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ROSEIRES SOIL SURVEY

REPORT No. 1

GEZIRA EXTENSION AREA
SOIL SURVEY AND LAND CLASSIFICATION

VOLUME I
THE REPORT

HUNTING TECHNICAL SERVICES LTD.
4 ALBERMARLE STREET
LONDON, S.W.1

SIR M. MACDONALD & PARTNERS
CONSULTING ENGINEERS
LION HOUSE
RED LION STREET
LONDON .. W.C.1

MAY 1963

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16th August, 1963.

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

Your Excellency,

ROSEIRES SOIL SURVEY

We have pleasure in submitting our Report No. 1 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 three volumes accompanied by an album of maps, contains the results of the semi-detailed soil survey and land classification for the Gezira Extension Area, referred to as Area 1 in the Contract. The fieldwork was carried out during the period from November 1962 to January 1963.

Preliminary assessments on the suitability of soils in the part of the area which was required for selection of the Managil Phase 5, Part 1, extensions were submitted to the Director of Agriculture on 31st December, 1962 and 29th January, 1963.

Draft copies of the Report Volumes I and II together with preliminary copies of the Album were submitted to the Director of Agriculture on 14th May, 1963.

The necessary agricultural and soil studies were undertaken on our behalf by Messrs. Hunting Technical Services Ltd. under the direction of Dr. Robert Smith, Consultant in Charge of the soil surveys.

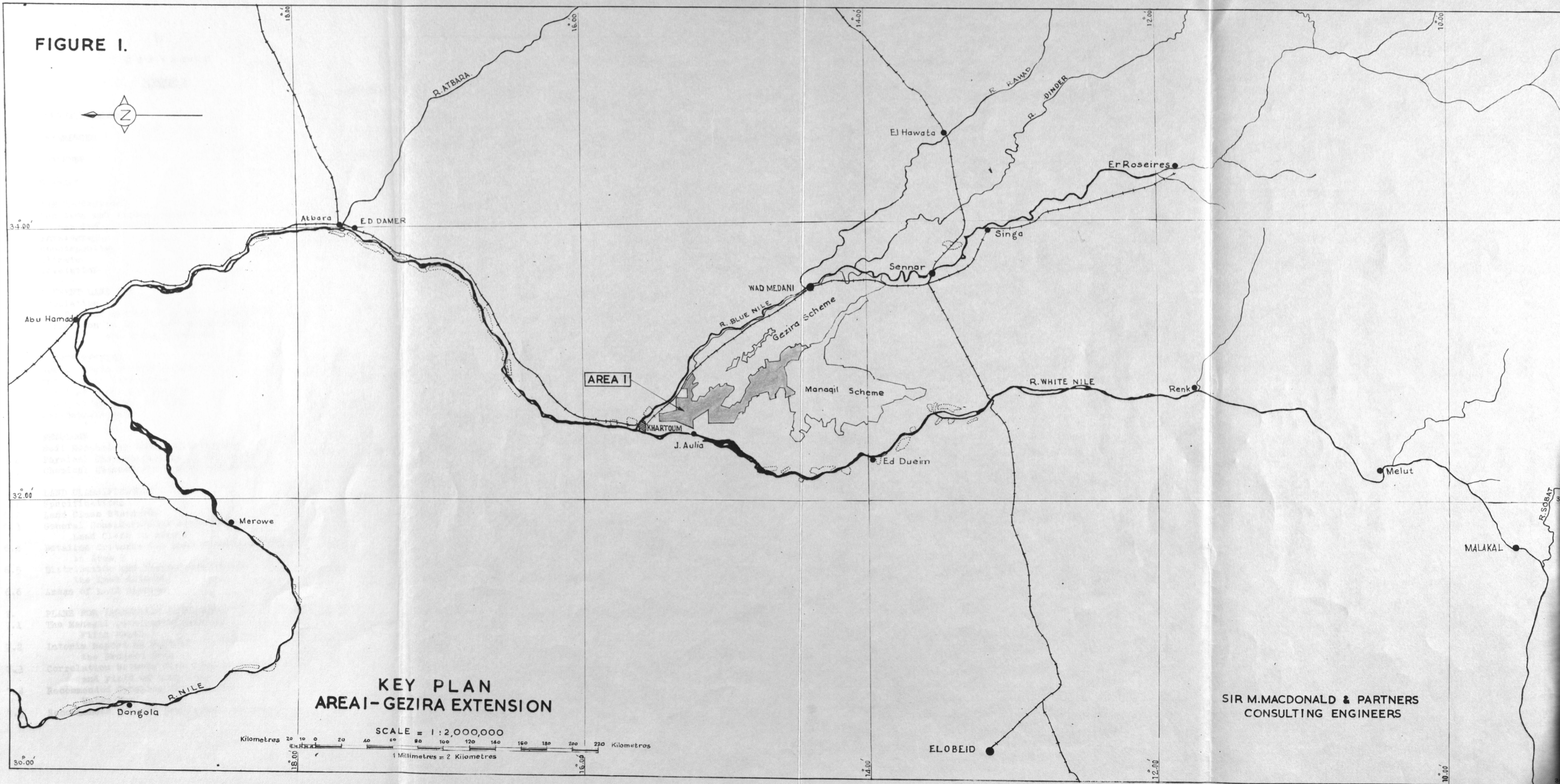
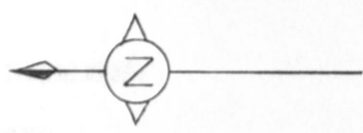
We are, Excellency,

Your obedient Servants,

R. H. Macdonald

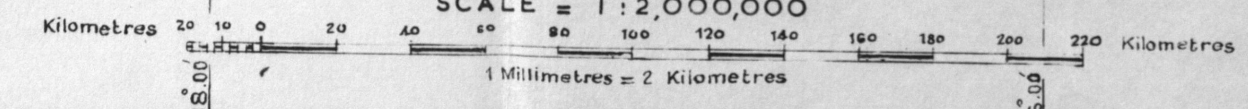
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FIGURE I.



**KEY PLAN
AREA I - GEZIRA EXTENSION**

SCALE = 1:2,000,000



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C O N T E N T S

TABLES IN VOLUME I

		PAGE	PAGE NO.
	ACKNOWLEDGMENTS		iv
	REFERENCES		v
	ANNEXURE		vii
CHAPTER 1.	SUMMARY		1
CHAPTER 2.	THE ENVIRONMENT		
2.1	Location and General Description of the Project Area		3
2.2	Physiography		4
2.3	Geomorphology		4
2.4	Climate		5
2.5	Vegetation		14
CHAPTER 3.	PRESENT LAND USE		
3.1	Population		16
3.2	The Present System of Arable Cultivation		16
3.3	Irrigation in the Neighbouring Gezira and Managil Schemes		17
CHAPTER 4.	SURVEY METHODS		
4.1	Aerial Photo Interpretation		22
4.2	Soil Survey Procedures		22
4.3	Field Permeability Studies		25
4.4	Chemical Analyses of Soils		27
4.5	Map Compilation		29
CHAPTER 5.	PEDOLOGY		
5.1	Soil Morphology and Classification		31
5.2	Physical Characteristics of the Soils		39
5.3	Chemical Characteristics of the Soils		45
CHAPTER 6.	LAND CLASSIFICATION		
6.1	Specifications		53
6.2	Land Class Standards		53
6.3	General Considerations determining Land Class in Area 1		55
6.4	Detailed Criteria for Land Classification in Area 1		56
6.5	Distribution and Characteristics of the Land Classes		57
6.6	Areas of Land Classes		59
CHAPTER 7.	PLANS FOR IRRIGATION DEVELOPMENT		
7.1	The Managil (Gezira) Extension, Fifth Phase		60
7.2	Interim Report on Part of the Project Area		60
7.3	Correlation between Clay Content of Soil and yield of Long Staple Cotton		63
7.4	Recommended Cropping Systems and Water Use		63
7.5	Recommended Limited Development in Area 1		64

TABLES IN TEXT

PAGE NO.

PAGE NO.

VOLUME II		PAGE NO.
2.42	Monthly Mean Temperature for Six Stations for 30 Year Period 1931-1960	6
2.43	Mean Duration of Bright Sunshine and Possible Percentage	7
2.44	Mean Daily Sunshine Hours and Amount of Radiation	8
2.451	Cloud Amount	9
2.452	Comparison between Cloudiness at Khartoum and Wad Medani	9
2.461	Total Annual Rainfall, 30 Year Mean (1931-60) for the 6 Stations	10
2.462	Monthly Rainfall (Average for 6 Stations) and Percentage of Annual Total	10
2.471	Mean Annual Relative Humidity at 0800 Hours	11
2.472	Diurnal and Monthly Variations in Percentage Relative Humidity for Average of 6 Stations	11
2.48	Wind Speed by Monthly Averages for Period 1957-61	12
2.4911	Mean Daily Evaporation by Piche Method	13
2.4912	Daily Piche Evaporation by Months for Weighted Mean of 6 Stations	13
2.492	Class A Mean Daily Evaporation by Months at Wad Medani 1958-62	14
4.22	Number and Types of Analyses carried out on Area 1 Soils	24
4.3	Coefficient of Conductivity	26
5.12	Soil Classification Chart	35
5.13	Frequency Distribution of Soil Series at All Sites in Area 1	37
5.211	Texture and Depth Distribution in the Sample Areas	39
5.212	Distribution of Topsoil Clay Percentages by Map Sheets	41
5.22	Hydraulic Conductivity in Relation to Soil Texture	42
5.311	Overall Salinity (E.C.) in Area 1	45
5.312	Depth Distribution of Salinity by Map Sheets	46
5.32	Composition of Soluble Salts	47
5.332	Exchangeable Cations	48
5.333	Exchangeable Sodium by Map Sheets	49
5.34	pH in Sample Areas by Depth	50
5.38	Organic Carbon Percentage by Horizon and Soil Order	51
5.39	Organic Nitrogen Percentage by Depth and Soil Order	52
6.4	Criteria for Determining Land Classes in Area 1	56
6.6	Areas of Land Classes 2, 3, 4 and 6 in Area 1	59

Table 1.3 Laboratory Analyses of 36 Sites Representative of Mapping Units

Table 1.4 Laboratory Analyses from 105 Pits from Sample Areas

Table 1.5 Laboratory Analyses from 360 Auger Borings

APPENDICES

(VOLUMES II and III)

PAGE NO.

VOLUME IIACKNOWLEDGEMENTS

APPENDIX 1

DESCRIPTIONS OF THE SEVEN SAMPLE AREAS

Sample Area 1	1
Sample Area 2	3
Sample Area 3	3
Sample Area 4	4
Sample Area 5	4
Sample Area 6	5
Sample Area 7	5

TEXT FIGURES

Following

6

Fig. 1. Sample Area 1	6
Fig. 2. Sample Area 2	6
Fig. 3. Sample Area 3	6
Fig. 4. Sample Area 4	6
Fig. 5. Sample Area 5	6
Fig. 6. Sample Area 6	6
Fig. 7. Sample Area 7	6

APPENDIX 2

SPECIMEN PROFILE DESCRIPTIONS, TOGETHER WITH LABORATORY DATA OF 15 SOIL SERIES AND ONE MEMBER OF A COMPLEX, AS FOLLOWS :-

V1 Soil Series	8
V2 Soil Series	9
V3 Soil Series	11
V4 Soil Series	12
V6 Soil Series	14
V8 Soil Series	15
V9 Soil Series	16
V10 Soil Series	17
V11 Soil Series	19
V12 Soil Series	20
E2 Soil Series	22
E3 Soil Series	24
E4 Soil Series	26
E5 Soil Series	28
E6 Soil Series	29
Vertic Orthustent Profile	30

VOLUME III

ANNEXURE

iv

APPENDIX 3

LABORATORY ANALYSES OF SOIL SAMPLES

Table 1.1 Detailed Laboratory Analysis of Eleven Sites Representative of Soil Series	1
Table 1.2 Values obtained for Cation Exchange Capacity by Various Methods	4
Table 1.3 Laboratory Analyses of 36 Sites Representative of Mapping Units	6
Table 1.4 Laboratory Analyses from 105 Pits from Sample Areas	11
Table 1.5 Laboratory Analyses from 860 Auger Borings	24

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

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

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The Macaulay Institute of Soil Research, Aberdeen, Scotland

The Director, for the secondment of Messrs. E. Lawrence and R. D. Law of the Soil Survey of Scotland to share the fieldwork in the Sudan.

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III. The Rooting Zone of Crops

The contract specifications mention the "rooting zone" without defining it.

There is a great deal of information on rooting habits of cotton in the Gezira derived from root washing experiments, and these show that the bulk of the roots are found in the upper (0-30 cm) layer of soil, though small numbers of roots are found at much deeper depths. This is a justification for basing the main agricultural assessment of the soils on the upper layer.

ANNEXURE

Interpretation of Laboratory Analysis for Soil and
Land Classification Purposes

by Robert Smith, (D.Sc. Agric.)

Consultant in Charge of the Soil Survey

1. General Specifications

The contract specifications require that the consultants shall carry out a scientific pedological soil survey as well as a precise land classification to assess the suitability of the lands for irrigated cultivation in general and for specific crops in particular, for the purpose of delineating irrigable lands within Area 1.

For a pedological survey the soil profiles must be sampled by horizons which vary in nature and depth from site to site. For land classification purposes, on the other hand, one is concerned with rooting depths of specific crops which are generally fairly constant. The purpose of this memorandum is to explain how soil characteristics defined by horizons, were interpreted for land classification purposes.

II. Soil Horizonation and Depth

The Gezira cracking clay soils have a characteristic profile which has been described by many workers. The topmost horizon, usually about 50 cm. thick, is dark brown (usually 10 YR 3/2, 3/3 or 4/2) with a granular surface and deep wide vertical cracks extending to the base of the horizon which has carbonate concretions but no gypsum. The subsoil horizon, usually 50-100 cm. thick, is dark grey (10 YR 3/2 or 3/1) and contains gypsum; there tends to be an increase in carbonates, clay content, salinity and exchangeable sodium. The deep subsoil is yellowish brown and there is a slight decrease in carbonates and clay contents. The layers are not sharply divided and deep tongues of the surface brown soil penetrate the grey layer; as a consequence the sample depth of the surface and subsoil horizons varies considerably from site to site.

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The problem of defining the depth of the rooting zone was discussed at a meeting at the Gezira Research Farm on 4th February, 1963, Dr. W.T.H. Williamson, Mr. L.H.F. Ochtman and Dr. K.H. Peters representing the client and Dr. T.N. Jewitt and Mr. C.W. Mitchell representing the consultant. The client's representatives stated that experience in the Gezira has shown high quality soils to have a depth of 90 cm. free from large accumulations of salts or alkali and that usable soils have a depth of 60 cm. of good soil.

Permissible limits of salinity and alkalinity and limiting clay contents were then adopted by the meeting and used in classifying the lands of Area 1. It will be noted that these depths do not regularly coincide with the depth of the pedological horizons.

IV. Land Classification Criteria used in Area 1

By the time the above decision was made the main survey, based on pedological horizon sampling was far advanced, leaving the problem of adapting the determination made at one series of depths to the others required for the land classification.

a) Salinity

Salinity (E.C.) was determined on the three major pedological horizons of the profile. The E.C. of the soil at limiting depths for land classification then determined as a weighted average.

b) Exchangeable Sodium was determined on the three major horizons for the first 130 sites (in the emergency area) and E.S.P. was calculated as a weighted average for the limiting depths of 0-60 cm, 0-90 cm for Vertisols and 0-50 cm for Entisols.

Thereafter, in order to complete the analytical programme in time for a preliminary assessment of the remaining project lands, exchangeable sodium was determined only on the upper horizon which was regarded as the rooting depth mentioned in the client's classification and from this estimates were made of the E.S.P. in the 0-60 cm layer. Most of these lands were classed as non-arable (Class 6) or special use lands (Class 4). On all sites classified as arable (Class 2 and Class 3 lands) exchangeable sodium is now being determined on the second horizon where the samples are still available so that E.S.P. can be calculated for the 0-90 cm. layer. This may result in a slight shift in the distribution of Class 2 as against Class 3 lands, but will not affect the total area of arable lands (Class 2 plus Class 3 lands). The reason why alkalinity classification on the upper sample alone yields nearly the same amount of arable land is that E.S.P.s greater than 20% are very rare in the second horizon when the value is less than 15% in the upper horizon.

c) Clay Content

As mentioned in the text of the report, there is positive correlation between clay content in the root zone and yield of long staple cotton on Gezira clay soils. For Class 2 lands the clay content must exceed 50%; where the clay content lies between 35% and 50% the land can not be better than Class 3 and where the clay content is less than 35% the land can not be better than Class 4.

Clay content was determined by mechanical analysis on upper and subsurface horizons on the first 120,000 feddans surveyed in Area 1. This data was used to calculate by weighted average the clay content of the top 90 cm. of soil so that the appropriate land class could be assessed.

Thereafter, in order to complete the analytical programme in time for a preliminary assessment of the remaining project lands, mechanical analysis was determined only on the upper horizon. The clay content of the top 90cm. was then estimated on the basis of this determination together with field estimates of texture in the surface and subsurface horizons. Most of these additional lands were classed as non-arable on the basis of high salinity or high exchangeable sodium.

1.3 Present land use is rain grown dura (*Sorghum vulgare*) combined with grazing. In the south where the average annual rainfall is about 350 mm. about 70-80 percent of the land is cultivated. In the north the rainfall of about 200 mm. is inadequate for dura and less than 10 percent is cultivated. After the dura harvest in November the inhabitants mostly move to the Gezira area as cotton pickers.

1.4 The soil survey shows that Area 1 consists of a clay plain becoming increasingly loamy northwards due to admixture with earlier sandy colluvial deposits and in the west with coarser channel deposits laid down by earlier channels of the Blue Nile.

The soils are moderately calcareous, are richly supplied with phosphate and potash but are low in organic matter and nitrogen. There is considerable salinity everywhere and it increases in amount and approaches near to the surface in the north.

