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SOIL SURVEY and LAND CLASSIFICATION of SANDY SOILS at MOTOPI

By

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TECHNICAL NOTE 20

SOIL SURVEY AND LAND CLASSIFICATION OF SANDY SOILS IN THE MOTOPI AREA

THE MOTOPI IRRIGATION SCHEME

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CONTENTS

1.1 Abstract

The report deals with a soil survey carried out in North Western Botswana at the left bank of the Boteti river, 55 miles East from Maun.

An area of 1,756 acres was surveyed on detailed level to assess the irrigation potential of the soils.

Water in this area forms no constraint to irrigated land use but some soil limitations are severe. Three kinds of soil were encountered, two formed on Kalahari sand and the other developed on calcrete. All soils are very extensive in the northern and central part of Botswana.

In the survey area the coarse textured soils as sands and loamy sands take up the largest acreage and occur near the river. It is on these soils that a small irrigation scheme of five acres is planned, (mapping unit M10). This scheme became operational in the meantime. The chief soil limitations are (1) very low fertility and (2) their texture - a homogeneous loamy fine sand.

No soils of this kind have been irrigated before in Botswana. Research as to the behaviour of these soils under (sprinkler) irrigation and their potential for adapted crops will be of extreme importance to future irrigated land use in Botswana.

1.2 Introduction

Field work for this soil investigation was carried out in November 1968 and in February 1969. From 2,000 acres covered by a first reconnaissance an initial 1,700 were selected for more detailed observations. Preliminary soil information was made available to the FAO and the Government shortly after the above mentioned data. This report refers to the detailed soil survey. The need and purpose for. (1) The survey was carried out by the FAO pedologist and his counterpart now Field Irrigation Officer in Mahalapye.

1.3 Acknowledgements

The help and co-operation received from the water engineer and the field irrigation officer during the execution of the survey are warmly acknowledged.

1.4 Summary of conclusions and recommendations

Three kinds of soil are recognised in the region. The coarse textured soils, such as fine sands and loamy fine sands, are developed on Kalahari sand material; the other one a medium textured soil developed on calcrete. Slope and depth phases were used. Six-soil mapping units are indicated on the soil and irrigation potential map. They are M10, M10b and M15, M16 and L20 and L21. Preliminary soil series names have been coined to the soils, namely, Motopi series (M.U, M10, M10b; Lenyaphiri series

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(1) the survey is described in the Amended Planops April 1970

(M.U, L20 and L21) and Boteti series (M.U, M15). The soils are very extensive in Northern and Central Botswana.

Their potential for irrigated farming is virtually unknown. A number of serious soil limitations occur, such as soil texture, soil fertility, soil depth and drainage. Some of these are not easily correctable such as depth and texture, but others can be improved (fertility). No class 5 and 6 land was surveyed, but class 2, 3 and 4 are encountered (See Table 1.)

Table 1.

Class 2 land	340	acres:	Mapping unit L20
Class 3 land	190	acres:	Mapping unit L21
Class 4 land	1,226	acres:	Mapping unit M10, M10b, M15, M16.
Total:	1,756	acres.	

The proposed irrigation scheme will be on the soils of M.U. M10 (class 4 land). Dominant limitations are soil texture and soil fertility. Recommended crops include groundnuts, potatoes, maize, sorghum, sunflower, castor oil and citrus and some fodder crops. Water application is to be handled with care. Although the soils are very rapidly permeable, waterlogging may occur in the deep sub-soil as a result of the compaction of the very fine sand grains. Heavy fertilization will be needed to ensure a continuous crop growth and yield. Nitrogen and phosphates are particularly low in concentration. The use of kraal manure is recommended. It is also recommended to take soil samples at regular intervals throughout the year to check the fertility level of the soil. Special analyses may be necessary to detect any trace element deficiency, such as Sinc and Iron. It is recommended to check the soil moisture variations in the soils at fixed times either with soil moisture blocks or in a well. This is to ensure that the correct amount of water is applied with relation to the soil drainage.

With correct management it is expected that the soil will produce satisfactory crops.

Chapter 1

THE ENVIRONMENT

1a. Location

The area is located in the northwest of Botswana on the north (left) bank of the Boteti river and situated in the State Lands. The northern boundary is the mainfoad from Francistown to Maun; the southern boundary the Boteti river; the western boundary the fence of the Veterinary Research Department and the eastern boundary is the P.W.D. road. The distance to Maun over the mainroad is 55 miles and to Francistown 255 miles. The approximate latitude and longitude for the area are 20° 12'S and 24° 10' E.

1b. The Climate

The climate is defined as semi-arid with distinct summer and winter seasons. The rainy season is mainly during the summer months from mid-October to mid-April. A few important climatological data, taken from the nearest meteorological station Maun, are represented in Table 2.

