unit is normally not both water receiving and shedding. The following classes are distinguished:

- receiving
- slightly receiving
- normal to (slightly) receiving
- normal
- normal to (slightly) shedding
- slightly shedding
- shedding.

Sixteen soil units were distinguished on the five parent materials occuring in the survey area. Reference is made to the Maunatlala soil map legend for all the occuring soil units. Of these, only the six analysed profiles from the five different main units will be discussed. These soil profiles are from the mapping units which at least did not at first sight show some obvious limitiation for small scale irrigated agriculture. The description of units are narrowed to specific situations.

A SOILS ON ALLUVIAL DEPOSITS

A15 **FAO:**[1] Arenic Orthic Luvisol, petric phase (1974)
Areni- Haplic Luvisol (1988)
ST :[2] Arenic Kanhaplic Haplustalf(1987)
Description: Moderately deep, well drained, reddish brown to brown sandy clay loam
Topography: Almost flat
Site: Normal
Profile: PN 150
Occurrence: Minor unit along the Lotsane River, west of Maunatlala village. It occurs in association with heavier Orthic Luvisols (A14) and Ferric Luvisols (G2d), the former being on the water receiving and the latter on the water shedding sites.
Characteristics: Slightly acid to neutral soils with weak to very weak subangular blocky structure, and often with a petric phase at 80cm or deeper.
Vegetation: Dense savanna of *Colophospermum mopane*, *Terminalia prunoides*, *Lonchocarphus copassa* and *Dichrostachys cinerea*.

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1. '1974' refers to the FAO/UNESCO Legend for the Soil Map of the World, and '1988' refers to the FAO/UNESCO/ISRIC revised legend

2. Soil Taxonomy (USDA 1975,1987)

G SOILS ON ACID IGNEOUS AND METAMORPHIC ROCKS

G2c **FAO:** Chromic Luvisol shallow petric phase (1974)
Rhodi - Chromic Luvisol (1988)
ST : Typic Rhodustalf (1987)

Description: Moderately deep, well drained, dark reddish brown to dark red sandy clay loam.
Topography: Almost Flat
Site: Normal
Profile: PN 155
Occurrence: Around Maunatlala village and north eastwards astride the Lotsane river. On more eroded areas, it occurs in association with very shallow Regosols (G1a) and with Ferric Luvisols (G2d) on more leached sites.
Characteristics: Slightly acid, weak subangular blocky structure, and shallow petric phase.

G6 **FAO:** Arenic Ferric Luvisol, petric phase (1974)
Areni- Ferric Lixisol (1988)
ST : Arenic Kanhaplic (1987)
Description: Deep, well drained, dark reddish brown to reddish brown loamy sand.
Topography: Almost flat
Site: Normal
Profile: PN 153
Occurrence: Eastern third of the survey area and mostly in association with relatively heavier and shallower Ferric Luvisols (G2d)
Characteristics: Slightly acid, very weak to weak fine and medium subangular blocky structure. Very frequent (>40%) fine iron-manganese reddish brown concretions.
Vegetation: Savanna of *Combretum apiculatum*, *Colophospermum mopane*, *Acacia nigrescens* and *Dichrostachys cinerea*.

G6a **FAO:** Ferric Luvisol, petric phase (1974)
Rhodi-Ferric Lixisol (1988)
ST : Kandic Rhodustalf
Description: Moderately deep, well drained, dark red to red sandy clay loam.
Topography: Almost flat
Site: Normal
Profile: PN 151, PN 154
Occurrence: Slightly acid, weak and very weak subangular blocky structure. Petric phase below 80 cm depth.
Vegetation; Savanna of *Colophospernum mopane*, *Combretum apiculatum*, *Acacia nigrescens*, *Sclerocarya caffra*, *Dichrostachys cineria* and *Acacia tortilis*.

G8 **FAO:** Chromic Luvisol, petric phase (1974)
Rhodic-Chromic Luvisol (1988)
ST : Typic Rhodustalf
Description: Moderately deep, well drained, dark red to red sandy clay loam.
Topography: Almost flat.
Site: Normal.
Profile: PN 152
Occurrence: North east of Maunatlala Village, South of Lotsane River. Occurs in association with relatively shallower Ferric Luvisols (G2d)
Characteristics: Slightly acid with very weak subangular blocky structure. Petric phase below 90cm.
Vegetation: Savanna of *Colophospermum mopane*, *Lonchocarpus capasa*, *Combretum apiculatum*, *Dichrostachys cinerea* and *Grewia bicolor*.

At all profile sites, the dominant grass species were *Aristida congesta* (Seloka) and *Eragrostis rigidior* (Rathathe). The grass cover was about 20% close to the village and 60% further away. The lower percentage cover near the village is due to human and animal disturbance.

4 LAND EVALUATION

4.1 Introduction

The essential concept of land evaluation is matching the requirements of a specified type of land use against the properties of a defined area of land and rating the land in terms of its ability to satisfy the requirements of the land use (Radcliffe, 1988)

Following steps are to be considered for the exercise:

- definition of the land use type(s)
- identification of the land use requirements
- identification of the land units
- evaluation and rating of the individual land characteristics
- evaluation of the overall land suitability

Two land use types are considered, namely portable/semi portable sprinkler irrigation and centre pivot irrigation.

Land use requirements are defined in terms of relevant land characteristics. These are measurable properties of the physical environment related to the productivity of land. They are described and measured during soil surveys, and can be used directly for the land evaluation exercise.

The identification of the land units of the Maunatlala area is based on a semi-detailed soil survey. Only relevant land units, downstream of the projected dam, and thus potentially irrigable without major pump installations, are considered.

By matching the land use requirements with the land units, the individual land characteristics are rated numerally on a normal scale from 0 to 100. Combining the different land characteristics, three indices can be calculated. The temperature index reflects the adaptability of a specific crop to the temperature regime of the area. The soil site index gives an appreciation of the land characteristics which do not influence crop production through the rooting system of the crop. The layered soil index regroups land characteristics which influence crop growth and yield through the root system of the crop; their importance decreases with depth. By combining these three indices in a multiplicative function, an overall phyical land suitability index is obtained; this index is crop, land and land use system specific.

4.2 Land Utilization Types

A land utilization type can be defined as a specific subdivision of a major kind of land use, serving as the subject of land evaluation and defined as precisely as possible in terms of produce and management.

The land evaluation exercise that is worked out here is aimed to evaluate land for currently used irrigation systems in Botswana.
Two types of irrigation are widespread; (a) the portable/semi portable sprinkler irrigation and (b) the centre pivot irrigation.

Portable and semi portable sprinkler system

Portable and semi portable sprinkler systems are mostly related to small scale irrigation, with irrigation units of maximum a few hectares.
An important factor which restrains the exploitation of bigger size fields is the technical and managerial expertise of the small farmer, and the capital availability. Considering capital availability, many farmers are limited by the number of sprinklers and respective pipe installation.
At the moment, irrigation frequency is low and it must be assumed that at least a 7 day period between 2 irrigation applications is a normal practice (independent of the soil type). This implies that the soil water storage is very important.

Management practices comprise mainly high fertilizer use, weeding, crop protection. No additional organic matter is used; liming is not a common practice.

The selection of crops is based on several factors, like : technical know-how of the farmer, suitability of climatological conditions (especially temperature and frost sensitiveness), current crop pattern, labour requirements, yield potential and marketing possibilities. The following crops are currently cultivated.

winter crops	**spring crops**	**summer crops**
carrot	tomato	maize
cabbage	potato	cowpea
onion		sorghum

A wide range of other crops are potentially suitable under irrigation in Botswana. Consequently the following crops are also considered for the evaluation.

winter crops	spring crops	summer crops
chickpea	phaseolus	eggplant
lettuce	safflower	groundnut
pea		pumpkin
raddish		sesame
spinach		soya
		sunflower
		sweetmelon
		watermelon

Central pivot system

The central pivot system in Botswana is especially used for medium and large scale irrigation schemes. The system is designed to irrigate circles of a large radius, with low manual labour intensity. The radius varies from 300 m to 500 m, which corresponds respectively with irrigated surfaces of 28 ha and 79 ha. Technical knowledge is high.

The application rate depends on the radius of the pivot,and is determined by the most distant point. For a 300 m pivot an average application rate of 10mm/15 min (or 40mm/h) is used. For a 500m pivot, it becomes 10mm/8 min (or 75mm/h). Thus in order to avoid erosion, a high soil infiltration rate is necessary. Under current irrigation schemes, the irrigation frequency is high; 1 application every 24 hours.

The management practices are almost the same as for small scale irrigation. Additionally small bunds crossed by ditches oriented at right angles are constructed to prevent run-off.

In addition to the selected crops for small-scale irrigation, cotton can be proposed as a large-scale crop.

4.3 Selection of Land Characteristics

The selection of relevant land characteristics depends on the land qualities which are related to crop production and management. The land qualities to be considered for the proposed land use types are :

- correct temperature regime
- ability for drainage and aeration
- capacity for water retention
- foothold for roots
- absence of floods
- nutrient availability
- absence of salinity and alkalinity
- ability for lay-out of field plan
- workability of the land

The relation between these land qualities and the corresponding land characteristics is listed below:

internal qualities	characteristics	external qualities
	climate	correct temperature regime
	topography	
ability for drainage and aeration	wetness	ability for lay out of field plan
	flooding	absence of floods
	drainage	
	physical characteristics	
foothold for roots	depth	
	texture	workability
capacity for water retention	surface stoniness	
	physical characteristics	
	coarse fragments	
nutrient availability	fertility characteristics	
	CaCO3	
	CEC soil	
absence of salinity	salinity	
absence of alkaline	alkalinity	

4.4 Rating of Land Characteristics

4.4.1 General

For each land characteristic, critical values in terms of limitation levels are determined for optimal, marginal and unsuitable conditions for the crop performance. If a land characteristic is optimal for plant growth, it has no limitation; on the other hand when the same characteristic is unfavourable for plant growth, it has a severe limitation.

Five degrees of limitations can be retained.

0 : no limitation - The characteristic is optimal for the proposed land utilization type.

1 : slight limitation - The characteristic is nearly optimal for the proposed land utilization type and affects productivity for not more than 20% with regard to the optimal benefit.

2 : moderate limitation - The characteristic has moderate influence on productivity; however benefit can still be made and the use of the land remains profitable.

3 : severe limitation - The characteristic has such an influence on the productivity of the land that use becomes marginal for the considered land utilization type.

4 : very severe limitation - Such limitations will not only decrease the productivity below profitable level, but may even totally inhibit the use of the land.

These limitation levels can be rated numeral on a normal scale. The relationship between limitation levels and numeral ratings is given in Table 2.

Table 2

RELATIONSHIP BETWEEN LIMITATION LEVELS AND NUMERAL RATINGS

Limitation level	Rating
0	100-98
1	98-85
2	85-60
3	60-45
4	<45

4.4.2 Temperature regime

There are three main effects of temperature upon plant growth:

- plant growth ceases below a critical temperature
- the growth rate varies with temperature
- very high or very low temperatures have adverse effects and may kill plants

Appropriate land characteristics for assessing temperature regime depend on the crop. Some crops, like potatoes, require a very strict temperature regime. Other crops, like some vegetables as radish and eggplant, have a much wider temperature range for optimal production.

Table 3 gives the critical temperature values for the proposed crops under irrigation in Botswana. It must be emphasized that different temperature characteristics (in kind and number) are used for the assessment. This is not a restriction because only the lowest rating is retained for the calculation of the overall suitability.