Exchangeable sodium is everywhere high and frequently reaches the limiting 15 percent of the exchangeable cations. It tends, like salinity, to increase towards the north and is the most important single soil limitation in Area 1.

Typical Gezira red soil is only found in the extreme south-east of the project area and in limited pockets elsewhere. Most of the soils are more saline, higher in exchangeable sodium and have a lower clay content than the true Gezira soils.

1.5 The specifications for the soil-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 were rarely met and the other soil limitations were associated with salinity, alkalinity and clay content. Detailed specifications were worked out with the Department of Agriculture, Research Division, Wad Madani. Particular note was taken of the

CHAPTER 1

SUMMARY

1.1 The semi-detailed soil survey and land suitability classification of Area 1, Extension Gezira (Managil) Scheme, covers a total area of 461,600 feddans.

1.2 The lands occupy a tract of level plain lying adjacent to the western edge of the most northerly parts of the Gezira Irrigation Scheme between the Blue and White Niles. The plain lies at an elevation of 380-400 metres above sea level and the maximum slope is about 1 in 6,000. The clay plain shows an increase in sandiness on the western side where there are occasional low dunes, known as qoz. The climate is very hot and very dry with an average annual rainfall of about 280 mm., mostly falling between June and September. The original vegetation, now much modified by human interference, was acacia tortilis - Maerua crassifolia desert scrub in the north, and semi-desert grassland on clay in the south.

1.3 Present land use is rain grown dura (sorghum vulgare) combined with grazing. In the south where the average annual rainfall is about 350 mm. about 70-80 percent of the land is cultivated. In the north the rainfall of about 200 mm. is inadequate for dura and less than 10 percent is cultivated. After the dura harvest in November the inhabitants mostly move to the Gezira area as cotton pickers.

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Exchangeable sodium is everywhere high and frequently reaches the limiting 15 percent of the exchangeable cations. It tends, like salinity, to increase northwards and is the most important single soil limitation in Area 1.

Typical Gezira clay soil is only found in the extreme south-east of the project area and in isolated pockets elsewhere. Most of the soils are more saline, higher in exchangeable sodium and have a lower clay content than the best Gezira soils.

1.5 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 were rarely met and the chief soils limitations were associated with salinity, alkalinity and clay content. Detailed specifications were worked out with the Department of Agriculture, Research Division, Wad Medani. Particular note was taken of the

positive correlation between clay content of soil and yield of long staple cotton.

The lands of Area 1 were classified as follows:-

Class 2 - good arable lands -	36,400 feddans
Class 3 - moderate arable lands -	137,000 feddans
Class 4 - limited arable or special use lands -	26,200 feddans
Class 6 - non-arable lands, not suitable for development -	262,000 feddans

1.6 The Gezira (Managil) Extension, Phase V, was designed to use the same basic cropping pattern and irrigation system as the existing Managil Extension Area. The results of the soil survey and land suitability classification survey of 461,600 feddans show that 56 percent of the total area is not suitable for any form of irrigation development (Class 6 lands) and that a further 6 percent could only be considered suitable for specialised horticultural, vegetable or pasture development (Class 4 lands). The original plan for the development of 200,000 feddans on a Managil type rotation must, therefore, be very considerably curtailed.

1.7 The following development procedure is recommended:-

The Managil type crop rotation with long staple cotton as the chief cash crop should only be considered on Class 2 and Class 3 lands which cover a gross area of 173,400 feddans. Where sufficiently large blocks of Class 2 and Class 3 lands are located close to the existing canal system, an irrigation design to serve the lands should be drawn up. The cost of supplying these lands with water should be carefully estimated, together with other development costs, with a view to deciding if the expected crop yields would show a reasonable return on the invested capital. A provisional estimate of crop yields would be average Gezira yields from Class 2 lands and 65 percent of Gezira yields from Class 3 lands. If more precise information on expected crop yields is required it is considered that this could be obtained from an economic study of crop yields from the Kab el Gidad and Abd el Magid irrigated areas, combined with a semi-detailed soil survey similar to that carried out on the Area 1 lands.

When the above-mentioned engineering, economic and soil surveys have revealed how much land is suitable for development in Area 1, and the shortfall from 200,000 feddans has been calculated, then additional lands to be supplied by gravity from the existing canals could be investigated to the west and north-west of the Managil irrigated lands. If the grand total of 200,000 feddans of suitable land cannot be found then consideration should be given to the development of Class 2 lands by pump projects in Areas 2, 3, 4 and 5 of the overall study area.

At some future time consideration should be given to the development of Class 3 and Class 4 lands of Area 1 for other types of crops and rotations, e.g. grain farming combined with fodder crops in association with the Department of Animal Husbandry, or irrigated forest plantations in association with the Department of Forests, etc.

CHAPTER 2

THE ENVIRONMENT

2.1 LOCATION AND GENERAL DESCRIPTION OF THE PROJECT AREA

Area 1 is a tract of level plain lying adjacent to the western edge of the most northerly parts of the Gezira Irrigation Scheme between the Blue and the White Niles.

It totals about 461,600 feddans. From the southernmost tip near Tabat in the Gezira Scheme to the northernmost extremity near Khartoum is a direct distance of about 125 km., but it varies in width from less than 5 to more than 30 km.

Apart from the irrigated area in the east its boundaries do not coincide with natural features but have been chosen to define an area estimated, on the basis of existing knowledge of topography and soils, to be most suitable for immediate expansion of the irrigated area.

The eastern edge adjoins the existing irrigation. The western boundary can be enclosed by a line joining the grid points given below along the following routes:

1. 15°15' N. 32°56' E.
2. Along the railway line to:
3. 15°18' N. 32°50' E., and then from here a straight line joining the following points:
 4. 15°16' N. 32°50' E.
 5. 15°16' N. 32°45' E.
 6. 15°21' N. 32°45' E.
 7. 15°21' N. 32°39'15" E.
 8. 15°25' N. 32°37'50" E.
 9. 15°26'10" N. 32°37' E.
 10. 15°28' N. 32°37' E.
 11. 15°28' N. 32°34' E.
 12. 15°20'30" N. 32°34' E., then along telegraph line to
 13. 15°13' N. 32°32'10" E.
 14. 15°13' N. 32°35'45" E.
 15. 15°06' N. 32°40' E.
 16. 15°06' N. 32°34' E.
 17. 14°55'15" N. 32°34' E.
 18. 14°54'05" N. 32°38'20" E.
 19. 14°53'45" N. 32°38'40" E.
 20. 14°53'45" N. 32°38'30" E.
 21. 14°51'20" N. 32°39' E.
 22. 14°51'20" N. 32°41'10" E.
 23. 14°50' N. 32°41'20" E.
 24. 14°49'45" N. 32°42'40" E.
 25. 14°47' N. 32°43'30" E.
 26. 14°47'10" N. 32°43'05" E.
 27. 14°46' N. 32°43'30" E.
 28. 14°46' N. 32°44' E.
 29. 14°44'30" N. 32°44'30" E.

30.	14°43'50" N.	32°41'15" E.
31.	14°41'20" N.	32°41'50" E.
32.	14°40'50" N.	32°43'10" E.
33.	14°39'30" N.	32°45'50" E.
34.	14°37' N.	32°46'30" E.
35.	14°36'10" N.	32°46' E.
36.	14°36'10" N.	32°44' E.
37.	14°31'30" N.	32°44' E.
38.	14°33' N.	32°46' E.
39.	14°32'30" N.	32°47' E.
40.	14°35'45" N.	32°48'30" E.
41.	14°35'45" N.	32°48'55" E.
42.	14°39'10" N.	32°54'30" E.
43.	14°38'30" N.	32°56'10" E.
44.	14°36' N.	32°57'50" E.
45.	14°35'30" N.	32°58'30" E.
46.	14°29'10" N.	33°02'30" E.
47.	14°28'05" N.	33°04'40" E.

2.2 PHYSIOGRAPHY

Almost the whole area is a flat, level expanse of clay plain falling gently and uniformly in level. The highest point in the area is the S.S.E. tip at just 400 m. above sea level and the lowest is the N.N.W. tip at 380.7, a fall of just about 20 m. in 125 km. or 1 in 6.250. As this axis of the area is roughly parallel to the main direction of slope, this gradient represents about the maximum likely to be encountered.

The main interruption to the uniformity of the clay plain is a definite increase in sandiness westwards culminating in a system of low dunes locally called "qoz" covering much of the southern and western part of the area, and perhaps representing old channel deposits of the Blue Nile. The material of which these dunes are composed is sandy loam to loam in texture. They are seldom more than 2-3 m. high and although their surface has been modified by wind, which has piled up small mounds around trees and grass tussocks, their original deposition was probably fluvial.

2.3 GEOMORPHOLOGY

2.31 Underlying Geology

The area is underlain at depth by the predominantly crystalline and felspathic metamorphic rocks of the Pre-Cambrian basement complex whose surface forms a platform on which the Mesozoic Nubian sandstone lies.

This deposit (Nubian sandstone) was found to be at least 150 m. thick in the Sarra region but little is known about its thickness in Area 1 where it underlies the alluvium of the clay plain. Five of the boreholes made for water by the Sudan Gezira Board in 1956-9 in the Managil Extension, however, lie near to the south edge of Area 1, between 14°31' and 14°32' N. and 32°42' and 32°55' E. Only one encountered possible Nubian sandstone, at 57 m. The others were still in alluvium at over 67 m. Although all encountered sandy substrata, the average depth of overlying clay was about 20 m., ranging from a

minimum of 6 to a maximum of about 30 m.

The alluvium appears to be of Quaternary age. Archaeological evidence from calcareous gravelly sands in the bed of the Blue Nile near Singa assigns them broadly to the post-Acheulian or "developed Levallois" stages of the Pleistocene. These sands are covered by 10 m. of heavy, dark Gezira clay which helps to date it as Pleistocene-Recent or more precisely post-Levallois but probably pre-dynastic and, therefore, possibly 50,000-10,000 B.C.

2.32 Mode of Origin of Gezira Clay

The mode of origin of the clay plain of which Area 1 forms a part is still controversial and many workers have contributed to the subject, among whom Lombardini, Willcocks, Lawson, Lyons, Ball, Andrew, Arkell and Tothill are the chief. The most up-to-date theory is that deposition was from a seasonal inundation of the Blue Nile and its tributaries whose higher situation and larger summer flood enabled its alluvium to cover all of Area 1, extending to the White Nile north of Jebel Aulia and at least into the central part of the Gezira plain midway between the rivers.

The clays are montmorillonitic and contain a mineral suite of which purplish augite is a prominent member, indicating derivation from the lavas and associated rock types of Ethiopia and from basement complex outcrops upstream of Roseires, particularly in the Didessa and Yabus valleys. The land has a slightly steeper slope than the White Nile plain and the soils appear somewhat more gypseous.

During the last stage of its formation the Gezira seems to have dried out annually. Two lines of evidence suggest this. First, the upper 180 cm. of soil contain many semi-fossil shells of the seasonally amphibious Amphipoda and Lanistes genera, but no lacustrine mollusca. Secondly, the Sabaloka gorge at this time was probably much as it is today so could not impound water. Tothill deduces an annual inundation of five months or so from the distribution of semi-fossil Cleopatra shells in the topsoils of a strip of land along the Blue Nile in places 25 km. wide. No direct evidence, however, yet exists to disprove a possible lacustrine origin of deeper layers.

2.33 Sub-Recent Geology

Low qoz cover some of the south-west part of Area 1. They are probably fluvial sands which have been slightly reworked by wind, and suggest that the Blue Nile has recently flooded across the area between the north end of the Managil ridge and the White Nile south of Jebel Aulia.

The most recent geological event appears to be a rejuvenation of the Blue Nile river system causing streams to incise. This has affected Area 1 only in probably much reducing the frequency of flooding.

2.4 CLIMATE

2.41 General

Area 1 lies near the boundary between tropical savannah and desert climates. It is generally hot and dry and receives almost

all its rain (about 280 mm.) between May and October.

The following meteorological stations lie close enough to the area to be representative of its general conditions:

1.	Khartoum	15°36' N.	32°32' E.
2.	Sudeira	15°10' N.	32°50' E.
3.	Qurashi	14°49' N.	33°10' E.
4.	Wad Shair	14°38' N.	33°04' E.
5.	Wad Medani	14°24' N.	33°30' E.
6.	Medina Block	14°22' N.	33°20' E.

These six stations report full data on temperature, rainfall, humidity, barometric pressure, wind force and direction, cloud amount and height, sunshine hours, and evaporation from Piche cylinders.

In addition, the Wad Medani station has a Class A evaporation pan and makes exhaustive micro-climatic observations of importance to agriculture.

2.42 Temperatures

The overall average annual temperature for 1931-1960 of the six stations is 28.4°C. The lowest is Wad Shair (27.3°C.) and the highest Khartoum (29.75°C.), so that variations within the area can only be slight.

The monthly means for the same period from the six stations are as follows:

Table 2.42 - Monthly Mean Temperature for Six Stations

for Thirty Year Period 1931-1960, measured in °C.

JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	YEAR
23.2	24.5	27.4	30.5	32.6	32.7	30.1	28.6	29.6	30.4	27.1	23.9	28.4

There are two maxima: one in May-June before, and the other in October after, the rains. The minimum is in January.

These averages conceal a very large diurnal temperature variation at all seasons. In Khartoum in January the average rose from 15.7°C. at dawn to 32.1°C. in the afternoon, while in May (generally the hottest month) it rose from 25.9°C. to 41.9°C. between these hours, changes of 16.4°C. and 16.0°C. respectively. In the Gezira stations these changes are even greater. The comparable figures for Wad Shair are 11.7°C. and 32.9°C. in January and 21.6°C. and 39.9°C. in May, variations of 21.2°C. and 18.3°C. respectively.

Differences between hottest and coldest recorded years are even greater. For instance, Khartoum's highest mean daily June maximum was 47.7°C., but its lowest mean daily June minimum in another year was only 19.9°C. Similarly, in the coldest recorded year the mean daily December minimum was 6.0°C., while the year with the warmest daily December had a mean maximum of 40.0°C.

Despite the wide variations, Area 1 is generally intensely hot except in December to February and during the summer rains, which are the pleasantest periods of the year.

2.43 Sunshine

Table 2.43 shows the sunshine records for Wad Medani.

Table 2.43 - Mean Duration of Bright Sunshine and Possible Percentage
(Stokes-Campbell Recorder and 1931-1960 Average)

	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Mean Hours per Day	10.6	10.6	10.5	10.6	9.9	9.6
% of Possible	93	91	87	85	77	74

	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	YEAR
Mean Hours per Day	7.7	7.7	8.9	10.0	10.7	10.5	9.8
% of Possible	60	61	73	85	93	93	81

The lower values from May to September clearly reflect the summer cloudiness, but even in July and August the sun shines for more than 60 percent of the time it is above the horizon.

2.44 Solar Radiation

The following table relates mean daily sunshine hours to radiation at Wad Medani.

2.45 Cloudiness

The following table gives the average cloud amounts for the five stations for which records exist.

Table 2.44 - Mean Daily Sunshine Hours and Amount of Radiation
(Five Year Means)

1958-1962						
	JAN.	FEB.	MARCH	APRIL	MAY	JUNE
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 in cal/cm ² /Sunshine Hour	45.4	48.1	51.5	52.5	53.4	56.3

1957-1961							
	JULY	AUG.	SEP.	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 in cal/cm ² /Sunshine Hour	65.6	62.3	55.9	51.8	45.6	43.5	52.1

Although actual radiation remains relatively constant through the year, this is only because the cloudiness of the summers reduces radiation to approximately the level experienced in the winter. Radiation of sunny hours is only 66 percent as great in December (43.5 cal/cm²) as in July (65.6 cal/cm²).

2.45 Cloudiness

The following table gives the average cloud amounts for the five stations for which records exist.

Station	Jan	Feb	Mar	Apr	May	Jun	Year
Wadi Medani	5.3	5.2	4.4	4.9			
Mean Annual:							
Khartoum	2.6	2.0	2.0	2.4			
Wadi Medani	2.7	3.0	2.3	2.6			

Table 2.451 - Cloud Amount (0-8)

	(1)	(2)	(2)	MEAN DAILY
	0800	SUDAN TIME (3) 1400	2000	
January	0.90	1.45	0.85	1.00
February	1.00	1.35	0.85	1.00
March	1.30	1.90	1.25	1.40
April	1.60	2.20	1.45	1.70
May	2.50	3.05	2.20	2.50
June	2.80	3.55	2.80	3.00
July	4.20	4.95	4.35	4.40
August	4.50	4.95	4.30	4.60
September	3.60	4.10	3.50	3.70
October	1.90	3.15	2.15	2.30
November	0.90	1.55	0.85	1.10
December	1.00	1.65	0.80	1.10
Year	2.10	2.85	2.15	2.30

- (1) Weighted average of Khartoum (30 years), Medina (11 years), Qurashi (9 years), Wad Medani (30 years) and Wad Shair (18 years).
- (2) Average of Khartoum and Wad Medani (30 years each).
- (3) G.M.T. + 2 hours.

Only in July and August is the sky more than half cloud-covered, and the annual average is about 29 percent. There is a tendency, especially in the winter, for cloudiness to reach a maximum at around midday and a minimum at night.

There is a slight difference between stations as the following table shows.

Table 2.452 - Comparison between Cloudiness at Khartoum and Wad Medani

Mean Annual Cloud Amount (0-8)

30 Year Means: Sudan Time

	0800	1400	2000	MEAN
January:				
Khartoum	1.4	1.6	1.0	1.3
Wad Medani	1.1	1.3	0.7	1.0
August:				
Khartoum	5.1	4.8	4.2	4.7
Wad Medani	5.3	5.1	4.4	4.9
Mean Annual:				
Khartoum	2.6	2.7	2.0	2.4
Wad Medani	2.7	3.0	2.3	2.6

In January Khartoum is cloudier at all times of the day; in August, and for the year as a whole, Wad Medani is. This reflects the dominantly southern origin of the cloud, except in the winter.

2.46 Rainfall

In semi-arid climates such as this, rainfall is extremely variable between different places, years, seasons and days.

Differences between stations are shown below.