Table 2: Climatological data.

months item	J	F	M	A	M	J	J	A	S	O	N	D	Mean Values
1	195	95	81	25	5	0.5	0	0	1	16	43	81	452 mm
2	32.0	31.0	30.9	30.5	27.9	24.8	25.1	28.5	32.6	35.0	34.2	32.5	30.5 grC
3	18.9	18.7	17.5	14.4	9.6	5.7	5.6	8.6	13.0	17.6	18.9	18.9	13.9 "
4	25.4	24.4	24.1	22.0	19.2	15.7	17.0	19.9	23.4	26.1	26.7	26.0	22.5 "
5	199	172	169	134	105	87	93	126	169	214	200	198	1860 mm
6	151	131	129	99	75	61	65	92	128	167	157	154	1408 "
7	140	121	119	91	67	55	58	83	118	155	146	143	1296 "
8	30.4	29.4	29.1	27.0	23.6	19.6	19.5	21.6	25.6	28.8	29.2	29.3	26.1 grC

1 = annual rainfall in mm
2 = mean of daily maximum temperature in gr.C
3 = mean of daily minimum temperature in gr.C
4 = monthly mean air temperature in gr.C.
5 = mean monthly evaporation from open water in mm
6 = mean monthly evaporation from short green crop
7 = mean monthly evaporation from wet bore soil
8 = mean monthly soil temperature in gr.C from 10-120 cm.

Source: The Agroclimatology of Botswana by J.G. Pike;
Project Technical Report No.1 1971 UNDP(SF) FAO Botswana Project
and
The Northern State Lands, Botswana by A. Blair Rains and A.D. McKay 1967.

Groundfrost may occur in lower lying areas during May-August but particularly from June to July. Highest evaporation is measured during October and November.

The soil climate is partly reflected in fig.1 and in Table 3 in which soil temperatures are given at different depths throughout the year. Individual soil temperature data for 0800, 1400 and 20.00 hrs follow the basic trend as indicated in fig.1.

The given mean temperatures for the soil temperature of the soil between 10 - 120 cm does not differ greatly from the values obtained at 30 cm and 60 cm. The latter are therefore omitted on the figure but are given in table 3.

Table 3: Mean soil temperatures at different depth

Soil depth	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
10 cm	31.0	30.2	30.3	27.1	22.5	18.8	18.4	22.3	26.9	30.3	30.3	29.9
30 "	30.4	29.2	28.9	26.7	22.9	19.4	19.1	21.5	25.6	29.0	29.0	29.4
60 "	30.3	29.2	28.6	27.0	24.2	20.3	19.8	21.6	25.0	28.0	28.3	29.0
120 cm	30.0	29.0	28.8	27.7	25.6	22.2	21.3	22.1	24.5	27.2	28.4	28.9
10-120 cm	30.4	29.4	29.1	29.0	23.6	19.6	19.5	21.6	25.6	28.7	29.2	29.3

Source: data obtained from Met. Office Maun; soils are very similar to map unit M10.

From January onwards there is a distinct downward trend in all soil temperatures, that persists till July. From then onwards the soil temperature rises till January. It evens off slightly during October - November.

The increase in soil temperature during the first half of the rainy season may restrict the water infiltration rate in the soil. However during the latter part of the rainy season the falling soil temperature gradient promotes a better transmitability for (rain) water.

Soil temperatures show the greatest amplitude with depth at 08.00 hrs and the smallest amplitude at 20.00 hrs.