Table 3

Temperature requirements of the considered crops

degree of limitation	**0**	**1**	**2**	**3**	**4**
carrot					
mean temp. growing period	16-21	12-16 21-25	8-12 25-29	4-8 29-35	<4 >35
cabbage					
mean temp. growing period	16-21	12-16 21-25	8-12 25-29	4-8 29-35	<4 >35
lettuce					
mean temp. growing period	15-20	12-15 20-22	8-12 22-24	4-8 24-27	<4 >27
pea					
mean temp. growing period	15-20	12-15 20-22	8-12 22-24	4-8 24-27	<4 >27
onion					
mean temp. growing period	16-21	15-16 21-25	14-15 25-29	12-14 29-35	<12 >35
radish					
mean temp. growing period	15-18	12-15 18-20	10-12 20-22	7-10 22-24	<7 >24
spinach					
mean temp. growing period	15-18	12-15 18-20	10-12 20-22	7-10 22-24	<7 >24
phaseolus					
mean temp. growing period	20-24	17-20 24-26	14-17 26-29	10-14 29-33	<10 >33

degree of limitation	**0**	**1**	**2**	**3**	**4**
eggplant					
mean temp.	22-25	19-22	17-19	15-17	<15
growing period		25-28	28-32	32-35	>35
pumpkin					
mean temp.	22-25	19-22	17-19	15-17	<15
growing period		25-28	28-32	32-35	>35
sweet melon					
mean temp.	22-25	19-22	17-19	15-17	<15
growing period		25-28	28-32	32-35	>35
watermelon					
mean temp.	22-25	19-22	17-19	15-17	<15
growing period		25-28	28-32	32-35	>35

Degree of Limitation	0	1	2	3	4
groundnut					
mean min temp,	18-20	18-16	16-14	14-12	<12
growing season		20-28	28-30	>30	
mean,	22-26	22-20	20-18	18-16	<16
growing season		26-28	28-30	30-32	>32
mean max temp	34-36	36-38	38-40	40-42	>42
growing season		34-15		<15	
Maize					
mean	22-25	22-18	18-16	16-14	<14
growing season		25-30	30-35	35-40	>40
mean min temp	16-18	16-12	12-9	9-7	<7
growing season		18-24	24-28	28-30	>30
safflower					
mean temp,	15-20	15-13	13-10	10-5	<5
month 1		20-22	22-24	24-26	>26
mean average	22-28	28-30	30-32	32-34	>34
month 2 to 4		22-20	20-17	17-12	<12
sesame					
mean min temp	18-20	18-16	16-14	14-12	<12
growing season		20-28	28-30	>30	
mean	24-27	27-28	28-30	30-38	>38
growing season		24-20	20-18	18-16	<16
mean max temp	34-36	36-38	38-40	40-42	>42
growing season		34-25	25-25		<15
Soya					
mean	22-25	22-18	18-16	16-14	<14
growing season		25-30	30-35	35-40	>40
mean min temp	16-15	16-12	12-9	9-7	<7
growing season		18-24	24-28	28-30	>30

degree of limitation	**0**	**1**	**2**	**3**	**4**
sunflower					
mean	22-23	23-25	25-27	27-30	>30
growing season		22-18	18-17	17-15	<15
white potato					
mean temp	17-19	19-23	23-27	27-30	>30
growing season		17-15	15-12	12-7	<7
mean temp	20-24	24-27	27-30	30-33	>33
month 1		20-17	17014	14-9	<9
mean night temp	12-14	14-16	16-18	18-20	>20
month 2		12-8	8-6	<6	
mean night temp	12-14	14-16	16-18	18-20	>20
month 3		12-8	8-6	<6	
mean min month 1	>9	9-7	7-5		<5
mean min month 2	>7	7-6	6-5	5-4	<4
mean min month 3	>7	7-6	6-5	5-4	<4
mean min month 4	>7	7-6	6-5	5-4	<4
tomato					
mean temp	20-23	18-20	14-18	14-10	<10
month 1		23-25	25-28	28-32	>33
mean temp	20-23	18-20	18-16	14-16	<14
month 2 to 4		23-25	25-30	30-35	>35
growing season	<6	6-10	>10		
citrus					
mean temp	25-30	30-33	33-35	35-38	<38
annual		25-20	20-15	15-13	<13
number of months with mean temp >38	0-1	1-2	2-4	4-6	<6
number of months with mean temperature <13	0-1	1-2	2-4	4-6	>6
chickpea					
mean temp	18-20	20-22	22-24	24-26	>26
growing season		18-16	14-12	16-14	<12

degree of limitation	0	1	2	3	4
cotton					
-------					
mean temp day vegetative stage	>30	30-35	25-20	<20	
mean temp day flowering stage	20-30	30-35	35-40	>40	
mean temp night flowering stage	12-18	18-22	22-27	>27	
mean temp ripening stage	27-32	32-38 >38	>38		
mean temp growing season	>26	26-24	24-22	22-20	>20
cowpea					
------					
mean temp	22-26	22-20	20-18	18-16	<16
growing season		26-30	30-32	32-34	>34
mean temp month 1	>18	18-17	17-16	16-15	<15
mean minimum coldest month	>18	18-16	16-13	13-7	<7

4.4.3 Topography

The dominant topographic factor that influences the suitability to irrigate an area is slope. The slope percentage is directly related to the ability for lay-out of field plan and to the erosion hazard. The considered land use type does not consider any land levelling. Sprinkler systems can be used on fields with relatively steep slopes. However on steeper slopes, erosion can become important without conservation techniques, and thus implies additional financial investment. It must be emphasized that the selection and rating of land characteristics/land qualities is done with regard to the 2 proposed irrigation systems. Other values have to be proposed for different land use types (e.g. furrow irrigation)

Following ratings are suggested:

Table 4

ASSESSMENT OF TOPOGRAPHY

a) Portable/semi-portable system

Slope%	degree of limitation
0-2	0
2-4	1
4-8	2
8-16	3
>16	4

b) **Centre Pivot System**

Slope%	degree of limitation
0-1	0
1-2	1
2-4	2
4-8	3
> 8	4

4.4.4 Wetness

Wetness limitations are evaluated with regard to flooding and drainage conditions. Following flood classes can be distinguished :

Fo : no flooding

F1 : low risk for flooding - 1 out of 5 years and easily correctable; corresponds with higher floodplains

F2 : high risk for flooding - more than 1 out of 5 years and difficult to correct ; corresponds with lower floodplains and river beds

Whereas sometimes a drainage system is included in the irrigation investments, this is not the case in Botswana. Shallow groundwater tables (less than 5m) rarely occur in Botswana. The water balance under irrigation is well controlled. The drainage conditions, which are directly estimated in the field, should not be assessed too severely. It must be emphasized that a well drained soil favours the leaching of salts.

Following criteria can be proposed :

Table 5

ASSESSMENT OF FLOODING

flooding class	degree of limitation
F0	0
F1	3
F2	4

Table 6

ASSESSMENT OF DRAINAGE

drainage class	degree of limitation
well	0
moderately well	1
imperfect	2
poor	3
very poor	4

4.4.5 Texture

For irrigation, texture has to be evaluated with regard to waterholding capacity and infiltration rate. The two different proposed irrigation systems have to be considered.

Under the actual management of the portable/semi-portable system, the irrigation frequency is approximately 7 days. This implies that the available water holding capacity of the soil must be high enough to store the application rate. The application intensity is some 10mm/h, what implies that a basic infiltration rate of minimum 10 mm/h is enough to avoid soil erosion and water losses.

Under a central pivot management system, irrigation is applied every day.
The water holding capacity is less important, but the soil requires a high basic infiltration rate in order to avoid soil erosion. Application intensities between 40 - 80 mm/h are normal. It should be noted that at the moment little information is available on water holding capacity and basic infiltration rates of Botswana soils.

Taking account of water losses and irrigation efficiency, the following ratings can be proposed :

Table 7

ASSESSMENT OF TEXTURE FOR SPRINKLER IRRIGATION

Textural class	Infiltration rate (cm/h)	Available water (vol%)	Limitation level
Cm*			4
C+60			4
C+60s	< 0.1	15	4
C-60			3
C-60s	0.2	20	3
SiC		21	3
SiCL	0.5		2
CL	0.8	19	2
L		16	1
SiL			1
SC		15	0
SCL	3.5		0
fSL			1
SL	7	12.5	1
cSL			2
LfS			2
LS	11	8-9	2
LcS			3
fS	12		3
S			4
cS		4	4

* explanation of symbols see appendix 4

Table 8

ASSESSMENT OF TEXTURE FOR CENTRE PIVOT IRRIGATION

Textural class	Infiltration rate (cm/h)	Available water (vol%)	Limitation level
Cm			4
C+60			4
C+60s	< 0.1	15	4
C-60			4
C-60s	0.2	20	4
SiC		21	4
SiCL	0.5		4
CL	0.8	19	4
L		16	4
SiL			4
SC		15	3
SCL	3.5		2
fSL			1
SL	7	12.5	1
cSL			0
LfS			0
LS	11	8-9	0
LcS			0
fS	12		0
S			0
cS		4	0

4.4.6 Depth

The soil depth is the thickness of the loose soil above a limiting layer which is impermeable for roots and/or percolating water.
Thus soil depth is related to the qualities "foothold for roots" and "ability for drainage and aeration". As the water balance is fairly well controlled, soil depth is assessed as a function of the minimum optimal root depth of the specified crop.

Table 9 gives the minimum optimal rooting depth of the considered crops. Three classes are considered here; deep rooting crops (100cm), medium deep rooting crops (75cm) and shallow rooting crops (50cm)

Table 9

SPECIFIC ROOTING DEPTH FOR DIFFERENT CROPS

crops	
summer crops	**minimum optimal rooting depth**
chickpea	100 cm
cotton	100 cm
cowpea	100 cm
eggplant	100 cm
groundnut	75 cm
maize	100 cm
pumpkin	100 cm
sesame	100 cm
sorghum	100 cm
soya	100 cm
sunflower	100 cm
sweet melon	100 cm
water melon	100 cm
spring crops	
phaseolus	75 cm
potato	50 cm
safflower	100 cm
tomato	100 cm
winter crops	
cabbage	50 cm
carrot	100 cm
lettuce	50 cm
onion	50 cm
pea	100 cm
radish	50 cm
spinach	50 cm

4.4.7 Coarse fragments (subsurface stoniness)

Subsurface stoniness must be evaluated mainly in function of water availability. Unconsolidated gravels or stones with at least 80% of the volume of the layer made of stones or gravels, and with a layer thickness of at least 30 cm, are considered as a barrier for root development.

Following criteria are proposed :

Table 10

ASSESSMENT OF COARSE FRAGMENTS

coarse fragments	degree of limitation
< 5	0
5-15	1
15-40	2
40-60	3
> 60	4

4.4.8 Surface stoniness

Surface stoniness is related to workability. The workability of land depends mainly on surface stoniness, structure, texture and drainage conditions. The two latter characteristics are already considered in the evaluation exercise. Structure is related to macroporosity and thus to infiltration rate, which is evaluated in function of the texture. Therefore workability can be assessed directly by the surface stoniness, and the stoniness of the top soil (top 20 cm).