Table 2.461 - Total Annual Rainfall (mm.) 30 Year Mean (1931-60)
for the Six Stations

<u>KHARTOUM</u>	<u>SUDEIRA</u>	<u>QURASHI</u>	<u>WAD SHAIR</u>	<u>WAD MEDANI</u>	<u>EL MEDINA</u>	<u>MEAN</u>
164	214	277	300	373	348	279

As these are arranged geographically from north to south, the general increase in that direction is shown. Both Wad Medani and El Medina have over twice the rainfall of Khartoum.

Variations from year to year are marked, and occasional storms can be very heavy. The highest daily recorded fall for the six stations over the 30 year period was 112 mm. at Qurashi on 26/7/48, but all six stations had recorded daily falls of over 79 mm. at least once during the period, and all have at least five days in an average year when more than 10 mm. falls and at least nineteen days when more than 1 mm. falls.

All six stations have the same pattern of seasonal rainfall variations. The following table averages them to give a picture of the area as a whole.

Table 2.462 - Monthly Rainfall (Average for Six Stations 1931-60) in mm.
and Percentage of Annual Total

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	TOTAL
mm.	0	Tr.	Tr.	2.0	11.0	22.0	86.0	103.0	46.0	9.0	Tr.	0	279.0
%	0	0	0	0.7	3.9	7.9	30.8	36.9	16.5	3.2	0	0	99.9

Over 99 percent of the total rainfall comes between May and October and over 67 percent in the two months of July and August alone.

2.47 Humidity

The following table shows the mean relative humidities for the six stations in the area.

(1) Weighted means for Khartoum, Wad Medani and Wad Shair (30 years), Qurashi and Medina (22 years), and Sudira (7 years).
(2) Khartoum and Wad Medani (30 years) averages.

Table 2.471 - Mean Annual Relative Humidity in % at 0800 Hours Sudan Time
(30 Year Means 1931-60 except where stated)

<u>KHARTOUM</u>	<u>SUDEIRA</u>	<u>QURASHI</u>	<u>WAD SHAIR</u>	<u>WAD MEDANI</u>	<u>EL MEDINA</u>	<u>WEIGHTED MEAN</u>
39	48 (7 yrs.)	42 (22 yrs.)	44	43	44 (22 yrs.)	43

Khartoum is the only station with a value below 40 percent. This indicates its somewhat drier general climate and probably also its distance from regions influenced by transpiration from irrigated crops. All the other stations are in the Gezira scheme.

Averaging all six stations to obtain general figures for monthly and diurnal changes gives the following table.

Table 2.472 - Diurnal and Monthly Variations in Percentage Relative Humidity from Six Stations near Area 1

<u>SUDAN TIME</u>	<u>JAN.</u>	<u>FEB.</u>	<u>MAR.</u>	<u>APR.</u>	<u>MAY</u>	<u>JUNE</u>
0800 ⁽¹⁾	38.0	30.0	23.0	20.0	30.0	45.0
1400 ⁽²⁾	18.5	14.0	10.5	10.5	14.5	20.0
2000 ⁽²⁾	27.5	21.5	16.5	16.0	22.5	29.0
<u>MEAN DAILY</u>	28.0	21.8	16.7	15.5	22.3	31.3

<u>SUDAN TIME</u>	<u>JULY</u>	<u>AUG.</u>	<u>SEP.</u>	<u>OCT.</u>	<u>NOV.</u>	<u>DEC.</u>	<u>YEAR</u>
0800 ⁽¹⁾	64.0	73.0	66.0	48.0	36.0	39.0	43.0
1400 ⁽²⁾	34.5	45.5	35.5	22.5	18.5	20.0	22.0
2000 ⁽²⁾	47.5	61.0	51.5	36.0	29.5	30.0	32.0
<u>MEAN DAILY</u>	48.7	59.8	51.0	35.5	28.0	29.7	32.3

(1) Weighted means for Khartoum, Wad Medani and Wad Shair (30 years), Qurashi and Medina (22 years), and Sudeira (7 years).

(2) Khartoum and Wad Medani (30 years) averaged.

In absolute terms values are generally low, never exceeding an average of 60 percent in any month and falling to less than 16 percent in April, the driest.

There are two peaks in the annual curve. The main maximum is in August, at the height of the rainy season, but there is a secondary one in December.

Maximum humidity comes in early morning and minimum in early afternoon at all seasons. The percentage value for the former is usually about twice that for the latter.

2.48 Wind Direction and Speed

At Khartoum, which can be considered representative of Area 1, the dominant wind is north from October to May and south-west from June to September.

The following table shows its average force.

Table 2.48 - Wind Speed by Monthly Averages for Period 1957-61

Knots/Hour

	JAN	FEB	MAR	APR	MAY	JUNE	JLY	AUG	SEP	OCT	NOV	DEC	YEAR
Khartoum	9.0	9.3	8.4	7.9	8.7	8.9	9.5	8.8	6.4	6.4	7.8	8.1	8.3
Wad Medani	7.0	8.3	7.2	6.8	7.5	10.3	9.6	7.2	6.0	4.5	6.0	6.2	7.2
MEAN	8.0	8.8	7.8	7.3	8.1	9.6	9.5	8.0	6.2	5.5	6.9	7.1	7.7

As with relative humidity, the annual curve has two peaks and two troughs. The strongest winds are in June (9.6 knots/h.), and the weakest in October (5.5 knots/h.), but there are secondary maxima and minima in February and April respectively.

Except in June and July, when it is more exposed to the southerly winds, Wad Medani always has lower values than Khartoum, illustrating the general decrease of wind force southwards in the Sudan.

The seasonal distribution of wind velocities is roughly the same as that for relative humidities. Both have main summer and secondary winter peaks although the exact months when these occur are different. It thus appears that the north wind has some influence in humidifying the Sudan's winter climate.

2.49 Evaporation

The intense evaporation dominates irrigated agriculture in the Northern Sudan. The climatic factors previously outlined are chiefly important to agriculture in their effects upon it.

Three direct methods of measuring evaporation are employed. Piche cylinders are used at all meteorological stations. The Wad Medani station also uses "Class A" tanks and Popoff cylinders.

The Piche cylinders allow water to diffuse into the air through porous plates from small glass flasks. "Class A" cylinders are open 4 ft. diameter tanks from which evaporation is measured directly by volume.

Popoff cylinders are filled with soil with and without a turf cover which is regularly saturated with water. Loss of weight due to evaporation and evapotranspiration respectively is measured gravimetrically.

2.491 Piche Evaporation

The difference in annual Piche evaporation between the six stations is as follows.

Table 2.4911 - Mean Daily Evaporation (Piche) (mm.) for Area 1

<u>KHARTOUM</u> <u>(30 yrs.)</u>	<u>SUDEIRA</u> <u>(8 yrs.)</u>	<u>QURASHI</u> <u>(22 yrs.)</u>	<u>WAD SHAIR</u> <u>(30 yrs.)</u>	<u>WAD MEDANI</u> <u>(30 yrs.)</u>	<u>EL MEDINA</u> <u>(22 yrs.)</u>	<u>MEAN</u>
16.5	16.8	13.9	15.3	15.1	12.8	15.0

There seems to be a slight tendency for evaporation to decrease southwards but the change is not regular.

Averaging the six stations together gives the following monthly distribution.

Table 2.4912 - Daily Piche Evaporation by Months (mm.)

for Six Stations averaged together
(Weighted Mean⁽¹⁾)

JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	YEAR
13.8	16.3	19.6	21.6	20.3	18.4	12.4	8.3	9.5	12.5	14.3	13.0	15.0

(1) Khartoum, Wad Shair and Wad Medani (30 years), Qurashi and El Medina (22 years) and Sudeira (8 years).

The daily evaporation throughout the year averages exactly 15 mm. which represents an annual total of 5.475 metres. The double maximum and minimum is again evident. Over 20 mm. a day evaporates in April and May but this decreases by more than half in August and September. There is a weak secondary maximum in the dry month of November falling to a weak second minimum in December.

2.492 "Class A" Evaporation

Records by this method only exist for one station - Wad Medani - for 1958-62 inclusive while even here there are some months incompletely recorded. The following table shows these results.

Table 2.492 - "Class A" Mean Daily Evaporation by Months at Wad Medani
(1958-62 mean) in mm.

JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	YEAR
9.7	11.5	14.0	15.3	16.6	14.2	9.2	7.2	7.3	8.9	9.6	8.6	11.0

This method shows the same general pattern as the Piche cylinders with the same double maxima in May and November, but readings are uniformly lower, and amount to a total annual evaporation of only just 4 metres. As this method is considered to give a more reliable measurement for evaporation from a free water surface, it seems that Piche values should be multiplied by a correction factor of about 0.73.

2.5 VEGETATION

Human and animal interference from cutting, grazing, gleaning and seasonal burning has everywhere so modified the natural vegetation of Area 1 that it is hard to find examples of the environmental climax. There is, however, an obvious basic distinction between the vegetation of the clay plains and that of the sandy areas known locally as qoz.

The north end of the area lies in the Acacia tortilis-Maerua crassifolia Desert Scrub zone, and the south end lies in the zone of Semi-Desert Grassland on Clay.

Generally, vegetation height, density and luxuriance on the clay plain increase from north to south, towards low places where moisture accumulates and where soil salts and alkali are at a minimum.

Characteristically Area 1 is an open, grassy, clay plain covered with low grasses among which Aristida funiculata, A. mutabilis, Chloris virgata SW and Schoenefeldia gracilis Kunth. are the chief. They are mainly from 20-50 cm. high. There are widely scattered low bushes, dominated by Acacia nubica ("laot") and Acacia tortilis ("seyal") but with some Zizyphus spinachristi ("sidr"), Balanites aegyptiaca ("heglig") and Maerua crassifolia on sites more favoured for moisture. "Nal" grass (Cymbopogon nervatus) is found mainly towards the south and on wetter sites, especially with higher percentage of clay and lower salts and alkali. It can thus be considered a rough indicator of good soil among sites of equal soil moisture. Vegetation tends to become more abundant where the soil is sandier and such herbs as Heliotropium spp. and grasses like Echinochloa colonum (L) Link and Cenchrus biflorus (Roxb.) are found.

The sandy soils, particularly on qoz, have a far denser vegetation cover which makes them easily recognizable in the field and on aerial photographs and bears out Smith's theory of their more favourable soil moisture economy. The dominants are Acacia tortilis, var. raddiana, Acacia tortilis (Forsk.) Hayne which is the same as A. spirocarpa Hochst, ex A. Rich, Zizyphus spinachristi (L) Wild., Balanites aegyptiaca and more occasional Acacia seyal, Acacia nubica and Calotropis procera.

Herbs include the following:

- Aerva javanica (Burm.f.) Juss. ex Schult.
- Cadaba farinosa (Forsk.)
- Citrullus colocynthis L.
- Corchorus depressus (L.) Christens
- Corchorus clitorius (L.)
- Crotolaria saltiana Andr.
- Echium arenarium Guss.
- Fagonia cretica
- Heliotropium spp.
- Indigofera spp.
- Solanum dubium

The following sedges and grasses were noted:

- Aristida spp.
- Cenchrus biflorus (Roxb.)
- C. mbopogon proximus (Hochst.) Stapf.
- Cyperus rotundus L. (a sedge)
- Echinochloa colonum (L.) Link.
- Panicum turgidum Forsk.

THE PRESENT SYSTEM OF WATER UTILIZATION

3.1 Geographical Distribution of Dams

Dam (Sorghum vulgare) is the only crop grown in the Area 1. As the mean annual rainfall for the whole area is only 219 mm, the cultivators make the maximum use of water to concentrate and hold rainwater on their fields. They also use quick growing varieties of dam that mature in about 60 days. Although the short variety is often grown, the most favored type is quick maturing variety which can yield a crop about 1-1 1/2 ft. high in 40 days. Crop yields probably average 1/3 ton per feddan and the average is probably only 1/4 ton per feddan.

In the south-eastern part of the Gezira, where the average rainfall is about 350 mm. per year, about 70% of the land is cultivated. This is on the edge of the Gezira about 100 km. from the White Nile, which is supposed to be about 1920 m. having established a high water table in the area.

In the northern Gezira, by contrast, the rainfall of about 200 mm. per year is inadequate for dam and only about 20% of the land is cultivated. Less than 10 percent of the total land is cultivated.

There is a slight concentration of dam fields along the edge of the Gezira area where there is a little higher rainfall from the tails of the canals.

3.2 Cultivation Practices

The harig system of cultivation is the general type. The underlying principle of this is to allow a shallow sowing in about 10 cm. ground for cultivation and reduce subsequent weeding, instead of 15-20 cm.

CHAPTER 3

PRESENT LAND USE

3.1 POPULATION

There are no detailed statistics giving the population of Area 1. The people live mainly in small villages scattered throughout the area devoted to rain grown dura. After the dura harvest in November these people move into the irrigated Gezira lands where the able-bodied members work as cotton pickers.

At the edge of the irrigated lands there are some larger villages with populations of up to 2,000 people. It is possible that some of these people may have interests both in irrigated tenancies and in dry land cultivation of dura.

The Gezira canals, which provide perennial drinking water, undoubtedly attract some villagers to live near the edge of the irrigated zone but in the main the villagers have their own water supply from wells about 40 metres deep.

3.2 THE PRESENT SYSTEM OF ARABLE CULTIVATION

3.21 Geographical Distribution of Crops

Dura (Sorghum vulgare) is the only crop grown in the Area 1 rainlands. As the mean annual rainfall for the whole area is only 279 mm. the cultivators make the maximum use of bunds to concentrate and hold rainwater on their fields. They also use quick growing varieties of dura that mature in about $2\frac{1}{2}$ months. Although the short Gassabi variety is often grown, the most favoured type is quick maturing Feterita which can yield a crop from a plant 3-4 ft. high in 70 days. Crop yields probably do not exceed $\frac{1}{3}$ ton per feddan and the average is probably only $\frac{1}{5}$ ton per feddan.

In the south-eastern part of the area, where the average rainfall is about 350 mm. per year, about 70-80 percent of the land is cultivated. This is on the edge of the zone around Managil and beyond, to the White Nile, which is mentioned by Tothill (1952) as having established a high reputation for grain production.

In the northern Gezira, by contrast, the rainfall of about 200 mm. per year is inadequate for dura and only basin areas covering less than 10 percent of the total lands are cultivated.

There is a slight concentration of dura fields around the edge of the Gezira area where there is a little haphazard spill from the tails of the canals.

3.22 Cultivation Practices

The hariq system of cultivation is in general use. The underlying principle of this is to allow controlled burning to clean the ground for cultivation and reduce subsequent weedings, Tothill (1952).

In this area at least four years' growth must be allowed for the grasses to form a dense mat. After the first rains, and when the new grass is just showing green, it is fired. If done at the right time this kills off the new young grass, leaving the land clean for cultivation.

Sowing is by seluka, spacing up to 1 m. or more, and about 4 seeds are used per hole. Closer spacing may probably sometimes be used to encourage the growth of a thinner, more palatable, straw. Once established, the dura plant grows well, but for full success requires not less than three heavy showers at about ten-day intervals.

Feterita is the common variety in Area 1, and Feterita Managil is a fairly well-known sorghum in the arid areas of East Africa.

3.23 Livestock

Almost nothing is known about the livestock population and husbandry in the project area. All that can be said is that cattle, sheep and goats are the main complement to dura growing in the area and that they depend on rough grazing supplemented by dura stalks. They are watered from village wells and the tail reaches of the Gezira canals when these are accessible.

3.3 IRRIGATION IN THE NEIGHBOURING GEZIRA AND MANAGIL SCHEMES

The object here is to emphasize those features of existing irrigation in the Gezira and Managil Schemes which have relevance to possible extension in Area 1.

3.31 Settlement, Tenancy and Labour

Both the Gezira and Managil Schemes are cultivated by tenants chosen by the Gezira Board, who operate the irrigation system, though the land is owned by the Government. Tenancies in the Gezira are 40 feddans, in the Abdel Majid extension 18 feddans, and in the Managil extension 15 feddans. The reduction of farm size and more intensive rotation at Managil was so that a family could manage without hired labour. In fact, it has resulted in multiple tenancies within families. But it is proposed to reduce each tenant yet further to 5 instead of 10 feddans of cotton in Phase V.

Tenants are chosen from existing owners of the unirrigated land of at least 2-3 years' standing. They receive 1-4 tenancies according to whether their previous ownership was 15-29, 30-44, 45-59 or over 59 feddans.

The Government provides the following public works in each new village:

- (1) Social market.
- (2) Boys' school.
- (3) Girls' school.
- (4) Shops, which are sold by auction.
- (5) Flour mills.
- (6) Human dispensary.
- (7) Animal dispensary.

Settlers are each given 20 m. square plots on which to build houses. They can build how and what they like. Usually they start with grass or mud houses, building afresh with brick when they can afford it.

Families normally do their own cultivation except during the cotton picking when extra labour is needed. Normally 1-2 extra workers are used per acre, depending on the quality of the crop. Tenants now receive free railway warrants from the Government for themselves and any labourers they can recruit for this work. The need for labour is sometimes so intense that farmers try to tempt workers away from their neighbours, by offering them more money. The block inspector must try to stop this and can have the offender called before the village council. If he persists he can be dismissed from his holding.

Labourers are generally recruited from the surrounding, un-irrigated parts of the Gezira where the people become available after they have harvested their dura in November, but many must be brought from further afield. They are paid on a piecework basis - generally 10 P.T. for picking 1 guffa (35 lb. basket) of cotton. The maximum possible rate would be about 3 guffas per day, the average being about one. The labourers have free housing and food from the tenant which is a further inducement for the latter to include dura in his rotation.

3.32 Water

The Gezira Scheme has a gross irrigable area of 980,000 feddans. forty-four percent of this is irrigated August-October; 31 percent November-December and 25 percent January-March. All the water comes from the Sennar dam, by free flow in the July-December flood season and from storage from January to June.