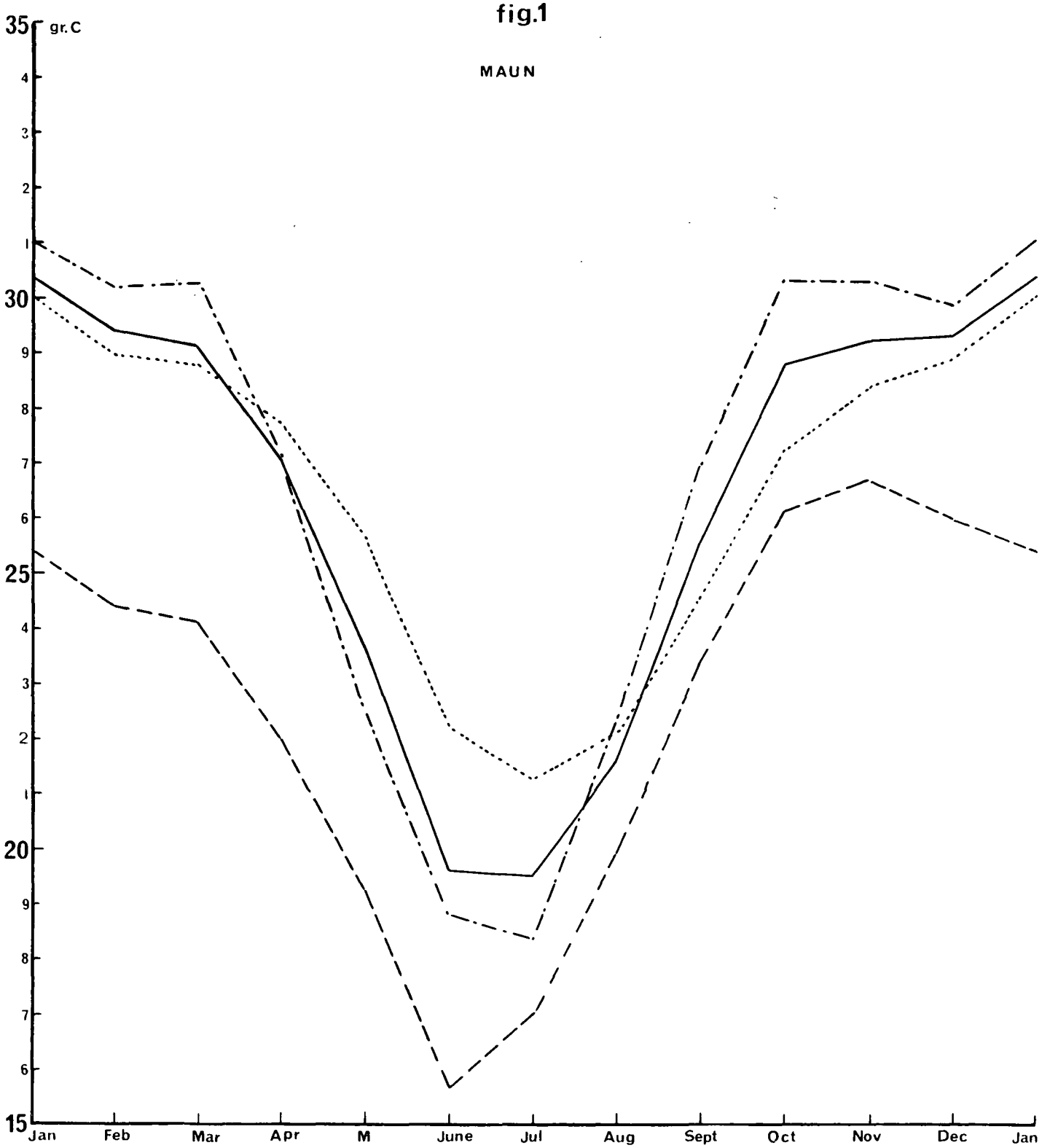
The soil temperature is classified as Hyperthermic (more than 22°C mean temperature at 50 cm depth).

1c. Physiography

According to the Provisional Geological Map of Botswana (1968) a variety of non to partly consolidated wind and/or water deposited sediments may be encountered. In the area the "hard" geology consists of calcrete. This material forms mainly the parent material of the soils encountered in the north to north eastern part of the survey area. In the remaining part sands of

fig.1

MAUN



——— mean monthly soil temperature from 10–120 cm

– – – – – " " air " .

—·—·—·— " " soil " at 10 cm

..... " " soil " at 120 cm

data from 1965–1970

w.siderius

the Kalahari type form the parent material. The sands are rounded and homogeneous in texture. Dominant grain sizes are from 100-300 micron, with emphasis on the 100-250 micron fraction (fine sand). The character of the sand and its sedimentary structure indicates eolian origin. However in riverine areas the sands may be redeposited by water.

The physiography comprises of a number of landscape elements:

(1) the present river floodplain;
(2) steep bank of the river;
(3) a narrow discontinuous levee;
(4) a number of plains which in the far south eastern part of the areas may be defined as river terraces and
(5) almost level to gentle undulating upland in which usually local depressions are encountered. These depressions (pans) are presumably formed by the solution of the underlying calcrete together with deflation. The highest ground is encountered in the eastern part of the survey area, where the soils are very sandy. Generally the slopes do not exceed 2%, except along the river and the tributary drainage course just on the far west of the area. The overall surface drainage is to the south and southwest. Localised drainage pattern are observed in the northern part of the area. Maximum relief differences are up to 10 m from the north east to the south.