Following classes of coarse fragments are to be distinguished :

- coarse gravel : 2,5 - 7,5 cm
- cobbles : 7,5 - 25 cm
- stones : > 25 cm

The criteria retained for the evaluation are given in Tables 11 and 12

Table 11

ASSESSMENT OF THE SURFACE STONINESS (gravel and cobbles)

% coarse fragments (gravel & cobbles)	degree of limitation
< 5	0
5-10	1
10-25	2
25-50	3
> 50	4

<u>Table 12</u>

ASSESSMENT OF THE SURFACE STONINESS (Stones)

% Surface stones	degree of limitation
0	0
< 0.1	1
0.1-0.5	2
0.5-5	3
>5	4

For the evaluation, the lowest rating for either coarse fragments or stones is retained.

4.4.9 Cation exchange capacity

The cation exchange capacity is a good parameter to predict the potential fertility of a soil under irrigation. As high fertilizer inputs are considered under the proposed management systems, the quantity of nutrients present in the soil is less important. Soil fertility can be determined by the capacity of the soil to retain added nutrients.

High demanding crops with top yields (tomatoes with a yield of 50 t/ha) require up to 300 kg K2O/ha, whereas medium demanding crops with high yields (potatoes 30-40t/ha; cabbage 40-50t/ha) 200kg K2O/ha and low demanding crops (onions 30-40t/ha; wheat 5t/ha) 100kg K2O/ha. These figures imply that a K-availability of 0.17meq/100g soil, 0.12meq/100g soil and 0.6meq/100g soil is required over the top 25cm of the soil. Based on an ideal cation ratio of Ca/Mg/K = 76/18/6 (Debaveye 1986), and considering a 50% base saturation, a CEC of respectively 6meq/100g soil, 4meq/100g soil and 2meq/100g soil are optimal for crop production. As under the irrigation management crop rotation is a common practice, the highest value of 6meq/100g soil should be retained as minimum optimum for the CEC.

It should be mentioned that the CEC of the top 25cm is evaluated, and not the CEC at depth. Organic matter substantially contributes to the retention of nutrients and the CEC soil of the upper soil layer reflects realistically the effective retention.

As rainfall in Botswana is low, and the efficiency of sprinkler irrigation rather high (up to 75%), nutrient leaching is limited and a low CEC-value should not be downgraded too much.

The following critical values are proposed (Table 13)

Table 13

ASSESSMENT OF CATION EXCHANGE CAPACITY

CEC/100g soil	degree of limitation
> 6meq	0
4-6meq	1
< 4meq	2

4.4.10 Calcium carbonate status

The presence of calcium carbonates is related to physical and chemical characteristics of the soil. An unconsolidated $CaCO_3$-horizon can prevent root penetration, especially if the lime is finely divided into the soil matrix. A high concentration of finely divided $CaCO_3$ may induce chlorosis for many crops.

In Botswana soils, a certain amount of lime is related to a good pH-value.

It must also be accepted that a certain amount of lime can improve soil structure and structure stability, especially in finer textured soils. However irrigated lands with a high lime content become more coherent and resistance to root penetration increases. With intense fertilizer use, especially with ammonium sulphate and other acid components, a certain amount of lime can buffer the soil against acidification.

Currently the $CaCO_3$% is not determined in the project laboratory. Consequently only the $CaCO_3$ classes, as determined by field observations can be assessed.

The following classes are distinguished, and tentatively correlated with the $CaCO_3$%.

Table 14

CORRELATION BETWEEN CaCO3 FIELD CLASSES AND CaCO3%

CaCO3 field class	% CaCO3
non calcareous	0
slightly calcareous	< 2
moderately calcareous	2-10
strongly calcareous	10-25
extremely calcareous	>25

The CaCO3 status is calculated over the crop rooting depth or to the impervious layer.

Considering all previously mentioned aspects of lime content, the following criteria are proposed :

Table 15

ASSESSMENT OF CaCO3 STATUS

CaCO3 class	degree of limitation
non calcareous	1
slightly calcareous	1
moderately calcareous	0
strongly calcareous	2
extremely calcareous	3

4.4.11 Salinity status

The amount of soluble salts in a soil affects crop production and yield. Tolerance to salt is very crop specific. Most of the target crops for irrigation in Botswana are medium salt tolerant : maize, tomato, cabbage, potato, carrot, onion, pea etc. They show yield reductions in the conductivity levels of 4 to 8mmhos/cm.

For practical reasons, the considered crops are divided into 3 groups of salt tolerance: sensitive, medium tolerant and tolerant crops (see Table 16).

Salinity also affects the suitability for irrigation because the amount of water, required for leaching, will depend on the salt content of the soil. Under sprinkler irrigation in Botswana, where water is very precious and rather scarce, leaching possibilities are limited.

The salinity is calculated over the rooting depth or to the impervious layer/

The rating of the salinity status is given in Table 17.

Table 16

SALINITY TOLERANCE AND ALKALINITY TOLERANCE OF DIFFERENT CROPS

crops	**salinity**	**alkalinity**
chickpea	2	1
cotton	3	3
cowpea	2	1
eggplant		
groundnut	2	1
maize	2	1
pumpkin	2	
sesame	2	2
sorghum	2	2
soya	2	1
sunflower	2	1
sweet melon	2	1
water melon	2	2
phaseolus	1	1
potato	2	1
safflower	2	2
tomato	2	2
cabbage	2	1
carrot	2	2
lettuce	2	2
onion	2	2
pea	2	1
radish	1	1
spinach	3	2

1 : sensitive
2 : medium tolerant
3 : tolerant

Table 17

RATING OF SALINITY STATUS

	electric conductivity in mmho/cm				
degree of limitation	**0**	**1**	**2**	**3**	**4**
sensitive	< 2	2 - 4	4 - 8	8 - 12	> 12
medium tolerant	< 4	4 - 8	8 - 12	12 - 16	> 16
tolerant	< 8	8 - 12	12- 16	16 - 30	> 30

4.4.12 Alkalinity status

Exchangeable sodium influences soil structure and permeability ; it has also a direct effect on the crop yields. The alkalinity status can be measured by the exchangeable sodium percentage (ESP). As with salinity, the tolerance of the crops to sodium saturation is very specific. Three classes of crop sensitiveness to alkalinity have been established: sensitive, medium tolerant and tolerant (see Table 16).

For the assessment of alkalinity, the ESP is calculated over the rooting depth or to an impervous layer.

Table 18

ASSESSMENT OF ALKALINITY STATUS

	exchangeable sodium percentage				
degree of limitation	**0**	**1**	**2**	**3**	**4**
sensitive	< 6	6 - 12	12 - 18	18 - 14	> 24
medium tolerant	< 10	10- 18	18 - 30	30 - 50	> 50
tolerant	< 18	18- 30	30 - 50	> 50	

4.6.1.1 Temperature index

The temperature index for a specific crop under irrigation is based on the temperature regime.

A set temperature characteristics reflects the adaptability of a crop to the temperature regime of a specific land unit. The ratings for each characteristic are calculated by linear interpolation comparing Table 3 with Table 20 . The most severe rating is considered as the temperature index.

4.6.1.2 Soil site index

Some land characteristics like topography, flooding, drainage, surface stoniness and cation exchange capacity (CEC) can be obtained directly by matching the land use requirements with the land units.

Ratings for topography, CEC, and surface stoniness are calculated by linear interpolation. For flooding and drainage, which are indicated as classes and not as numeral values, the mean value of the corresponding numeral rating is taken.

The combination of the ratings of each soil site characteristic gives the soil site index (equation 1).

$$I_{site} = \frac{Y1 \times Y2 \times Y3 \times Y4 \times Y5}{10^8} \qquad \text{(equation 1)}$$

where

Y1 = rating for topography
Y2 = rating for flooding
Y3 = rating for drainage
Y4 = rating for surface stoniness
Y5 = rating for CEC

4.6.1.3 Layered soil index

Some land characteristics like texture, % coarse fragments, $CaCO_3$ - status, salinity and alkalinity, influence crop growth and yield through the root system of the crop, and their importance decreases with depth. To take this into account, and also to reflect the presence of an impermeable or inert layer within the rooting depth, these factors are rated as a function of the depth at which they occur.

In practice, the soil profile is divided into 25cm thick layers and the weighted average of these factors is multiplied with a specific weight factor for each layer up to the minimum optimal rooting depth of the crop.

The layered soil index is obtained following the equation:

$$I_{\text{layered RD}} = \frac{\sum_{i=1}^{n} Li.\ WF.\ TH}{10^{n-2}} \qquad \text{(equation 2)}$$

Li: ratings of the layered soil characteristics : texture, coarse fragments, CaCO3 status, salinity, alkalinity
WF: weight factor
TH: thickness of the layer
RD: specific rooting depth of the crop

In equation (2), the thickness factor 'TH' is equal to 25cm or the depth from the upper limit of the layer to the upper limit of a root restricting layer, whichever is smaller.

Thus the depth to a root restricting layer is rated indirectly through a reduction of the thickness of the bottom layer and a rating of '0' for all layers below the upper limit of a root restricting layer, compared against the specific rooting depth.

4.6.1.4 Rating of the overall land suitability

By combining the temperature index, the soil site index and the layered soil index, an overall index, or land index is obtained, following the equation:

$$I_{\text{land}} = \frac{I_{\text{temperature}} \times I_{\text{site}} \times I_{\text{layered}}}{10^4} \qquad \text{(equation 3)}$$

The land index reflects the suitability of a specific land unit for a specific land use type in physical terms, on a scale from 0 to 100 without estimates of costs and returns of the land use type:

4.6.2 Example

Some 24 crops are evaluated for 6 different land units. As an example one crop, tomatoes, will be evaluated for one land unit, namely a ferric Luvisol with petric phase (G2d) for sprinkler irrigation. The calculation of the different indices is done step by step.

4.6.2.1 Temperature index

The best sowing date for tomatoes is calculated (see section 4.7.1) to be in September. A growing period of 120 days is considered. Comparing Table 3 with Table 20 following ratings can be calculated:

	real value	rating
- mean temp. month 1 :	20,9°C	100
- mean temp. month 2,3,4:	23,9°C	92
- difference mean day and mean night temp. of the growing period :	6.8°C	95

The rating for each parameter is obtained by linear interpolation, following the equation :

$$\text{rating} = A - \frac{(B)}{C} \times D \qquad \text{(equation 4)}$$

A: rating corresponding with the highest class limit in which the actual value falls.
B: the difference between the value given for the highest class limit and the actual value of the parameter.
C: the difference between the upper and lower values of the class in which the actual value falls.
D: the difference between the upper and lower ratings of the class in which the actual value falls

Thus for the mean temperature of months 2, 3 and 4, this gives:

$$\text{rating} = 98 - \frac{(23,9 - 23)}{25 - 23} \times (98-85)$$

$$\text{rating} = 92$$

The lowest rating of the temperature characteristics gives the climatic index, thus:

$$I_{\text{temperature}} = 92$$

4.6.2.2 Soil Site index

Comparing the land use requirements (see section 4.4) with Table 19, the following ratings can be calculated:

characteristic	real value	rating
topography	0.5	100
flooding	no flooding	100
drainage	moderately well	91,5
surface stoniness	0	100
CEC/100g soil for top 25cm	6,6meq	100

The ratings for topography surface stoniness and CEC are calculated following equation 4. For flooding and drainage, which are indicated as classes and not as nominal values, the mean value of the corresponding numerical rating is taken.

