THE REPUBLIC OF THE SUDAN
MINISTRY OF AGRICULTURE

ROSEIRES SOIL SURVEY

REPORT No. 4a

RAHAD EAST BANK EXTENSION

SEMI-DETAILED SOIL SURVEY AND LAND CLASSIFICATION

VOLUME I

THE REPORT

HUNTING TECHNICAL SERVICES LTD.
4 ALBEMARLE STREET
LONDON, W.1

MAY 1965

SIR M. MACDONALD & PARTNERS
CONSULTING ENGINEERS
LION HOUSE
RED LION STREET
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Red

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28th June, 1965.

H.E. The Minister of Agriculture,
Ministry of Agriculture,
Khartoum,
SUDAN.

Your Excellency,

ROSEIRES SOIL SURVEY

REPORT NO. 4A (AREA 3C EXTENSION)

RAHAD EAST BANK EXTENSION

We have pleasure in submitting our Report No. 4a for the Roseires Soil Survey Project, the study of which was entrusted to us, by the Contract for Soil Survey of Irrigable Lands in the Sudan, signed on 27th September 1962.

The Report, which is in two volumes accompanied by an Album of Maps, contains the semi-detailed soil survey and land classification for the area along the Rahad East Bank, referred to as area 3C extension in the Contract.

The interpretation of the land classes, as agreed with the World Bank, is that Classes 2, 3a and 4a are all suitable for a long staple cotton rotation of the Managil type. These land classes have self-mulching soils of high clay content which Finck and Ochtman show to be capable of producing high cotton yields; at the same time the level of exchangeable sodium does not have a depressive effect on the yields of long staple cotton which is one of the more alkali-tolerant of the arable crops. Classes 31 and 41 may be used for fruit, vegetables or forest areas or for village sites.

In Chapter 6 of this Report we have made general recommendations for irrigated crops in the Project Area.

The necessary agricultural and soil studies were undertaken by Messrs. Hunting Technical Services Limited under the direction of Dr. Robert Smith, Consultant in charge of the Soil Surveys.

We are, Excellency,

Your obedient servants,

I S G Matthews

SIR M. MACDONALD & PARTNERS.

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ACKNOWLEDGEMENTS

The compilation of a report of this kind cannot be complete without reference to many organisations and individuals, both in the Sudan and the United Kingdom, who have assisted us by providing information, advice or facilities. Among the many who have assisted us in this way are the following, to whom our thanks are due.

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The many members of both administrative and technical staff in the Ministry of Agriculture including the Director of Agriculture, the Assistant Director (Projects) and the Chief Research Officer, with their staff in Khartoum and Wad Medani, for their helpfulness in many matters affecting the conduct of the survey.

The members of the Ministry of Irrigation and Hydro-Electric Power including the Director of Irrigation and the Assistant Director (Development) with their staff, for their help.

The members of the Survey Department, the Sudan Gezira Board, the Geological Survey Department, the Department of Meteorology, and the officers of local administration and police, for practical help and technical advice in obtaining our results.

University of Khartoum:

Professor Whiteman, Head of the Department of Geology, and Mr. L. Berry of the Geography Department, for their help. Professor K.G.N. Macleay, Head of the Botany Department, for identifying our plant specimens.

The Macaulay Institute of Soil Research, Aberdeen, Scotland:

The Director, for the secondment of Messrs. J.S. Bibby and J.H. Stevens of the Soil Survey of Scotland to share the field work in the Sudan.

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ROSEIRES SOIL SURVEY

List of Reports Submitted to the Ministry of Agriculture Republic of the Sudan

<u>1962/63 Period</u>

Report No. 1. Gezira Extension Area (Area 1). Semi-Detailed Soil Survey and Land Classification.

Report No. 2. Blue Nile East Bank, Guneid to Khartoum (Area 3D). Soils and Engineering Reconnaissance.

Report No. 3. The Nile from Kareima to the Third Cataract (Area 4A). Soils and Engineering Reconnaissance.

Report No. 4. Rahad and Dinder Area. (Areas 3B and 3C). Semi-Detailed Soil Survey and Land Classification.

<u>1963/64 Period</u>

Report No. 4A. Rahad East Bank Extension (Area 3C Extension) Semi-Detailed Soil Survey and Land Classification.

Report No. 5. The Nile from Khartoum to Kareima, (Area 4B). Soils and Engineering Reconnaissance.

Report No. 6. The White Nile East Bank, Rabak to Khartoum (Area 5A) Soils and Engineering Reconnaissance.

Report No. 7. Blue Nile East Bank, Guneid to Khartoum (Area 3D). Semi-Detailed Soil Survey and Land Classification of Selected Areas

Report No. 8. The Nile from Kareima to the Third Cataract (Area 4 North). Semi-Detailed Soil Survey and Land Classification of Selected Areas.

Report No. 9. Dinder-Blue Nile Gezira, Sennar to Confluence (Area 3A and Part Area 2A). Semi-Detailed Soil Survey and Land Classification.

GLOSSARY

Ardeb	-	A volume measure for agricultural produce equalling 198 litres. 1 ardeb of dura weighs 336 rotls 1 " of dukhn " 360 " 1 " of simsim " 264 "
Bamia	-	Lady's fingers or okra, Hibiscus esculentus Linn.
Dukhn	-	The food grain, Pennisetum typhoideum (Burm.) Stapf. and Hubbard.
Dura	-	The great millet, Sorghum vulgare, Pers.
Feddan	-	An area of land approximately equal to one acre: 1 feddan = 1.038 acres = 0.420 hectares.
Haboob	-	A strong wind usually accompanied by thick dust.
Hafir	-	A pool usually made by man for the storage of water.
Heglig	-	A ubiquitous tree with straight green spines and edible fruit, Balanites aegyptiaca Del.
Kankar	-	Dark coloured, hard, rounded to semi-rounded calcium carbonate concretions.
Kantar	-	A unit of weight; normally 1 kantar = 100 rotls = 99.05 lb. In the Gezira 1 kantar of cotton means 315 rotls or 312.01 lb. unginned cotton.
Kerrib	-	Gullied land resulting from steep run-off in deep homogeneous clay plains. It consists of eroded water channels cutting from the plain into the valley.
Kitr	-	A common shrub or small tree with well developed thorns and highly scented blossoms, Acacia mellifera Benth.

Limoon - The lime, Citrus aurantiifolia (Christm.) Swingle.

Lubia - The bean, Dolichos lablab Linn.

Marisa - Beer made from various grains but chiefly dura; a valuable protective food.

Qoz - A sand hill or sand dune.

Piastre - P. T. for short, a unit of money. 100 P. T. = £1.000 Sudanese.

Rotl - A measure of weight approximately one pound:

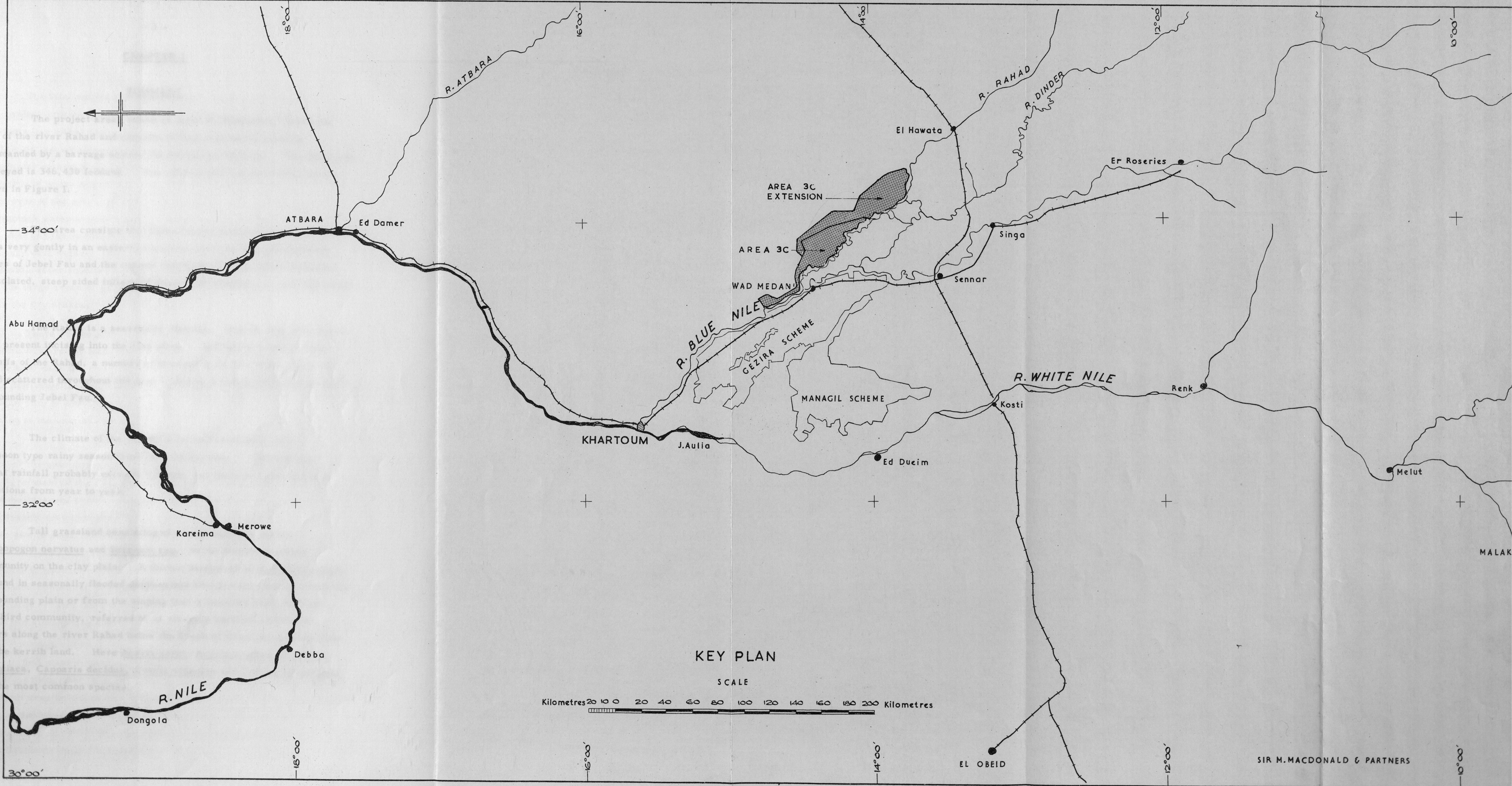
112 lb. = 113 rotls.

100 rotls - 99.05 lb. = 44.94 kg.

Seluka - A digging stick with foot rest; also applied to the land cultivated by the seluka.

Simsim - The valuable oil seed crop, Sesamum orientale Linn.

Terus - A small earth bund built with hand tools for impounding rain water for watering rain grown dura. Commonly used in Blue Nile, Khartoum and Northern Provinces.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CHAPTER 1

SUMMARY

1.1

The project area, known as Area 3C Extension, lies to the east of the river Rahad and consists of that area which could be commanded by a barrage across the Rahad near Mafaza. The total area surveyed is 346,430 feddans. The location and extent of this area is shown in Figure I.

1.2

The area consists of a superficially monotonous clay plain which rises very gently in an easterly direction and from which the granite ridges of Jebel Fau and the conical inselberg of Jebel Buweida emerge as isolated, steep sided inliers of Basement Complex i.e. pre-Cambrian age.

The Rahad is a seasonally flowing, meandering river which is at present incising into the clay plain. In addition to the ancient cut-offs of the Rahad, a number of seasonally flooded depressions are found scattered throughout the area including a broad shallow depression surrounding Jebel Fau.

1.3

The climate of the region is hot and semi-arid with a monsoon type rainy season from June till October. The average annual rainfall probably exceeds 500 mm. but there are considerable variations from year to year.

1.4

Tall grassland consisting of annual species, mainly Cymbopogon nervatus and Sorghum spp., is the most widespread community on the clay plain. A thicket dominated by Acacia mellifera is found in seasonally flooded depressions which collect run-off from the surrounding plain or from the sloping land around the rock outcrops. The third community, referred to as riverain bushland and thicket, occurs along the river Rahad below the break of slope between the plain and the kerrib land. Here Acacia seyal, Acacia arabica, Balanites aegyptiaca, Capparis decidua, Boscia octandra and Cadaba rotundifolia are the most common species.

1.5

The total settled population in and immediately adjacent to the project area is estimated at about 12,000. Most of the inhabitants live either along the kerrib lands of the Rahad and Blue Nile or just outside to the east of the project area. The major factor determining the distribution of the settlement is the availability of water supplies. The clay plain which forms the project area of the soil survey is virtually devoid of both domestic and livestock water supplies and it is only the seasonal river Rahad in the west and the pediment area of Jebel Fau in the east, which yield dry season well water. Both these places support sedentary populations and provide water supplies needed by nomads whose herds of cattle graze the large areas of grassland in the centre and south of the project area in the dry season.

There are no pump schemes within the area and most of the rain fed crops are for local need. Cultivation is confined to the areas of settlement near the river or close to Jebel Fau. The average area of cultivated land per family is between ten and twenty feddans and the staple crop is dura (Sorghum vulgare) the yields of which vary according to the variable rainfall.

1.6

The soil survey was carried out according to the specifications of the Agreement of the 27th September, 1962. The minimum density of observations was to be one auger site for each 250 feddans, but the actual density achieved in the field, counting all the observation sites, was one site to about 240 feddans. The total number of soil profiles sampled was 1446 but 1488 profile analyses were carried out which means that 42 profiles were subjected to two different kinds of analysis as explained in the text. Field permeability tests were carried out at 9 pit sites. Two tests were made at seven of these sites and three tests at two sites giving a total of twenty tests.

1.7

Soil classification is based on the U.S. Department of Agriculture System of 1960, the Seventh Approximation. All the soils of the project area belong to one Soil Order of Vertisols. The Vertisols belong to the Sub-Order of Usterts and the Great Group of Grumusterts (self mulching clays). The Grumusterts are further divided into Orthic Grumusterts and Natrargidic Grumusterts. It will be of interest to soil classifiers the world over to learn that quite large areas of Natrargidic Grumusterts have been recognised and mapped in the Republic of the Sudan. At the time of publication of the Seventh Approximation in 1960 there was considerable doubt as to whether self mulching clays would ever have E.S. P's exceeding 15. The soil survey of the Gezira Extension Area (Report No. 1) gave indications of the possible existence of Natrargidic Grumusterts but the evidence was not conclusive. In this project area, where the clay content is much higher (about 70 per cent), the soil survey shows conclusively that large areas of self-mulching clays have E.S.P.'s exceeding 15 and that Natrargidic Grumusterts do in fact exist.

The Orthic and Natrargidic Grumusterts have been further sub-divided into families on the basis of clay content and these families have been sub-divided into Series on the basis of their soluble salt content.

1.8

The specifications for the semi-detailed land classification survey are based on those of the U.S. Department of the Interior, Bureau of Reclamation, suitably modified for Sudan conditions. Topographic limitations are rarely met with and the chief soil limitations were associated with salinity, alkalinity and low clay content. Detailed specifications were worked out with the Department of Agriculture Research Division at Wad Medani, and subsequently with the representatives of the World Bank in Washington.

1.9

In classifying land for cotton in the Gezira Scheme the concept of Sodium Value was used. Sodium value is derived by expressing the total extractable sodium (i.e. soluble + exchangeable) in mg. equivalents per 100 gm. of clay. This value is calculated from a bulked sample from the 0-90 cm. layer of the soil profile. On the basis of a number of trials the Sodium Value limit for good cotton land was taken at 25 and for medium cotton land at 35. By using the clay percentage, Soluble Sodium and Exchangeable Sodium of the 0-45 cm. and 45-90 cm. routine samples taken during the 1963-64 semi-detailed survey, it has been possible to calculate the Sodium Values of the soils.

A good correlation has been obtained in which the division between class 4a and class 6a corresponds to a Sodium Value of rather less than 25. As all experimental evidence indicates that high clay land with a Sodium Value of 25 or less will grow good cotton crops, it appears justifiable to include class 4a land in the cotton rotation.

1.10 The lands were classified as follows:-

Land Class	Area in Feddans
2, good arable lands	41,110
3a, moderate arable lands	220,660
4a, limited arable lands	33,640
6, non-arable lands	51,020
Total	346,430

1.11 In Roseires Report No. 4, covering the Rahad and Dinder lands, we pointed out that, whereas the Ten Year Plan of Economic and Social Development outlines in detail a proposed irrigation development plan for the Gezira Extension Area, no such detailed plan is given for the Rahad East Bank lands. Since then, however, the Client has contracted with the Consultant to prepare such a plan under the contract for the Rahad Pre-Investment Survey. In this report, therefore, we discuss agronomic suitability, but not economic suitability, of the climatically adapted crops which might be grown under irrigation in the project area.

1.12 The discussion about irrigated crops should be studied in conjunction with Chapter 6 of Report No. 4 which discusses the merits of some short season crops for a flood irrigation project and of some long season crops for a perennial irrigation system on the Rahad East Bank Lands. This report brings the discussion up-to-date by considering crop response in relation to the revision of the land class specifications carried out at the World Bank in Washington in August 1964.

1.13 The climatically adapted crops of the Northern Rainlands of the Republic of the Sudan, which can all be classed as tropical crops, may be grouped into three categories, those grown commercially, those tested at the research stations but not yet grown commercially, and those that have had a trial planting at some time or other. It is noteworthy that only eleven crops are grown commercially in this large zone:- cotton, (long and medium staple) dura, lubia, wheat, groundnuts, pigeon pea, onions, garlic and sugar cane under irrigation and cotton (short staple), dura, dukhn, sesame and groundnuts without irrigation in the rainlands. The explanation for the small number of commercial crops probably lies in the environmental control exercised by the harsh, semi-arid, lowland climate together with excessively low permeability of clay soils or with excessively high permeability and low water holding capacity of very sandy soils.

1.14 Bearing in mind that the soils of the project area consist almost entirely of virtually undrainable clay soils we consider that crops agronomically suitable for irrigated agriculture on the Rahad East Bank lands are as follows:- cotton (long, medium and short staple), dura, wheat, rice, groundnuts, sesame, safflower, lubia, phillipesara, clitoria, pigeon pea, onions and garlic.

A further list of crops which are probably agronomically suitable include such potentially important crops as jute, kenaf, sunn hemp, maize, sunflower and sugar cane. We consider that all crops known to require free-draining soils must be considered unsuitable for the project area; these crops include castor, tobacco, citrus fruits, mango, banana, dukhn and melons.

1.15 Only in the case of long staple cotton is there a sufficiently detailed record of commercial crop yields, together with research findings, to justify an accurate prediction of yields in the project area. Research workers have shown that yields of long staple cotton are correlated positively with clay content and the depth to a saline-alkali subsoil but negatively with extractable sodium and salinity in the upper 90 cm.

Because research work has shown that long staple cotton is more tolerant to high exchangeable sodium than other climatically adapted crops we have concluded that it may safely be grown on land classes 2, 3a and 4a; there is a total area of nearly 300,000 feddans in the project area that could be used for long staple cotton rotation.

The expected yield of long staple cotton in the project area may be predicted from the clay content of the soils which have an average clay content of 71.5 per cent in the 0-45 cm layer. By applying the clay-yield formula of Finck and Ochtman it can be predicted that the long term average yield of long staple cotton grown on a wide rotation under good management would be about 130 per cent of the average Gezira yield or about 5.8 kantars per feddan.

The project area, in fact, lies within the zone, which includes the southern Gezira and Managil blocks, where conditions are optimum for long staple cotton production. Within this zone the prospects of receiving adequate presowing rains are good whereas the possibility of waterlogging from excessive rain is low. The soils of the project area, although non-draining, are well structured and of very high clay content yet only moderately alkaline. The project area, therefore, has optimum soil and climatic conditions for the production of long staple cotton and could be expected to produce the highest sustained yields in the country if planted to long staple cotton.

CHAPTER 2

THE ENVIRONMENT

2.1 Location and General Description

The land within the project area of the soil survey lies to the East of the river Rahad, and consists of that area which could be commanded by a barrage across the Rahad near Mafaza.

The western boundary is formed by the "kerrib"[1] lands along the river Rahad from Tuneidba to a point 16 kilometres south of Ein el Luweiga, and by the eastern limit of the soil survey carried out in 1963 (Report No. 4) as far north as Latitude 14° 33'. The eastern boundary is a proposed line for a canal running northwards from Tuneidba, past the western edge of Jebel Fau.

The total area surveyed is 346,430 feddans.

2.2 Physiography

The project area consists of a superficially monotonous clay plain which rises very gently in an easterly direction, and from which the granite ridges of Jebel Fau and the conical inselberg of Jebel Buweida emerge as isolated, steep-sided inliers of Basement Complex age.

The Rahad is a seasonally flowing, meandering river which is at present being incised into the clay plain. The river flows from July to late November or early December, after which its discharge decreases rapidly, so that by February the channel contains a series of discontinuous pools (Arabic "rahad"). The most recently abandoned meander channels are comparable in size and radius of meander curvature to the present day Rahad, but the most ancient channels are considerably wider, suggesting a greater discharge during a former wetter period.