During the irrigation season water flows continuously in the main canals down to the ends of the major distributaries. As water is applied to the land only by daylight, supplies are stored nightly in the minor distributaries. The Managil Scheme follows the same essential system except that its use of a 3 course rather than a 4 course rotation necessitates a greater watering rate. Sixty-seven percent of the total area of 800,000 feddans is irrigated August-October, 50 percent November-December and 33 percent January-March.

The construction of Roseires dam will make much more water available, though it is as yet undecided whether and to what extent it will benefit the Gezira-Managil Area. If it is available here it can intensify and expand cultivation in both areas, and will of course thus benefit the irrigation of Area 1.

The following crops are thus grown under irrigation in the Gezira and Managil schemes.

Cotton (Gossypium spp.) Long-staple varieties are grown on the basis of the agricultural system in both the Gezira and Managil schemes. This is not the place to consider all species of cotton, but long-staple cotton, or perhaps a combination of a long-staple type like gulf, will almost necessarily dominate the agriculture in any irrigation development of Area 1.

Dura (Sorghum durum) The long-staple dura of Blue Nile Province is cultivated with fine stone and a sowing habit that ensures a crop

3.33 Rotational Systems

In the Gezira there is an eight-year rotation: Resting - Cotton - Resting or Lubia - Resting - Dura - Resting - Resting - Cotton. This means that the farmer each year has 10 feddans under cotton, 5 under dura, 1-2 under lubia and the balance of 23-24 in fallow.

The Managil rotation is a six-year one: Cotton - Resting - Cotton - Lubia - Dura - Resting, and is thus considerably more intensive than the Gezira as the watering rates (given above) show.

Experimental work on improving rotations is carried out by the Gezira Board at Wad En Nain, near Wad Medani, in the Gezira Scheme, and at at Kheir Bageiq, near Ma'tuq, in the Managil Scheme.

The Wad En Nain farm is trying to improve the income of the tenant on the Gezira rotation while adhering to the cotton basis and maintaining its high yields. The following intensifications to a six-year cycle have been tried: Cotton - Resting - Cotton - Lubia - Dura - Resting. This was then intensified to: Cotton - Phillipesara - Cotton - half Groundnuts, half Legume and Vegetables - Dura followed by Wheat - Resting. But wheat after dura is very exhausting to the soil and wheat should be sown between 7th and 24th November, which is difficult right after dura. Accordingly this has been changed to: Cotton - Phillipesara - Cotton - Groundnuts - early maturing Dura then Lubia or Brown Cowpea or Clitoria - Resting. This is generally recommended now.

At Kheir Bageiq farm near Ma'tuq an attempt is being made to find improvements to the Managil rotation. This is the counterpart station to Wad En Nain in the Gezira. It is likewise attempting intensification by introducing extra legumes into the rotation. It is: Cotton - Phillipesara - Cotton - Groundnuts - half Dura and half Cowpeas or Clitoria tenatea - Resting.

This rotation replaces one fallow with a rain-grown legume and the lubia (which is badly grown because it is mainly intended as a draw for labourers' cattle) with a cash crop of groundnuts, whose hay is also useful as fodder although there is little leaf left after the groundnuts have been beaten off. The reduction of dura by half leaves room for a necessary fodder of cowpeas and clitoria.

Cattle and cattle products will thus play a much bigger part.

3.34 The Main Crops

The following crops are thus grown under irrigation in the Gezira and Managil Schemes.

- (1) Cotton (Gossypium spp.) Long-staple varieties are grown and form the basis of the agricultural system in both the Gezira and Managil Schemes. This is not the place to consider all aspects of this crop, but long-staple cotton, or perhaps an introduction of a medium-staple type like Acala, will almost necessarily dominate the agriculture in any irrigation development of Area 1.
- (2) Dura (Sorghum vulgare) The irrigated dura of Blue Nile Province is a Feterita with fine stems and a tillering habit that ensures a crop

even if all the primaries are lost to locusts. It is sown at the end of July, or earlier if rain permits, and harvest is completed before the cotton picking begins at the end of December. Although the average yield is little more than $\frac{1}{2}$ ton/feddan, yields of three times this amount are obtained from good land. The more palatable Gassabi and the recently introduced Dwarf White Milo are being grown to an increasing extent.

The need for edible straw encourages fine-stemmed varieties such as the 'Abu Kalleiga' type of Feterita in the Gezira and to a heavier seed rate with all varieties than is compatible with optimum grain yield.

(3) Lubia (Dolichos lablab) This is the third most important crop in the Gezira and Managil Schemes, and is the chief annual leguminous fodder crop in the Sudan.

It is sown in holes by 'seluka' or 'toria' and seed rate varies with expectation of growth, so that in winter spacing is closer as, though it grows all the year round, it prefers hot weather. It is highly responsive to good seed-bed, freedom from early weed growth and careful watering, which can increase yields fivefold. Neglect of these things can also destroy its value as a soil improver.

A good yield would be 5 tons of greenstuff per feddan in this Area, and if beans are the main objective 4 ardebs/feddan may be achieved, but as the bean harvest is normally subordinated to forage requirements 1 or 2 ardebs are more usual.

None of the other crops grown in the Gezira and Managil Schemes are nearly as important as these three. The chief now are probably:

(4) Groundnuts (Arachis hypogaea) Two varieties are grown in the Gezira: Ashford, which is the higher yielding, and Barberton. Experimentally 1.5-2 tons per feddan is attainable but the usual Sudan yield is 1 ton per feddan. The crop is being tried for introduction both at Wad En Naim and Kheir Bageiq, and it is hoped that it can replace lubia in the rotation and also provide a cash crop.

(5) Wheat (Triticum vulgare) During the war this was grown in the Gezira as an alternative to the import of wheat flour, and Blue Nile Province as a whole added about 20,000 feddans of irrigated wheat to the traditional rotations. It was quite successful and has begun a taste which has remained.

It has generally been regarded as a crop of the riverain lands north of Khartoum because of its need of cooler weather and, if sown in this area, has little hope of success if sown after November because of the return of hot weather in the spring.

It will grow on all except extremely coarse soils. It is less salt tolerant than barley but more so than either cotton or dura. Its cultivation is being encouraged by the agricultural authorities in Blue Nile Province because the increasing demand for it necessitates expensive importation into the Sudan. In some parts of the Gezira official sanction is enabling it to begin to replace lubia. This is bad for the soil as it replaces a restorative legume with an exhausting cereal. Average commercial yields range from about 500-750 kg. feddan, averaging 600, but experimental yields are about 1,000 kg./feddan.

(6) Other Legumes: Phillipesara, Brown Cowpeas and Clitoria (Phaseolus trilobus, Vigna unguiculata and Clitoria tenatea) are three new legumes which are now being introduced via the Wad En Nain and Kheir Bageiq experimental farms, in order to meet the increasing emphasis on livestock husbandry in the rotations. Phillipesara is replacing the first resting season and is grazed in place. Cowpeas or clitoria or lubia are to follow early maturing dura in the new suggested Gezira rotation and the first two together occupy half the land after groundnuts in the new Managil rotation. As the phillipesara provides the grazing, half of these can be baled as a necessary reserve. The clitoria is the slowest to start but is hardy and drought tolerant and should be left over into the succeeding fallow.

(7) Vegetables Many of these are grown and many more have been tried, including bania, molochea, eggplant, tomatoes, onions, sweet potatoes, sugar beet, carrots, cauliflowers and turnips, at Wad En Nain alone.

3.35 Livestock

Large numbers of cattle, sheep and goats graze in the Gezira on lubia, dura stalks and cotton leaves, depending on the season. There is today a strong impetus in the Ministry of Agriculture and the Gezira Board to emphasize livestock husbandry and attention is being given to enriching the rotations with fodder crops and introducing better stock bulls.

The following are the main correlations between photographic image and soil data which were found:-

<u>PHOTOGRAPHIC IMAGE</u>	<u>PROBABLE SOIL CHARACTERISTICS</u>
1. Rippled or meered surfaces or with a large "scroll" pattern (of river meanders) and with park-like vegetation of scattered trees.	Qm formations and sandy soil probably of fluvial origin.
2. Smooth grey colour with small angular blocks.	Clay plain with rain dura fields.
3. Black speckles on lighter background.	Clay plain with mounds composed of sand-sized clay aggregates.
4. Dark grey and black patches.	Flat surface.
5. Whitish lines and smudges.	Puddled or salty surface.

4.2 SOIL SURVEY PROCEDURE

As mentioned in the contract documents, the semi-detailed survey of Area 1 was a matter of extreme urgency and was commenced as soon as the field parties arrived in Khartoum in November 1962.

The consultant in charge and the chief soil surveyor first carried out a preliminary study of general soil and terrain

CHAPTER 4

SURVEY METHODS

4.1 AERIAL PHOTO INTERPRETATION

This is an essential tool in soil mapping as it reveals all characteristics with a surface expression. Its usefulness is, however, largely dependent upon the quality of the photographs, the amount of field and analytical data available and the interpreter's experience of the area under consideration.

The method adopted was to select seven "sample" areas evenly scattered over Area 1 which appeared to cover the main variations and contrasts of surface pattern visible on the photographs. Soil pits were dug, described and sampled in each and an attempt was made to correlate the data thus obtained with the photographic pattern. This familiarized the team with typical profiles and the photographic image characteristic of their surfaces but, as field work for the semi-detailed soil survey had to proceed before laboratory data from them was available, they could not be fully classified and mapped in advance of it.

After the semi-detailed soil survey had been completed and analytical results received, final classification and mapping was carried out by stereoscopic examination of the aerial photographs. Sites were first classified and marked on the prints and then the best possible lines drawn round them.

The following are the main correlations between photographic image and soil data which were found:-

<u>PHOTOGRAPHIC IMAGE</u>	<u>PROBABLE SOIL CHARACTERISTICS</u>
1. Rippled or smeared surface or with a large "scroll" pattern (of river meanders) and with park-like vegetation of scattered trees.	Qoz formations and sandy soil probably of fluvial origin.
2. Smooth grey colour with small angular blocks.	Clay plain with rain dura fields.
3. Black speckles on lighter background.	Clay plain with mounds composed of sand-sized clay aggregates.
4. Dark grey and black patches.	Wet surface.
5. Whitish lines and smudges.	Puddled or salty surface.

4.2 SOIL SURVEY PROCEDURE

As mentioned in the contract documents, the semi-detailed survey of Area 1 was a matter of extreme urgency and was commenced as soon as the field parties arrived in Khartoum in November 1962.

The consultant in charge and the chief soil surveyor first carried out a preliminary study of general soil and terrain

conditions in conjunction with a study of the photo mosaics and aerial photographs (3rd-14th November).

4.21 Sample Areas

Seven sample areas, each of about 2.5 km², were selected on the photographs. Two, and part of a third, lay outside the survey boundary as finally given; six were rectangular, about 3.2 km. x 0.8 km.; and one was about 1.6 km. square.

The four additional soil surveyors arrived in Khartoum on 12th and 13th November and moved to field headquarters at Fawwar on 15th November. They immediately commenced work on the seven Sample Areas, each of 2.5 km² extent, which had been selected by the consultant and chief soil surveyor. At 106 sites pits were dug to a depth of 2 m., the soil profile was accurately described and 360 soil samples were taken by horizons for the following laboratory analyses:-

- Mechanical analysis (International fractions).
- Salinity test (E.C. on saturation extract).
- pH on 1:5 suspension and soil paste.

4.22 Semi-Detailed Reconnaissance Survey

On completion of the survey of the Sample Areas it would have been useful to have awaited completion of the soil analyses before proceeding further. As the large field party was already in the field and could not remain idle for several weeks, however, it was decided to proceed immediately with the routine semi-detailed survey. A provisional soil classification of the Sample Areas, based on morphological characters observed in the field, was carried out and correlated with patterns observed on the air photographs. This was followed by aerial photo interpretation of all the prints which were annotated according to the main variations and contrasts of surface patterns. There is little topographic contrast in the project area and the presence of fire patterns which cut across and obscure soil patterns rendered interpretation difficult on the photographs which, between prints, showed considerable variability in tone due to non-uniform processing conditions. In general, the results of the photo interpretation were rather less useful than is normally expected from this essential tool of soil mapping.

It was decided that the semi-detailed soil survey should commence with routine soil observations and that sampling at selected representative sites for soil mapping units and for soil series units should be carried out at the end of the routine survey when the soil pattern was well established. It was found that Australian Jarret type augers of 2 ins. diameter worked very satisfactorily in the Gezira clays and these tools were used for the routine soil examination of 872 sites (20 to 3 m. depth and 852 to 2 m.). Soil samples taken from major horizons and subsoils at these sites, numbering 2,636, were sent for the following analyses:-

- Salinity test (E.C. on saturation extract)
on major horizons and subsoils.
- Clay content of the air dry soil
on major horizons.
- Exchangeable sodium
on major horizons.

106 / 175 Km²
6 / Km²

The exchangeable sodium percentage (E.S.P.) is calculated from the exchangeable sodium content and from the cation exchange capacity (C.E.C.) determined for the representative profile of the corresponding series.

At selected representative sites throughout the project area a further 36 pits were then accurately described (using methods and terminology of the U.S.D.A. Handbook No. 18 and Munsell Soil Colour Charts) and sampled by horizons.

A total of 77 samples from 25 sites of representative mapping units were sent for the following analyses:-

- Mechanical analysis (International fractions).
- Salinity test (E.C. on saturation extract).
- Soluble sodium on saturation extract.
- Soluble and exchangeable sodium.
- pH on soil paste.

A total of 39 samples from 11 sites at series level were sent for the following analyses:-

- Cation exchange capacity.
- Exchangeable cations.
- Nature of the soluble salts.
- Total carbonates as CaCO₃.
- Organic N.
- Organic C.
- Total K, in the rooting zone only.
- Total P, in the rooting zone only.

The grand total of all analyses from Sample Areas and semi-detailed survey is shown in Table 4.22

Table 4.22 - Number and Types of Analyses carried out on Area 1 Soils

TYPE OF SOIL ANALYSIS	TOTAL NUMBER OF SAMPLES ANALYSED
Cation Exchange Capacity	39
Exchangeable Cations (Na, K, Ca, Mg)	39
Soluble Cations (Na, K, Ca, Mg)	39
Soluble Anions (Cl, SO ₄ , CO ₃ , HCO ₃)	39
Total Carbonates as CaCO ₃	39
Organic Nitrogen	39
Organic Carbon	39
Total K (Conc. acid extract)	39
Total P (Conc. acid extract)	39
Soluble Na (Saturation extract)	101
Exchangeable Na (Sat. extract)	1,175
E.C. on Saturation Extract	3,026
pH (paste)	110
pH (1:5 suspension)	399
Mechanical Analysis	1,744
TOTAL ANALYSES	6,906

In addition, the following studies were initiated:-

1. Special soil samples were collected for despatch to Europe for clay mineral analysis.
2. Field permeability studies by the pour-in method were carried out at 41 sites on a total of 52 horizons.
3. A set of 39 samples from 11 representative series sites was sent to the Soil Science Section, Gezira Research Station, Wad Medani, for their information.

Field work for the semi-detailed survey of Area 1 was completed on 10th January. The total number of sites examined is as follows:-

	<u>NUMBER OF SITES</u>
2 metre pits in Sample Areas	105
Other 2 metre pits	36
3 metre bores	20
2 metre bores	<u>852</u>
TOTAL	<u>1,013</u>

The total area surveyed was 461,600 feddans and the density of soil examination sites was about 1 for each 500 feddans.

4.3 FIELD PERMEABILITY STUDIES

Field permeability tests were carried out at 41 pit sites. Two tests were made at 11 of these sites so a total of 52 tests was made.

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

Apparatus:

Land Rover	Clean gravel
2 x 40 gallon drums	Mirror
2" Jarret auger	50 cc. graduated cylinder
10 m. rubber tubing	250 cc. graduated cylinder
2 screw clamps	Stopwatch
2 m. measuring tape	Thermometer

Procedure:

The tests were carried out in or beside the 2 m. pits dug in the Sample Areas of the soil survey whose textural layers had previously been defined and described. 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 proved abortive through water escaping down concealed cracks after the test was started. Such escape nullifies the value of many results in the clay soil because it destroys the conditions on which the theoretical calculations depend.

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 errors 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 and 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:

$$K = \frac{864Q}{Cu r h}$$

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 (of conductivity) obtained from Table 4.3.

Table 4.3 - 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 5.

4.4 CHEMICAL ANALYSES OF SOILS

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

4.41 Mechanical Analysis: Bouvoucos Hydrometer Method

40 grams soil soaked with 250 ml. water and 11 ml. of 10 percent sodium hexametaphosphate solution overnight; next morning dispersed in electric stirrer for 10 minutes, transferred to 1 litre measuring cylinder, shaken and readings taken after 4 minutes, 2 hours and 7 hours. With every reading the temperature is recorded and corrections made for temperature and dispersing agent content. The readings are also corrected for moisture content, when required, by performing separate moisture determination.

4.42 pH

Potentiometric determination using glass electrode on saturation extract, soil paste or 1:5 extract as required.

4.43 Electrical Conductivity

By using Solubridge on saturation extract or soil paste as required.

4.44 Total Nitrogen

Kjeldahl digestion, followed by distillation of freed ammonia into the boric acid solution and titration with 0.05 N.HCl.

4.45 Total Organic Carbon

Wet oxidation of organic matter by Walkley-Black rapid method (ref. C. S. Piper, Soil and Plant Analysis, 1942, page 223).

4.46 Total Extractable Phosphorus

From hydrochloric acid extract prepared by A.E.A. provisional method (ref. Piper, Soil and Plant Analysis, 1942, page 140), a suitable aliquot is taken, and the phosphorus content determined by reduction with ascorbic acid in sodium hexametasulphite medium to molybdophosphoric blue (ref. Fogg D. N. & Wilkinson N. T. 1958, Analyst 83: 406).

4.47 Total Extractable Potassium

A suitable aliquot is taken from the same hydrochloric acid extract, sesquioxides precipitated by ammonia, filtrate reacidified with HCl and suitably diluted for reading on flamophotometer, against 10 ppm. standard.

4.48 Carbonate as Incorporated Calcium Carbonate

Gasiometrical determination in Collins calcimeter (ref. Collins S. H. 1906, J.Soc. Chem. Ind. 25: 518). The volume of CO₂ 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.