1d. Natural vegetation

On the Provisional map of the vegetation types of Botswana the area falls into the region of the Northern Kalahari and Bush Savanna (2b). Information collected during the soil investigations reveals a dense woodland in the immediate vicinity of the Boteti river and an open woodland with considerable undergrowth in the remaining part of the area. The mixed riverine woodland consists of Combretum glomeruliflorum (modubu), Acacia tortilis (mosu), Acacia giraffae (mogotlho); Acacia nilotica (mokhi) and Acacia erubescens (moloto). The map refers to mapping units M10, M10b and L20. On the higher plains (mapping unit M10 corresponds). Dichrostachys cenerea (moselesele); Terminalia prumicides (motsiara); Grewia flora (moretlwa) and Acacia giraffae are observed. Towards the east Terminalia sercea (mogonono) a specific indicator of sandy soils, is encountered in increasing number and size. (M.U.M15). The vegetation of the upland with local repressions is characterized as a mixed open woodland. The dominant species are Acacia tortilis and Terminalia prunioides. Corresponding map units L20 and L21. Some years ago a part of the area in the south west was cleared. At present a number of re-established weeds, shrubs, wild fruit and grasses are found. Some typical species are: Boscia spp; Cucimis spp; Hibiscus spp; Sanseveria spp; Scrotolaria spp; Krochloa spp; and Abbiscia anthelmintia.

It is believed that part of the cleared area was cropped but for one season only under rainfed conditions. From roots and crop debris it appears that maize, cotton and sunflowers were grown. No yield data are available.

1e. Other

Communication to the area consists of the mainroad, Maun-Francistown. Also an airstrip exists in the north west corner of the region. It needs renovation before it can be put back into use again. When the river is in flow water transport is feasible to the other river bank and over limited distances upstream and downstream.

Water supply for the planned irrigation scheme will be obtained from the Boteti river by free open water pumping. The river at the site contains water the whole year either flowing or in pools. Two such pools are encountered. It is estimated that enough water is available for intensive irrigated practices during the year for a five acre plot.

The available data on the quality of the water are obtained from the Thamalabane river at Maun. The sample was taken on the 9th March, 1970 and as such represent not a favourable condition. The water during this time of the season is standing water and the salt concentration will have increased.

However the data indicate that the water has a low salinity and low sodium hazard and can be used safely for irrigation.

The SAR value is 2.85; the pH 7.6; T.D.S. at 120° C is 144; the sum of anians is 120 p.p.m and the sum of cations 39 p.p.m. HCO_3 is the dominant anian, followed by Cl and SO_4 (respectively 100,14 and 5 p.p.m. The fluor concentrations was 1 p.p.m. Dominant catian is Ca (13 p.p.m.), followed by sodium and magnesium (each 10 p.p.m) and potassium (6 p.p.m.)

Chapter 11

SURVEY AND LABORATORY METHODS

No large scale aerial photography is available for the area. Therefore no photo-interpretation prior to field work could be carried out. However made available was a 1:5,000 contour plan of the region prepared by the water engineer. This map was used in the field and was reduced to a 1:10,000 scale for the report. Soil observations were made by auger on a traverse line basis. Traverses were 300 m apart and observations were made every 300 m. North-south and east-west lines were used. Due to the relative simple soil pattern no greater density in observations was considered necessary. As augers were used riverside or Thompson augers of nearly 3 inches in diameter. Four soil pits were described and sampled. A total of 23 samples were taken. The soil pits were 1 - 2 m wide and 1.80 m deep, unless rock was encountered within this depth.

The analyses were carried out at the soil laboratory of a consultant firm in Johannesburg. For description of the laboratory methods see the soils report of the Study Catchment Area. No analyses were carried out on the saturation extract as the resistance of the paste was not less than 200 ohms. Also no nitrogen determinations were done. The percentage nitrogen is believed to be extremely low (see also the percentage carbon.)

Chapter 111

111a. General properties of the soils

The texture of the soils in the riverine area is a loamy fine sand throughout. The percentage of fine sand is 60% or more. The clay percentage of the soils within 100 cm from the surface may range from 2 - 8%. On the higher ground in the east the soil texture is exclusively a fine sand to sand. The clay percentage is very low from 0-100 cm depth.

Soils of the upland area, which are developed on calcrete, have a loamy fine sand texture in the topsoil and a sandy loam texture in the subsoils. The percentage of clay increases generally from 7-18% within 100 cm depth.

No visible ped structure is encountered in the soils. In the sandy soils a structureless single grained soil mass is observed. In some cases faint thin lamination can be found. In the upland soils structure is massive. Often structural elements are destroyed or misformed by biological activity (ants).

The consistence of the soils depends mainly on the amount of clay encountered in the soils. In the coarse textured soils the consistence when dry is slightly increasing with depth from loose to slightly hard. When moist the consistence ranges from loose to very friable and is non sticky and non plastic when wet.

The consistence of the finer textured soils is slightly hard when dry, friable moist and slightly sticky and plastic when wet.

A number of Permeability tests were carried out on the topsoil horizons of all soils encountered in the area. They indicate excessive rapid permeability of 7 - 8 inches per hour for the topsoil horizons as well as for the horizons at 30 cm depth. Some of the soils on the upland are slightly less permeable, but permeability is still 5 inches for an hour on the average in the topsoil.