In addition to the ancient cutoffs of the Rahad, a number of seasonally flooded depressions is found scattered throughout the area. The most extensive of these leads from the western margin of Jebel Fau, while a smaller elongated depression lies west of Jebel Buweida.

1. "kerrib" : gullied terrain resulting from steep run-off in deep homogeneous clay plateaux.

A study of the aerial photographs indicates that a broad shallow depression surrounds Jebel Fau. This appears to be similar to the scarp-foot hollows of east-central Sudan.

The origin of such piedmont hollows is obscure, but appears to be due partly to the concentration of sub-surface eluviation of weathered material at the hillfoot, and partly to local gullying.

2.3 Geology

2.31 Underlying Geology

The information in this section is derived from the Geological Map of the Sudan at scale 1:1,000,000, dated 1952. Most of the clay plain appears to be underlain by Basement Complex gneiss. Jebel Fau is shown as an inlier of soda-granite, also of the Basement Complex. In the extreme north of the project area, rounded quartzite pebbles are commonly found at the soil surface, and further west, in the area studied during the 1962-63 season, red sandy loams are found in which are embedded fine iron-stained quartzite pebbles. Such soils are known to occur over Nubian Sandstones at Rabak, so it appears that some, at least, of the soils characterised by abundant quartz pebbles at the surface overlie sandstones and conglomerates of the Nubian series.

Part of the clay plain in the south-east may be underlain by the more recent (Quarternary) sands and clayey sands of the Umm Ruwaba series.

2.32 Superficial Deposits

Apart from the Basement Complex outcrops of Jebel Fau and Jebel Buweida, the solid geology of the area is obscured by a considerable thickness of clay. Nowhere did any of the 3 - metre auger-holes bored during the survey penetrate to the underlying material.

The superficial clays of this region are dark grey cracking clays, very uniform in appearance. They are similar to those of the Gezira plain, but generally exhibit self-mulching characteristics to a much greater degree. It is probable that, unlike the Gezira soil, the majority of these clays have been derived from Basement Complex material by sheet-flooding.

Towards the Rahad, the colluvial clays were probably interdigitated with alluvial deposits. The clays throughout the area have remained undisturbed sufficiently long to have developed a characteristics soil profile, with the exception of the re-worked clays lining the old meander channels adjacent to the Rahad.

2.4 Climate

2.41 General

The climate in this region is hot and semi-arid. The year can be divided into four seasons:-

Winter, November to March. Cool and dry, with predominantly north winds. It is less cool in the south than in the north, as the sun is higher, the days are longer, and the winds have been warmed by their passage over the desert.

Spring, April and May. Hot and dry, still with predominantly north winds, heated by the stronger sun on the Sahara. Further south, the peak temperatures are lower, and occur earlier, owing to the onset of the rainy season. Dust storms or 'haboobs' occur at this time and at the start of the rainy season. These are more frequent further north, where the scanty vegetation is insufficient to protect the soil surface.

Summer, June to August. Warm and moist. This is the season in which almost all the rain falls. The wind is predominantly from the south.

Autumn, September to October. Hot and sticky. The south winds have ceased, and the north wind has not yet started.

The meteorological data in this report are taken from the following stations:-

Wad Medani
Gedaref
Wad el Huri

None of these stations is in the survey area, but they are equidistant to the North-West, the East and the South, and give a good idea of the range of climate to be expected.

2.42 Temperature

Figure II shows the monthly mean maximum and minimum temperature. The annual means for all the stations are:-

	Maximum	Minimum
Wad Medani	36.9	19.6
Gedaref	36.0	20.9
Wad el Huri	36.5	19.5

The highest temperatures are in April and May. A secondary maximum occurs in October. The lowest temperatures are in January throughout the project area, though the day temperatures at this time are slightly higher than in August, when the day temperatures are depressed by the high humidity.

2.43 Sunshine

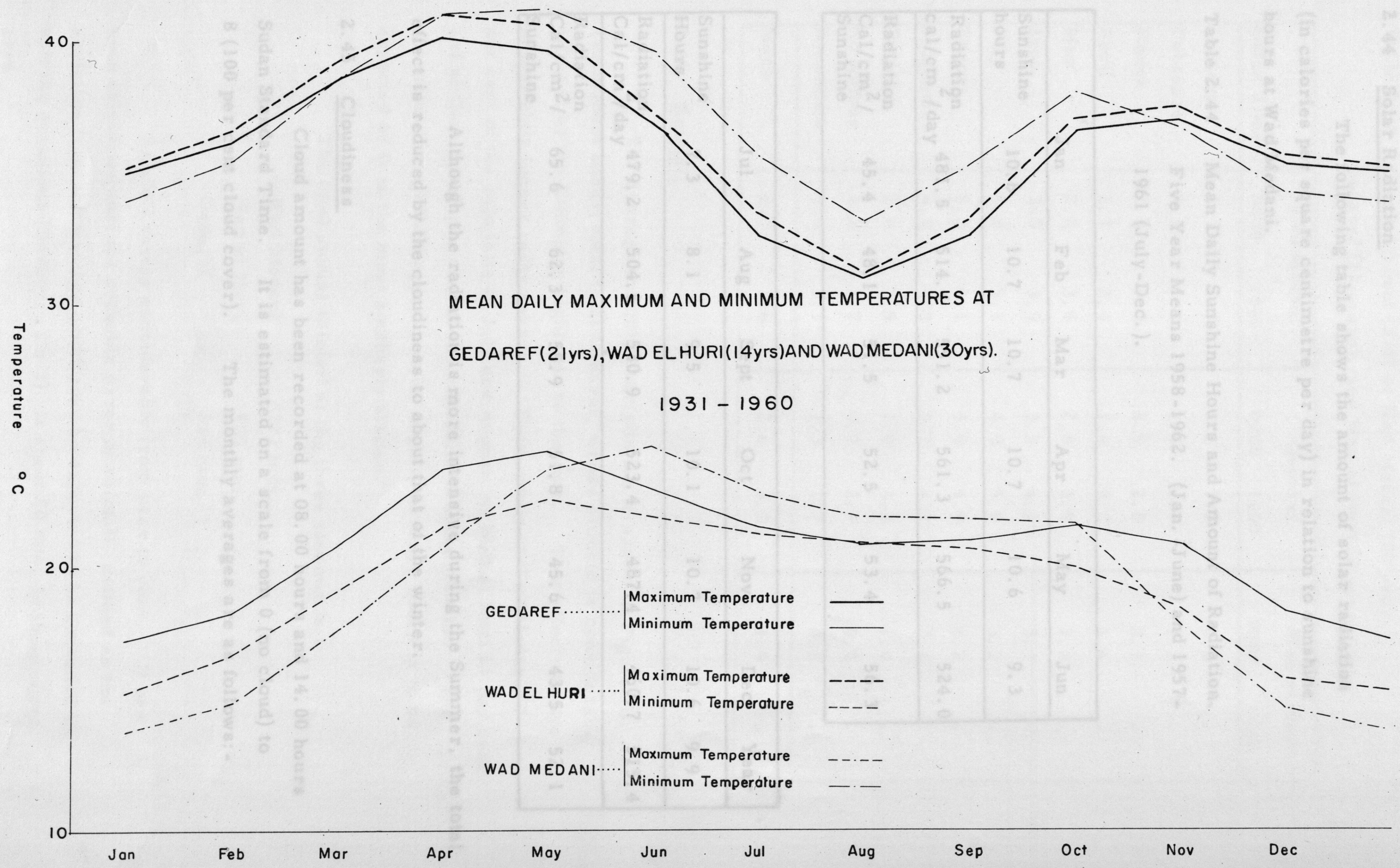
The following table for Wad Medani should be representative of conditions in the project area.

Table 2.43 Mean Duration of Bright Sunshine and Percentage of Possible Total. (Stokes-Campbell Recorder) 1931-1961.

	Jan	Feb	Mar	Apr	May	Jun
Mean hrs. per day	10.6	10.6	10.5	10.6	9.9	9.6
	93	91	87	85	77	74

	Jul	Aug	Sept	Oct	Nov	Dec	Year
Mean hrs. per day	7.7	7.7	8.9	10.0	10.7	10.5	9.8
	60	61	73	85	93	93	81

Fig. II


MEAN DAILY MAXIMUM AND MINIMUM TEMPERATURES AT
GEDAREF(21yrs), WAD EL HURI(14yrs) AND WAD MEDANI(30yrs).
1931 – 1960
GEDAREF
Maximum Temperature
Minimum Temperature
WAD EL HURI
Maximum Temperature
Minimum Temperature
WAD MEDANI
Maximum Temperature
Minimum Temperature
Temperature °C
40
30
20
10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

2.44 Solar Radiation

The following table shows the amount of solar radiation (in calories per square centimetre per day) in relation to sunshine hours at Wad Medani.

Table 2.44 Mean Daily Sunshine Hours and Amount of Radiation. Five Year Means 1958-1962. (Jan.-June) and 1957-1961 (July-Dec.).

	Jan	Feb	Mar	Apr	May	Jun
Sunshine hours	10.6	10.7	10.7	10.7	10.6	9.3
Radiation $cal/cm^2/day$	481.5	514.4	551.2	561.3	566.5	524.0
Radiation $Cal/cm^2/$ Sunshine	45.4	48.1	51.5	52.5	53.4	56.3

	Jul	Aug	Sept	Oct	Nov	Dec	Year
Sunshine Hours	7.3	8.1	9.5	10.1	10.7	10.6	9.9
Radiation $Cal/cm^2/day$	479.2	504.5	530.9	523.4	487.4	460.7	515.4
Radiation $Cal/cm^2/$ Sunshine	65.6	62.3	55.9	51.8	45.6	43.5	52.1

Although the radiation is more intensive during the Summer, the total effect is reduced by the cloudiness to about that of the winter.

2.45 Cloudiness

Cloud amount has been recorded at 08.00 hours and 14.00 hours Sudan Standard Time. It is estimated on a scale from 0 (no cloud) to 8 (100 per cent cloud cover). The monthly averages are as follows:-

Table 2.45 Cloud Amount (0-8) at Wad Medani (30 years), Gedaref (21 years), and Wad el Huri (2 years).

	Wad Medani		Gedaref		Wad el Huri	
Sudan Time:-	0800	1400	0800	1400	0800	1400
January	1.1	1.3	1.3	1.6	0.8	-
February	1.1	1.3	1.4	1.7	1.3	-
March	1.8	1.9	2.9	2.5	2.1	-
April	2.1	2.4	1.9	3.2	1.6	-
May	2.8	3.4	2.8	3.9	1.8	-
June	3.5	3.9	3.5	4.1	3.1	-
July	5.0	5.1	4.9	5.0	3.2	-
August	5.3	5.1	4.9	4.9	4.2	-
September	4.5	4.3	3.7	4.1	3.1	-
October	2.4	3.5	1.9	4.2	1.4	-
November	1.2	1.7	0.7	2.6	0.2	-
December	1.4	1.7	1.3	1.7	0.5	-
Mean	2.7	3.0	2.6	3.3	1.9	-

2.46 Rainfall

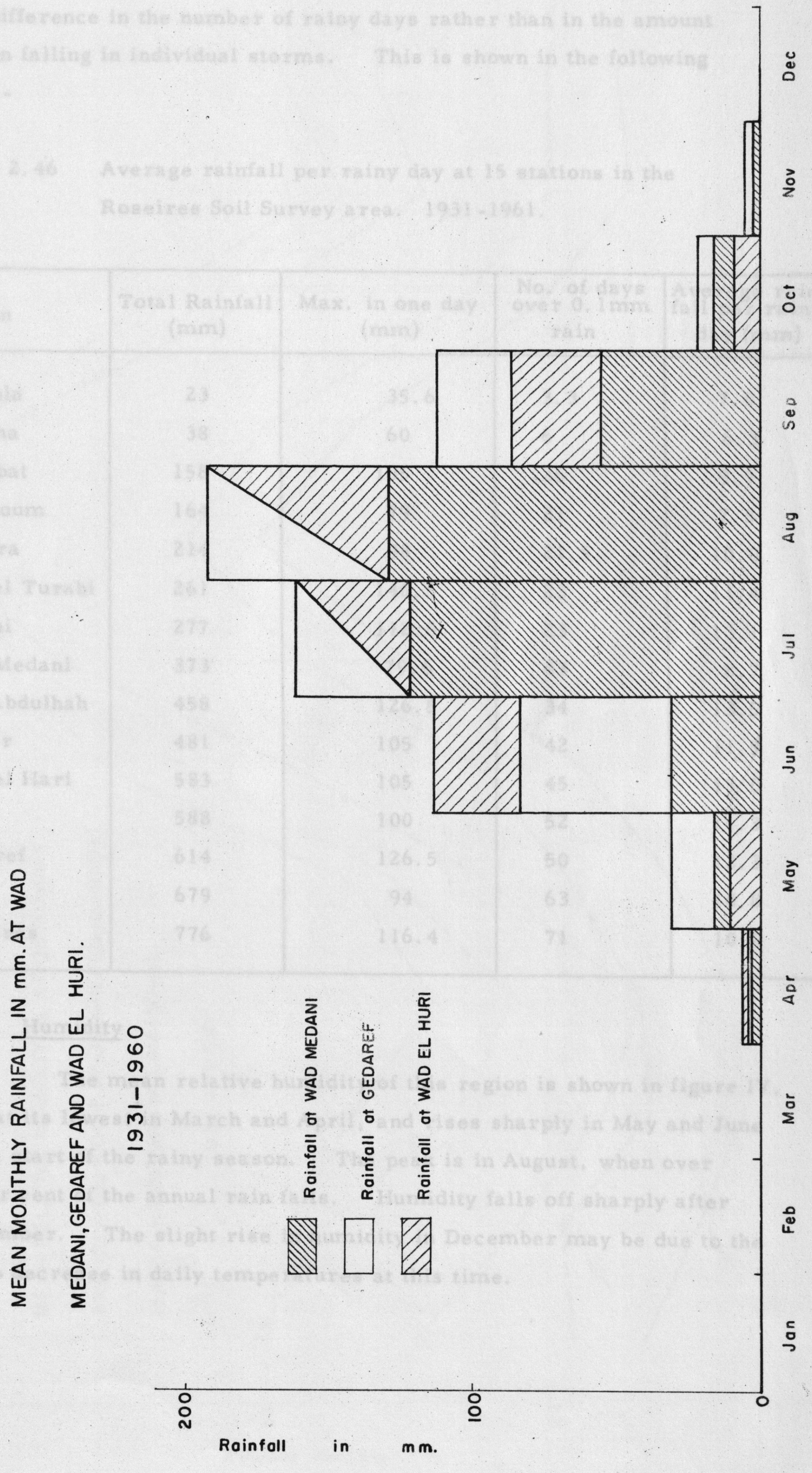
The average monthly precipitation is shown in Figure III. The highest annual total is at Gedaref, whose climate is considerably affected by the Ethiopian highlands to the east. This effect results in a slightly longer rainy season. Thus, while at Wad Medani 67 per cent of the rain falls in July and August, at Wad el Huri 61 per cent and at Gedaref 58 per cent of the rain falls in these months. The season at Wad el Huri appears to be slightly earlier, which is to be expected as it is the most southerly station.

The total annual rainfall at the three stations is:-

Wad Medani	373 mm.
Wad el Huri	583 mm.
Gedaref	614 mm.

Rainfall varies considerably from year to year. It has been calculated that the probable error of rainfall, defined as the deviation from the average which may be expected to be exceeded on half the occasions (Barbour, Ch. 3), is about 80 mm. in the project area.

Fig. III


MEAN MONTHLY RAINFALL IN mm. AT WAD
MEDANI, GEDAREF AND WAD EL HURI.
1931-1960
Rainfall at WAD MEDANI
Rainfall at GEDAREF
Rainfall at WAD EL HURI
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
100
200
Rainfall in mm.

The variation in rainfall from one region to another is due to a difference in the number of rainy days rather than in the amount of rain falling in individual storms. This is shown in the following table:-

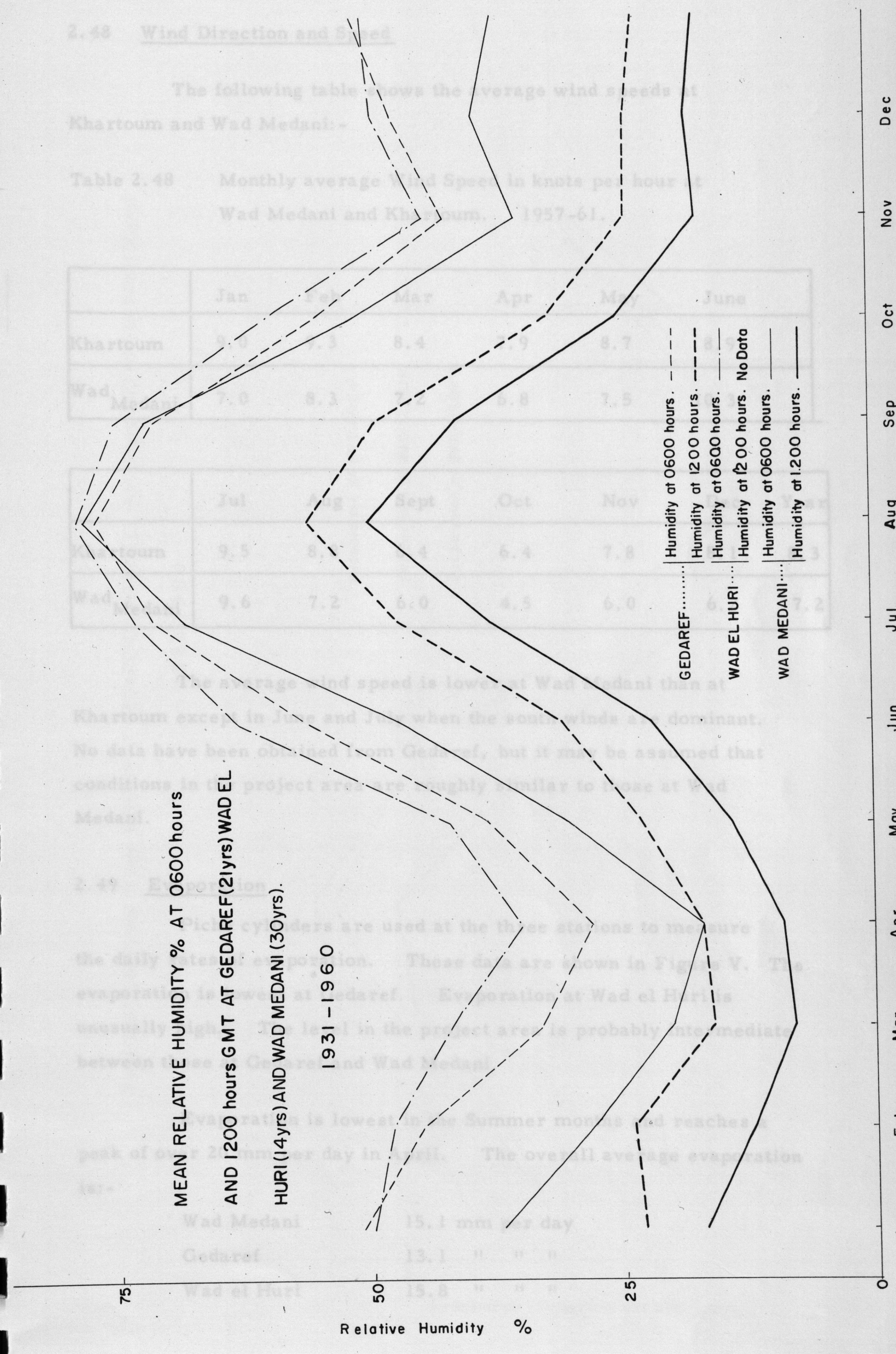
Table 2.46 Average rainfall per rainy day at 15 stations in the Roseires Soil Survey area. 1931-1961.

Station	Total Rainfall (mm)	Max. in one day (mm)	No. of days over 0.1mm rain	Average rainfall per rainy day (mm)
Dongola	23	35.6	3.3	7.0
Kerima	38	60	6	6.3
Shambat	158	105	26	9.9
Khartoum	164	79	21	7.8
Sudeira	214	98	21.5	10.0
Wad el Turabi	261	146.5	23	11.4
Qrashi	277	112.0	23	13.1
Wad Medani	373	79.6	43	8.7
Hag Abdulhah	458	126.5	34	13.5
Sennar	481	105	42	11.5
Wad el Hari	583	105	45	13.0
Singa	588	100	52	11.3
Gedaref	614	126.5	50	12.3
Tozi	679	94	63	10.8
Roseires	776	116.4	71	10.9

2.47 <u>Humidity</u>

The mean relative humidity of this region is shown in figure IV. It is at its lowest in March and April, and rises sharply in May and June at the start of the rainy season. The peak is in August, when over 30 per cent of the annual rain falls. Humidity falls off sharply after September. The slight rise in humidity in December may be due to the sharp decrease in daily temperatures at this time.

