REPUBLIC OF KENYA

MINISTRY OF AGRICULTURE

Land Development Extension Division

Technical Study on Cost Estimates for four Rice Schemes in Nyanza Province

Valley Bottom Development in the Lake Victoria Basin

3. Soil Conditions

(Final report)

May 1982

NEDECO
Netherlands Engineering Consultants
The Hague The Netherlands

B.V. Infra Consult
Deventer
The Netherlands

Netherlands Soil Survey Institute
Wageningen
The Netherlands

A.F. van Holst
F. de Vries
J.J. Vleeshouwer

nedeco

This report is financed by the European Communities from credits of the European Development Fund and is presented by NEDECO for the consideration of the Government. It does not necessarily reflect either the opinion of the latter nor the Commission of the European Communities.

Netherlands Soil Survey Institute
Staringgebouw
Wageningen

Report no. 1617

VALLEY BOTTOM DEVELOPMENT

in the

LAKE VICTORIA BASIN

SOIL CONDITIONS

of

4 SMALLHOLDER RICE REHABILITATION SCHEMES

(final report)

A.F. van Holst
F. de Vries
J.J. Vleeshouwer

Wageningen, October 1981
May 1982

CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

A detailed soil survey was carried out by the Netherlands Soil Survey Institute in Nyanze Province, Kenya, in the period June-August 1981 at the request of Nedeco, B.V. Infra Consult, Consulting Engineers, Deventer.

This soil survey was done within the framework of the Study on Valley Bottom Development in the Lake Victoria Basin and deals with 4 smallholder Rice Rehabilitation schemes. Infra Consult B.V. received the assignment for this project from the Irrigation and Drainage Branch of the Ministry of Agriculture in Kenya.

The soil survey team consisted of Ir. A.F. van Holst (team leader), Ing. F. de Vries and Ing. J.J. Vleeshouwer (project leader).

Mr. L.M. Weide (B.V. Infra Consult) performed the field tests for the hydraulic conductivity.

The cooperation and assistance of the Kenya Soil Survey, of the National Irrigation Board, and of provincial and local authorities in the four areas is much appreciated. Special acknowledgement is due to Mr. F.N. Muchena (Head of Kenya Soil Survey), Mr. B.J.A. van der Pouw (Soil Survey Specialist of K.S.S.) and Mr. A.P.M. Bastiaansen (Provincial Irrigation Unit in Nyanza Province).

The Director

Ir. R.P.H.P. van der Schans.

Note:
At the request of Nedeco this report and the appendices were presented as a first draft in October 1981. After the acceptance of the report and the appendices by the Irrigation and Drainage Branch of the Ministry of Agriculture, Kenya, the final report and appendices were issued in May 1982.
The final maps were drawn by NEDECO from draft maps compiled by the Netherlands Soil Survey Institute.

SUMMARY

This report presents the results of the soil survey of four areas in the western part of Nyanza Province. Within the framework of the Study on the Valley Bottom Development, four smallholder rice rehabilitation schemes (total area of 760 ha) were investigated. The three areas located in the Kano Plain, viz. Wasare, Awach Kano and Kore, are part of an extended plain of lacustrine origin, that in places has been altered by fluvial activity. Two major physiographic units can be distinguished in these areas: alluvial plain and lacustrine plain. The soil maps are presented in Appendix VI.

Wasare area (163.5 ha) is characterized by stratified, often coarse-textured, fluvial material in the east, and by black, heavy lacustrine clay in the west. In the transitional zone, the clay is overlain by fluvial sediments of variable texture and thickness. Nine soil mapping units have been identified. Seasonal flooding is a common feature. Rice cultivation is restricted to a few irrigated parts of the area.

Awach Kano area (194 ha) mainly comprises a lacustrine plain with fine-textured clay. Stratified, fine-textured, fluvial sediments prevail along both branches of the Awach Kano river which border the area. Five soil mapping units have been distinguished. In places, seasonal floods have resulted in severe gully erosion.

At present no rice is grown because of the lack of irrigation water.

Kore areas (115.9 ha) mainly consist of black, lacustrine clay. Minor parts belong to the alluvial plain with fine-textured fluvial sediments over lacustrine clays. Only two soil mapping units have been identified. Both areas are almost completely devoted to rice cultivation.

Maugo area (286.3 ha), north of Homa Bay, consists of a 5 km long stretch along the Maugo river. The river valley, bordered by rhyolite hills, varies in width.

The lacustrine plain with black, lacustrine clay, forms the major part of the area. The alluvial plain - though smaller - is restricted to

areas bordering the river. It is composed of stratified, fine- and coarse-textured sediments, which are often underlain by lacustrine clay. Older alluvial sediments (terrace remnants) are also encountered.

The footslope, a small transitional area between the hills and the plain, consists of soils with a varied textural composition, in places shallow over rock.

Variations in salinity, lime content and sodicity of the soils have been distinguished. Sixteen soil mapping units have been identified. The area is subject to seasonal flooding to various depths. In places, severe gully erosion and regressive erosion occur. Only a small proportion of the extensive area that was irrigated in the past is at present in use for the cultivation of rice.

Suitability for irrigated rice

The soils have been classified for their suitability for small-scale irrigated rice. The criteria applied in the land suitability evaluation - valid for all four areas - are presented in Table 4.1. The classification involved appraising the soil and land qualities and subsequently assigning the soil mapping units to four major suitability classes, according to the severity of their limitations.

The results are as follows:

Suitability class	Wasare area		Awach Kano area		Kore areas		Maugo area	
	extent in ha	in %	extent in ha	in %	extent in ha	in %	extent in ha	in %
highly suitable (1)	81.5	49.8	145.5	75.0	105.2	90.8	196.8	68.7
mod. suitable (2c)	-	-	32.5	16.8	10.7	9.2	47.5	16.6
margin.suitable (3c)	22.0	13.5	16.0	8.2	-	-	-	-
margin.suitable (3t)	-	-	-	-	-	-	6.5	2.3
unsuitable (NSc)	60.0	36.7	-	-	-	-	13.0	4.5
unsuitable (NSrs)	-	-	-	-	-	-	2.5	0.9
unsuitable (NStd)	-	-	-	-	-	-	1.5	0.5
unsuitable (NStn)	-	-	-	-	-	-	18.5	6.5
Total area	163.5	100	194.0	100	115.9	100	286.3	100

Some 70% of all the soils are highly suitable. The major limitations of the class 2 and 3 soils concern texture, hydraulic conductivity and sodicity. The major limitations of the unsuitable soils are predominantly coarse textures and high hydraulic conductivities and to a lesser extent soil depth, soil reaction, salinity and slope.

1 INTRODUCTION AND SURVEY PROCEDURE

1.1 Structure of the report

This report proceeds from a general outline of the survey procedure (ch. 1.2) to a discussion of the general chemical and physical characteristics of the soils (ch. 2). The mapping of the soils is discussed in Chapter 3 and the method of assessing their suitability for the small-scale cultivation of irrigated rice is outlined in Chapter 4.

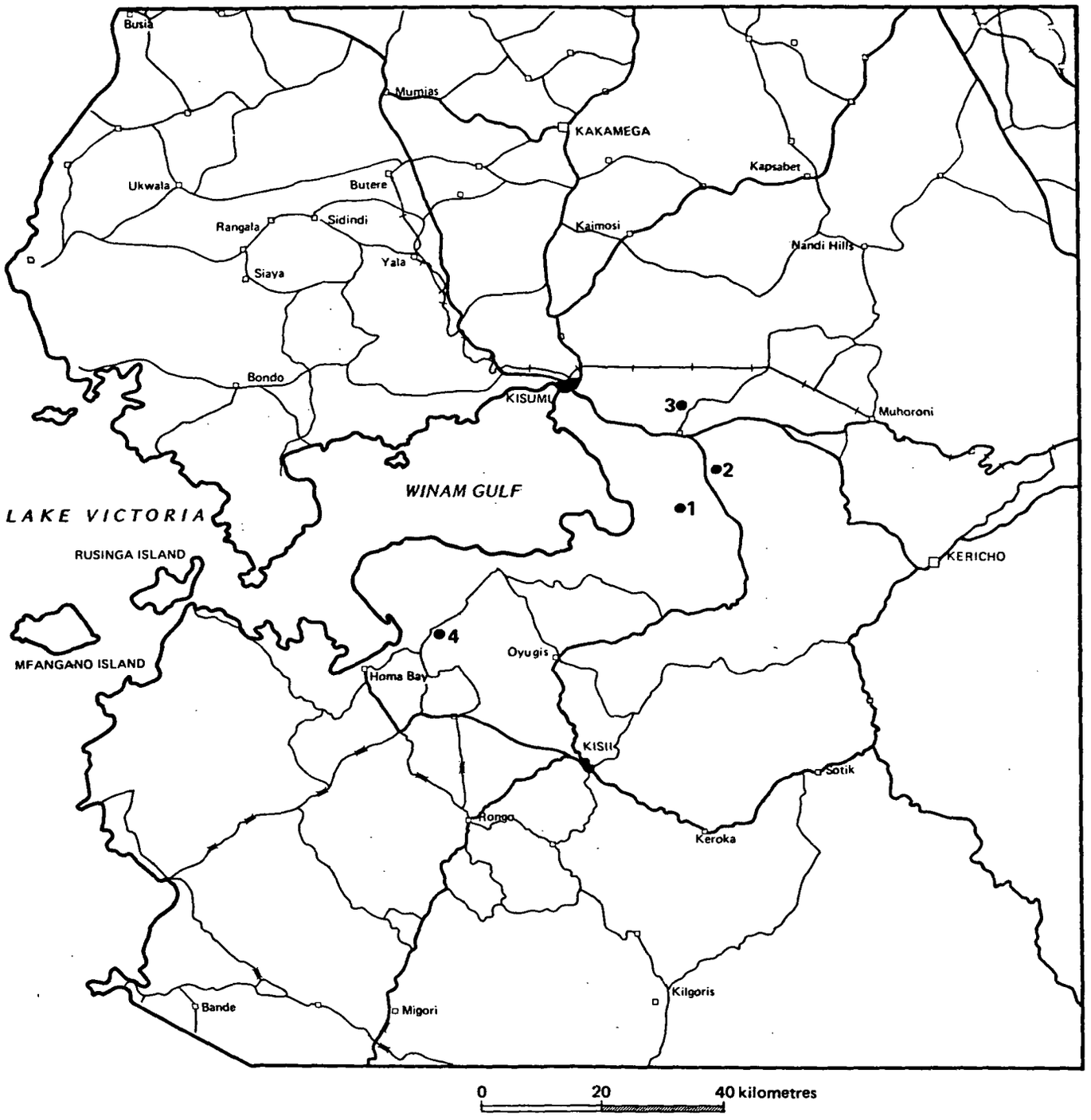
Chapters 5-8 deal with the individual areas. Each of these chapters has a similar layout: a general description of the physical characteristics of the area (geology, parent material, hydrology) and its present land use; a brief account of the general soil characteristics and soil classification; and then descriptions of the individual mapping units appearing on the appropriate detailed soil map. In the final chapter (ch. 9) the suitability of the land for the small-scale cultivation of irrigated rice is discussed, area by area.

There are six Appendices. Appendices I and II give details of the field and laboratory methods respectively, to supplement Chapters 1 and 2. In Appendix III the terminology used to characterize the physical and chemical properties of the soils is explained. Data from representative soil profiles from each area are presented in Appendix IV, and Appendix V gives data on field measurements of hydraulic conductivity and infiltration rate. Appendix VI comprises the detailed soil maps.

1.2 Survey procedure

1.2.1 Areas surveyed

In accordance with the terms of reference of the "Study on Valley Bottom Development in the Lake Victoria Basin" (K.S.S. 1981) the soil survey covered a gross area of 760 ha that was 20 per cent



1. Wasare
2. Awach Kano
3. Kore
4. Maugo

Fig. 1 Location of the surveyed areas

larger than the area of the 4 rice rehabilitation schemes. The 4 areas that were surveyed lie in the western part of Nyanze Province, near Lake Victoria (see Fig. 1). Further details of the individual areas are given in tabular form below:

Name of the area	Extent (ha)	District	Geographical designation	Sheet No. of Topo. map, scale 1:50 000
1 Wasare	163.5	Kisumu	Kano Plains	116/4 (Nyakach)
2 Awach Kano	194.0	Kisumu	Kano Plains	116/2 (Kisumu east)
3 Kore I and II	115.9	Kisumu	Kano Plains	116/2 (Kisumu east)
4 Maugo	286.3	South Nyanza	Kendu area	116/3 (Kendu Bay)
Total	759.7			

Most of the areas were reasonably accessible, except for the submerged parts of Kore I and II and the yam fields in the centre of the Maugo area that remained flooded during the period of the survey.

1.2.2 Procedures

The methods applied during the execution of the soil survey in June-August 1981 were according to and derived from:

- Standards for Soil Survey in Kenya (K.S.S. 1980)
- Guidelines for the soil surveys to be carried out within the frame-work of the "Study on Valley Bottom Development in the Lake Victoria Basin" (K.S.S. 1981).

The base maps used during the survey were at a scale of 1:2 500. They provided sufficient topographical detail (e.g. plot boundaries; number and location of benchmarks) for augerings and pits to be located accurately.

Aerial photography at scale 1:12 500 was available, although not in stereoscopic coverage. The scale, date (1970) and lack of stereoscopy of these photographs precluded their systematic use. Uncontrolled mosaics were prepared and used for general information and orientation.

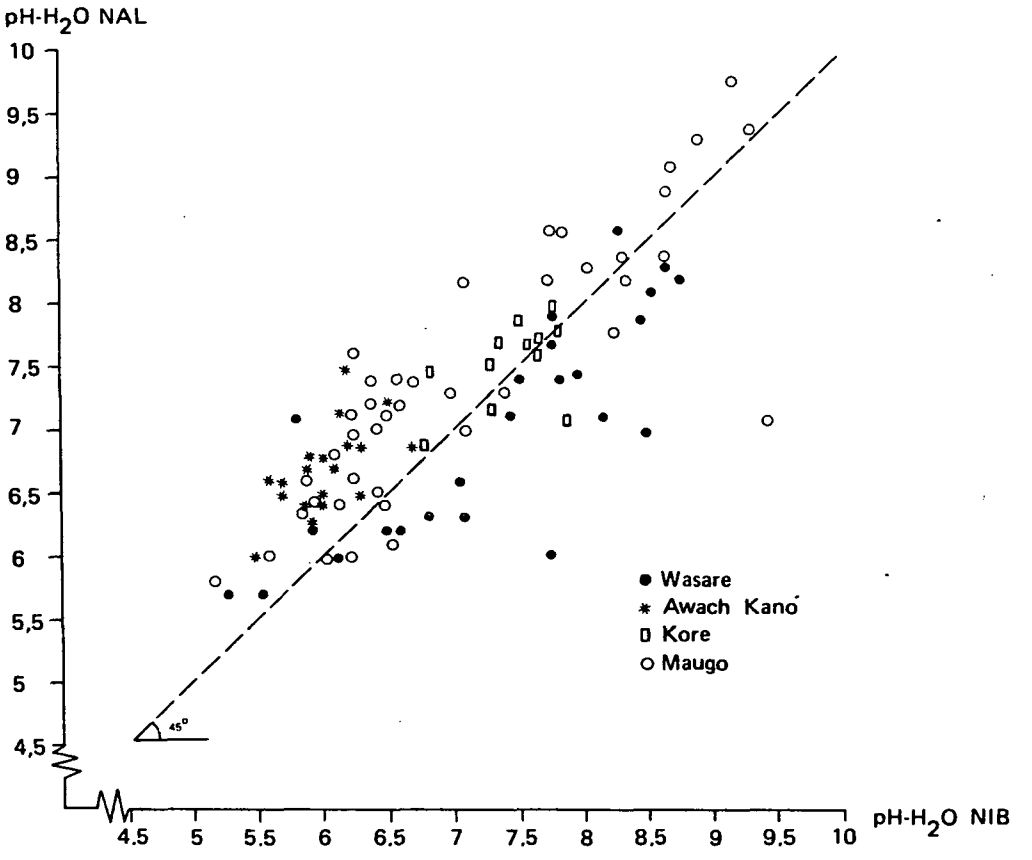


Fig. 2.1 Relation between pH-H_2O values as determined by the NAL and by the NIB laboratory

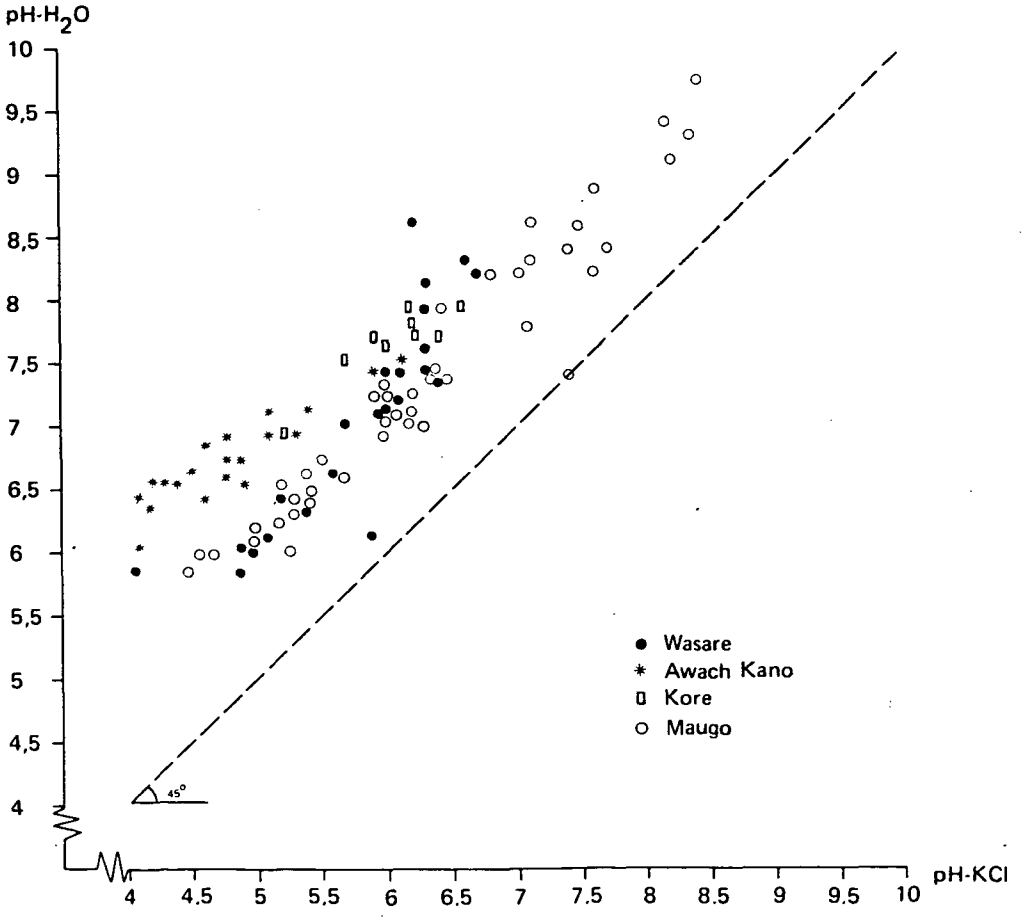


Fig. 2.2 Relation between pH-H_2O and pH-KCl values determined by the NAL from 99 samples

2 GENERAL CHEMICAL AND PHYSICAL PROPERTIES OF THE SOILS

2.1 Chemical properties

Data on soil reaction and soil salinity were compiled from 1750 samples collected during the soil survey in all augerings at four different depths and analysed in the National Irrigation Board laboratory (Ahero) and 99 samples collected from 17 profile pits representative of the major soil mapping units and analysed in the National Agricultural Laboratory (Nairobi).

2.1.1 Soil reaction

To enable the results from the two laboratories to be compared the data on soil reaction analysed by the NAL from the 99 were correlated with the corresponding data from the NIB laboratory (fig. 2.1). The narrow range of the slightly acid soils of Awach Kano and of the moderately alkaline soils of Kore contrast with the wide pH range of the Wasare and Maugo soils.

As figure 2.1 shows, the reaction of the Awach Kano, Kore and Maugo soils as determined by NAL differs by roughly ½ to 1 pH unit from that of the NIB data (note the 45^{o} line). The reaction of the Wasare soils reveals an opposite relation: the NAL data are ½ to 1 pH unit lower than those of the NIB laboratory. These minor shifts in pH remain predominantly within the class limits.

The relation between the pH-H_2O and pH-KCl values (NAL data from 99 samples) is given in fig. 2.2. The pH-H_2O is approximately 1 to 1½ unit higher than the pH-KCl.

2.1.2 Soil salinity

The electrical conductivity values of the 1:2.5 v/v soil samples, measured in the NIB laboratory, were used to determine the soil salinity.

Area	Observation (pit) No.	Depth in cm	Texture % < 0.002 mm	ECe mS/cm (NAL)	EC 1:2.5 v/v mS/cm (NIB)	Ratio ECe/EC 1:2.5 v/v
Wasare	3	160-170	78	1.15	0.70	1.64
Kore	1	130-150	64	2.15	1.02	2.11
	1	160-170	60	3.00	1.28	2.34
Kore	2	110-120	54	3.50	2.16	1.62
	2	150-165	52	2.60	1.02	2.55
	2	175-180	66	2.30	1.12	2.05
Maugo	3	50- 70	60	1.00	0.68	1.47
	3	95-115	56	1.50	0.76	1.97
Maugo	4	25- 35	68	1.60	0.116 [1]	13.8 [2]
	4	180-190	74	1.25	0.70	1.79
Maugo	5	8- 15	60	1.45	0.74	1.96
	5	25- 32	62	2.60	1.36	1.91
	5	45- 53	64	2.00	1.40	1.43
	5	65- 75	66	2.80	1.12	2.50
	5	95-110	72	3.00	1.92	1.56
	5	130-140	64	2.40	1.48	1.62
					Average ratio:	1.90

1) should probably be 1.16

2) should probably be 1.38

Table 2.1 Calculation of the ECe and EC (1:2.5 v/v) ratios

textural class \ hydraulic conductivity class (cm/day)	very slow (< 3)	slow (3 to 10)	mod. slow 10 to 20	moderate (20 to 40)	mod. rapid (40 to 80)	rapid (80 to 160)	very rapid (> 160)
fine clay	9	17	3	1	1		
clay	35 (2)	13 (2)	11	10	2		
clay loam	11 (2)	5 (1)	3 (1)	4			
loam							
sandy loam							2
sand							
stratified sand to clay			3	3	1		1

Table 2.2 Frequency distribution of hydraulic conductivity classes over the various textural classes, measured in non saline, moist or wet soils without distinct cracks (n = 135).
(2) Number of measurements in slightly salire layers (n = 8).

Textural class \ Infiltration rate class (cm/day)	very slow (< 1)	slow (1 to 10)	mod. slow (10 to 25)	mod. rapid (25 to 50)	rapid (50 to 100)	very rapid (> 100)	
heavy clay	6	4	1				
clay	10	4	5	4	2	2	
clay loam				3	1		
loam							
sandy loam		1			1		

Table 2.3 Frequency distribution of infiltration rate classes over the various textural classes, measured in moist or wet woils without distinct cracks (n = 44)

The EC (1:2.5 v/v) values are related to the ECe values (electrical conductivity of the extract of a saturated paste). See Table 2.1 for the calculation of the conversion factor.

For coarser-textured material a higher conversion factor should be used, but there were insufficient laboratory data to do this.

2.1.3 Soil sodicity

Sodic soils have more than 6% saturation with exchangeable sodium in some horizons within 100 cm of the surface (FAO-Unesco 1974). Based on the available laboratory data analysed at NAL and partly supported by the degree of dispersion observed in the samples analysed in the NIB laboratory, in some areas a sodic phase was distinguished. The sodicity of soils given in the legend and in the description of the mapping units is a rough indication only. A reliable differentiation would require laboratory determinations of the ESP values of many more soil samples.

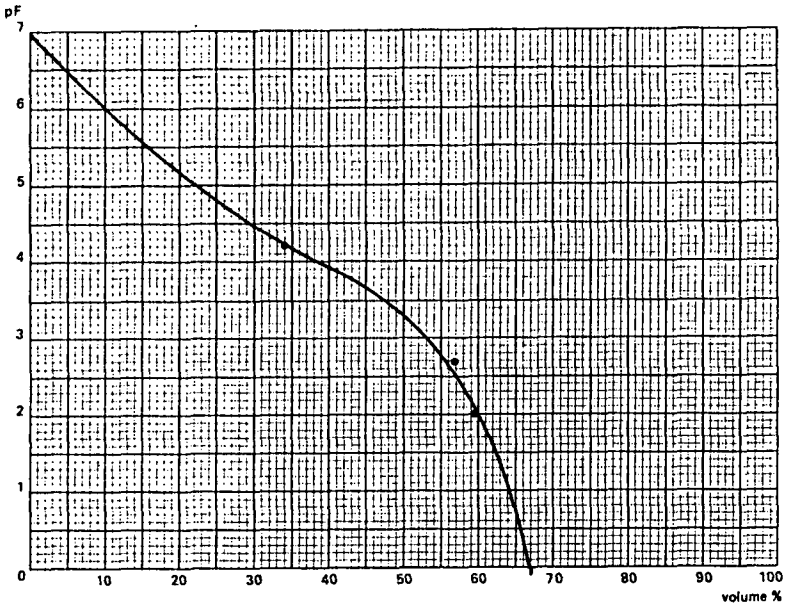
2.2 Physical aspects

All data and relevant information about depth, textural class and moisture conditions, are presented in Appendix V.

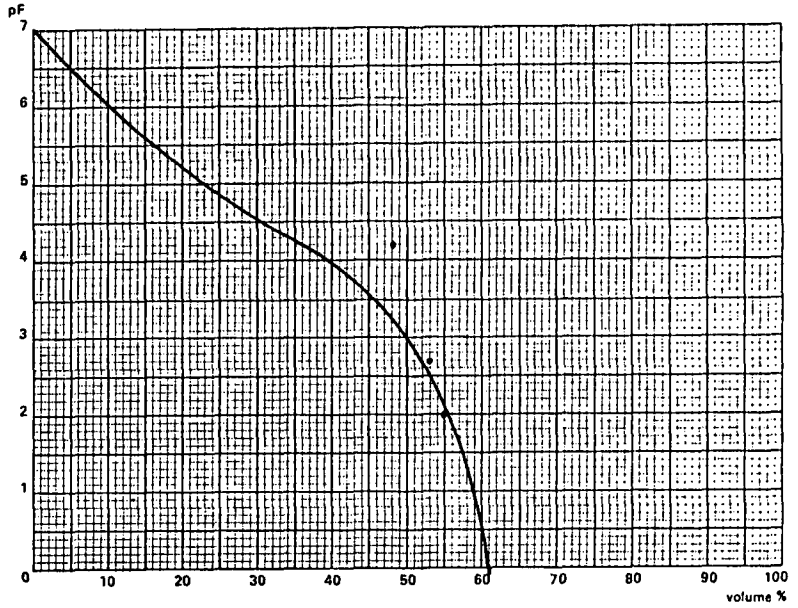
2.2.1 Hydraulic conductivity

To show the relation between textural class and hydraulic conductivity, the frequency distribution of both parameters was plotted. Data from wet or moist soils were used. Soils with distinct cracks were excluded. A total of 135 combinations which fulfil these requirements, was plotted (Table 2.2). Eight combinations with slightly saline properties are shown in parenthesis. As the results show, clay and heavy clay predominantly had a very slow to slow hydraulic conductivity. The hydraulic conductivity of clay loam ranged from very slow to moderate.