The soil site index is obtained following equation 1.

$$I_{site} = \frac{100 \times 100 \times 91,5 \times 100 \times 100}{10^8}$$

$$I_{site} = 91,5$$

4.6.2.3 Layered soil index

The layered soil characteristics are recalculated per unit layer of 25 cm up to the minimum optimal rooting depth of the crop (which is assumed to be 100cm for tomatoes), or up to an impermeable or inert layer.
Doing so Table 21 can be derived from Table 19.

Table 21

LAYERED SOIL CHARACTERISTICS OF SOIL UNIT G2d RECALCULATED PER UNIT LAYER OF 25 cm.

layered soil characteristics	0-25cm	25-50cm	50-75cm	75-100cm
texture	loamy sand	sandy clay loam	sandy clay loam	
% coarse fragments	0	10	10	
$CaCO_3$ status(%)	0	0	0	
salinity Ec (mmho/cm)	0	0	0	
alkalinity ESP (%)	0	2	2	
depth to impervious layer : 55cm				

Comparing Table 21 with the land use requirements ratings can be calculated for each layered soil characteristic per unit layer of 25cm. (see Table 22).

TABLE 22

RATINGS FOR THE LAYERED SOIL CHARACTERISTICS OF SOIL UNIT G2d PER UNIT LAYER OF 25 cm

layered soil characteristics	0-25cm	25-50cm	50-75cm	75-100cm
texture	72,5	100	100	
% coarse fragments	100	91,5	91,5	
$CaCO_3$ status	91,5	91,5	91,5	
salinity	100	100	100	
alkalinity	100	100	100	

The following weight factors are recommended by Biot et al (1984) as a function of the minimum optimum rooting depth:

150cm : 6 layers of 25cm : 2.00 - 1.50 - 1.00 - 0.75 - 0.50 - 0.25
125cm : 5 layers of 25cm : 1.75 - 1.30 - 0.90 - 0.65 - 0.40
100cm : 4 layers of 25cm : 1.50 - 1.15 - 0.75 - 0.60
75cm : 3 layers of 25cm : 1.40 - 1.00 - 0.60
50cm : 2 layers of 25cm : 1.30 - 0.70

Following equation (2) the layered soil index for tomatoes (minimal optimum rooting depth = 100cm) can be calculated as follows:

$$25 \times 72,5 \times 100 \times 91,5 \times 100 \times 100 \times 1,5 = 2488.10^8$$
$$25 \times 100 \times 91,5 \times 91,5 \times 100 \times 100 \times 1,15 = 2407.10^8$$
$$(55-50) \times 100 \times 91,5 \times 91,5 \times 100 \times 100 \times 0,75 = 314.10^8$$
$$(75-55) \times 0 \times 0 \times 0 \times 0 \times 0 \times 0,75 = 0$$
$$25 \times 0 \times 0 \times 0 \times 0 \times 0 \times 0.60 = 0$$

$$I_{layered} = \frac{2488.10^8 + 2407.10^8 + 314.10^8}{100.10^8} = 52$$

4.6.2.4 Land index

Following equation (3), the overall land index is obtained by multiplication of the temperature index, the soil site index and the layered soil index.

Thus:

$$I_{land} = \frac{92 \times 95 \times 52}{10^4} = 43$$

This land index reflects the actual suitability on a numeral scale from 0 to 100 of the G2d soil with the given climate for tomatoes under sprinkler irrigation.

4.7 RESULTS

4.7.1 Temperature index

Comparing Table 3 with Table 20, the temperature index can be calculated for a specific crop and a specific planting date. Table 23 gives an example for the calculation of the temperature index for maize.

The temperature index, presented by the lowest rating of the different temperature characteristics, is calculated for 12 planting months. It appears that only for the planting months September, October and January the temperature requirements of the crop are fully satisfied (or index = 100). Thus these months can be considered as the optimal planting months for maize production. The same excercise has been carried out for all the considered crops. Table 24 presents the temperature indices and consequently the optimal planting months. Several crops, especially vegetables show a wide range for optimal planting dates, while for other crops, the optimal planting date is well determined.

Based on the temperature index, one can conclude that most of the proposed crops are not, or only slightly limited by temperature at one or another time of the year.

An exception should be made for cotton and especially for potatoes. The main limitation for cotton is the relative low temperatures during the vegetative stage. Potatoes are a problem crop for the area. Very sensitive to frost, the winter months with frost risk (June, July) have to be avoided for potato growth. August is the optimal planting month, but from October on night temperatures are too high for good tuber formation.

Table 23

ASSESSMENT OF TEMPERATURE FOR MAIZE FOR DIFFERENT PLANTING MONTHS

Planting month	mean temp (°C)	rating	mean min temp (°C)	rating
January	23,3	100	17,0	100
February	21,1	95	14,3	92
March	18,3	86	10,7	74
April	15,7	58	7,5	49
May	14,8	51	6,0	38
June	15,9	59	7,1	46
July	18,2	86	9,8	67
August	21,0	95	13.3	89
September	23,2	100	16,3	100
October	24,2	100	17,9	100
November	24,7	100	18,8	96
December	24,5	100	18,5	97

Table 24

OPTIMAL PLANTING TIMES AND CORRESPONDING INDICES FOR THE CONSIDERED CROPS

crop	planting month	duration growing period (days)	degree of limitation	temperature index
summer crops				
chickpea	march, july	120-140	0	100
cotton	october	180	2	76
cowpea	november	120-140	0	100
eggplant	november	70-120 (a)	0	100
groundnut	november	90-120 (b)	1	96
maize	october	120-130	0	100
pumpkin	summer	100-120	0	100
sesame	november	100-140	1	93
soya	november	100-130	0	100
sunflower	october	130-150	1	91
sweet melon	summer	50-90	0	100
water melon	summer	75-110	0	100
sorghum	november	90-120	0	100
spring crops				
phaseolus	september	60-90 (c)	0	100
potato	august	90-120 (d)	3	54
safflower	august	120-180	0	100
tomato	september	90-130	1	91
winter crops				
chickpea	march	120-140	0	100
cabbage	winter	90-150	0	100
carrot	winter	60-85	0	100
lettuce	winter	40-85	0	100
onion	winter	100-140	0	100
pea	winter	65-100	0	100
radish	winter	22-40	0	100
spinach	winter	40-50	0	100

(a) short variety eggplant
(b) sequential branched groundnut
(c) green phaseolus
(d) early potatoes   medium potatoes : 120-150 days

4.7.2 Land Index

Table 25 and 26 give the overall land suitability for the different soils and crops under respectively sprinkler and centre pivot irrigation. The following conclusions, related to the different soil units, can be drawn.

Table 25

LAND INDICES FOR SPRINKLER IRRIGATION

	G2c	G2d	G6a1	G6a2	G8	A15	G6
chickpea	44	48	72	69	62	50	55
cotton	33	36	55	52	47	38	42
cowpea	44	48	71	69	62	50	55
eggplant	44	48	72	69	62	50	55
groundnut	51	55	75	70	62	54	55
maize	44	48	71	69	62	50	55
pumpkin	44	48	72	69	62	50	55
sesame	41	45	67	64	62	47	51
sorghum	44	48	72	69	62	50	55
soya	44	48	71	69	62	50	55
sunflower	40	43	64	62	56	46	50
sweetmelon	44	48	71	69	62	50	55
watermelon	44	48	72	69	62	50	55
phaseolus	53	57	78	73	65	56	57
potato	32	36	44	39	37	29	30
safflower	44	48	72	69	62	50	55
tomato	40	44	66	63	56	46	50
cabbage	60	66	81	73	68	53	55
carrot	44	48	72	69	62	50	55
lettuce	60	66	81	73	68	53	55
onion	60	66	81	73	68	53	55
pea	44	48	71	69	62	50	55
radish	60	66	81	73	68	53	55
spinach	60	66	81	73	68	53	55

Table 26

LAND INDICES FOR CENTRE PIVOT IRRIGATION

	G2c	G2d	G6a1	G6a2	G8	A15	G6
chickpea	61	49	51	57	52	51	52
cotton	46	37	40	43	40	39	40
cowpea	61	49	51	57	52	51	52
eggplant	61	49	51	57	52	51	52
groundnut	69	57	54	60	55	58	54
maize	61	49	51	57	52	51	52
pumpkin	61	49	51	57	52	51	52
sesame	57	46	52	53	48	47	48
sorghum	61	49	52	57	52	51	52
soya	61	49	51	57	52	51	52
sunflower	55	44	46	51	47	46	47
sweetmelon	61	49	51	57	52	51	52
watermelon	61	49	52	57	52	51	52
phaseolus	72	59	56	62	57	60	56
potato	45	40	31	36	33	36	33
safflower	61	49	52	57	52	51	52
tomato	56	45	47	52	47	46	47
cabbage	83	74	58	66	61	67	61
carrot	61	49	52	57	52	51	52
lettuce	83	74	58	66	61	67	61
onion	83	74	58	66	61	67	61
pea	61	49	51	57	52	51	52
radish	83	74	58	66	61	67	61
spinach	83	74	58	66	61	67	61

Chromic Luvisol/shallow petric - G2c

Soil site index

No limitations regarding the soil site index can be observed. The almost flat topography does not limit the lay out of the irrigation schemes. The soil is well drained and no floods occur. The cation exchange capacity of the topsoil guarantees the retention of fertilizer, even for high demanding crops.

Layered soil index

The loamy sand texture is too coarse for sprinkler irrigation, and results together with the high gravel content in a low available water holding capacity. For centre pivot irrigation, the texture permits a quick infiltration of water, and thus this type of irrigation is more convenient. The main limitation is the rooting depth of the soil. Shallow rooting vegetables can produce an acceptable yield, but grain crops cannot.

Soil/management improvements

Under the proposed irrigation systems, no real soil improvements can be proposed. higher irrigation frequency (2 or 3 days instead of 7 days) can give better resul for sprinkler irrigation, but will result in more labour and equipment input.

Ferric Luvisol/shallow petric - G2d

Soil site index

A slight limitation for drainage can be mentioned.

Layered soil index

The major limitation of this soil is its shallowness (55cm). Grain crops and deep rooting vegetables such as carrots and peas, will be limited seriously for their root development.

Soil/Management improvements

No soil or management improvements can be proposed.

Arenic ferric Luvisol/petric G6

Soil site index

This soil is limited by its low CEC value (2.6meq/100g soil). Fertilizer leaching is obvious especially under high application rate.

Layered soil index

Although coarse fragments content increases rapidly with depth, the effective rooting depth should not be considered as a limitation. Gravel % and concretions % will decrease available water content for plant growth. The sandy clay loam texture is more suitable for sprinkler than for centre pivot irrigation.

Soil Management improvements

An increase of the CEC value of the topsoil is a major soil improvement; organic matter application can be proposed.

Ferric Luvisol/petric G6a

Soil site index

The main limitation is the low cation exchange capacity of the top soil (4,3 - 4,9 meq/100g soil). Fertilizer leaching under high application rate is possible.

Layered soil index

For sprinkler irrigation no major limitations can be observed. The soil has a high available water holding capacity. Crop production is slightly limited by the effective rooting depth. For centre pivot irrigation, the sandy clayloam texture is limiting in relation to its infiltration rate which is not high enough.

Soil/management improvements

The major soil improvement is organic matter application in order to increase the cation exchange capacity.

A slight lime application can also be considered (as for all other soils of Maunatlala). For centre pivot irrigation, the irrigation intensity or the speed of the pivot can be reduced.

Chromic Luvisol/petric - G8

Soil site index

The low CEC value (4,2 meq/100g soil) constitutes a limitation for fertilizer application.