Fig. IV



MEAN RELATIVE HUMIDITY % AT 0600 hours
AND 1200 hours G M T AT GEDAREF (2 yrs) WAD EL
HURI (4 yrs) AND WAD MEDANI (30 yrs).
1931 - 1960
GEDAREF .... Humidity at 0600 hours.
Humidity at 1200 hours.
WAD EL HURI .... Humidity at 0600 hours.
Humidity at 1200 hours. No Data
WAD MEDANI .... Humidity at 0600 hours.
Humidity at 1200 hours.
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
75
50
25
0
Relative Humidity %

2.48 Wind Direction and Speed

The following table shows the average wind speeds at Khartoum and Wad Medani:-

Table 2.48 Monthly average Wind Speed in knots per hour at Wad Medani and Khartoum. 1957-61.

	Jan	Feb	Mar	Apr	May	June
Khartoum	9.0	9.3	8.4	7.9	8.7	8.9
Wad Medani	7.0	8.3	7.2	6.8	7.5	10.3

	Jul	Aug	Sept	Oct	Nov	Dec	Year
Khartoum	9.5	8.8	6.4	6.4	7.8	8.1	8.3
Wad Medani	9.6	7.2	6.0	4.5	6.0	6.2	7.2

The average wind speed is lower at Wad Medani than at Khartoum except in June and July when the south winds are dominant. No data have been obtained from Gedaref, but it may be assumed that conditions in the project area are roughly similar to those at Wad Medani.

2.49 Evaporation

Piche cylinders are used at the three stations to measure the daily rates of evaporation. These data are shown in Figure V. The evaporation is lowest at Gedaref. Evaporation at Wad el Huri is unusually high. The level in the project area is probably intermediate between those at Gedaref and Wad Medani.

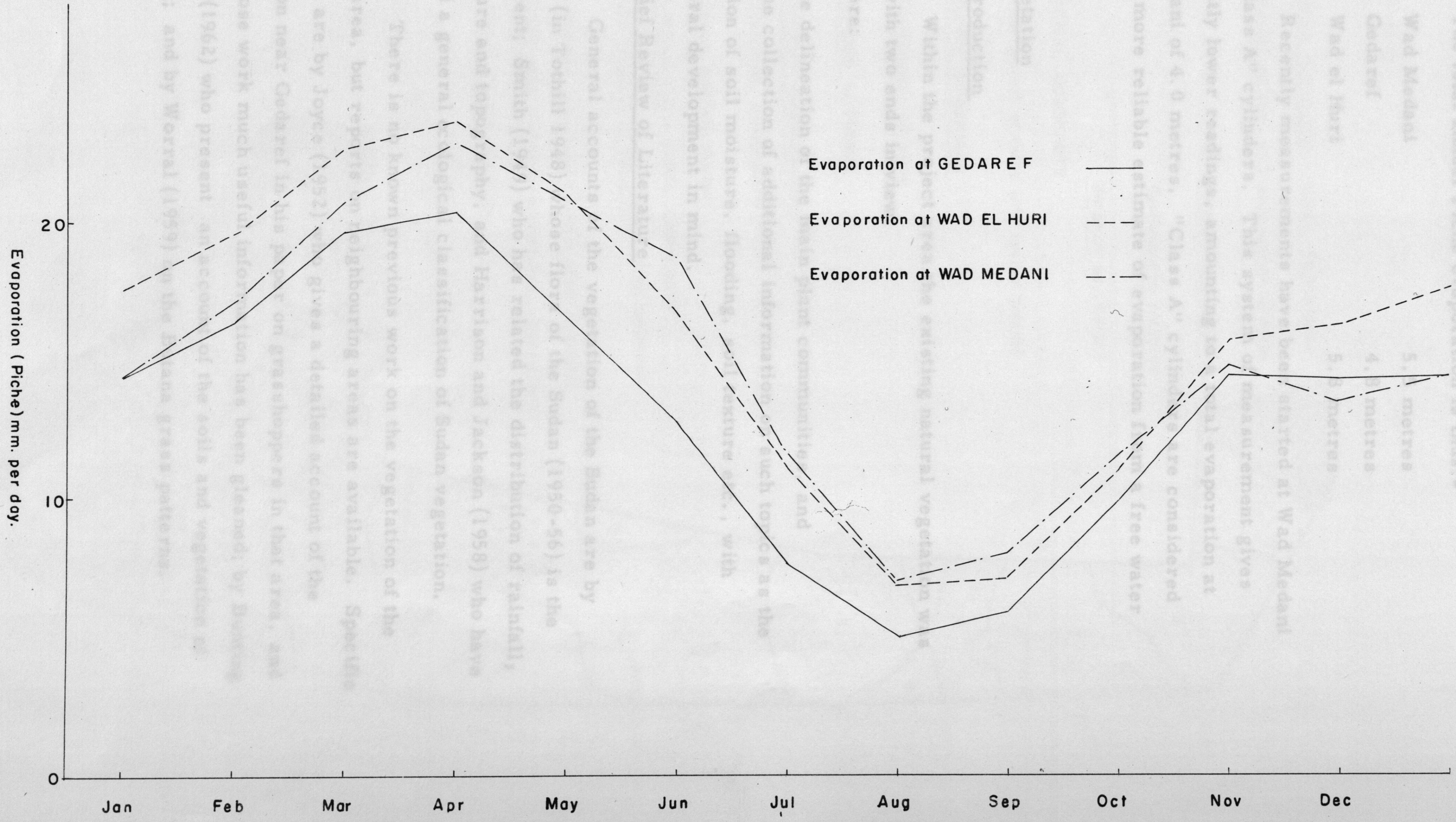
Evaporation is lowest in the Summer months and reaches a peak of over 20 mm per day in April. The overall average evaporation is:-

Wad Medani	15.1 mm per day
Gedaref	13.1 " " "
Wad el Huri	15.8 " " "

Fig. V

EVAPORATION(Piche) IN mm PER DAY AT GEDAREF(21yrs),WAD EL HURI(14yrs) AND WAD MEDANI(30yrs).

1931–1960



The total annual Piche evaporation is thus:-

Wad Medani	5.5 metres
Gedaref	4.8 metres
Wad el Huri	5.8 metres

Recently measurements have been started at Wad Medani using "Class A" cylinders. This system of measurement gives consistently lower readings, amounting to a total evaporation at Wad Medani of 4.0 metres. "Class A" cylinders are considered to give a more reliable estimate of evaporation from a free water surface.

2.5 Vegetation

2.51 Introduction

Within the project area the existing natural vegetation was studied with two ends in view.
These were:

1) the delineation of the main plant communities, and
2) the collection of additional information on such topics as the distribution of soil moisture, flooding, soil texture etc., with agricultural development in mind.

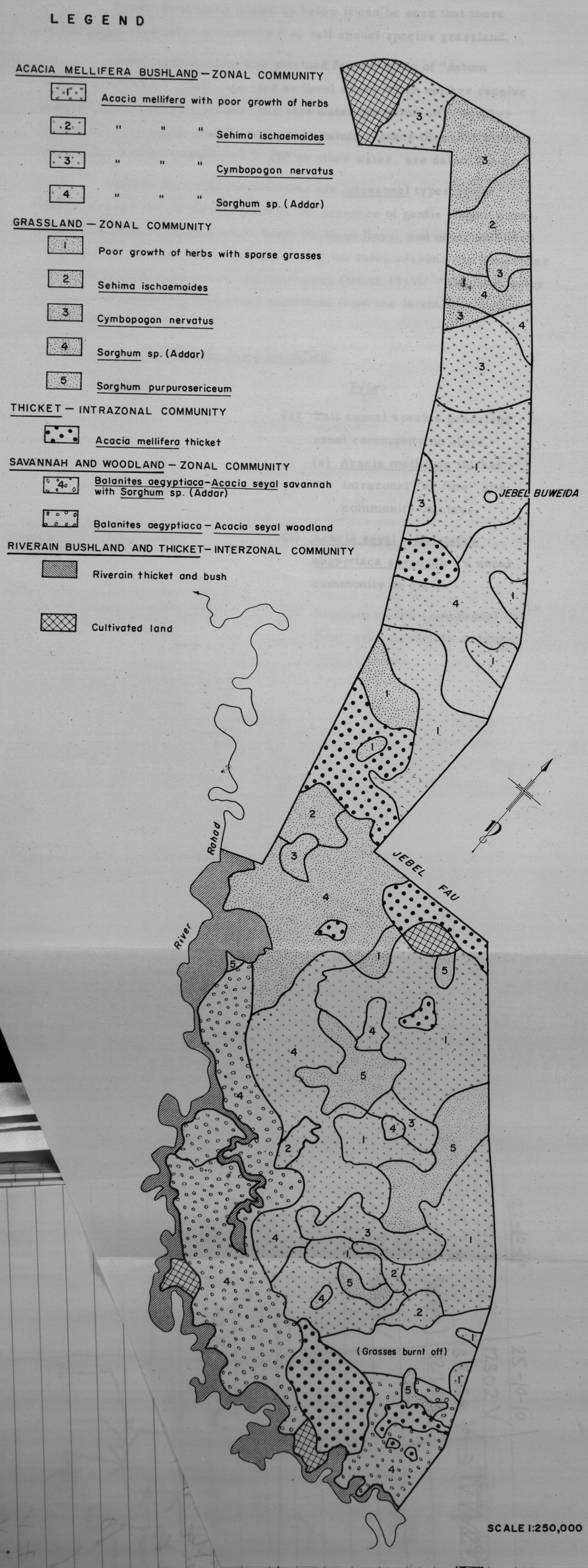
2.52 Brief Review of Literature

General accounts of the vegetation of the Sudan are by Andrews (in Tothill 1948) whose flora of the Sudan (1950-56) is the most recent; Smith (1949) who has related the distribution of rainfall, soil texture and topography, and Harrison and Jackson (1958) who have produced a general ecological classification of Sudan vegetation.

There is no known previous work on the vegetation of the project area, but reports on neighbouring areas are available. Specific accounts are by Joyce (1952) who gives a detailed account of the vegetation near Gedaref in his paper on grasshoppers in that area, and from whose work much useful information has been gleaned; by Bunting and Lea (1962) who present an account of the soils and vegetation of the Fung; and by Worral (1959) on the Butana grass patterns.

Fig. VI

VEGETATION MAP



2.53 System of Classification Adopted

From the scheme drawn up below it can be seen that there is one zonal vegetation community i.e. tall annual species grassland.

Zonal communities are obtained from a study of "datum sites" which Smith (1949) regarded as level areas which neither receive discharges from higher ground, nor lose water from run off. In other words all soils which absorb their whole rainfall (other than that which is lost by "in situ" evaporation), and no other water, are datum sites.

Within the zonal communities are intrazonal types whose limits are defined by factors such as the presence of gentle convex areas, former meander channels which form drainage lines, and other localised depressions likely to be inundated during the rainy season. Such meander channels may be considered "on flow" sites (Smith 1949). "Off flow" sites also occur supporting intrazonal variations from the datum site plant association.

2.54 List of Plant Communities Identified

Form	Type
A. Grassland	(1) Tall annual species grassland - a zonal community on clays. (a) Acacia mellifera thicket - intrazonal "on flow" site community on clays.
B. Savannah	(1) Acacia seyal - Balanites aegyptiaca savannah - a zonal community on clays.
C. Bushland and Thicket	(1) Riverain mixed - interzonal "on flow" site community on clays, silty clays etc.

Synonymy of Other Workers

The boundary between Andrew's (in Tothill 1948) "Acacia - Short-Grass Scrub" and "Acacia - Tall-Grass Forest" probably lies across the project area. They are synonomous with the "Acacia - Short-Grass Country" and "Acacia- Tall-Grass Country" of Smith (1949), and the "Acacia mellifera Thornland low rainfall on clay" and "Acacia-Balanites Savannah and grass areas, low rainfall on clay" of Harrison and Jackson (1958).

2.55 Description of Each Plant Community

A. Grassland

(1) Tall annual species grassland is the most widespread type. Towards the north of the project area Acacia mellifera becomes gregarious on datum sites and the north might more correctly be included in the second form "Bushland and Thicket" as "Acacia mellifera thicket and bushland low rainfall on clay."

The most commonly occurring tall grasses are Cymbopogon nervatus an unidentified Sorghum species referred to below by its Arabic name "Addar", and Sorghum purpurosericeum. These tall grasses were occasionally associated with patches of Sehima ischaemoides a short annual. It was possible to recognise and to map by aerial photographic interpretation the following pure stands and communities:-

a) Poor growth of dicotyledons.
b) Pure stands of Cymbopogon nervatus.
c) Pure stands of Sehima ischaemoides.
d) Pure stands of Sorghum species (Addar).
e) Pure stands of Sorghum purpurosericeum.

The map of these communities is a generalised one as patchiness occurs on a local scale due to factors such as local variations in precipitation which are discussed in detail below, along with other phenomena.

Joyce (1952) has listed the following annual grasses of the Gedaref district in ascending order of their water requirements.

Aristida adscensionis
Schoenefeldia gracilis
Heteropogon contortus
Cymbopogon nervatus
Sorghum sp. (Addar)
Sorghum purpurosericeum

The order is correct for the project area if Sehima ischaemoides is inserted in place of Heteropogon contortus which was not found. The distribution of the two Sorghum species in the project area suggests that there is some other factor in addition to different water requirements affecting distribution. 'Addar' seems to grow best where shade is provided by true growth and it is absent on Grumaquert soils.

The five categories mapped are described below:

a) Poor growth of Dicotyledons

These areas are characterised by a very thin cover of dicotyledons with a few grasses. The exposure of the soil surface to the sun and late rains results in a flaky rain crust and a six centimetre mulch of fine granular clay which obscures deep cracks. The most common species are Ocimum basilicum, Leonites pallida, Monechma bracteatum, Digeria alterniflora and Ipomea sp.. Aristida adscensionis, A. stipoides and Sorghum sp. (Addar) are the most common graminiferous species.

It is clear that this community increases northwards as rainfall reliability decreases, and also eastwards away from the Rahad as ground rises. This latter increase might be explained by run off to the west, but observation over a number of seasons would be required before definite conclusions could be made.

b) Pure stands of Cymbopogon nervatus and

c) Pure stands of Sehima ischaemoides

These areas are most common in the north of the project area for they have the lowest water requirements. (Aristida adscensionis and Schoenefeldia gracilis do not occur as dominants in the project area). In the south, they are associated with Acacia mellifera thickets on intrazonal "on flow" sites.

The taller annual Cymbopogon nervatus reaches a height of 4 feet whilst Sehima ischaemoides rarely reaches 1 foot and at the end of the season lays close to the ground. In some instances these grasses are found growing together or as patches one within another. The difference between their ecological requirements is very critical (Worrall 1959) and very often ground litter of a previous season's growth of Sehima is found in a pure stand of Cymbopogon. There does appear to be some difference in their response to grazing and burning (Roseires Report No. 9).

d) "Addar"

Stands 10 feet to 14 feet high grow towards the Rahad. It is difficult to explain the distribution shown on the map except in terms of "on flow" receipt. The distribution may be explained in part by the presence of stands of Acacia seyal and Balanites aegyptiaca which favours "Addar". These trees are absent to the east on the higher ground where the grass is uncommon and also "Addar" is the most commonly occurring graminiferous species in the northern part of the Acacia seyal - Balanites aegyptiaca woodland of the East Central Sudan. (See note on mulching effect of litter).

e) Pure stands of Sorghum purpurosericeum

This grass grows as a pure dominant on clays in the south of the area and appears to be associated with very extensive but shallow depressions which are not pronounced enough to be colonised by Acacia mellifera.

After the grass is dead it breaks in the wind about a third of the way up the stem, so that a stretch of it looks like arrested waves of the sea.

2.551 Factors Affecting the Distribution of Grasses

THE HERB LAYER: Within each of these grass stands was an associated herb layer, the development of which depends on the characteristics of the preceding rainy season. As the field work for this report was carried out at the end of the dry season, very little information on the ephemerals and herbs has been collected. Joyce (1952) has indicated the importance of this herb layer in deciding the distribution of grasshopper species in the neighbouring Gedaref district.

Soil Series

There is no apparent coincidence of the above five vegetation units and the soil series found in the project area.

The Water Demands of Annual Grasses

The presence of annuals and the absence of perennials can be explained in terms of the high clay content of the soils (between 70-80%) and the existing rainfall regime. In clays of this nature there is less penetration of rainwater and therefore, more water available to the surface horizon. Bunting and Lea (1962) in the Fung and Joyce (1952) in the Gedaref district, are of the opinion that the depth to which the rain penetrates is between 35 and 80 cms. These findings were in keeping with results of the studies on depth of cracking in soils of the project area. Beneath this depth the soil may remain dry and hard in a season of poor rains, or the moisture penetration front may penetrate to the permanently moist layer at about 120 cms. in a year of heavy rains. In the dry season, cracking accompanied by drying will generally proceed until the water content of the top 60 cms. has been reduced to the extent that no water is available for plant growth. In these conditions perennials which transpire during the dry season are replaced by annuals, the water demands of which are confined to the rainy season. They complete their development before the soil dries out to the depth where the roots are operative; that is before cracking has been completed.

<u>Mulching Effect of Litter</u>

The factor which inhibits evaporation most is protection from the sun and the dampest soils during the early rains are those with the thickest cover of litter from the previous season. Since the annual grasses most prolific in growth and providing the greatest ground cover are usually those of the highest rainfall requirement, their establishment itself inhibits loss of water by evaporation. It is believed that these annuals, particularly 'Addar' spread from favourable positions beneath trees as adjacent sites are afforded shade and lower losses from evaporation. Glover et al (1962) described how in Kenya, water penetration beneath isolated <u>Balanites aegyptiaca</u> trees was deeper than on the open plain due to the funnelling effect of the canopy, and how the tree roots penetrated deeply into the clay immediately below the trunk with little lateral spread, allowing other plant species to grow in profusion right up to the trunk. This may explain the particular distribution of 'Addar' which occupies the wooded strip of land running along the Rahad.

Where there is a cover of annual grasses the coarse structure of the soil surface is quite characteristic. The soft, fine granular clay mulch is usually absent and wide, deep cracks are exposed to the surface. In the absence of a cover of vegetation the cracks are obscured and infilled at the surface by the clay mulch.

Effects of Disturbance

Where ants have been active and other disturbance has taken place, a special grass community is found which is characteristic of lighter textured soils elsewhere. The main constituents are Schoenefeldia gracilis, Aristida stipoides, A. adscensionis, A. mutabilis, Dinebra retroflexa and Chloris virgata. In these disturbed soils, the water penetration front is most rapidly moving within the profile and the water penetrates into the deeper areas where roots are not operative. Under these conditions annuals with the lowest water requirements are most successful.

Effects of Local Variations in Rainfall

Rainfall is extremely local in its distribution with an area receiving only half as much as another a few kilometres away. It explains the patchy distribution of species within the generalised pattern. Annual vegetation seeds may be dormant for several seasons, germinating only when conditions are favourable, so that great seasonal variations in vegetation occur. The differences may be very small and this is demonstrated clearly along the motor road between El Fau and El Luega. Close to the clay road, within 2 to 3 metres, the vegetation is usually tall 'Addar', but beyond this occurs a sparse cover of dicotelydons. The splash from vehicles and water accumulating in tracks is enough to improve the moisture status of the flanking strips and give a good cover of vegetation.

Variation in growth occurs according to the particular character of the rainy season. Joyce (1952) states that, in the Gedaref district, densest and strongest growth was recorded in areas where heavy, early rains and an absence of drought resulted in an early break down of the straw and uninterrupted growth of both herbs and grasses. In areas of poor early rain and severe drought non-graminaceous plants suffered a severe set back. Generally annual grasses are favoured by good well distributed rains, while herbs are favoured by poor rains not broken by long drought.

Effects of Grazing

The project area was grazed by cattle and goats from the local villages and particularly by nomads'herds of camels and cattle ranging throughout. There was no evidence of overstocking or degrading of the pastures except in the close neighbourhood of routes and villages. It is possible that Sehima ischeamoides has been grazed out in places as it occurs only in isolated areas far from villages.

Effects of Burning

At the time of survey (February to May 1964) the area was free from fires except in the south near Tuneidba and there was no evidence over the greater part of the area of burning of the "harig" type from the previous season. The general absence of arborescent species in the project area is thought to be an expression of water availability rather than evidence of past burning; the only trees and bushes that do occur in the area are found in the zone of densest settlement where the burning and browsing are most intense.

(a) Acacia mellifera thicket

Within the tall annual species grassland the intrazonal "on flow" site community of dense A. mellifera bushes 3 to 4 metres high is found, particularly in depressions which collect run off from the surrounding plain, or from the sloping land around the rock outcrops of Jebel Fau. After a rainstorm of less than 25 mm. water temporarily accumulated in the hollows during early May. The soils in these depressions are usually grey-brown (10YR 4/1).