Permeability in the subsoil is much slower and may cause impeded drainage especially on the shallower soils. It is expected that the permeability of the sandy soils will decrease in the deep subsoils due to compaction and slight cementation by carbonates. However no waterlogging is expected when water applications are made on the right time and of the right amount.

The average field capacity for the (loamy) fine sands is estimated at 1.55 inches/foot and for the sandy loams at 2.30 inches/foot. Wilting point at 15 bar moisture on the coarse texture soils is variable between 2.4 and 4.9. On the finer texture soils it increases regularly with depth from 6,3 to 19.0 within 100 cm from the surface.

The available moisture will be 0.95 and 1.40 inches/foot for the coarse and finer soils respectively.

The soil colour for the coarse textured soils is defined as dark brown in the 10 YR hue; values of 2 - 3 and a chroma of 2, although the chroma of the topsoil may be lower (1). The value is increasing to 4 - 5 with depth. Dry values are usually 1 - 2 units higher than the moist values. A similar range in colour is observed for the fine sandy loams.

The pH is quite variable in the sands, mainly depending on the percentage of free lime in the soils. Low pH values are encountered when the percentage carbonate is low.

Therefore pH values may range from strongly acid to mildly alkaline. With depth the pH may increase with 0,6 - 1,6 point. Soils of the upland are neutral in the topsoil but may be strongly alkaline within 100 cm depth, (regular increase from 7,0 to 8,0).

All clay/S ratio's are below 3,5 in all soils. In addition all soils contain soft carbonates within or below 100 cm depth. Only in the upland soils are relatively large quantities of carbonates encountered within 100 cm from the surface.

Some of the soil properties are represented in Table 4.

Table 4: Soil properties (mean values)

Properties	depth in cm	Map Unit M10	Map Unit M15	Map Unit L20
pH water	0-10	6.4	6.7	7.0
	10-100	5.7	7.7	8.0
	100+	6.0	7.8	8.5
clay %	0-10	3	2	7
	10-100	5	3	11
	100+	6	7	18
siH %	0-10	20	13	20
	10-100	19	11	26
	100+	20	11	23
Total sand %	0-10	76	85	73
	10-100	75	86	62
	100+	73	82	60
S value	0-10	3.83	3.55	8.15
	10-100	3.75	2.90	n.d.
	100+	4.88	2.45	n.d.
CEC clay	0-10	114	220	138
	10-100	78	146	178
	100+	66	45	153
% C	0-10	0.42	0.45	0.18
	10-100	0.21	0.15	0.36

The only available data on trace elements are from the Agricultural Experimental Station at Moshu, about 18 miles southwest of Maun. The soils on the higher topographical positions are described as being similar to the coarse textured soils at Motopi. However, the pH is in general several points higher in the topsoil at Moshu than at Motopi. The pH at Moshu ranges from 7,1 - 8,5 (average 7,7) or from neutral to strongly alkaline.

At Motopi the pH of the topsoil varies from 6,3 - 6,7 (average 6,5) or slightly acid. Only in one case was a pH of 6,0 observed at Moshu. However, all soils are non saline (ECe of less than 4 minhos/cm.)

The average values of a number of trace elements for the site at Moshu from seven samples are given in meg per liter of soil in table 5.

Table 5: Trace element values of topsoil samples (mean values)

Element	Mean	Range	Recommended value
N	9.9	4-17	100-300
P	13	6-27	100-200
K	103	73-151	200-300
Mg	128	83-200	150-250
S	17	5-22	100-200
Ca	574	304-1350	500-1000
Mn	1.17	0.16-1.75	2-10
B	0.38	0.10-0.60	1-2
Cu	8.7	6.6 - 9.5	25-50
Zn	2.1	1.7 - 2.5	25-50
Fe	21	15-30	80-150
Na	13	12-15	25-50

Especially the Nitrogen, Phosphate, Sulphur and Iron and Zinc values are very low. Main deaseses encountered on the experimental plot are Chlorosis and a nitrogen deficiency on cowpeas and sorghum.

111b. The soil classification and mapping units

The soils were classified in the field according to the criteria laid down in Technical Note No. 12 and the definition as set out in the Soil Survey Manual and the FAO guidelines for Soil Description.

In the coarse textured soils the horizonation is very poorly defined, only the soil colour separates the topsoil from the rest of the solum (within 100 cm depth.) As such the soil morphology for the mapping units M10, M10b is described as an orthic A horizon overlying Brown apedal B horizon. (Form XXVIII Series 21).

For Map Unit M15 the morphology is an orthic A overlying Regic Sand (Form XXVII series 4).

For the finer textured upland soils (Mapping Units L20 and L21) the horizonation is slightly better defined. In these soils the morphology is described as an ochric A overlying a brown apedal B with lime. The structure is less than moderately developed (Form XXVIII - series 42). The Mapping Units (see also appendix I, 6.3) are described as follows:-

M10 - deep, dark brown loamy fine sand, very homogeneous morphology; in level to almost level positions.