4.49 Carbonate and Bicarbonate in Saturation Extract

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

4.410 Chlorides in Saturation Extract

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

4.411 Sulphate in Saturation Extract

1 ml. of suitably diluted saturation extract is added to a medium of glycerol and glucose solution, barium sulphate generated, and determined turbidimetrically in electric photometer.

(Ref. Current Science Vol. 31, No. 10, October 1962, page 419)

4.412 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)

4.413 Soluble Sodium and Potassium in Saturation Extract

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

4.414 Exchangeable Sodium and Potassium

12.5g. of soil are soaked in 50 ml. of normal ammonium chloride, left for one hour and 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. Leaching is continued until 250 ml. of filtrate are collected. The filtrate (5 ml.) is diluted 20 times and sodium read off on 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.

4.415 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 of soil leached and filtrate collected. Five grams of soil are

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).

4.416 Cation Exchange Capacity

Both Middleton ammonium oxalate method and sodium acetate method are used (the latter one ref. Agric. Handbook No. 60, U.S. Dept. of Agric.). In most instances it was not possible to get reasonable and reproducible results, and the C.E.C. was computed by summation of exchangeable cations which showed a fairly good agreement with clay percentage. For instance, the average clay percentage in the samples C1336-73, 1378-80, 1384-86 and 5001-13 was 40 percent, and the average C.E.C. in these samples was 38. A similar trend can be observed with the R samples, the averages being there 34.6 and 34.4 respectively.

4.5 MAP COMPILATION

4.51 The Base Maps

The 1/50,000 Sudan Survey Contoured Map of the Gezira dated 1928 and 1929 was used, the Survey Department kindly supplying chronaflex positives from the original compilations of the following Sheets: 11, 12, 19, 20, 27, 28, 35 and 36. That part of Area 1 appearing on Sheets 37 and 45 was small and so Sir M. MacDonald & Partners combined the relevant parts of the two on to a new single sheet which they labelled 37/45.

All Sheets were brought up-to-date by plotting the boundaries of existing Gezira and Managil irrigation from plans supplied by the Ministry of Irrigation and Hydro-Electric Power.

Pit, borehole and field permeability sites are shown on the base map by the following numbered symbols:

- 2 m. pit
- ⊙ 2 m. auger boring
- △ 3 m. auger boring
- * site of permeability study

The numbers are preceded by letters identifying the technician who observed the site in question.

The accuracy of their positions is not always very high, and there may be locally an error of as much as 1 cm. on the maps (500 m. on the ground) though most would be within 0.4 cm. (200 m. on the ground). This is because of the difficulty of transferring information accurately from aerial photographs used in the field, showing only occasional villages, wells and beacons, to semi-controlled mosaics and old maps.

4.52 The Soil Maps

A coded soil classification is marked beside each site on the soil maps and explained in the legend and in Chapter 5 of this Report.

Boundaries were first determined stereoscopically on the aerial photographs and then transferred freehand on to the maps.

4.53 The Land Class Maps

5.1 The coded land classification is marked beside each site on the land class maps and explained in the legend in Chapter 6 of this Report. Origins

Boundaries were first determined stereoscopically on the aerial photographs and then transferred freehand on to the maps. The area is representative of this clay except for somewhat coarser soil textures, especially in the north and south-west, and higher levels of salinity-alkalinity.

The top two metres of soil appears to have been deposited from seasonal Blue Nile floods. The steady northward increase in soil sandiness, despite the absence of surface dunes, almost certainly reflects the proximity of the Tertiary land surface. Eubian sandstone outcrops at Ondurman and in several places close to the east bank of the Blue Nile between Wad Nadani and Khartoum. It seems likely that it is to be found at shallow depth in the northern extremity of Area 1.

As has been previously mentioned, the low undulating ground terrain in the south and west parts of the Area were probably recently deposited by the Blue Nile along a meandering flood course, but have since been somewhat reworked by wind.

5.12 Soil Classification System

The soils of the project area have been classified according to the specifications of the U.S. Department of Agriculture (1960), the Seventh Approximation. See Table 5.12 and the album of soil maps. The soil orders, suborders, great groups and subgroups are defined as follows:-

Vertisols are clayey mineral soils containing more than 35 percent of an expanding lattice type clay and having more than 30 milliequivalents 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 column. They are characterized 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 are found throughout the world in the subhumid to arid regions. The central concept is one of soils that crack widely and that often reabsorb from water that runs into the cracks rather than from water that percolates through the soil. If the surface wulches during the dry season there may be a significant amount of surface material that sloughs into the cracks. The moistening and swelling of a layer, with dry soil above and below, causes shearing

CHAPTER 5

PEDOLOGY

5.1 SOIL MORPHOLOGY AND CLASSIFICATION

5.11 Origins

The geological environment of Area 1 is given in Chapter 2 and brief mention is made of the mode of origin of the Gezira clay. The area is representative of this clay except for somewhat coarser soil textures, especially in the north and south-west, and higher levels of salinity-alkalinity.

The top two metres of soil appears to have been deposited from seasonal Blue Nile floods. The steady northward increase in soil sandiness, despite the absence of surface dunes, almost certainly reflects the proximity of the Tertiary land surface. Nubian sandstone outcrops at Omdurman and in several places close to the east bank of the Blue Nile between Wad Medani and Khartoum. It seems likely that it is to be found at shallow depth in the northern extremity of Area 1.

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Vertisols 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 from water that percolates through the soil. If the surface mulches during the dry season there may be a significant amount of surface 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.

Usterts are generally restricted to the drier climatic range of the vertisols. Soil colours show chromas of more than 1.5 throughout the upper 30 cm. and lack distinct or prominent mottling within the surface 75 cm. The hues are often redder than 10 YR.

Grumusterts have, when dry, a loose, porous mulch of discrete, very hard aggregates, dominantly less than 3 mm. in diameter; they do not have a platy or massive surface crust containing uncoated silt and sand grains that persists after drying.

Orthic Grumusterts have, throughout each pedon (soil unit), moist colour values of 3.5 or less and dry values of 5 or less to a depth of 30 cm. They have less than 15 percent extractable sodium in all parts of the upper 30 cm.

Mazusterts have a platy or massive surface crust, the upper surface of which has a light coloured matrix of uncoated silt and sand thick enough to be visible in cross section without magnification, or that have fragments of such a crust in the plough layer.

Orthic Mazusterts have a surface horizon 30 cm. or more thick and colours throughout that are as dark or darker than 3.5 when moist and 5 when dry. They have less than 15 percent extractable sodium throughout the upper 30 cm.

Natrargidic Mazusterts have 15 percent or more extractable sodium in some part of the upper 30 cm. They are usually dry throughout the soil.

Entisols are soils either without natural genetic horizons or with only the beginnings of horizons. The horizons present are so weakly expressed that they fail to meet the requirements of any of the diagnostic horizons, except the albic (white) horizon and those that are produced through cultivation by man. At one extreme in age an Entisol might consist of very recent alluvium; at the other extreme in age it may include quartz sands that have been in place for many thousands of years. These soils are found throughout a wide range of climates. The central concept includes soils in deep regolith or earth with no horizons except a plough layer. Colour is not of significance in defining the Entisols.

Ustents are Entisols that, unless irrigated, are dry soils. They include many of the soils of arid and semi-arid regions of the world that have been called Lithosols, Regosols and Alluvial soils. The Ustents have ochric epipedons (light coloured surface horizons). They lack other diagnostic horizons, although they may have discernible secondary carbonates or accumulations of salts. They may even show slight cementation in some horizons, enough to give few to many hard or very hard disconnected nodules. Unless the soil is irrigated, moisture is held at tensions of more than 15 atmospheres throughout the soil for more than half the year. If irrigated, the soil soon becomes dry when irrigation ceases.

Psammustents are dry, coarse textured soils that are below the wilting point for most of the year. The coarse textured horizons extend to 50 cm. or more and include sands and loamy sands but exclude very

gravelly and stony soils. These soils are often found on at least partially stabilized dunes. Some of the sands have been deposited by water on fans or on flood plains. The vegetation is scattered and is zerophytic if perennial.

Oxic Psammustents include soils that have been highly weathered chemically during some previous period. The sand fraction is dominantly quartz, 95 percent or more. The clay fraction is mostly 1:1 lattice clay and free oxides but the clay content is too low for an oxic horizon (accumulation of clay and sesquioxides).

Orthustents include dry, loamy soils with textures finer than loamy fine sand extending to 50 cm. or more. They have an ochric epipedon that may or may not be slightly darker than the underlying horizons or layers. Weak cementation that is not destroyed by soaking in acid is permitted in the lower horizons if only cemented nodules are present. Accumulations of secondary lime, gypsum or salts may be seen as efflorescences or mycelia. Distinct CS and SA horizons may be present but not gypsic or salic horizons (accumulations of gypsum exceeding 5 percent or soluble salts exceeding 2 percent). Redistribution of carbonates sufficient to give a CA horizon underlying a horizon that has lost its carbonates is not permitted, for the leached horizon comes within the definition of a cambic horizon (a changed or altered horizon). These soils are found on flood plains, fans and uplands throughout the arid and semi-arid regions of the world. Vegetation, if undisturbed, consists of annuals and zerophytic perennials.

Orthic Orthustents are loamy soils extending to 30 cm. or more, having less than 40 percent expanding lattice clay and in lower horizons lacking cementation into small nodules that will not soften in acid. Secondary accumulations of gypsum and salts that do not constitute gypsic or salic horizons are permitted but not required. Visible secondary lime is also permitted but leached surface horizons lying on CA horizons are excluded.

Vertic Orthustents have more than 40 percent expanding lattice clay but lack the cracks, slickensides, gilgai or structure diagnostic for Vertisols. In other parts of the world these soils are generally shallow over basic rock. In the project area, however, they consist of isolated mounds of wind blown material aggregated to fine sand size.

5.13 Soil Classification Problems

Two problems arose with using the Seventh Approximation:

- (1) The Orthic Grumusterts and Orthic Mazusterts, differing only in surface structure, resemble each other so closely in this Area that the distinction between them is less practically important than the family and series differentiations within each. Accordingly, in the soil mapping the cognate series from the two subgroups were mapped together, viz. V2 with V6 and V4 with V8 (V5 and V7 were not found). The actual difference between the two subgroups is at best small, but in this Area the rainfall is sufficient generally to form a slight surface crust strongly suggestive of, but just insufficient for, the Orthic Mazustert designation.

(2) Many soils which have an exchangeable sodium percentage in the topsoil of over 15 nevertheless have Grumusert surface characteristics. Such a condition is not recognized as possible in the Seventh Approximation where it seems to be assumed that an E.S.P. of over 15 necessarily involves a Mazustert type topsoil. It is possible that salinity, free carbonate or some other such soil condition may explain the retention of a surface dust mulch but this has not been clearly established. Certainly the frequent high exchangeable sodium approaching a "natric" horizon and the faint "textural B" horizon often approaching an "argillio" horizon support the Seventh Approximation contention that leached Mazusterts tend to change towards Natrargids.

The solution of these problems is related and depends on further detailed research into the mechanisms of soil formations in Vertisols. Specifically, the relationships between soil texture, salinity, exchangeable sodium, surface structure and cracking and the Gezira climate with its effect on soil water movements require elaboration.

The scheme of soil classification adopted in the mapping is given in Table 5.12 and the frequency distribution of classified sites in Table 5.13.

Table 5.12 SOIL CLASSIFICATION CHART
U.S.D.A. 1960 SYSTEM

ORDER	SUBORDER	GREAT GROUP	SUBGROUP	FAMILY	SERIES	
2. VERTISOLS (Cracking clays)	2.2 USTERTS (Drier climatic range)	2.21 GRUMUSTERTS (Self-mulching surface)	2.210 ORTHIC GRUMUSTERTS (Non-alkali; E.S.P. less than 15 in top 30 cm.)	1. 35-50% clay	V. 1. Saline (E.C. exceeds 4 mmhos in top 30 cm.) 2. Non-saline (E.C. less than 4 mmhos in top 30 cm.) 3. Saline 4. Non-saline	
			2.220 ORTHIC MAZUSTERTS (Non-alkali)	1. 35-50% clay 2. Over 50% clay	5. Saline - not found in Area 1 6. Non-saline - mapped with V2 in Area 1 7. Saline - not found in Area 1 8. Non-saline - mapped with V4 in Area 1	
			2.22 MAZUSTERTS (Crusty surface)	NATRARGIDIC MAZUSTERTS (Alkali; E.S.P. exceeds 15 in top 15 cm.)	3. 35-50% clay 4. Over 50% clay	9. Saline 10. Non-saline 11. Saline 12. Non-saline

(continued)

Table 5.12 (continued)

SOIL CLASSIFICATION CHART
U.S.D.A. 1960 SYSTEM

ORDER	SUBORDER	GREAT GROUP	SUBGROUP	FAMILY	SERIES
1. ENTISOLS	1.3 USTENTS	1.31 PSAMMU- STENTS	1.31-9 ORTHIC PSAMMUSTENTS	1. 0-5% clay	E. 1. Not found in Area 1 2. Non-saline, non-alkali
				2. 5-15% clay	
		1.32 ORTHUSTENTS	1.320 ORTHIC ORTHUSTENTS	1. 15-25% clay	3. Saline and/or alkali
2. 25-35% clay	4. Non-saline, non-alkali 5. Saline and/or alkali 6. Non-saline, non-alkali				
			1.322-2 VERTIC ORTHUSTENTS	1. More than 40% clay	

Table 5.13 - Frequency distribution of Soil Series
at All Sites in Area 1

SOIL SERIES NO.	NUMBERS OF SITES	PERCENTAGE OF TOTAL
V.1	29	3
V.2	211	21
V.3	38	4
V.4	206	21
V.6	4	*
V.8	1	*
V.9	85	8
V.10	132	13
V.11	47	5
V.12	117	12
E.2	5	*
E.3	15	1
E.4	22	2
E.5	42	4
E.6	57	6
E.7	1	*
TOTAL	1,012	100

* Less than 1 percent.

5.14 Profile Development

The climate of the Gezira is hot and dry. Annual evaporation is over 2 m., almost ten times the rainfall. Profile development is, thus, in the "Aridosol" direction. The following main trends in profile development have been noted:

I In the Vertisols (soils with over 35 percent of clay)

(1) At the immediate surface, there is a strong tendency to form a granular mulch of aggregated clay particles everywhere except where surface water accumulated sufficiently to form a 1-2 cm. crust with bleached kankars and quartz grains embedded in it.

(2) Vertical cracks usually extend to at least 50 cm., although they are frequently obscured at the surface by vegetation or dust mulch. They are most conspicuous in low places where moisture had been greatest before drying out and in recently harvested dura fields, especially towards their wettest corners where the dura plants must have accounted for much of the desiccation.

(3) There tends to be an increase in clay percentage, salinity and exchangeable Na in the second horizons due almost certainly to leaching. Sampling was insufficiently refined to determine the exact depths of clay, salt and exchangeable sodium maxima respectively. The

content of all three fell again slightly in the subsoil. Full data on these trends are given later in this chapter.

(4) Subsoils, especially on land not used for rain dura, tend to be indurated and very hard to dig or bore. Whether this is due to chemical cementation or only physical compaction is unknown.

(5) There is a very characteristic colour change down the profile. The top horizon, usually about 50 cm. thick, tends to be dark brown (usually 10YR 3/2, 3/3 or 4/2). This rests on a dark grey horizon (10YR 3/2 or 3/1), usually 50-100 cm. thick, which in turn overlies a yellowish-brown deep subsoil. The layers are not sharply divided and deep tongues of the surface brown soil penetrate the grey layer. The explanation of the colour succession is still uncertain. It has been suggested (Finck, 1961) that the brownness of the surface soil may be due to micro-organic oxidation and dehydration of iron compounds under conditions of aeration and intense seasonal desiccation, while the greyness of the subsoil may be associated with the higher humus content, and more stable, damp, saline, anaerobic conditions. The presence of fossil soil profiles may also help explain this higher organic matter at depth, the yellow-brown subsoil and the distribution of kankars mentioned below.

(6) CaCO_3 was usually found throughout the profiles, mainly as small, hard, blackened kankars in the top 40 cm. or so but then as white concretions, increasing in size downwards to a maximum of 5 percent or so at about 1 m. They usually decreased in quantity below about 150 cm. and the fine kankars reappeared towards 2 m. This rather suggested the presence of a buried soil below 1.5 m. or so.

(7) Gypsum is common, but less so than carbonate. It almost never appears at shallower depth than 50 cm. and is usually less than 3 percent or so of the soil material, rarely rising to 5 percent. Its maximum concentration tends to be at greater depth than that of CaCO_3 - usually below 1 m.

Nowhere, however, is horizonation sufficiently marked to remove the Vertisols into another soil order. The general pattern is only one of modification by mild leaching of clay, salts, alkali, gypsum and carbonates to variable accumulation zones generally between 50 and 200 cm. in depth.

II In the Entisols

Where these soils are original river flood deposits, forming low dunes (qoz), they have been subjected to considerable reworking by wind action which has interfered with their profile development. Because, however, they are the soils with less than 35 percent clay, they are more permeable and so respond more actively to the limited leaching. The following profile features have been noted:

- (1) A fairly smooth, uncracked surface, often with a slight crust.
- (2) A slight textural B horizon. The 50-100 cm. soil zone generally has several percent more clay than the 0-50 cm. zone.
- (3) Generally lower salinity than in the Vertisols; it reaches its maximum concentration at lower depths - usually below 1 m.
- (4) Exceptionally high exchangeable sodium at all depths. The values are even higher than those in the Vertisols and are thus probably associated with the greater leaching of soluble salts from the surface layers and the smaller reserves of free CaCO₃ in the soil material.

5.2 PHYSICAL CHARACTERISTICS OF THE SOILS

Four qualities are considered under this heading: texture, hydraulic conductivity, structure and consistency.

5.21 Texture

Texture is one of the most distinct characteristics of Area 1. It is mainly a plain of heavy clays with occasional small sandy areas.