The root system of Acacia mellifera has a very wide lateral spread on the surface soil. Roots frequently reach out 8 to 15 metres from the trunk at a depth of 25 cms. below the surface. They are able to take advantage of the accumulated surface water and, unlike Acacia seyal and Balanites aegyptiaca do not rely on obtaining water from the subsoil below.

In the densest thickets grasses are shaded out, except for occasional Aristida stipoides and A. adscensionis, but where the bushes are thinner, either Cymbopogon nervatus or Sehima ischaemoides is dominant. The absence of the annual grasses with the higher water requirements is probably due to the rapid exhaustion of the water supplies in the surface horizon by the bushes.

(b) Savannah

(1) Acacia seyal - Balanites aegyptiaca savannah

In the south of the project area thin stands of these species mark the northern limit of this zonal community which is dominant over the clay plains south of the 480 mm. isohyet. The Savannah merges imperceptively with the riverain vegetation towards the Rahad.

(c) Bushland and Thicket

(1) Riverain mixed

Close to the Rahad below the break of slope, between the plateau and the "Kerrib"[1] land, where clearing has not taken place, there is a heterogenous assemblage of species. Acacia seyal, A. arabica, Balanites aegyptiaca, Capparis decidua, Boscia octandra and Cadaba rotundifolia are common. Crateva adansoni sometimes forms undergrowth. On higher levels of alluvium Ziziphus spina-christi forms dense thickets.

Above the break of slope, moving towards the river, the order of appearance of tree and bush species is listed below together with the distance in kilometres away from river of their first appearance.

Cadaba rotundifolia	5
Balanites aegyptiaca	4
Capparis decidua	3
Acacia seyal	2
Boscia octandra	1
Salvadora persica (rare)	1

(1) "Kerrib" - Arabic, the terrain resulting from steep run-off in deep homogenous clay (Smith 1949).

2.56 Check List of Flora

No check list of flora has been appended as only those species which could be identified at the end of the dry season have been mentioned in the text; any check list based on field work at that part of the year would be far from complete.

The authorities of species mentioned are the same as those in Andrews (1950-1956).

2.6 Population and Land Use

2.61 Population Figures and Ethnic Groups

The total settled population in and immediately adjacent to the project area is very small and is estimated at 12,000. This figure is based on the 1955 population census supplemented by hut counts on the ground and from air photographs. Most of the inhabitants live either along the kerrib lands of the Rahad and the Blue Nile or just outside the project area.

In addition there are two distinct groups of nomads moving through the area from the Butana in the north east and from the Blue Nile in the west. There were about 1300 Butana nomads camped in tents along the Rahad during April 1964.

The people are nearly all Arab and Shukriya are the best represented tribe. There are several small villages of West Africans along the Rahad in the most southerly section of the project area. They have been settled here for approximately 30 years and are farmers like their Arab neighbours. Most of the villages contain members of only one tribe. In a few cases there may be a minority group belonging to a second tribe which forms a small outlying settlement 50-200 yards from the main village.

2.62 Distribution of the Population

The major factor determining the distribution of the settlement is the availability of water supplies. The clay plain which forms the project area of the soil survey is virtually devoid of both domestic and livestock water supplies and it is only the seasonal river Rahad in the west and the pediment area of Jebel Fau in the east which yield dry season well water. Both these places support sedentary population and provide the water supplies needed by nomads. Very few scattered settlements in the extreme north of the clay plain, appear to be confined to that part of the plain underlain by the Nubian sandstones from which the water supply is derived. The bulk of the clay plain underlain by dry Basement Complex rocks is devoid of settlement.

The shortage of water has led to the development of a transhumant sector within the village dwelling people. These live in villages in the Butana where they cultivate, and graze their stock during the rainy season. Inadequate water supplies then force them to move to a second village by the Rahad for the dry season. Within the Jebel area water supplies of some villages dry up and these villages in turn move to the Rahad rather than transport water daily several miles by donkey. Some village populations south of Ein el Luweika travel only a few miles between their dry and rainy season homes.

Settlement along the Rahad is confined to places where water is available. The river flows only during part of the year, but pits (1 - 6 metres deep) are dug in the river bed and yield water for domestic and livestock needs. The settlement within this zone has many pioneer characteristics with large areas still unsettled between villages. Where villages do occur, they are often small and of recent origin. They lie in Hosh Rural Council, or Gedaref North Rural Council, and are ill provided with services, being isolated from the administrative centres. The Jebel settlements however, are not so cut off as the main motor route between Gedaref and Medani cuts through the area.

2.63 Present Land Use and Occupations of the People

2.631

All agricultural activity is within the traditional sector. There are no pump schemes within the area and most of the rain-fed crops are for local need. Cultivation is confined to the areas of settlement near the river or close to Jebel Fau.

The average area of cultivated land per family is between ten and twenty feddans. The staple crop is dura (Sorghum vulgare) and yields vary according to the available rainfall and probably fluctuate between 1.5 and 4 ardebs per feddan. The crop is grown on flat ground, rainfall being suficient to render unnecessary the building of "terus" for water conservation. It is likely that crop failures due to inadequate rainfall, or poorly distributed rains within the season, occur once in five years.

Cultivations are done manually by traditional methods and there are no tractors in the project area.

Along the banks of the Rahad there is some "gerf" cultivation but it is not well developed as the population is low. Nomads' animals often destroy the crops and together with the absence of markets these factors have precluded its development. In West African villages a certain amount of vegetables is grown for home consumption.

2.632 Livestock

Animals make a significant yet variable contribution to family income, and provide a valuable source of protein in the absence of vegetables.

There are usually two or three goats per family, or the families with a higher income may replace them with a cow. Camels are not common in the villages and are usually limited to those sections of the community engaging in commerce. There are rarely more than half a dozen in a village of 200 people.

The settled villages of the Rahad have few animals. The area is troubled by flies during the rains and complicated arrangements have to be made for nomads to take them north to the Butana. Sheep are not suited to these conditions and number less than one per family. West Africans show no interest in livestock. As income from tillage is reliable and vegetables adequate, there is not a great need for a large number of animals in the present village economy.

The economy of the nomadic groups is, however, based on livestock. The animals which include herds of cattle, camels and sheep are brought into the area in the dry season from the Butana to water at the wells of Jebel Fau. A complicated timetable has developed for each tribal group to water their animals on a particular day at a specific time, and local villagers make similar arrangements for their livestock. Some nomadic groups rely on watering points along the Rahad.

2.633 Dry Season Employment

People in the riparian villages of the Rahad undertake little outside work in the dry season. With the security afforded by good yields of dura on land only recently brought into cultivation, there appears to be no particular incentive. In addition these communities are isolated from market centres and have little opportunity for widening their range of demand.

There is little evidence that these people go cotton picking. There is no shortage of grazing for the animals which are few in number; the livestock fodder available in the Gezira is considered to be an important incentive to some villagers further north to go cotton picking.

The inhabitants of the Fau region are not unaccustomed to outside work and make journeys to Gedaref and Medani. El Fau village lies astride this route.

Charcoal burning in the riverine area is carried out by nomads. The woodland close to the river is gradually being cleared and particular preference is shown for Acacia seyal (Toleh). Charcoal will fetch 30 to 40 piastres a sack in Medani. Camel owners within the villages often work cutting wood and "Nahl" grass (Cymbopogon nervatus) for house construction.

CHAPTER 3

SURVEY METHODS

3.1 Aerial Photo Interpretation

Aerial Photographs at a scale of 1:25,000 were provided by the Sudan Government. These were used for the following purposes:-

(i) Made up into Mosaics at a scale of 1:50,000, they were used as base maps on which all the field data were recorded.

(ii) The individual prints were used for navigation and the accurate plotting of investigated sites and other data.

(iii) The prints and mosaics were studied before the with the aid stereoscope to give a three-dimensional image, in order to eliminate areas that were topographically unsuitable for soil survey, and to select sites at which preliminary 'sample' areas could be placed to give an idea of the range of soil types occurring in the area.

(iv) After completion of the soil survey, the prints were studied in detail, to obtain information on topographical features, land use, population, and vegetation patterns, and to attempt to use some of these features in mapping the soils.

3.11 Interpretation of Patterns Visible on the Aerial Photographs

(i) Land Types. The 3C Extension area consists of an extensive clay plain which rises gradually towards the north-east. To the west the meandering and incised River Rahad bounds the area, while occasional granite inliers emerge from the clay plain to the north and west (e.g. Jebel Buweida, Jebel Fau). Cutoffs and abandoned meander channels are common along the Rahad, and occur up to 5 kilometres away from the river. A broad shallow depression extends from Jebel Fau to the Rahad. Several small closed depressions are scattered elsewhere throughout the area.

Jebel Fau forms the most conspicuous relief feature in this region, and from the air appears as a narrow range of parallel crescentic ridges arranged transversely to the general trend of the range. Rock outcrops appear dark grey, while light grey represents the pediments peripheral to the Jebel. To the south and west, Jebel Fau appears to be bounded by a shallow scarp foot depression, containing frequent Acacia seyal bushes and thickets of Acacia mellifera, which finally succeeds to the light grey grassy plain. The sand and gravel alluvial fans emerging from the jebel appear white, while greys and dark greys are the colours characteristic of the clay plain.

(ii) Drainage. The Rahad is conspicuous on the prints both for its meandering course and for the dense border of woodland along its banks. A narrow zone of sloping gullied land occurs on either side of the river, and is separated from the clay plain by a more or less sharp break of slope. The "kerrib" zone consists of closely spaced white lines arranged in a dendritic pattern, and usually characterised by black dots representing Acacia seyal and Balanites aegyptiaca.

Several of the ancient meanders are larger and less curved than those now active, and enclosed within one meander loop were two crescentic depressions representing earlier, more direct courses of the river. The Rahad appears to be incised within a larger channel and when viewed stereoscopically on the aerial photographs it appears to have the valley-in-valley form of a rejuvenated river. Many of the ancient cutoffs are composite and consist of several sub-parallel channels, while the majority of the ancient meander channels are considerably wider than the present river. In fact, the widest channels were those which were least well defined on the prints, and were presumably among the most ancient. This would seem to suggest a somewhat greater discharge at an earlier period, followed by rejuvenation and entrenchment of the river. A narrow, sinuous channel parallels the Rahad for over twenty kilometres, and appears to mark a recently abandoned course of the river.

Both the Rahad and the larger abandoned channels are separated from the main clay plain by a perceptible break of slope which has given rise to soil creep with its concomitant arcuate vegetation pattern. The older channels appear dark grey with large black dots scattered along them representing Acacia seyal, while the smaller active gullies have minute black dots representing Acacia mellifera set against a grey background. Ill-defined field patterns reveal that some of the former meander channels are cultivated, but the majority of them appear on the prints as discontinuous grey bands, often conspicuous for their tree cover in an otherwise grassy area.

(iii) Other relief features. A single isolated granite inselberg emerges from the clay plain in the north-west of the project area. On the clay piedmont zone around the Jebel are several narrow black arcuate lines of vegetation due to soil creep, while a broad white circle shows that an extensive pediment fringes the conical outcrop.

Seasonally flooded depressions may be recognised on the prints by their roughly circular shape, uniformly grey colour and absence of vegetation. The soils underlying these depressions are dark grey and in these instances it is possible to delineate the soil boundaries from the prints with a fair degree of accuracy.

(iv) Vegetation. Acacia mellifera ('kitr') shows perhaps the most distinctive pattern in this area consisting of small black dots of uniform size grouped in clusters, and often so dense that the dots coalesce and form a dark grey background. Acacia mellifera tends to prefer the lower, moister sites, and so in the vicinity of Jebel Fau it occupies the depression encircling the massif, while Acacia seyal occurs in narrow bands between the individual ridges, and may be recognised on the prints by its broad, irregular crown and varying size. Where Acacia mellifera occupies the shallow gullies which emerge from the Jebel, it has a strictly dendritic pattern, showing the close relationship which exists between vegetation and small-scale features of the landscape.

In the extreme north-east of the project area are a series of wide, sub-parallel dark grey bands upon which Acacia mellifera is conspicuously concentrated. These bands often overlap, and may have originated as camel tracks which subsequently attracted the run-off and so gave rise to the intensely localized distribution of the 'kitr' in this area. Within the more open 'kitr' woodland, the mature trees are often grouped in small circles, around the rim of shallow depressions.

The origin of these shallow circular hollows is obscure although it should be noted that young 'kitr' bushes may occasionally be seen grouped around abandoned threshing pits in formerly cultivated areas. The existence of dense clumps of Aristida grass within the more open Acacia mellifera woodland gives these areas a patchy appearance, in which grey and white alternate according to how closely spaced the 'kitr' bushes may be.

Extensive grey and light grey patches represent wild sorghum ("Addar"), and Sorghum purpurosericeum ('aris'). Uniformly dark grey areas criss-crossed by white tracks are areas with a poor growth of herbs and scattered grasses, particularly "Addar" and Sorghum purpurosericeum.

Cymbopogon nervatus occurs either as large white patches amidst the Acacia mellifera scrub or as small grey patches on a light grey or white background. Sehima ischaemoides grassland appears white, or, very occasionally, light grey.

Between the Rahad and the very long abandoned channel representing its former course, irregularly spaced dots of varying size represent a thin woodland of Acacia seyal and Balanites aegyptiaca. The former tree often occurs in scattered clumps on the clay plain, occasionally in association with Cadaba rotundifolia; which is depicted by small, irregular, widely spaced black dots.

The dura fields north of Jebel Fau stand out against a white background of grassland in which angular grey patches show where burning once took place.

(v) Land Use. Three dominant forms of land use may be distinguished within the project area:-

(a) the cultivation of rain-fed dura

(b) grassland

(c) woodland, with occasional shifting cultivation, generally by semi-nomadic herdsmen.

The fields adjacent to the Rahad form small irregular quadrilaterals, while occasional small narrow fields occur along the edge of areas of higher ground encircled by meander cut-offs. Some of the meander channels are also cultivated. North of Jebel Fau the fields are in scattered clearings in the Acacia mellifera woodland, whule in the far north-east several groups of very large fields, some up to 1 kilometre long, occur in the thin 'kitr' woodland. Near Jebel Fau the fields appear as large grey quadrilaterals on a light grey (i.e. grassy and treeless) background.

The grassland areas have been described in Section 4; and are frequently traversed by camel tracks which fan outwards towards the river. These appear dark grey on a light grey (grassy) background, but light grey by contrast with very dark grey background if the area has been recently burnt.

Dense Acacia mellifera woodland is dominant and frequently alternates with discontinuous grassy clearings. Several isolated fields without bunds occur at rare intervals along the main camel routes. Field enquiry showed that these are generally used once and then abandoned.

(vi) Population and settlement. The area is in general sparsely settled with the majority of villages localized along the banks of the Rahad. Several small villages are situated in and around Jebel Fau, while in the extreme north-east the project area enters a zone of nucleated villages dispersed at roughly even intervals throughout the cultivated land.

Irregular tracks radiating towards the river indicate the routes followed by Shukria nomads with their herds of cattle and camels, while inter-village communications depend upon a more or less regular network of tracks.

3.2 Soil Survey Procedure

3.21 Semi-detailed Survey

The survey was carried out between February 23rd and April 29th 1964, with a team of five soil surveyors working from the Forestry Department rest house at Jebel Fau. Aerial photography, at a scale of 1:25,000, was supplied by the Sudan Survey Department, who also supplied mosaics at a scale of 1:50,000.

The sampling density required was at least one site for every 250 feddans sampled on a grid, which corresponds to a grid approximately one kilometre square. As the Sudan Survey Department had cut traces on a two kilometre grid, the sites were located on the ground on this grid, and then plotted accurately on the mosaics. This eliminated the errors which result from drawing up a grid on the mosaics and then transferring it to a base map, due to variations in scale of the mosaics.

Auger holes were dug to a depth of two metres using a 5 cm. Jarret auger. Approximately 1 site in 20 was bored to 3 metres. The sites were described according to the U.S.D.A system, by visible horizons, the definitive features being colour, texture and structure. Descriptions of structure are valid only in pits. After being subjected to vigorous augering very little remains of the original structure and in this area of near uniform texture, colour was the principal definitive feature in bores. Each site was sampled by fixed depth between 0-45, 45-90 and 90-150 cm., which corresponded to the positions of the major pedogenetic horizons as revealed in pits (See 4.22 and Appendix 2).

In this survey area, the soils proved too uniform for different types to be clearly identified on the basis of field descriptions, so pits for representative analyses were sited on as wide a range of types of land as possible on the basis of photo-interpretation and field inspection. As most soil series in the project area had already been covered during the survey of area 3c (Roseires Report No.4) only one of the representative sites was selected for analysis in greater detail.

3.22 Sample Areas

One sample area was investigated in an attempt to establish the level of continuity of physical and chemical characteristics in profiles of the clay plain of the project area, and also to establish a common basis for observation and description of soil profiles among the members of the team. The sample area consisted of 5 pits spread over a distance of 1 kilometre.

3.23 Chemical Analyses

Routine sites

Top two layers - 0-45 cm and 45-90 cm:-

Mechanical analysis.

Moisture saturation percentage of soil paste.

Salinity (Electrical Conductivity of the saturation extract in mmhos/cm).

Soluble sodium in mg-equivalent/100gm. soil.

Exchangeable sodium in mg-equivalent/100 gm. soil.

Third layer - 90-150 cm.:-

E.C. and Saturation percentage ~~only~~.

Representative profiles

Samples from all major visible horizons.

All analyses as for routine sites together with pH of soil paste.

Sample area profiles

Samples from all major visible horizons.

All analyses as for routine sites together with pH of soil paste and 1:5 dilution.

Soil series profiles

Samples from all major visible horizons of selected profiles representing the soil series mapped.

All analyses as for sample area profiles together with the following:-

Total nitrogen per cent.

Total organic carbon per cent.

Available phosphorus and potassium in mg/100 gms. soil.

Soluble anions in saturation extract in mg. equivalents/litre i.e. Carbonate, Bicarbonate, Sulphate and Chloride.

Soluble cations in saturation extract in mg. equivalents/litre i.e. Sodium, Potassium, Calcium, Magnesium.

Exchangeable cations in mg. equivalent/100 gms. soil, i.e. Sodium, Potassium, Calcium, Magnesium.

Cation exchange capacity in mg. equivalents/100 gms. soil.

The Exchangeable Sodium Percentage is calculated as follows:-

$$\text{E.S.P.} = \frac{\text{exchangeable Na in mg. - equivalents/100 gms soil}}{\text{C.E.C. or clay percentage}} \times 100.$$

3.24 Soil profiles analysed

The total number of profile analyses is as follows:-

Routine sites: 2 metre bores and pits	-	1381
3 metre bores	-	59
Representative pits (including 39 at routine sites)	-	45
Sample area pits (including 3 at routine sites)	-	5
Total soil profile analyses		1490

The total number of profiles sampled is 1443, of which 45 were subjected to two different kinds of analysis.

Eight sites were sampled for analysis at series level in the 1964-65 field season. The analytical data, together with comments, will be submitted as soon as possible, as a supplement to this report.

3.3 Field Permeability Studies

Field permeability tests were carried out at 9 pit sites. Two tests were made at 7 of these sites and three tests at two sites so a total of 20 tests were made.

The method was adapted from the type 'A' test described in the United States Bureau of Reclamation Manual, 1951, as used by Hunting Technical Services Ltd. in their Kirkuk (Iraq) and Pangani (Tanganyika) projects.

Apparatus:

Land Rover	Clean gravel
2 x 4 gallon drums	Mirror
2" Jarret auger	50 cc. graduated cylinder
10m. rubber tubing	250 cc. graduated cylinder
2 screw clamps	Stopwatch
2 m. measuring tape	Thermometer

Procedure:

The tests were carried out in previously described major horizons of the 2 - metre pits dug in the sample areas and at representative sites. Horizons more than 25 cm. had to be used as the method is unreliable where the length of the test section is less than five times the diameter of the bore. The top of the horizon was cut back as a step in the pit and a hole bored in it vertically with the jarret auger. The bore was examined with a mirror and was only used if no cracks were visible. Despite this caution many tests may well have been influenced by water escaping down concealed cracks after the test was started. As a result, the hydraulic conductivity values are liable to be rather high.

If the inflowing water is colder than the soil, dissolved air comes out of solution as it enters the soil and the bubbles produced block the soil pores and reduce the soil permeability. As the water was if anything slightly warmer than the soil, however, it was considered that possible error from this source could be neglected.

After boring, the depth of the hole was measured in centimetres. A few handfuls of gravel were then put in a 1 m. length of auger tubing inserted. The hole was then filled with gravel. The top of the gravel is considered to be the top of the test section.

Its depth below the top of the hole was measured and subtracted from the total hole depth to give h, the height of the test section. The gravel is needed to prevent the hole collapsing when wetted and the auger tubing is needed to facilitate the introduction of the water.