M10b - "do" but gently sloping.

M15 - deep, dark brown fine sand; slightly calcareous with depth.

M16 - as M15 but moderately deep.

L20 - deep, brown fine sandy loam; calcareous, in flat to almost flat position.

L21 - "do" but moderately deep.

Soils under the M10 and M10b symbols are tentatively called Motopi Series. Soils with symbol M15 are named Boteti series. Soils under the symbol L20 and L21 are tentatively called Lanyaphiri Series. For higher level classification and correlation see appendix 1,6.1.

Chapter IV

INTERPRETATION OF THE SURVEY DATA.

IVa. Suitability of the soils for irrigated land use.

For the classification of the land for irrigated farming the outlines are applied as defined in Technical Note No. 11 Part II. There is no class 1, 5 and 6 land.

Land with soil mapping unit L20 - class 2

" " " " " L21 - class 3

" " " " " M10, M16b, M15, M16 - class 4

Land class definition and limitations:

Class 2 land: Moderately good irrigable land; the main limiting factor is wetness due to slow drainage of the soil in the subsoil. This is caused by the occurrence of calcrete. In addition the soil surface is uneven in places (see Chapter Ic).

Class 3 Land: Marginal irrigable land. The main limiting factor is the soil depth, caused by calcrete that is encountered between 50-90 cm from the surface. Also ponding occurs due to slow drainage of the subsoil.

Class 4 Land: Limited arable land - special use. The dominant limitation for irrigated crop growth is the soil texture and the accompanying very low inherent fertility. The soils of M.U. M16 have in addition a depth limitation as calcrete is encountered between 50 - 90 cm from the surface.

The proposed 5 acre irrigation scheme will be located on class 4 land. The amount of information available of irrigated farming on these kind of soils is extremely limited in Botswana. Therefore most of the cultivation carries the character of research. However a number of crops may do well under irrigation in the described environment if the proper crop management is established. They include amongst others groundnuts (Arachis hypogae L); sunflowers, potatoes, maize and sorghum and fodder crops. The cultivation of oil producing crops such as castor oil plant (Ricinus communis L) is to be considered. In addition citrus and olive trees are expected to do well.

Heavy application of fertilizer, either straight or combined will be needed to obtain sustained yield. As can be seen from Table 5 there is a severe nitrogen and Phosphate deficiency, in addition the sulphur concentration is very low.

The trace elements iron and zinc show also very low values. Also for optimum yield is a supply of organic matter in the form of farm yard manure, compost or greenmanure. The kraal manure must be as well rotted as possible to achieve maximum results. Kraal manure also helps to improve the physical soil characteristics.

When cultivating groundnuts the application of Ammonium sulphate must be considered. The production of fodder crops such as lucerne is possible but the soil (M10) may need loaming as the optimum pH for lucerne is between pH 6.5 and pH 7.2.

The nutrient requirements for lucerne are however very high; therefore sufficient quantities of nutrients must be applied.

APPENDIX I

(a) High level soil classification and correlation

Soils of the Boteti series are similar to a soil described by Bawden (1965, p.11 and 23, profile F). The site was located on the fringe of the Lake Ngami Flood Plain, 2 miles east of Sehitwa. A similar soil was also observed by Blair (1967, App.II, profile 7) at a site north of the Nata Ranch.

The soils of the Boteti series are very extensive and are believed to cover a much larger area as indicated by Langdale - Brown (1963, p.90 area D).

Soils of the Lenyaphiri series are common in Northern Botswana (Blair 1967 App. profile 3). Often the alkaline phase of the soil is described (see also Blair 1967, p.45 and 59). The soils are very extensive and occur mainly outside the riverine areas. An admixture in the soil of windblown material is common.

Soil Correlation and Classification Table.

Motopi series + Boteti series.

7th approximation:	Order Entisols; Suborder Rsamment;
U.S.D.A.	Great Group Torri; Subgroup Typic.
Soil Map of the World:	Dystric Rhegosols.
Soil Map of Africa:	Weakly developed soils; Juvenile soils on riverine and lacustrine allurium (Bo)
Provisional Soil Map of Botswana:	Sub Desert Sands; III - A.
Blair a.o. (1967)	Juvenile soils on recent deposits Riverine alluvium (2a)

Lenyaphiri series:

7th approximation:	Order Aridisols; Suborder orthods;
U.S.D.A.	Great Group Calciorthods; Sub Group Typic/Aguic.
Soil Map of the World:	Calcic Xerosols.
Soil Map of Africa:	Weakly developed soils; Juvenile soils on recent deposits, etc. Not differentiated (Bo).
Provisional Soil Map of Botswana:	Young soils on fairly recent material (II B); soils on former lake basins, (sandy, freely drained soils).
Blair a.o. (1967):	Halomorphic soils; (b) with sub desert sands on lacustrine deposits often calcrete, much windblown material.