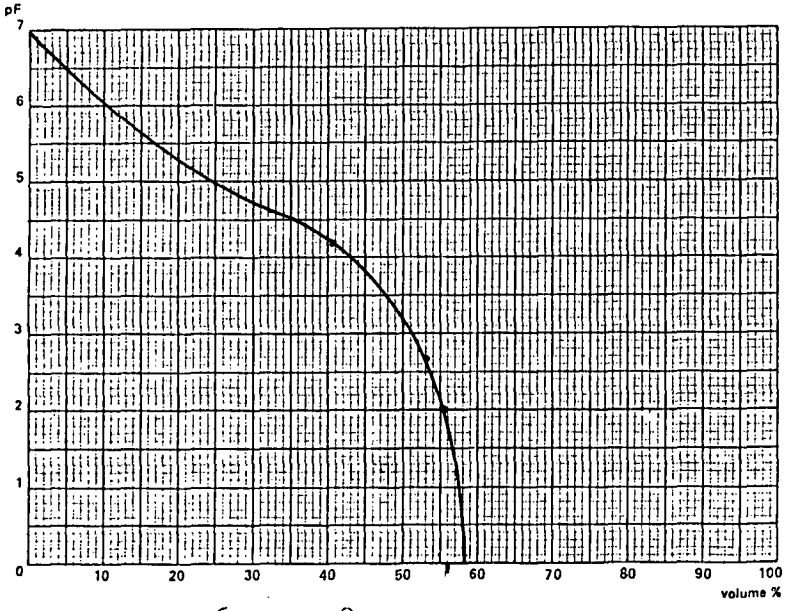
Fig. 2.3a Moisture retention curves



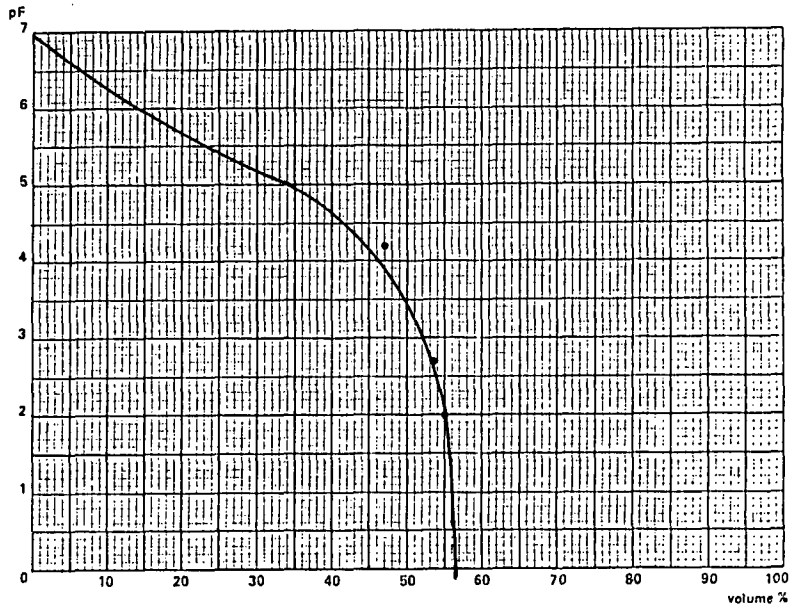
Wasare No. 3 5 - 10 cm



Wasare No. 3 30 - 35 cm



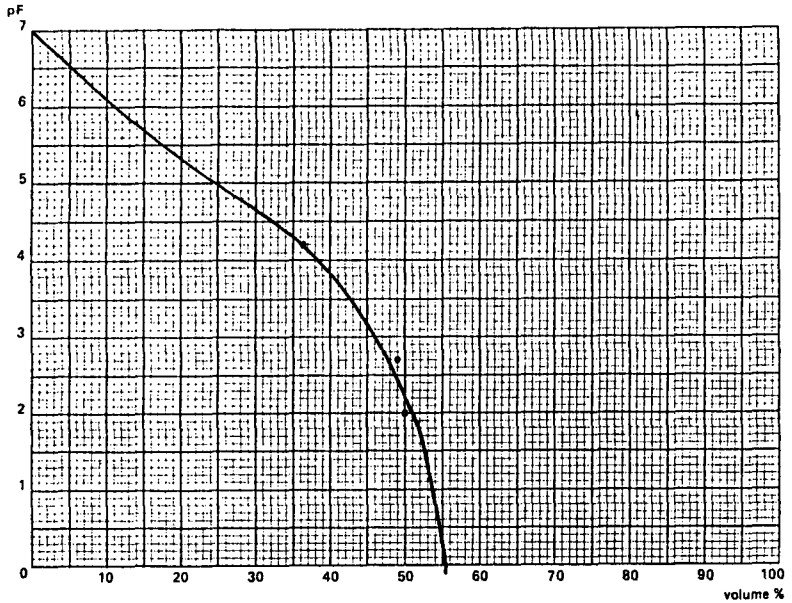
Maugo No. 6 18 - 25 cm



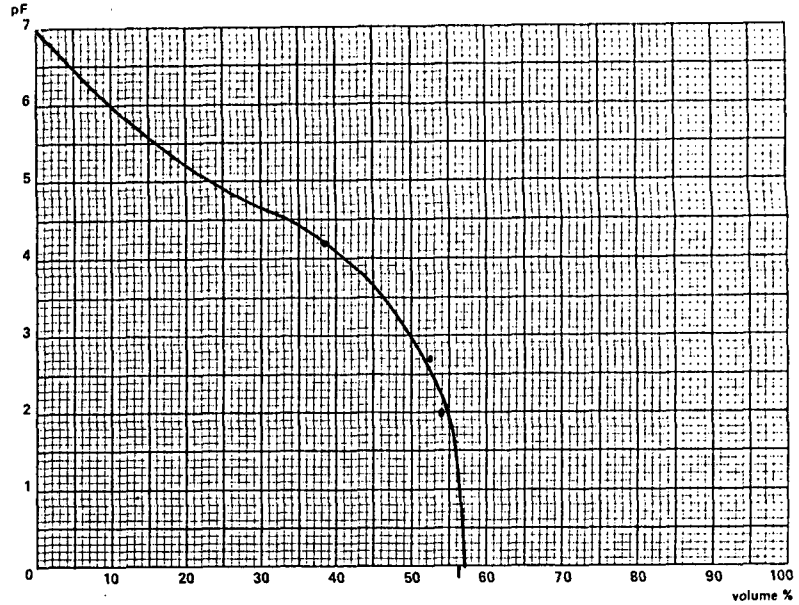
Maugo No. 6 30 - 36 cm

Fig. 2.3a Moisture retention curves

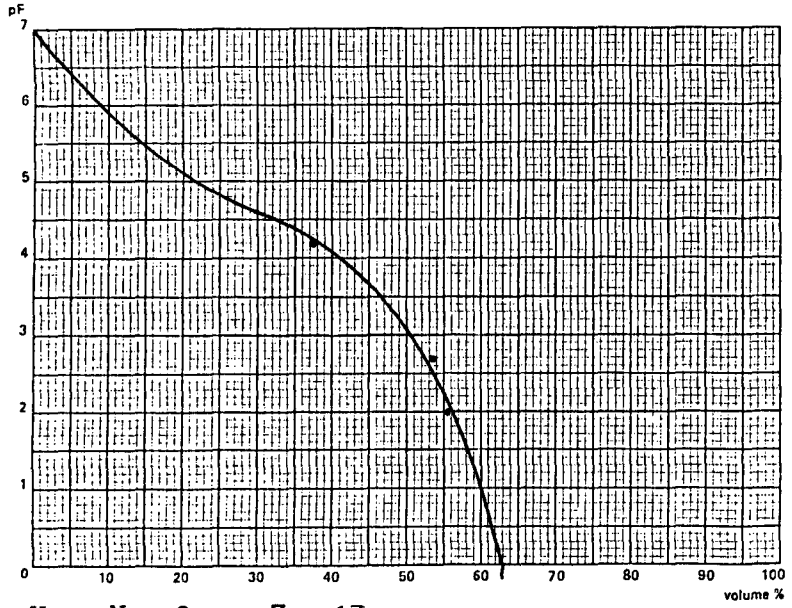
Fig. 2.3b Moisture retention curves



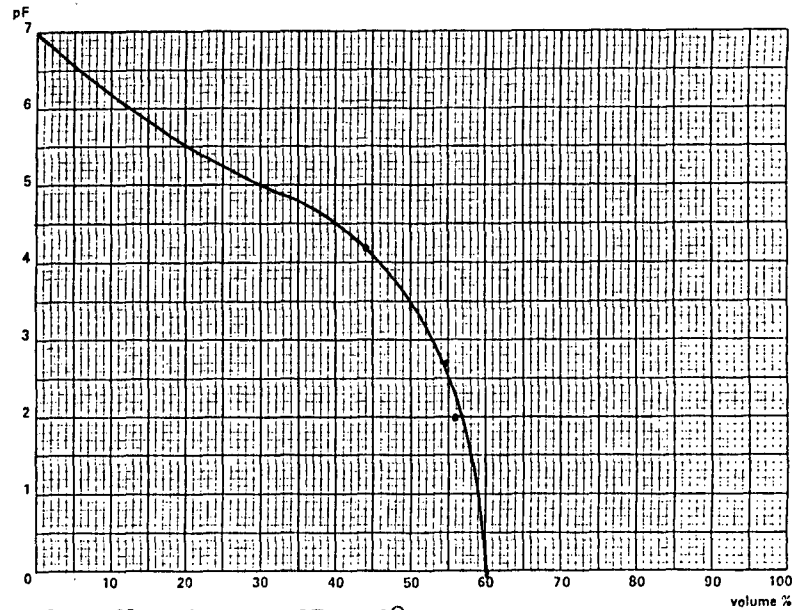
Kore No.1 8 - 15 cm



Kore No. 1 30 - 37 cm



Kore No. 2 7 - 13 cm



Kore No. 2 23 - 28 cm

Fig. 2.3b Moisture retention curves

Area	Profile pit no.	Soil mapping unit	Depth of sample (cm)	Organic matter %	Clay content %	Particle') density g. cm^{-3}	Bulk density g. cm^{-3}	Volume percentage of water at pF = 2.0 (F.C.)	pF = 2.7	pF = 4.2 (W.P.)	Total pore') space %
Wasare	3	PlA1	5 - 10	1.9	68	2.76	0.909	59.5	56.9	34.1	67.1
			30 - 35	0.9	56	2.76	1.075	55.0	52.8	48.3")	61.0
Kore	1	PfA1	8 - 15	1.4	50	2.73	1.217	50.2	48.9	36.6	55.4
			30 - 37	1.1	70	2.78	1.209	53.9	52.7	38.7	56.5
	2	PlA1	7 - 13	1.5	50	2.73	1.012	55.6	53.6	37.5	62.9
			23 - 28	1.4	66	2.77	1.104	56.0	54.8	44.1	60.1
Maugo	6	PlA4	18 - 25	2.3	60	2.73	1.204	55.6	53.2	40.7	55.9
			30 - 36	1.5	62	2.76	1.198	56.2	53.6	47.2")	56.6

') Calculated values

") Unreliable value

Table 2.4: Physical data on the soils, from core samples

The values for stratified material are even more wide-ranging because of the variation in texture.

2.2.2 Infiltration rate

The relation between textural class and infiltration rate is presented in a frequency distribution of both parameters in Table 2.3. Only moist or wet, non-cracked soils were considered.

The infiltration rate of heavy clay was predominantly very slow to slow. Clay generally had a very slow to slow infiltration rate, but in a considerable number of measurements, the infiltration rate varied from moderately slow to rapid and even to very rapid.

The infiltration rate of clay loam ranged from moderately rapid to rapid.

2.2.3 Water retention and available moisture

The average values of the volume percentage of water in the eight horizons (samples in triplicate) were determined at three different suction forces. The results are presented in Table 2.4.

Soil moisture content at three pF values were used to compile the moisture retention curves (Fig. 2.3a and 2.3b).

Note that the values of the moisture content at pF = 4.2 in the sub-surface horizons of Wasare and Maugo do not fit the curve, probably because of errors during the sampling and/or the analysis. The low values of the bulk density and the high total pore space shown in Table 2.4) imply that the top layers are unripe, mainly because of puddling.
Moisture availability is summarized in Table 2.5.

Area	No. of samples	Depth (cm)	in volume percentages		
			unavailable moisture >pF = 4.2	productive available moisture pF = 2.3-3.7	aeration porosity <pF = 2.0
Wasare	3	5-10	34.1	13.0	7.6
		30-35	35.0	12.0	6.0
Kore	1	8-15	36.6	9.0	5.2
		30-37	38.7	9.0	2.6
Kore	2	7-13	37.5	11.0	7.3
		23-28	44.1	7.0	4.1
Maugo	6	18-25	40.7	9.0	0.3
		30-36	43.0	7.0	0.4

Table 2.5 Available moisture for various pF values

The amount of productive available moisture is low, in except the Wasare samples. The average value was 10% or 10 mm/dm.

Although not strictly relevant for irrigated soils, it is clear that the soil moisture storage capacity is low.

As a rule, the pore sizes between 3000 and 30 µm govern the hydraulic conductivity. Transferred to the equivalent pore diameters 3000 µm (pF = 0.1) and 30 µm (pF = 2.0) the aeration porosity ranges from 0.3-7.6% (average 3.3). This low value, in combination with the total pore space, implicates a very low hydraulic conductivity when wet. In dry conditions the soils crack severely and consequently have a high hydraulic conductivity. The practival implications of the data are the necessities for

- very good levelling, because each area should receive the same amount of water; and
- a frequent supply of irrigation water because of the very low soil moisture storage capacity,

moreover, no additional moisture can be expected from the subsoil, because the groundwater level is deep (and should be kept deep to prevent salinization) and because the hydraulic conductivity is low in these fine-textured soils.

3 THE MAPPING OF THE SOILS

3.1 Scale of the maps

The soil maps for each area appear in Appendix V of this report. They have been produced at a scale of 1:2 500 in order to provide a direct link with the maps of the irrigation layout, which are to be prepared at this scale. The actual soil observation density allows for final soil maps at a scale of 1:5 000.

3.2 How the mapping units were derived

The soils were grouped in the legend on the basis of their physiographic location in the landscape and the nature of their parent material. Thus, the first step was to identify the physiographic units in the survey areas, as these provide the initial code letter of the final mapping unit. Three physiographic units were present:

- Footslote (code F)
- Alluvial Plain (code Pf)
- Lacustrine Plain (code Pl).

The nature of the parent material provides the next element of the mapping unit code. In the 4 survey areas only 2 parent materials were distinguished:

- colluvial material (code C)
- alluvial material (code A).

The final component of the code of the mapping unit deals with colour, texture, drainage conditions, etc.

For this classification the following information was used:

- data from augerings, profile pits and field observations of the micro-, meso- and macro-relief, and the vegetation and land use;
- data on the pH and EC of soil samples taken from 4 different depths from almost all the soil augerings and profile pits (Analysis done by the National Irrigation Board Laboratory at Ahero);

- analysis of soil samples from representative profiles (done by the National Agricultural Laboratory, Nairobi) - see Appendix IV.

The soil classification of the mapping units is based on the FAO-Unesco Soil Map of the World legend (FAO-Unesco, 1974) as tentatively modified by the Kenya Soil Survey (Siderius and Van der Pouw, 1980).

Details of the mapping units used in each of the 4 survey areas are given in Chapters 5.5, 6.6, 7.5 and 8.6, respectively.

Land characteristics \ Land suitability class		Class 1	Class 2	Class 3	Class NS
to-po-graphy	slope	less than 1%	less than 1%	less than 2%	lands that do not meet the minimum requirements of the other classes
	micro- and meso relief	smooth, except for gilgai, irrigation bunds and other minor undulations	smooth, except for gilgai, irrigation bunds and other minor undulations	somewhat irregular, mainly due to rill erosion and shallow gully erosion	
soil depth		exceeds 90 cm	exceeds 90 cm	more than 90 cm	
soil texture		clay or heavy clay within 40 cm	- stratified clay loam and clay or - less than 80 cm stratified loam and clay over clay and heavy clay	less than 80 cm stratified sandy loam and clay loam over clay and heavy clay	
hydraulic conductivity when wet[1)]		slow or very slow within 40 cm	- moderately slow or - moderate over slow or very slow within 80 cm	moderately rapid over slow or very slow within 80 cm	
soil reaction		pH-H_2O <8.5 to at least 80 cm depth	pH-H_2O <8.5 to at least 50 cm depth	pH-H_2O <8.5 to at least 50 cm depth	
soil salinity[1)]		non-saline to at least 100 cm depth	- non-saline to at least 80 cm depth or - non-saline to at least 50 cm depth over not more than slightly saline	- non-saline to at least 50 cm depth over not more than slightly saline	
soil sodicity		non-sodic to at least 100 cm depth	non-sodic to at least 100 cm depth	sodic within 100 cm depth	

1) for specifications see Appendix III

Table 4.1 Minimum criteria for the suitability for small scale irrigated rice
Specifications relevant for Valley Bottom Development Project

Table 4.2 Suitability classes for small-scale irrigated rice

Suitability class	Description	Suitability class with main limiting factor(s)
1	Highly suitable Land suitable for sustained irrigated rice production; minimum costs of development and management associated with the land	-
2	Moderately suitable Land of moderate productivity; slight to moderate limitations in soil qualities or requiring moderate costs for development	2c
3	Marginally suitable Land of restricted productivity for irrigated rice; moderate to severe limitations in soil qualities and - in addition - requiring relatively high costs for development (i.e. levelling) or requiring relatively high costs for levelling	3t 3c
NS	Unsuitable Land that is unsuited for sustained production of irrigated rice; severe limitations in topography and/or soil characteristics	NSc NStd NSrs NStn

Key to codes for main limiting factors:

t slope and micro- and meso relief

d soil depth

c soil texture and hydraulic conductivity

r soil reaction

s soil salinity

n soil sodicity

4 METHODOLOGY OF ASSESSING LAND SUITABILITY FOR SMALL-SCALE IRRIGATED RICE

4.1 Classification system used

Many countries have adopted the land classification system of the Bureau of Reclamation of the U.S. Department of the Interior to classify irrigated land. This system cannot be directly applied because of the lack of economic data. Therefore the Kenya Soil Survey has modified the system to take account of local conditions in Kenya (Muchena, 1981). In this report we have broadly followed the Kenya Soil Survey's proposed criteria for land suitability classification for irrigation, though we have made some modifications to allow for soil conditions in the project area. Our land suitability classes are based on the physical and chemical constraints of the area.

To determine the suitability of the various mapping units, the limitations in soil and land qualities have to be evaluated and then compared with the minimum criteria of the various suitability classes (Table 4.1).

4.2 Land suitability classes

The suitability has been assessed on the assumption that:

- flood control works will be constructed, in order to protect the area from flooding and erosion;
- sufficient good quality irrigation water will be transported to the areas concerned. Irrigability is therefore not considered in the appraisal;
- adequate measures will be taken to remove drainage water and superfluous irrigation water. Drainability is therefore not considered in the assessment;
- adequate measures will be taken to prevent soils from salinization when cultivated.

Four suitability classes have been distinguished (Table 4.2). Classes 2, 3 and NS (unsuitable) have been subdivided according to the main limiting factor(s). These factors and their codes are given in Chapter 4.3 and in Table 4.2.

It should be remembered that the suitability presented is only valid for irrigated rice. Soils that are only marginally or moderately suitable for irrigated rice, may well be more suited to other irrigated crops, such as maize, millet or vegetables, or even for the cultivation of non-irrigated crops.

4.3 Land qualities and specific criteria

4.3.1 General

Rice requires a number of special conditions that have to be considered when the suitability of the land is evaluated:

- a slowly permeable soil, or a soil that can be made slowly permeable, because rice should be partly submerged when it is growing;
- a level topography for uniform distribution of water;
- no salitiny in the soil to a depth of at least 50 cm. Rice is known to grow on soils with a saline subsoil at shallow depth, but this needs special management practices and much experience. Moreover, under these conditions a relatively large and continuous water supply is required and even then yields are not optimal;
- no alkalinity or extreme acidity within 50 cm depth because these restrict the effective rooting depth.

The following land qualities, which determine the suitability of the land in the investigated areas, were considered:

topography	soil reaction
soil depth	soil salinity
soil texture and hydraulic conductivity	soil sodicity

Below, each of the above-mentioned land characteristics is dealt with in further detail.

4.3.2 Topography (in the suitability classes this limiting factor is indicated by the code "t")

The limiting topographic factors have been derived from the macro topography (slope) and meso- and micro-relief.

Slope deals with differences in topography over larger distances, mainly expressed by the length and steepness of the slope. Of the areas investigated, only part of the footslope in the Maugo area has a slope exceeding two per cent (mapping unit FC2). In all other areas slope is not a limiting factor in the land appraisal.

Meso-relief concerns medium sized differences in topography over short distances. The presence of small, shallow erosion gullies in the almost flat areas or of an uneven surface resulting from rill erosion is considered to be a limitation, because the land would have to be levelled and this would add to the costs of reclamation.

Micro-relief is characterized by irregularities and undulations found over short distances, e.g. cow foetoes, tussocks and uneven ploughed land. These minor undulations are not considered to be a limitation, because in most cases they can be removed by ploughing.

4.3.3 Soil depth (in the suitability classes this limiting factor is indicated by the code "d")

This land characteristic is only relevant for part of the footslope in the Maugo area (mapping unit FC2), where rock starts at approx. 30 cm depth. In all other areas soils are deeper than 100 cm, usually even deeper than 200 cm.

4.3.4 Soil texture and hydraulic conductivity (in the suitability classes this limiting factor is indicated by the code "c")

Both qualities are dealt with together here, because in these areas they are closely related: hydraulic conductivity under moist or wet conditions is very dependent on soil texture (see Table 2.2).

Based on these findings and on the irrigation practices observed in the field, the minimum criteria for soil texture and hydraulic conductivity, mentioned in Table 4.1, were composed.

Remark: Note that the hydraulic conductivity of a soil becomes slower when that soil is puddled.

4.3.5 Soil reaction (in the suitability classes this limiting factor is indicated by the code "r")

No extremely acid (pH-H_2O < 4.5) reactions were found in the areas studied and only in a few places were strongly alkaline (pH-H_2O > 8.5) reactions found in the subsoil, e.g. in mapping units PfA31 and PfA32 in the Maugo area.

Therefore soil reaction is a limiting factor of only minor importance in the areas studied.

4.3.6 Soil salinity (in the suitability classes this limiting factor is indicated by the code "s")

Soil salinity is an important characteristic for evaluating the suitability of the land (see paragraph 4.3.1). Much attention was therefore given to the EC values of the soils (see also Chapter 2 and Table 2.1).

The minimum salinity criteria, given in Table 4.1 largely correspond with those given by KSS (Muchena, 1981), but have been adapted to the salinity conditions prevailing in the areas.

4.3.7 Soil sodicity (in the suitability classes this limiting factor is indicated by the code "n")

Sodic soil horizons were only found in the subsoil below 100 cm, except in mapping units PfA31 and PfA32 in Maugo.

Therefore sodicity is a soil characteristic of minor importance in these areas. For further details see Chapter 2.

5 SOILS OF THE WASARE AREA

5.1 Geology and parent material

The Wasare area belongs to the flat part of the Kano Plain. The latter is an extended, infilled valley surrounded by relatively high hills, except on the lake side. Several rivers originating in the hilly hinterland flow across the Kano Plain and terminate either in swamps or directly in the lake.

During the Pleistocene the Kano Plain was part of the present lake. As the level of the lake fell, lacustrine clay sediments were deposited in swamps and marshes. A period of erosion and sedimentation followed, during which streams deposited new materials and reworked older (lacustrine) sediments. This created a series of alluvial plains with complex areas of stratified levee soils alternating with soils on heavy lacustrine clays (D'Costa and Ominde, 1973). Most of the soils in the Wasare area have developed on fluvial sediments. The western rim along the Reru beach barrier is comprised of soils developed on lacustrine sediments.

The northern part of the area is drained by and subject to flooding from the lower reaches of the Asawo river. The central part of the area is influenced by the Usungo drift, while the south is affected by the Omondo drift. Materials of varying, often coarse, textural composition have been deposited in levees along the streams. They are partly underlain by heavy lacustrine clay (Kano clay) at variable depth.

5.2 Hydrology and flooding

The area is nearly flat to very gently undulating and drains northwestwards. The western part, which is not subject to flooding, is flat. The higher parts of the levees escape flooding or are flooded by 10 to 20 cm of water. The lower-lying areas with lacustrine sediments are subjected to considerable seasonal floods.

5.3 Land use

The higher areas with fluvial sediments are cultivated with maize, millet and sugar cane. Grazing is the main land use of the lower-lying areas, partly on abandoned rice fields. In some areas, water is tapped from the rivers and streams. Adjoining areas are irrigated and used for growing rice.

5.4 General soil characteristics and soil classification

Most of the soils are non-saline throughout. The heavy lacustrine clay soils have a slightly saline subsoil below 150 cm. The soil reaction is predominantly moderately alkaline. The upper part of the soils developed on fluvial sediments is usually slightly calcareous. The heavy lacustrine clay subsoil is non-calcareous and in places is sodic.

Soils on the lacustrine sediments are poorly drained, those on the fluvial sediments are moderately well drained. The soils on the lacustrine sediments with a fluvial cover are from imperfectly to moderately drained. Groundwater often occurs between 100-200 cm, usually in conjunction with the stratified, coarse-textured soils of the levees. In irrigated areas with heavy lacustrine soils, groundwater is encountered at shallower depth. Non-irrigated, heavy lacustrine clays have groundwater considerably deeper than 2 m. Where levee material overlies lacustrine clay, the groundwater generally starts between 150 cm and 200 cm.

In contrast with the almost negligible hydraulic conductivity of the heavy lacustrine clay, the hydraulic conductivity of the overlying heterogeneous fluvial top layers ranges from slow to rapid.

All the soils of the Alluvial Plain developed on recent and subrecent fluvial sediments have been classified as Fluvisols. The soils entirely developed on fluvial sediments have been classified as calcaric Fluvisols, while those in which fluvial sediments overlie lacustrine sediments have been classified as calcaric and eutric Fluvisols. The latter are not calcareous within 50 cm of the surface.

All soils of the Lacustrine Plain developed on lacustrine sediments have been classified as pellic Vertisols.

The major groups and subgroups are outlined in Table 5.1.

Physiography	Parent material	Major soil group	Subgroup
alluvial plain	recent and sub-recent fluvial sediments	Fluvisols	calcaric Fluvisols
	recent and sub-recent fluvial sediments over lacustrine sediments	Fluvisols	calcaric Fluvisols eutric Fluvisols
lacustrine plain	lacustrine sediments	Vertisols	pellic Vertisols

Table 5.1 Subgroups of soil classification in relation to physiography and parent material

Table 5.2 gives the extent of the 9 soil mapping units distinguished. They are described in Chapter 5.5.

Soil mapping unit	extent in ha	%
PfA11	6.5	4.0
PfA12	13.1	8.3
PfA21	19.0	11.6
PfA22	12.0	7.3
PfA23	10.0	6.1
PfA24	17.5	10.7
PfA25	3.5	2.1
PlA1	54.0	33.0
PlA2	27.5	16.8
Total area	163.5	100.0

Table 5.2 Absolute and relative extent of the soil mapping units.

5.5 Description of the soil mapping units

5.5.1 Soils developed on recent and subrecent fluvial sediments

The soils of the alluvial plain on this parent material have been placed in two soil mapping units. Their main characteristics are the stratification and the irregular texture of their profiles. Coarse-textured layers alternate with medium and fine ones over short distances. Surface overwash and slightly gravelly subsoils frequently occur. The soil mapping units differ in clay content of the topsoil and in drainage condition.

Mapping unit: PfA11

Topography:
macro: flat to very gently undulating; the relatively high parts in the surveyed area and part of a levee along the Asawo river.
meso : some irrigation canals.
micro: uneven ploughed land.

Overwash: in places loose, slightly gravelly, coarse sand on the surface, especially in the southernmost area.

Vegetation/land use: maize, millet, sugar cane, some grazing.

Drainage conditions: moderately well to well drained;predominantly not subject to flooding, lower parts seasonally flooded up to 20 cm deep; groundwater level ranging from 160 to > 200 cm (June 1981).

Soils: are characterized by fluvial sediments with a prominent stratification. The brown to dark brown topsoil ranging in thickness from 10 to 30 cm is usually coarse-textured: loose sand to friable coarse sandy loam and loam. In the subsoil, up to 2 m, dark brown, slightly gravelly sand and coarse sandy loam layers alternate with loam, clay loam and clay layers. Considerable differences in texture are often marked by many mottles. Very heterogeneous soils.

Chemical aspects: non-saline throughout; moderately alkaline; slightly to moderately calcareous,except for the pure sand layers in the topsoil; non-saline groundwater.

Physical aspects: only a few small cracks were observed; the hydraulic conductivity in the various textured layers ranged from moderately rapid for sand to slow for clay (when wet); in places the vertical hydraulic conductivity might be impeded by the presence of intercalated heavier layers; however the rapid horizontal hydraulic conductivity of some coarse layers can result in great losses of irrigation water.

Soil classification: calcaric FLUVISOLS.

Soil suitability for irrigated rice: unsuitable (class NSc).

Mapping unit: PfA12

Topography:
macro: flat to very gently undulating.
meso : in places camber beds; irrigation canal.
micro: some bunds; few termite mounds; rills.

Overwash/stoniness: in the southwest of the survey area a sand veneer is occasionally present (overwash), resulting from rill erosion originating outside the area; in the southernmost area the subsoil contains gravel and stones below 150 cm.

Vegetation/land use: predominantly maize (mixed with cotton); some millet, sugar cane and grassland.

Drainage conditions: imperfectly drained; higher places are not flooded, in the lower areas the seasonal flood height is about 15 cm; groundwater level ranging from 175 to > 200 cm (June, 1981), the latter level is usually found in the southernmost area.

Soils: These soils are also characterized by a marked stratification of the fluvial sediments. A 20-60 cm thick topsoil of brownish black to grayish yellow brown, mottled, very firm, slightly cracking clay and sandy clay overlies a complex of stratified, sandy loam to clay loam with intercalations of coarse sand and fine gravel (stratified). Layers of dark brown, friable loam alternate with brownish black, mottled, firm clay loam. Mottles go as deep as 2 m. The amount of coarse sand and fine gravel tends to increase below a depth of 90 cm. This occurs mainly in the southern area.

Chemical aspects: non-saline, except for the slightly saline subsoil of observation No. 106; usually moderately alkaline, though in the southern area some observation points show more differentation: neutral to moderately alkaline topsoils overlie moderately, in places strongly alkaline subsoils; predominantly slightly calcareous, in the southern region often a non calcarous topsoil; in places sodic subsurface horizons below 65 cm; non-saline groundwater.

Physical aspects: Cracks moderately common (width up to 3 cm; polygon diameter 30-40 cm); under wet conditions the hydraulic conductivity of these heterogeneous soils varies from moderately rapid to slow (see also mapping unit PfA11).

Soil classification: calcaric FLUVISOLS.

Soil suitability for irrigated rice: unsuitable (class NSc).

Representative profile: Appendix IV-A, profile pit No. 1.

5.5.2 Soils developed on recent and subrecent fluvial sediments over lacustrine sediments (Kano clay).

The soils of the alluvial plain on this parent material have been grouped into 5 soil mapping units characterized by the following sequence: clay or clay loam topsoil over stratified coarse- and medium-textured fluvial material over heavy lacustrine clay. The subdivision is mainly based on the depth at which the heavy lacustrine

clay subsoil begins (within 40-60 cm, within 60-80 cm or > 90 cm) and/or on its thickness, thus implying a variable thickness of the fluvial cover. The depth at which the slowly permeable layer starts affects the soils suitability for irrigated rice.

The soils of these mapping units are transitional between the preceding two mapping units with soils on fluvial sediments (PfA11 and PfA12) and the following two mapping units (PlA1 and PlA2).

Mapping unit: PfA21

Topography:
macro: flat to very gently undulating.
meso : irrigation canal; in places camber beds.
micro: bunds, cow foetoes.

Overwash: in places a very slight overwash of sand.

Vegetation/land use: predominantly grassland; maize, millet, sugar cane; in irrigated areas,paddy fields.

Drainage conditions: imperfectly to moderately well drained; seasonal floods from 5 to 30 cm deep;groundwater usually at a depth between 110 and 180 cm, in places > 200 cm (June 1981); the presence of groundwater in some areas is related to the supply of irrigation water; the paddy fields are often only partially submerged.

Soils: have a 15-30 cm thick topsoil of brownish black, firm, slightly cracking clay over a stratified complex of sandy clay loam to clay loam. Dark brown, slightly mottled, friable, (coarse) sandy loam and loam layers of variable thickness alternate with brownish black, mottled firm clay loam and with thin sheets of sometimes slightly gravelly coarse sand. These medium-textured fluvial layers are always underlain by lacustrine brownish black, mottled, firm clay to heavy clay (Kano clay), starting between 110 and 180 cm. The consistency of the topsoil of the paddy fields is very sticky and plastic; subsoils below the groundwater level are usually sticky and slightly plastic.

Chemical aspects: non-saline; moderately alkaline; the fluvial sediments, except for the top 20 cm, are slightly to moderately calcareous, the lacustrine clayey subsoil is frequently non-calcareous; groundwater is moderately alkaline and non-saline.

Physical aspects: in places cracks 2-3 cm wide and with a polygon diameter of 20-40 cm; under wet conditions the topsoil has a slow hydraulic conductivity, the hydraulic conductivity of the heterogeneously textured layers below range from moderately rapid to slow, the subsoil of lacustrine clay has a very slow hydraulic conductivity.

Soil classification: calcaric FLUVISOLS.

Soil suitability for irrigated rice: unsuitable (class NSc).

Mapping unit: PfA22

Topography:
macro: nearly flat.
meso : camber beds.
micro: few bunds, belonging to abandoned rice fields.

Overwash: in places a very slight overwash.

Vegetation/land use: grassland, partly on former rice fields; some maize.

Drainage conditions: imperfectly drained; some areas free from floods, in others seasonal floods up to 20 cm deep; groundwater level > 200 cm (June 1981).

Soils: have a 15-30 cm thick topsoil of brownish black, firm, cracking clay over brownish black to dull yellowish brown, mottled,stratified,

friable sandy loam and loam and firm clay loam with some coarse sand (fluvial sediments). Almost everywhere between 60 and 80 cm underlain by lacustrine, brownish black to black, firm clay to heavy clay at least 80 cm thick.

Chemical aspects: non-saline, in the southeastern area a slightly saline subsoil (> 160 cm) in places; moderately alkaline, except for the upper 20-50 cm (neutral); slightly calcareous, though the subsoil is predominantly calcareous.

Physical aspects: 2-3 cm wide cracks are present with polygons of 20-40 cm diameter when wet, the topsoil has a slow hydraulic conductivity, the underlying medium- and fine-textured layers have a moderately rapid to slow hydraulic conductivity and the subsoil of lacustrine clay has a very slow hydraulic conductivity.

Soil classification: calcaric FLUVISOLS.

Soil suitability for irrigated rice: marginally suitable (class 3c).

Remarks:

1. This mapping unit also includes soils, especially in the southeast, that lack the intermediate fine-textured layers such as sandy loam and loam. At the same time, between 150 and 170 cm the subsoil changes from heavy clay towards clay loam.
2. These soils are comparable with those of mapping unit PfA21, the difference being that the lacustrine clay subsoil occurs at a shallower depth.

Mapping unit: PfA23

Topography:
macro: flat to very gently undulating.
meso : irrigation canal.
micro: some shallow erosion rills.

Overwash: slight overwash, consisting of coarse sand and fine gravel.

Vegetation/land use: (overgrazed) grassland with some rushes, sugar cane, maize.

Drainage conditions: imperfectly drained; seasonal floods in the lower places to a maximum of 20 cm; groundwater level > 200 cm (June 1981).