Mechanical analyses were done in the laboratory. Sand percentages range mainly between 25 and 50 percent and silt (.002-.05 mm.) between 5 and 20 percent. Clay ranged between extreme values of 78 percent (R143 = 120-150 cm.) and 7 percent (L250 = 90-165 cm.) for individual horizons, but mainly fell between 40 and 60 percent.

Table 5.211 shows the mechanical analyses averaged by horizons for the seven Sample Areas. Caution should be used in interpreting these figures as they are averages from fifteen pits in each Sample Area (eleven pits in Sample Area 5), but they are sufficient to indicate the main trends and, as they are evenly distributed over the whole of Area 1, they are roughly representative of it and its surrounds.

Table 5.211- Texture and Depth Distribution in the Sample Areas

	SAMPLE AREAS (From North To South)							MEAN
	1	2	3	4	5	6	7	
<u>Top Horizons</u>								
Bottom Mean Depth (cm.)	31.3	33.4	32.6	28.9	40.7	33.5	27.8	32.3
% S.	49.8	39.3	35.8	41.1	56.1	40.1	34.9	41.9
% Si.	6.6	12.5	9.9	12.3	6.3	9.6	10.0	9.7
% C.	43.6	48.2	54.3	46.6	37.6	50.3	55.1	48.4

Table 5.211- Texture and Depth Distribution in the Sample Areas
(continued)

	SAMPLE AREAS (From North To South)							MEAN
	1	2	3	4	5	6	7	
<u>Second Horizons</u>								
Bottom Mean Depth (cm.)	103.3	104.1	86.3	78.3	110.1	86.4	73.1	90.9
% S.	38.0	31.4	31.5	34.9	52.2	35.3	30.2	35.6
% Si.	10.7	11.1	13.8	11.9	7.9	10.1	10.1	10.9
% C.	51.3	57.5	54.7	53.2	39.9	54.6	59.7	53.5
<u>All Lower Horizons</u>								
Bottom Mean Depth (cm.)	176.3	195.1	171.5	156.7	185.0	182.1	184.0	177.6
% S.	46.7	28.7	32.7	37.7	51.4	35.8	26.4	35.6
% Si.	10.8	16.5	10.6	12.2	8.3	11.1	10.9	12.6
% C.	42.5	54.8	56.7	50.1	40.3	53.1	62.7	51.8

The general picture in Area 1 can be seen from the column of mean values. If all three horizons of all Sample Areas are averaged together, it appears that the average mechanical composition of the top 177.6 cm. of soil is 36.7 percent sand, 11.6 percent silt and 51.7 percent clay.

Despite variability between the Sample Areas and between individual sites in each, it can be seen that there is generally a top major horizon ending at about 30 cm. and a second one ending at about 90 cm.

Although the seven Sample Areas are listed in the table according to geographical location from north to south, the differences between them in soil texture are not really significant and are dominated by whether or not an individual Sample Area contained dunes.

All Areas agree in having a higher clay content in the second than in the top horizon, and all but Sample Areas 3 and 7, which are on the heaviest clay soils, show a decrease in the third horizon. The silt fraction remains moderately constant throughout, though the overall average shows a slight increase down the profile to the bottom. The sand fraction everywhere quite abruptly decreases from the top to the second horizon, remaining relatively constant below.

It is hard to tell whether this pattern of textural change down the profile is due to pedogenetic or to surface geological effects. The former seems more likely though both probably operate. Normal profile development would tend to destroy the silt fraction most quickly and to move clay down the profile. This has probably been locally

affected, especially in Sample Areas 4 and 5, by surface accumulations of windborne sand, but on the whole it is possible to infer a general tendency to the formation of a "textural B" horizon which is nowhere sufficiently developed to qualify as an "argillic" horizon.

A comprehensive analysis was made of the topsoil sample depths and clay percentages for the whole of Area 1. Nine hundred and sixty-one topsoil samples were considered. Their average depth was 47.4 cm. and their average clay percentage was 46.3. As the clay percentage in the presently irrigated Gezira Scheme is 50 to 60 percent (Jewitt, 1955), it will be seen that this Area has a markedly coarser texture.

Breaking this down according to the nine 1/50,000 scale Map Sheets into which the Area is divided, yields the following diagram:

(The mean depths over which these values were assessed are not included to avoid confusing the table, but they were as follows:

Sheet 11: 48.92 cm.	Sheet 20: 46.57 cm.	Sheet 35: 48.06 cm.
Sheet 12: 44.03 cm.	Sheet 27: 46.98 cm.	Sheet 36: 49.61 cm.
Sheet 19: 44.86 cm.	Sheet 28: 49.70 cm.	Sheet 37/45: 42.83 cm.

Table 5,212 - Distribution of Topsoil Clay Percentages by Map Sheets

11	12	19
41.4 (140 sites)	45.6 (36 sites)	43.5 (193 sites)
20	27	28
49.6 (51 sites)	48.7 (131 sites)	52.2 (85 sites)
35	36	37/45
41.1 (32 sites)	46.0 (241 sites)	55.5 (52 sites)

Within the Area there is at least as marked a decrease in clay percentage westwards as northwards. It should be remembered that most of the qoz lie on Sheets 35 and 36 and that they strongly depress the mean values. Otherwise there can be seen a very pronounced decrease in clay from south-east to north-west. On Sheets 28 and 37/45 the fine soil series of the Vertisols are dominant; elsewhere the coarser soil series. As dunes are very infrequent on both Sheet 11 and Sheet 37/45, the difference in clay content suggests a marked difference in the character of the Vertisols between the extremities of the Area. Whereas in the north the coarser textures are due probably to admixture of sands and silts from the surrounding and shallowly underlying Tertiary land surface, in the south-west they are due to relatively recent flood sediments from the Blue Nile.

5.22 Hydraulic Conductivity

This is closely related to texture. The method for making field tests of soil hydraulic conductivity was outlined in Chapter 4. Results are listed below in ascending order of percentage clay of the soils on which they were done.

Of the 52 tests made, 15 results had to be regarded as useless. Thirteen tests (at sites C105, C106, C108, C109, C111, C222, E102, L108, L109, M101, M102 (2) and R104) were nullified by losing water down hidden cracks, at one test (L109) the hole collapsed and at one test (C104) the height of test section was less than ten times the radius of the hole.

Table 5.22 - Hydraulic Conductivity in Relation to Soil Texture

TEST NO.	% SAND	% CLAY	FIELD TEXTURE	HYDRAULIC CONDUCTIVITY m/day/unit Gradient	
C108B	26	13	C	0.041)	
L105	61	26	SCL+C+VfSL	0.024)	
C101B	(60)*	(27)	fSCL	Nil	Mean for 0-49% C 0.028 m/day
C112	49	40	C	0.029)	
R101	52	41	SiC+fSCL+CL	0.032)	
M103	45	43	C	0.033)	
L101	48	46	SiL	0.028)	
R105	46	46	C	0.011)	
C101A	40	50	C	1.148)	
C115	37	50	C	0.034)	
C116A	35	50	C	0.111)	Mean for 50-54% C 0.142 m/day
R104B	(10)	(50)	(SiC)	0.028)	
R102B	32	51	CL	0.012)	
R108	42	52	SC+C	0.014)	
M106	38	52	C	0.008)	
R102A	36	53	SiC+CL	0.026)	
M108	32	53	C	0.028)	
R106	32	54	SiC-SiCL	0.010)	
L107	34	55	SiCL	0.016)	Mean for 55-59% C 0.080 m/day
C110	30	55	C	0.073)	
L103A	36	56	SiC	0.035)	
C104	33	56	C	0.112)	
M104	36	58	Heavy C	0.008)	
C102	34	58	C	0.305)	
C116B	22	58	C,SiCL	0.012)	
M107	32	59	C	0.003)	

Table 5.22 - Hydraulic Conductivity in Relation to Soil Texture

(continued)

TEST NO.	% SAND	% CLAY	FIELD TEXTURE	HYDRAULIC CONDUCTIVITY m/day/unit Gradient	
L104	(20)	(60)	C	0.006)	
C226	(20)	(60)	Heavy C	1.960)	
M105	33	61	C+CL	0.004)	
C109B	30	61	C	0.013)	
E103	28	61	C	0.064)	Mean for 60-64% C 0.234 m/day
C103	28	61	C	0.026)	
C107	27	61	C	0.143)	
R103	26	62	C	0.089)	
R107	30	64	CL-C+CL	0.025)	
L106	26	64	SCL	0.009)	
C117	24	67	C	0.030)	Mean for over 64% C 0.019 m/day
L103B	30	68	C	0.008)	

* Brackets indicate that figures are assumed from the field texture as no laboratory data is available.

It can be seen from the percentages of clay that practically all the tests were done on Gezira clay soil. The three sites with less than 40 percent clay also gave very low readings. Most of the higher readings are almost certainly due to water escaping into the ubiquitous cracks, and this probably also explains why no direct correlation can be seen between hydraulic conductivity and percentage clay. All that can be said is that the great majority of the reasonable values fall between 0.5 and 10 cm./day.

If the two obviously unreasonable values from C101A and C226 are neglected, the average for the rest is 0.041 m./day on an average clay percentage of 53. This could perhaps be taken as a rough value for the clay soils of Area 1, whose overall average clay percentage was given above as 46.3.

5.23 Structure

Few quantitative measurements were made of soil structure and so reliance must be placed on qualitative field assessments. There are marked structural differences between Vertisols and Entisols.

5.231 Vertisols

These are dominated by their tendency to crack deeply from the surface, forming parallelepiped aggregates separated by slickensides especially in the heaviest clays at depth. Cracking appears to be most intense in the heaviest clays especially where vegetation (notably dura) increases the evapotranspiration draft on soil moisture. On the whole the structural distinction between Grumusterts and Mazusterts outlined in the Seventh Approximation appears in the Gezira except that high exchangeable sodium values are frequently found in soils which have a loose, self-mulching surface soil.

The Grumusterts tend to have the following structure profile when dry:

0-1 cm.: A thin surface crust usually polygonally cracked, trampled and broken but thickly strewn with small, rounded, black kankars.

1-3 cm.: Loose, granular mulch of fine aggregates with some kankars. In detail, the aggregates become coarser downwards and merge into:

3 cm. to 30-50 cm.: A horizon with much vertical cracking. The cracks are often obscured from the surface by the fine material but are visible in profile. They usually are 2-4 cm. wide at the surface, forming a 30-60 cm. network and becoming finer downwards to disappear at 50-60 cm. The soil material itself is blocky, varying between angular and subangular, and there is a definite and steady increase in size and decrease in strength downwards from very fine to medium or coarse, and from strong to weak.

Below 30-50 cm.: A massive subsoil zone which is almost completely uncracked or with only occasional very fine cracks.

Well developed profiles of Mazusterts are so rare in the Area that it is hard to get a definite picture of their normal structure profile. No clear structural differences could be seen between the Orthic and Natrargidic subgroups especially as the latter seemed to contain so many profiles which would have been considered Grumusterts but for their high E.S.P.

The characteristic "mazic" (crusty) surface was occasionally seen, though it is not certain that it is always in "mayaas" (large, shallow depressions) or where there is more surface water. The "mazic" differs from the "grumic" surface in having a slightly thicker and harder platy surface crust, though this is still generally not more than 1 cm. thick, and some bleaching of the tops of the small, quartz kankars and quartz fragments which lie on the surface. The distinction between Orthic Grumusterts and Orthic Mazusterts depends on these surface differences alone and, as they were found hard to make and seem to be less relevant to local agriculture than the diagnostic differences at family and series level, the cognate series of the two subgroups were mapped together (e.g. V2 with V6 and V4 with V8).

No clear and consistent distinction between the subsoil structures of Grumusterts and Mazusterts has been recognized.

5.232 Entisols

These tended to be of three types - the qoz soils of the southwest, the clay mounds, and the normal loamy soils in the north.

Neither the qoz soils nor those on the clay mounds have a structure profile. All coarse textured layers tend to be structureless and crumble to single grain. In this way the aggregated granules which form the clay mounds behave just like sand. Fine textured layers on the qoz and fine textured substrata under all wind-blown deposits, however, tend to be massive.

The normal loamy soils in the north, which resemble the clay plain except for having less than 35 percent clay, are generally massive throughout. Their tendency to salinity reduces cracking

chemically while the thorn vegetation cover and absence of cultivation reduces the potential transpiration draft and thus reduces cracking physically.

5.24 Consistency

This is usually a direct reflection of soil texture and moisture, though salinity also has some effect.

The soils were almost invariably dry near the surface and almost dry or only slightly moist at depth, so considerations of the stickiness and plasticity of wet soil never arose.

The Vertisols tended to become harder or firmer down the profile, being soft in the top 2-3 cm. and becoming very hard or firm below about 50 cm. Below 100 cm., however, the slight increase in subsoil moisture usually had the effect of making them slightly more friable. The profiles with dry subsoils, however, usually remained very hard or extremely hard to 2 m.

Among the Entisols, the qoz and clay mound soils were generally dry and soft, becoming slightly hard or hard below about 50 cm. The Orthustents of the northern plain, however, show the same transition from soft to very hard or firm consistency with depth as do the Vertisols.

5.3 CHEMICAL CHARACTERISTICS OF THE SOILS

5.31 Salinity

Salinity was measured as electro-conductivity (E.C.) on saturation extract in millimhos/cm. at 25°C. It was the only analysis carried out on all of the 3,026 samples taken in the Area.

These results have been analysed and E.C. has been related to geographical distribution and depth. Again, it is necessary to emphasize that this statistical treatment has not been subjected to tests of significance due to lack of time but that the results should be regarded only as general indications of probable trends.

Altogether 2,894 samples were considered; 943 of these were topsoils, 954 second horizons and 997 third and lower horizons. The following table summarizes the relationship of salinity to depth for Area 1.

Table 5.311 - Overall Salinity (E.C.) in Area 1

MEAN SAMPLE DEPTH (cm.)	AVERAGE E.C.
0- 47.4	2.65
47.4-106.0	5.81
106.0-175.1	4.83
Weighted mean: 0-175.1	4.44

The general pattern is one of a non-saline top half-metre becoming slightly saline in the second half-metre with a slight drop in the second metre. There appears thus to be a definite leaching process at work enriching the second half-metre and, to a certain extent, the deeper subsoil at the expense of the top half-metre. The overall mean of 4.44 represents a salt percentage of 0.28 if multiplied by a conversion factor of 0.064.

The following table shows the distribution of values according to the nine Map Sheets.

Table 5.312 - Depth Distribution of Salinity by Map Sheets

SHEET NO.	TOP HORIZONS		SECOND HORIZONS		LOWEST HORIZONS		ALL HORIZONS WEIGHTED MEAN.
	DEPTH cm.	E.C.	DEPTH cm.	E.C.	DEPTH cm.	E.C.	E.C.
11	48.92	4.67	102.45	8.04	167.72	6.29	6.37
12	44.03	3.89	104.95	5.49	169.28	3.66	4.38
19	44.86	3.25	109.92	6.62	177.31	5.47	5.12
20	46.57	2.63	113.80	5.53	190.81	4.37	4.17
27	46.98	2.34	103.47	6.55	156.02	5.02	4.70
28	49.70	2.21	114.37	6.33	175.31	5.81	4.76
35	48.06	1.59	113.94	4.36	187.26	3.28	3.08
36	49.61	1.67	102.42	4.13	180.92	3.91	3.27
37/45	42.83	1.28	98.87	3.37	190.80	3.54	2.80

The differences in horizon depths between Map Sheets are not significant and reflect not only horizons but also the sampling policy of the individual soil surveyors. The differences in salinity are, however, highly suggestive. When the salinity values are considered in relation to the location of the Map Sheets it can be seen that there is a steady increase in salinity from south-east to north-west. The overall average on Sheet 11 is more than double that on Sheet 37/45. This is visible at all depths, but is most marked towards the soil surface. The Sheets 35, 36 and 37/45 all have less than half the top-soil salinity found on Sheets 11, 12 and 19, and the extreme contrast is shown between Sheets 11 and 37/45, the former having over three times the salinity of the latter.

Furthermore, the proportional increase with depth is greater in the south than in the north and has a deeper maximum. On Sheets 11 and 12 the second horizons have less than double the salinity of the topsoils while in the southern Sheets 35, 36 and 37/45 they have almost treble. The intermediate sheets are transitional in character. On Sheets 11, 12, 19 and 20 the third horizon is considerably less saline than the second but in the south this tendency seems somewhat less marked, until in Sheet 37/45 the maximum is in the bottom layer.

These data show that salinity decreases, and the depth to its maximum accumulation in the profile increases, from north-west to south-east in the Area.

On the whole, Entisols tended to be lowest in salinity, Mazusterts intermediate and Grumusterts highest, as might be expected from the greater permeability of Entisols and the subjection to surface water of the Mazusterts.

5.32 Composition of Soluble Salts

Thirty-nine analyses were done to determine the ionic composition of these soluble salts. Each showed a very wide range of values, as can be seen from Appendix 1. The following table is an attempted simplification by averaging the 14 Entisol samples and the 25 Vertisol samples together. It has no statistical significance and only indicates order of magnitude.

Table 5.32 - Composition of Soluble Salts

	ANIONS meq./litre				CATIONS meq./litre			
	CO ₃	HCO ₃	Cl	SO ₄	Na	K	Ca	Mg
Vertisols	1.0	12.7	11.6	24.8	38.8	0.2	5.5	3.7
Entisols	0.4	15.4	33.0	14.9	30.6	16.4	17.0	14.5
MEAN	0.8	13.7	19.2	21.3	35.9	6.0	9.6	7.6

Sodium composes about two-thirds of the cations whereas chloride and sulphate are about equally important and form about three-quarters of the anions. The high potassium in the Entisols is due mainly to one site near an old village (C222), and this high potassium cannot be considered typical. Neither is it typical that Entisols contain more soluble salts than Vertisols, but certain contrasts between the two soil orders are suggestive.

Whereas more than half the salts in the Vertisols are sodium sulphate, the Entisols are dominated, though far less exclusively so, by sodium chloride, and have relatively much greater amounts of the alkaline earths.