APPENDIX Ib

Map Unit : M10
Profile No. B1
Location: Motopi Irrigation Scheme at 0/105
Land Form: Flat to almost flat plain (possible middle terrace)
Vegetation: Original vegetation cleared but believed to have been an open woodland of Terminalia serecea, Dichrostachys cenerea, and Grewia flora.

(b) Profile description B1

A11	0-10 cm	Very dark greyish brown (10 YR 3/2) moist and dark greyish brown (10 YR 4/2) dry fine sandy loam, structureless single grained; soft dry, loose moist, non sticky non plastic wet; common fine, few medium and thick roots, very faint ripple lamination presumably from original wind deposit; faint (sample B01001). Smooth boundary.
A12	10-30 cm	Very dark greyish brown (10 YR 3/2) moist and greyish brown (10 YR 5/2) dry loamy fine sand; structureless, single grained; consistence as horizon above, few fine, medium and thick roots; very faint lamination; faint smooth (sample B01002). boundary
A12	30-60 cm	"do"; faint smooth boundary; (sample B01003).
A13	60-90 cm	Very dark greyish brown (10 YR 3/2) moist and greyish brown (10 YR 5/2) dry loamy fine sand; structureless single grained; soft dry, loose moist, non sticky non plastic wet; few medium white (10 YR 8/2) pockets of quartz sand; few fine and medium roots; very faint lamination; smooth gradual boundary; (sample B01004).
A14	90-120 cm	Same as horizon above, but with slightly less roots and a slight increase in white sand pockets; smooth gradual boundary; (sample B01005)
A15	120-160 cm	Dark greyish brown (10 YR 4/2) dry, 10 YR 3.5/2) moist fine sandy loam, structureless single grained; slightly hard dry, slightly friable moist, non sticky non plastic wet; few fine and medium roots; faint smooth boundary (sample B01006)
A16	160-200 cm	Dark greyish brown (10 YR 4/1.6) moist brown (10 YR 5/3) dry fine sandy loam; structureless single grained; slightly hard dry, friable moist, very slightly sticky non plastic wet; few fine and medium roots; common small and medium irregular patches of pure quartz sand; (sample B01007)
	200-250 cm	"dc" auger, no sample.
	250-320 cm	Brown (10 YR 5/3) moist and white (10 YR 8/2) dry very fine sand, no sample.

Profile description B2

Map Unit : M10
Profile number : B2
Location: Motopi Irrigation Scheme 50 miles east of EMA bench mark
Land Form: Lower part of a riverine plain (possible lower terrace)
Vegetation: Dense to open woodland of Combretum glomeruli, Acacia tortilis, Acacia nilotica and Acacia erubescens.

A11	0-10 cm	Very dark grey (10 YR 3/1) moist and greyish brown (10 YR 5/2) dry loamy fine sand; structureless single grained; soft dry, loose moist very slightly sticky non plastic wet; many fine and medium roots; smooth gradual boundary; (sample B02008).
A12	10-40 cm	Very dark greyish brown (10 YR 3/2) moist and greyish brown (10 YR 5/2) dry loamy fine sand; structure and consistence as horizon above; common fine, medium and thick roots; few fine tabular pores, smooth gradual boundary; (sample B02009).
A13	40-75 cm	Very dark greyish brown (10 YR 2/2) moist and dark greyish brown (10 YR 3.6/2) dry loamy fine sand; structureless single grained; hard dry, friable moist, very slightly sticky non plastic wet, common fine, few medium and thick roots; few fine add medium tabular pores; few fine and medium pockets of quartz sand; smooth gradual boundary (sample B02010).
AC	75-105 cm	Very dark greyish brown (10 YR 2/2) moist and dark greyish brown (10 YR 4/1.6) dry; loamy fine sand; structure and consistence as horizon above; common fine and medium pockets of quartz sand and lime; few fine medium and thick roots; few krotovina; few fine charcoal fragments up to 1cm in diameter; few coarse tabular pores; smooth gradual boundary; (sample B02011).
	105-140 cm	Dark greyish (10 YR 4/1.4) moist and greyish brown (10 YR 5/2) dry loamy fine sand; structure and consistence as above horizon; few fine and medium roots; common small pockets of white quartz smooth gradual boundary; (sample B02012).
ACA	140-170 cm	Greyish brown (10 YR 5/2) moist and light brownish grey (10 YR 6/2) dry fine sandy loam; structureless single grained; soft dry, friable moist, slightly sticky and non plastic wet; few fine and medium roots; common fine patches of soft carbonates; (sample B02013).
Cca	170-190 cm	"do" (no sample).
	190-300 cm	Light grey (10 YR 7/2) moist and white (10 YR 8/1) dry very fine sand; common soft carbonate concretions; auger; (no sample).