Soils: have a 10-25 cm thick topsoil of brownish black to dark brown, mottled, very firm clay, in places mixed with coarse sand grains. Below is a stratified complex ranging from dull yellowish brown to brown, friable coarse sandy loam to brownish black, very firm clay loam (fluvial sediments). At a depth between 40 and 80 cm there is a transition to brownish black and black, mottled, very firm heavy clay (lacustrine sediments). The thickness of this layer is usually limited to 60-80 cm. The deeper subsoil is often coarser-textured: dark brown, firm loam and/or clay loam, in places with some gravels, probably also of lacustrine origin.

Chemical aspects: non-saline; moderately alkaline, except for the upper 20 cm (neutral); topsoil and lacustrine heavy clay subsoil are non-calcareous, intermediate coarser-textured, fluvial layers are slightly calcareous.

Physical aspects: only a few small cracks were observed; when wet, the fluvial parts of these soils have variable hydraulic conductivities depending on the texture of the layers: ranging from moderately rapid to slow. The lacustrine clay subsoil has a very slow hydraulic conductivity.

Soil classification: eutric FLUVISOLS.

Soil suitability for irrigated rice: marginally suitable (class 3c).

Mapping unit: PfA24

Topography:
macro: flat to very gently undulating.
meso : some irrigation canals; camber beds.
micro: bunds; in places 20-30 cm high hummocks caused by rill erosion.

Overwash: near irrigation canals often a very thin overwash of coarse sand and/or fine gravel is present.

Vegetation/land use: predominantly maize, some grassland and some paddy fields.

Drainage conditions: moderately well to imperfectly drained; the seasonal floods do not affect the higher parts of this unit; in the lower parts floods 40 cm deep are not unusual; groundwater is often encountered between 140 and 190 cm, sometimes it is encountered below 200 cm (June 1981).

Soils: typically have fluvial sediments with a distinct stratification over lacustrine heavy clay. The 20-30 cm thick topsoil is heterogeneous and ranges from dull yellowish brown, slightly gravelly sandy loam to brown, silty clay loam and brownish black clay. The coarse-textured layers below the topsoil consist of slightly gravelly, coarse (loamy) sand, mottled loam and/or clay loam (fluvial sediments). Between 90 and 110 cm they are abrubtly underlain by lacustrine brownish black, in places mottled, very firm, heavy clay. In a few observations the top of the heavy clay subsoil was found at a depth of about 150 cm.

Chemical aspects: non-saline; moderately alkaline, but the heavy clay subsoil frequently showed a neutral reaction; slightly calcareous, except locally in the top 20 cm and in the lacustrine clay subsoil which was often non-calcareous; groundwater predominantly non-saline and in places slightly saline.

Physical aspects: a moderate number of cracks were observed, width 2-3 cm, polygon diameter 30 to 40 cm; in places these soils have a slaked surface; in spite of the relatively high water level the

crops on these coarse-textured soils suffer from drought; under wet conditions the hydraulic conductivity of the fluvial sediments varies from rapid to slow, considerable lateral losses of irrigation water can be expected, the heavy clay subsoil has a very slow hydraulic conductivity.

Soil classification: calcaric FLUVISOLS.

Soil suitability for irrigated rice: unsuitable (class NSc).

Representative profile: Appendix IV-A, profile pit No. 2.

Mapping unit: PfA25

Topography:
macro: flat
meso : camber beds in many places.
micro: uneven ploughed land.

Overwash: in places a very slight overwash of coarse sand and fine gravel.

Vegetation/land use: maize.

Drainage conditions: imperfectly drained; mostly not affected by floods but in places floods up to 20 cm deep; groundwater > 200 cm (June 1981).

Soils: have a 10-20 cm thick topsoil of brownish black, firm, in places slightly gravelly, clay loam and clay over dark brown, stratified, loose, coarse sand and/or friable sandy loam. Between 40 and 60 cm these fluvial layers are underlain by brownish black, mottled, very firm heavy clay of lacustrine origin.

Chemical aspects: non-saline; moderately alkaline; slightly calcareous, except for the top 20 cm and the lacustrine heavy clay subsoil below 100 cm.

Physical aspects: almost no cracks were observed; the hydraulic conductivity of the fluvial sediments ranges from rapid to slow, the lacustrine heavy clay subsoil has a very slow hydraulic conductivity (in wet conditions).

Soil classification: calcaric FLUVISOLS.

Soil suitability for irrigated rice: unsuitable (class NSc).

Remarks: These soils are related to those of the preceding unit (PfA24) but the lacustrine heavy clay occurs nearer the surface. Soils are transitional to the adjacent Vertisols (mapping unit PlA2).

5.5.3 Soils developed on lacustrine sediments (Kano clay)

The soils of the lacustrine plain on this parent material have been grouped into two soil mapping units and consist of deep, lacustrine, cracking heavy clay throughout, with a very slow hydraulic conductivity. The main characteristic that separates the almost identical soils of both units is the shallow occurrence of a slightly saline subsoil. The soils in at least one of the units indicate sodic subsurface layers.

Mapping unit: PlA1

Topography:
macro: nearly flat.
meso : irrigation canals.
micro: bunds, some disused and disturbed cow foetoes; some rills; cracks.

Fig. 5.1 Paddy fields which are insufficiently irrigated develop distinct cracks after drying out. Note the roots that bridge the cracks.

Fig. 5.2 Progressive dessication results in crop failure.

Overwash: none.

Vegetation/land use: in the areas where irrigation water is supplied (observation No.'s: 30, 37 and 102): paddy fields; in the southern parts of this mapping unit grassland with rushes, often on abandoned rice fields,in these drier areas more maize, millet and sugar cane.

Drainage conditions: poorly drained; the height of the seasonal flood varies: in the northernmost area it is about 100 cm, in the southern area it varies from 60 cm in the north to 30-40 cm in the centre and 10-20 cm in the east. No flooding occurs in the southeastern part (profile pit No. 2); groundwater level predominantly > 200 cm, except near irrigated areas where groundwater was often encountered between 100 cm and 200 cm below surface (June 1981).

Soils: consist entirely of lacustrine sediments. They have a 20-30 cm thick topsoil of brownish black, mottled, very firm, cracking clay to heavy clay with a very coarse prismatic structure disintegrating into coarse angular blocky elements. The irrigated paddy fields have a puddled layer with a sticky, plastic consistency. The topsoil overlies black, slightly mottled, very firm, cracking heavy clay, usually with a coarse prismatic structure. Mottles often go as deep as the crack depth (50-70 cm). Abundant root galleries are present. The transition to brownish black, very firm clay is frequently encountered between 140 and 160 cm; in places a coarser-textured subsoil is present.

Chemical aspects: non-saline, only in a very few observations was a slightly saline subsoil found, starting at about 150 cm; topsoils usually have a neutral soil reaction and can be underlain by neutral or moderately alkaline subsoils; predominantly non-calcareous throughout, in places, however, slightly calcareous; in places sodic subsoil below 160 cm; groundwater is predominantly non-saline and in places slightly to moderately saline.

Physical aspects: the dry areas within this mapping unit show many cracks ranging from 2-5 cm wide, 50 cm deep and the polygon size is 10-40 cm. The worst cracking occurs in the southwest in severely desicated soils. The non-submerged parts of the present paddy fields reveal spontaneous and intensive cracking (Fig. 5.1 and 5.2). When wet, these soils have a very slow hydraulic conductivity throughout.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Representative profiles: Appendix IV-A, profile pits Nos 3 and 4.

Mapping unit: PlA2

Topography:
macro: flat.
meso : irrigation canals.
micro: bunds, partly out of order and broken; very slight rill erosion near the beach barrier; cow foetoes; cracks.

Overwash: none.

Vegetation/land use: predominantly grassland on abandoned rice-fields; irrigated paddy fields; maize.

Drainage conditions: poorly drained; the seasonal flood varies in height, in the northernmost part it is about 100 cm, in the south it is 40-60 cm, in the higer places in the centre only 10-20 cm; groundwater level > 200 cm, near paddy fields 100-200 cm (June 1981).

Soils: These soils also consist entirely of lacustrine sediments. They have a 20-30 cm thick topsoil of brownish black, slightly mottled, very firm, cracking clay to heavy clay with a very coarse prismatic structure falling apart into medium angular blocks. The puddled layer of the present irrigated paddy fields is sticky and plastic. The subsoil consists of black, slightly mottled (up to 70 cm), very firm, cracking heavy clay. In places the subsoil changes between 140 and 160 cm into a brownish black, very firm clay.

Chemical aspects: non-saline, very often slightly saline subsoil deeper than 150 cm, in places even starting between 80 and 100 cm; predominantly a neutral soil reaction and slightly calcareous; groundwater is non-saline.

Physical aspects: in the dry, non-submerged areas, many prominent cracks are present 4-10 cm wide, up to 40 cm deep and with a polygon diameter between 20 and 50 cm; soils here are deeply desiccated too, under wet conditions these soils have a very slow hydraulic conductivity.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Remarks: These soils are comparable with those of mapping unit PlA1, except for the slightly saline subsoil.

6 SOILS OF THE AWACH KANO AREA

6.1 Geology and parent material

The geology of the area is very similar to that of the Wasare area (see Chapter 5.1). Fluvial activity has resulted in the formation of alluvial plains on the large lacustrine plain.

A large proportion of the Awach Kano area is occupied by heavy clay soils developed on lacustrine sediments. This central part is not affected by the two branches of the Awach Kano river (which almost surround the study area) in the sense that no widespread sedimentation of fluvial deposits has taken place, though the area is subject to seasonal floods. In recent times, the Awach Kano branch has deposited material of varying textural composition, over heavy lacustrine clay along the northeastern border (Fig. 6.2). In a vast tract along the southern branch of the river the fluvial activity has resulted in the deposition of eroded and reworked Kano clay, sometimes intercalated with discrete clay loam layers and usually underlain by the heavy lacustrine clay.

6.2 Hydrology and flooding

The areas with fluvial deposits are almost flat to very gently undulating. They are often slightly raised above the general land surface: the central, lower-lying part is flat. The general drainage is from southeast to northwest; the overall gradient is 0.3%.

During the wet season most of the area is flooded approximately 60 cm deep for varying periods. In the higher areas, floods 30 cm deep are not unusual.

6.3 Erosion

Frequent sheetfloods cause severe gully erosion. In places gullies (irrigation canals destroyed by regressive erosion) go as deep as

Fig. 6.1 Abandoned rice fields with broken bunds on mapping unit PIA2. These fields were deserted, because insufficient irrigation water can be provided as a result of accelerated erosion of the Awach Kano river, just outside the area.

1.5 m and are up to 2 m wide. Narrow areas bordering the southern branch of the river are affected in places by lateral erosion (widening of the river bed).

6.4 Vegetation/land use

Grazing is by far the most important land use, quite often on recently abandoned rice fields (Fig. 6.1). Overgrazing is common. The higher areas have some maize and millet fields and in places scrub.

6.5 General soil characteristics and soil classification

Soils are non-saline and non-calcareous throughout, with the exception of the recent fluvial deposits, where some calcareous intercalations occur. The soil reaction is usually slightly acid for the upper levels, becoming strongly acid at depths between 50 and 80 cm.

During the survey no groundwater was encountered within 2 m in the entire area. The heavy clay soils on lacustrine sediments have a very slow hydraulic conductivity. The same is true for the heavy subsoils overlain by fluvial deposits. The hydraulic conductivity of the latter ranges from moderately rapid to slow.

The soils on the fluvial deposits are imperfectly drained. On the central lower-lying area they are poorly drained.

The soils of the Alluvial Plain developed on recent fluvial sediments over lacustrine sediments have been classified as calcaric Fluvisols.

The soils of the Alluvial Plain developed on recent and subrecent fluvial sediments over lacustrine sediments have been classified as untric Gleysols and gleyic Cambisols.

The soils of the Lacustrine Plain have been classified as pellic Vertisols and dystric Planosols. The important feature that separates the Vertisols from the Planosols is the presence of a bleached, eluvial horizon in the latter.

The major groups and subgroups are outlined in Table 6.1.

Physiography	Parent material	Major Soil Group	Subgroup
alluvial plain	recent fluvial sediments over lacustrine sediments	Fluvisols	calcaric Fluvisols
	recent and sub-recent fluvial sediments over lacustrine sediments	Gleysols Cambisols	eutric Gleysols gleyic Cambisols
lacustrine plain	lacustrine sediments	Vertisols Planosols	pellic Vertisols dystric Planosols

Table 6.1 Soil classification subgroups in relation to physiography and parent material.

Table 6.2 gives the extent of the 5 soil mapping units distinguished. They are described in Chapter 6.5.

Soil mapping unit	Extent in ha	%
pFa11	16.0	8.2
PfA21	29.0	14.9
PfA22	32.5	16.8
PlA1	27.5	14.2
PlA2	89.0	45.9
total area	194.0	100.0

Table 6.2 Absolute and relative extent of the soil mapping units.

6.6 Description of the soil mapping units

6.6.1 Soils developed on recent fluvial sediments over lacustrine sediments (Kano clay)

The soils of the alluvial plain on this parent material have been grouped into one soil mapping unit. They are characterized by variable textured, stratified top layers of recent fluvial origin over heavy

Fig. 6.2 Stratified, recent fluvial sediments, consisting of alternating layers of clay loam, clay and loamy sand over heavy lacustrine clay.
Photograph of profile pit No. 1; soil mapping unit PfA11.

lacustrine clay (Fig. 6.2). Because of their higher position (on levees) along the river and near its outlet, the soils continue to be affected by rill and gully erosion.

Mapping unit: PfA11

Topography:
macro: flat, relatively high position along river channel (levee).
meso : in northernmost part some erosion gullies (depth ½-1 m; width up to 2 m).
micro: in places 30-40 cm high and 40-60 cm wide hummocks, 20-50 cm apart, formed by rill erosion.

Overwash: one coarse-textured, gravelly spot near the river course (observation no. 15); gully bottoms consist of coarse sand and fine gravel.

Vegetation/land use: grazing, partly on recently abandoned rice plots; some maize fields.

Drainage conditions: imperfectly to poorly drained depending on the depth of the underlying, slowly permeable heavy clay layer; seasonally flooded to a depth of 60 cm; groundwater level > 200 cm (July 1981).

Soils: a 10-25 cm thick topsoil of brownish black to dark brown, mottled, friable to firm loam and clay loam with a medium blocky structure overlies brownish black, in places strongly mottled, friable, stratified clay and/or clay loam of fluvial origin; inclusions of coarse loamy sand layers with a platy structure are present. Between 50 and 80 cm these fluvial sediments are abruptly underlain by lacustrine, black, very hard, heavy clay and clay of lacustrine origin (Fig. 6.2). Usually this layer has a coarse angular blocky structure. The upper part of the heavy clay layer is strongly mottled.

Chemical aspects: non-saline; the medium-textured, fluvial layers are usually slightly acid to neutral and slightly calcareous; the lacustrine heavy clay subsoil is strongly to slightly acid and non-calcareous.

Physical aspects: in places 1-2 cm wide cracks were observed with polygons up to 30 cm wide, indicating an initially high hydraulic conductivity in the dry season; under wet conditions the topsoil and fluvial layers have a moderately rapid to slow hydraulic conductivity; the lacustrine heavy clay subsoil has a very slow hydraulic conductivity.

Soil classification: calcaric FLUVISOLS.

Soil suitability for irrigated rice: marginally suitable (class 3c).

Representative profile: Appendix IV-B, profile pit No. 1.

6.6.2 Soils developed on recent and subrecent fluvial sediments over lacustrine sediments (Kano clay)

The soils of the alluvial plain on this parent material have been placed in two soil mapping units. They have in common a slightly higher position in the terrain. In general they are characterized by the following textural sequence: clay or clay and clay loam of fluvial origin over lacustrine heavy clay. The differentiating features are that the soils of unit PfA22 reveal some stratification in the fluvial, fine-textured upper part and have a lacustrine heavy clay subsoil deeper than 100 cm. Locally the heavy clay is absent. The soils of unit PfA21 (transitional to those developed on the lacustrine sediments), unlike the levee-like soils, are more uniform and their lacustrine heavy clay subsoil begins at a much shallower depth (between 50 and 80 cm).

Mapping unit: PfA21

Topography:
macro: almost flat.
meso : a deeply eroded irrigation canal is present in the southeast.
micro: in places broken bunds; cow foetoes; scattered uneven ploughed plots.

Overwash: none.

Vegetation/land use: overgrazed grassland, partly on recently abandoned rice fields.

Drainage conditions: imperfectly drained; seasonally flooded to a depth ranging from 10 to 60 cm; groundwater level > 200 cm (July 1981).

Soils: a 20-25 cm thick topsoil of brownish black, faintly mottled, friable to firm, slightly cracking clay with a coarse prismatic structure overlies brownish black, mottled, friable clay of fluvial origin with a coarse prismatic structure disintegrating into medium angular blocks; pressure faces. In most places a black, strongly mottled, firm (lacustrine) heavy clay layer at least 60 cm thick is present, starting between 50 and 80 cm. The subsoil consists of brownish black, friable clay with a medium angular blocky structure; in places it is clay loam.
The subsoil (> 140 cm) occasionally contains weathered rock fragments and/or white patches of a buried eluvial horizon. This material was presumably formed in a pre-lacustrine period.

Chemical aspects: non-saline throughout; slightly acid with a tendency to strongly acid deeper than 80 cm; usually non-calcareous.

Physical aspects: in places a few small cracks are present (width 1-2 cm, polygon diameter 30 cm); predominantly desiccated soils; when wet, the fluvial upper part of these soils to a depth of 50 cm to 80 cm has a slow hydraulic conductivity, the underlying lacustrine heavy clay has a very slow hydraulic conductivity.

Soil classification: eutric GLEYSOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Representative profile: Appendix IV-B, profile pit No. 2.

Remarks:

1. This mapping unit includes soils without a heavy clay subsoil having a clay texture throughout.

2. The fluvial origin of the top layers is demonstrated by the local presence of thin patches and layers of coarse sand within 50 cm of the surface.

Mapping unit: PfA22

Topography:
macro: almost flat; this mapping unit comprises the higher parts within the surveyed area.
meso : the southern margin of this unit slopes towards the Awach Kano river; some erosion gullies and sheet erosion is present along the main channel.
micro: cow foetoes; uneven ploughed plots; small dikes often around the huts.

Overwash: none.

Vegetation/land use: overgrazed grassland, sometimes with dense thorn scrub; some millet and maize/cotton fields.

Drainage conditions: imperfectly drained: seasonally flooded, usually not exceeding a depth of 30 cm on the higher ground; groundwater level > 200 cm (July 1981).

Soils: a 20-40 cm thick topsoil of brownish black, firm clay to silty clay with a fine angular blocky structure overlies brownish black to dark brown, mottled, firm clay and clay loam with a fine angular blocky structure and root galleries (fluvial material). A black, mottled, firm to very firm heavy lacustrine clay with a coarse prismatic structure, disintegrating into medium blocks usually starts between 100 and 150 cm.
On the higher land the heavy lacustrine clay subsoul is absent. Soils then have clay loam and loam texture throughout (observations Nos 25 and 34), are strongly mottled and sometimes contain yellow/red stains from weathered rock.

Chemical aspects: non-saline; slightly acid, in places strongly acid subsoil starting between 80 and 160 cm; the coarse-textured soils show a neutral reaction; predominantly non-calcareous.

Physical aspects: very few, small cracks (1-1½ cm wide) with polygons of 20-30 cm diameter; soils usually have a slaked surface, occasionally with a platy, curling crust; desiccated soils; the fluvial clay to silty clay top layers have a moderately slow hydraulic conductivity; the underlying heavy lacustrine clay subsoil has a very slow hydraulic conductivity, the lighter variants have a moderately slow hydraulic conductivity (valid for moist/wet conditions).

Soil classification: gleyic CAMBISOLS.

Soil suitability for irrigated rice: moderately suitable (class 2c).

Representative profile: Appendix IV-B, profile pit No. 3.

Remarks: Under dry conditions the soils occasionally show evidence of a white eluvial horizon within the top - 60 cm (intergrade to dystric Planosols).

6.6.3 Soils developed on lacustrine sediments (Kano clay)

The soils of the lacustrine plain have been grouped into two soil mapping units. The soils have a very similar texture profile: clay or heavy clay of lacustrine origin throughout with a very slow hydraulic conductivity.

Mapping unit PlA2 comprises soils that are situated in a shallow depression within the vast plain composed of soils of mapping unit PlA1. The main difference between the soils of PlA1 and PlA2, however, is the presence of a bleached, eluvial sub-surface horizon within 40 cm depth in the soils of unit PlA2. Therefore the soils of the latter unit have been classified as Planosols. The adjacent black, cracking clay soils without a bleached horizont (unit PlA1) have been classified as Vertisols.

Mapping unit: PlA1

Topography:
macro: flat; lowest parts of the lacustrine plain.
meso : severely eroded irrigation canals up to 1.5 m deep and 1.5-2.5 m wide are present in both delineated areas.
micro: irregular broken bunds; cow foetoes; in places hummocks, wide cracks.

Overwash: none.

Vegetation/land use: grassland with rushes and sedges on recently abandoned rice fields.

Drainage conditions: poorly drained; seasonally flooded to a depth of at least 60 cm; groundwater level > 200 cm (July 1981).

Soils: have a 20-25 cm thick topsoil of brownish black, mottled, very firm, cracking clay with a coarse prismatic structure disintegrating into medium angular blocky elements. This horizon overlies brownish black, mottled, extra firm, cracking heavy clay with a very coarse prismatic structure. Black, firm clay with a fine angular blocky structure and with pressure faces on the peds starts between 70 cm and 140 cm.

Chemical aspects: non-saline throughout; slightly acid, though sometimes strongly acid between 50 cm and 160 cm and occasionally up to 200 cm; non-calcareous.

Physical aspects: cracks, although not abundant, from 1 to 5 cm wide, polygons have a diameter of 30-50 cm. This suggests that the hydraulic conductivity is high in the dry season; when wet, the hydraulic conductivity of the entire profile is very slow.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Representative profile: Appendix IV-B, profile pit No. 4.

Remarks: Severe gully erosion continues to the present day.

Mapping unit: P1A2

Topography:
macro: flat; sloping 0.3% northwestwards.
meso : some scattered, 1-1.5 m deep eroded irrigation canals; in the western part of this unit close to the tarmac road to Ahero rill erosion has resulted in a hummocky surface (hummocks 30-40 cm high, 20-40 cm wide, 20-50 cm apart).
micro: irregular broken bunds; cow foetoes.

Overwash: none.

Vegetation/land use: grassland with rushes and sedges on predominantly recently abandoned rice fields (Fig. 6.1).

Drainage conditions: poorly drained; seasonally flooded to a depth of up to 60 cm; groundwater level > 200 cm (July 1981).

Soils: have a 15-25 cm thick topsoil of brownish black to dark brown, mottled, very firm, slightly cracking clay, usually over a 10-20 cm thick (bleached) eluvial horizon of brownish gray to grayish yellow brown (when dry), faintly mottled, firm clay. The transition to the subsoil occurs between 30 and 50 cm and is abrupt. This subsoil consists of black, faintly mottled, very firm heavy clay. In places the subsoil changes between 90 and 160 cm into brownish black, faintly mottled, firm clay. These soils have medium prismatic structure, disintegrating into medium angular blocky elements.

Chemical aspects: non-saline; slightly acid with a tendency to strongly acid in the A and E horizons; in places strongly acid subsoils deeper than 160 cm; non-calcareous.

Physical aspects: small cracks (width 1-2.5 cm) are present, although not abundant, diameter of polygons 20-40 cm; usually deep desiccated soils with a slaked surface; when wet, these soils have a very slow hydraulic conductivity.

Soil classification: dystric PLANOSOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Representative profile: Appendix IV-B, profile pit No. 5.

Remarks:

1. In the southern part a thin intercalation of coarse sand and weathered rock fragments occasionally encountered within 70 cm.
2. Soils in the western part sometimes have a thin (10-30 cm) cover of fluvial, dark brown, mottled clay loam.
3. Rill and gully erosion are still active.

7 SOILS OF THE KORE AREAS

7.1 Geology and parent material

Within the Kano Plain the Kore areas form the transition between the lower-lying swamps with lacustrine deposits and the slightly higher areas where fluvial material has been deposited on the lacustrine deposits. The geological history is similar to that of the Kano Plains: deposits of lacustrine clay have in places been eroded and reworked by fluvial activity.

Most of the Kore areas consist of heavy clay soils derived from lacustrine sediments. Several rivers have deposited fine-textured fluvial material in levees along their banks. These levees are slightly higher than the adjacent lacustrine plain; their degree of development, however, is not consistent. The soils on these levees usually consist of a mottled clay loam to clay, abruptly underlain by heavy lacustrine clay.

7.2 Hydrology and flooding

The upper course of the Ombeyi river with faintly developed levees forms the northern boundary of Kore I; the upper course of the Miriu river flows along the southern border of Kore II. Both meandering rivers arise in the papyrus swamps and flow southwest, ultimately into Lake Victoria. In their turn the swamps collect the waters from various rivers and streams that drain the Nyando escarpment and adjoining areas.

The extended lacustrine plain is flat with an overall slope of 0.2% from east to west; areas with fluvial sediment are flat to nearly flat with slightly sloping channel banks.

Floods are frequent: in Kore I they can be up to 40 cm deep and in Kore II up to 60 cm deep, though the higher land is less affected. Because the floodwaters are reinforced by the adjacent swamps, in the wet season the inconvenience of the floods can be prolonged for some time.

7.3 Land use

Paddy is by far the most important crop. To date, the area under paddy has been expanding. Reclamation works are in progress along the northern fringes of the areas and in between the Kore areas. A minor portion of the areas consists of swampy grassland.

7.4 General soil characteristics and soil classification

Soils are non-saline and non-calcareous; in places slightly saline and/or slightly calcareous subsoils are found below 160 cm. The soil reaction is slightly acid to neutral, often moderately alkaline at a depth of 80 cm and below. Note that soils contain a relatively high level of exchangeable sodium from about 100 cm onwards (sodic).

The soils on fluvial sediments are imperfectly to poorly drained. The soils on the lacustrine sediments are very poorly drained. Both areas have impeded drainage and are partly waterlogged for much of the year.

Groundwater was not encountered within 2 m depth.
The hydraulic conductivity of the soils ranges from moderately slow to very slow.

The soils of the Alluvial Plain have developed on recent and subrecent sediments over lacustrine sediments. They have been classified as eutric Fluvisols.

All the soils of the Lacustrine Plain have developed on lacustrine sediments. They have been classified as pellic Vertisols.

The groups and subgroups are outlined in Table 7.1.

Physiography	Parent material	Major Soil Group	Subgroup
alluvial plain	recent and sub-recent fluvial sediments over lacustrine sediments	Fluvisols	eutric Fluvisols
lacustrine plain	lacustrine sediments	Vertisols	pellic Vertisols

Table 7.1 Subgroups of soil classification in relation to physiography and parent material

Table 7.2 gives the area of the two soil mapping units distinguished. They are described in Chapter 7.5.

Soil mapping unit	Kore I extent in ha	%	Kore II extent in ha	%	Total area extent in ha	%
PfA1	8.5	10.4	2.2	6.4	10.7	9.2
PlA1	73.2	89.6	32.0	93.6	105.2	90.8
	81.7	100.0	34.2	100.0	115.9	100.0

Table 7.2 Absolute and relative extent of the soil mapping units

7.5 Description of the soil mapping units

7.5.1 Soils developed on recent and subrecent fluvial sediments over lacustrine sediments (Kano clay)

The soils of the alluvial plain on this parent material have been grouped into one soil mapping unit. Soils have a fluvial cover of clay loam to clay overlying heavy lacustrine clay. The non-stratified heavy subsoil starts between 45 and 100 cm.

Mapping unit: PfA1

Topography:
Macro: the part of the levee bordering the lacustrine plain is flat; the part of the levee along the (former) river channel slopes gently; the levee in Kore II is more pronounced than in Kore I, except for the westernmost part of the latter.
Micro: bunds, cow foetoes, trenches.

Overwash: none.

Vegetation/land use: predominantly grassland; some paddy fields; maize and millet on the highest ground.

Drainage conditions: imperfectly to poorly drained; seasonally flooded up to 30 cm deep, except for the higher parts; groundwater level usually > 200 cm (July 1981), although there are places with water on the surface.

Soils: have a 45-80 cm thick (Kore I) or 70-100 cm thick (Kore II) topsoil of brownish black to dark brown, mottled, friable to firm, clay loam to clay of fluvial origin over black, mottled, very firm, lacustrine heavy clay, in places between 140 and 170 cm changing into brownish black, faintly mottled, firm (lacustrine) clay. Medium angular blocky structure throughout.

Chemical aspects: non-saline, in general salt concentration tends to increase with depth, in some places slightly saline subsoils (> 160 cm) are found. Slightly saline groundwater was encountered in observations Nos 7 and 12 (Kore II); Kore I soils are slightly acid to neutral throughout, Kore II soils are neutral, with a moderately alkaline subsoil below 80 cm; in both areas soils are predominantly non-calcareous; in places sodic subsoil below 90 cm.

Physical aspects: no cracks were observed because moist to wet soil conditions prevail; hence, the clay loam to clay fluvial top layers have a moderately slow hydraulic conductivity, the lacustrine heavy clay subsoil has a very slow hydraulic conductivity.

Soil classification: eutric FLUVISOLS.

Soil suitability for irrigated rice: moderately suitable (class 2c).

Representative profile: Appendix IV-C, profile pit No. 1.

Remarks: Topsoil material is used for pottery.

7.5.2 Soils developed on lacustrine sediments (Kano clay)

The soils of the lacustrine plain belonging to this mapping unit have a uniform textural profile. They consist entirely of lacustrine sediments. These paddy soils have a cracking heavy clay that tends to have a coarser texture below 150 cm. There is evidence of sodic properties of the subsurface layers.

Mapping unit: PlA1

Topography:
macro: flat; sloping 0.2% westwards.
meso : irrigation canals; some termite mounds.
micro: bunds; trenches, cow foetoes, hummocks.

Overwash: none.

Vegetation/land use: Kore I, irrigated paddy fields and grassland with rushes and sedges; Kore II almost entirely irrigated paddy fields and papyrus swamp.

Drainage conditions: very poorly to poorly drained; frequently flooded to a depth ranging from 15-40 cm (Kore I) and from 30-60 cm (Kore II); paddy fields in Kore I usually have 5-20 cm water on the surface, in Kore II slightly more (10-20 cm); grassland is very wet and ponded; groundwater level presumably > 200 cm (July 1981), proper observation was hindered by surface water.

Soils: have a 10-20 cm thick topsoil of black, muddy, sticky and plastic, cracking clay to heavy clay (puddle layer); consistency under grassland is firm. This horizon is underlain by black, faintly mottled, very firm, cracking heavy clay. In places at a depth between 130-150 cm, the subsoil changes into a brownish black to dark brown, firm clay. The upper part of these soils has a fine angular blocky structure with pressure faces; the subsoil is massive. Root galleries throughout the profiles.

Chemical aspects: non-saline; soils in Kore I have a slightly acid topsoil and are neutral below 50 cm; Kore II soils show a neutral soil reaction, but sometimes are moderately alkaline at depths below 80 cm; non-calcareous, scattered observations reveal a slightly calcareous subsoil below 150 cm; in places sodic subsoil below 100 cm; groundwater is non-saline.

Physical aspects: the prevailing moist or wet soil conditions prevent the soils from cracking, however in the non-submerged parts of the paddy fields cracking starts immediately and intensively; the hydraulic conductivity of the soils is very slow.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Representative profile: Appendix IV-C, profile pit No. 2.

Remarks:

1. Soils usually become relatively drier with depth (note also the consistency in the representative profile).
2. Very occasionally small weathered rock fragments and/or calcium carbonate concretions were found.