5.33 Exchange Capacity and Exchangeable Cations

5.331 Exchange Capacity

Considerable difficulty was experienced in measuring this, as the table appended with the laboratory analyses shows. In the end it was concluded that the safest method was to base it on a summation of the exchangeable cations.

Although there is considerable variation from sample to sample, there is a general confirmation that percentage clay is a good general guide to exchange capacity. Of the 39 samples on which exchangeable cation determinations were made from all varieties of texture, the average clay was 39.3 percent and the average summation of exchangeable cations was 39.6 meq./100 g. soil.

5.332 Exchangeable Cation Composition

Thirty-nine analyses of exchangeable cation composition were carried out. Fourteen were on 4 Entisol profiles and 25 were on 7 Vertisol profiles. There is enormous variation in values obtained between sites and horizons. Ca is usually, but not always, dominant, Na second in importance, Mg third and K fourth. Averages can be little more than suggestive but the following table shows them for these two soil orders.

Table 5.332 - Exchangeable Cations

	%C	EXCHANGEABLE CATIONS meq./100 g.				CATION EXCHANGE CAPACITY (SUMMATION) meq./100 g.
		Na	K	Ca	Mg	
Entisols (E3 and E4 Soils)	33.6	3.6	4.6	22.0	5.0	35.2
Vertisols (V2, V4, V10, V12 and Vertic Orthustents)	42.5	11.7	0.6	24.1	5.5	42.0
MEAN	39.3	8.8	2.1	23.4	5.3	39.6

The dominance of Ca is emphasized but the importance of exchangeable sodium, especially in the Vertisols, and of exchangeable magnesium everywhere is brought out. The high value for exchangeable K in the Entisols is due to one of the profiles being on an old village site which probably had much organic waste.

The importance of exchangeable sodium makes it desirable to give it a section to itself.

5.333 Exchangeable Sodium

This was the only exchangeable cation on which many analyses were done because of its great importance to soil permeability and thus soil fertility. Very few analyses were done of deeper layers, but those that were done on samples from the first 50,000 feddans of Managil Phase V, Part I, Area in the south-east show a marked increase with depth from a value of 7.52 m.e./100 g. in the 101 topsoils to 9.03 in the 217 subsoils to give an average of 8.55 in subsoil horizons. Individual values ranged from 1.09 to 14.73.

A comprehensive analysis of top horizons was, however, made by Map Sheets and this is shown in the following table.

Table 5.333 - Exchangeable Sodium by Map Sheets

MAP SHEET	NO. OF SAMPLES	AVERAGE HORIZON DEPTH	AVERAGE % CLAY	AVERAGE EXCHANGEABLE SODIUM m.e./100 g.	ASSUMED ESP FROM CEC=% CLAY
11	134	0-48.9	41.4	8.48	20.48
12	17	0-44.0	45.6	11.42	25.04
19	166	0-44.9	43.5	6.41	14.71
20	51	0-46.6	49.6	6.84	13.79
27	98	0-47.0	48.7	6.66	13.68
28	84	0-49.7	52.2	8.25	15.80
35	19	0-48.1	41.1	7.08	17.23
36	217	0-49.6	46.0	6.89	14.98
37/45	33	0-42.8	55.5	7.37	13.28
TOTAL WEIGHTED MEANS	819	0-47.4	46.3	7.28	15.72

A rough general increase from south-east to north-west is visible, but the trend is less clear than it was for salinity values. Sheets 12 and 35 probably average too few values to give very meaningful results.

As an exchangeable sodium percentage of over 15 is considered limiting agriculturally, the overall mean of 15.72 is serious. Its close approach to the limiting value underlines the importance of making E.S.P. calculations correctly. Cation exchange capacity is considered to be 1 m.e. per 1 percent clay and the percentage clay is normally taken to be the C.E.C. Large deviations from this basis could make a difference in the overall assessment of the Area.

5.34 pH

pH determinations on 1:5 suspension were made on 399 samples and on saturated paste on 110 samples; 340 of the former were in the Sample Areas. They are well distributed over the project area and are analysed in the table below. The usual caution applies to using it as no test of statistical significance has been applied.

Exchangeable sodium tends to increase northward...
 Thirty-nine analyses were done, 15 on 7 Vertisol pits, and 14 on 14 Entisol pits. They ranged from a maximum of 12.3 percent CaCO₃ in one of the former to a minimum of 0.3 percent in one of the latter. The average value was 5.45 percent, being 5.75 percent in Vertisols and 4.33 percent in Entisols. On the whole these values did not increase with depth, so it appears that the Area as a whole has a good reserve of carbonates in case acid soil amendments are used. It appears to be chemically too inert, however, to arrest the alkalinizing evident in so much of the desert.
 No analyses were made of gypsum. It tends to be present in smaller quantities and at greater depths than the carbonates, and so

Table 5.34 - pH in Sample Areas by Depth (1:5 suspension)

SAMPLE AREA	MAP SHEET	FIRST HORIZONS		SECOND HORIZONS		LOWER HORIZONS		ALL DEPTHS MEAN pH
		MEAN BOTTOM DEPTH (cm.)	MEAN pH	MEAN BOTTOM DEPTH (cm.)	MEAN pH	MEAN BOTTOM DEPTH (cm.)	MEAN pH	
1	12	31.3	9.5	103.3	9.3	176.3	9.4	9.4
2	19	33.4	8.8	104.1	8.7	195.1	8.9	8.8
3	19-27	32.6	9.2	86.3	8.9	171.5	9.0	9.0
4	27	28.9	9.0	78.3	8.7	156.7	8.9	8.9
5	35	40.7	9.5	110.1	9.4	185.0	9.4	9.4
6	36	33.5	9.2	86.4	9.3	182.1	9.0	9.2
7	37/45	27.8	9.4	73.1	9.3	184.0	9.0	9.2
MEAN		32.3	9.2	90.9	9.1	177.6	9.1	9.13

The overall average for all depths is 9.1 and there is a slight tendency for pH to fall slightly below the top horizon to a constant level. Mean pHs of the Sample Areas range from 9.4 to 8.8, but no clear geographical trend is discernible in their distribution.

pH does, however, show opposite trends to those of salinity, and probably reflects the close interrelation of the two values. pH maxima are generally in the surface horizons with minima in the second horizons, except in Sample Areas 6 and 7 in the south where minima are only reached in the lower horizons.

pH values on saturated paste are almost invariably lower, reflecting the effect of exchangeable sodium.

Exchangeable sodium tends to increase northwards and downwards in profiles, but pH shows no consistent geographical change and, if anything, tends to be at a maximum in the topsoils.

5.35 Calcium Carbonate and Gypsum

Calcium carbonate was abundantly visible in most profiles, usually in kankars near the surface and as white concretions at depth.

Thirty-nine analyses were done, 25 on 7 Vertisol pits, and 14 on 4 Entisol pits. They ranged from a maximum of 12.3 percent CaCO₃ in one of the former to a minimum of 0.38 percent in one of the latter. The average value was 5.46 percent, being 5.75 percent in Vertisols and 4.93 percent in Entisols. On the whole these values did not much decrease with depth, so it appears that the Area as a whole has a good reserve of carbonate in case acid soil amendments are used. It appears to be chemically too inert, however, to arrest the alkalization evident in so much of the Gezira.

No analyses were made of gypsum. It tends to be present in smaller quantities and at greater depths than the carbonate, and so

would be a less reliable reserve for soil amendment even if more easily exploitable.

5.36 Phosphate

This was determined on an HCl extract in 39 analyses and reported as phosphate in mg./100 g. soil. Values do not vary much between profiles or depths and the Entisols, rather surprisingly, have as much phosphate as do the Vertisols. In fact the minimum value recorded was 15 mg./100 g. soil in the topsoil of the same Entisol profile that had the highest recorded value of 100 mg./100 g. in the second horizon.

The average in the 25 samples of the 7 Vertisol sites was 51.2 mg./100 g. soil and in the 14 samples from 4 Entisol sites was 49.7 mg./100 g. of soil, giving an overall figure of 50.7. It should be remembered that HCl extractable phosphate by no means necessarily represents what is available to plant roots, but the analyses indicate good reserves of phosphate.

5.37 Potassium

This was determined on the HCl extract from the same 39 samples as used for the phosphate determinations. Levels were uniformly high, varying from a minimum of 125 to a maximum of 2,140 mg./100 g. soil, but except in the old village site all values were under 700 mg./100 g. soil.

The overall average was 470 mg./100 g. soil, being 350 in the Vertisols and 685 in the Entisols, though this last figure should be treated with reserve. On the whole, it is clear that potassium levels are abundantly adequate for high fertility.

5.38 Organic Carbon

This analysis was done on the same 39 samples. Results were fairly uniform between sites and at different depths at the same site. The highest value recorded was 1.5 percent on a surface soil and the lowest 0.12 percent on the second and third horizons of the same Vertisol profile.

Averaging values by depth and soil order gives the following rough table.

Table 5.38 - Organic Carbon Percentage by Horizon and Soil Order

	TOP HORIZONS	SECOND HORIZONS	ALL LOWER HORIZONS	MEAN
Vertisols	0.61 (7)	0.76 (7)	0.40 (11)	0.56
Entisols	0.62 (4)	0.65 (4)	0.62 (6)	0.63
MEAN	0.61	0.72	0.48	0.58

The figures in brackets give the number of observations. The lack of difference between soil orders and the uniformity with depth are remarkable.

LAND CLASSIFICATION

The average figure of 0.58 is lower than desirable for agricultural use and demonstrates the poverty of these soils in organic matter.

5.39 Organic Nitrogen

The uniformity of these values, done on the same 39 samples, is notable. The minimum was 0.010 percent and the maximum was 0.078 percent, but the great majority of values fall about mid-way between these two extremes. Averaged by depth and soil order they give the following table.

Table 5.39 - Organic Nitrogen Percentage by Depth and Soil Order

	TOP HORIZONS	SECOND HORIZONS	ALL LOWER HORIZONS	MEAN
Vertisols	.034 (7)	.028 (7)	.025 (11)	.028
Entisols	.038 (4)	.045 (4)	.027 (6)	.035
MEAN	.036	.034	.026	.031

As with carbon, the uniformity with depth is remarkable in all soils. The relatively higher values in the Entisols is probably due to the better natural vegetation cover they carry.

An average of 0.030 percent is, however, much lower than is desirable for high fertility. If the average nitrogen value is related to that of carbon, a C/N ratio of almost 19 is obtained. As 11 is considered normal in good humic soils, the nitrogen deficiency here is evidently even greater than that of organic carbon.

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 Area 1 these policies were observed. Class 3 was not used (although its definition is given below for the sake of completeness), but Class 4 was used to identify sandy and "pod" soils which, whilst not being totally unusable, will demand a specialized irrigated agriculture quite different from that on the Gessira clays.

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

CHAPTER 6

LAND CLASSIFICATION

6.1. 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 V, Irrigated Land Use, 1951.

The objective of the soil survey and land suitability classification was 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 Gezira (Managil) Extension Scheme. 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, thereby showing the boundaries of the irrigable areas.

6.2. 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 uses. Class 5 is land needing further investigation, and Class 6 is permanently non-arable.

The observation density used on the project was approximately one 2 m. bore per 500 feddans with every fiftieth to 3m. 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 Area 1 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 identify sandy and "qoz" soils which, whilst not being totally unusable, will demand a specialized irrigated agriculture quite different from that on the Gezira clays.

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, minimum 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 for 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 fertilization, or more extensive soil improvement practices. They may have uneven topography, moderate to high concentration of salines 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 probably 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 drains. 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.

6.3. GENERAL CONSIDERATIONS DETERMINING LAND CLASS IN AREA 1

The following sections outline the criteria used in determining land classes. These criteria were adopted after full discussions about soils and the agronomy and economics of climatically adapted crops with the Director and officers of the Department of Agriculture's Research Division at Wad Medani. In this way the U.S.B.R. system of land classification was adjusted where necessary for satisfactory application under Sudan conditions.

6.31 Topography.

Area 1 is a flat, level, open plain without rocks or stones, and with so few trees or shrubs that clearing and development costs would be negligible. The only topographic features influencing land class are the low sand dunes (qoz) in the south and small, windblown mounds of aggregated clay particles in parts of the centre and north. The qoz rise to a maximum height of 2.3 m. but are generally barely perceptible above the plain.

The clay mounds, however, are locally a limitation, downgrading land which would otherwise be Class 2 to Class 3 because of the cost of levelling the land where they occur. Their presence is indicated by postscripting the letter "t" after land classes 3 or 6.

6.32 Soil Profiles

The main land class determinants are soil profile characteristics. In addition to the distinguishing 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 Area 1 reaches the standards quoted above as requisite for Class 1 land.

DISTRIBUTION AND CHARACTERISTICS OF THE LAND CLASSES

Class 2 is therefore the best land. It comprises every topographically level soil whose potential productivity is not further limited by clay contents less than 50%, alkali or salinity. These limitations are indicated respectively by the postscripts "l", "a" and "s" written after the land class. If the combination of these limitations is not serious enough to make the land non-arable, it becomes Class 3. Otherwise it is downgraded to Class 6. Class 4 is specifically reserved for lands whose only limitation is soil texture coarser than 35 percent clay. Clay contents of less than 50% are regarded as limiting because of the establishment by Finck of a positive correlation between the clay content of Gezira soil and yield of long staple cotton. This correlation has not been established for other climatically adapted crops but, because long staple cotton would be the chief cash crop of the project area and yields would be depressed on such soils, they have been down-graded in the land classification.

6.4. DETAILED CRITERIA FOR LAND CLASSIFICATION IN AREA 1

Table 6.4 gives the exact criteria used in determining the land classes of individual sites. The failure to meet any condition of a given land class automatically assigns a site to the next lower class. Class 6 includes all sites which fail to qualify for a higher land class. The postscripts t, l, a and s are used only for Classes 3 and 6.

TABLE 6.4

CRITERIA FOR DETERMINING LAND CLASSES IN AREA 1

	LAND CLASS		
	2	3	4
<u>SOILS LIMITATIONS</u>			
Texture (% Clay) (l)	Over 50	Over 35	Over 5
Exchangeable Sodium, Percentage (a)	Less than 15 to 90 cm.	Less than 15 to 60 cm. 20 to 90 cm.	Less than 15 to 50 cm. 20 to 100 cm.
E.C.(millimhos/cm. at 25°C.) (s)	Less than 4 to 60 cm. 6 to 90 cm.	Less than 4 to 30 cm. 8 to 90 cm.	Less than 4 to 50 cm. 8 to 100 cm.
<u>TOPOGRAPHIC LIMITATIONS</u>			
Windblown dunes of sand or aggregated clay (t) Height		1-2½ metres	Less than 2.5 metres.
% of Land Surface covered		10-25%	Less than 25%

6.5. DISTRIBUTION AND CHARACTERISTICS OF THE LAND CLASSES

Class 2 land is flat, level plain with soil containing over 50 percent of clay and lacking harmful accumulations of salts or alkali.

36,400 Feddans have been thus mapped, mainly concentrated towards the south eastward, constituting 8 percent of the total. They are composed of Orthic Grumusterts and Orthic Mazusterts - Soil Classes V4 and V8. With the type of irrigation regime practised in the Gezira, there should be no need of drainage, and the water table is deep enough (about 40 metres) not to present a problem.

Class 3 land. Class 3 land is flat, level clay plain which has all the requirements of Class 2 land except that the surface 30 cm. of soil has less than 50 percent of clay. The importance of high clay percentage to productivity has been pointed out by Finck and Ochtman (1961). Class 3 land tends to be concentrated in the south, to the west of the best lands but east of the lands near the White Nile which are coarser and saltier. It includes some Orthic Grumusterts and Orthic Mazusterts (Soil Groups V2 and V6).

Class 3a lands are rare and include those occasional sites which fail to qualify as Class 2 because their E.S.P. lies between 15 and 20 in the 60 to 90 cm. soil zone. They include some Orthic Grumusterts and Orthic Mazusterts (V4 and V8 soils).

Class 3la lands are likewise rare and are limited by a topsoil texture of less than 50 percent clay and an E.S.P. of between 15 and 20 in the 60 to 90 cm. soil zone. They include some Orthic Grumusterts and Orthic Mazusterts (V2 and V6 soils).

Class 3s lands. These are lands whose limitation is an E.C. of between 4 and 8 in the 30 to 60 cm. soil zone and/or 6 and 8 in the 60 to 90 cm. zone. They include some Orthic Grumusterts and Orthic Mazusterts (V4 and V8 soils).

Class 3ls lands. These are lands limited by texture of less than 50 percent clay in the top 30 cm. and an E.C. of between 4 and 8 in the 30 to 60 cm. zone and/or between 6 and 8 in the 60 to 90 cm. zone. They include some Orthic Grumusterts and Orthic Mazusterts (V2 and V6 soils).

Class 3as lands. These are lands limited by an E.C. of between 4 and 8 in the 30 to 60 cm. soil zone and/or between 6 and 8 in the 60 to 90 cm. soil zone. They include some Orthic Grumusterts and Orthic Mazusterts (V4 and V8 soils). E.S.P. > 15

Class 3las lands. These are Class 3 lands with the maximum possible soils limitations. Textures are less than 50 percent clay in the top 30 cm; E.C. is between 4 and 8 in the 30 to 60 cm. zone and/or between 6 and 8 in the 60 to 90 cm. zone; E.S.P. is between 15 and 20 in the 60 to 90 cm. zone.

Classes 3t, 3lt, 3at, 3st, 3lat, 3lst, 3ast and 3last are land classes as given above and also suffering a topographic limitation due to the presence of aggregated clay mounds 1-2½ metres high which cover 10-25 percent of the land surface. They consist entirely of Orthic Grumusterts or Orthic Mazusterts (V2, V4, V6 and V8 soils).

Class 4 land. This class has been used specifically to include the sandy soils of the low undulating "qoz" which are strung out in a rough S.E.-N.W. direction across the south and central part of the project area. They almost certainly represent old flood deposits from a temporary course of the Blue Nile which rounded the northern end of the Managil ridge and entered the White Nile south of Jebel Auliya.