Layered soil index

Texture is near to excellent for sprinkler, but limiting for centre pivot irrigaticn. The available water holding capacity is reduced in depth by the amount of coarse fragments.

Soil/management improvements

The application of organic matter will increase the CEC.

Arenic orthic Luvisol - A15

Soil site index

The main limitation is the low CEC value (3,2 meq/100g soil). For centre pivot irrigation, a slope of 1,5% can cause erosion problems.

Layered soil index

Texture is limiting for sprinkler and for centre pivot irrigation. Soil depth limits rooting for deeper rooting crops.

Soil/management improvements

The application of organic matter will increase the CEC.

4.7.3 Influence of soil depth on land capability for irrigation

Most of the mapped soil units have a limitation for effective rooting depth for grain crops. If one considers the cultivation of shallow rooting vegetables, like cabbage, lettuce and onions, this depth limitation disappears and the land index for those crops will increase.

The high land indices for shallow rooting crops may give a somewhat optimistic view of the land suitability for irrigation. In order to maximise revenues, an occupation of the land during most part of the year is necessary, as is crop rotation.

Most vegetables can be cultivated in winter time, but high temperatures limit their yield in summer. During the hottest months, emphasis should be put on grain crops, which are all deep rooting (1m).

The overall appreciation of the land capability index should thus be based more on grain crops than on vegetables. In other words, shallow soils are limited for irrigation because crop rotation and full occupancy of the land over the year is not flexible.

An additional problem for vegetables is that with the isolated location of Maunatlala, their marketing will be very difficult.

4.7.4 Choice of the irrigation system

With the high artificial water application intensities required for centre pivot irrigation, sandy soils are prefered.

Considering management systems and size of centre pivots currently used in Botswana, these soils should be as homogeneous as possible over an area of at least 25ha.

Technical know how and managerial skills of the farmer must be high. Comparing the land indices in tables 25 and 26, one can conclude that the Maunatlala soils are less suitable for centre pivot irrigation than for sprinkler irrigation.

4.7.5 Choice of suitable soils for irrigation

Considering the flexibility of crop rotation (see section 4.7.3) and the preference to use sprinkler irrigation, one can compare the land indices for maize (Table 27).

Table 27

LAND INDICES FOR MAIZE UNDER SPRINKLER IRRIGATION

Soil Unit	Land index	extent (ha)
G2c	44	555
G2d	48	1282
G6	55	950
G6a	69/71	250
G8	62	324
A15	50	-

The ferric Luvisol (G6a) is the highest rated soil, followed by the chromic Luvisol (G8) and gives the best possibilities for irrigation. Soil Units A15, G8 and G6 will give lower yields; G2c and G2d and soils show severe limitations (soil depth, stoniness) and should not be cultivated under irrigation.

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APPENDIX 1: SOIL PROFILE DESCRIPTION AND ANALYTICAL DATA

SOIL PROFILE DESCRIPTION — Profile: PN 0150 Unit: A15 Status: 2

SHEET : 2227D1
LOCATION : 1km West of Maunatlala along the road to Raphiri.
AUTHOR(S): B.G.Moganane L.S.Lekoma
CLASSIFICATION FAO: Areni-Haplic Luvisol(1988) Arenic Orthic Luvisol (1974) petric (skeletic) phase
ST : Arenic kanhaplic Haplustalf

GRID : NF-633-011
COORD: 22-35-50-S 27-36-58-E
DATE : 23/11/88

AGRO CLIM.ZONE: 3B4
ELEVATION : 838 m
SMR: aridic to ustic

LANDFORM : pediment
TOPOGRAPHY: almost flat
SURF. CHAR: moderate sealing, no cracks, nil evidence of salt,
LAND USE: traditional grazing
SPECIES : Trees - Colophospermum mopane (dom.) Terminalia prunioides Lonchocarpus capassa
: Shrubs - Colophospermum mopane (dom.) Terminalia prunioides Dichrostachys cinerea Grewia bicolor
: Grasses/forbs- Aristida congesta (dom)

LAND ELEMENT : not applicable
MICRO TOPOGRAPHY: low hummocks
VEGETATION: dense savanna

POSITION: intermediate part
SLOPE : 1 - 2 % straight
GRASSCOVER: 10 - 30 %

PARENT MATERIAL: colluvium
MOIST. COND: dry 0 - 90 cm
SURF.STONES: none
EROSION : moderate sheet erosion

ROCK TYPE: acid igneous/metamorphic
ROCK OUTCROP: none

GEOL.UNIT: Waterberg Lotsane frm
DRAINAGE : well drained
HUMAN INF: nil

REMARKS: This is typical soil between the hills and the river.More erosion at about 50 metres from the river.

SAMPLES: A: 0 - 15 B: 25 - 45 C: 55 - 75

A 0 - 15 cm 6YR 3/4 (moist) and 6YR 5/4 (dry), sand, weak medium and coarse subangular and angular blocky structure, soft, many fine and medium pores, non calcareous, common very fine and fine and few medium roots, gradual wavy boundary.

Bt1 15 - 50 cm 5YR 3/4 (moist) and 6YR 4.5/4 (dry), loamy sand, weak coarse and very coarse subangular blocky structure, hard, patchy thin cutans, common fine and medium pores, very few fine angular quartz rock fragments, non calcareous, few very fine and fine and few medium and coarse roots, clear wavy boundary.

Bt2 50 - 80 cm 7.5YR 4/4 (moist) and 7.5YR 5/4 (dry), sandy clay loam, very weak coarse and very coarse subangular blocky structure, very hard, broken moderately thick cutans, few fine and medium pores, few fine and medium angular quartz rock fragments, non calcareous, very few very fine and fine roots, clear wavy boundary.

Cr 80 - 90 cm 10YR 5/6 (moist) and 10YR 6/ 6 (dry), sandy clay, frequent fine angular quartz rock fragments, non calcareous,

S T A N D A R D   S O I L   A N A L Y S I S   R E S U L T S

PROFILE: PN 0150

SAMPLE	DEPTH		pH		EC	m	P	m	C	N	CEC	Ca	Mg	K	Na	EXAC	PBS	CARBO	Particle size (weight %)								CECclay	METH	PRETR
			H2O	CaCL2	mS/cm		ppm		weight %		ù---------		meq/100gr soil			---------ù	%	%	vcS	cS	mS	fS	vfS	cSi	fSi	Clay	meq/100gr		
A	0	15	5.8	5.5	0.0		3	B	0.2	0.00	2.6	1.3	1.0	0.2	0.0	0.0	96	0.0	9	19	24	25	9	2	2	10	19	H	N
B	25	45	6.3	5.2	0.0		0	B	0.1	0.00	4.0	1.8	1.8	0.5	0.2	0.0	>100	0.0	5	19	26	22	10	3	4	12	30	H	N
C	55	75	7.8	6.6	0.8		0	B	0.1	0.00	12.2	3.2	6.2	0.8	0.2	0.0	84	0.0	9	13	16	14	4	4	4	36	33	H	N

Soil Survey of Botswana FAO/BOT/85/011 last changed : 02/02/90 Print date: 12/02/90

EC : Electrical Conductivity m : method ... * = saturated paste not marked = 1:5 in water

P : Available Phosphorus determination m : method ... O = Olsen B = Bray

C : Organic Carbon determination Walkley-Black method

N : Total Nitrogen determination Kjeldahl method

CEC and bases : Ammonium acetate method

EXAC : Exchangeable acidity extracted with KCl

CARBO : Free Carbonates by destruction with HCl

PART.SIZE DETERMINATION METHOD: H = Hydrometer Method, P = Pipette Method, * = Not Known
PRETREATMENT: O = Organic Matter, F = Free Iron Oxides, C = Carbonates, S = Soluble Salts N = None

SOIL PROFILE DESCRIPTION | Profile: PN 0151 Unit: G06a Status: 2

SHEET : 2227D1
LOCATION : 2km ENE of Maunatlala Primary School.
AUTHOR(S): B.G.Moganane L.S.Lekoma
CLASSIFICATION FAO: Rhodi-Ferric Lixisol(1988) Ferric Luvisol (1974) petric (skeletic) phase
ST : kandic Rhodustalf

GRID : NF-666-017
COORD: 22-35-30-S 27-38-52-E
DATE : 23/11/88

AGRO CLIM.ZONE: 3B4
ELEVATION : 853 m
SMR: aridic to ustic

LANDFORM : pediment
TOPOGRAPHY: almost flat
SURF. CHAR: slight sealing, no cracks, nil evidence of salt,
LAND USE: traditional dryland farming

LAND ELEMENT : not applicable
MICRO TOPOGRAPHY: low hummocks
VEGETATION: savanna

POSITION: intermediate part
SLOPE : 0.5 - 1.0% straight
GRASSCOVER: 10 - 30 %

SPECIES : Trees - Colophospermum mopane (dom.) Combretum apiculatum Acacia nigrescens Sclerocarya caffra
: Shrubs - Colophospermum mopane (dom.) Dichrostachys cinerea Acacia tortilis subs. heterocantha Grewia bicolor
: Grasses/forbs- Aristida congesta (dom) Eragrostis rigidior

PARENT MATERIAL: in situ weathered
MOIST. COND: dry 0 - 100 cm
SURF.STONES: none
EROSION : slight sheet erosion

ROCK TYPE: acid igneous/metamorphic
ROCK OUTCROP: none

GEOL.UNIT: Intrusives
DRAINAGE : well drained
HUMAN INF: nil

REMARKS:

SAMPLES: A: 0 - 20 B: 25 - 45 C: 55 - 75

A	0 - 20 cm	2.5YR 3/5 (moist) and 3YR 4/5 (dry), sandy loam (16% clay), weak coarse and very coarse subangular blocky structure, hard, many fine and medium pores, non calcareous, common very fine and fine roots, clear smooth boundary.
Bt1	20 - 50 cm	2.5YR 3/5 (moist) and 2.5YR 4/6 (dry), sandy clay loam (25% clay), weak medium and coarse subangular blocky structure, slightly hard, patchy thin clay cutans on pedfaces, common fine and medium pores, few fine rounded slightly weathered quartz rock fragments, non calcareous, common very fine and fine roots, gradual smooth boundary.
Bt2	50 - 85 cm	10R 3/5 (moist) and 2.5YR 4/7 (dry), sandy clay loam (32% clay), weak medium and coarse subangular blocky structure, hard, broken thin clay cutans on pedfaces, common fine and medium pores, few fine angular slightly weathered quartz rock fragments, non calcareous, few fine and medium and few coarse roots, clear wavy boundary.
Cr	85 - 100 cm	frequent fine and medium angular quartz rock fragments, non calcareous,

STANDARD SOIL ANALYSIS RESULTS

PROFILE: PN 0151

SAMPLE	DEPTH		pH		EC m	P m	C	N	CEC	Ca	Mg	K	Na	EXAC	PBS	CARBO	Particle size (weight %)								CECclay	METH	PRETR
			H2O	CaCL2	mS/cm	ppm	weight %		ù--------		meq/100gr soil			--------ù	%	%	vcS	cS	mS	fS	vfS	cSi	fSi	Clay	meq/100gr		
A	0	20	6.1	5.0	0.0	1 B	0.3	0.00	4.3	2.7	0.8	0.5	0.0	0.0	93	0.0	6	16	20	22	10	4	6	17	19	H	N
B	25	45	6.0	5.1	0.0	0 B	0.3	0.00	7.1	3.9	1.5	0.6	0.1	0.0	86	0.0	0	11	18	22	10	5	5	31	19	H	N
C	55	75	6.1	5.4	0.2	0 B	0.2	0.00	6.4	4.1	1.6	0.1	0.5	0.0	98	0.0	9	14	14	15	7	4	4	32	17	H	N