Fig. 8.1 "Bottleneck" in the Maugo valley near benchmark No. 4. Such narrow passages of the river cause considerable differences in height of flooding: upstream approx. 1 m, downstream much less.
In the valley (dark on the photograph) sugar cane on soils of mapping unit PfA13 (foreground) and yams on soils of mapping unit PlA5 (middle). The higher lying part behind the valley (lighter on the photograph) is cultivated with maize and consists of soils developed on old alluvial sediments (older terrace; mapping unit PfA31).

8 SOILS OF THE MAUGO AREA

8.1 Geology and parent material

The study area lies on the lower course of the Maugo river, just before the latter debouches into the Awach Tende river.

A large proportion of the area on the lacustrine plain with lacustrine sediments is flat. In the alluvial plain the development of the levees along the Maugo river varies. In the long central section with fluvial sediments the terrain is almost flat (< 1% slope). The levees are only slightly higher than the adjoining areas with lacustrine sediments. In the northernmost part along the Awach Tende river and also in the south along the Maugo, the levees are more pronounced. In places where terrace remnants with old alluvial deposits occur, the relief is usually very gently undulating, although the edges of the terraces have been smoothed by fluvial processes. Parts of the higher footslopes slope gently.

The following interpretation of the genesis of the area is based on field observations.

After the early Maugo river had cut a channel in rhyolite rock, marl must have been deposited. Subsequent erosion has removed these deposits, though in a few places - in valleys adjacent to the present river course - some outcrops testify to the former presence of marl. The river bed aggraded with calcareous material was also eroded at a later stage.In places remnants of the former floodplain (terrace) are found (Fig. 8.1),though nowadays they are covered with younger deposits. These terrace remnants mainly occur along the hill slopes and as isolated, elevated areas in the floodplain.

During the Pleistocene period, when the whole area was part of an enlarged Lake Victoria, lacustrine deposits (Fig. 8.5) were laid down. These deposits can be correlated with the Kano clay, because the level of the lake in Pleistocene times is thought to have been 1220 m, considerably higher than the present altitude of the Maugo area (1170 m). The present-day Maugo river has only caused minor changes. Bands of stratified fluvial and reworked lacustrine deposits

along its course (levees) alternate with vast areas of basin-like lacustrine deposits. The genesis of the area is reflected in the pattern of the various soil parent materials. Most of the Maugo valley is occupied by black lacustrine clay sediments, usually encountered in places with a basin-like environment. Several separate areas delimited by the meandering river have been recognized. Fluvial deposits are found adjacent to the present and former river bed. Stratified, fine- and medium-textured material prevails,especially in the long and narrow strip along the river. Coarser variants are restricted to the southernmost and northernmost borders of the area. Transitions between both parent materials also occur, as distinct lacustrine sediments are overlain by fluvial sediments. The latter vary in thickness, texture and time of sedimentation.

The isolated terrace remnants, although affected by lacustrine sediments, are characterized by calcareous clay and clay loam deposits whose chemical properties differ considerably from those of the lacustrine sediments.

Minor parts of the area bordering the surrounding hills have colluvial and lacustrine sediments of varied texture over rhyolite rock at variable depth.

8.2 Hydrology and flooding

The Maugo river in this area is confined within a valley of varying widt. The overall length of the stream between benchmark 7 where the river enters the area and its outlet near the bridge in the murram road to Kendu Bay is 5.5 km; the fall is roughly 23.5 m, hence the gradient is about 0.4%.

In the long river valley the seasonal floods vary greatly from place to place, because of variations in the width of the valley. "Bottlenecks" occur where the water is detained and the floods can reach a height of about 1 m e.g. near benchmarks 4 and 6 (Fig. 8.1). The influence is not restricted to those locations, but also affects large areas on the upstream side where floods 40-90 cm deep are common. In the northern part of the area where water can spread out more easily,

Fig. 8.2 The New Maugo Branch was formed by erosion of former irrigation canals.

Fig. 8.3 Lateral corresion causes to fall huge lumps of soil into the present stream.

Fig. 8.4 Gully formed by regressive erosion as a result of seasonal overland flow.

floods 30-40 cm deep frequently occur. Near the northwestern outlet, floods up to 60 cm deep can occur. The terrace remnants are also prone to floods up to 30 cm deep. The footslopes are only rarely flooded.

During the survey (August 1981) most of the area west of benchmark 3 on both sides of the river was irrigated, although insufficient irrigation water was supplied to inundate all the paddy fields.

8.3 Erosion

During the wet season a large volume of water has to pass through the Maugo river valley. Consequently, overflowing and serious flooding occur. Simultaneously, the erosion of irrigation canals is intensified. A striking example of the latter can be found in the northern section of the area (northeast of benchmark 1) where the Maugo river has abandoned its former channel and has taken a new, shorter course through a former irrigation canal. Here the stream is cutting down very rapidly (2-3 m) and has also widened the channel considerably (3-4 m) (Figs 8.2 and 8.3). In this section, northwest of benchmark 1, strong overland flow has caused severe regressive erosion in deep gullies (Fig. 8.4). Near benchmark 4, in the narrow part of the river valley, many gullies (up to 1 m deep, ½-1 m wide) are present (spillways), which discharge superfluous water eastwards. They merge into an eroded irrigation channel bordering the northeast side of the area near benchmark 3.

In the southernpart of the area erosion has destroyed several irrigation canals. In places the recently dug "Japanese" irrigation canal near benchmark 6 has captured the waters of the Maugo river. The former course with a slight gradient has been abandoned; the flow in the new canal is rapid and leads to deepening of the canal bottom. Thus lateral corrasion can be expected.

Another aspect of the erosion of irrigation canals is the occasional presence of sheets of coarse sands (overwash), spread out over the downstream side of the affected canals.

8.4 Land use

Grassland, often on abandoned rice fields, is by far the most important land use in the northern and southern parts of the area that have lacustrine sediments. Irrigated paddy fields occur in the central section, west of benchmark 3. The almost permanently flooded area north of benchmark 6, also on lacustrine sediments, is used for the cultivation of vegetables and yams and some paddy. The areas along the Maugo river with groundwater within 1 to 2 m depth have a variety of crops such as maize, millet, sugar cane and vegetables. The first two are often found on the higher parts of the levees of the Maugo and Awach Tende rivers. On the footslopes and the terrace remnants, maize, cotton and millet are the main crops.

8.5 General soil characteristics and soil classification

The soils on the lacustrine sediments are poorly to very poorly drained. The soils of the alluvial plain on fluvial sediments throughout are mostly well to imperfectly drained and in some places are poorly drained. Whenever the fluvial deposits are underlain by lacustrine sediments, the drainage conditions range from poor to imperfect. The soils on the terrace remnants are usually moderately well drained, as are the soils on the colluvial sediments of the footslopes.

Over most of the area no groundwater is encountered within 200 cm. In a narrow strip bordering the Maugo river, groundwater is sometimes encountered within 200 cm, except in the severely eroded northern stretch of the river. The vast area lying roughly between benchmarks 6 and 4, which has impeded drainage, is almost permanently flooded and often has a groundwater level within 50 cm.

The soils that are predominantly developed on lacustrine sediments have a very slow hydraulic conductivity, as do the comparable soils with a moderatly thick, fine-textured fluvial cover. Soils on stratified, coarse, fluvial material have a rapid or moderately

rapid hydraulic conductivity, while the underlying lacustrine subsoils have a slow to very slow hydraulic conductivity. The hydraulic conductivity of the soils ranges from moderately rapid to slow and very slow, depending on the texture of the fluvial sediments.

The soils of the footslope developed on old colluvial sediments over rhyolite have been classified as eutric Cambisols and eutric Regosols.

The soils of the Alluvial Plain developed on recent and subrecent fluvial sediments have been classified as eutric Fluvisols.

The soils of the Alluvial Plain developed on recent and subrecent fluvial sediments over lacustrine sediments have been classified as eutric Fluvisols and pellic Vertisols respectively. The soils of the Alluvial Plain developed on old alluvial sediments (older terrace) have been classified as calcic Cambisols. Because of the prevailing sodic and saline properties of the soils, they have been characterized as sodic and as saline/sodic phase.

The soils of the Lacustrine Plain developed on black lacustrine sediments have been classified as pellic Vertisols.
The major groups and subgroups are outlined in Table 8.1.

Physiography	Parent material	Major Soil Group	Subgroup
footslope	old colluvial sediments over rhyolite	Cambisols Regosols	eutric Cambisols eutric Regosols
alluvial plain	recent and sub-recent fluvial sediments	Fluvisols	eutric Fluvisols
	recent and sub-recent fluvial sediments over lacustrine sediments	Fluvisols Vertisols	eutric Fluvisols pellic Vertisols
	old alluvial sediments (old terrace)	Cambisols	calcic Cambisols, sodic phase calcic Cambisols, saline/sodic phase
lacustrine plain	lacustrine sediments	Vertisols	pellic Vertisols

Table 8.1 Subgroups of soil classification in relation to physiography and parent material

Table 8.2 gives the extent of the 16 soil mapping units distinguished. They are described in Chapter 8.6.

Soil mapping unit	Extent in ha	%
FC1	6.5	2.3
FC2	1.5	0.5
PfA11	11.5	4.0
PfA12	2.0	0.7
PfA13	41.5	14.5
PfA21	1.5	0.5
PfA22	4.0	1.4
PfA23	17.0	5.9
PfA31	18.5	6.5
PfA32	2.5	0.9
PlA1	63.5	22.2
PlA2	23.5	8.2
PlA3	28.5	9.9
PlA4	40.3	14.1
PlA5	22.0	7.7
PlA6	2.0	0.7
Total area	286.3	100.0

Table 8.2 Absolute and relative extent of the soil mapping units.

8.6 Description of the soil mapping units

8.6.1 Soils developed on old colluvial sediments or on old colluvial sediments and lacustrine sediments over rhyolite

The soils of the footslope on this parent material have been grouped into two soil mapping units. These soils, occuring in scattered patches over the area, are situated on the transition from the level plain to the adjacent hills.

Colluvial material of varied textural composition overlies rhyolite rock, although in places intercalations of black clay of lacustrine origin can be found. The depth of the solum is the only differentiating criterion. It separates the shallow soils of unit FC2 from those of

unit FC1 where rock is present at a depth varying between 90 cm and 160 cm.

Weathered rock fragments and stones throughout the profile are common features.

Mapping unit: FC1

Topography:
macro: very gently sloping, usually regular slope; lowest spurs of bordering hill.
meso : trenches
micro: uneven ploughed land; cow foetoes.

Overwash/rockiness: except for the easternmost area, soils are characterized by the presence of overwash on the surface and intercalations of coarse sand, fine gravel, stones and/or weathered rock fragments within the profile; in the two easternmost areas rhyolite rock starts between 90 and 160 cm. Calcium carbonate concretions occur above the rock.

Vegetation/land use: arable land with maize/cotton.

Drainage conditions: moderately well drained; little affected by seasonal floods (maximum 20 cm deep); no groundwater within 200 cm (July 1981).

Soils: have a 25-40 cm thick topsoil of brownish black, friable clay loam with weathered rock fragments and fine gravel. The topsoil usually overlies a brownish black to dark brown, slightly mottled, friable clay loam with many red and yellow weathered rock fragments (colluvial sediments) in places. Stratified, thin beds of coarse sand are also encountered here. In the easternmost delineated area the clay loam sediments are interrupted by a 50 cm thick layer of black mottled, firm heavy clay (lacustrine sediments) abruptly underlying the topsoil.

Chemical aspects: non-saline, slightly acid to neutral; non-calcareous; in both northeastern areas moderately alkaline and slightly calcareous from 80 cm onwards.

Physical aspects: no cracks observed; slightly slaked surface; under wet conditions the hydraulic conductivity of the soils is moderately slow, that of the intermediate heavy clay is very slow.

Soil classification: eutric CAMBISOLS.

Soil suitability for irrigated rice: marginally suitable (class 3c).

Mapping unit: FC2

Topography:
macro: gently undulating to undulating; regular slope (2-6%).
micro: uneven ploughed land.

Stoniness/rockiness: in places fairly stony; rock (rhyolite) present within 35 cm.

Vegetation/land use: grassland, maize.

Drainage conditions: moderately well drained; no flooding.

Soils: consist of 30-35 cm dark brown to dull yellowish brown, friable, very gravelly, loam and clay loam over rhyolite rock.

Chemical aspects: non-saline; slightly acid; non-calcareous.

Physical aspects: no cracks observed; the loam and clay loam layers of these soils have a moderate hydraulic conductivity (wet conditions).

Soil classification: eutric REGOSOLS.

Soil suitability for irrigated rice: unsuitable (class NStd).

8.6.2 Soils developed on recent and subrecent fluvial sediments

The soils of the Alluvial Plain on this parent material have been classed into three soil mapping units. Almost all of these slightly higher-lying levee soils border the Maugo and Awach Tende rivers. The soils are stratified, their textural profiles nevertheless differ considerably. The units have been separated on the basis of differences in texture profile and drainage status.

The soils of unit PfA11 are well to imperfectly drained and distinctly stratified: clay and clay loam layers of variable thickness frequently alternate with layers of coarse sand. In contrast, the soils of unit PfA12 are faintly stratified with layers of clay and clay loam that have a narrow range in clay content. Unit PfA13 consists of imperfectly to poorly drained, stratified, finer-textured soils. The sequence and the thickness of the various layers is very variable.

Mapping unit: PfA11

Topography:

macro: flat to very gently undulating; levee of Maugo river; slightly higher than the surroundings.

meso : former river channel; some gullies towards old river channel and Japanese canal.

micro: unused bunds; uneven ploughed land; furrows with crops on small ridges; rills; cow foetoes.

Overwash: very frequently a slight overwash of coarse sand and fine gravel on the surface, predominantly in the eastern part.

Vegetation/land use: maize, millet, sugar cane, cassava, grassland.

Drainage conditions: well to imperfectly drained; the seasonal flood ranges in depth from 30 cm (eastern part) to 60-70 cm (western part); groundwater level often > 200 cm, in the western part of the delineation along the meandering Maugo river course the groundwater level varies from 100-200 cm (August 1981).

Soils: are characterized by distinct stratification. Most of these soils consists of dark brown to brownish black, mottled, friable to firm clay loam with coarse sand grains. Brownish black to black, mottled, firm clay layers of various thickness are present at various depths. These layers are frequently intercalated with stratified, coarse-textured material, ranging from slightly gravelly, coarse sand to loam with coarse sand grains, usually of varying thickness. The subsoil from about 150 cm onwards is a black, friable clay loam throughout.

Chemical aspects: non-saline; predominantly slightly acid, in places strongly acid from 50 cm onwards; non-calcareous; the northernmost delineated area is moderately alkaline and slightly calcareous because of the presence of an adjacent marl outcrop; groundwater is non-saline.

Physical aspects: small cracks (width ½-1 cm) with a polygon diameter of 20-30 cm were in places observed; in places a slaked surface with thin, small crusts; under wet conditions these heterogeneous soils have a variable hydraulic conductivity ranging from moderately rapid for the coarse-textured material to slow for the clay layers.

Soil classification: eutric FLUVISOLS.

Soil suitability for irrigated rice: unsuitable (class NSc).

Remarks: Fluvial sediments sometimes contain charcoal inclusions.

Mapping unit: PfA12

Topography:
macro: flat to very gently undulating; levee; deep (5 m) incised Awach Tende river.
meso : few deep (1-2.5 m) grass-covered erosion gullies.
micro: uneven ploughed land.

Overwash: none.

Vegetation/land use: millet (excellent crop).

Drainage conditions: moderately well to imperfectly drained; the depth of the seasonal flood is about 30 cm; groundwater > 200 cm (July 1981).

Soils: have a 20 cm thick topsoil of dark brown to brownish black, mottled clay loam over stratified dark brown, mottled, friable clay loam and firm clay. The stratification is mainly caused by minor differences in clay content between the layers and also by slight differences in colour. Only thin intercalations of loam are present.

Chemical aspects: non-saline; slightly acid; predominantly non-calcareous.

Physical aspects: no cracks observed; slaked surface; under wet conditions soils have moderately slow hydraulic conductivity.

Soil classification: eutric FLUVISOLS.

Soil suitability for irrigated rice: moderately suitable (class 2c).

Mapping unit: PfA13

Topography:

macro: flat to very undulating; levees in varying stages of development; this mapping unit includes a relatively narrow strip of slightly higher soils along the present (and in places along the abondoned) courses of the Maugo and the Awach Tende rivers. The terrain slopes from the channel towards the adjacent basin areas.

meso : in places former river channel; in places severe erosion with deep gullies; many spillways, especially in the neightbourhood of benchmark 4,incised up to 1 m; eroded and current irrigation canals; some trenches.

micro: rills and hummocks in the northwesternmost part and near benchmark 4; bunds, some unused; cow foetoes; termite mounds on the highes sites along the Awach Tende river; uneven ploughed land.

Overwash/stoniness: Rare patches of very slight overwash of red/yellow, weathered rock fragments on the surface.

Vegetation/land use: in the northern half of this mapping unit, especially on the higher places close to the channel: maize, millet, cotton; in the lower areas, grassland, sometimes with shrubs; the same applies for the southern part, although here sweet potaties, sugar cane and vegetables (yam, bean) were also noted (Fig. 8.1); in areas prone to erosion (gullies and spillways) many bushes.

Drainage conditions: imperfectly to poorly drained, depending on textural differences and/or position with respect to the channel; in this long narrow mapping unit the seasonal flood varies greatly in depth: from 30 cm along the Awach Tende river in the east to about 60 cm in the west; at its southern end the depth of flooding increases gradually from 30 cm in the north to 50-60 cm in the southwest; in narrow stretches, e.g. near benchmark 4, the floods can be 80-100 cm deep (Fig. 8.1); in the latter area, groundwater is frequently encountered between 80-200 cm, elsewhere, invariably > 200 cm (August 1981).

Soils: are heterogeneous. They have in common a slightly higher elevation in the terrain, a varied land use, a brownish colour and mottles, and, moreover, a relatively narrow range in texture; clay loam, clay and heavy clay. The sequence of the different textured layers varies from place to place. It is believed that these soils have developed on lacustrine sediments reworked and redeposited by fluvial processes.
Soils usually have a 15-25 cm thick topsoil of brownish black, mottled, slightly cracking, friable clay loam to firm clay. Thin topsoils are often underlain by heavy clay. In wet sites the consistency of the topsoil is slightly plastic and slightly sticky. The stratification of the underlying subsoil varies from place to place: brownish black, firm clay layers of variable thickness alternate with layers of black, very firm silty clay and/or brownish black, friable clay loam. In places these clay loam/silty clay layers are absent. In places thin pockets of coarse sand and/or some coarse grains are encountered.

Chemical aspects: non-saline throughout; predominantly slightly acid, below 160 cm slightly acid to neutral; rarely a moderately alkaline soil reaction; non-calcareous, in scattered places slightly calcareous below 110 cm, groundwater is non-saline.

Physical aspects: few cracks were observed; in the southern part cracks (1-1.5 cm wide, polygon diameter 25-40 cm) are often present; in several places a slightly slaked surface with thin crusts; under wet conditions the soils of this mapping unit have a varied hydraulic conductivity: heavy clay very slow; clay loam moderately slow. The sequence of layers varies from place to place, making it difficult to generalize about the hydraulic conductivity of these soils.

Soil classification: eutric FLUVISOLS.

Soil suitability for irrigated rice: moderately suitable (class 2c).

Representative profile: Appendix IV-D, profile pit No. 1.

Remarks: This mapping unit also includes some small patches of soils along the Awach Tende river which are very similar to those of unit PfA12. Inclusions of soils of mapping unit PlA5 were also encountered.

8.6.3 Soils developed on recent and subrecent fluvial sediments over lacustrine sediments

The soils of the Alluvial Plain on this parent material have been placed into three soil mapping units. All these soils have in common an intermediate position between the levee soils and the soils of the lacustrine plain. Fluvial material of variable thickness and texture overlies lacustrine clay sediments. The soil of units PfA21 and PfA22 are marked by stratified, coarse- and medium-textured top layers. They have been differentiated according to the thickness of the recent fluvial cover. The upper part of the soils of unit PfA23 is usually a non-stratified clay, occasionally with some sand grains.

Mapping unit: PfA21

Topography:
macro: flat to very gently undulating
meso : very few eroded irrigation canals (depth 1 m, width 1-3 m).
micro: rills, hummocks, sand ridges (< 30 cm high).

Overwash: a slight overwash of (coarse) sand.

Vegetation/land use: grassland with rushes.

Drainage conditions: imperfectly drained; the seasonal flood ranges from 50 cm in the northern delineation to 80 cm in the south; groundwater level 135-200 cm (August 1981).

Soils: have a 50-70 cm thick top layer of stratified material of various textures. Layers of mainly black, very friable sandy loam or loam alternate with layers of dark brown, mottled, friable clay loam. Coarse sand grains and thin layers of sand, weathered rock fragments and calcium carbonate concretions are almost always present in the top 70 cm. The subsoil is of lacustrine origin and consists of brownish black, slightly mottled, firm clay changing at a depth of about 140 cm into dull yellowish brown, slightly mottled, firm clay loam with $CaCO_3$ concretions.

Chemical aspects: non-saline; moderately alkaline soils in the northern area, slightly acid in the south; predominantly non-calcareous, slightly calcareous below 140 cm onwards; groundwater is moderately saline.

Physical aspects: no cracks observed; under wet conditions the medium- and coarse-textured top layers have a variable hydraulic conductivity ranging from rapid to moderate; the subsoil has a slow to moderately slow hydraulic conductivity.

Soil classification: eutric FLUVISOLS.

Soil suitability for irrigated rice: unsuitable (class NSc).

Remarks: Erosion and sedimentation by river spillways can be expected during the flood season.

Mapping unit: PfA22

Topography:

macro: flat to very gently undulating.

meso : some irrigation canals, often eroded.

micro: bunds, hummocks, rills and low sand ridges, uneven ploughed land.

Overwash: a slight overwash of coarse sand.

Vegetation/land use: millet, maize, grassland, often on abandoned rice fields.

Drainage conditions: imperfectly to poorly drained; seasonally flooded (to 60-80 cm depth); groundwater level usually > 200 cm, in places 180-200 cm (August 1981).

Soils: have a 20-40 cm thick, stratified, coarse-textured, fluvial top layer consisting of brownish black to dark brown, slightly mottled, loose coarse loamy sand to friable clay loam. The topsoil abruptly overlies black to brownish black, strongly mottled, firm, cracking clay of lacustrine origin. The clay subsoils throughout, which were almost invariably present, tend to become blacker with depth (> 120 cm). In some places there is a decrease in clay content to clay loam below 120 cm.

Chemical aspects: non-saline; slightly acid soils, usually a neutral soil reaction below 160 cm; non-calcareous; groundwater is non-saline.

Physical aspects: cracks ½-2 cm wide were present, polygon diameter 15-30 cm; in places a slaked surface with a thin crust; under wet conditions the hydraulic conductivity of the coarse-textured topsoil ranges from moderately rapid to moderately slow, the subsoil has a slow hydraulic conductivity.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: moderately suitable (class 2c).

Remarks: Soils are comparable with those of mapping unit PfA21, the latter have a more pronounced and thicker fluvial cover.

Mapping unit: PfA23

Topography:
macro: flat; this unit comprises soils in the transitional zone between lacustrine plain and the present or former levees of the Maugo and Awach Tende rivers.
Meso : in places severe regressive erosion with deep (½-1½m) and wide (½-3 m) gullies (badlands); some (eroded) irrigation canals; the southernmost and northernmost areas are not affected by erosion.
micro: hummocks, rills, bunds, uneven ploughed land; cow foetoes.

Stoniness: very occasionally some small weathered rock fragments, in the northern areas in the deeper subsoil, in the south mainly in the topsoil.

Vegetation/land use: grassland, partly on abandoned rice fields; millet, maize and cotton.

Drainage conditions: poorly to imperfectly drained; the depth of the seasonal flood varies per area: in the north about 30 cm, in the centre up to 100 cm and in the south 40-70 cm; groundwater level > 200 (July 1981); water level in New Maugo Branch about 3.5 m below the surface.

Soils: have a 20-40 cm thick topsoil of dark brown to brownish black, mottled, firm, slightly cracking, fluvial clay, in places mixed with a small amount of coarse sand grains. The subsoil consists of black, faintly mottled, very firm, cracking lacustrine heavy clay to clay, but in the southern area of lacustrine clay only. In general the subsoils tend to become slightly less fine-textured below 120 cm. Soils have a distinct coarse to very coarse prismatic structure, disintegrating into coarse angular blocks. Many pressure faces were found on the peds of the subsurface horizons.

Chemical aspects: non-saline, except for some rare spots with gypsum crystals in the deeper subsoil which are slightly saline; slightly acid, from 150 cm usually a neutral reaction; non-calcareous.

Physical aspects: cracks were not often observed, if present they were ½-1½ cm wide, sometimes, however, cracks up to 4 cm with a polygon diameter of 30-40 cm; in places a slaked surface with 3-6 cm large crusts; under wet conditions soils have a very slow hydraulic conductivity.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Representative profile: Appendix IV-D, profile pit No. 2.

Remarks: Soils are very similar to those of mapping unit PlA3; the latter lack the 20-40 cm thick cover of fluvial material.

8.6.4 Soils developed on old alluvial sediments (older terrace)

The soils of the Alluvial Plain on this parent material have been classed into 2 soil mapping units.

These soils have clay to clay loam textures with many calcium carbonate concretions. Moreover, they are calcareous and have a strongly alkaline soil reaction. Other striking chemical properties are the salinity and the sodicity of the soils.

The drainage status forms the main differentiating criterion between the units.

Mapping unit: PfA31

Topography:

macro: very gently undulating; relatively high camber beds between hills and/or low-lying alluvial plain.

meso : sheet erosion along the lower fringes.

micro: uneven ploughed land; cow foetoes; gilgai-like surface with infilled cracks.

Overwash/stoniness: in places some rhyolite stones; frequently calcium carbonate concretions on the surface and in the profile, in variable amounts and sizes (½-2 cm), especially on the lower margins.

Vegetation/land use: maize, millet, cotton and grassland.

Drainage conditions: well to moderately well drained; higher parts are not affected by the seasonal floods, lower areas have floods from 20 to 40 cm deep (Fig. 8.1); groundwater nowhere within 200 cm (August 1981).

Soils: have a 20-25 cm thick topsoil of brownish black, faintly mottled, friable, slightly cracking clay to clay loam. The topsoil is underlain by brownish black to dull yellowish brown, sometimes faintly mottled, friable clay loam throughout. Calcium carbonate concretions of various sizes and quantities are present, moreover patches of soft powdery lime occur. Very often, abruptly below the topsoil a 20-40 cm thick intermediate layer of black, faintly mottled, firm clay is encountered, usually lacking the aforementioned concretions. In the main area, rock is occasionally found at a depth of about 120 cm.

Chemical aspects: non-saline, in places slightly saline subsoil starting between 50 and 80 cm; neutral to moderately alkaline but from 50 to 80 cm onwards strongly alkaline, in places very strongly alkaline; slightly to moderately calcareous, except for the top 20 cm; sodic properties throughout the profile.

Physical aspects: only a few cracks were observed, ½ to 2 cm wide; in places a moderately slaked surface with crusts (thickness 1-2 mm, diameter 5-8 cm); under wet conditions soils have moderately slow hydraulic conductivity, the intermediate clay layer has a slow hydraulic conductivity.

Soil classification: calcic CAMBISOLS, sodic phase.

Soil suitability for irrigated rice: unsuitable (class NStn).

Representative profile: Appendix IV-D, profile pit No. 3.

Remarks: It is assumed that the sodicity that is encountered in profile pit No. 3 is valid for the mapping unit as a whole. This is supported by the observed degrees of dispersion in the soil samples analysed by the NIB laboratory.

Mapping unit: PfA32

Topography:
macro: flat (to very gently undulating).
meso : some small step-like ridges resulting from erosion.
micro: few bunds and cow foetoes.

Overwash: none.

Vegetation/land use: grassland; some paddy fields; 10-30% bare ground in grassland because of high salinity.

Drainage conditions: imperfectly drained; the seasonal flood ranges from 30 to 50 cm; groundwater level just below 200 cm (August 1981); areas are affected by seepage of saline water from the more elevated hinterland.

Soils: have a 20-30 cm thick topsoil of brownish black to black, faintly mottled, firm clay over brownish black clay. At a depth of 50-70 cm the subsoil changes into a grayish yellow brown, friable clay loam with calcium carbonate concretions.

Chemical aspects: slightly saline throughout; strongly to very strongly alkaline; non- to slightly calcareous; presumably sodic properties; slightly saline and strongly alkaline groundwater.

Physical aspects: no cracks observed; in places severely slaked surface; under wet conditions soils have a slow hydraulic conductivity.

Fig. 8.5 Soils of mapping unit PIA2 consist of cracking heavy clay of lacustrine origin.

Soil classification: calcic CAMBISOLS (saline, sodic phase).

Soil suitability for irrigated rice: unsuitable (class NSrs).

8.6.5 Soils developed on lacustrine sediments

The soils of the lacustrine plain on this parent material have been grouped into six soil mapping units. These units comprise soils of black, cracking clay to heavy clay over clay loam of lacustrine origin. They are poorly drained; are neither saline nor calcareous except for the subsoil. Soil reaction ranges from slightly acid (topsoil) to neutral and moderately alkaline (subsoil).

Various differentiating criteria have been used to separate the six mapping units.

The poorly drained soils consist of black, cracking clay to heavy clay throughout.

The soils of unit PlA2 have strongly mottled clay over deep black clay (Fig. 8.5). The soils of unit PlA3 usually have a topsoil of clay loam to clay. A moderately to strongly alkaline subsoil is characteristic for the soils of unit PlA4.

The soils of unit PlA5 are characterized by a very poor drainage status and have muddy topsoils. If rock is present in the subsoil between 80 cm and 190 cm, these soils have been grouped in a separate unit (PlA6).

Mapping unit: PlA1

Topography:
macro: flat.
meso : deeply incised New Maugo Branch (width 4-6 m; depth 2-3 m; Fig. 8.2 and 8.3); in places severely regressive erosion

(Fig. 8.4) with deep gullies, merging with main erosion channel; irrigation canals.

micro: rills; hummocks, bunds, partly disused; cow foetoes; uneven ploughed land with small depressions; cracks.

Stoniness: in only a very few places bordering the hill slopes red/yellow weathered rock fragments in the upper 25 cm.

Vegetation/land use: mainly grassland, often with rushes and sedges; partly on abandoned rice fields in the westernmost area; irrigated paddy fields;attempts at irrigation in the eastern part.

Drainage conditions: poorly drained; the seasonal flood in the eastern and southern areas varies from 30-60 cm in depth; in the large western area it ranges from 60-90 cm; groundwater level > 200 cm, river level about 250 cm (July 1981); submerged paddy fields only in the southern area.

Soils: have a 10-20 cm thick topsoil of brownish black to black, slightly mottled, very firm, cracking clay over black, mottled, very firm, cracking clay and heavy clay. Distinct cracks up to 5 cm wide, separate very coarse prismatic elements, the latter disintegrate into coarse prisms and/or medium angular blocks. Pressure faces, slickensides and root galleries are present, mottles along root channels go as deep as the cracks. The irrigated paddy fields have a 20-30 cm thick, slightly sticky, plastic puddled layer. In most cases the texture is heavy clay throughout, however, in places between 130 and 180 cm the subsoil changes into brownish black, friable clay. In the western area especially the subsoil sometimes contains calcium carbonate concretions.

Chemical aspects: non-saline throughout; the soils in the eastern area have a slightly to strongly acid reaction, but below 160 cm are neutral; elsewhere the soils are neutral to slightly acid, with a moderately alkaline subsoil in places; non-calcareous, except for some spots with a slightly calcareous subsoil starting > 130 cm; groundwater is non-saline.

Physical aspects: the dry areas within this mapping unit reveal many distinct cracks ranging in width from 3 to 5 cm, polygon size from 40 cm to 60 cm and the cracks range from 40 cm to 100 cm deep; the non-irrigated areas have deeply desiccated soils; under wet conditions these soils have very slow hydraulic conductivity.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Representative profile: Appendix IV-D, profile pit No. 4.