In order to be Class 4, these lands must have between 5 and 35 percent clay, an E.C. of under 4 and an E.S.P. of under 15 in the top 50 cm. of the profile. The topography must be even enough not to preclude irrigation development, so if dune formations are present they must be less than 2.5 metres high and occupy less than 25 percent of the land surface.

Class 4 indicates usefulness for special purposes. It is considered that these sandy soils while not suitable for cotton would produce good horticultural crops, ground nuts and perhaps sugar cane if carefully irrigated.

Class 6 lands. These are considered to be unsuited to irrigation in their present state due to one or a combination of the following deficiencies: high salinity or high alkalinity, sometimes combined with coarse texture and/or uneven topography.

As no soil in the project area has less than 5 percent clay, which is the only textural reason it could be degraded to Class 6, and as nowhere do mounds or dunes over 2.5 metres high cover more than 25 percent of the surface, Class 6 designation depends on salinity and alkali conditions alone. The l and t subscripts are, however, retained to show a contributory Class 3 type textural or topographical limitation at a site which has been downgraded to Class 6 because of salinity or alkali conditions.

Class 6a lands. These are lands whose limitation is an E.S.P. of over 15 in the top 60 cm. and/or over 20 in the 60 to 90 cm. layer. They consist of Natrargidic Mazusterts (V12 soils) and some Orthic Grumusterts and Orthic Mazusterts with alkaline subsoils (V4 and V8). It is considered that their physical condition, due to high exchangeable sodium, will be such that they are unsuited to irrigation.

Class 6s lands. These are lands whose non-irrigability is due to an E.C. in the surface soil of over 4 and/or in the 30 to 90 cm. layer of over 8. They comprise some of the Orthic Grumusterts and Orthic Mazusterts (V3 and V5 soils).

Class 6as lands. These are non-irrigable because of having both an E.C. in the surface soil of over 4 and/or in the 30 to 90 cm. layer of over 8 and an E.S.P. in the topsoil of over 15 and/or an E.S.P. in the 60 to 90 cm. layer of over 20. They comprise some of the Natrargidic Mazusterts (V11 soils).

Class 6la lands. These lands have topsoil textures with less than 50 percent clay and an E.S.P. of over 15 in the top 60 cm. and/or over 20 in the 60 to 90 cm. layer. They include some of the Natrargidic Mazusterts (V10 soils).

Class 6ls lands. These lands have less than 50 percent clay in the top 30 cm. of soil and an E.C. of over 4 in this same layer and/or an E.C. of over 8 in the 30 to 90 cm. layer. They include some Orthic Grumusterts and some Orthic Mazusterts (V1, V2, V5 and V6 soils).

Class 6las lands. These lands combine limitations of coarse texture, salinity and alkali. At least one of the two latter are too serious for the land to be considered as Class 3. They therefore have less than 50 percent clay in the top soil combined with

- (a) Class 6 salinity and Class 3 exchangeable sodium percentages, or
- (b) Class 3 salinity with Class 6 exchangeable sodium percentages, or
- (c) salinity and exchangeable sodium percentages both of which are Class 6.

They comprise some Natrargidic Mazusterts (V9 and V10 soils).

Class 6at, 6st, 6ast, 6lat, 6lst, 6last. These land classes are defined as above except that all suffer the additional limitation of having aggregated clay mounds more than 1 metre high and covering more than 25 percent of the land surface.

6.6. AREAS OF LAND CLASSES.

Table 6.6. shows the area in feddans of the different land classes in Area 1.

TABLE 6.6.

Land Class	Area, Feddans	Percentage of Total
2	36,400	8
3	137,000	30
4	26,200	6
6	262,000	56

In October, 1962, the consultants received from the Chief Pedologist of the Ministry of Agriculture a map showing the area to be covered by semi-detailed survey which was a gross project area of about 608,000 feddans. Another plan submitted by the Ministry of Irrigation and Hydro-Electric Power (S.I.P. Plan No. 63/1962) gave a gross area of 463,000 feddans.

At meetings in Khartoum on 6th and 5th December between the consultant and the client the boundary of the project area was agreed and a map prepared showing the limits of the area to be surveyed. It was estimated that the gross area, after exclusion of 13,000 feddans in the Khartoum Green belt and 13,000 feddans of low ground S.E. of Nile Station, was about 386,000 feddans. To this was added an area of about 26,000 feddans of land in the south which lay within the original boundary of the Chief Pedologist and which had been surveyed prior to 6th December. The gross area thus became about 412,000 feddans. When the survey was completed and the area carefully measured, it was found that the gross area surveyed was about 461,600 feddans.

7.2. INTERIM REPORTS ON PART OF THE PROJECT AREA

At a meeting on 5th December, 1962, the client requested advance information as to the suitability of soils in 30,000 feddans of land described as Masgila Phase 2, Part 1, which is being reclaimed during the 1962-63 season.

On 31st December the consultants produced a preliminary assessment of this land, based on full field data but limited laboratory data. The provisional method of classification used the following criteria:-

CHAPTER 7

PLANS FOR IRRIGATION DEVELOPMENT

7.1. THE MANAGIL (GEZIRA) EXTENSION, FIFTH PHASE.

The Ten Year Plan of Economic and Social Development, 1961/62 to 1970/71, envisages the completion of Part II of the Fourth Phase of the Managil Extension and the undertaking of the Fifth Phase. The 1962 Report of the Economic Planning Secretariat, Ministry of Finance and Economics, states:- "The Plan envisages the completion of Part II of the Fourth Phase of the Managil Extension and undertaking of the Fifth Phase. The additional area that will be brought under cultivation as a result of the completion of Part II of Phase IV is about 90,000 feddans. The Fifth Phase of the Managil Extension involves the excavation of a branch canal for utilizing initially the surplus stored water from Khashm el Girba and then from Roseires Dam when completed, and the development of 200,000 feddans. Total investment on Managil Extension is LS. 14.2 million. The project is an extension of the Gezira Scheme and will be operated and maintained on the same lines and practices as that of the adjoining Gezira. Cotton and dura will be grown in a three course rotation, providing greater employment and opportunities to labourers and tenants besides increased revenue to the Government".

The lands referred to above as the Managil Extension, Fifth Phase, are described in the contract as approximately located between latitude $14^{\circ} 30' N$, and $15^{\circ} 30' N$. and longitude $32^{\circ} 30' E$. and $33^{\circ} 00' E$; it was considered that the semi-detailed soil survey would cover a gross area of about 350,000 feddans in order to select a net irrigable area of 200,000 feddans, if available.

In October, 1962, the consultants received from the Chief Pedologist of the Ministry of Agriculture a map showing the area to be covered by semi-detailed survey which gave a gross project area of about 608,000 feddans. Another plan submitted by the Ministry of Irrigation and Hydro-Electric Power (S.I.D. Plan No. 62/13093) gave a gross area of 463,000 feddans.

At meetings in Khartoum on 6th and 8th December between the consultant and the client the boundary of the project area was agreed and a map prepared showing the limits of the area to be surveyed. It was estimated that the gross area, after exclusion of 15,000 feddans in the Khartoum Green belt and 13,000 feddans of low ground S.E. of Baqeir Station, was about 386,000 feddans. To this was added an area of about 28,000 feddans of land in the south which lay within the original boundary of the Chief Pedologist and which had been surveyed prior to 6th December. The gross area thus became about 414,000 feddans. When the survey was completed and the area carefully measured, it was found that the gross area surveyed was about 461,600 feddans.

7.2. INTERIM REPORTS ON PART OF THE PROJECT AREA.

At a meeting on 6th December, 1962, the client requested advance information as to the suitability of soils in 50,000 feddans of land described as Managil Phase 5, Part 1, which is being canalized during the 1962-63 season.

On 31st December the consultants produced a preliminary assessment of this land, based on full field data but limited analytical data. The provisional method of classification used the following criteria:-

	<u>Good Soil</u>	<u>Moderate Soil</u>
E.C.	Under 4 mmhos to 1 metre	Under 4 mmhos to 50 cm.
Exchangeable Sodium	Under 7.5 m.e.% to 1 metre	Under 7.5 m.e.% to 50 cm.

Using these criteria the soils were provisionally classified as follows:-

	<u>No. of Sites</u>	<u>Nominal Area in Feddans</u>
Good Soil	10	5,000
Moderate Soil	41	21,000
Bad Soil	50	25,000
<u>Total</u>	<u>101</u>	<u>51,000</u>

It was considered that good soil (roughly equivalent to U.S.B.R. land class 2) would yield well under irrigation, that moderate soil (roughly equivalent to U.S.B.R. land class 3) would be worth irrigating but would not yield a large return and that bad soil would almost certainly not yield economic returns without using costly amendment procedures. The preliminary soil assessment map (Drawing No. S.M.7) showed that the soils become progressively worse to the north of the area examined.

On receipt of this interim report the client decided to use only 25,000 feddans of good and moderate land in the southern part of Phase 5, Part 1, and urgent request was then made to the consultants to produce a preliminary soils assessment of about 71,500 feddans of land to the west of the original area to try and locate 25,000 feddans of suitable land for canalization to substitute for the northern part of Phase 5, Part 1, which had mostly bad soil.

On 29th January, 1963, the consultant produced a revision of the preliminary assessment of the first 50,000 feddans of Managil Phase V, Part 1, and a preliminary assessment of a further 71,500 feddans of adjacent land to the westwards. The revision was based mainly on a re-calculation of the exchangeable sodium data; the exchangeable sodium percentage (E.S.P.) was estimated on the basis of clay content which gives a reasonable measure of cation exchange capacity. The criteria used were as follows:-

	<u>Good Soil</u>	<u>Moderate Soil</u>
E.C.	Under 4 mmhos to 1 metre	Under 4 mmhos to 50 cm.
E.S.P.	Under 15 to 1 metre	Under 15 to 50 cm.

Using these criteria the soils were provisionally classified as follows:-

Phase V, Part 1

	<u>No. of Sites</u>	<u>Nominal Area in Feddans</u>
Good	15	7,500
Moderate	45	22,500
Bad	42	21,000
<u>Total</u>	<u>102</u>	<u>51,000</u>

Western Area

	<u>No. of Sites</u>	<u>Nominal Area in Feddans</u>
Good	46	23,000
Moderate	55	27,500
Bad	<u>42</u>	<u>21,000</u>
<u>Total</u>	<u>143</u>	<u>71,500</u>

As a result of this report the client was able to redesign the canal system to command rather less than 50,000 feddans of good and moderate soils by the following modifications:-

- (i) Extension of Huda major to serve an additional 8,000-10,000 feddans of land to the north of the present Managil boundary.
- (ii) Inclusion of the area north of Km. 44.5 on the branch canal up to latitude 14° 45' north.
- (iii) The minor canal on the branch canal south of Km. 44.5 to be excavated through to the drain line, but Abu XX to be omitted in areas of bad soils.
- (iv) Major canals Nos. 3 and 4 with oftakes at Km. 44.5 to be included in the canalization.
- (v) Minor canal No. 10 to be omitted from the area south of Km. 44.5 pending receipt of final report.

During discussions with the client on 23rd February, 1963, the Director of Agriculture raised the question of whether it was justifiable to develop the moderate soils when there were large areas of good soils not yet developed in other parts of the Sudan. The Permanent Secretary, Ministry of Irrigation and Hydro-Electric Power, pointed out that capital costs of canalisation were low in the Gezira extension whereas they would be much higher for new areas. For the consultants, Dr. R. Smith stressed that the preliminary soils classification was based on physical characteristics only and that if economic factors were also considered then the moderate soils would probably be upgraded to some extent because of the favourable location of the new lands and the low capital cost of extending the canal system.

This discussion was continued further in Khartoum and Wad Medani. The discussions were summarized by the Chief Pedologist in a letter to the Director of Agriculture on 3/3/1963 as follows:-

"We fully agree with the criteria used for classifying the soils as 'good', 'moderate' and 'bad' in the preliminary assessment provided one realises that such a classification is a general one with no reference to any specific crop such as cotton.

"Dr. Finck's productivity studies (1958 - 1960) in the Gezira revealed that there is a positive correlation between the clay content of the soil and cotton yield levels. This correlation seems to be confirmed by the cotton yields in the Managil.

"In the 'further 71,500 feddans' of Phase V the clay content of the soil appears to be appreciably lower (average top soil 44%, average sub soil 31%; maximum top soil 59%, maximum sub soil 53%) than in the first 51,000 feddans of Part I, Phase V (average top soil 54%, average sub soil 57%; maximum top soil 66%, maximum sub soil 84%). According to the above-mentioned clay yield correlation a clay content of 58% was found to correspond with

a relative cotton yield of 100%, i.e. the average Gezira cotton yield level. This would indicate that the 'good' land of the first 51,000 feddans is expected to give not more than an average Gezira cotton yield, whereas the 'good' land of the next 71,500 feddans is expected to produce only 65% of an average Gezira cotton yield (according to the regression curve of the clay-yield formula). The 'moderate' land may yield less in both cases since there salinity and alkalinity may have adverse effects as well.

"As I understood that cotton will still be the crop of major importance in this Phase V area you may wish to take the points raised above into consideration. Once more I should like to stress that the above limitation does not apply to crops in general; some crops may respond in a similar way as cotton whereas other crops may prefer lighter (more sandier) soils."

7.3. CORRELATION BETWEEN CLAY CONTENT OF SOIL AND YIELD OF LONG STAPLE COTTON.

The productivity studies carried out in the Gezira, 1958-1960, revealed that there is a positive correlation between clay content of the soil and yield of long staple cotton as described by Finck (1959, 1960a, 1960b), Finck & Ochtman (1961) and Ochtman (1960). This correlation was incorporated into the final land classification system adopted in this report (See Chapter 6). All non-saline, non-alkali soils containing from 35-50% clay were downgraded from Land Class 2 to Land Class 3 on the grounds that the yield of the main cash crop would be reduced to 40-75% of the average Gezira yield (about 4.5 Kantars per feddan).

7.4. RECOMMENDED CROPPING SYSTEMS AND WATER USE

7.4.1. Cropping Systems

The Managil Extension, Fifth Phase, has been designed to use the same basic cropping system as Managil, with long staple cotton as the chief cash crop. As described by Fadda & Kordofani (1961) the rotation practised is as follows:-

1st Year	Cotton
2nd Year	Lubia (Dolichos lablab)
3rd Year	Dura
4th Year	Fallow (resting)
5th Year	Cotton
6th Year	Fallow (resting)

Improvements within this basic rotation generally involve the substitution of a forage legume in place of one or both of the fallows. Research at the Gezira Research Station described by Ferguson (private communication) indicates that only the following general rotation pattern can be safely recommended:-

1st Year	Long term summer non-legume
2nd Year	Winter legume
3rd Year	Short-term summer non-legume
4th Year	Long term summer legume
5th Year	Winter non-legume
6th Year	Short term summer legume

The crops generally recommended for this rotation in the project area are: cotton, wheat, groundnuts, safflower, dura, lubia, phillipesara (forage legume) and clitoria (forage legume).

7.42 Water Use.

The irrigation system intended for use in the project area has been used in the Gezira for many years and has given reasonably satisfactory results. Cotton is watered by gravity once every 14 days in the dry period October to March. From sowing in mid-August to October the crop is given only light waterings, when necessary, to avoid flooding and waterlogging should irrigation be followed by heavy rain. Water consumption by this method has been estimated at 400-500 cubic metres per feddan per irrigation when measurement was made at the canal outlets, and at 300-325 cubic metres per feddan per irrigation when measured at the irrigated site. The difference is accounted for by evaporation losses and, to a small extent, by seepage and the occasional break in canal banks. Recent work, reported by Fadda & Kordofani, has established that 15% to 20% of the irrigation water given after the 1st January can be saved without loss of yield either by ceasing irrigation in the second half of February, or by prolonging the watering interval to three weeks in the January to March period.

Of the other crops recommended for the project area, the long term summer crops require an irrigation regime as for cotton. Short term summer crops require a regime as for dura, which is sown in July-August usually without prewatering, irrigated 3 or 4 times up to the end of October and harvested in November-December. Winter crops require a regime as for wheat which is sown in November on prewatered land, grown entirely on irrigation water applied at fortnightly intervals and harvested in March.

7.5. RECOMMENDED LIMITED IRRIGATION DEVELOPMENT IN AREA 1.

The results of the soil survey and land suitability classification survey of about 461,600 feddans show that over half the total area is not suitable for any form of irrigation development (Class 6 lands) and that a considerable area could only be considered suitable for specialized horticultural vegetable or pasture development (Class 4 lands). The original plan for the development of 200,000 feddans on a Managil type rotation must therefore be very considerably curtailed.

The following development procedure is recommended:-

7.51. The Managil Type Crop Rotation with long staple cotton as the chief cash crop should only be considered on Class 2 and Class 3 lands which together total 173,400 feddans.

7.52. Where sufficiently large blocks of Class 2 and Class 3 lands are located close to the existing canal system, an irrigation design to serve these lands should be drawn up. The cost of supplying these lands with water should be carefully estimated, together with other developmental costs, with a view to deciding if the expected crop yield would show a reasonable return on the invested capital. A provisional estimate of crop yields would be average Gezira yields from Class 2 lands and 65% of Gezira yields from Class 3 lands. If more precise information on expected crop yields is required, it is considered that this could be obtained from an economic study of crop yields from the Kab-el Gedad and Abdel Magid irrigated areas, combined with a semi-detailed soil survey similar to that carried out on the Area I lands.

7.53 When the engineering and economic studies have revealed how much land is suitable for development in Area 1, and the shortfall from 200,000 feddans has been calculated, then additional lands to be supplied by gravity from the existing canals could be investigated to the west and north west of the Managil irrigated lands. If the grand total of 200,000 feddans of suitable land can not be found, then consideration should be given to the development of Class 2 lands by pump projects in Areas 2, 3, 4 or 5 of the overall study area.

7.54 At some future time consideration should be given to the development of Class 3 and Class 4 lands of Area 1 for other types of crops and rotations e.g. grain farming combined with fodder crops in association with the Department of Animal Husbandry, or irrigated forest plantations in association with the Department of Forests, etc.