Soil Survey of Botswana FAO/BOT/85/011 last changed : 28/09/89 Print date: 12/02/90

EC : Electrical Conductivity m : method ... * = saturated paste not marked = 1:5 in water

P : Available Phosphorus determination m : method ... O = Olsen B = Bray

C : Organic Carbon determination Walkley-Black method

N : Total Nitrogen determination Kjeldahl method

CEC and bases : Ammonium acetate method

EXAC : Exchangeable acidity extracted with KCl

CARBO : Free Carbonates by destruction with HCl

PART.SIZE DETERMINATION METHOD: H = Hydrometer Method, P = Pipette Method, * = Not Known
PRETREATMENT: O = Organic Matter, F = Free Iron Oxides, C = Carbonates, S = Soluble Salts N = None

SOIL PROFILE DESCRIPTION — Profile: PN 0152 — Unit: G08 — Status: 2

SHEET : 2227D1
LOCATION : 4.2km NE of Maunatlala Primary School.
AUTHOR(S): B.G.Moganane L.S.Lekoma
CLASSIFICATION FAO: Rhodi-Chromic Luvisol(1988) Chromic Luvisol (1974) petric (skeletic) phase
ST : Typic Rhodustalf

GRID : NF-680-034
COORD: 22-34-37-S 27-39-40-E
DATE : 24/11/88

AGRO CLIM.ZONE: 3B4
ELEVATION : 838 m
SMR: aridic to ustic

LANDFORM : plain
TOPOGRAPHY: almost flat
SURF. CHAR: slight sealing, no cracks, nil evidence of salt,
LAND USE: traditional grazing
SPECIES : Trees - *Colophospermum mopane* (dom.) *Lonchocarpus capassa* *Combretum apiculatum*
: Shrubs - *Colophospermum mopane* (dom.) *Dichrostachys cinerea* *Grewia bicolor*
: Grasses/forbs- *Aristida congesta* (dom) *Eragrostis rigidior*
PARENT MATERIAL: in situ weathered
MOIST. COND: dry 0 - 90 cm
SURF.STONES: none
EROSION : slight sheet erosion

LAND ELEMENT : not applicable
MICRO TOPOGRAPHY: even
VEGETATION: savanna
ROCK TYPE: acid igneous/metamorphic
ROCK OUTCROP: none

POSITION: intermediate part
SLOPE : 0.5 - 1.0% straight
GRASSCOVER: 30 - 70 %
GEOL.UNIT: Basement complex
DRAINAGE : well drained
HUMAN INF: nil

REMARKS:

SAMPLES: A: 0 - 0 B: 0 - 0 C: 0 - 0

A	0 - 20 cm	5YR 3/4 (moist) and 5YR 4.5/6 (dry), loamy sand, weak coarse and very coarse subangular blocky structure, slightly hard, few fine pores, few fine angular quartz rock fragments, non calcareous, few very fine and fine roots, clear wavy boundary.
Bt1	20 - 50 cm	2.5YR 3/5 (moist) and 2.5YR 4/5 (dry), sandy clay loam, very weak medium and coarse subangular blocky structure, hard, patchy thin cutans on pedfaces, common fine and medium pores, few fine angular quartz rock fragments, non calcareous, few fine and medium roots, gradual wavy boundary.
Bt2	50 - 90 cm	2.5YR 3/5 (moist) and 2.5YR 4/7 (dry), sandy clay loam, very weak medium and coarse subangular blocky structure, hard, broken moderately thick cutans on pedfaces, few fine and medium pores, frequent fine and medium angular quartz rock fragments, non calcareous, few very fine roots, clear wavy boundary.
Cr	90 cm +	very frequent medium angular quartz rock fragments, non calcareous,

S T A N D A R D   S O I L   A N A L Y S I S   R E S U L T S

PROFILE: PN 0152

SAMPLE	DEPTH		pH		EC	m	P	m	C	N	CEC	Ca	Mg	K	Na	EXAC	PBS	CARBO	Particle size (weight %)								CECclay	METH	PRETR
			H2O	CaCL2	mS/cm		ppm		weight %		ù---------		meq/100gr soil			---------ù	%	%	vcS	cS	mS	fS	vfS	cSi	fSi	Clay	meq/100gr		
A	0	0	5.3	4.2	0.0		1	B	0.3	0.00	3.6	2.1	0.5	0.3	0.0	0.5	81	0.0	2	13	21	31	14	6	4	11	21	H	N
B	0	0	5.6	4.8	0.0		0	B	0.2	0.00	6.5	3.6	1.4	0.3	0.1	0.5	83	0.0	0	10	19	24	11	14	2	21	28	H	N
C	0	0	5.4	4.6	0.0		0	B	0.1	0.00	8.3	5.4	1.8	0.1	0.3	0.5	92	0.0	10	13	14	15	8	6	4	32	25	H	N

Soil Survey of Botswana FAO/BOT/85/011   last changed : 28/09/89   Print date: 12/02/90

EC : Electrical Conductivity   m : method ...   * = saturated paste   not marked = 1:5 in water

P : Available Phosphorus determination   m : method ...   O = Olsen   B = Bray

C : Organic Carbon determination   Walkley-Black method

N : Total Nitrogen determination   Kjeldahl method

CEC and bases : Ammonium acetate method

EXAC : Exchangeable acidity extracted with KCl

CARBO : Free Carbonates by destruction with HCl

PART.SIZE DETERMINATION   METHOD: H = Hydrometer Method, P = Pipette Method, * = Not Known
PRETREATMENT: O = Organic Matter, F = Free Iron Oxides, C = Carbonates, S = Soluble Salts N = None

SOIL PROFILE DESCRIPTION Profile: PN 0153 Unit: G06 Status: 2

SHEET : 2227D1
LOCATION : 3.3km East North East of Maunatlala Primary School.
AUTHOR(S): B.G.Moganane L.S.Lekoma
CLASSIFICATION FAO: Areni-Ferric Lixisol(1988) Arenic Ferric Luvisol (1974) petric (skeletic) phase
ST : Arenic kanhaplic Haplustalf
LANDFORM : plain
TOPOGRAPHY: almost flat
SURF. CHAR: slight sealing, no cracks, nil evidence of salt,
LAND USE: traditional grazing
SPECIES : Trees - Combretum apiculatum (dom.) Colophospermum mopane Acacia nigrescens Commiphora mollis
: Shrubs - Colophospermum mopane (dom.) Combretum apiculatum Dichrostachys cinerea Acacia tortilis subs. heterocantha
: Grasses/forbs- Aristida congesta (dom)
PARENT MATERIAL: in situ weathered
MOIST. COND: dry 0 - 130 cm
SURF.STONES: none
EROSION : slight sheet erosion

GRID : NF-677-023
COORD: 22-35-10-S 27-39-30-E
DATE : 24/11/88
LAND ELEMENT : not applicable
MICRO TOPOGRAPHY: low hummocks
VEGETATION: savanna
ROCK TYPE: acid igneous/metamorphic
ROCK OUTCROP: none

AGRO CLIM.ZONE: 3B4
ELEVATION : 853 m
SMR: aridic to ustic
POSITION: intermediate part
SLOPE : 0.5 - 1.0% straight
GRASSCOVER: 30 - 70 %
GEOL.UNIT: Basement complex
DRAINAGE : well drained
HUMAN INF: nil

REMARKS:

SAMPLES: A: 0 - 0 B: 0 - 0 C: 0 - 0

A 0 - 30 cm 7.5YR 3/3 (moist) and 7.5YR 5.5/4 (dry), sand (8% clay), weak medium and coarse subangular blocky structure, slightly hard, common fine and medium pores, very few fine angular quartz rock fragments, non calcareous, common fine roots, clear smooth boundary.

Bt1 30 - 75 cm 5YR 3/4 (moist) and 5YR 5.5/6 (dry), loamy sand (11% clay), weak fine and medium subangular blocky structure, slightly hard, few fine and medium pores, few fine angular quartz rock fragments, very few fine irregular hard iron-manganese reddish-brown concretions, non calcareous, common fine and medium roots, gradual smooth boundary.

Bt2 75 - 90 cm 5YR 4/5 (moist) and 7.5YR 5.5/6 (dry), loamy sand (14% clay), very weak fine and medium subangular blocky structure, slightly hard, patchy thin cutans, few very fine and fine pores, few fine angular quartz rock fragments, very few fine irregular hard iron-manganese reddish-brown concretions, non calcareous, common fine and medium roots, clear wavy boundary.

Cco 90 - 130 cm slightly hard, weakly cemented, frequent fine and medium angular quartz rock fragments, very frequent fine irregular hard iron-manganese reddish-brown concretions, non calcareous, few very fine and fine roots,

Soil Survey of Botswana FAO/BOT/85/011 last changed : 28/09/89 print date: 12/02/90

S T A N D A R D   S O I L   A N A L Y S I S   R E S U L T S

PROFILE: PN 0153

SAMPLE	DEPTH		pH		EC	m	P	m	C	N	CEC	Ca	Mg	K	Na	EXAC	PBS	CARBO	Particle size (weight %)								CECclay	METH	PRETR
			H2O	CaCL2	mS/cm		ppm		weight %		ù---------		meq/100gr soil			---------ù	%	%	vcS	cS	mS	fS	vfS	cSi	fSi	Clay	meq/100gr		
A	0	0	5.5	4.3	0.0		1	B	0.3	0.00	2.5	2.0	0.5	0.3	0.0	0.2	>100	0.0	0	18	22	32	15	3	3	6	20	H	N
B	0	0	5.5	4.3	0.0		1	B	0.3	0.00	2.3	1.3	0.7	0.3	0.1	0.2	>100	0.0	5	14	23	28	14	6	3	6	18	H	N
C	0	0	5.2	4.1	0.0		1	B	0.0	0.00	2.5	1.3	0.8	0.3	0.1	0.5	100	0.0	0	17	28	30	10	1	2	12	20	H	N

Soil Survey of Botswana   FAO/BOT/85/011   last changed : 28/09/89   Print date: 12/02/90

EC : Electrical Conductivity   m : method ...   * = saturated paste   not marked = 1:5 in water

P : Available Phosphorus determination   m : method ...   O = Olsen   B = Bray

C : Organic Carbon determination   Walkley-Black method

N : Total Nitrogen determination   Kjeldahl method

CEC and bases : Ammonium acetate method

EXAC : Exchangeable acidity extracted with KCl

CARBO : Free Carbonates by destruction with HCl

PART.SIZE DETERMINATION   METHOD: H = Hydrometer Method, P = Pipette Method, * = Not Known
PRETREATMENT: O = Organic Matter, F = Free Iron Oxides, C = Carbonates, S = Soluble Salts N = None

SOIL PROFILE DESCRIPTION — Profile: PN 0154 Unit: G06a Status: 2

SHEET : 2227D1
LOCATION : 6km East of Maunatlala Primary School.
AUTHOR(S): B.G.Moganane L.S.Lekoma
CLASSIFICATION FAO: Rhodi-Ferric Lixisol(1988) Ferric Luvisol (1974) petric (skeletic) phase
ST : kandic Rhodustalf

GRID : NF-707-019
COORD: 22-35-22-S 27-41-15-E
DATE : 24/11/88

AGRO CLIM.ZONE: 3B4
ELEVATION : 853 m
SMR: aridic to ustic

LANDFORM : plain
TOPOGRAPHY: almost flat
SURF. CHAR: slight sealing, no cracks, nil evidence of salt,
LAND USE: traditional dryland farming, crops: sorghum, maize
SPECIES : Trees - Colophospermum mopane (dom.) Sclerocarya caffra
: Shrubs - Colophospermum mopane (dom.) Combretum apiculatum Acacia tortilis subs. heterocantha
: Grasses/forbs- Aristida congesta (dom) Eragrostis rigidior
PARENT MATERIAL: in situ weathered
MOIST. COND: dry 0 - 100 cm
SURF.STONES: none
EROSION : slight sheet erosion

LAND ELEMENT : not applicable
MICRO TOPOGRAPHY: termite mounds
VEGETATION: savanna
ROCK TYPE: acid igneous/metamorphic
ROCK OUTCROP: none

POSITION: intermediate part
SLOPE : 0.5 - 1.0% straight
GRASSCOVER: 30 - 70 %
GEOL.UNIT: Basement complex
DRAINAGE : well drained
HUMAN INF: ploughing

REMARKS: Vegetation is a regrowth in the old field.