The hole is then filled to the mark with water from the drum through the rubber hose. The screw clamp on the hose is used to maintain the water surface at the level of the top of the gravel. The rate of inflow is measured at 5 minute intervals by catching the flow in a graduated cylinder for a timed period. This rate steadily decreases at first but becomes more uniform after 20 minutes, and the final reading of the rate of flow is taken when the readings have become reasonably constant - generally 30-45 minutes after the commencement of the test.

From the final reading the permeability is deduced from the formula given below:-

$$K = \frac{864Q}{Curh}$$

where K = coefficient of permeability in m/day/unit hydraulic gradient

Q = rate of steady inflow in ml/sec.

r = radius of bore in cm.

h = height of water column in cm.

Cu = coefficient obtained from Table 3.3.

Table 3.3 - Coefficient of Conductivity

h/r	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5
Cu	32.0	32.9	33.7	34.5	35.3	36.1	36.9	37.8

h/r	14.0	14.5	15.0	16.0	17.0	18.0	19.0	20.0
Cu	38.6	39.4	40.2	41.9	43.5	45.2	46.8	48.5

Results of the tests are given in Chapter 4.

3.4 Chemical Analyses of Soils - Methods

The following methods were used by Agricultural Services (Sudan) Ltd., in making the determinations.

(i) Mechanical Analysis: Bouyoucos Hydrometer Method

40 grams soil ~~were~~ are soaked with 250 ml. water and 11 ml. of 10 per cent sodium hexametaphosphate solution overnight, and dispersed the next morning in an electric stirrer for 10 minutes, transferred to a 1 litre measuring cylinder, shaken and readings taken after 4 minutes, 2 hours and 7 hours in order to estimate percentages of sand silt and clay, respectively. With every reading the temperature is recorded and corrections made for temperatures and dispersing agent content. The readings are also corrected for soil moisture content, when required, by performing separate moisture determinations.

(ii) pH

Potentiometric determinations using a glass electrode on the soil paste or 1:5 suspensions, were carried out.

(iii) Electrical Conductivity

Calculated by using a Solubridge on the saturation extract.

(iv) Total Nitrogen

Estimation of Organic plus ammonia nitrogen, by Kjeldahl digestion, followed by distillation of freed ammonia into a boric acid solution and titration with 0.05 N.HCl.

(v) Organic Carbon

Wet oxidation of the organic matter by the Walkley-Black rapid method (C.S. Piper, 1942, page 223).

(vi) Total extractable Phosphorus

Extracted using constant boiling hydrochloric acid on a sand bath for a few hours (C.S. Piper, 1942). Estimated by reduction of an aliquot portion, with ascorbic acid in sodium hexametasulphite, to molybdophosphoric blue, and comparison with standards on the absorption spectrophotometer.

(vii) Total extractable Potassium

Extracted during the above process. An aliquot is taken, treated with ammonia to precipitate the sesquioxides, reacidified, and compared with standards flamephotometrically.

(viii) Carbonate as Incorporated Calcium Carbonate

Gasiometrical determination in Collins calcimeter (Collins S.H. 1906). The volume of CO_2 generated from a known weight of the soil is reduced to standard conditions, and calculated as if the total volume were derived from calcium carbonate only.

(ix) Carbonate and Bicarbonate in Saturation Extract

A suitable aliquot of saturation extract is pipetted and titrated first against phenol phothalein indicator (it is essential to add always the same amount of indicator to the same volume) followed by titration against methyl-orange.

(x) Chlorides in Saturation Extract

A suitable aliquot is pipetted into a porcelain evaporating dish, and the chloride content determined by Mohrs method (ref. Vogel, Quantitative Analyses) using 5 per cent potassium chromate as indicator, and titrated with 0.02 N silver nitrate solution.

(xi) Sulphate in Saturation Extract

1 ml. of suitably diluted saturation extract is added to a medium of glycerol and glucose solution. Barium sulphate is generated and determined turbidimetrically in the electric photometer. (ref. Current Science Vol. 31, No. 10, October 1962, page 419).

(xii) Soluble Calcium and Magnesium in Saturation Extract

A suitable aliquot of saturation extract is titrated with 0.01 N sodium versenate solution first against the Eriochrome Black T indicator, and a second aliquot against the Purpurate (Murexide) indicator. It is essential in this second titration to work as much as possible with equal volumes as the end point of titration against Purpurate varies with the dilution. (Ref. Agric. Handbook No. 60, U.S. Dept. of Agriculture).

(xiii) Soluble Sodium and Potassium in Saturation Extract

Appropriately diluted saturation extract is analysed on flame-photometer for Na viz K.

(xiv) Exchangeable Sodium and Potassium

12.5g of soil are soaked in 50 ml. of normal ammonium chloride, left for one hour then leached a few times (about four times) by decantation. Then the soil is transferred into the filter and leached with successive portions of normal ammonium chloride when drained. The filtrate (5 ml.) is diluted 20 times and sodium read off on the flamephotometer against 10 ppm. sodium standard containing the same amount of ammonium chloride. Zero is set with 0.05 N. ammonium chloride. In another portion of suitably diluted filtrate potassium is determined flamephotometrically against standards containing the same amount of ammonium chloride. From these readings the sum of soluble plus exchangeable sodium viz. potassium are calculated. By subtracting the soluble sodium and potassium from saturation extract data the net figures for exchangeable sodium and potassium are obtained.

(xv) Exchangeable Calcium and Magnesium

The method is essentially that described in C.S. Piper, Soil and Plant Analysis, page 170, the difference being only in the amount taken and leached twice with 250 ml. of normal sodium chloride. Ca viz. calcium plus magnesium are determined by versenate titration (ref. Agric. Handbook No.60, U.S. Dept. of Agriculture, page 94).

(xvi) Cation Exchange Capacity

The clay is converted into a sodium clay using sodium acetate. Soluble salts are washed out with 95 per cent alcohol, and sodium is released by ammonium acetate. It is estimated flamephotometrically (ref. U.S.D.A. Handbook No.60).

3.5 Map Compilation

3.51 The Base Maps

The base maps were based on the Sudan Survey maps, at a scale of 1:50,000:- sheets Nos. 55G-2-3, 55G-2-4, 55G-5-2, 55G-5-4, 55G-6-1, 55G-6-3, 55K-3-1, 55K-3-2, on which have been adjusted the locations on the river Rahad, roads, villages and other features according to information on the aerial photographs.

Pit, auger hole and field permeability sites are indicated on the base maps by the following numbered symbols:-

o .... 2 metre auger hole.

◎ .... 3 metre auger hole.

△ .... 2 metre pit.

☆ .... Site of permeability test.

The first figure of the number against a site identifies the soil surveyor responsible.

3.52 The Soil Maps

A coded soil classification is marked against each site on the soil maps, and explained in the legend and Chapter 4 of this report.

The soil boundaries were first determined on overlays on the aerial photo mosaics using photo-interpretation where possible, and traced on to the base maps.

3.53 The Land Class Maps

3.531 Compilation

A coded land classification is marked beside each site on the land class maps. The code is explained in the map legend and a fuller explanation is given in Chapter 5 of this report. The land class boundaries were determined using the same system as for the soil class boundaries described above (3.52).

3.532 Matching Boundaries with Area 3C, Surveyed in 1962-63

When the land class maps of Area 3C extension, surveyed in the 1963-64 season, were matched with adjoining land class maps of Area 3C, surveyed in the 1962-63 season, it was found that the boundaries of land classes did not always match very well across the edges of adjoining map sheets. The discrepancies were mostly between the arable classes 2 and 3 and the limited arable class 4, rather than with Class 6, so that the blocks of arable and limited arable land could be said to map quite well across the boundaries of the two areas surveyed in different seasons. This is fairly well in accordance with the aims of a semi-detailed reconnaissance land classification survey which is to separate arable from non-arable land with considerable accuracy while delineating boundaries between classes and sub-classes in less detail (See 5.2).

The discrepancy in land class boundaries as between the two areas is almost certainly caused by the different sampling depths used between the two field seasons.

In the 1962-63 field season each soil surveyor was allowed to use his own discretion in deciding on the sampling depths of the characteristic but rather ill-defined major horizons of the clay soils as brought up in the soil auger. This resulted in randomized sampling depths which could be used quite satisfactorily for soil classification but which were very difficult to use for land classification. The average depth of the top sample in area 3C was 73 cm and many of the upland soils at the eastern edge of the map sheets were sampled 0-90 cm. This bulk sampling eliminated the possibility of observing changes in E.S.P., E.C. and clay content down the profile. In these cases it was not possible to separate areas of Class 3a land which in 1962-63 were characterised by an increased E.S.P. in the 60-90 cm layer. There was therefore a tendency for land classes 2 and 4a to increase at the expense of land class 3a.

In the second field season it was decided to take samples at the fixed depths of 0-45 cm, 45-90 cm and 90-150 cm which careful study had shown to correspond generally with the thicknesses of the three main horizons of the Gezira type clays. The specifications for E.S.P., E.C. and clay content were then worked out for these horizons and agreement as to their application was reached at a meeting with World Bank Officers in Washington in August 1964. These are the specifications listed in Table 5.4 of this report.

Examination of the numerous data in Appendix 2 of this report will show that many of the upland soils have a characteristic profile, having low E.C. throughout and showing a sharp increase in E.S.P. from the 0-45 cm horizon to the 45-90 cm horizon. For instance, site No. 6492 having an E.S.P. of 9 in the 0-45 cm layer and an E.S.P. of 16 in the 45-90 cm layer is land class 3a. If, however, the two horizons were bulked together, as in parts of Area 3C, the average E.S.P. would be 12.5 and the site would become Class 2. Similarly, site No. 2420 having an E.S.P. of 13 in the 0-45 cm layer and an E.S.P. of 21 in the 45-90 cm layer is land Class 3a but bulking of the two horizons would result in an average E.S.P. of 17 and the site would become Class 4a. These examples illustrate the difficulties attendant on the use of the method of "weighted averages" (used in the 1962-63 field season) which must assume that the characteristics measured are uniform throughout the horizon sampled. Although not ideal that is the only workable method of relating randomized sample depths to the fixed relationship required for land classification.

CHAPTER 4

PEDOLOGY

4.1 Introduction

4.11 Parent Material

The project area forms an extension south-eastwards of the area covered by Report No. 4. The soils in the north-west and along the river Rahad are alluvial clays similar to those described in that report. These merge eastwards into colluvial clays formed from ancient igneous and metamorphic rocks. These clays are similar in appearance to the alluvial clays, but show some differences in the distribution of salts down the profile.

4.12 Soil Forming Processes

The soil environment is one of level or very gently sloping land under savannah or grassland vegetation in a semi-arid monsoon-type climate. The montmorillonitic clays are characterised by a considerable capacity for expansion on wetting. The result of the alternate wet and dry seasons on these clays is typically the formation of wide deep cracks and the breaking up of the surface into small blocky fragments. These fragments fall down the cracks resulting in a continuous self-mulching process which accounts for many characteristics of the profile.

The rainfall appears to be sufficient to cause some movement of salt, and possibly of clay, down the profile. The downward movement of clay is counteracted by the self-mulching process.

4.13 A Typical Soil Profile

The following characteristics are typical of profiles within the area:-

<u>Surface:</u> Level or slightly hummocky with a system of wide cracks, which may be partly or completely obscured by a granular or fine blocky mulch normally 1-2 cm. deep, though it may extend to 5 cm.

<u>First Horizon:</u> 0-50 cm. Dark greyish brown clay, the surface mulch merging into a strong coarse prismatic structure with secondary platiness or blockiness. Pronounced laminations are normally present, often slightly concave between the main vertical cracks. The wide vertical cracks generally disapear at the base of the horizon. Few pores are visible. Roots are frequent, especially toward the surface. Dark coloured calcium carbonate concretions ('kankars') are frequent and abundant; very small white calcium carbonate concretions are present.

<u>Second Horizon:</u> 50-100 cm. Very dark greyish-brown clay, occasionally weakly mottled. The structure is weak to moderate coarse angular blocky, with many fine cracks. Often cracking is oblique, associated with small smear surfaces or slickensides, near the top of the horizon. Lower down, vertical cracks appear which extend to about 150 cm. Larger slickensides are normally found towards the base of the horizon. Pores are rare, and ped faces appear smooth. Roots are common, associated with cracks. Occasional "kankars" are found, and frequent very small white calcium carbonate concretions.

<u>Third Horizon:</u> 100-160 cm. Generally very dark greyish-brown clay. In some profiles this horizon is considerably darker than the second horizon. Weak brownish mottles are frequent. Structure is generally weak coarse angular or sub-angular blocky. Large slickensides are found, especially near the base of the horizon, at angles of up to 60^{o} to the horizontal. These intersect to give rise to diamond-shaped structures. Vertical cracks persist to the base of this horizon. Few or no pores are visible. Occasional roots are found, associated with the wide cracks. Occasional "kankars" are found. Calcium carbonate also occurs as large soft aggregates and hard white concretions up to 1 cm. diameter, often up to 2 or 3 per cent near the bottom of the horizon. Gypsum crystals are found in a few profiles.

<u>Fourth Horizon:</u> Below 160 cm. Dark greyish-brown clay. In a few profiles the dark colour of the horizons above extends through this horizon. Strong dark grey and brown or yellowish brown mottles are abundant. The structure is moderate medium to coarse angular blocky and the soil is less compact than in the horizon above. Large slickensides are abundant, at angles of up to 60^{o} to the horizontal, and diamond-shaped parallellepiped structures are common. Vertical cracks are rare. Few or no pores are visible. Roots are found

only a few profiles, generally in dense Acacia scrub. "Kankars" are rare. Calcium carbonate is found as large whitish concretions and soft aggregates, up to 2 or 3 per cent of the soil. Gypsum crystals are found in a few profiles.

Generally, at the time of the survey (March 1964) the soil was dry to about 30 cm and slightly moist below.

4.2 Physical Characteristics of the Soils

4.21 Field Observations

Physical characteristics important in the assessment of the soils are their texture and their structure (measured by field assessment of visible structure) consistency and hydraulic conductivity. Field estimates of texture, colour, visible structure, consistency and visible salt accumulations were recorded in the soil surveyor's field notes. Texture was also assessed in the laboratory by mechanical analysis of the soil samples. Hydraulic conductivity was measured in the field in major horizons of selected profiles.

4.22 Texture

Field assessment of texture was carried out by manipulation of wetted samples of soil from the major horizons of the profile. The laboratory analysis was carried out on the top two routine samples of each profile, and on all samples taken from visible horizons in soil pits.

The soils are so uniformly fine-textured that it was rarely possible to observe textural differences in the field. Any accurate assessment of clay content is obtained from the mechanical analysis of soil samples.

Table 4.22 Percentage Clay in the Soil Samples from all Routine Sites in the Project Area.

Depth	Clay percentage (% of total sites)							
	< 55	55-59	60-64	65-69	70-74	75-79	79	
0-45 cm.	1	2	4	20	54	17	2	100%
45-90 cm.	1	3	4	14	52	24	2	100%

The average clay percentages in the 0-45 cm. and 45-90 cm. layers are 71.5 per cent and 72 per cent respectively. In most profiles the clay percentage increases slightly down the profile. In many it decreases sharply.

Analyses of 30 soil pits show the following distribution of clay percentage down the profile:-

	Average Depth	Average Clay %
1st Horizon	0-52 cm.	73
2nd Horizon	52-102 cm.	74
3rd Horizon	102-162 cm.	75
4th Horizon	Below 162 cm.	75

The clay percentage is very constant down the profile, and the slight apparent increase is due to a lower clay percentage in the upper horizons of a few pits.

59 holes were augered to a depth of three metres. As these were subjected to the normal routine sampling procedure, textures below 90 cm. were estimated in the field to the United States Department of Agriculture standards without the additional confirmation of mechanical analysis. In one profile, sandy clay was encountered. In all the others, clay extended to the full depth of three metres.

4.23 Soil Colour

The dominant soil colour in the area is dark greyish brown (10 YR 4/2 and 2.5 Y 4/2). There is very little variation in the colour of the topsoil, though it appears slightly redder in hue towards the north-west. In certain depressions, which are seasonally flooded, grey colours are found, ranging from 10YR 4/1 to 5Y 5/1. The colour of the second and third horizons is generally very dark greyish brown (2.5Y 3/2). In some profiles the third horizon is darker (e.g. 10YR 2/1). Mottles are uncommon in the second horizon, but dark brown (7.5 YR 4/2) or dark yellowish brown (10 YR 4/4) mottles are common in the third horizon.

The fourth horizon is generally dark greyish brown, with abundant strong dark brown or yellowish brown mottles.

4.24 Soil Structure

Owing to the difficulty of correlating the field assessment of soil structure made by individual surveyors in an area of such uniformity as the project area, it has not been possible to use structure as a factor in classifying individual profiles. Also, structure can only be estimated in profile pits, as soil samples taken from auger holes have had their structure destroyed or drastically altered.

Soil structures throughout the area are similar to those described in Section 4.13.

The condition of the surface depends upon the vegetation cover. Under dense stands of Sorghum grasses, wide deep cracks are exposed, with a medium to fine blocky mulch and no rain crust. Where grass cover is sparse or absent there is generally a rather deeper (up to 5 cm.) soft granular mulch, often obscuring the wide cracks in the underlying soil. Under dense stands of Acacia mellifera, the surface mulch is again deep, often with a thin rain crust, and there is little or no surface indication of the underlying cracks, which are generally only 1-2 cm. wide.

From the pattern of cracks and slickensides in the profile it appears that the present self-mulching cycle extends to about 50 cm., which is probably the depth to which rain-water penetrates in normal years.

The platiness or wavy laminations which are a feature of the first horizon appear to be the result of compaction in the lower part of the horizon due to the incorporation of material sloughed down the cracks, and resultant upward movement of the soil between the cracks.

The re-appearance of vertical cracks lower in the second horizon may represent a former self-mulching cycle, which extended to about 160 cm.

4.25 Soil Consistence

Consistence is the capacity of the soil to resist rupture or deformation. It is estimated in the field by crushing the soil aggregate between the fingers. This estimate is purely qualitative, and it has not been possible to use it in classifying individual soil profiles.

Soil consistence in the project area is related to the structures down the profile. The surface mulch and rain cap are soft to loose, the individual aggregate being very easily crushed in the fingers. Below about 5 cm. the aggregates become progressively harder. Between about 50 and 160 cm. the soil is very hard; the aggregates are not easy to separate and are very difficult to crush or deform with the hands. Below 160 cm. the soil becomes less hard. The aggregates separate more easily and can be crushed fairly easily with the hands.

4.26 Visible Salt Accumulations

The only salts visible in field inspections of soil profiles are calcium carbonate and gypsum.

Calcium carbonate is present in three forms:-

(i) Dark coloured, hard, rounded concretions, up to about 1 cm. diameter.

(ii) Light coloured, hard, rounded or angular concretions, which may reach 2-3 cm. diameter in the lower horizons.

(iii) Light coloured, soft, aggregates, sometimes up to 2 or 3 cm. diameter, and sometime incorporating small hard concretions.

The dark-coloured concretions are frequent in the surface mulch and down to about 50 cm. Below this depth they become fewer, and are rarely found below the 3rd horizon. Light coloured hard concretions are most frequent at the base of the third horizon and in the upper part of the horizon below, at about 150 cm. They become smaller towards the surface, and concretions over 0.5 cm. diameter are uncommon above the third horizon, while very small hard white specks are abundant in the surface horizon.

The light coloured, soft, aggregates are concentrated mainly about the base of the third horizon, becoming fewer at greater depth. They are not normally found in the horizons above.

Deposition of calcium carbonate is due partly to evaporation and partly to increase in temperature. The concentration at about 150 cm. may represent the greatest depth to which evaporation extends, or possibly an old swamp land surface.

The small specks commonly found in the upper horizons of the soil are probably the result of solution of calcium carbonate in the rainwater and re-deposition during the winter.

The dark coloured concretions are rounded and show signs of solution or abrasion, indicating that they have not been formed recently. Their distribution in the surface horizon suggests that they have migrated up the profile in the self-mulching process, and tend to remain at the surface, while the finer and so more mobile particles are washed down the cracks by rainwater (or wind action). Worral (1957) has suggested that the dark-coloured concretions are formed as light coloured ones. Small quantities of manganese and other salts, present as small dark specks in the concretions, migrate outwards and form a hard dark outer coating over the calcium carbonate.

Gypsum crystals were found generally in the third horizon, sometimes concentrated in a narrow band, though generally spread over a considerable depth. They were normally found together with calcium carbonate concretions and soft aggregates. Concentrations of up to 10 per cent were found in some profiles in the extreme north, though elsewhere concentrations rarely exceeded 1 per cent (estimated in the field).

While gypsum occurred in over 50 per cent of the profiles in the extreme north, over most of the area it was found in less than 25 per cent of the profiles. It occurs usually as brownish lens-shaped aggregates of fine crystals, though in some profiles it was found as separate grey crystals.

4.27 Hydraulic Conductivity

Hydraulic conductivity tests were carried out on 9 profiles, by the method described in Chapter 3. In 7 profiles, tests were carried out on two horizons and in 2 profiles tests were carried out on three horizons, giving a total of 20 tests.