Remarks:

1. Severe gully erosion is still in progress.
2. In some places evidence of eluviation (bleached ped surface within 60 cm) was encountered (intergrade to Planosols).
3. The data from profile pit No. 4 reveal the presence of a sodic subsoil below 70 cm. However, there is insufficient evidence from observed degrees of dispersion in other samples to characterize all the soils of this mapping unit as sodic.

Mapping unit: PlA2

Topography:
macro: flat
meso : (eroded) irrigation canals (up to 50 cm wide; 60 cm deep)
micro: bunds, partly broken; cow foetoes; uneven ploughed land; small gullies and rills; in places gilgai-like surface (height 1-3 cm; diameter 10-30 cm).

Overwash: none.

Vegetation/land use: predominantly grassland on abandoned rice fields; some millet.

Drainage conditions: poorly drained; the seasonal floods range from 60 cm to 80 cm deep; groundwater almost everywhere > 200 cm (August 1981); evidence of a perched water level was found in profile pit No. 5 where the soil was dry to about 3 m, but where the water level rose to 155 cm within 2 hours.

Soils: have a 10-20 cm thick topsoil of brownish black, slightly mottled, very firm, cracking clay abruptly underlain by brownish black, strongly mottled, very firm, cracking clay. The many distinct mottles have dark to bright reddish brown colours (Fig. 8.5). In the easternmost area the subsoil consists of brownish black, friable clay loam, starting between 70 and 90 cm. Between 80 cm and 110 cm the subsoil in the western part of the area changes into black, firm clay. Here thin (< 10 cm) intercalations of clay loam are encountered within 50 cm in places.

Chemical aspects: non-saline, with a tendency to increasing electrical conductivity with depth; the eastern area has slightly acid soils, in the western part the topsoils to a depth of 40 cm to 80 cm are frequently strongly acid overlying slightly acid or neutral subsoils; non-calcareous, except for some deeper subsoils (> 150 cm); groundwater is non-saline.

Physical aspects: cracks, although not abundant, ranging from 1-2 cm wide, polygon diameter from 10 to 30 cm; in places a slaked surface with thin crusts is present; under wet conditions these clay soils have a very slow hydraulic conductivity.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Representative profile: Appendix-IV-D, profile pit No. 5.

Remarks:

1. In places along the southern border of this unit, soils with a thin (< 25 cm), clay loam cover of fluvial origin have been included.
2. At various sites and at various depths within the profiles small

reddish yellow, weathered rock fragments (rhyolite) were found.

3. The analytical data from the sampled profile pit No. 5 reveal the presence of a sodic subsoil from 130 cm onwards.

Mapping unit: PlA3

Topography:

macro: flat to very gently undulating; this unit forms the transition between the relatively low-lying lacustrine plain and the higher levee of the former Maugo river or the bordering footslopes.

meso : erosion gullies (depth 60-80 cm; width 100 cm) in the westernmost part of the area; camber beds.

micro: uneven ploughed land; small rills in cropped areas originating from higher hinterland; in places gilgai-like surface (height 1-3 cm; diameter 30-50 cm); cow foetoes.

Overwash/stoniness: in places bordering the footslope a very slight overwash of rock fragments and/or (coarse) sand is present (colluvial veneer); here the subsoil below 150 cm contains weathered rock fragments and/or calcium carbonate concretions.

Vegetations/land use: mainly millet, grassland; some maize and cotton.

Drainage conditions: poorly drained; seasonal flood approximately 30 cm deep, except in the westernmost and the easternmost part of the area where flooding is 60-80 cm deep; no groundwater within 200 cm (July 1981).

Soils: have a 15-25 cm thick topsoil of brownish black or black friable, slightly cracking clay abruptly overlying brownish black, faintly mottled, very firm heavy clay to clay. In places the top 40 cm of these profiles contains sand and/or fine gravel (overwash). In the southwestern part of the delineated area the subsoil changes between 80 and 140 cm into brownish black to dark brown,friable clay loam to

clay, often with white patches and/or concretions of calcium carbonate (> 140 cm). A brownish black, firm clay subsoil throughout is found in the east.

Chemical aspects: non-saline, in places where $CaCO_3$ concretions occur the subsoil below 100 cm is slightly,sometimes moderately, saline; as a rule slightly acid soils, sometimes with a neutral subsoil (> 100 cm), rarely a moderately alkaline soil reaction accompanied by $CaCO_3$ concretions; predominantly non-calcareous, where concretions are present, slightly calcareous below 100 cm.

Physical aspects: cracks were rarely found, if present they ranged in width from 1-3 cm and the polygon diameter was up to 60 cm; slaked surfaces with thin crusts were often present; under wet conditions soils have a very slow hydraulic conductivity, though the deeper subsoil with a clay-loam texture has a moderately slow hydraulic conductivity.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Remarks:

1. In the northeastern part soils with a thin (20 cm) fluvial cover are locally present.
2. The soils of this unit greatly resemble those of unit PlA1, except for the coarser-textured topsoil.

Mapping unit: PlA4

Topography:

macro: flat.

meso : irrigation canals in use; severely eroded irrigation canals and gullies in and along the western and eastern side of the main area (width up to 2-3 m; depth 1-1½ m); many spillways and gullies east of benchmark 4.

Fig. 8.6 The valley of the Maugo river is here rather wide (foreground) but becomes much more narrow in the distance. Here rice is cultivated succesfully on soils of mapping unit PIA4.

micro: uneven ploughed land; bunds; cow foetoes; hummocks and rills (< 20 cm); in place gilgai-like relief (height 1-2 cm; diameter 20-40 cm).

Overwash/stoniness: only rarely a very slight overwash of sand and fine gravel; in the subsoil, usually below 140 cm, some weathered rock fragments or calcium carbonate concretions.

Vegetation/land use: predominantly irrigated paddy fields (Fig. 8.6); grassland with rushes and sedges; some maize/cotton mix and millet.

Drainage conditions: poorly drained. In the northern part of the unit the seasonal flood is about 30 cm, but in places where the Maugo river is confined in narrow passages between the hills, the depth of flooding can attain 100 cm (observations Nos 11, 115, 127, 131). In the southernmost area the flood is 60-80 cm; groundwater level usually > 200 cm, in scattered places it is between 10 cm and 200 cm (August 1981); in several places evidence of a perched water level; submerged paddy fields are mainly found west and northwest of benchmark 3.

Soils: have a 10-25 cm thick topsoil of black, faintly mottled, very firm, slightly cracking clay. The puddled layer in the irrigated paddy fields has a slightly sticky, plastic consistency. The topsoil is underlain by black, mottled, very firm, cracking clay to heavy clay with pressure faces and many slickensides. Usually the texture of the profiles becomes slightly coarser with depth. Subsoils consisting of brownish black to dark brown friable clay loam frequently start between 120 and 150 cm, although their presence is not restricted to particular areas.

Chemical aspects: predominantly non-saline, in the northeastern part slightly saline from 50 cm onwards, in a few places slightly to moderately saline groundwater; soils invariably increase in alkalinity with depth, the top 50 cm is predominantly slightly acid changing to a neutral reaction below 80 cm, the subsoils below 150 cm both in the eastern part near benchmark 3 and also in the westernmost area are strongly to moderately alkaline; up to 80-140 cm they are non-calcareous, changing to slightly calcareous, in the western area they are

slightly calcareous below 30 cm.

Physical aspects: soils in general show some cracks (width 1-3 cm, polygon diameter 20-40 cm); in places distinct slaked surface; under wet conditions soils have a very slow hydraulic conductivity; the clay loam subsoil with a slow hydraulic conductivity is sufficiently covered by impeding heavy clay.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitbale (class 1).

Representative profile: Appendix D2, profile pit No. 6.

Remarks: The data from profile pit No. 6 reveal sodic properties throughout the profile. This probably results from the influence of soils with sodic properties in the adjacent mapping units PfA31 and PfA32. In other areas of unit PlA4 the degree of dispersion in auger samples does not justify the designation "sodic phase".

Mapping unit: PlA5

Topography:
macro: flat.
meso : irrigation canals; some erosion gullies, up to 1 m deep and 2 m wide.
micro: bunds, cow foetoes; uneven ploughed land; many small rills often < 20 cm deep and wide, to carry the continuous overland flow of river water.

Overwash/stoniness: in the western part of this unit, near the steep hillslope, a slight overwash of weathered rock fragments on the surface, in places this material can be found throughout the profile.

Vegetation/land use: mainly yam (Fig. 8.1) and paddy fields; some grassland.

Drainage conditions: very poorly drained; the northern part of the area is almost permanently flooded, the southern part is inundated for most of the year; the seasonal floods range from 70-100 cm deep; groundwater level 0-50 cm (August 1981).

Soils: have a 50-70 cm thick top layer of brownish black, mottled, muddy, sticky and plastic, cracking clay. In paddy fields this top layer is no more than 30 cm thick; under grassland the topsoil usually has a very firm consistency. The underlying subsoil consists of a black, slightly mottled, firm clay which in places changes between 120 cm and 150 cm into a brownish black to dark brown, friable clay loam. The latter sometimes holds weathered rock fragments and/or calcium carbonate concretions.

Chemical aspects: soils and groundwater are both non-saline; in general slightly acid soils, neutral below 80 cm, in rare places a moderately alkaline subsoil (> 160 cm); non-calcareous, in places slightly calcareous from 120 cm onwards, a marl outcrop outside the area north of benchmark 5 results in calcium carbonate being present at shallower depths in the adjacent soils.

Physical aspects: because of the prevailing moist/wet conditions almost no cracks observed, if present they are 1-2 cm wide; under wet conditions soils have a very slow hydraulic conductivity.

Soil classification: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Remarks: On the soils surface below the yam vegetation, many small rills with running water.

Mapping unit: P1A6

Topography:
macro: flat to very gently undulating.
micro: bunds, cow foetoes.

Stoniness/rockiness: in the southwestern part a slight overwash of rock fragments; close to the boundary of the mapped area gravel and stones on the surface; within 2 m rocks are present, usually overlain by calcium carbonate concretions (size 2-10 mm).

Vegetation/land use: grassland, partly on abandoned rice fields.

Drainage conditions:poorly drained; seasonally flooded to a depth of 30-40 cm; no groundwater within auger depth (July 1981).

Soils: have a 20 cm thick topsoil of black, faintly mottled, very firm, cracking clay to heavy clay over black, firm, cracking clay to heavy clay. Between 70 and 110 cm the soil changes into dull yellowish brown, friable clay loam with calcium carbonate concretions. Rock is present at variable depth, starting between 80-190 cm.

Chemical aspects: non-saline; these soils increase in alkalinity: starting with a slightly acid topsoil (20 cm) over neutral towards a moderately alkaline subsoil (> 80 cm); slightly to moderately calcareous except for the top 60 cm.

Physical aspects: some cracks; under wet conditions the clay layers have a very slow hydraulic conductivity, that of the intermediate clay loam is moderately slow.

Soil classiciation: pellic VERTISOLS.

Soil suitability for irrigated rice: highly suitable (class 1).

Table 9.1 Main land characteristics and land suitability classes for irrigated rice in the Wasare area, assuming that flood protection and sufficient irrigation water are provided

Mapping unit	Topography: Macro relative height	Topography: Meso	Topography: Micro	Soil texture	Hydraulic conductivity when wet	Soil reaction ($pH-H_2O$)	Soil salinity	Soil sodicity	Present land use/vegetation	Land suitability class
PfA11	flat to very gently undulating; relatively high parts in the area	some irrigation canals	uneven ploughed land	stratified, gravelly coarse sand, sandy loam and clay loam	slow to moderately rapid	7.9-8.4	non-saline	non-sodic	arable land with maize, millet and sugar cane; some grassland	NSc
PfA12	flat to very gently undulating	partly camber beds; irrigation canal	some bunds; few termite mounds; rills	20-60 cm clay and sandy clay over stratified sandy loam to clay loam	slow to moderately rapid	7.9-8.4	non-saline	non-sodic	arable land with maize; some grassland	NSc
PfA21	flat to very gently undulating	irrigation canal; partly camber beds	bunds; cow foetoes	30 cm clay over stratified sandy clay loam to clay loam; below 110-180 cm clay to heavy clay	slow to moderately rapid; below 110-180 cm very slow	7.9-8.4	non-saline	non-sodic	mainly grassland; in places arable land with maize, millet and sugar cane; irrigated rice fields	NSc
PfA22	flat	camber beds	few bunds	30 cm clay over stratified sandy loam to clay loam, with in places coarse sand; below 60-80 cm clay to heavy clay	slow to moderately rapid; below 60-80 cm very slow	7.9-8.4	non-saline; in places slightly saline subsoil (>160 cm)	non-sodic	grassland; partly on former rice fields; some maize	3c
PfA23	flat to very gently undulating	irrigation canal; coarse-textured ridge about 50 cm high	some shallow erosion rills	20 cm clay over stratified sandy loam to clay loam; below 40 to 80 cm clay to heavy clay	slow to moderately rapid; below 40-80 cm very slow	7.9-8.4	non-saline	non-sodic	grassland with rushes; sugar cane; maize	3c
PfA24	flat to very gently undulating	some irrigation canals; camber beds	bunds; in places hummocks	stratified coarse loamy sand to clay loam; below 90-110 cm heavy clay	slow to rapid; very slow below 90-110	7.9-8.4 below 90-110 cm often 6.6-7.3	non-saline	non-sodic	maize, some grassland and irrigated ricefields	NSc
PfA25	flat	camber beds	uneven ploughed land	40-60 cm stratified slightly gravelly coarse sandy loam to clay over heavy clay	slow to rapid; below 40-60 cm very slow	7.9-8.4	non-saline	non-sodic	maize	NSc
PlA1	flat	irrigation canals	bunds, partly disturbed; cow foetoes; some rills;	clay to heavy clay	very slow	6.6-8.4	non-saline	non-sodic	irrigated rice fields; grassland, often on abandoned ricefields; maize millet and sugar cane	1
PlA2	flat	irrigation canals	bunds, partly disturbed; in places very slight rill erosion; cow foetoes	clay to heavy clay	very slow	6.6-7.3	non-saline; subsoil below 80 cm often slightly saline	non-sodic	grassland on abandoned rice fields; irrigated paddy fields; maize	1

9 THE SUITABILITY OF THE LAND FOR SMALL-SCALE IRRIGATED RICE

9.1 Wasare area

The main land characteristics of each soil mapping unit are presented in Table 9.1. Table 9.2 gives the suitability classes, the mapping units occurring in each class and the absolute and relative extent of the suitability classes. About 50% of the soils are highly suitable; viz. the soils developed on lacustrine sediments. The soils developed on recent and subrecent fluvial sediments are marginally suitable or unsuitable, depending on the thickness, the stratification and the hydraulic conductivity of the fluvial top layers and the depth at which the lacustrine subsoil begins.

No soils of moderate suitability are present in the area.

Suitability class	Soil mapping units	Extent in ha	%
1	PlA1; PlA2	81.5	49.8
3c	PfA22; PfA23	22.0	13.5
NSc	PfA11; PfA12; PfA21; PfA24; PfA25	60.0	36.7
	Total area:	163.5	100.0

Table 9.2 Land suitability classes, their extent, and the mapping units in each class.

Class 1

The soils of mapping units PlA1 and PlA2 have been classified as highly suitable. They do not have important limitations. Mapping unit PlA2 has a slightly saline subsoil below 80 cm. This should be kept in mind when digging canals, because the material derived from the subsoil must not be used for levelling purposes.

Class 3

The soils of mapping units PfA22 and PfA23 are marginally suitable (class 3c). Within 80 cm they have stratified, fluvial sediments

Table 9.3 Main land characteristics and land suitability classes for irrigated rice in the Awach Kano area, assuming that flood protection and sufficient irrigation water are provided

Mapping unit	Topography			Soil texture	Hydraulic conductivity when wet	Soil reaction ($pH-H_2O$)	Soil salinity	Soil sodicity	Present land use/vegetation	Land suitability class
	Macro relative height	Meso	Micro							
PfA11	flat; relatively high position along river channel	in places gullies (up to 1 m deep and 2 m wide) in the northernmost part	in places hummocks	50-80 cm stratified loam to clay over clay to heavy clay	moderately rapid to slow; below 50-80 cm very slow	6.1-7.3; below 50-80 cm 5.1-6.5	non-saline	non-sodic	grassland; some maize	3c
PfA21	flat	only one deep gully in the southeastern part	broken bunds; cow foetoes; uneven ploughed land	50-80 cm clay over heavy clay	slow; below 50-80 cm very slow	6.1-6.5	non-saline	non-sodic	grassland; partly on abandoned rice fields	1
PfA22	flat; the relatively higher parts of the area	some erosion gullies; sheet erosion along the main channel	uneven ploughed land; cow foetoes	100-150 cm clay, silty clay and clay loam over heavy clay	moderately slow; below 100-150 very slow	6.1-6.5; in places below 80-150 cm 5.1-5.5	non-saline	non-sodic	grassland, in places with thorny shrubs; some millet and maize	2c
PlA1	flat; lowest parts of the area	eroded irrigation canals up to 1.5 m deep and 2.5 m wide	broken bunds; cow foetoes; in places hummocks	clay to heavy clay	very slow	6.1-6.5; in places between 50 and 160 cm 5.1-5.5	non-saline	non-sodic	grassland on abandoned rice fields	1
PlA2	flat	some scattered eroded irrigation canals, up to 1.5 m deep and 2.5 m wide	irregular broken bunds	clay to heavy clay	very slow	6.1-6.5; in places deeper than 160 cm 5.1-5.5	non-saline	non-sodic	grassland on abandoned rice fields	1

with sandy loam or loamy layers over clay to heavy clay. The main limitation of these soils is the relatively rapid hydraulic conductivity of the stratified, fluvial deposits. Their marginal suitability for irrigated rice does not mean that they are unsuitable for other kinds of land use.

Class NS

60 ha of the area has been classificied as unsuitable (class NSc). This class consists of mapping units PfA11, PfA12, PfA21, PfA24 and PfA25. Soils either have more than 80 cm of stratified, fluvial sediments or 40 to 80 cm of coarse-textured (sand to clay loam) stratified, fluvial sediments over heavy lacustrine sediments. The main limitation of these soils is their rapid hydraulic conductivity caused by the stratified, fluvial layers (class NSc).

9.2 Awach Kano area

The main land characteristics of each soil mapping unit are presented in Table 9.3. Table 9.4 gives the suitability classes, the mapping units, occurring in each class and the absolute and relative extent of the suitability classes. The soils developed on lacustrine sediments and on fine-textured fluvial sediments over lacustrine sediments are highly suitable. These soils cover 75% of the area. The soils developed on fluvial sediments with a texture of clay loam and clay over lacustrine sediments are moderately suitable. No soils unsuitable for irrigated rice occur in the area.

Suitability class	Soil mapping units	Extent in ha	%
1	PfA21; PlA1; PlA2	145.5	75.0
2c	PfA22	32.5	16.8
3c	PfA11	16.0	8.2
	Total area	194.0	100.0

Table 9.4 Land suitability classes, their extent and the mapping units in each class.

Table 9.5 Main land characteristics and land suitability classes for irrigated rice in the Kore areas, assuming that flood protection and sufficient irrigation water are provided

Mapping unit	Topography: macro relative height	Topography: meso	Topography: micro	Soil texture	Hydraulic conductivity when wet	Soil reaction ($pH-H_2O$)	Soil salinity	Soil sodicity	Present land use/vegetation	Land suitability class
PfA1	flat; the relatively higher part of the area		bunds; cow foetoes	45-100 cm clay loam to clay over heavy clay	moderately slow; below 45-100 cm very slow	6.1-7.3; in places deeper than 80 cm 7.9-8.4	non-saline; in places slightly saline >160 cm	in places sodic subsoil from 90 cm	grassland; some irrigated paddy fields; maize and millet	2c
PlA1	flat	irrigation canals; some termite mounds	bunds; trenches; cow foetoes, hummocks	clay to heavy clay	very slow	6.1-7.3; in places 7.9-8.4 deeper than 80 cm	non-saline	in places sodic subsoil from 100 cm	irrigated paddy fields; swamp; grassland	1

Class 1

The soils of mapping units PfA21, PlA1 and PlA2 are highly suitable. All these soils have a slow or very slow hydraulic conductivity because of their fine-textured clay. They do not have important limitations, though the eroded irrigation canals could be detrimental to a certain extent when using these soils for irrigated rice.

Class 2

The soils of mapping unit PfA22 have been classified as moderately suitable (class 2c). Soils have 100 to 150 cm clay loam to clay over heavy clay. The moderately slow hydraulic conductivity of the clay loam to clay layers is the main limitation.

Class 3

The soils of mapping unit PfA11 are marginally suitable for irrigated rice (class 3c). Because of the loam to clay texture of the top 80 cm, the hydraulic conductivity is the limiting factor. However, these soils offer good prospects for crops such as maize, millet and vegetables.

9.3 Kore areas

The main land characteristics of the two soil mapping units are presented in Table 9.5. Table 9.6 gives the suitability classes, the mapping units occurring in each class and the absolute and relative extent of the suitability classes. In both areas only highly suitable and moderately suitable soils are found. The highly suitable soils developed on lacustrine sediments cover about 90% of the area. The soils developed on recent and subrecent fluvial sediments over lacustrine sediments are moderately suitable for irrigated rice.

No marginally suitable or unsuitable soils are present in the areas.

Suitability class	Soil mapping units	Extent in ha	%
1	PlA1	105.2	90.8
2c	PfA1	10.7	9.2
	Total area	115.9	100.0

Table 9.6 Land suitability classes, their extent and the mapping units in each class

Table 9.7 Main land characteristics and land suitability classes for irrigated rice in the Maugo area, assuming that flood protection and sufficient irrigation water are provided

Mapping unit	Topography: macro relative height	Topography: meso	Topography: micro	Soil texture	Hydraulic conductivity when wet	Soil reaction ($pH-H_2O$)	Soil salinity	Soil sodicity	Present land use/vegetation	Land suitability class
FC1	very gently, undulating	trenches	uneven ploughed land; cow foetoes	90-160 cm clay loam over rock	moderately slow	6.1-7.3; in places from 80 cm 7.9-8.4	non-saline	non-sodic	maize;cotton	3t
FC2	gently undulating; regular slope (2-6%)		uneven ploughed land	30 cm gravelly loam and clay over rock	moderate	6.1-6.5	non-saline	non-sodic	grassland; maize	NStd
PfA11	flat to very gently undulating; slightly higher than surroundings	former river channel; some gullies	bunds; uneven ploughed land; furrows; rills; cow foetoes	150 cm stratified clay loam and clay with gravelly coarse sand and loam layers over clay loam	slow to moderately rapid	6.1-6.5; locally 7.9-8.4; in places 5.1-5.5 from 50 cm	non-saline	non-sodic	maize; millet; grassland; sugar cane; cassava	NSc
PfA12	flat to very gently undulating	a few 1-2.5 m deep gullies	uneven ploughed land	stratified clay loam and clay	moderately slow	6.1-6.5	non-saline	non-sodic	millet	2c
PfA13	flat to very gently undulating; narrow stripof slightly higher soils along the river	in places former river channel; in places gullies to 1.5 m deep; in places spillways; some eroded and current rigation canals	rills and hummocks; bunds cow foetoes; uneven ploughed land	stratified clay loam; clay and heavy clay	very slow to moderately slow	6.1-6.5; in places deeper than 160 cm 7.9-8.4	non-saline	non-sodic	maize, millet; cotton; sugar cane; potatoes; vegetables; grassland; scrub on eroded land	2c
PfA21	flat to very gently undulating	very few gullies up to 1 m deep and 3 m wide	rills; hummocks; sand ridges (30 cm high)	50-70 cm stratified sandy loam to clay loam over clay	moderate to rapid; below 50-70 slow to moderately slow	partly 7.9-8.4; partly 6.1-6.5	non-saline	non-sodic	grassland	NSc
PfA22	flat to very gently undulating	some irrigation canals; often eroded	bands; hummocks; rills; ridges; uneven ploughed land	20-40 cm stratified coarse loamy sand to clay loam over clay	moderately slow to moderately rapid; below 20-40 cm slow	6.1-6.5 below 160cm 6.6-7.3	non-saline	non-sodic	millet; maize, grassland	2c
PfA23	flat	in places gullies up to 1.5 m deep and 3 m wide; some eroded irrigation canals	hummocks; rills; bunds; uneven ploughed land	clay; in places heavy clay from 40 cm	very slow	6.1-6.5; deeper than 150 cm 6.6-7.3	non-saline; in places slightly saline deeper than 150 cm	non-sodic	grassland; millet, maize, cotton	1
PfA31	very gently undulating; relatively high parts of the area	sheet erosion along the lower margins	uneven ploughed land; cow foetoes	clay loam to clay	moderately slow to slow	6.6-8.4; deeper than 50-80 cm 8.5-9.5	non-saline; below 50-80 cm slightly saline	sodic throughout	maize; millet; cotton; grassland	NStn
PfA32	flat		few bunds and cow foetoes	50-70 cm clay over clay loam	slow	8.5-9.5	slightly saline	sodic	grassland; irrigated paddy fields	NSrs

Table 9.7 Main land characteristics and land suitability classes for irrigated rice in the Maugo area, assuming that flood protection and sufficient irrigation water are provided (continued)

Mapping unit	Topography: macro relative height	Topography: meso	Topography: micro	Soil texture	Hydraulic conductivity when wet	Soil reaction ($pH-H_2O$)	Soil salinity	Soil sodicity	Present land use/vegetation	Land suitability class
P1A1	flat	some gullies up to 3 m deep and 6 m wide; irrigation canals	rills; hummocks; bunds; cow foetoes; uneven ploughed land	clay and heavy clay	very slow	6.1-7.3; in places 5.1-6.5	non-saline	non-sodic	grassland; irrigated paddy fields	1
P1A2	flat	(eroded) irrigation canals, 50 cm deep 60 cm wide	bunds; cow foetoes; uneven ploughed land; small gullies and rills	clay; in places clay loam from 70-110 cm	very slow	5.6-6.5; in places 4.5-5.5 to 40-80 cm depth	non-saline	non-sodic	grassland; millet	1
P1A3	flat to very gently undulating	in places gullies up to 60-80 cm deep and 100 cm wide; camber beds	uneven ploughed land; small rills; cow foetoes	20 cm clay over clay or heavy clay; in places clay loam from 80-140 cm	very slow	6.1-6.5; in places deeper than 100 cm 6.6-7.3 or 7.9-8.4	non-saline; in places moderately saline subsoil deeper than 100 cm	non-sodic	millet; grassland; maize; cotton	1
P1A4	flat	irrigation canals; in places gullies up to 1.5 m deep and 3 m wide	bunds; uneven ploughed land; hummocks and rills; cow foetoes	120-150 cm clay and heavy clay over clay loam	very slow	50 cm 6.1-6.5 increasing to 8.5-9.5 deeper than 150 cm	non-saline; in places slightly saline from 50 cm	in places sodic from 50 cm	irrigated paddy fields; grassland; maize; cotton; millet	1
P1A5	flat	irrigation canals; some gullies	bunds; uneven ploughed land; small rills; cow foetoes	clay; in places clay loam from 120-150 cm	very slow	6.1-6.5; deeper than 80 cm 6.6-7.3; in places 7.9-8.4 below 160 cm	non-saline	non-sodic	yam; irrigated paddy fields; grassland	1
P1A6	flat to very gently undulating		bunds; cow foetoes	70-110 cm clay to heavy clay over clay loam; rock within 2 m	very slow; from 70-110 cm moderately slow	increasing from 6.1-6.5in the upper 20 cm to 7.9 8.4 below 80 cm	non-saline	non-sodic	grassland	1

Class 1

The soils of mapping unit PlA1 are highly suitable. There are no limitations.

Class 2

The soils of mapping unit PfA1 have been classified as moderately suitable (class 2c). The main limitation is the moderately slow hydraulic conductivity of the top layers resulting from the clay loam to clay texture.

9.4 Maugo area

The main land characteristics of each soil mapping unit are presented in Table 9.7. Table 9.8 gives the suitability classes, the soil mapping units occurring in each class and the absolute and relative extent of the suitability classes. The fine-textured soils developed on lacustrine sediments and the soils on fluvial sediments not exceeding 40 cm in thickness over lacustrine sediments, are highly suitable. These soils cover about 70% of the area. The medium-textured soils developed on fluvial sediments, are moderately suitable.

The very slightly sloping soils developed on old colluvial sediments. over rhyolite are marginally suitable or unsuitable. The old alluvial sediments without rhyolite in the subsoil are also marginally suitable or unsuitable. The soils with more than 80 cm stratified, fluvial material in the top are unsuitable, as are the soils developed on 40 to 80 cm coarse-textured fluvial sediments over lacustrine sediments.

Suitability class	Soil mapping units	Extent in ha	%
1	PfA23; PlA1; PlA2; PlA3; PlA4; PlA5; PlA6	196.8	68.7
2c	PfA12; PfA13; PfA22	47.5	16.6
3t	FC1	6.5	2.3
NStn	PfA31	18.5	6.5
NStd	FC2	1.5	0.5
NSc	PfA11; PfA21	13.0	4.5
NSrs	PfA32	2.5	0.9
	Total area	286.3	100.0

Table 9.8 Land suitability classes, their extent, and the mapping units in each class

Class 1

The soils of mapping units PfA23, PlA1, PlA2, PlA3, PlA4, PlA5 and PlA6 are highly suitable. There are no important limitations, except for a few deep gullies in some places within mapping units PfA23, PlA1 and PlA4. In places the latter mapping unit has a slightly saline and sodic subsoil starting below 50 cm.

Class 2

The soils of mapping units PfA12, PfA13 and PfA22 have been classified as moderately suitable (class 2c), because of their moderately slow hydraulic conductivity. In places, gullies and former river channels can hamper the suitability. The soils have good prospects for crops such as maize, millet and vegetables.

Class 3

The slightly sloping soils of mapping unit FC1 and PfA31 have been put in class 3t. These soils have a limitation because of the topography. Mapping unit PfA31 also has a limitation because of its sodic properties (class 3tn).

Class NS

The soils of mapping unit FC2 are unsuitable because of the slope and the soil depth (class NStd). The rock starts at about 30 cm.

The main limitation of the soils of mapping units PfA11 and PfA21 is their rapid hydraulic conductivity (class NSc). Soil mapping unit PfA32 consists of alkaline and slightly saline sodic soils (class NSrs).

REFERENCES

Bie, S.W., V. D' Costa and J.Makin. 1966. Ahero Pilot Irrigation Schema. Soils report. Soil Survey Unit, Kenya.

D'Costa, V. and S.H.Ominde. 1973. Soil and land use survey of the Kano Plain - Nyanza Province - Kenya. Dep. of Geography, Univ. of Nairobi, Occasional Memoir No. 2.

FAO. 1977. Guidelines for soil profile description (2nd edition). FAO/UN, Rome.

FAO-Unesco. 1974. Soil map of the world. Volume I. Legend. Unesco, Paris.

Hinga, G., F.N.Muchena and C.M.Njihia. 1980. Physical and chemical methods of soil analysis. Nat. Agric. Lab., Nairobi.

International Institute for Land Reclamation and Improvement. 1974. In: Drainage principles and applications. Publication 16 - volume III: Surveys and Investigations. ILRI - Wageningen.

Kenya Soil Survey. 1981. Guidelines for the soil surveys to be carried out within the framework of the "Study on Valley Bottom Development in the Lake Victoria Basin".

Muchena, F.N. 1981. Proposed criteria for land suitability classification for irrigation. Internal Communication No. 23. Kenya Soil Survey, Nairobi.

Richards, L.A. (ed) 1954. Diagnosis and improvement of saline and alkaline soils. Agricultural handbook 60, USDA.