SAMPLES: A: 0 - 0 B: 0 - 0 C: 0 - 0

Ap	0 - 20 cm	5YR 3/5 (moist) and 5YR 4.5/6 (dry), loamy sand, weak coarse subangular blocky structure, hard, common fine and medium pores, very few fine angular quartz rock fragments, non calcareous, few very fine and fine roots, clear smooth boundary.
Bt1	20 - 55 cm	2.5YR 3/5 (moist) and 2.5YR 4/6 (dry), sandy clay loam, weak coarse and very coarse subangular blocky structure, slightly hard to hard, patchy thin cutans, common fine and medium pores, few fine angular quartz rock fragments, non calcareous, few fine and medium roots, gradual smooth boundary.
Bt2	55 - 90 cm	2.5YR 3/7 (moist) and 2.5YR 4/7 (dry), sandy clay, very weak coarse and very coarse subangular blocky structure, very hard, broken moderately thick cutans, few fine and medium pores, few fine angular quartz rock fragments, non calcareous, few very fine and fine roots, clear wavy boundary.
Cr	90 - 100 cm	frequent medium angular quartz rock fragments, non calcareous,

Soil Survey of Botswana FAO/BOT/85/011 — last changed : 28/09/89 — print date: 12/02/90

S T A N D A R D   S O I L   A N A L Y S I S   R E S U L T S

PROFILE: PN 0154

SAMPLE	DEPTH		pH		EC	m	P	m	C	N	CEC	Ca	Mg	K	Na	EXAC	PBS	CARBO	Particle size (weight %)								CECclay	METH	PRETR
			H2O	CaCL2	mS/cm		ppm		weight %		ù---------		meq/100gr soil			---------ù	%	%	vcS	cS	mS	fS	vfS	cSi	fSi	Clay	meq/100gr		
A	0	0	5.8	4.9	0.0		2	B	0.3	0.00	4.1	2.6	0.7	0.5	0.0	0.5	93	0.0	4	13	24	27	15	2	2	12	24	H	N
B	0	0	5.9	5.1	0.1		0	B	0.1	0.00	5.3	2.6	1.0	0.6	0.1	0.5	81	0.0	6	13	21	20	8	5	3	24	20	H	N
C	0	0	5.8	5.3	0.5		0	B	0.1	0.00	5.8	3.8	1.4	0.3	0.2	0.2	98	0.0	7	13	18	17	7	3	6	29	18	H	N

Soil Survey of Botswana FAO/BOT/85/011   last changed : 28/09/89   Print date: 12/02/90

EC : Electrical Conductivity   m : method ...   * = saturated paste   not marked = 1:5 in water

P : Available Phosphorus determination   m : method ...   O = Olsen   B = Bray

C : Organic Carbon determination   Walkley-Black method

N : Total Nitrogen determination   Kjeldahl method

CEC and bases : Ammonium acetate method

EXAC : Exchangeable acidity extracted with KCl

CARBO : Free Carbonates by destruction with HCl

PART.SIZE DETERMINATION   METHOD: H = Hydrometer Method, P = Pipette Method, * = Not Known
PRETREATMENT: O = Organic Matter, F = Free Iron Oxides, C = Carbonates, S = Soluble Salts N = None

SOIL PROFILE DESCRIPTION Profile: PN 0155 Unit: G02c Status: 2

SHEET : 2227D1
LOCATION : 3.6km North East North of Maunatlala village.
AUTHOR(S): B.G.Moganane L.S.Lekoma
CLASSIFICATION FAO: Rhodi-Chromic Luvisol(1988) Chromic Luvisol (1974) shallow petric (skeletic) phase
ST : Typic Rhodustalf
LANDFORM : plain
TOPOGRAPHY: almost flat
SURF. CHAR: slight sealing, no cracks, nil evidence of salt,
LAND USE: traditional grazing
SPECIES : Trees - Colophospermum mopane (dom.) Acacia tortilis subs. heterocantha Combretum apiculatum
: Shrubs - Colophospermum mopane (dom.) Dichrostachys cinerea Combretum apiculatum Acacia tortilis subs. heterocantha
: Grasses/forbs- Aristida congesta (dom) Eragrostis rigidior
PARENT MATERIAL: in situ weathered
MOIST. COND: dry 0 - 70 cm
SURF.STONES: very few gravel
EROSION : moderate sheet erosion

GRID : NF-668-040
COORD: 22-34-15-S 27-39-00-E
DATE : 24/11/88
LAND ELEMENT : not applicable
MICRO TOPOGRAPHY: even
VEGETATION: savanna
ROCK TYPE: acid igneous/metamorphic
ROCK OUTCROP: none

AGRO CLIM.ZONE: 3B4
ELEVATION : 838 m
SMR: aridic to ustic
POSITION: intermediate part
SLOPE : 0.5 - 1.0% straight
GRASSCOVER: 30 - 70 %
GEOL.UNIT: Basement complex
DRAINAGE : well drained
HUMAN INF: nil

REMARKS: This profile has been truncatedto an extend that the Bt is almost at the surface.

SAMPLES: A: 0 - 0 B: 0 - 0

A 0 - 10 cm 5YR 3/4 (moist) and 5YR 4/6 (dry), sandy loam, weak coarse subangular blocky structure, slightly hard, common fine and medium pores, non calcareous, few very fine and fine roots, clear smooth boundary.

Bt 10 - 45 cm 2.5YR 3/5 (moist) and 2.5YR 3/6 (dry), sandy clay loam, weak subangular blocky structure, hard, patchy thin cutans, common fine and medium pores, few fine angular quartz rock fragments, non calcareous, few very fine roots, clear wavy boundary.

C 45 - 70 cm weak very coarse subangular and angular blocky structure, common fine and medium pores, very frequent fine and medium angular quartz rock fragments, non calcareous, few very fine and fine roots,

S T A N D A R D   S O I L   A N A L Y S I S   R E S U L T S

PROFILE: PN 0155

SAMPLE	DEPTH		pH		EC	m	P	m	C	N	CEC	Ca	Mg	K	Na	EXAC	PBS	CARBO	Particle size (weight %)								CECclay	METH	PRETR
			H2O	CaCL2	mS/cm		ppm		weight %		ù---------		meq/100gr soil			---------ù	%	%	vcS	cS	mS	fS	vfS	cSi	fSi	Clay	meq/100gr		
A	0	0	6.2	5.4	0.0		3	B	0.2	0.00	4.1	2.5	1.0	0.3	0.0	0.0	93	0.0	6	12	17	33	14	5	3	10	32	H	N
B	0	0	6.4	5.6	0.0		0	B	0.2	0.00	7.8	5.7	2.4	0.1	0.2	0.0	>100	0.0	0	22	22	32	10	3	2	10	73	H	N

Soil Survey of Botswana FAO/BOT/85/011 last changed : 28/09/89 Print date: 12/02/90

EC : Electrical Conductivity m : method ... * = saturated paste not marked = 1:5 in water

P : Available Phosphorus determination m : method ... O = Olsen B = Bray

C : Organic Carbon determination Walkley-Black method

N : Total Nitrogen determination Kjeldahl method

CEC and bases : Ammonium acetate method

EXAC : Exchangeable acidity extracted with KCl

CARBO : Free Carbonates by destruction with HCl

PART.SIZE DETERMINATION METHOD: H = Hydrometer Method, P = Pipette Method, * = Not Known
PRETREATMENT: O = Organic Matter, F = Free Iron Oxides, C = Carbonates, S = Soluble Salts N = None

SOIL PROFILE DESCRIPTION — Profile: MC 0050 Unit: G02d Status: 2

SHEET : 2327A3
LOCATION : North West of Makwati,8km East of Budungwe hill.
AUTHOR(S): A.Remmelzwaal B.G.Moganane
CLASSIFICATION FAO: Haplic Lixisol(1988) Ferric Luvisol (1974) petric (skeletic) phase
ST : kandic Paleustalf

GRID : NE-146-283
COORD: 23-15-23-S 27-08-32-E
DATE : 15/04/82

AGRO CLIM.ZONE: 2D3
ELEVATION : 922 m
SMR: ustic to aridic

LANDFORM : plain
TOPOGRAPHY: almost flat
SURF. CHAR: no cracks, nil evidence of salt,
LAND USE: traditional grazing
SPECIES : Trees - Combretum apiculatum (dom.) Acacia nigrescens Sclerocarya caffra
: Shrubs - Acacia tortilis subs. heterocantha
: Grasses/forbs-

LAND ELEMENT :
MICRO TOPOGRAPHY: even
VEGETATION: savanna

POSITION:
SLOPE : - 1 %
GRASSCOVER:

PARENT MATERIAL: in situ weathered
MOIST. COND: moist 0 - 55 cm
SURF.STONES: none
EROSION : nil

ROCK TYPE: gneiss
ROCK OUTCROP: none

GEOL.UNIT: Basement complex
DRAINAGE : moderately well drained
HUMAN INF: nil

REMARKS: Analytical clay content low compared to field estimate.

SAMPLES: A: 0 - 20 B: 40 - 55

A 0 - 25 cm 10YR 3/2.5 (moist), loamy coarse sand to coarse sandy loam, massive structure, hard friable, common very fine and fine pores, non calcareous, common roots, clear smooth boundary.