All the tests were done on cracking clays of the order Vertisols. The results are shown in table 4.271 below, in relation to the clay percentage.

Table 4.271 Hydraulic Conductivity in Relation to Clay Content.

Site	Depth of Described Horizon	Soil Particles %			Hydraulic Conductivity (m/day/Unit Gradient)	
		Sand	Silt	Clay		
5544	142-200	4	14	82	0.069	
5728	95-135	7	14	79	0.026	
5653	96-176	10	12	78	0.029	Mean for
5496	160-200	9	14	77	0.066	76-82%
5526	49-115	9	14	77	0.036	clay
5544	60-142	9	14	77	0.040	0.053
5496	110-160	12	11	77	0.054	
8383	114-151	11	13	76	0.039	
8383	151-200	11	13	76	0.121	
5536	60-120	9	16	75	0.037	
5653	176-200	10	15	75	0.049	
5578	150-200	10	15	75	0.049	Mean
5536	120-200	12	13	75	0.049	for
6621	94-174	12	14	74	0.026	71-75%
5728	135-200	12	14	74	0.026	clay
5578	38-90	13	14	73	0.039	0.039
5578	90-150	13	14	73	0.033	
5526	115-158	14	14	72	0.063	
5496	174-200	15	14	71	0.034	
6621	174-200	15	14	71	0.026	

The results show much greater uniformity than was found in other project areas. There is too little variation in clay content among the profiles tested to allow a correlation to be made between hydraulic conductivity and clay content.

The readings correspond roughly with those from areas 3B and 3C (Roseires Report No. 4).

In eight profiles, tests were carried out on the 3rd. (compact) horizon, and the 4th horizon. In table 4.272 below, it can be seen that in all but two profiles the conductivity of the 4th horizon is greater than that of the 3rd horizon. This corresponds with the findings in the Sennar area (Roseires Report No. 9).

Table 4.272 Hydraulic Conductivity of Deep Horizons in 8 Profiles.

	3rd Horizon		4th Horizon	
	Depth (cm.)	Conductivity	Depth (cm.)	Conductivity
5496	110-160	0.054	160-200	0.066
5536	60-120	0.037	120-200	0.049
5544	60-142	0.040	142-200	0.069
5578	90-150	0.033	150-200	0.049
5653	96-176	0.029	176-200	0.049
5728	95-135	0.026	135-200	0.026
6621	94-174	0.026	174-200	0.026
8383	114-151	0.039	151-200	0.121
Average		0.036		0.057
Average Clay % = 76			Average Clay % = 76	

The data shown here is very limited, and merely serve to indicate that the permeability of the clay is very low.

4.3 Chemical Characteristics of the Soils

Detailed chemical analyses of the soils of the project area may be examined in Appendices 1 and 2. As expected, they are similar in chemical characteristics to the soils of area 3C as described in Roseires Report No. 4, pages 42-50 and appendices.

The very detailed analyses at series level are unfortunately not available for inclusion with this report so that this discussion of the chemical characteristics of the soils is somewhat curtailed.

Arrangements have been made for the following sites to be sampled at series level:-

Site No.	Soil Series	Land Class
2376	V4	2
4607	V4	3a
5496	V4	2
5565	NV4	6a
5598	NV4	4a
6534	V4	3a
8250	V4	3a
8326	NV4	6a

The analytical data, together with comments, will be submitted as soon as possible as a supplement to this report.

4.31 Salinity

Salinity was measured as the electrical conductivity of the saturation extract in mmhos/cm. at 25 ^{o}C. The test was carried out on all soil samples.

Salinity as a limiting factor in soil classification was found in very few sites in the project area. The distribution of salinity within the profile is shown in the following table.

Table 4.31 Salinity as Expressed by Electrical Conductivity in mmhos/cm., in the 0-45 cm., 45-90 cm., and 90-150 cm. Layers.

E. C. (mmhos/cm)	Occurrence as Percentage of Total Sites		
	0-45 cm.	45-90 cm.	90-150 cm.
0 - <1	88	19	3
1 - <2	8	46	21
2 - <3	2	23	44
3 - <4	1	7	22
4 - <5	*	4	8
5 - <6	*	1	2
6 and over	*	*	*
Total	100	100	

* less than 1 per cent.

The distribution shown in this table indicates salinity a good deal lower than in the Sennar area, although the rainfall there is as high as in the project area. A very similar distribution was found north-east of the Guneid sugar scheme (Roseires Report No. 7). It is suggested that this low salinity is a characteristic of clays originating as piedmont deposits from ancient igneous and metamorphic rocks, while the Gezira type clays, originating as alluvial deposits from the recent volcanic rocks of the Ethiopian Highlands, are characterised by relatively high salinity.

4.32 Exchangeable Sodium

The exchangeable sodium content of the soils in the project area is very uniform, the average in the 0-45 cm layer of the soil is 9.4 meq/100 gm., and in the 45-90 cm layer it is 14 meq/100 gm. soil.

The exchangeable sodium percentage (E.S.P.) was calculated on the assumption that clay content and the cation exchange capacity of the soil are equal. The value obtained is used as a criterion for soil and land classification.

The following table (4.32) shows the levels of exchangeable sodium percentage in the project area.

Table 4.32 Exchangeable Sodium Percentage in the 0-45 cm and 45-90 cm layers.

3C Ext

E.S.P.	Occurrence as percentage of total sites	
	0-45 cm	45-90 cm
0 - < 5	2	*
5 - < 10	30	2
10 - < 15	41	15
15 - < 20	16	45
20 - < 25	6	24
25 - < 30	3	9
30 - < 35	1	4
35 and over	1	1
Total	100%	100%

* less than 1 per cent.

It can be seen from the table that exchangeable sodium is slightly more than 5 per cent higher in the second layer than in the first.

The average levels are slightly lower than in the Sennar and Guneid areas, though similar to those found north-east of the Guneid pump scheme.

4.33 pH

The pH on soil paste was determined for all samples from representative pits, and pH on soil paste and 1:5 dilution was determined for all samples from sample area pits.

The range of values found in the project area is

pH, paste:	7.4 to 8.2
pH, 1:5 dilution:	7.6 to 8.2

This range is lower than might be expected in alkali soils, and a possible explanation is the high reserve of free calcium carbonate in the soil, which neutralises the carbon dioxide produced by plant roots and soil organisms. In the absence of these reserves of calcium carbonate the carbon dioxide, as carbonate and bicarbonate anions, would be neutralised by sodium from the exchange complex, resulting in a high pH.

This effect of free calcium carbonate in the soil, which is maintained in the surface horizon by the self-mulching process, may contribute to the maintenance of the structure of the soils of the project area.

4.4 Soil Classification

4.41 Definitions

The classification of soils within the project area is based on the Seventh Approximation, U.S. Department of Agriculture (1960). See Table 4.421 and the album of soil maps. The soil orders, sub-orders, groups and sub-groups are defined as follows:-

Order: Vertisols are clayey mineral soils containing more than 35 per cent and usually more than 40 per cent of an expanding lattice type clay and having more than 30 milli-equivalents exchange capacity per 100 grams of soil in all horizons below the surface 5 cm. When not irrigated they exhibit cracks 1-25 cm wide, extending from the surface to the middle of the solum. They are characterised by one or more of the following:-

(1) Gilgai (microrelief of basins and mounds)

(2) Slickensides close enough to intersect, or,

(3) At some depth between 25-100 cm wedge-shaped or parallelepiped structural aggregates with their long axis tilted 10-60 degrees from the horizontal.

Vertisols normally are developed on montmorillonitic parent materials derived from limestones or basic igneous rocks and are found throughout the world in the subhumid to arid regions. The central concept is one of soils that crack widely and that often remoisten from water that runs into the cracks rather than water that percolates through the soil. If the surface mulches during the dry season there may be a significant amount of material that sloughs into the cracks. The moistening and swelling of a layer with dry soil above and below, causes shearing within the soil and produces slickensides and wedge-shaped or parallelepiped structures.

Sub-Order: Usterts:

These are generally restricted to the drier parts of the climatic range of the Vertisols.

Within the surface horizon, soil colours show chromas or more than 1.5 and lack distinct or prominent mottling. The hues are often redder than 10YR.

<u>Great Group: Grumusterts:</u>

Have a self-mulching surface, which when dry, consists of a loose granular mulch of fine aggregates, mostly less than 3 mm in diameter.

<u>Sub-Groups:</u>

<u>Orthic Grumusterts</u> exhibit moist colour values of 3.5 or less in the surface horizon and have less than 15 per cent exchangeable sodium in all parts of the surface horizon.

<u>Natrargidic Grumusterts</u> resemble the Orthic Grumusterts in all respects but that of the exchangeable sodium percentage in the surface horizon, which is greater than 15 per cent.

4.42 <u>Classification of the Soils of the Project Area</u>

The scheme of soil classification adopted for the compilation of the soil maps is set out as a chart in Table 4.421 which shows that all the soils belong to one Soil Order of Vertisols as defined above.

The Vertisols belong to the Sub order of Usterts and the Great Group of Grumusterts (self-mulching clays). The Grumusterts are further divided as Orthic Grumusterts and Natrargidic Grumusterts. It will be of interest to soil classifiers the world over to learn that quite large areas of Natrargidic Grumusterts have been recognised and mapped in the Republic of the Sudan. At the time of the publication of the U.S.D.A. book on soil classification (The Seventh approximation) in 1960 there was considerable doubt as to whether self mulching clays would ever have E.S.P's exceeding 15. The soil survey in the Gezira Extension area gave indications of the possible existence of Natrargidic Grumusterts but the evidence was not conclusive because of the presence of fragile surface raincaps associated with clay contents between 35 and 40 per cent. (See Roseires Report

No. 1 pp. 33-34). In the project area, however, where the clay content is much higher (about 70 per cent) the soil survey shows conclusively that large areas of self-mulching clays have E.S.P's exceeding 15 and that Natrargidic Grumusterts do, in fact, exist.

The Orthic and Natrargidic Grumusterts have been further sub-divided into families on the basis of clay content and these families have been sub-divided into Series on the basis of their soluble salt content. The salinity status is considered to be a suitable differentiating criterion for soil series in Vertisols because of their low permeability and the relative stability of the salt profile. Soils are regarded as saline when the E.C. of the surface horizon exceeds 4 millimhos per centimetre at 25^{o}C.

The frequency distribution of classified sites shown in table 4.422 shows that in the project area the soil pattern consists entirely of Vertisols. Of the Vertisols, 72 per cent are Orthic Grumusterts, and the remainder are Natrargidic Grumusterts. 99 per cent of the sites were classified as of low salinity.

The uniformly high clay content of the soils in the project area is shown by the fact that all but 3 profiles have over 50 per cent clay in the surface horizon.

SOIL CLASSIFICATION CHART

(U.S.D.A. 1960 System)

TABLE 4.421

Order	Sub-order	Group	Sub-Group	Family	Series
Vertisols	Usterts (Drier climatic range)	Grumusterts (self-mulching surface)	Orthic Grumusterts (Non alkali: E.S.P. less than 15 in top horizon)	1. 35-50% clay	V. 1. Saline (E.C. exceeds 4 mmhos in surface horizon) 2. Non Saline (E.C. less than 4 mmhos in surface horizon)
				2. Over 50% clay	3. Saline 4. Non Saline
			Natrargidic Grumusterts (Alkali: E.S.P. more than 15 in top horizon)	1. 35-50% clay	N.V. 1. Saline 2. Non Saline
				2. Over 50% clay	3. Saline 4. Non Saline

TABLE 4.422

Frequency Distribution of Mapping Units at all Routine Sites in the Project Area

Mapping Units	Number of Sites	Percentage of Total
Soil Series		
V.2	1	*
V.3	5	*
V.4	1039	72
N.V.2	2	*
N.V.3	10	1
N.V.4	383	27
Total	1440	100

* Less than 1 per cent

CHAPTER 5

LAND CLASSIFICATION

5.1 Specifications

The Sudan Government specifications for the semi-detailed land classification were based on those of the United States Department of the Interior Bureau of Reclamation Manual, Vol. 5., Irrigated Land Use, 1951.

The objective of the soil survey and land suitability classification was to assess the suitability of the land for irrigated cultivation in general and for specific crops in particular for the purpose of delineating lands to be irrigated within the project area.

The results of the survey were to be incorporated into a land suitability classification map for irrigated cultivation, classifying in broad lines according to the U.S. Bureau of Reclamation standards, but adjusted where necessary for satisfactory application under Sudan conditions. The land suitability classification maps at scale 1:50,000 would show land classes 1, 2, 3, 4 and 6 and are the most objective method available of delineating the irrigable areas.

5.2 Land Class Standards

The Bureau of Reclamation capability classes are numbered from 1 to 6. The higher the number, the lower is the capability rating. The first three classes, 1, 2 and 3, are considered arable with progressively increasing limitations on their use and/or with increasing costs of reclamation and management. Class 4 is land suited only to special use. Class 5 is land needing further investigation, and Class 6 is permanently non-arable.

The observation density used on the project was approximately one 2m. bore per 250 feddans with every twentieth to 3 m. This closely approximates to the standards given in the Manual for "semi-detailed reconnaissance". The objective of this type of survey is to separate arable from non-arable land with considerable accuracy, while delineating boundaries between classes and sub-classes in less detail. The Manual states "Generally, Classes 1, 2, 3 and 6 and their sub-classes are mapped. Special sub-classes under Classes 4 and 5 are differentiated when conditions warrant".

In the project area these policies were observed. Class 5 was not used (although its definition is given below for the sake of completeness), but Class 4 was used to indicate those lands where, though profitable irrigation should still be possible, higher levels of exchangeable sodium in the soil may restrict the range of crops which can be grown more seriously than can be accepted for Class 3 land.

The following are the definitions of land classes 1-6, as given in the Manual.

Class 1 - Arable

Lands that are highly suitable for irrigation farming, being capable of producing sustained and relatively high yields of a wide range of climatically adapted crops at reasonable cost. They are smooth lying with gentle slopes. The soils are deep and of medium to fairly fine texture with mellow, open structure allowing easy penetration of roots, air and water and having free drainage yet good available moisture capacity. These soils are free from harmful accumulations of soluble salts or can readily be reclaimed. Both soil and topographical conditions are such that no specific farm drainage requirements are anticipated, mimimum erosion will result from irrigation, and land development can be accomplished at relatively low cost. These lands potentially have a relatively high payment capacity.

Class 2 - Arable

Lands of moderate suitability for irrigation farming being measurably lower than Class 1 in productive capacity, adapted to a somewhat narrower range of crops, more expensive to prepare for irrigation or more costly to farm. They are not so desirable nor of such high value as lands of Class 1, because of certain correctable or non-correctable limitations. They may have a lower available moisture capacity, as indicated by coarse texture or limited soil depth; they may be only slowly permeable to water because of clay layers or compaction in the subsoil; or they may also be moderately saline which may limit productivity or involve moderate costs of leaching. Topographic limitations include uneven surface, requiring moderate costs for levelling, short slopes requiring shorter length of runs, or steeper slopes necessitating special care and greater costs to irrigate and prevent erosion. Farm drainage may be required at moderate cost and loose rocks or woody vegetation may have to be removed from the surface. Any one of the limitations may be sufficient to reduce the lands from Class 1 to Class 2, but frequently a combination of 2 or more of them is operating. The Class 2 lands have intermediate payment capacity.

Class 3 - Arable

Lands that are suitable for irrigation development but are approaching marginality for irrigation and are of distinctly restricted suitability because of more extreme deficiencies in the soil, drainage or topographic characteristics than described for Class 2 lands. They may have good topography but because of inferior soils they have restricted crop adaptability and require larger amounts of irrigation water or special irrigation practices, and demand greater fertilisation, or more extensive soil improvement practices. They may have uneven topography, moderate to high concentration of salts or restricted drainage, susceptible to correction but only at relatively high costs. Generally greater risk may be involved in farming Class 3 lands than the better classes of land, but under proper management they are expected to have adequate payment capacity.

Class 4 - Limited Arable or Special Use Land

Lands are included in this class only after special economic and engineering studies have shown them to be arable. They may have an excessive, specific deficiency or deficiencies susceptible of correction at high cost, but are suitable for irrigation because of existing or contemplated intensive cropping such as for truck or fruits: or, they may have one or more excessive non-correctible deficiencies thereby limiting their utility to meadow, pasture, orchard or other relatively permanent crops, but are capable of supporting a farm family and meeting water charges if operated in units of adequate size or in association with better lands. The deficiency may be inadequate drainage, excessive salt content requiring extensive leaching, unfavourable position allowing periodic flooding or making water distribution and removal very difficult, rough topography, excessive quantities of loose rock on the surface or in the plough zone, or cover such as timber.

Class 5 - Presently Non-Arable

These lands are non-arable under existing conditions but have potential value sufficient to warrant tentative segregation for special study prior to completion of the classification, or they are lands in existing projects whose arability is dependent upon additional scheduled project construction or land improvements. They may have a specific soil deficiency, such as excessive salinity, very uneven topography, inadequate drainage or excessive rock or tree cover. In the first instance, the deficiency or deficiencies of land are of such nature and magnitude that special agronomic, economic or engineering studies are required to provide adequate information, such as extent and location of farm and project drains, or probable payment capacity under the anticipated land use, in order to complete the classification of the lands. The designation of class 5 is tentative and must be changed to the proper arable class or class 6 prior to completion of the land classification. In the second instance, the effect of the deficiency or the outlay necessary for improvement is known, but the lands are suspended from an arable class until the scheduled date of completion of project facilities and land, development such as project and farm drainage. In all instances, class 5 lands are segregated only when the conditions existing in the area require consideration of such lands for competent appraisal of the project possibilities; such as when an abundant supply of water or shortage of better land exists, or when problems related to land development, rehabilitation and resettlement are involved.

Class 6 - Non-Arable

Lands in this class include those considered non-arable under the existing project or the project plan because of failure to meet the minimum requirements for the other classes of land, arable lands definitely not susceptible to delivery of irrigation water or to provision of project drainage, and classes 4 and 5 land when the extent of such lands or the detail of the particular investigation does not warrant their segregation. Generally, Class 6 comprises: steep, rough, broken or badly eroded lands: lands with soils of very coarse or fine texture, or shallow soils over gravel, shale, sandstone or hardpan, and lands that have inadequate drainage and high concentration of soluble salts or sodium. Excluding the position sub-classes the Class 6 lands do not have sufficient payment capacity to warrant consideration for irrigation.

5.3 General Considerations Determining Land Class in the Project Area

The following sections outline the criteria used in determining land classes. These criteria have been adopted after a comprehensive study of the requirements of climatically adapted crops on the basis of research data from the Sudan and other arid and semi-arid countries. The intention of the U.S.B.R. system of land classification is that it should be a guide to the anticipated capacity of the land to produce sustained economic returns on the basis of a comparison of land resources and economic experience in areas similar to that under study, and an analysis of the probable influence of individual physical land factors on the economics of production in the area under consideration.

In this spirit, the land classification has been developed in the light of economic experience in the Gezira, and experimental evidence on the various limiting factors from the Gezira Research Farm at Wad Medani and from other countries.

5.31 Topography:

Area 3c (E) is an almost flat, level, open plain without rocks or stones. Clearing costs of the areas of woodland would be very small and so of no consequence in the land classification. Topographic features influencing land class are the Kerrib lands along the river and an old meander channel close to the river in the south of the project area, where the slope of the land is too great to allow irrigation.. These lands were excluded from the soil survey area during the preliminary study of the aerial photographs.

5.32 Soil Profiles

The main land class determinants are soil profile characteristics. In addition to the soil limitations described below, there is an overall limitation of low nitrogen and organic matter in all soils in the area and extremely low permeability in all the clay soils. Because of these features, which restrict the range of climatically adapted crops that can be grown, it is considered that none of the project area qualifies as Class 1 land according to the standards quoted above.

The soils of the clay plains of the East Central Sudan are alkaline clay soils.. Nearly thirty per cent of the sites sampled in area 3C(E) have over fifteen per cent exchangeable sodium in the 0-45 cm layer, which in most parts of the world would be associated with marked structural breakdown, and the development of soils with a sandy surface and a very compact horizon with a hard columnar structure which would break down to a sticky mass on irrigation, with no aeration for plant roots.

This form of profile development has not occurred in the Natrargidic grumusterts studied in the project area. The soils are self-mulching to a depth of at least 50 cm, and consequently there is no separation of the clay from the sand and silt. The pronounced cracking assists penetration of the irrigation water, and aeration of the soil. Experiments in the Gezira have shown that after the first irrigation water penetrates down the cracks to depths of 90 cm or more, so that penetration of the irrigation water, and hence the amount of moisture available to plant roots, is not directly dependant on the rather low permeability of the clay. Although a gradual increase in the dispersion of the clay fraction, and hence a decrease in pore space, occurs during the season, the effect is completely remedied by the introduction of a fallow every third year.