Siderius, W. and Van der Pouw, B.J.A. 1980. The application of FAO/UNESCO terminology of the soil map of the world legend for soil classification in Kenya. Miscellaneous soil paper M15. Kenya Soil Survey, Nairobi.

Siderius, W. (ed) 1980. Standards for soil survey in Kenya. Miscellaneous soil paper M22. Kenya Soil Survey, Nairobi.

Soil Survey Staff S.C.S. 1951. Soil Survey Manual. Agric. Handbook No. 18. USDA.

USBR staff. 1953. Bureau of reclamation manual - land classification for irrigated land use, Vol. V, Part 2. U.S. Department of the Interior, Denver, Colorado.

Weg, R.F. van de. 1978. I: Guidelines for subdivision of geology (based mainly on lithology) in relation to soil mapping and map legend construction.

II: Definitions of land forms in relation to soil mapping and map legend construction.
Internal communication No. 13. K.S.S. - Nairobi.

Weg, R.F. van de (ed). 1978. Field guidelines for the annotation of the Soil Profile Description Form. Internal Communication No. 17. K.S.S. - Nairobi.

APPENDIX I: FIELD METHODS USED IN THE SOIL SURVEY

Soil Survey

Augerings, profile pits and soil boundaries were plotted on the 1:2 500 base maps.

Augerings were made to a depth of 2 m and described according to the "Guidelines for Soil Description" as used by the K.S.S. The standard K.S.S. sheet for field augerings was used. In a few observations the required depth was not reached because of the presence of stones and/or gravel in the subsoil. Also, in areas with extremely hard clay soils, augering to 2 m depth was not always possible.

Soil pits 2 m deep were dug at representative sites in the major soil mapping units. At these sites, detailed profile descriptions were made, using the K.S.S. soil profile description forms. The subsoil to 4 m depth was investigated by augering in the bottom of the pit, unless prevented by the presence of stones etc., and described on the same forms.

Briefly, the observation density was:

Name of area	Extent (ha)	Number of augerings	Number of profile pits	Observation density per ha
Wasare	163.5	94	4	1 per 1.67
Awach Kano	194.0	53	5	1 per 3.34
Kore	115.9	48	2	1 per 2.35
Maugo	286.3	209	6	1 per 1.33
Total	759.7	404	17	1 per 1.80 (overall density)

Compared with the required density of 1 observation per 2 ha there are marked differences in observation density between the various areas, because of soil conditions. In the Awach Kano and Kore areas, which have fairly uniform soils, the density is considerably lower than in the other two areas where fluvial deposition has resulted in a more intricate soil pattern requiring a higher number of observations. Approximately 4 per cent of the observations are profile pits.

Field tests for infiltration and hydraulic conductivity

At 50 sites near soil pits and auger holes, scattered over the various soil mapping units in the 4 areas, hydraulic conductivity and/or infiltration rate were measured. Hydraulic conductivity was measured at 46 sites at 1-4 different depths: in all, 81 determinations were made in duplicate. The infiltration rate was measured at 28 sites at 1 or 2 different depths (a total of 32 determinations in duplicate).

To measure infiltration, single rings of diameter 0.30 m were used. The saturated hydraulic conductivity was measured by the augerhole method if groundwater was within sufficient distance of the soil surface. If the groundwater was absent or too deep, conductivity was measured according to the inversed auger hole method. Documentation on all methods can be found in Publication 16 of the International Institute for Land Reclamation and Improvement (1974).

The data on infiltration and hydraulic conductivity are presented in Appendix V.

APPENDIX II: LABORATORY METHODS FOR SOIL ANALYSIS

Three laboratories were involved in analysing soil samples.

1. Laboratory of the National Irrigation Board, Ahero

Routine soil samples were taken at 20 cm, 50 cm, 80 cm and 160 cm depth at all observation sites. The electrical conductivity (EC) and pH of these samples were measured at the Ahero Irrigation Research Station by two of the laboratory assistants. The EC and pH were measured in 1:2.5 ratio (v/v) of soil/water. Where groundwater was encountered, this was also sampled and its EC and pH determined. A total of 1750 samples, including approximately 60 groundwater samples, was analysed.

2. National Agricultural Laboratory (NAL), Nairobi

99 soil samples and 17 topsoil samples for fertility analysis were taken from 17 representative profile pits and delivered to NAL for chemical analysis. The methods of analysis were those described by Hinga et al. (1980).

For the fertility analysis of the 17 topsoil samples the following were determined:

pH - 1:1 soil water suspension

Na, Ca, Mg, Mn and P extracted in 0.01 N HCl and 0.025 N H_2SO_4 mixture first three read on flame photometer; latter three determined calorimetrically

N - Kjeldahl method

C - Walkley-Black method (uncorrected values)

Hp - Exchangeable acidity of samples < pH 5.5 determined by leaching with $BaCl_2$

The following analyses were carried out on the 99 soil samples:

pH-H_2O with soil/water ratio 1:2.5 v/v

pH-KCl with soil/water ratio 1:2.5 v/v

EC (mS/cm) with soil/water ratio 1:2.5 v/v

pH and electrical conductivity (ECe) of the saturation extract if EC (1:2.5) was greater than 0.8 mS/cm

$CaCO_3$ equivalent - gravimetric determination of loss of CO_2

C% - Walkley-Black (uncorrected values)

CEC - at pH 8.2 (sodium acetate)

Exchangeable cations - at pH 7.0 (ammonium acetate).

3. Laboratory for Soil and Crop Testing, Oosterbeek (The Netherlands)

Most of the profile pits were dry and cracked and therefore no core samples were taken. Core samples (in triplicate) were taken from the topsoil and first subsoil horizon in only 4 moist profile pits. The soil moisture content was determined at pF values of 2.0, 2.7 and 4.2.

APPENDIX III: DIFFERENTIATING CRITERIA USED IN THE LEGEND AND THE DESCRIPTIONS OF THE MAPPING UNITS

Texture, structure and other characteristics e.g. pores, cutans, consistency have been described according to "Guidelines for soil profile description" (FAO, 1977).

Soil colour has been described according to the Japanese "Revised Standard Soil Color Charts".

Soil reaction. The categories used were:

Class	pH-H_2O rates
extremely acid	< 4.5
strongly acid	4.5 - 5.5
slightly acid	5.6 - 6.5
neutral	6.6 - 7.3
moderately alkaline	7.4 - 8.4
strongly alkaline	8.5 - 9.0
very strongly alkaline	> 9.0

Soil salinity. The categories used were:

Salinity class	ECe (mS/cm)	EC (1:2.5 v/v) [1] (mS/cm)
non-saline	0 - 4	0 - 2.1
slightly saline	4 - 8	2.1 - 4.2
moderately saline	8 - 16	4.2 - 8.4
strongly saline	> 16	> 8.4

[1] valid for material with a clay texture.

Hydraulic conductivity. The categories used were:

Hydraulic conductivity class	Rates in cm/day
very slow	< 3
slow	3 - 10
moderately slow	10 - 20
moderate	20 - 40
moderately rapid	40 - 80
rapid	80 - 160
very rapid	> 160

Infiltration rate. The categories used were:

Class	Rates in cm/day
very slow	< 1
slow	1 - 10
moderately slow	10 - 25
moderately rapid	25 - 50
rapid	50 - 100
very rapid	> 100

APPENDIX IV

DESCRIPTION OF AND ANALYTICAL DATA FROM REPRESENTATIVE SOIL PROFILES IN THE 4 SURVEY AREAS

APPENDIX IV - A

WASARE AREA

LABORATORY DATA

Profile no.: 1 Area: Wasare

Mapping unit: PfA12

Horizon	A1	AC	C1	C2	2E	2EC	2C1	3C1
Depth of sample (cm)	5-15	25-35	45-56	66-73	80-83	87-97	110-130	150-165
TEXTURE								
Sand % 2.0 - 0.05 mm	32	20	52	54	54	40	36	50
Silt % 0.05 - 0.002 mm	20	30	0	22	20	16	14	19
Clay % 0.002 - 0 mm	48	50	48	24	26	44	50	31
Texture class	C	C	SC	SCL	SCL	SL	C	SCL
CHEMICAL DATA								
pH-H_2O (1:2.5 v/v)	6.0	7.0	7.1	7.9	8.6	8.1	8.3	8.2
pH-KCl "	5.0	5.7	6.0	6.3	6.2	6.3	6.6	6.7
EC (mS/cm) "	0.40	0.45	0.45	0.30	0.17	0.30	0.40	0.50
$CaCO_3$ (%)	n.d.	n.d.')	n.d.')	0.13	n.d.	n.d.	1.28	2.84
C (%)	1.82	0.38	0.35	0.18	0.41	0.24	0.15	0.21
N (%)								
C/N								
CEC (me/100g), pH 8.2	29.8	32.8	33.5	18.4	12.2	19.2	29.0	29.0
Exch. Ca (me/100g)	19.7	22.5	22.5	14.3	7.5	10.5	19.7	25.0
" Mg "	4.87	3.03	3.03	2.02	1.03	1.62	2.63	2.52
" K "	1.82	1.18	1.11	0.74	0.48	0.94	1.53	1.82
" Na "	1.00	1.30	2.17	1.80	0.92	1.50	2.35	2.85
Sum of cations	27.4	28.0	28.8	18.9	9.9	14.6	26.2	32.2
Base sat. %, pH 8.2	92	85	86	>100	81	76	90	>100
ESP at pH 8.2	3	4	6	10	8	8	8	10
Saturation extract:								
Moisture %								
pH-paste								
ECe (mS/cm)								

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	15.0
Mg "	4.2
K "	0.76
Na "	1.96
P (ppm)	18
Mn (me/100g)	0.87
Exch. acidity (me/100g)	–
pH-H_2O (1:1 v/v)	6.1
C %	1.64
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	5-15	6.35	0.146
AC	25-35	8.50	0.246
C1	45-56	8.15	0.188
C2	66-73	8.45	0.250
2E	80-83	8.30	0.206
2EC	87-97	8.55	0.208
2C1	110-130	8.65	0.316
3C1	150-165	8.75	0.310

') $CaCO_3$ content of these horizons is not representative for this mapping unit

Area: Wasare

Profile no.: 1

Mapping unit: PfA12

Soil classification: calcaric FLUVISOLS

Physiography: alluvial plain in Kano plain

Topography: flat; bunds

Vegetation/landuse: grass

Drainage conditions: imperfectly drained; seasonally flooded up to 10 cm; on sampling date no groundwater within 3.80 m

Profile description:

A1	0- 16 cm	brownish black (10YR2/2 dry and moist) clay; few, fine, faint iron mottles; strong, fine angular blocky structure; common moderately thick pressure faces; few macropores; very hard when dry; very frequent, coarse, for a great part dead roots; clear, smooth transition to
AC	16- 40 cm	brownish black (10YR2/2 moist) clay with coarse sand; few, fine, faint iron mottles; moderate, medium, prismatic structure falling apart into moderate, medium, angular blocks; abundant, moderately thick pressure faces; common macropores; firm when moist; common medium roots; clear, smooth transition to
C1	40- 64 cm	brownish black (10YR3/2 moist) stratified clay loam and sandy clay; common, medium, distinct dull yellowish brown iron mottles; common biopores; firm when moist; very few (<1%), very fine (<5 mm), manganese concretions; common, medium roots; abrupt, wavy transition to
C2	64- 80 cm	brown to brownish black (7,5YR4/3 to 10YR3/2 moist) strongly stratified coarse sandy loam to clay loam; common, medium, distinct iron mottles; weak, fine, prismatic structure; common biopores; friable when moist; slightly calcareous; very few, fine roots; abrupt, smooth transition to
2E	80- 83 cm	grayish yellow brown (10YR6/2 dry and wet) sandy clay loam with coarse sand; common, medium, distinct iron mottles; weak, fine prismatic structure; few macropores; very hard when dry; very few, fine roots; abrupt, clear transition to
2EC	83-100 cm	brown (10YR4/4 moist) sandy loam to clay loam; common, medium, distinct iron mottles; moderately coherent massive structure; few macropores; friable when moist; strongly alkaline; few (<10%), very fine (<5 mm) manganese concretions; very few, fine roots; gradual, irregular transition to
2C1	100-139 cm	dull yellowish brown (10YR5/4 dry) and (10YR4/3 moist) slightly gravelly clay; common, fine, distinct mottles; moderately massive coherent structure; many biopores; very friable when moist; strongly alkaline; moderately calcareous; few (<10%), very fine (<5 mm), manganese concretions; few, fine roots; gradual, wavy transition to
3C1	139-180 cm	brown (10YR4/4 moist) stony, sandy clay loam; few, fine, faint mottles; very friable when moist; strongly alkaline; moderately calcareous; few (<10%), very fine (<5 mm), manganese concretions; common, fine roots
3C2	180-210 cm	dull yellow orange (10YR6/4 moist) slightly gravelly clay loam; common, medium, distinct yellowish brown mottles; friable when moist; slightly calcareous; no roots
3C3	210-380 cm	dull yellow orange (10YR6/4 moist) clay loam to clay; common, medium, distinct yellowish brown mottles; friable when moist; slightly calcareous

LABORATORY DATA

Profile no.: 2 Area: Wasare

Mapping unit: 8fA 24

Horizon	A1	C 1	C2	C 3	C 4	2C1
Depth of sample (cm)	10-20	30-40	42-52	55-70	82-92	110-140
TEXTURE						
Sand % 2.0 - 0.05 mm	18	12	8	8	10	12
Silt % 0.05 - 0.002 mm	42	32	42	18	10	22
Clay % 0.002 - 0 mm	40	56	50	74	80	66
Texture class	SiC/SiCL	C	C	C	C	C
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	7.1	7.4	7.7	7.9	7.4	6.0
pH-KCl "	6.0	6.1	6.3	6.3	6.3	4.9
EC (mS/cm) "	0.14	0.35	0.40	0.45	0.45	0.70
$CaCO_3$ (%)	n.d.	0.73	0.47	1.15	2.81	n.d.
C (%)	0.15	0.53	0.32	0.53	0.53	0.29
N (%)						
C/N						
CEC (me/100g), pH 8.2	35.7	35.8	38.0	37.4	46.0	36.0
Exch. Ca (me/100g)	7.7	31.5	33.5	32.5	34.5	25.0
" Mg "	1.07	4.65	6.37	6.00	6.45	6.02
" K "	0.33	1.06	1.48	1.44	1.67	2.73
" Na "	trace	0.80	1.30	1.50	1.80	1.97
Sum of cations	9.1	38.0	42.7	41.4	44.4	35.7
Base sat. %, pH 8.2	25	>100	>100	>100	97	99
ESP at pH 8.2	<1	2	3	4	4	5
Saturation extract:						
Moisture %						
pH-paste						
ECe (mS/cm)						

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	19.1
Mg "	5.8
K "	0.83
Na "	0.88
P (ppm)	40
Mn (me/100g)	0.87
Exch. acidity (me/100g)	-
pH-H_2O (1:1 v/v)	6.2
C %	1.34
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	10-20	7.45	0.352
C 1	30-40	7.78	0.258
C 2	42-52	7.75	0.490
C 3	55-70	7.75	0.396
C 4	82-92	7.86	0.53
2C1	110-140	7.68	0.52
2C 3	380	7.55	3.36

Area: Wasare

Profile no.: 2

Mapping unit: PfA24

Soil classification: calcaric FLUVISOLS

Physiography: alluvial plain in Kano plain

Topography: flat; uneven ploughed land;bunds 20 to 30 cm high

Vegetation/landuse: grassland with herbs

Drainage conditions: imperfectly to moderately well drained; no flooding; on sampling date groundwater level at 345 cm depth

Profile description:

A1	0- 20 cm	brownish gray (10YR4/1 dry) and brownish black (10YR3/1 moist) silty clay loam; no mottles; strong, very fine subangular blocky structure; many macropores; very hard when dry; common medium roots; abrupt, smooth transition to
C1	20- 42 cm	brown (10YR4/4 dry) and grayish yellow brown (10YR4/2 moist) stratified loamy sand and clay; few, fine, distinct iron mottles; granular structure, common macropores; loose when dry; slightly calcareous; common medium roots; abrupt, smooth transition to
C2	42- 52 cm	grayish yellow brown (10YR4/2 dry and moist) slightly stratified loam and clay; common, fine, distinct mottles along root channels; weak, fine, platy structure; common vertical biopores (root channels); soft when dry; slightly calcareous; few, medium roots; clear, wavy transition to
C3	52- 80 cm	brownish gray (10YR4/1 dry) and brownish black (10YR3/1 moist) clay with thin loam layers; many, medium, distinct, dark reddish brown iron mottles; moderate, coarse prismatic structure; common thin pressure faces; common macropores; very hard when dry; slightly calcareous; few, medium roots; clear, smooth transition to
C4	80- 95 cm	grayish yellow brown (10YR4/2 dry) and brownish black (10YR3/1 moist) stratified loam and clay; few, fine, faint iron mottles; strong, fine platy structure; common macropores; slightly hard when dry; moderately calcareous; few, medium roots; gradual, wavy transition to
2C1	95-165 cm	black (10YR2/1 dry and moist) heavy clay; common, medium, distinct iron mottles; strong, very coarse prismatic structure; abundant, moderately thick pressure faces; common macropores; extra hard when dry; few, fine roots
2C2	165-300 cm	brownish black (10YR3/1 moist) heavy clay; common, fine, faint mottles; very firm when moist
2C3	300-380 cm	brownish black (10YR3/1 moist) clay loam; friable when moist

LABORATORY DATA

Profile no.: 3 Area: Wasare

Mapping unit: PeA1

Horizon	A1	AC	C1	2C1		
Depth of sample (cm)	5-15	25-35	90-110	160-170		
TEXTURE						
Sand % 2.0 - 0.05 mm	10	16	10	6		
Silt % 0.05 - 0.002 mm	22	28	22	16		
Clay % 0.002 - 0 mm	68	56	68	78		
Texture class	C	C	C	C		
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	6.3	6.6	6.3	7.4		
pH-KCl "	5.2	5.6	5.4	6.0		
EC (mS/cm) "	0.65	0.50	0.50	0.85		
$CaCO_3$ (%)	n.d.	n.d.	n.d.	0.08		
C (%)	1.10	0.54	0.84	0.33		
N (%)						
C/N						
CEC (me/100g), pH 8.2	31.8	33.0	38.0	34.7		
Exch. Ca (me/100g)	21.0	22.5	18.0	22.5		
" Mg "	5.67	6.05	4.27	4.05		
" K "	1.85	1.42	1.53	2.73		
" Na "	1.00	1.17	2.35	6.30		
Sum of cations	29.5	31.1	26.2	35.6		
Base sat. %, pH 8.2	93	94	69	>100		
ESP at pH 8.2	3	3	6	18		
Saturation extract:						
Moisture %				76.1		
pH-paste				7.9		
ECe (mS/cm)				1.15		

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	16.4
Mg "	5.1
K "	0.86
Na "	1.22
P (ppm)	28
Mn (me/100g)	1.27
Exch. acidity (me/100g)	-
pH-H_2O (1:1 v/v)	6.3
C %	0.99
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	5-15	6.85	0.22
AC	25-35	7.05	0.272
C1	90-110	7.08	0.256
2C1	160-170	7.55	0.70
	gr. water (220)	8.30	4.02

Area: Wasare

Profile no.: 3

Mapping unit: P1A1

Soil classification: pellic VERTISOLS

Physiography: lacustrine plain (Kano plain)

Topography: flat; irrigation system (bunds, irrigation canals)

Vegetation/landuse: rushes; grasses; irrigated rice fields nearby

Drainage conditions: poorly drained; seasonally flooded up to 50 cm; on sampling date groundwater level at 220 cm depth

Profile description:

A1	0- 19 cm	brownish black (10YR3/1 moist) heavy clay; common, fine, faint iron mottles; moderately coherent massive structure; common, thin slickensides; few macropores; sticky and plastic when wet; frequent, medium roots; clear, smooth transition to
AC	19- 47 cm	brownish black (10YR3/1 moist) heavy clay; many, medium, faint iron mottles; strong, fine, angular blocky structure; abundant, moderately thick slickensides; few macropores; friable when moist; common, fine, for the greater part dead roots; gradual, smooth transition to
C1	47-160 cm	black (10YR2/1 moist) heavy clay; few, fine, faint iron mottles; moderate, fine, angular blocky structure; few, moderately thick pressure faces; few macropores; friable when moist; few, fine for the greater part dead roots; gradual, smooth transition to
2C1	160-210 cm	brownish black (10YR3/1 moist) heavy clay; few, fine, faint mottles; moderately coherent massive structure; many macropores; friable when moist; slightly calcareous; no roots
2C2	210-260 cm	brownish black (10YR3/2 moist) clay loam; common, fine, distinct, dull yellowish brown mottles; very friable when moist
2C3	260-390 cm	dull yellowish brown (10YR5/4 moist) clay loam; friable when moist; very few (<1%), very fine (<5 mm) rock fragments

LABORATORY DATA

Profile no.: 4 Area: Wasare

Mapping unit: PlA1

Horizon	A1	AC	C1	C2	C3	C4
Depth of sample (cm)	3-9	20-30	50-60	75-85	100-110	135-140
TEXTURE						
Sand % 2.0 - 0.05 mm	12	10	14	10	8	80
Silt % 0.05 - 0.002 mm	22	26	22	16	36	6
Clay % 0.002 - 0 mm	66	64	64	74	56	14
Texture class	C	C	C	C	C	SL
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	5.7	6.2	6.2	6.2	5.7	7.1
pH-KCl "	4.8	5.2	5.2	5.8	4.2	6.0
EC (mS/cm) "	0.50	0.40	0.45	0.20	0.30	0.40
$CaCO_3$ (%)						
C (%)	2.15	0.63	0.60	1.04	0.93	0.54
N (%)						
C/N						
CEC (me/100g), pH 8.2	38.0	37.0	33.0	37.0	37.0	11.0
Exch. Ca (me/100g)	20.0	19.0	19.5	15.0	13.0	11.5
" Mg "	6.42	7.52	5.27	4.41	7.62	5.26
" K "	1.76	1.44	1.44	1.36	1.85	1.31
" Na "	0.92	1.25	1.40	1.40	1.50	0.52
Sum of cations	29.1	29.2	27.6	22.2	24.0	18.6
Base sat. %, pH 8.2	77	79	84	60	65	>100
ESP at pH 8.2	2	3	4	4	4	5
Saturation extract:						
Moisture %						
pH-paste						
ECe (mS/cm)						

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	15.3
Mg "	4.9
K "	0.67
Na "	1.20
P (ppm)	16
Mn (me/100g)	0.72
Exch. acidity (me/100g)	-
pH-H_2O (1:1 v/v)	5.6
C %	1.14
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)	
A1	3-9	5.77	0.40	
AC	20-30	6.55	0.364	
C1	50-60	6.67	0.274	
C2	75-85	5.85	0.244	
C3	100-110	5.29	0.344	
C4	135-140	5.79	0.90	
2C2	390	7.20	0.68	

Area: Wasare

Profile no.: 4

Mapping unit: PlA1

Soil classification: pellic VERTISOLS

Physiography: lacustrine plain (Kano plain)

Topography: flat; bunds, cracks

Vegetation/landuse: grass and some herbs; abandoned rice fields, now in use as grassland

Drainage conditions: poorly drained; no flooding; on sampling date no groundwater within 4 m.

Profile description:

A1	0- 11 cm	black (10YR2/1 dry and moist) heavy clay; few, fine, distinct brown iron mottles; strong, very coarse prismatic structure; abundant thick pressure faces; common macropores; extra hard when dry; abundant, coarse roots; abrupt, smooth transition to
AC	11- 47 cm	black (2,5Y2/1 dry and moist) heavy clay; few, fine, faint iron mottles; strong, very coarse prismatic structure falling apart into strong, medium angular blocks; abundant, thick pressure faces; few macropores; extra hard when dry; frequent, fine roots; gradual, smooth transition to
C1	47- 68 cm	black (10YR2/1 dry and moist) heavy clay; few, fine, faint iron mottles; strong, medium sub-angular blocky structure; abundant, thick pressure faces; few macropores; extra hard when dry; few, fine roots; clear, smooth transition to
C2	68- 96 cm	brownish black (10YR2/2 dry) and black (10YR1,7/1 moist) heavy clay; common, medium, faint iron mottles; strong, medium, angular blocky structure; abundant, thin pressure faces; few macropores; very hard when dry; common, fine dead roots (root gallery)gradual, smooth transition to
C3	96-120 cm	brownish black (7,5YR3/1 dry) and black (7,5YR2/1 moist) heavy clay; few, fine, faint iron mottles; moderate, medium angular blocky structure; few, medium thick pressure faces; few macropores; very hard when dry; few, fine dead roots; gradual, smooth transition to
C4	120-250 cm	black (7,5YR2/1 moist) sandy loam[1]); moderately coherent massive structure; few macropores; firm when moist; few, fine dead roots to 170 cm, below 170 cm no roots
C5	250-300 cm	brownish black (10YR2/2 moist) clay; firm when moist
2C1	300-380 cm	brownish black (10YR3/1 moist) clay loam; friable when moist; below 340 cm non to slightly calcareous
2C2	380-400 cm	grayish yellow brown (10YR4/2 moist) clay loam; few, fine, faint mottles; friable when moist; very few (<1%), very fine (<5 mm) rock fragments

[1]) field estimation of the texture was, however, heavy clay

APPENDIX IV - B

AWACH KANO AREA

LABORATORY DATA

Profile no.: 1 Area: Awach Kano

Mapping unit: PfA11

Horizon	A1	C1g	2Eb	2C1		
Depth of sample (cm)	3-8	40-55	75-85	110-140		
TEXTURE						
Sand % 2.0 - 0.05 mm	22	32	22	18		
Silt % 0.05 - 0.002 mm	44	34	28	18		
Clay % 0.002 - 0 mm	34	34	50	64		
Texture class	C	CL	C	C		
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	7.4	6.9	6.6	6.3		
pH-KCl "	5.9	5.1	4.8	4.2		
EC (mS/cm) "	0.35	0.09	0.09	0.11		
$CaCO_3$ (%)	0.22	3.13	n.d.	n.d.		
C (%)	0.56	0.29	0.47	0.41		
N (%)						
C/N						
CEC (me/100g), pH 8.2	34.8	31.9	32	32.9		
Exch. Ca (me/100g)	18.9	17.2	11.3	14.3		
" Mg "	3.42	2.42	2.37	3.03		
" K "	1.76	1.44	1.31	1.42		
" Na "	0.32	0.15	0.32	0.55		
Sum of cations	24.4	21.2	15.3	19.3		
Base sat. %, pH 8.2	70 ')	66 ')	48	59		
ESP at pH 8.2	1	<1	1	2		
Saturation extract:						
Moisture %						
pH-paste						
ECe (mS/cm)						

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	16.9
Mg "	4.0
K "	0.92
Na "	0.97
P (ppm)	16
Mn (me/100g)	1.94
Exch. acidity (me/100g)	-
pH-H_2O (1:1 v/v)	7.6
C %	0.57
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	3-8	7.54	0.268
C1g	40-55	6.25	0.044
2Eb	75-85	5.66	0.100
2C1	110-140	5.88	0.056
3C1	330	7.28	0.518

') Base saturation of these horizons might not be correct (see also data on pH and $CaCO_3$ content)

Area: Awach Kano

Profile no.: 1

Mapping unit: PfA11

Soil classification: calcaric FLUVISOLS

Physiography: levee

Topography: flat; erosion gullies 0.50 to 1.0 metres deep; cow foetoes

Vegetation/landuse: grassland with some herbs and shrubs

Drainage conditions: imperfectly drained; seasonally flooded up to 60 cm; no groundwater within 3.80 m depth

Remarks: profile description is made in the talus of an erosion gully

Profile description:

A1	0- 10 cm	grayish yellow brown (10YR4/2 dry) and brownish black (10YR3/2 moist) clay loam; few, fine, faint iron mottles; moderate, medium angular blocky structure; few, thin pressure faces; few macropores; hard when dry; slightly calcareous; common, fine roots; clear, smooth transition to
C1g	10- 69 cm	brown (10YR4/4 dry) and dark brown (10YR3/4 moist) stratified loam and clay loam with thin, coarse loamy sand layers; common, fine, distinct bright brown iron mottles; depending on texture the structure is moderate, medium platy, or weak, coarse prismatic; common biopores, few macropores; slightly hard to hard when dry; slightly calcareous; very few (<1%), very fine manganese concretions in sand layers; up till 53 cm common, fine roots; clear, smooth transition to
2Eb	69- 90 cm	grayish yellow brown (10YR5/2 dry) and brownish black (10YR3/1 moist) clay; few, fine, distinct bright reddish brown (5YR5/8) iron mottles; weak, coarse prismatic structure; few, thin pressure faces; few biopores, common macropores; very hard when dry; few, fine roots; gradual,wavy transition to
2C1	90-180 cm	black (10YR2/1 moist) heavy clay; few, fine, faint mottles; moderate to strong, coarse angular blocky structure; few, thin pressure faces; few macropores; extra hard when dry; few, very fine roots
2C2	180-270 cm	brownish black (10YR3/2 moist) clay; few, fine, faint mottles; structure not observed; very hard when dry; no roots
3C1	270-330 cm	brownish black (2,5Y3/2 moist) and dull yellow (2,5Y6/4 moist) clay loam; few, fine, distinct olive brown mottles; slightly hard when dry; few (<1%), fine (<5 mm) carbonate concretions; slightly calcareous
3C2	330-380 cm	yellowish brown (2,5Y5/4 moist) clay loam; few, fine, faint mottles; soft when dry; slightly calcareous

LABORATORY DATA

Profile no.: 2 Area: Awach Kano

Mapping unit: PfA21

Horizon	A1	C1g	C2g	2C1		
Depth of sample (cm)	3-13	30-60	90-120	150-170		
TEXTURE						
Sand % 2.0 - 0.05 mm	20	18	16	30		
Silt % 0.05 - 0.002 mm	36	32	22	26		
Clay % 0.002 - 0 mm	44	50	62	44		
Texture class	C	C	C	C		
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	6.7	6.9	6.5	6.5		
pH-KCl "	4.8	5.3	4.3	4.4		
EC (mS/cm) "	0.06	0.20	0.16	0.20		
$CaCO_3$ (%)	n.d.	0.09	none	none		
C (%)	0.88	0.62	0.53	0.32		
N (%)						
C/N						
CEC (me/100g), pH 8.2	27.0	31.2	34.7	30.8		
Exch. Ca (me/100g)	8.8	13.9	13.0	13.0		
" Mg "	2.36	1.97	1.97	3.12		
" K "	1.27	1.67	0.86	0.75		
" Na "	tr.	0.72	0.52	1.00		
Sum of cations	12.4	18.3	16.4	17.9		
Base sat. %, pH 8.2	46	59	47	58		
ESP at pH 8.2	<1	2	1	3		
Saturation extract:						
Moisture %						
pH-paste						
ECe (mS/cm)						

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	8.3
Mg "	2.9
K "	0.82
Na "	0.59
P (ppm)	8
Mn (me/100g)	2.88
Exch. acidity (me/100g)	-
pH-H_2O (1:1 v/v)	5.7
C %	1.07
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	3-13	5.85	0.072
C1g	30-60	6.68	0.120
C2g	90-120	5.95	0.148
2C1	150-170	6.30	0.188
2C3	350	5.60	0.258

Area: Awach Kano

Profile no.: 2

Mapping unit: PfA21

Soil classification: eutric GLEYSOL

Physiography: alluvial plain in Kano plains

Topography: flat; ploughed land, some small cracks

Vegetation/landuse: grassland

Drainage conditions: imperfectly drained; seasonally flooded up to 60 cm; no groundwater within 380 cm depth

Profile description:

A1	0- 15 cm	dull yellowish brown (10YR4/3 dry) and brownish black (10YR3/2 moist) clay; few, fine, distinct iron mottles; moderate, coarse prismatic structure; common biopores; hard when dry; frequent, medium roots; clear, smooth transition to
C1g	15- 80 cm	brownish black (10YR3/1 dry) and black (10YR2/1 moist) clay; common, medium distinct, brown iron mottles; strong, coarse prismatic structure falling apart into strong, medium angular blocks; few, thin pressure faces; common biopores; very hard when dry; common, fine roots; gradual, wavy transition to
C2g	80-135 cm	brownish black (10YR3/1 dry) and black (10YR2/1 moist) clay; common, medium, distinct dark reddish brown iron mottles; moderate, medium angular blocky structure; few, thin pressure faces; few bio- and macropores; very hard when dry; till 135 cm few, fine roots, below 135 cm no roots; gradual, wavy transition to
2C1	135-180 cm	brownish black (10YR3/1 dry) and black (10YR2/1 moist) clay; many, medium, prominent reddish brown iron mottles; weak, medium angular blocky structure; common, moderately thick clay skins and humus coatings; very few biopores; very hard when dry; few, fine (<10 mm), soft, weathered rock fragments; few, fine (<10 mm), manganese concretions; slightly calcareous
2C2	180-220 cm	grayish yellow brown (10YR4/2 moist) clay loam; common, fine, distinct mottles; structure not observed; very hard when dry; slightly calcareous
2C3	220-380 cm	dark brown (10YR3/3 moist) clay; few to common, fine, faint mottles; very hard when dry; slightly calcareous

LABORATORY DATA

Profile no.: 3 Area: Awach Kano

Mapping unit: Bf Az2

Horizon	A1	AC	C1g	2C2g	2C3g	
Depth of sample (cm)	5-12	20-30	50-85	115-125	140-160	
TEXTURE						
Sand % 2.0 - 0.05 mm	16	16	14	16	16	
Silt % 0.05 - 0.002 mm	40	32	36	22	18	
Clay % 0.002 - 0 mm	44	52	50	62	66	
Texture class	C/Sic	C	C	C	C	
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	7.1	6.9	7.5	6.8	6.6	
pH-KCl "	5.4	4.7	6.1	4.6	4.5	
EC (mS/cm) "	0.07	0.09	0.06	0.15	0.16	
$CaCO_3$ (%)						
C (%)	0.68	0.74	0.50	0.53	0.24	
N (%)						
C/N						
CEC (me/100g), pH 8.2	23.4	23.8	29.0	34.8	31.8	
Exch. Ca (me/100g)	10.5	9.7	11.3	13.4	15.1	
" Mg "	3.82	2.52	1.97	3.62	4.03	
" K "	1.80	1.11	1.18	1.44	1.42	
" Na "	0.40	0.70	0.80	0.70	0.70	
Sum of cations	16.5	14.0	15.3	19.2	21.3	
Base sat. %, pH 8.2	71	59	53	55	67	
ESP at pH 8.2	2	3	3	2	2	
Saturation extract:						
Moisture %						
pH-paste						
ECe (mS/cm)						

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	9.0
Mg "	3.6
K "	0.84
Na "	0.63
P (ppm)	22
Mn (me/100g)	2.00
Exch. acidity (me/100g)	0.2
pH-H_2O (1:1 v/v)	5.4
C %	0.60
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	5-12	6.15	0.058
AC	20-30	6.20	0.060
C1g	50-85	6.17	0.054
2C2g	115-125	5.95	0.078
2C3g	140-160	5.74	0.156
2C3g	200	6.17	0.458
2C5g	360	7.68	0.356

Area: Awach Kano

Profile no.: 3

Mapping unit: PfA22

Soil classification: gleyic CAMBISOLS

Physiography: alluvial plain in Kano plains

Topography: flat; cow foetoes; some cracks

Vegetation/landuse: grassland

Drainage conditions: imperfectly drained; seasonally flooded up to 30 cm; no groundwater within 3.60 m

Profile description:

A1	0- 15 cm	dark brown (10YR3/3 dry) and brownish black (10YR3/2 moist) silty clay; very few, fine, very faint iron mottles; moderate fine subangular blocky structure; common macropores; soft when dry; frequent, medium roots; clear, smooth transition to
AC	15- 33 cm	brownish grey (10YR4/1 dry) and black (10YR2/1 moist) clay; few, fine, faint grayish yellow brown iron mottles; weak, moderate prismatic structure falling apart into moderate, medium, angular blocks; common, thin pressure faces; many macropores; slightly hard when dry; frequent, medium roots; clear, smooth transition to
C1g	33-110 cm	brownish black (10YR3/1 dry) and black (10YR2/1 moist) clay; common, fine, faint brown iron mottles; strong, fine angular blocky structure; common, thin pressure faces; few macropores; very hard when dry; few, fine for the greater part dead roots; gradual, wavy transition to
2C2g	110-129 cm	as above but few, fine faint iron mottles; few (2%), fine (<5 mm), weathered yellow rock fragments; very few, fine roots; gradual, wavy transition to
2C3g	129-220 cm	brownish black (10YR2/2 dry and moist heavy clay; few, fine, faint iron mottles; weak, coarse prismatic structure falling apart into strong, medium angular blocks; common, thin pressure faces; few bio- and macropores; very hard when dry; few (2%), fine (<5 mm) weathered yellow rock fragments; very few, fine roots till 180 cm, below 180 cm no roots
2C4g	220-250 cm	dark brown (10YR3/4 moist) clay loam; common, fine distinct yellowish brown mottles; soft when dry, friable when moist; slightly calcareous
2C5g	250-360 cm	dark brown (10YR3/3 moist) loam; few, fine, faint mottles; soft when dry, friable when moist; few (3%), fine (5 mm) manganese concretions; till 280 cm few (<2%), fine (<10 mm), slightly weathered rock fragments

LABORATORY DATA

Profile no.: 4 Area: Awach Kano

Mapping unit: PeA1

Horizon	A1	C2	C3	C4		
Depth of sample (cm)	5-20	40-55	120-140	175-185		
TEXTURE						
Sand % 2.0 - 0.05 mm	10	18	16	20		
Silt % 0.05 - 0.002 mm	28	30	28	22		
Clay % 0.002 - 0 mm	62	52	56	58		
Texture class	C	C	C	C		
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	6.9	6.5	7.2	6.7		
pH-KCl "	5.1	4.9	5.1	4.7		
EC (mS/cm) "	0.09	0.10	0.14	0.12		
$CaCO_3$ (%)						
C (%)	0.94	0.38	0.44	0.41		
N (%)						
C/N						
CEC (me/100g), pH 8.2	36.0	30.0	29.1	26.0		
Exch. Ca (me/100g)	16.8	13.0	13.0	11.7		
" Mg "	3.03	2.63	3.82	2.42		
" K "	1.67	1.31	1.11	0.96		
" Na "	0.17	0.62	1.00	0.80		
Sum of cations	21.7	17.6	18.9	15.9		
Base sat. %, pH 8.2	60	59	65	61		
ESP at pH 8.2	<1	2	3	3		
Saturation extract:						
Moisture %						
pH-paste						
ECe (mS/cm)						

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	11.8
Mg "	3.4
K "	0.92
Na "	0.50
P (ppm)	12
Mn (me/100g)	1.32
Exch. acidity (me/100g)	0.1
pH-H_2O (1:1 v/v)	5.2
C %	1.10
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	5-20	6.29	0.146
C2	40-55	6.26	0.116
C3	120-140	6.48	0.128
C4	175-185	6.14	0.108
C6	330	6.55	0.146
C7	380	6.74	0.126

Area: Awach Kano

Profile no.: 4

Mapping unit: P1A1

Soil classification: pellic VERTISOLS

Physiography: lacustrine plain (Kano plain)

Topography: flat; eroded irrigation canal (1-1.5 m deep, 2-3 m wide); bunds; cowfoetoes; common cracks 3 to 5 cm wide, 70 to 100 cm deep

Vegetation/landuse: abandoned rice fields; irrigation system out of use; at present grassland with mainly grasses and some rushes, 20% bare ground

Drainage conditions: poorly drained; seasonally flooded up to about 1 metre; on sampling date no groundwater within 4 m

Remarks: profile description is made in the talud of an eroded irrigation canal

Profile description:

A1	0- 23 cm	dull yellowish brown (10YR4/3 dry) and brownish black (10YR2/3 moist) clay; few, fine, distinct iron mottles; coarse prismatic structure falling apart into strong, medium angular blocks; common, thin pressure faces; common biopores; extra hard when dry; common, medium roots; clear, smooth transition to
C1	23- 30 cm	brownish black (10YR3/2 dry and moist) cracking clay; few, fine, distinct iron mottles; coarse prismatic structure; common biopores; extra hard when dry; common, fine roots; gradual, wavy transition to
C2	30- 70 cm	drak brown (10YR3/3 dry) and brownish black (10YR2/3) cracking clay; common, fine, faint to distinc iron mottles; very coarse, moderate prismatic structure; few, thin pressure faces; few biopores; below 60 cm very few, very fine (<5 mm) manganese concretions; few, fine roots; diffuse transition to
C3	70-170 cm	brownish black (10YR2/2 moist) clay; common, fine, faint iron mottles; moderate, fine angular blocky structure; common, moderately thick pressure faces; few biopores; friable when moist; very few, very fine (<5 mm) manganese concretions; very few, very fine roots; diffuse transition to
C4	170-190 cm	brownish black (10YR3/2 moist) clay; common, fine, faint iron mottles; weak, fine angular blocky structure; few, thin pressure faces; few macropores; friable when moist; very few, very fine roots
C5	190-300 cm	brownish black (10YR3/2 moist) clay loam; few, fine, faint mottles; structure not observed; friable when moist; no roots
C6	300-350 cm	brownish black (10YR3/1 moist) clay loam; common, medium faint yellowish brown (10YR5/8) mottles; friable when moist; below 320 cm almost weathered, fine (<10 mm) rock fragments
C7	350-390 cm	dull yellowish brown (10YR5/3 moist) loam; few, fine, faint mottles; friable when moist

LABORATORY DATA

Profile no.: 5 Area: Awach Kano

Mapping unit: 8l A2

Horizon	A1g	Eg	C1g	C1g	C2g	
Depth of sample (cm)	10-20	30-40	50-60	100-110	150-160	
TEXTURE						
Sand % 2.0 - 0.05 mm	16	16	12	12	22	
Silt % 0.05 - 0.002 mm	28	26	18	14	26	
Clay % 0.002 - 0 mm	56	58	70	74	52	
Texture class	C	C	C	C	C	
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	6.4	6.7	6.5	6.0	6.4	
pH-KCl "	4.6	4.7	4.2	4.1	4.1	
EC (mS/cm) "	0.16	0.12	0.15	0.14	0.06	
$CaCO_3$ (%)						
C (%)	0.97	0.41	0.59	0.41	0.29	
N (%)						
C/N						
CEC (me/100g), pH 8.2	34.9	29.0	38.0	35.7	29.8	
Exch. Ca (me/100g)	15.9	13.2	15.1	14.3	11.1	
" Mg "	2.92	3.03	4.32	4.25	3.27	
" K "	1.53	1.32	1.44	1.48	1.02	
" Na "	0.40	0.40	0.70	0.70	0.40	
Sum of cations	20.8	18.0	21.6	20.7	15.8	
Base sat. %, pH 8.2	59	62	57	58	53	
ESP at pH 8.2	1	1	2	2	1	
Saturation extract:						
Moisture %						
pH-paste						
ECe (mS/cm)						

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	12.1
Mg "	3.1
K "	0.82
Na "	0.50
P (ppm)	8
Mn (me/100g)	1.47
Exch. acidity (me/100g)	-
pH-H_2O (1:1 v/v)	5.6
C %	1.40
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1g	10-20	5.96	0.094
Eg	30-40	5.94	0.078
C1g	50-60	5.73	0.052
C1g	100-110	5.51	0.054
C2g	150-160	5.93	0.038
C4g	370	5.43	0.066

Area: Awach Kano

Profile no.: 5

Mapping unit: PlA2

Soil classification: dystric PLANOSOLS

Physiography: lacustrine plain (Kano plain)

Topography: flat; some irrigation canals are eroded (1-1.50 m deep, about 2 m wide); bunds; cow foetoes

Vegetation/landuse: abandoned rice fields; disused irrigation system; at present grassland; mainly grasses and rushes; 10% bare ground

Drainage conditions: poorly drained; seasonally flooded up to about 30 cm; no groundwater within 380 cm

Remarks: profile description is made in the talus of an eroded irrigation canal

Profile description:

A1g	0- 25 cm	dull yellowish brown (10YR5/3 dry) and brownish black (10YR3/2 moist) clay; few, fine, faint iron mottles; strong, medium prismatic structure falling apart into strong, fine angular blocks; few, thin pressure faces; common bio- and macropores; extra hard when dry, sticky and plastic when wet; frequent, medium roots; gradual, wavy transition to
Eg	25- 42 cm	brownish black (10YR3/2 moist) grayish yellow brown (10YR5/2 dry) clay; common, fine, faint brown (10YR4/6) iron mottles; strong, medium prismatic structure falling apart into strong, medium angular blocks; few, thin pressure faces; common biopores; extra hard when dry, sticky and plastic when wet; very few, very small yellow weathered stones; common, fine roots; gradual, irregular transition to
C1g	42-140 cm	brownish black (10YR2/2 dry and moist heavy clay; till 100 cm few, fine, faint iron mottles; strong, medium prismatic structure falling apart into weak, medium angular blocks, below 100 cm massive structure; abundant, moderately thick slickensides and pressure faces; very few biopores, few macropores; extra hard when dry, sticky and plastic when wet; till 70 cm few, fine roots; below 70 cm few, fine, dead roots; clear, smooth transition to
C2g	140-180 cm	brownish black (10YR2/2 dry and moist) clay; few, medium, distinct yellowish brown iron mottles; moderately coherent massive structure; common, moderately thick pressure faces; no biopores, common macropores; very hard when dry, friable when moist; few, fine, soft yellow weathered rock fragments; till 150 cm few, fine dead roots, below 150 cm no roots
C3g	180-320 cm	brownish black (10YR2/2 moist) clay; few to common, fine mottles; structure not observed; friable when moist
C4g	320-380 cm	brownish black (10YR3/1 moist) clay loam; common, medium, distinct reddish brown mottles; friable when moist; strongly acid

APPENDIX IV - C

KORE AREAS

LABORATORY DATA

Profile no.: 1 Area: Kore

Mapping unit: PfA1

Horizon	A1	ACg	2C1	2C2	2C3	
Depth of sample (cm)	4-14	30-50	90-110	130-150	160-170	
TEXTURE						
Sand % 2.0 - 0.05 mm	20	14	16	16	16	
Silt % 0.05 - 0.002 mm	30	16	14	20	24	
Clay % 0.002 - 0 mm	50	70	70	64	60	
Texture class	C	C	C	C	C	
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	7.5	7.7	7.1	7.8	7.7	
pH-KCl "	5.7	6.0	6.2	6.2	6.4	
EC (mS/cm) "	0.28	0.30	0.35	1.20	1.25	
$CaCO_3$ (%)	n.d.	0.31	n.d.	0.26	0.39	
C (%)	0.79	0.65	0.62	0.53	0.41	
N (%)						
C/N						
CEC (me/100g), pH 8.2	43.0	59,0	55.0	49.0	40.0	
Exch. Ca (me/100g)	23.0	31.5	33.5	33.5	31.5	
" Mg "	6.57	7.42	7.12	6.87	6.57	
" K "	1.83	1.44	0.61	0.80	0.86	
" Na "	0.91	2.84	6.42	9.05	8.92	
Sum of cations	32.3	43.2	47.7	50.2	47.9	
Base sat. %, pH 8.2	75	73	87	>100	>100	
ESP at pH 8.2	2	5	12	18	22	
Saturation extract:						
Moisture %				91.8	86.1	
pH-paste				7.9	7.3	
ECe (mS/cm)				2.15	3.0	

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	19.4
Mg "	6.3
K "	1.26
Na "	0.98
P (ppm)	4
Mn (me/100g)	1.08
Exch. acidity (me/100g)	-
pH-H_2O (1:1 v/v)	6.6
C %	1.09
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	4-14	6.85	0.138
ACg	30-50	7.35	0.238
2C1	90-110	7.88	0.58
2C2	130-150	7.84	1.02
2C3	160-170	7.75	1.28
2C4	240	7.18	3.56

Area: Kore I + II

Profile no.: 1

Mapping unit: PfA1

Soil classification: eutric FLUVISOLS

Physiography: levee (along old river channel)

Topography: flat; sloping towards channel, height difference 1 m over 30 m

Vegetation/landuse: grasses, herbs, some thorny shrubs (2%); sisal plants (1%)

Drainage conditions: imperfectly drained; no flooding

Profile description:

A1	0- 17 cm	brownish black (10YR2/3 moist) clay; few, fine, faint iron mottles; weak, medium angular blocky structure; common, thin pressure faces; common bio- and macropores; friable when moist; common, fine roots; gradual, wavy transition to
ACg	17- 68 cm	brownish black (10YR3/2 moist) heavy clay; few, fine, faint iron mottles; weak, medium angular blocky structure; common, thin pressure faces; common bio- and macropores; friable when moist; common, fine roots; clear, irregular transition to
2C1	68-120 cm	black (10YR2/1 moist) heavy clay; few, fine faint iron mottles; weak, medium angular blocky structure; common, thin pressure faces; few bio- and macropores; very firm when moist; few to common, very fine roots; gradual, wavy transition to
2C2	120-157 cm	black (10YR2/1 moist) clay; few, fine, faint iron mottles; weak, medium angular blocky structure; few macropores; friable when moist; slightly calcareous; few to common, very fine roots; clear, smooth transition to
2C3	157-235 cm	brownish black (10YR3/2 moist) clay; no mottles; weak, medium angular blocky structure; few macropores; friable when moist; slightly calcareous; very few, very fine roots
2C4	235-280 cm	brownish black (10YR3/2 moist) clay loam; few, fine, faint mottles; very hard when dry, friable when moist; slightly calcareous
2C5	280-380 cm	dark brown (10YR3/3 moist) clay loam; few, fine, distinct yellow mottles; very hard when dry, friable when moist; non calcareous

Remarks: - in most soils of this unit the fluvial material contains less clay
- this profile has an ESP of 12 within 100 cm depth.
Therefore, it should be classified as "sodic phase". There is, however, no sufficient evidence from the degree of dispersion in samples of augerings to characterize all soils of this mapping unit as "sodic phase".

LABORATORY DATA

Profile no.: 2 Area: Kore

Mapping unit: PlA1

Horizon	A	AC	C1	C2	C3	2C1	2C2	
Depth of sample (cm)	6-14	30-42	62-69	80-90	110-170	150-165	175-180	
TEXTURE								
Sand % 2.0 - 0.05 mm	20	14	10	14	16	18	14	
Silt % 0.05 - 0.002 mm	30	20	24	20	30	30	20	
Clay % 0.002 - 0 mm	50	66	66	66	54	52	66	
Texture class	C	C	C	C	C	C	C	
CHEMICAL DATA								
pH-H_2O (1:2.5 v/v)	6.9	7.6	7.9	7.9	7.2	7.7	7.7	
pH-KCl "	5.3	6.0	6.6	6.2	6.2	6.2	6.2	
EC (mS/cm) "	0.15	0.25	0.50	0.60	2.10	1.50	1.35	
$CaCO_3$ (%)	0.25	n.d.	0.33	n.d.	n.d.	0.33	0.26	
C (%)	0.88	0.82	0.68	0.53	0.59	0.41	0.56	
N (%)								
C/N								
CEC (me/100g), pH 8.2	47.0	55.0	55.0	55.0	48.0	44.0	48.0	
Exch. Ca (me/100g)	31.5	35.5	36.5	33.5	35.5	31.5	35.5	
" Mg "	10.28	10.30	10.27	7.42	7.27	7.00	9.52	
" K "	4.67	3.23	1.17	0.90	1.11	0.67	0.82	
" Na "	0.80	1.70	12.17 1)	2.85	4.55	6.05	7.42	
Sum of cations	47.3	50.7	49.5 2)	44.7	48.4	45.2	53.3	
Base sat. %, pH 8.2	>100	92	99 2)	81	>100	>100	>100	
ESP at pH 8.2	2	3	2 2)	5	9	14	15	
Saturation extract:								
Moisture %					78.1	76.4	89.1	
pH-paste					7.2	7.7	7.6	
ECe (mS/cm)					3.50	2.60	2.30	

FERTILITY ASPECTS: (depth in cm)	0-20		
Ca (me/100 g)	26.0		
Mg "	6.9		
K "	0.56		
Na "	1.68		
P (ppm)	226		
Mn (me/100g)	1.24		
Exch. acidity (me/100g)	—		
pH-H_2O (1:1 v/v)	6.0		
C %	1.77		
N %			

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A	6-14	6.75	0.24
AC	30-42	7.28	0.46
C1	62-69	7.50	0.59
C2	80-90	7.75	0.68
C3	110-120	7.28	2.16
2C1	150-165	7.65	1.02
2C2	175-180	7.58	1.12
2C4	360	8.06	0.82

1) should probably be 1.22

2) these figures are based on Exch. Na of 1.22

Area: Kore I + II

Profile no.: 2

Mapping unit: P1A1

Soil classification: pellic VERTISOLS

Physiography: lacustrine plain (Kano plain)

Topography: flat; bunds; cow foetoes

Vegetation/landuse: grasses, rushes and reeds

Drainage conditions: very poorly drained; frequently flooded up to 30 cm; no groundwater within 3.80 m

Remarks: water in cow foetoeson the surface; the soil is wet to 74 cm, below 74 cm it is relatively dry

Profile description:

A1	0- 19 cm	brownish black (10YR2/2 moist) clay; weak,fine angular blocky structure; slightly sticky and slightly plastic when wet; common,fine roots; diffuse transition to
AC	19- 58 cm	black (10YR2/1 moist) heavy clay; weak to moderate, fine angular blocky structure; abundant, thin pressure faces; few macropores; slightly sticky and plastic when wet; till 25 cm common, fine roots, below 25 cm few, very fine roots; gradual, smooth transition to
C1	58- 74 cm	brownish black (10YR2/2 moist) heavy clay; moderately coherent massive structure; few macropores; friable when moist; common, very fine for the greater part dead roots; gradual, smooth transition to
C2	74-102 cm	black (10YR2/1 moist) heavy clay; very few, fine, faint mottles; moderately to strongly coherent massive structure; few macropores; firm to very firm when moist; common, very fine for the greater part dead roots; clear, smooth transition to
C3	102-132 cm	brownish black (10YR2/3 moist) clay; very few, fine, faint mottles; moderately to strongly coherent massive structure; (few,thin pressure faces); few macropores; very firm when wet; very few (<1%), fine (<5 mm) weathered rock fragments; few, very fine for the greater part dead roots; clear, smooth to wavy transition to
2C1	132-172 cm	brownish black (10YR3/2 moist) clay; few, fine, faint mottles; moderately coherent massive structure; (few, thin pressure faces); few bio- and macropores; very few (<1%), fine (<5 mm) weathered rock fragments; slightly calcareous; few, very fine for the greater part dead roots; gradual, smooth transition to
2C2	172-260 cm	brownish black (10YR2/2 moist) heavy clay; few, fine, faint mottles; weak,medium angular blocky structure; few, thin pressure faces; few bio- and macropores; firm when moist; slightly calcareous; no roots
2C3	260-330 cm	brownish black (10YR2/2 moist) clay; few, fine, faint mottles; very firm when moist; slightly calcareous
2C4	330-380 cm	dull yellowish brown (10YR5/3 moist) clay loam; few, medium, faint mottles; friable when moist; moderately calcareous; below 370 cm very few (<5%), fine (<10 mm) calcium carbonate concretions

APPENDIX IV - D

MAUGO AREA

LABORATORY DATA

Profile no.: 1 Area: Maugo

Mapping unit: PfA13

Horizon	Ap	A1	2C	3C1	3C2	3C3	3C4	3C5
Depth of sample (cm)	0-8	15-20	30-37	50-60	76-81	95-105	130-140	160-170
TEXTURE								
Sand % 2.0 - 0.05 mm	21	23	24	20	48	32	32	38
Silt % 0.05 - 0.002 mm	29	39	36	38	14	30	28	30
Clay % 0.002 - 0 mm	50	38	40	42	38	38	40	32
Texture class	C	CL	C/CL	C	SC	CL	C/CL	CL
CHEMICAL DATA								
pH-H_2O (1:2.5 v/v)	5.9	5.9	6.5	7.2	7.2	7.4	7.3	7.4
pH-KCl "	4.6	4.6	5.2	6.0	6.0	6.3	6.0	6.3
EC (mS/cm) "	0.40	0.20	0.15	0.15	0.15	0.20	0.25	0.20
$CaCO_3$ (%)								
C (%)	2.03	0.91	0.82	0.94	0.79	0.85	0.85	0.55
N (%)								
C/N								
CEC (me/100g), pH 8.2	39.0	24.2	25.6	28.3	22.9	17.2	20.6	17.1
Exch. Ca (me/100g)	31.9	28.4	24.9	28.3	22.9	28.4	26.5	22.9
" Mg "	4.6	3.8	3.2	3.7	6.6	3.6	3.8	3.6
" K "	1.15	0.76	0.58	0.65	0.52	0.60	0.72	0.67
" Na "	0.64	0.25	0.33	0.54	0.72	0.54	0.35	0.53
Sum of cations	38.3	33.2	29.0	33.2	30.7	33.1	31.4	27.7
Base sat. %, pH 8.2	98	>100	>100	>100	>100	>100	>100	>100
ESP at pH 8.2	2	1	1	2	3	3	2	3
Saturation extract:								
Moisture %								
pH-paste								
ECe (mS/cm)								
FERTILITY ASPECTS: (depth in cm)	0-20							
Ca (me/100 g)	12.2							
Mg "	8.5							
K "	0.58							
Na "	0.68							
P (ppm)	20							
Mn (me/100g)	1.18							
Exch. acidity (me/100g)	0.1							
pH-H_2O (1:1 v/v)	5.3							
C %	2.06							
N %	0.23							

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
Ap	0-8	6.05	0.092
A1	15-20	6.25	0.044
2C	30-37	6.41	0.056
3C1	50-60	6.51	0.072
3C2	76-81	6.62	0.054
3C3	95-105	6.71	0.102
3C4	130-140	6.97	0.096
3C5	160-170	7.29	0.10
3C6	250	6.34	0.078
3C7	350	6.85	0.168
3C8	450	6.85	0.250
gr. water	±170	6.49	1.04
river water	-	7.01	0.114

Area: Maugo

Profile no.: 1

Mapping unit: PfA13

Soil classification: eutric FLUVISOLS

Physiography: alluvial plain (levee)

Topography: flat; relatively high spot; ploughed land

Vegetation/landuse: 45% herbs, 50% bare ground; near river shrubs (5%); arable land (fallow)

Drainage conditions: imperfectly drained; seasonally flooded up to 90 cm; on sampling date groundwater

Remarks: profile pit is situated near river; water level in river about 30 cm minus surface (rising)

Profile description:

Ap	0- 8 cm	brownish black (10YR2/3 moist) clay; moderate, very fine, columnar structure; many macro- and biopores; friable when moist; very few (<1%), very fine (<5 mm) rhyolite fragments; common, very fine and few, fine roots; clear, smooth transition to
A1	8- 27 cm	brownish black (2,5Y3/1 moist) clay loam; few, fine, faint iron mottles; strong, coarse, prismatic structure falling apart into strong, medium angular blocks; common, thin pressure faces; many macro- and biopores; very firm when moist; very few (<2%), very fine (<5 mm) rhyolite fragments; few, very fine and fine roots; abrupt, wavy transition to
2C	27- 40 cm	brownish black (10YR2/3 moist) clay loam; common, medium, faint iron mottles; strong, very coarse angular blocky structure; few, thin pressure faces; many macro- and biopores; firm when moist; very few (<1%), very fine (<5 mm) rhyolite fragments; few, very fine and fine roots; abrupt, wavy transition to
3C1	40- 73 cm	brownish black (10YR3/2 moist) clay; few, fine, faint iron mottles; moderate, very coarse prismatic structure falling apart into strong, very coarse angular blocks; common to abundant, moderately thick pressure faces; common macro- and biopores; firm when moist; few, very fine and fine roots; gradual, smooth transition to
3C2	73- 84 cm	brownish black (10YR2/3 moist) silty clay; few, medium, faint iron mottles; strong, coarse angular blocky structure; few, thin pressure faces; few macropores, common biopores; firm when moist; few, very fine and very few, fine roots; abrupt, smooth transition to
3C3	84-118 cm	brownish black (10YR2/2 moist) clay loam; few, fine, faint iron mottles; weak, very coarse prismatic structure falling apart into strong, medium angular blocks; common, moderately thick pressure faces; common macropores, few biopores; very firm when moist; few, very fine and very few, fine roots; clear, wavy transition to
3C4	118-153 cm	brownish black (10YR3/2 moist) clay loam; common, fine, faint iron mottles; moderately, coherent massive structure; common, moderately thick pressure faces; few macro- and biopores; friable when moist; very few (<1%), very fine (<5 mm) charcoal nests; very few, very fine roots; gradual, wavy transition to
3C5	153-180 cm	brownish black (10YR3/2 moist) clay loam; few, medium faint iron mottles; weakly coherent massive structure; very few macro- and biopores; very friable when moist; no roots
3C6	180-290 cm	brownish black (10YR3/2 moist) clay; stratified with sand; few, medium, faint iron mottles; friable when moist
3C7	290-350 cm	brownish black (10YR3/1 moist) clay loam to clay; few, fine, faint iron mottles; friable when moist; non to slightly calcareous
3C8	350-470 cm	brownish black (10YR3/1 moist) stratified loam and clay loam; few, fine, faint mottles; friable when moist

LABORATORY DATA

Profile no.: 2 Area: Mango.