Bt 25 - 55 cm 7.5YR 4/3 (moist), sandy clay loam (30% clay), very weak medium and coarse subangular blocky structure, hard to very hard firm, broken moderately thick clay cutans, common very fine and fine pores, few slightly weathered quartz rock fragments, non calcareous, common fine roots,

C 55 cm + very frequent weathered gneiss and very frequent fine and medium slightly weathered quartz rock fragments,

S T A N D A R D   S O I L   A N A L Y S I S   R E S U L T S

PROFILE: MC 0050

SAMPLE	DEPTH		pH		EC m	P m	C	N	CEC	Ca	Mg	K	Na	EXAC	PBS	CARBO	Particle size (weight %)								CECclay	METH	PRETR
			H2O	CaCL2	mS/cm	ppm	weight %		ù---------		meq/100gr soil			---------ù	%	%	vcS	cS	mS	fS	vfS	cSi	fSi	Clay	meq/100gr		
A	0	20	6.1	5.5	0.0	0	0.6	0.00	6.6	3.8	0.9	0.6	0.0	0.0	80	0.0	15	23	18	18	8	4	3	12	34	P	0
B	40	55	5.9	5.4	0.0	3	0.5	0.00	6.6	3.7	1.1	0.5	0.1	0.0	82	0.0	14	23	17	15	6	3	3	20	23	P	0

Soil Survey of Botswana FAO/BOT/85/011   last changed : 28/09/89   Print date: 04/12/89

EC : Electrical Conductivity   m : method ...   * = saturated paste   not marked = 1:5 in water

P : Available Phosphorus determination   m : method ...   O = Olsen   B = Bray

C : Organic Carbon determination   Walkley-Black method

N : Total Nitrogen determination   Kjeldahl method

CEC and bases : Ammonium acetate method

EXAC : Exchangeable acidity extracted with KCl

CARBO : Free Carbonates by destruction with HCl

PART.SIZE DETERMINATION   METHOD: H = Hydrometer Method, P = Pipette Method, * = Not Known
PRETREATMENT: O = Organic Matter, F = Free Iron Oxides, C = Carbonates, S = Soluble Salts N = None

APPENDIX 2 : RECALCULATED LAND CHARACTERISTICS FOR STANDARD 25CM THICK LAYERS

Profile No: PN 150		Soil Unit: A15		
land characteristics	0-25	25-50	50-75	75-100
topography (%)	1.5			
flooding (class)	Fo			
drainage (class)	well			
texture (class)	LS	LS	SC	SC
coarse fragments (%)	1	2.5	10	10
surface stoniness (%)	0			
CaCo3 status (%)	0	0	0	0
CEC soil (meq/100g soil)	3.2			
salinity (mmho/cm)	0	0	0.2	0.2
alkalinity (ESP)	2	5	1	1
depth to impervious layer (cm)	80			

Profile No: PN 151	Soil Unit: G6a			
land characteristics	0-25	25-50	50-75	75-100
topography (%)	0.75			
flooding (class)	Fo			
drainage (class)	Well			
texture (class)	SCL	SCL	SCL	SCL
coarse fragments (%)	2	10	10	10
surface stoniness (%)	0			
CaCO3 status (%)	0	0	0	0
CEC soil (meq/100g soil)	4.9			
salinity (mmho/cm)	0	0	0	0
alkalinity (ESP)	0.3	1.4	7.8	7.8
depth to impervious layer (cm)	85			

Profile No: PN 152	Soil Unit: G8			
land characteristics	0-25	25-50	50-75	75-100
topography (%)	0.75			
flooding (class)	Fo			
drainage (class)	Well			
texture (class)	SL	SCL	SCL	SCL
coarse fragments (%)	10	10	26	26
surface stoniness (%)	0			
CaCO3 status (%)	0	0	0	0
CEC soil (meq/100g soil)	4.2			
salinity (mmho)	0	0	0	0
alkalinity (ESP)	0.3	1.5	3.6	3.6
depth to impervious layer (cm)	90			

Profile No: PN 153	Soil Unit: G6			
land characteristics	0-25	25-50	50-75	75-100
topography (%)	0.75			
flooding (class)	Fo			
drainage (class)	well			
texture (class)	LS	SCL	SCL	SCL
coarse fragments (%)	2.5	11	13	42
surface stoniness (%)	0			
CaCO3 status (%)	0	0	0	0
CEC soil (meq/100g soil)	2.5			
salinity (mmho/cm)	0	0	0	0.1
alkalinity (ESP)	0	1.5	1.9	2.5
depth to impervious layer (cm)	130+			

Profile No: PN 154	Soil Unit: G6a			
land characteristics	0-25	25-50	50-75	75-100
topography (%)	0.75			
flooding (class)	Fo			
drainage (class)	well			
texture (class)	SL	SCL	SCL	SCL
coarse fragments (%)	4	10	10	10
surface stoniness (%)	0			
CaCO3 status (%)	0	0	0	0
CEC soil (meq/100g soil)	4.3			
salinity (mmho/cm)	0	0	0.1	0.1
alkalinity (ESP)	0.4	1.9	3.2	2.5
depth to impervious layer (cm)	90			

Profile No: PN 155	Soil Unit: G2c			
land characteristics	0-25	25-50	50-75	75-100
topography (%)	0.75			
flooding (class)	Fo			
drainage (class)	well			
texture (class)	LS	LS	LS	
coarse fragments (%)	6	20	60	
surface stoniness (%)	2.5 (gravel)			
CaCO3 status (%)	0	0	0	
CEC soil (meq/100g)	6.3			
salinity (mmho/cm)	0.1	0.1	0.1	
alkalinity (ESP)	1.5	2.6	2.6	
depth to impervious layer (cm)	70			

Profile No: MC 50	Soil Unit: G2d			
land characteristics	0-25	25-50	50-75	75-100
topography (%)	0.5			
flooding (class)	Fo			
drainage (class)	moderately well			
texture (class)	LS	SL/SCL	SL/SCL	
coarse fragments (%)	0	10	10	
surface stoniness	0			
CaCO3 status (%)	0	0	0	
CEC soil (meq/100g soil)	6.6			
salinity (mmho/cm)	0.0	0.0	0.0	
alkalinity (ESP)	0.0	2.0	2.0	
depth to impervious layer (cm)	55			

APPENDIX 3 : ASSESSMENT OF THE INDIVIDUAL LAND CHARACTERISTICS FOR SPRINKLER AND CENTER PIVOT IRRIGATION

Profile No: PN 150		Soil Unit: A15			
land characteristics		0-25 cm	25-50 cm	50-75 cm	75-100 cm
topography	sprinkler center pivot	100 91.5			
flooding		100			
drainage		100			
texture	sprinkler	72.5	72.5	100	100
	centre pivot	100	100	52.5	52.5
coarse fragments		100	100	91.5	91.5
surface stoniness		100			
CaCO3 status		91.5	91.5	91.5	91.5
CEC soil		80			
salinity	sensitive crop	100	100	100	100
	medium tol.crop	100	100	100	100
	tolerant crop	100	100	100	100
alkalinity	sensitive crop	100	100	100	100
	medium tol.crop	100	100	100	100
	tolerant crop	100	100	100	100
depth to impervious layer (cm)		80			

Profile No: PN 151		Soil Unit: G6a			
land characteristics		0-25 cm	25-50 cm	50-75 cm	75-100 cm
topography		100			
flooding		100			
drainage		100			
texture	sprinkler	100	100	100	100
	centre pivot	72.5	72.5	72.5	72.5
coarse fragments		100	91.5	91.5	91.5
surface stoniness		100			
CaCO3 status		91.5	91.5	91.5	91.5
CEC soil		91			
salinity	sensitive crop	100	100	100	100
	medium tol.crop	100	100	100	100
	tolerant crop	100	100	100	100
alkalinity	sensitive crop	100	100	94	94
	medium tol.crop	100	100	100	100
	tolerant crop	100	100	100	100
depth to imperious layer (cm)		85			

Profile No: PN 152	Soil Unit: G8			
land characteristics	0-25 cm	25-50 cm	50-75 cm	75-100 cm
topography	100			
flooding	100			
drainage	100			
texture — sprinkler	91.5	100	100	100
texture — centre pivot	91.5	72.5	72.5	72.5
coarse fragments	91.5	91.5	76	76
surface stoniness	100			
CaCo3 status	91.5	91.5	91.5	91.5
CEC soil	86			
salinity — sensitive crop	100	100	100	100
salinity — medium tol.crop	100	100	100	100
salinity — tolerant crop	100	100	100	100
alkalinity — sensitive crop	100	100	100	100
alkalinity — medium tol.crop	100	100	100	100
alkalinity — tolerant crop	100	100	100	100
depth impervious layer (cm)	90			

Profile No: PN 153		Soil Unit: G6			
land characteristics		0-25 cm	25-50 cm	50-75 cm	75-100 cm
topography		100			
flooding		100			
drainage		100			
texture	sprinkler	72.5	100	100	100
	centre pivot	100	72.5	72.5	72.5
coarse fragments		100	90	88	58
surface stoniness		100			
CaCO3 status		91.5	91.5	91.5	91.5
CEC soil		76			
salinity	sensitive crop	100	100	100	100
	medium tol.crop	100	100	100	100
	tolerant crop	100	100	100	100
alkalinity	sensitive crop	100	100	100	100
	medium tol.crop	100	100	100	100
	tolerant crop	100	100	100	100
depth to impervious layer (cm)		130+			

Profile No: PN 154		Soil Unit: G6a			
land characteristics		0-25 cm	25-50 cm	50-75 cm	75-100
topography		100			
flooding		100			
drainage		100			
texture	sprinkler	91.5	100	100	100
	centre pivot	91.5	72.5	72.5	72.5
coarse fragments		100	91.5	91.5	91.5
surface stoniness		100			
CaCO3 status		91.5	91.5	91.5	91.5
CEC soil		87			
salinity	sensitive crop	100	100	100	100
	medium tol.crop	100	100	100	100
	tolerant crop	100	100	100	100
alkalinity	sensitive crop	100	100	100	100
	medium tol.crop	100	100	100	100
	tolerant crop	100	100	100	100
depth to impervious layer (cm)		90			

Profile No: PN 155		Soil Unit: G2c			
land characteristics		0-25 cm	25-50 cm	50-75 cm	75-100
topography		100			
flooding		100			
drainage		100			
texture	sprinkler	72.5	72.5	72.5	
	centre pivot	100	100	100	
coarse fragments		97	80	45	
surface stoniness		100			
CaCO3 status		91.5	91.5	91.5	
CEC soil		100			
salinity	sensitive crop	100	100	100	
	medium tol.crop	100	100	100	
	tolerant crop	100	100	100	
alkalinity	sensitive crop	100	100	100	
	medium tol.crop	100	100	100	
	tolerant crop	100	100	100	
depth to impervious layer (cm)		70			

Profile No: MC 50		Soil Unit: G2d			
land characteristics		0-25 cm	25-50 cm	50-75 cm	75-100 cm
topography		100			
flooding		100			
drainage		91.5			
texture	sprinkler	72.5	100	100	
	centre pivot	100	72.5	72.5	
coarse fragments		100	91.5	91.5	
surface stoniness		100			
CaCO3 status		91.5	91.5	91.5	
CEC soil		100			
salinity	sensitive crop	100	100	100	
	medium tol.crop	100	100	100	
	tolerant crop	100	100	100	
alkalinity	sensitive crop	100	100	100	
	medium tol.crop	100	100	100	
	tolerant crop	100	100	100	
depth to impervious layer (cm)		55			

APPENDIX 4 : LIST OF ABBREVIATIONS USED

Cm	:	massive clay
SiCm	:	massive silty clay
C+60,	:	very fine clay, vertisol structure
C+60,s	:	very fine clay, blocky structure
C-60,	:	clay, vertisol structure
C-60,s	:	clay, blocky structure
SiC	:	silty clay
CL	:	clay loam
Si	:	silt
SiL	:	silt loam
SC	:	sandy clay
L	:	loam
SCL	:	sandy clay loam
fSL	:	fine sandy clay loam
CSL	:	coarse sandy loam
SL	:	sandy loam
LfS	:	loamy fine sand
LS	:	loamy sand
LcS	:	loamy coarse sand
fS	:	fine sand
S	:	sand
cS	:	coarse sand

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