The most important internal features influencing the capacity of the soils of the project area to produce crops are the soil structure (influenced by the capacity of the soil to crack widely and to a considerable depth on drying, and the degree of dispersion of the clay), and its alkalinity and salinity. There is at present no way of assessing the above structural features, sufficiently consistent for this soil survey, but they appear to be strongly related to the percentage of clay in the soil. The clay is mainly montmorillonite, with a very marked capacity for expansion on wetting, and its percentage will markedly affect the degree of cracking of the soil. Research in the Gezira has shown that there is a very good correlation between cotton yields and the percentage of clay in the soil, so the criteria used in the soil survey for land classification are clay percentage, alkalinity and salinity.

5.321 Clay Percentage

Finck and Ochtman (1961) have shown that a good correlation exists between cotton yields and clay percentage between 40 and 70 per cent, with an average yield of about 58 per cent clay. No work has been done on the relationship between the clay percentage and other crops but it has been found that where cotton does well the associated crops e.g. Sorghum and Dolichos also do well. In classification we have therefore adopted a lower limit of fifty per cent clay for Class 2 and 35 per cent for Class 3.

5.322 Soil Salinity

The tolerance of crop plants to salinity has been studied in detail in many parts of the world, and the tolerance of many crop plants has been clearly established. The effect of salinity, apart from toxic effects and induced nutrient deficiencies caused by excessive concentrations of specific anions or cations, is to make the osmotic pressure of the soil solution so high that plants cannot take up sufficient moisture for normal growth. The osmotic pressure is a function of the total concentration of salts in the solution, and is estimated by measurement of the electrical conductivity of the soil saturation extracts. Generally in the Gezira about eighty per cent of the cations in the saturation extract are sodium.

Figures for total soluble salts per cent in 6" steps are shown below for an area in the northern Gezira shortly after irrigation started and for a plot at the research station.

Step	Northern Gezira		Plot 202 G.A.R.S.	
1	0.04 %)		0.084)	
2	0.11)	EC = 1.9	0.072)	EC = 1.4
3	0.19)		0.090)	
4	0.38)		0.097)	
5	0.45)	EC = 7.7	0.106)	EC = 1.8
6	0.51)		0.118)	

7	0.51	0.178
8	0.48	0.314
9	0.46	0.411
10	0.45	0.406

From this it can be seen that in the more saline northern Gezira salt contents are noticeably greater only in the top 4 feet and the main increase occurs at the 18" to 24" soil depth. If a 90 per cent saturation percentage is assumed then EC's can be calculated from per cent salts by the formula.

$$\frac{\text{per cent salts} \times 100}{0.064 \times 90}$$

Using this the average EC's in the layers comparable to our samples would be as shown in the above table.

In the following sections it is shown that there is downward movement of soluble salts with irrigation but these do not necessarily leach out of the rooting zone. It is generally considered that the main zone of accumulation is just below the rooting zone but it would be dangerous to assume that high limits for salinity can be accepted for better class land in the hope that sufficient leaching would take place.

Investigations of the movement of soluble salts in the soil were carried out at the Gezira Research Farm between 1924 and 1931 (Greene and Peto, 1935). This was stimulated by the abandonment, in various parts of the world, of large tracts of land due to rising salts. It was found that salts appear to sink an inch or two when the soil is watered, and to rise again when the soil dries out. These changes were traced, not to displacement of salts through the soil, but to swelling and shrinking of the relatively non-saline surface soil, which causes the land surface ro rise and fall a few centimetres in relation to the subsoil. Apart from these apparent changes, it was found that there was no upward movement of salts, and that in fact there may be a small downward movement of salts, through the soil profile. It was found that salts added to the surface soil by the application of soil improvers or by other means were rapidly washed down by rain and irrigation water, and that in course of time the soil returned to its normal profile. Salt introduced in the irrigation water was also washed down from the surface layers. The observations recorded showed an increase in the average salt content of a 6 foot column of soil roughly equivalent to the amount of salts (about 1 ton per acre per 3 year) introduced in the irrigation water.

Jewitt and Middleton (1955) followed up these investigations with an examination of the salt distribution in the soil profiles in the two main cotton rotation experiments at the Gezira Research Farm. They found that in none of the rotations, which had been irrigated from 1931 to 1953, the year in which the plots were sampled, was there any evidence of an increase in the content of soluble salts. In the plots which received the highest number of irrigations the total soluble salt content was lower, and the depth to the first sharp increase in soluble salts was greater, than in those with fewer irrigations, which indicated that over a long period of irrigation (very much longer than that studied by Greene and Peto in 1935) there was a removal of salts from the top 6 feet of the profile, in excess of additions of salt in the irrigation water.

The water of the Blue Nile is very pure, having on the average about 9 parts per million of sodium. Also, the Sodium Adsorption Ratio (S.A.R.) is very low. The value calculated for the water of the Barakat III Canal (T.N. Jewitt, 1955) during the irrigation season 0.6. Over a long period in the absence of a build-up of salts in the profile, the distribution of cations in the exchange complex would tend towards an equilibrium in which the exchangeable sodium percentage is about 0.25.

The above evidence indicates that, although there is unlikely to be any build-up of soluble salts in the profile (in fact, there should be a gradual removal), the amount of movement of salts in the profile during one or even several irrigation seasons will be so small that leaching is out of the question as an economic means of improving the productivity zone (0-90 cm) has been down-graded, but a higher limit of tolerance has been allowed below the rooting zone.

5.323 Soil Alkalinity

The evidence of the effect of exchangeable sodium on plant growth in the absence of other associated limiting factors is scanty. In most soils, marked breakdown of structure occurs at all exchangeable sodium percentages over about 15, and this seriously inhibits growth and yield of crop plants.

A number of experiments have been carried out in artificial media and in soil treated with conditioners, which show that most plants will tolerate a relatively high level of exchangeable sodium. Ratner (1955) in pot experiments with wheat and oats showed that the yield was affected only by exchangeable sodium levels of 50 per cent and over. Pearson and Bernstein (1958) showed that yields of wheat and barley were affected by an exchangeable sodium level over 40 per cent while that of oats was affected by a level of 18 per cent or less. Chang and Dreyne (1955) showed that a reduction in the yields of cotton and alfalfa was first observable at about 35 per cent exchangeable sodium. At this level, soil conditioners gave no increase in yields of cotton, though alfalfa yields were improved. This indicated that exchangeable sodium was exerting a direct effect on crop growth as well as an indirect effect by destroying soil structure.

These experiments indicate that most of the crops likely to be grown in the project area will produce satisfactory yields at exchangeable sodium levels of up to about 40 per cent in the absence of structural breakdown. For wheat and cotton a tolerance of 40-60 E.S.P. is quoted by the U.S.D.A. Bulletin No. 216, again in the absence of deleterious physical effect.

Estimations of exchangeable sodium on samples from the Gezira Research Farm are rare. Figures for exchangeable sodium, though not clay percentage, are available for samples from two cotton rotation experiments (Jewitt, 1956): The three Course Rotation (T.C.R.) and the Combined Rotation (C.R.). The yields of both were well up to the average in the surrounding commercial cotton areas, but the yields of the former rotation were considerably higher than in the latter.

This difference was related to the exchangeable sodium contents of the top three feet of the soils, which are:-

		at 50% Clay E.S.P.
T.C.R.	- 9.4 mg. e. per 100 gm. soil =	18.8
C.R.	- 13.4 " " " + =	26.8

As has been mentioned earlier (Chapter 4 and section 5.32), the clay soils of the Blue Nile region and the Gezira are exceptional in that, though they are generally alkaline, they have a very strong propensity to cracking and self-mulching. Also, it is thought that some form of inorganic bonding influences the dispersion behaviour of the clay in the Gezira soils, so that it is not solely conditioned by the exchangeable sodium level. In view of these exceptional features it would be expected that the soils would produce better crops than it indicated by their alkalinity.

In our land classification, an attempt has been made to take into account the exceptional structural characteristics of the soil, by adopting a more liberal approach to exchangeable sodium as a limiting factor. Although the evidence of the tolerance of cotton to high E.S.P. levels is fairly clear, we recognise that there is no experimental evidence to indicate the performance of the crops normally associated with cotton in the Gezira (Dolichos and Sorghum). Field observations indicate that where cotton does well, the associated crops also do well. We have included in Class 4 those lands, with E.S.P.'s between 15 and 20 in the 0-45 cm layers, as it is possible that the range of crops other than cotton may in these lands be seriously restricted, justifying their inclusion in Class 4 rather than 3.

5.4 Detailed Criteria for Land Classification in the Project Area

The following limitations of soil profile characteristics have been adopted for the land classes. See Table 5.4.

Table 5.4 - Criteria for determining Land Classes in the Project Area.

LAND CLASS	SAMPLE DEPTH	CLAY CONTENT	E.C.	E.S.P.
2	0- 45 cm	exceeds 50%	less than 4	less than 15
	45- 90 cm	not limiting	" " 5.3	" " 15
	90-150 cm	" "	" " 8	not limiting
3 1	0- 45 cm	35-50%	less than 4	less than 15
	45- 90 cm	not limiting	" " 5.3	" 15
	90-150 cm	" "	" " 8	not limiting
3 a	0- 45 cm	exceeds 50%	less than 4	less than 15
	45- 90 cm	not limiting	" " 5.3	15-25
	90-150 cm	" "	" " 8	not limiting
3 al	0- 45 cm	35-50%	less than 4	less than 15
	45- 90 cm	not limiting	" " 5.3	15-25
	90-150 cm		" " 8	not limiting
3 s	0- 45 cm	exceeds 50%	4-5.3 and/or	less than 15
	45- 90 cm	not limiting	5.3-8 and/or	" " 15
	90-150 cm	" "	8-12	not limiting
3 sl	0- 45 cm	35-50%	4-5.3 and/or	less than 15
	45- 90 cm	not limiting	5.3-8 and/or	" " 15
	90-150 cm	" "	8-12	not limiting
3 as	0- 45 cm	exceeds 50%	4-5.3 and/or	less than 15
	45- 90 cm	not limiting	5.3-8 and/or	15-25
	90-150	" "	8-12	not limiting
3 asl	0- 45 cm	35-50%	4-5.3 and/or	less than 15
	45- 90 cm	not limiting	5.3-8 and/or	15-25
	90-150 cm	"	8-12	not limiting
4a	0- 45 cm	exceeds 50%	less than 5.3	15-20
	45- 90 cm	not limiting	" " 8	less than 25
	90-150 cm	" "	" " 12	not limiting
4 1	0- 45 cm	5-35%	less than 5.3	less than 15
	45- 90 cm	not limiting	" " 8	" " 20
	90-150 cm	" "	less than 12	not limiting
6 a	0- 45 cm	exceeds 5%	less than 5.3	exceeds 15 or 20 and/or
	45- 90 cm	not limiting	" " 8	exceeds 20 or 25
	90-150 cm	" "	" " 12	not limiting
6 s	0- 45 cm	exceeds 5%	exceeds 5.3 and/or	less than 15 or 20
	45- 90 cm	not limiting	exceeds 8 and/or	" " 20 or 25
	90-150 cm	" "	exceeds 12	not limiting
6 as	0- 45 cm	exceeds 5%	exceeds 5.3 and/or	exceeds 15 or 20 and/or
	45- 90 cm	not limiting	exceeds 8 and/or	exceeds 20 or 25
	90-150	" "	exceeds 12	not limiting
6 1	0- 45 cm	less than 5%	not limiting	not limiting
	45- 90 cm	not limiting	" "	" "
	90-150 cm	" "	" "	" "

Note: Not all categories shown on this table were mapped in the project area.

The land classes are grouped into mapping units as follows:-

Class 2.

Class 3a, 3s, 3as, 3l, 3al, 3d, 3asl.

Class 4a.

Class 6.

5.5 A Note on Sodium Value and Exchangeable Sodium Percentage

In classifying land for cotton cultivation in the Gezira, the concept of "Sodium Value" was used. Sodium Value is derived by expressing the total extractable Sodium (Soluble + Exchangeable) in mg. equiv. per 100 gm. clay. This value is calculated from a bulked sample from the 0-90 cm layer of the soil profile. On the basis of a number of trials the Sodium Value limit for good cotton land was taken as 25 and for medium cotton land as 35.

By using the clay percentage, Soluble Sodium, and Exchangeable Sodium of the 0-45 cm and 45-90 cm routine samples taken during the 1963-64 semi-detailed survey, it has been possible to calculate the Sodium Values of the soils. The following table shows the Sodium Values of a random selection of 324 profiles from the project area, which is roughly representative of the southern extreme of the Gezira plain.

Table 5.5 Sodium Value in Relation to Land Class of a Random Selection of Profiles from the Project Area.

Na value	Land Class according to mapping units (Total Sites)			
	2	3	4	6
0-15	56	58		
15-25	2	125	32	18
25-35			3	27
35-45				3

As would be expected, a good correlation appears, in which the division between class 4a and class 6a corresponds to a Sodium Value of rather less than 25. In profiles where salinity is also limiting, the Sodium Values are slightly higher.

As all experimental evidence indicates that high clay lands with a sodium value of 25 or less will grow good cotton crops, it appears justifiable to include class 4 land in the cotton rotation.

5.6 Distribution and Characteristics of the Land Classes

Class 2 land is relatively uniform plain, with soil containing over 50 per cent clay, and lacking harmful accumulations of salts or alkali.

41,110 feddans (12 per cent of the total area) have been mapped in this land class. It occurs in small units, especially immediately north-east of Jebel Fau and in the south-east of the project area, on the clay plain away from the river.

Class 3a land exhibits the same general characteristics as the above class, but has a slightly higher level of exchangeable sodium in the 45-90 cm. layer. Profiles which have been downgraded on the basis of salinity or low clay content have been mapped in this category, as they are too rare to justify separate treatment.

220,660 feddans (63 per cent of the total area) have been mapped in this land class. The only large areas which fail to qualify for this class are along the Rahad and immediately south and south-west of Jebel Fau.

Class 4a land has a slightly higher level of alkalinity in the 0-45 cm. layer than the above class, but is similar in other respects. Class 4 profiles with less than 50 per cent clay are too rare to merit separate treatment, and are included in this category on the maps.

33,640 feddans (10 per cent of the total area) have been mapped, almost all associated with class 6 land along the river Rahad and south of Jebel Fau.

Class 6 land within the project area has almost all been downgraded on the basis of alkalinity, in either the 0-45 cm. layer or the 45-90 cm. layer.

51,020 feddans (15 per cent of the total area) have been mapped in this land class. The land along the river Rahad, which appears to consist partly or wholly of alluvium deposited by the river, is almost all class 6 land. There is also a broad belt of class 6 land in what appears to be a wide shallow depression extending south-westwards from Jebel Fau.

CHAPTER 6

NOTES ON POSSIBLE CLIMATICALLY ADAPTED CROPS TO BE GROWN UNDER IRRIGATION IN THE PROJECT AREA.

6.1 General Considerations

In Roseires Report No. 4, covering the Rahad and Dinder Lands, we pointed out that, whereas the Ten Year Plan of Economic and Social Development outlines in detail a proposed irrigation development plan for the Gezira Extension Area (Roseires Survey Area 1), no such detailed plan is given for the Rahad East Bank Lands. Since then, however, the Client has contracted with the Consultant to prepare such a plan under the contract for the Rahad Pre-Investment Survey. The purpose of the discussion which follows, therefore, is to discuss the agronomic suitability of climatically adapted crops which might be grown under irrigation in the project area. The discussion thus avoids any possibility of prejudging the results of the Rahad Pre-Investment Survey but at the same time it fulfils the requirements of the Contract of 27 September 1962 which are as follows:-

Article 2 states that the Consultant shall carry out soil surveys and land suitability classifications in order to assess the suitability of the lands for irrigated cultivation in general and for specific crops in particular for the purpose of delineating lands to be irrigated within the project area.

Article 5 (viii) states that the Consultant's survey report shall contain recommendations for irrigated crops.

This discussion should be studied in conjunction with Chapter 6 of Report No. 4 which discusses the merits of some short season crops for a flood irrigation project and of some long season crops for a perennial irrigation system on the Rahad Bank lands (Area 3C). It is anticipated that the arable lands of Area 3C and Area 3C extension will be developed as one unit and that the cropping systems will be standardised for all the lands on the Rahad East Bank. Report No. 4a, however, endeavours to bring the discussion up-to-date by considering the revision of the land class specifications carried out at the World Bank in Washington in August 1964. This revision occurred after publication of Report No. 4 and could be referred to only in an annexure to that report. Report No. 4a now incorporates the substance of this annexure into Chapter 6.

6.2 The Climatically Adapted Crops of the Northern Rainlands of the Sudan.

The climatically adapted crops of the northern rainlands of the Republic of the Sudan are essentially tropical crops. See table 6.2. The climatically adapted crops listed in table 6.2 have been grouped into three categories, those grown commercially within the northern rainlands, those tested at the research stations but not grown commercially, and those that have had a trial planting at some time or another. The commercial crops are further subdivided into those grown under irrigation as against the rain-grown crops.

It is surprising at first sight to note the small number of crops grown commercially in this large zone. The explanation for this probably lies in the environmental control exercised by the harsh, semi-arid, lowland climate together with excessively low permeability of clay soils as in the project area or with excessively high permeability and low water holding capacity of sandy soils as in Northern Kordofan.

Only eleven crops are grown commercially within the northern rainlands. The most important of these are grown under irrigation in the Gezira and Managil Schemes and the private pump schemes on the Blue Nile and White Nile:- long staple cotton grown on a wide rotation with dura (a grain sorghum) and lubia (a forage legume). Two other cash crops, wheat and groundnuts, have recently been introduced into the Gezira and Managil irrigation schemes. The pulse crop, pigeon pea, is also grown extensively there as a windbreak at the edges of the cotton fields. Onions and garlic are grown as garden crops in the small plots in which the Gezira and Managil tenant farmers may grow crops of their own choice.

Sugar cane is a very recent addition to the irrigated commercial crops of the northern rainlands. As part of the Ten Year Plan of Economic and Social Development 1961-62 to 1970-71, sugar cane replaced long staple cotton as the chief cash crop of Government's Guneid Pump Scheme on the Blue Nile between Wad Medani and Khartoum (See Roseires Report No. 7). The sugar cane is processed in a new sugar factory with a capacity of 60,000 tons of refined sugar per year which commenced operations at Guneid early in 1963.

A number of commercial crops are grown without irrigation in the rainlands. These consist of dura, short staple cotton and sesame on the clay lands and dukhn, groundnuts and sesame on the sandy lands. It is worth emphasizing here that the rain-grown groundnut of the Northern Kordofan sands is a different variety from the groundnut grown under irrigation on the Gezira clays and that these varieties are not interchangeable from one environment to the other.

Table 6.2 Climatically Adapted Crops of the Northern Rainlands of the Sudan

Type of Crop	1. Commercial Crops Irrigated	1. Commercial Crops Rain-grown	2. Research Tested Crops	3. Other Crops
Fibres	Cotton (long staple) (med. ")	Cotton (short staple)	Jute Kenaf	Sunn Hemp Roselle
Cereals	Dura Wheat	Dura Dukhn	Maize Rice	
Oilseeds	Groundnuts	Groundnuts Sesame	Safflower Castor	Sunflower Soya Bean
Fodders	Lubia		Phillip-esara Clitoria	Leucena glauca Sudan grass
Pulses	Pigeon Pea		Cowpea	Cluster Bean Velvet Bean
Garden Crops	Onions Garlic		Chillies	Tomatoes Melons
Industrial Crops	Sugar cane		Sugar-Beet Tobacco	
Fruits			Citrus Mangoes	Bananas Guavas

6.3 Agronomic Suitability of Crops to the Clay Soils of the Project Area

Bearing in mind that the soils of the project area consist almost entirely of virtually undrainable clay soils we have prepared a list of crops (Table 6.31) which may be considered agronomically suitable for irrigated agriculture on the Rahad East Bank lands.

Of the climatically adapted crops that are considered probably unsuitable for the project area some, such as dukhn and melons, are adapted to sandy soils. Others, such as castor, tobacco, citrus, mango and banana are known to require a free draining soil and would not be expected to grow well on the impermeable clays of the project area. Yet others, such as soya bean, cluster bean, velvet bean and sugar beet have not yielded well under test and must be regarded as being only marginally adapted to the climatic environment of the northern rainlands.

A considerable number of crops are listed as being probably suitable for irrigated agriculture on the Rahad East Bank lands. These include such potentially important crops as jute, kenaf, sunn hemp, maize, sunflower, and sugar cane. At the present time there is insufficient knowledge, either from trials or commercial experience to be more definite as to their agronomic suitability for the project area. It is hoped, however, that these crops will be further considered when more information as to their suitability becomes available.

The crops of proven agronomic suitability for clay soils of the northern rainlands are:- cotton (long, medium and short staple), dura, wheat, rice, groundnuts, sesame, safflower, lubia, phillipesara, clitoria, pigeon pea, onions and garlic. Most of these are commercial crops but a few, such as safflower and rice which have been fully tested at the research stations, have not yet been grown commercially in the northern rainlands.