Profile description B3:

Map Unit : M15
Profile Number: B3
Location: Motopi Irrigation scheme at bench mark No. 75.
Land Form: Flat to almost flat riverine plain.
Vegetation: Open woodland of Acacia giraffae and Terminalia sericea.

A11	0-10 cm	Very dark greyish brown (10 YR 3/2) moist and greyish brown (10 YR 5/2) dry fine sand; structureless single grained; soft dry, loose moist, non sticky non plastic wet; many fine and medium and a few coarse roots; smooth gradual boundary; (sample B03014)
A12	10-33 cm	Very dark greyish brown (10 YR 3/2) moist and greyish brown (10 YR 4.6/2) dry fine sand; structure and consistence as horizon above; common fine and medium roots; smooth gradual boundary (sample Bo3015)
A13	33-62 cm	Very dark greyish brown (10 YR 3/2) moist and dark greyish brown (10 YR 4.4/2) dry fine sand; structureless single grained; slightly hard dry; slightly friable moist, non sticky non plastic wet; few fine and medium and occasional coarse roots; few fine tabular pores; smooth diffuse boundary; (sample B03016)
ACca	62-130 cm	Dark greyish brown (10 YR 4/2) moist and greyish brown (10 YR 5/2) dry fine sand; structure and consistence as above; very few fine, medium and coarse roots; very few small pockets of white quartz sand and of soft carbonates; smooth gradual boundary; (sample B03017) from 62-90 cm; sample B03018 from 90-130 cm; textur from 90-130 is loamy fine sand.
Cca	130+	"do" increase of soft carbonates with depth; (no sample).

Profile description B4
Map Unit : L20
Profile number: B4
Location: Motopi Irrigation Scheme at bench mark L1 85
Land Form: Flat to almost flat upland with minor highs and lows due to undulating calcrete substratum.
Vegetation: Open woodland of Acacia subulata and some Acacia erubescens.

A11	0-0.3 cm	Dark grey (10 YR 4/1) moist and light brownish grey (10 YR 6/2) dry fine sandy loam; very fine lamination (1mm) slightly hard dry; smooth surface; sharp smooth boundary; (no sample).
A12	0.3-14 cm	Very dark greyish brown (10 YR 3/2) moist and dark greyish brown (10 YR 4/1.6) dry fine sandy loam; weak fine subangular blocky structure; slightly hard dry, slightly friable moist, very slightly sticky and plastic wet; common fine and medium roots; few fine and medium tabular pores; smooth gradual boundary; (sample B04019)
A13	14-32 cm	Very dark greyish brown (10 YR 3/2) moist and dark greyish brown (10 YR 4/2) dry; fine sandy loam; structureless; slightly hard dry, friable moist, slightly sticky and plastic wet; common fine and medium roots; very few fine tabular pores; smooth gradual boundary; (sample B04020).
Aca	32-58 cm	Very dark greyish brown (10 YR 3/2) moist and dark grey (10 YR 4/1) dry fine sandy loam; structureless; slightly hard dry, friable moist, slightly sticky and plastic wet; few fine and medium roots; few medium and coarse patches of soft carbonates increasing to common with depth; smooth sharp boundary; (sample B04021).
ACca	58-76 cm	Dark grey (10 YR 4/1.4) moist and light brownish grey (10 YR 6/2) dry fine sandy loam; structureless; slightly hard dry, friable moist, slightly sticky slightly plastic wet; very few fine roots; many fine medium and coarse subrounded and angular $CaCO_3$ fragments; smooth gradual boundary; (sample B04022)
C	76-125 cm	Greyish brown (2.5 Y 5/2) moist white (10 YR 8/1) dry weathered calcrete of sandy loam texture; very to slightly hard dry; hardness increasing with depth (sample B04023).
R	125 + cm	Calcrete.

APPENDIX Ic.

The Map Legend:

Soil symbol	Description
M10	Deep, dark brown loamy fine sand; structureless; flat to almost flat positions.
M10b	As "M10" but gently sloping.
M15	Deep, dark brown fine sand, structureless; flat to almost flat positions.
M16	As "M15" but moderately deep (average depth 60 cm).
L20	Deep, brown fine sandy loam; highly calcareous; flat to almost flat position.
L21	As "L20" but moderately deep (average depth 75 cm).

The presence of soft lime is indicated with a small letter c; the depth with a+ (plus) or - (minus) sign.

c- : soft lime is encountered between 50-90 cm depth

c+ : soft lime is encountered below 100-150 cm depth

Local depressions (pans) are indicated by a normal wetness sign.

A described and sampled soil pit appears on the map as a black dot with a number (for example B2.)