Only in the case of long staple cotton is there a sufficiently detailed record of commercial crop yields, together with research findings, to justify an accurate prediction of yields in the project area. (See 6.4).

Table 6.31 **Estimated Agronomic Suitability of the Climatically Adapted crops to the Clay Soils of the Project Area**

Type of Crop	1. Crops of Proven Suitability	2. Crops Probably Suitable	3. Crops Probably Unsuitable
Fibres	Cotton long staple med. " short "	Jute Kenaf Sunn Hemp Roselle	
Cereals	Dura Wheat Rice	Maize	Dukhn
Oilseeds	Groundnuts Sesame Safflower	Sunflower	Castor Soya
Fodders	Lubia Phillipesara Clitoria	Cowpea Sudan Grass Guinea Grass	
Pulses	Pigeon pea	Cowpea	Cluster Bean Velvet Bean
Garden Crops	Onions Garlic	Chillies Tomatoes	Melons
Industrial Crops		Sugar Cane	Sugar Beet Tobacco
Fruits		Guava	Citrus Mango Banana

Table 6.32 Vernacular and Botanical Names of the Climatically Adapted Crops of the Northern Rainlands of the Sudan

A. Fibres

1. Cotton
   (i) Long staple Egyptian Cotton, Gossypium barbadense L.
   (ii) Medium to short staple American Cotton, Gossypium hirsutum.
2. Jute, Corchorus olitorius L. and Corchorus capsularis L.
3. Kenaf, Hibiscus cannabinus L.
4. Sunn Hemp, Crotolaria juncea L.
5. Roselle or Kerkade (Sudan) Hibiscus sabdariffa var. altissima

B. Cereals

1. Dura (Sudan) or Great Millet, Sorghum vulgare Pers.
2. Wheat, Triticum vulgare Host.
3. Rice, Oryza sativa L.
4. Maize, Zea mays L.
5. Dukhn (Sudan) or Bulrush millet, Pennisetum typhoideum (Burm) Stapf & Hubbard

C. Oilseeds

1. Groundnut or Ful Sudani, Arachis hypogea L.
2. Sesame or Sim Sim (Sudan), Sesamum orientale L.
3. Safflower, Carthamus tinctorius L.
4. Sunflower, Helianthus annuus L.
5. Castor Bean, Ricinus communis L.
6. Soya Bean, Glycine max Merr.

D. Fodders

1. Lubia (Sudan), Dolichos lablab L.

2. Phillipesara, Phaseolus trilobus Ait.

3. Clitoria or Butterfly Pea or Kordofan Pea,
Clitoria ternatea L.

4. Cowpea or Lubia helu (Sudan), Vigna unguiculata L. Walp.

E. Pulses

1. Pigeon Pea or Ads sudani, Cajanus indicus Spr.

2. Cluster Bean or Guar, Cyamopsis psoralioides DC.

3. Velvet Bean, Mucuna spp.

F. Garden Crops

1. Onion, Allium cepa L.

2. Garlic, Allium sativum L.

3. Chillies, Capsicum spp.

G. Industrial Crops

1. Sugar cane, Saccharum officinarum L.

2. Sugar Beet, Beta vulgaris var. saccharatum

3. Tobacco, Nicotina tabacum L.

H. Fruits

1. Citrus Fruits (Citrus spp.)

(i) Lime or limoon (Sudan)
C. aurantifolia or C. acida

(ii) Bitter orange
C. aurantium L. or
C. limonia or
C. vulgaris

(iii) Sweet orange,
C. sinensis Osb.

(iv) Bortugan tangerine,
C. delisiosa Swin.

(v) Yousef Effendi grapefruit,
C. decumana L.

(vi) Pomelo
C. decumana L. or C. grandis L.

(vii) Italian lemon,
C. lomonia Osb.

2. Mango, Mangifera indica L.

3. Banana, Musa spp.

6.4 The Agronomy of Long Staple Cotton in Relation to the Project Area

6.41 Soil Conditions Affecting Cotton Yields in the Gezira Area

The Department of Agriculture's Research Division over the years has studied the productivity records of the Gezira Scheme and of some pump projects, notably Dueim, endeavouring to find relationships between yield variations and measurable soil characteristics. The following criteria were found to be of importance to the yield of long staple cotton:-

6.411 Clay Content

Research work in the Sudan shows that long staple cotton, the chief cash crop of the irrigated lands, yields best on soils of high clay content which do not contain limiting amounts of soluble salts or exchangeable sodium. Finck and Ochtman (1961) show that, on the Vertisol soils south of Khartoum, cotton yields are positively correlated with clay contents between 40 and 70 per cent. The actual yields shown below (see table 6.411) are from Tom's (1960) paper on soil productivity of the Sudan Gezira as expressed by cotton yields. The basic mean yield of the Gezira Scheme is taken as 4.45 kantars per feddan of L cotton.

Table 6.411 The Relationship Between Clay Content of Vertisols and Yield of Long Staple Cotton

Clay Content Per cent	Relative Yield Per cent	Actual Yield Kantars/Feddan
70	130.6	5.81
65	117.7	5.24
60	104.9	4.67
58	100.0	4.45
50	79.2	3.52
46.4	70.0	3.12
40	53.5	2.38

The causal factor linking yields of long staple cotton to clay content has not been determined. It has been suggested, however, that the excellent crumb structure of the self-mulching soils which is related to high clay content may be the factor enhancing cotton yields. In view of the fact that all soils of low and high clay content, contain appreciable exchangeable sodium it is possible that a deterioration of soil structure occurs first in soils of lower clay content at E.S.P. levels that would not cause structural deterioration in soils of high clay content.

It is not known whether the correlation between clay content and high yield is valid for other crops beside long staple cotton.

6.412 Extractable Sodium

Investigations had also shown the yield of long staple cotton to be correlated inversely with the content of extractable sodium (soluble plus exchangeable) in relation to clay content of the top 3 feet (90 cm) of soil. This relationship was then used to evaluate soils for long staple cotton production on the basis of their "sodium values" (extractable Na per 100 gram of oven dry clay in the 0-90 cm layer) as follows:

Sodium Value	Land Class
0-25	good
25-35	medium
over 35	bad

Finck and Ochtman (1961) considered that although the correlation between cotton yield and "sodium value" was not as good as that between cotton yield and clay content, nevertheless the sodium value had a use in excluding sodic (alkali) soils. These authors point out that if one assumes that 50 per cent of the extractable sodium is exchangeable then a sodium value of 30 would correspond to an E.S.P. of 15 which is the Internationally accepted limit for sodic (alkali) soil. Our own investigations have shown, however, that exchangeable sodium almost always exceeds soluble sodium in Gezira type soils and that a "sodium value" of 30 would correspond to an E.S.P. of about 20 to 25. From this indirect evidence we can assume that in soils of high clay content (over 50 per cent clay) the long staple cotton can tolerate an E.S.P. somewhat in excess of 15 without suffering a serious reduction in yield.

6.413 Salinity

The salinity standards used in the Sudan since 1942 for the selection of cotton lands are as follows:-

(i) Good lands have less than 0.3 per cent total soluble salts.
(ii) Medium lands have less than 0.5 per cent total soluble salts.

As pointed out by Finck and Ochtman (1961) these salinity levels are rarely encountered and so land tended to be judged on "sodium value" and clay content alone.

In view of the fact that the Gezira type soils are virtually undrainable we consider that lower salinity levels than those generally used internationally maybecome limiting under irrigated conditions. We therefore place the salinity limits for arable lands as follows:-

	E.C.
Surface horizon (0-60 cm)	Less than 6
Sub-surface horizon	Less than 8

Research work has shown that under the extensive type of irrigation practised in the Gezira, salt contents of this order tend to diminish in the top metre and to increase slightly in the second metre of soil where they do not interfere with crop yields.

6.414 Subsoil Salinity - Alkalinity

Investigations of unthrifty cotton crops in the Managil Extension Scheme by the Gezira Research Division show that cotton plants become unthrifty and yields suffer if the cotton roots are unable to penetrate to a full depth of 90 cm. The tendency of roots of unthrifty plants to branch off horizontally at certain depths was attributed by the investigation team to the presence of highly saline layers or to dense clays of high exchangeable sodium content in the subsoil. For this reason our specification for salinity and alkalinity limits has been extended to 90 cm.

6.42 An Assessment of the Suitability of the Project Area Lands for Long Staple Cotton Production

We have used the data showing the relationship between cotton yields and soils factors enumerated above to assess the suitability of the project lands for long-staple cotton production and to predict yields of long staple cotton on the arable soils there.

Because Gezira research workers have shown that long staple cotton is more tolerant to high exchangeable sodium than the average climatically adapted crops we have concluded that long staple cotton may safely be grown on land classes 2, 3a and 4a the areas of which (chapter 5) are as follows:-

Land Class		Area (feddans)
2		41,110
3a		220,660
4a		33,640
	Total:	295,410

There is thus a total area of nearly 300,000 feddans that could be used for a long staple cotton rotation. The distribution of these lands is shown in figure VII.

The expected yields of long staple cotton in the project area may be predicted from the clay content of the soils. Chapter 4 shows that the average clay content in the 0-45 cm layer is 71.5 per cent and that 93 per cent of the soils have clay contents between 65 and 80 per cent.

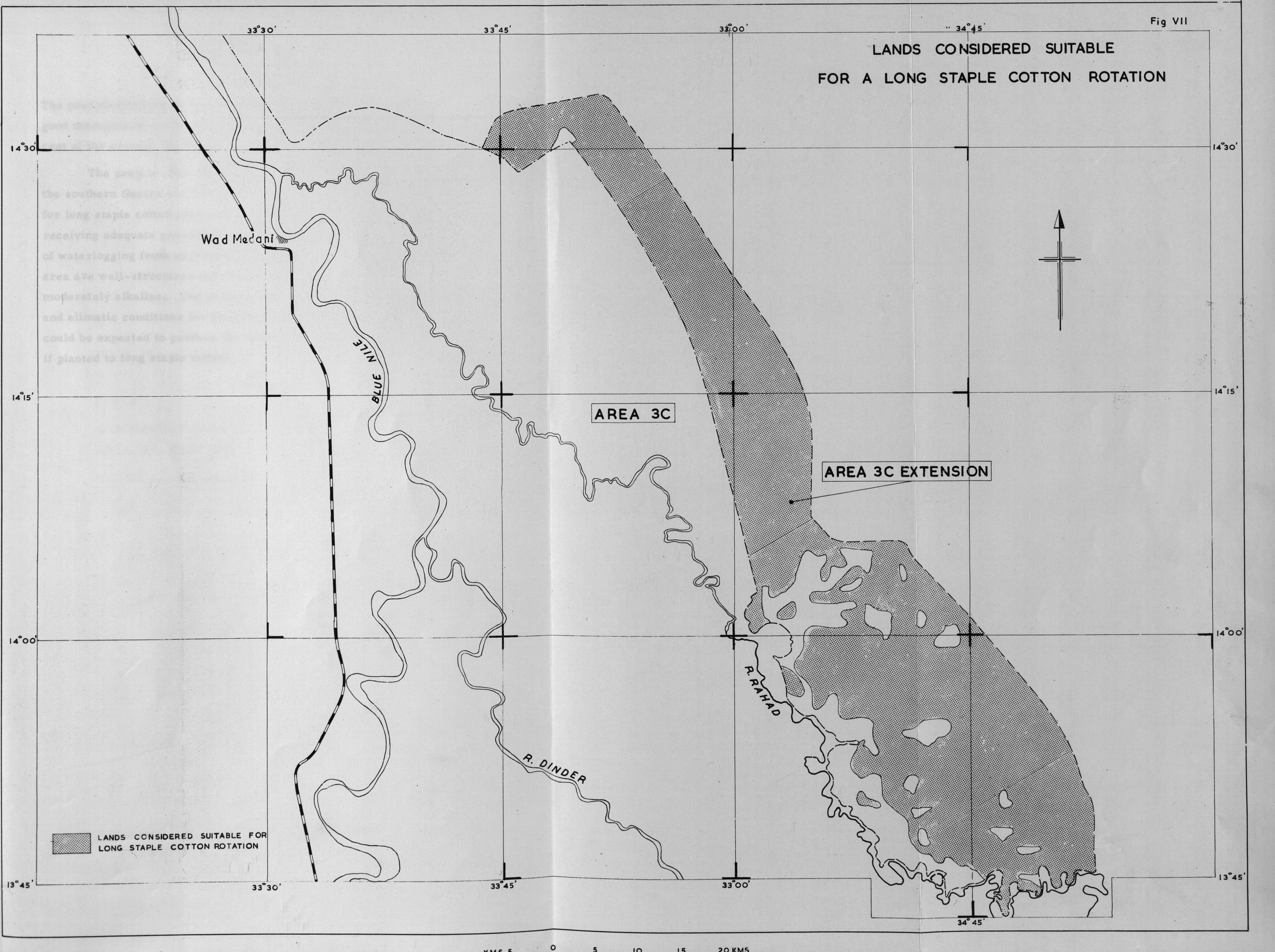


Fig VII

LANDS CONSIDERED SUITABLE FOR A LONG STAPLE COTTON ROTATION

The predicted long term average yield of long staple cotton under good management in the project area is, therefore, about 130 per cent of the average Gezira yield or about 5.8 kantars per feddan.

The project area, in fact, lies within the zone, which includes the southern Gezira and Managil blocks, where conditions are optimum for long staple cotton production. Within this zone the prospects of receiving adequate presowing rains are good whereas the possibility of waterlogging from excessive rain is low. The soils of the project area are well-structured and of very high clay content yet only moderately alkaline. The project area, therefore, has optimum soil and climatic conditions for the production of long staple cotton and could be expected to produce the highest sustained yields in the country if planted to long staple cotton.

APPENDIX 1.

DESCRIPTION OF THE SAMPLE AREA

TABLE 1.1

LABORATORY DATA FROM SAMPLE AREA SOIL PROFILE

FIGURE 1. Sample Area 1

APPENDIX 1.

Sample Area 1

Sample Area

Pit Number	Soil Series
4536	V_4
4537	V_4
5475	V_4
5476	V_4
6490	V_4

Location The sample area is about 22 kilometres from El Fau, just north of the road to Ein el Luweiga. It consists of five pits over 1 kilometre in a north-south line.

Topography All the pits are on level land, with apparently a very gentle slope to the south.

Vegetation The ground surface was largely bare, with a sparse growth of herbs, principally Ocimum sp., and few grasses including Sorghum sp. and Aristida sp. Acacia mellifera bushes were abundant in the south, thinning out northwards.

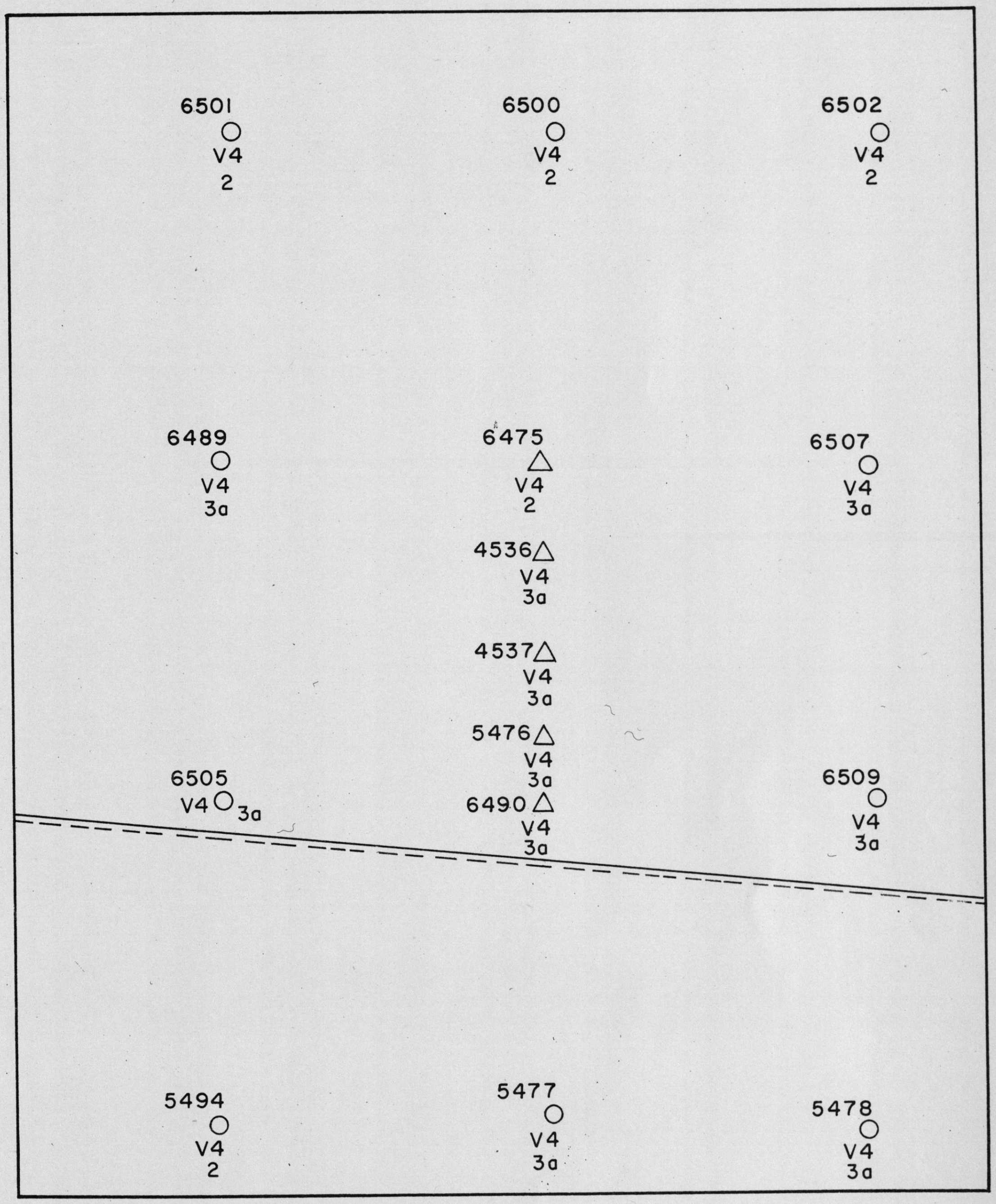
Soil Profiles The soils are all in series V_4, with about 70 per cent clay in the surface horizon and E.S.P. ranging from 10 to 12 in the surface horizon and from 14 to 20 in the second horizon. Salinity is low in all profiles.

Soil colours are the same in all profiles. The surface and second horizons are dark greyish brown (10 YR 4/2) to very dark greyish brown (10 YR 3/2). The third horizon is very dark grey (10 YR 3/1), and the bottom horizon is dark brown (10 YR 4/3) to dark yellowish brown (10 YR 4/4).

Table 1.1 Laboratory Data from the Sample Area Profiles.

Sample No.	Bore No.	Depth (cm.)	Mechanical Analysis Sand 2.0–0.02 mm.	Silt 0.02–0.002 mm.	Clay 0.002 mm.	E.C. mmhos/cm. at 25°C.	Sol.Na. Meq. 100g.	Exch.Na. Meq. 100g.	pH paste	pH 1:5
41741	4536	0-55	9	14	77	0.52	0.48	7.52	7.85	8.10
2		55-108	9	14	77	1.90	2.05	13.55	7.70	8.10
3		108-169	14	14	72	3.80	4.50	12.30	7.75	8.00
4		169-200	9	11	80	2.60	2.88	13.92	7.40	7.65
41745	4537	0-79	9	14	77	0.80	0.80	9.60	7.85	8.25
6		79-134	9	15	76	2.20	2.55	12.65	7.85	8.05
7		134-174	9	11	80	2.20	2.84	13.16	7.75	8.00
8		174-200	21	12	67	4.50	4.60	10.10	8.20	8.05
51532	5475	0-77	9	14	77	0.65	0.57	9.43	7.90	-
3		77-136	5	11	84	2.20	2.40	12.00	8.02	-
4		136-180	12	16	72	4.00	4.40	11.20	8.02	-
5		180-215	5	11	84	1.50	1.57	10.43	7.98	-
51536	5476	0-55	2	13	85	0.60	0.52	9.48	7.80	7.90
7		55-106	27	11	62	1.60	1.60	12.80	7.80	8.20
8		106-169	7	11	82	2.40	2.50	12.70	7.75	8.00
9		169-200	22	13	65	3.80	3.42	11.38	7.75	8.00
61473	6490	0-40	12	13	75	0.46	0.45	8.75	7.98	
		40-180	12	11	77	1.70	1.70	12.30	7.90	
		180-200	14	11	75	3.20	3.67	11.13	7.90	

SAMPLE AREA 1



LEGEND

Soil Series Symbol...........V4,NV4 etc
Land Class Symbol..............2 ,3a etc
Soil Series Boundary.... — — — —

ROSEIRES SOIL SURVEY

RAHAD AND DINDER AREA

AREA 3C EXTENSION

SAMPLE AREA I

SCALE – 1:20,000