Mapping unit: PfA23

Horizon	A_1	AC	2C1	2C2	2C3	2C4	2C5	
Depth of sample (cm)	5-15	25-35	50-60	80-95	115-125	140-150	170-180	
TEXTURE								
Sand % 2.0 - 0.05 mm	22	20	16	14	16	18	20	
Silt % 0.05 - 0.002 mm	32	30	24	14	16	16	20	
Clay % 0.002 - 0 mm	46	50	60	72	68	66	60	
Texture class	C	C	C	C	C	C	C	
CHEMICAL DATA								
pH-H_2O (1:2.5 v/v)	6.6	6.7	6.4	6.6	7.1	7.4	8.2	
pH-KCl "	5.6	5.5	5.3	5.4	6.2	7.4	7.0	
EC (mS/cm) "	0.20	0.20	0.30	0.15	0.25	0.40	0.30	
$CaCO_3$ (%)								
C (%)	1.18	0.82	1.08	1.06	0.79	0.71	0.74	
N (%)								
C/N								
CEC (me/100g), pH 8.2	26.6	34.2	28.5	35.2	28.4	28.4	25.2	
Exch. Ca (me/100g)	21.9	26.5	26.4	28.4	29.9	30.0	26.4	
" Mg "	5.2	6.2	6.9	6.9	6.9	6.8	6.2	
" K "	0.91	1.04	1.12	0.95	0.76	0.76	0.96	
" Na "	0.24	0.34	0.34	0.86	1.30	1.02	2.01	
Sum of cations	28.3	34.1	34.8	37.1	38.9	38.6	35.6	
Base sat. %, pH 8.2	>100	100	>100	>100	>100	>100	>100	
ESP at pH 8.2	1	1	1	2	5	4	8	
Saturation extract:								
Moisture %								
pH-paste								
ECe (mS/cm)								
FERTILITY ASPECTS: (depth in cm)	0-20							
Ca (me/100 g)	11.8							
Mg "	7.2							
K "	0.40							
Na "	0.68							
P (ppm)	28							
Mn (me/100g)	1.24							
Exch. acidity (me/100g)	—							
pH-H_2O (1:1 v/v)	5.9							
C %	1.45							
N %	0.16							

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A_1	5-15	6.25	0.128
AC	25-35	6.08	0.068
2C1	50-60	5.80	0.106
2C2	80-95	5.82	0.038
2C3	115-125	6.18	0.10
2C4	140-150	6.57	0.192
2C5	170-180	7.08	0.328
2C6	210	7.78	0.548
2C7	300	8.26	0.420
2C8	400	8.44	0.800

Area: Maugo

Profile no.: 2

Mapping unit: PfA23

Soil classification: pellic VERTISOLS

Physiography: alluvial plain

Topography: flat; deep (3 to 4 m) erosion gullies; flat part between gullies is bumpy, cracks

Vegetation/landuse: grassland, shrubs (30%), grasses (40%), bare ground (30%)

Drainage conditions: poorly drained; seasonally flooded up to 90 cm; on sampling date no groundwater within 4 m

Remarks: severe regressive erosion near gullies; profile description is made in the talus of a gully

Profile description:

A1	0- 23 cm	dark brown (10YR3/3 dry) and brownish black (10YR2/3 moist) clay with sand nests; few, fine, faint iron mottles; strong, coarse prismatic structure falling apart into strong, coarse angular blocks; common macro- and biopores; extra hard when dry; few, very fine and very few, fine roots; abrupt, smooth transition to
AC	23- 45 cm	brownish black (10YR2/2 dry and moist) clay with sand nests and some coarse sand grains; common, fine, distinct, brown iron mottles; strong, very coarse prismatic structure falling apart into strong, very coarse angular blocks; few, thin pressure faces; common macropores, many biopores; extra hard when dry; few, very fine and very few, fine roots; clear, smooth transition to
2C1	45- 71 cm	brownish black (7,5YR3/1 dry) and black (7,5YR2/1 moist) clay; common, fine, faint to distinct iron mottles; strong, very coarse prismatic structure falling apart into strong, very coarse angular blocks; common, thin pressure faces; few macropores, common biopores; extra hard when dry; few, very fine and very few, fine roots; clear, smooth transition to
2C2	71-111 cm	black (10YR1,7/1 moist) heavy clay; common, medium distinct, bright brown iron mottles especially on horizontal ped faces and along root channels; strong, coarse prismatic structure falling apart into strong, coarse angular blocks; common, moderately thick pressure faces; few macro- and biopores; very firm when moist; common, very fine and few, fine roots; gradual, wavy transition to
2C3	111-134 cm	black (10YR2/1 moist) heavy clay; common, fine, distinct, bright brown iron mottles; moderate, coarse prismatic structure falling apart into strong, coarse angular blocks; abundant, moderately thick pressure faces, few slickensides; very few macro- and biopores; very firm when moist; few, fine dead roots (root galleries); clear, wavy transition to
2C4	134-160 cm	black (10YR2/1 moist) heavy clay; few, fine, faint iron mottles; moderate, medium angular blocky structure; abundant, moderately thick pressure faces; few slickensides; very few macropores; firm when moist; no roots; abrupt, smooth transition to
2C5	160-200 cm	brownish black (10YR2/2 moist) clay; moderate, medium subangular blocky structure; few, fine pressure faces; very few macropores; friable when moist
2C6	200-220 cm	brownish black (10YR3/1 moist) clay; few, fine, faint yellowish brown mottles; friable when moist; very few (<1%), fine (<15 mm) carbonate concretions; slightly calcareous
2C7	220-340 cm	grayish yellow brown (10YR4/2 moist) clay loam; few, fine, faint mottles; friable when moist; very few (<1%), fine (<15 mm) carbonate concretions; moderately calcareous
2C8	340-400 cm	dull yellow orange (10YR6/4 moist) slightly gravelly clay loam; few, fine, faint mottles; friable when moist; very few (<2%), fine (<15 mm) carbonate concretions

LABORATORY DATA

Profile no.: 3 Area: Maugo

Mapping unit: PpA31

Horizon	Ap	AC	C1	C2	C3	
Depth of sample (cm)	5-12	18-24	32-38	50-70	95-115	
TEXTURE						
Sand % 2.0 - 0.05 mm	24	20	18	16	18	
Silt % 0.05 - 0.002 mm	28	22	18	24	26	
Clay % 0.002 - 0 mm	48	58	64	60	56	
Texture class	C	C	C	C	C	
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	8.2	8.6	8.3	8.4	9.1	
pH-KCl "	6.8	7.1	7.1	7.4	8.2	
EC (mS/cm) "	0.30	0.70	0.70	1.00	1.10	
$CaCO_3$ (%)	1.50	3.80	3.90	5.40	1.86	
C (%)	0.74	1.15	0.91	0.47	no soil	
N (%)						
C/N						
CEC (me/100g), pH 8.2	37.2	36.0	45.2	37.2	36.2	
Exch. Ca (me/100g)	26.5	40.9	39.4	42.9	28.4	
" Mg "	7.0	4.8	5.2	5.2	4.6	
" K "	0.92	1.00	1.12	1.04	1.04	
" Na "	2.82	4.73	6.80	10.61	11.79	
Sum of cations	37.2	51.4	52.5	59.8	45.8	
Base sat. %, pH 8.2	100	>100	>100	>100	>100	
ESP at pH 8.2	8	13	15	29	33	
Saturation extract:						
Moisture %				61.4	48.2	
pH-paste				7.8	7.7	
ECe (mS/cm)				1.00	1.50	

FERTILITY ASPECTS: (depth in cm)	0-20	
Ca (me/100 g)	19.6	
Mg "	6.4	
K "	0.40	
Na "	4.20	
P (ppm)	48	
Mn (me/100g)	0.42	
Exch. acidity (me/100g)	—	
pH-H_2O (1:1 v/v)	7.5	
C %	1.06	
N %	0.12	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
Ap	5-12	7.75	0.464
AC	18-24	7.85	0.620
C1	32-38	8.05	0.80
C2	50-70	8.32	0.68
C3	95-115	8.69	0.76
C5	270	8.98	2.40
C5	370	9.39	2.00

Area: Maugo

Profile no.: 3

Mapping unit: PfA31

Soil classification: calcic CAMBISOLS, sodic phase

Physiography: terrace remnant bordering flood plain

Topography: flat between hills, sloping towards main channel, ploughed land, small cracks

Vegetation/landuse: arable land; millet and maize

Drainage conditions: well drained; seasonally flooded up to 5 cm; on sampling date no groundwater within 370 cm

Profile description:

Ap	0- 16 cm	brownish black (10YR3/1 moist) clay; few, fine, faint iron mottles; strong, coarse prismatic structure falling apart into moderate, fine angular and subangular blocks; common macro- and biopores; friable when moist; slightly calcareous; frequent, fine roots; clear, smooth transition to
AC	16- 28 cm	brownish black (10YR3/1 moist) clay; few, fine, faint iron mottles; moderate, coarse prismatic structure falling apart into moderate, medium angular blocks; few, thin slickensides; common thin, pressure faces; common macro- and biopores; friable when moist; slightly calcareous; frequent, fine roots; clear, smooth transition to
C1	28- 42 cm	brownish black (10YR3/1 moist) heavy clay; few, fine faint mottles; strong, very coarse prismatic structure falling apart into weak, medium angular blocks; few, thin slickensides; common, thin pressure faces; common macro- and biopores; friable when moist; slightly calcareous; very few (<1%), very fine (<5 mm) carbonate concretions; few, very fine roots; clear, wavy transition to
C2	42- 81 cm	grayish yellow brown (10YR4/2 moist) clay; few, fine, faint mottles; strong, fine angular blocky structure; few, fine pressure faces; common macro- and biopores; slightly hard when dry, friable when moist; moderately calcareous; few (8%), fine (5-20 mm) carbonate concretions; few, very fine roots; gradual, wavy transition to
C3	81-150 cm	grayish yellow brown (10YR4/2 dry and moist) clay; common, fine, faint mottles; moderate, fine to medium angular blocky structure; common macro- and biopores; slightly hard when dry and friable when moist; strongly alkaline; slightly calcareous; very few (<5%), fine (5-20 mm) carbonate concretions; very few, very fine roots
C4	150-200 cm	grayish yellow brown (10YR4/2 dry) and brownish black (10YR3/2 moist) clay; no mottles; soft when moist; slightly calcareous; very few (<5%), fine (5-20 mm) carbonate concretions
C5	200-370 cm	dull yellowish brown (10YR4/2 moist) clay loam; few, fine, faint mottles; soft when moist; strongly to very strongly alkaline; slightly calcareous; very few (<1%), very fine (<5 mm) carbonate concretions

LABORATORY DATA

Profile no.: 4 Area: Mango

Mapping unit: PlA1

Horizon	A1	AC	C1	C2	2C1	2C2	2C3	
Depth of sample (cm)	5-15	25-35	50-60	75-85	105-115	140-160	180-190	
TEXTURE								
Sand % 2.0 - 0.05 mm	20	16	16	16	18	14	20	
Silt % 0.05 - 0.002 mm	22	16	24	12	18	10	6	
Clay % 0.002 - 0 mm	58	68	60	72	64	76	74	
Texture class	C	C	C	C	C	C	C	
CHEMICAL DATA								
pH-H_2O (1:2.5 v/v)	6.4	6.3	6.4	7.0	7.8	8.2	8.4	
pH-KCl "	5.4	5.3	5.4	6.3	7.1	7.6	7.7	
EC (mS/cm) "	1.25	0.50	0.60	0.65	0.75	0.75	0.80	
$CaCO_3$ (%)	n.d.	n.d.	n.d.	2.50	2.20	1.50	5.0	
C (%)	1.68	1.88	0.88	0.79	0.65	0.59	0.38	
N (%)								
C/N								
CEC (me/100g), pH 8.2	32.8	31.2	36.0	35.2	33.2	39.2	34.2	
Exch. Ca (me/100g)	10.2	29.9	29.8	41.0	45.0	46.3	40.9	
" Mg "	5.4	6.6	6.2	8.0	6.8	6.9	6.0	
" K "	0.80	1.00	0.92	1.29	1.48	0.96	0.88	
" Na "	6.72 1)	0.75	1.66	3.12	4.20	6.23	9.40	
Sum of cations	17.1 2)	38.3	38.6	53.4	57.5	60.4	57.2	
Base sat. %, pH 8.2	52 2)	>100	>100	>100	>100	>100	>100	
ESP at pH 8.2	2 2)	2	5	9	13	16	27	
Saturation extract:								
Moisture %		130					139	
pH-paste		7.3					8.2	
ECe (mS/cm)		1.60					1.25	

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	16.0
Mg "	8.2
K "	0.56
Na "	0.84
P (ppm)	24
Mn (me/100g)	0.88
Exch. acidity (me/100g)	—
pH-H_2O (1:1 v/v)	5.7
C %	2.74
N %	0.25

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	5-15	6.48	0.486
AC	25-35	5.78	0.116
C1	50-60	6.14	0.210
C2	75-85	7.11	0.346
2C1	105-115	8.25	0.376
2C2	140-160	8.35	0.60
2C3	180-190	8.65	0.70
2C3	230	8.89	0.72
2C4	300	9.39	0.88
2C4	380	8.95	0.60

1) should probably be 0.67

2) these figures are based on Exch. Na of 0.67

Area: Maugo

Profile no.: 4

Mapping unit: P1A1

Soil classification: pellic VERTISOLS

Physiography: lacustrine plain

Topography: flat; deep (2 to 3 m) erosion gullies; irrigation system (canals and bunds); 2 cm wide cracks, about 100 cm deep

Vegetation/landuse: grasses and shrubs; grassland

Drainage conditions: poorly drained; seasonally flooded up to 90 cm; on sampling date groundwater level at 390 cm

Remarks: profile description is made in the talus of an erosion gully

Profile description:

A1	0- 17 cm	brownish black (10YR3/1 dry) and black (10YR2/1 moist) clay; few, fine, faint iron mottles; strong, medium prismatic structure, falling apart into strong, medium angular blocks; common, thin pressure faces; few macropores, many biopores; extra hard when dry; few, fine and medium roots; clear, smooth transition to
AC	17- 42 cm	brownish black (10YR3/1 dry) and black (10YR2/1 moist) heavy clay; common, medium, distinct yellowish brown iron mottles along root-channels; strong, coarse prismatic structure, falling apart into strong, fine prismas composed of strong, medium angular blocks; common, thin pressure faces; common, moderately thick pressure faces; few macropores, common biopores; extra hard when dry; few, fine and medium roots; gradual, smooth transition to
C1	42- 65 cm	brownish black (10YR3/1 dry and moist) clay; few, fine, distinct iron mottles; strong, very coarse prismatic structure falling apart into strong, medium angular blocks; common, thin pressure faces; few macro- and biopores; extra hard when dry; very few, fine roots; gradual, wavy transition to
C2	65- 94 cm	brownish black (10YR3/1 dry and moist) heavy clay; few, fine, faint iron mottles; strong, coarse to very coarse prismatic structure falling apart into strong, medium angular blocks; few, thin slickensides; common, thin pressure faces; few macro- and biopores; extra hard when dry; very few, fine roots; clear, wavy transition to
2C1	94-126 cm	brownish black (7,5YR3/1 moist) heavy clay; very few, fine, faint iron mottles; weak, very coarse prismatic structure falling apart into weak, coarse angular blocks; few, thin pressure faces; few macropores, very few biopores; extra firm when moist; slightly calcareous; very few (<1%), very fine (<5 mm) carbonate concretions; common, fine dead roots (root galleries); gradual, wavy transition to
2C2	126-175 cm	brownish black (7,5YR3/1 moist) heavy clay; no mottles; weakly, coherent massive structure; few, thick slickensides; common, thin pressure faces; few macro- and biopores; firm when moist; slightly calcareous; very few (<1%), very fine (<5 mm) carbonate concretions; till 140 cm common, fine, dead roots (root galleries), below 140 cm no roots; clear, wavy transition to
2C3	175-250 cm	brownish black (10YR2/2 moist) heavy clay; few, fine faint mottles; weakly coherent massive structure; few biopores; friable when moist; strongly alkaline; slightly calcareous; below 195 cm very few (<1%), fine (<10 mm) carbonate concretions
2C4	250-400 cm	dull yellowish brown (10YR5/4 moist) clay loam; few, fine, faint mottles; friable when moist; strongly to very strongly alkaline; slightly calcareous; very few (<1%), fine (<10 mm) carbonate concretions

LABORATORY DATA

Profile no.: 5 Area: Maugo

Mapping unit: PlA2

Horizon	A1	AC	2C	3C1	3C2	3C3	3C4	
Depth of sample (cm)	5-11	20-30	42-47	60-70	95-115	135-145	155-165	
TEXTURE								
Sand % 2.0 - 0.05 mm	20	20	32	20	22	20	20	
Silt % 0.05 - 0.002 mm	14	22	30	32	34	34	32	
Clay % 0.002 - 0 mm	66	58	38	48	44	46	48	
Texture class	C	C	CL	C	C	C	C	
CHEMICAL DATA								
pH-H_2O (1:2.5 v/v)	5.8	6.0	6.9	7.0	7.2	7.6	6.1	
pH-KCl "	4.5	5.0	6.0	6.2	6.1	6.4	5.0	
EC (mS/cm) "	0.20	0.20	0.20	0.25	0.30	0.20	0.20	
$CaCO_3$ (%)				1.1			1.1	
C (%)	1.82	1.67	0.91	1.12	1.33	1.30	1.27	
N (%)								
C/N								
CEC (me/100g), pH 8.2	32.3	31.2	25.6	34.6	29.2	33.2	33.2	
Exch. Ca (me/100g)	25.4	22.9	18.9	28.3	26.4	26.4	26.4	
" Mg "	6.2	5.8	6.8	5.2	4.6	4.6	5.0	
" K "	1.00	1.00	0.60	0.80	0.76	0.76	0.68	
" Na "	0.65	0.22	0.24	0.54	0.86	10.2	3.81	
Sum of cations	33.3	29.9	26.5	34.8	32.6	42.0	35.9	
Base sat. %, pH 8.2	>100	96	>100	>100	>100	>100	>100	
ESP at pH 8.2	2	1	1	2	3	31	11	
Saturation extract:								
Moisture %								
pH-paste								
ECe (mS/cm)								

FERTILITY ASPECTS: (depth in cm)	0-20		
Ca (me/100 g)	14.2		
Mg "	8.0		
K "	0.44		
Na "	0.56		
P (ppm)	28		
Mn (me/100g)	0.98		
Exch. acidity (me/100g)	-		
pH-H_2O (1:1 v/v)	6.3		
C %	1.59		
N %	0.19		

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	5-11	5.20	0.046
AC	20-30	5.58	0.044
2C	42-47	6.29	0.064
3C1	60-70	6.45	0.088
3C2	95-115	6.38	0.120
3C3	135-145	6.25	0.174
3C4	155-165	6.65	0.244
3C5	200	6.55	0.476
3C7	300	7.40	0.532
3C7	380	7.49	0.508
gr.water	± 200	7.15	1.72

Area: Maugo

Profile no.: 5

Mapping unit: P1A2

Soil classification: pellic VERTISOLS

Physiography: lacustrine plain

Topography: flat; irrigation system (bunds and canals), ploughed land; gilgai microrelief

Vegetation/landuse: grasses (85%), herbs (10%), shrubs (5%); grassland; abandoned rice fields

Drainage conditions: poorly drained; seasonally flooded up to 90 cm; on sampling date groundwater level at 160 cm

Profile description:

A1	0- 14 cm	brownish black (10YR3/1 dry) and black (10YR2/1 moist) heavy clay; few, fine, faint iron mottles; strong, very coarse prismatic structure falling apart into strong, coarse angular blocks; few, thin pressure faces; common macro- and biopores; very hard when dry; strongly acid; common, very fine and fine roots; clear, smooth transition to
AC	14- 40 cm	brownish black (7,5YR3/1 moist) clay; few, fine, faint iron mottles; strong, very coarse prismatic structure falling apart into moderate, coarse angular blocks; few, thin pressure faces; few macropores, common biopores; very firm when moist; common, very fine and fine roots; abrupt, smooth transition to
2C	40- 48 cm	brownish black (10YR3/2 moist) clay loam; common, fine, distinct, bright reddish brown iron mottles; moderate, medium platy structure; few macropores, common biopores; friable when moist; very few (<1%), very fine (<5 mm) iron concretions; few, very fine and fine roots; clear, wavy transition to
3C1	48- 83 cm	brownish black (7,5YR3/1 moist) clay; many, medium, prominent dark red iron mottles along old rootchannels; strong, medium, prismatic structure falling apart into weak, coarse angular blocks; few, thin pressure faces; few macro- and biopores; firm when moist; very few (<1%), very fine (<5 mm) iron concretions; few, very fine and very few, fine roots; gradual, wavy transition to
3C2	83-129 cm	brownish black (7,5YR3/1 moist) clay; common, medium, distinct, bright reddish brown iron mottles; weak, medium prismatic structure falling apart into moderate, medium angular blocks; few, thin pressure faces; few macro- and biopores; firm when moist; few, very fine and very few, fine roots; clear, wavy transition to
3C3	129-149 cm	black (10YR2/1 moist) clay; few, fine, faint iron mottles; weak, medium angular blocks; few macropores and very few biopores; friable when moist; very few, very fine roots; gradual, wavy transition to
3C4	149-170 cm	black (10YR1,7/1 moist) clay; weak, medium angular blocky structure; few macropores and very few biopores; friable when moist; slightly calcareous; very few, very fine roots
3C5	170-260 cm	black (10YR2/1 moist) clay; firm to friable when moist; moderately calcareous; no roots
3C6	260-290 cm	brownish black (7,5YR3/1 moist) clay; firm when moist; slightly calcareous; very few (<1%), fine (<10 mm) carbonate concretions
3C7	290-380 cm	brown (10YR4/4 moist) clay loam; friable when moist; slightly calcareous

LABORATORY DATA

Profile no.: 6 Area: Maugo

Mapping unit: PlA4

Horizon	A1	AC	C1	C2	2C1	2C2	2C3	
Depth of sample (cm)	8-15	25-32	45-53	65-75	95-110	130-140	160-170	
TEXTURE								
Sand % 2.0 - 0.05 mm	18	18	14	14	14	16	12	
Silt % 0.05 - 0.002 mm	22	20	22	20	14	20	14	
Clay % 0.002 - 0 mm	60	62	64	66	72	64	74	
Texture class	C	C	C	C	C	C	C	
CHEMICAL DATA								
pH-H_2O (1:2.5 v/v)	7.4	8.6	8.9	9.4	9.3	9.8	7.1	
pH-KCl "	6.4	7.5	7.6	8.2	8.3	8.4	6.0	
EC (mS/cm) "	0.80	0.95	1.25	1.65	1.65	1.60	0.70	
$CaCO_3$ (%)	n.d.	n.d.	n.d.	3.7	4.2	3.3	1.7	
C (%)	1.33	0.88	1.09	0.79	0.58	0.36	0.18	
N (%)								
C/N								
CEC (me/100g), pH 8.2	26.6	34.3	34.2	32.6	31.2	24.8	34.3	
Exch. Ca (me/100g)	35.4	29.8	22.7	17.5	20.9	22.0	33.4	
" Mg "	5.2	5.0	5.0	4.8	5.4	6.2	6.6	
" K "	0.84	0.88	1.00	1.16	1.16	1.00	1.20	
" Na "	4.72	7.33	6.35	8.92	8.92	7.51	0.74	
Sum of cations	46.2	43.0	35.1	32.4	36.4	36.7	41.9	
Base sat. %, pH 8.2	>100	>100	>100	99	>100	>100	>100	
ESP at pH 8.2	18	21	19	27	29	30	2	
Saturation extract:								
Moisture %	215.2	143.2	165.3	109.6	210,0	95.4		
pH-paste	7.1	7.6	8.1	8.5	8.6	8.5		
ECe (mS/cm)	1.45	2.60	2.00	2.80	3.00	2.40		

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	10.8
Mg "	7.8
K "	0.42
Na "	9.20
P (ppm)	30
Mn (me/100g)	0.94
Exch. acidity (me/100g)	—
pH-H_2O (1:1 v/v)	7.0
C %	2.38
N %	0.73

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	8-15	6.40	0.74
AC	25-32	7.75	1.36
C1	45-53	8.66	1.40
C2	65-75	9.32	1.12
2C1	95-110	8.88	1.92
2C2	130-140	9.15	1.48
2C3	160-170	9.45	0.92
2C4	240	9.35	0.60
2C4	280	9.18	0.62
gr. water	±170	8.67	2.40

Area: Maugo

Profile no.: 6

Mapping unit: PlA4

Soil classification: pellic VERTISOLS [1])

Physiography: lacustrine plain

Topography: flat; irrigation system (canals and bunds)

Vegetation/landuse: grasses and rushes; grassland

Drainage conditions: very poorly to poorly drained; seasonally flooded up to 90 cm; on sampling date groundwater level at 170 cm

Remarks: irrigated paddy fields in the surroundings

Profile description:

A1	0- 19 cm	brownish black (10YR2/2 moist) clay; few, fine, faint iron mottles; strong, very coarse prismatic structure falling apart into strong, coarse angular blocks; common, thick pressure faces; many macro- and biopores; extra firm when moist; common, very fine and frequent, fine roots; clear, smooth transition to
AC	19- 37 cm	black (10YR2/1 moist) heavy clay; few, fine, faint iron mottles; strong, medium and coarse angular blocky structure; few, moderately thick pressure faces; common macropores, few biopores; very firm when moist; few, very fine and very few, fine roots; gradual, smooth transition to
C1	37- 60 cm	black (10YR2/1 moist) heavy clay; very few, fine, faint iron mottles; moderate, medium and coarse angular blocky structure; common, thin pressure faces; few macropores; very firm when moist; strongly alkaline; few, very fine and very few, fine roots; clear, smooth transition to
C2	60- 82 cm	brownish black (10YR2/2 moist) heavy clay; moderate, very coarse prismatic structure falling apart into moderate, coarse angular blocks; common, thick slickensides; common, moderately thick pressure faces; very few macropores; very firm when moist; very strongly alkaline; very few (<1%), very fine (<5 mm) carbonate concretions; very few, very fine dead roots (root galleries); clear, wavy transition to
2C1	82-117 cm	brownish black (10YR2/2 moist) heavy clay; moderately coherent massive structure; abundant, thick slickensides; common, moderately thick pressure faces; very few macropores; firm when moist; strongly alkaline; slightly calcareous; very few (<1%), very fine (<5 mm) carbonate concretions; very few, very fine dead roots; gradual, wavy transition to
2C2	117-152 cm	yellowish grey (2,5Y4/1 moist) heavy clay; few, fine, faint mottles; moderate, medium angular blocky structure; few, moderately thick slickensides; few, thin pressure faces; few macropores; friable when moist; very, strongly alkaline; slightly calcareous; very few (<1%), fine (<10 mm) carbonate concretions; few, very fine dead roots; gradual, wavy transition to
2C3	152-180 cm	brownish black (2,5Y3/2 moist) heavy clay; weakly coherent massive structure; few, thin pressure faces; very few macropores and few biopores; friable when moist; very strongly alkaline; slightly calcareous; very few (<1%), fine (<20 mm) carbonate concretions; no roots
2C4	180-290 cm	dull yellowish brown (10YR5/4 moist) clay loam; few, fine, faint mottles; friable when moist; very strongly alkaline; slightly calcareous; very few (<1%), fine (<10 mm) carbonate concretions

[1]) This particular profile has sodic properties throughout and should be classified as pellic Vertisols, sodic phase. Soils of mapping unit PLA4 are, however, predominantly not sodic within 100 cm depth (see also remarks in unit description)

APPENDIX V

FIELD MEASUREMENTS OF HYDRAULIC CONDUCTIVITY

AND INFILTRATION RATE IN ALL FOUR AREAS

Area: Awach Kano

Soil mapping unit	Location (No. of observation)	Depth in cm	Textural class(es)	Moisture conditions	Infiltration rate measurement cm/day	Infiltration rate class	Hydraulic conductivity measurement cm/day	Hydraulic conductivity class	Remarks
PfA21	pit 2	72	clay	very dry	4-8	slow			cracks to 80 cm
		0- 70	clay				7-12	slow to mod. slow	cracks to 80 cm
		70-145	clay				1-5	slow	
PlA1	pit 4	77	loam	dry	3-5	slow			cracks to 110 cm
PlA2	pit 5	95	heavy clay	dry	<1	very slow			cracks to 95 cm
Area: Kore									
	Kore I								
PfA1	17	0- 55	clay	moist			<1	very slow	
		50-200	heavy clay				7-8	slow	
	Kore II								
	pit 1	0	clay		2-9	slow			
		65	heavy clay		<1	very slow			
		0- 70	heavy clay				<1-2	very slow	
		70-150	clay over heavy clay				1-2	very slow	
	Kore II								
	7	0- 90	clay loam	moist			4-10	slow	
		90-200	clay				<1-5	very slow to slow	
	Kore II								
	8	0- 85	clay loam	moist			<1	very slow	
		85-170	clay				<1	very slow	
	Kore I								
PlA1	14	0-200	heavy clay	moist			3-13	slow to mod. slow	
	Kore I								
	15	0	clay		<1	very slow			
		0-120	clay				1-2	very slow	
		120-200	clay				7-8	slow	
	Kore I								
	29	0-140	clay	wet			5-7	slow	
		140-200	clay				3-21	slow to mod. slow	
	Kore II								
	pit 2	0	clay	moist	8-37	slow to mod. rapid			
		40	heavy clay		<1	very slow			
		0-120	clay and heavy clay				1-6	slow	
		120-200	clay and heavy clay				8-20	slow to mod. slow	

Area: Wasare

Soil mapping unit	Location (No. of observation)	Depth in cm	Textural class(es)	Moisture conditions	Infiltration rate		Hydraulic conductivity		Remarks
					measurement cm/day	class	measurement cm/day	class	
PfA11	14	20	clay loam	very dry	504-576	very rapid			cracks
		45- 80	sandy loam				643	very rapid	cracks
		100-200	sandy clay loam to clay				21-35	mod. slow to mod. rapid	
PfA21	24	55	clay	moist	39-60	mod. slow to rapid			
		15- 50	sandy loam				267-380	very rapid	
		100-190	clay				23-26	moderate	
PfA22	13	70-200	clay	dry			10-12	mod. slow	
PfA24	29	0	sand	dry	10-18	mod. slow			cracks to 40 cm
		0- 60	strat. sand to loamy sand				36-71	mod. rapid	cracks
	31	0	clay	wet	10-14	mod. slow			
		10- 90	clay loam and sand				72-187	rapid to very rapid	
		90-200	heavy clay				<1-4	very slow to slow	
	42	0	clay loam	moist	29-42	mod. rapid			
		40-160	strat. loamy sand to loam				14-19	mod. slow	
		160-200	clay				<1-10	slow	
PfA25	16	25- 60	loamy sand to sandy loam	very dry			145-402	rapid to very rapid	cracks
		90-200	heavy clay				19-32	moderate	cracks
PfA1	pit 3	0	heavy clay	wet	1-6	slow			
		50	heavy clay		2	slow			
		0- 45	heavy clay				1-3	very slow	
		45-160	heavy clay				<1	very slow	
		160-210	heavy clay				5-8	slow	
		210-320	clay loam				<1	very slow	
	48	50-200	heavy clay	wet			2-5	slow	
	102	70-150	heavy clay	very dry			5-9	slow	
		150-200	clay loam				9-28	mod. slow to moderate	
PlA2	39	0	heavy clay	moist	4-12	slow to mod. slow			
	35	80-200	heavy clay	wet			5-11	slow	
	47	0	heavy clay		1-6	slow			
		70-200	heavy clay				2-6	slow	

Area: Maugo (sheet 1)

Soil mapping unit	Location (No. of observation)	Depth in cm	Textural class(es)	Moisture conditions	Infiltration rate		Hydraulic conductivity		Remarks
					measurement cm/day	class	measurement cm/day	class	
PfA11	189	0	sandy loam	dry	4-98	slow to rapid			
		0- 50	sandy loam and clay loam				18-26	moderate	
PfA13	pit 1	0	clay	moist	127	very rapid			
		0- 90	clay loam and clay				78	mod. rapid	
		90-190	clay loam				11-21	mod. slow	
	87	65-100	clay	dry			66-109	mod. rapid to rapid	cracks
		110-200	clay loam	moist			<1-3	very slow	
	110	40- 80	clay loam	moist			25-31	moderate	
		80-200	clay loam				15	mod. slow	
	139	0	clay	moist	13-44	mod. slow to mod. rapid			
		0- 60	clay				24-36	moderate	
		60-200	clay loam and clay				18-26	mod. slow to moderate	
PfA23	66	70-145	heavy clay	moist			3-11	slow	
	78	0	clay	dry	662	very rapid			cracks
		40	heavy clay	dry	>700	very rapid			cracks
		90-198	heavy clay	moist			5-7	slow	
	197	0	clay loam	dry	35-65	mod. rapid to rapid			
		0- 60	clay loam				1-3	very slow	
		60-200	clay				<1	very slow	
PfA31	93	30	clay	dry	<1	very slow			
		0- 45	clay loam and clay				1-4	very slow to slow	
		50-200	clay loam				<1	very slow	slightly saline
	144	0	clay	dry	<1	very slow			
		0- 80	clay				<1-3	very slow	slightly saline
		80-200	clay loam				7-15	slow to mod. slow	slightly saline
	170	0- 45	clay loam	dry			<1	very slow	
		45- 98	clay				1-3	very slow	slightly saline

Area: Maugo (sheet 2)

Soil mapping unit	Location (No. of observation)	Depth in cm	Textural class(es)	Moisture conditions	Infiltration rate		Hydraulic conductivity		Remarks
					measurement cm/day	class	measurement cm/day	class	
PlA1	31	50-130	clay	dry			2-3	very slow	
		135-160	clay				6-12	slow to mod. slow	
	46	0	clay	wet	12-65	mod. slow to rapid			
		0-100	clay				<1	very slow	
		160-200	clay loam				<1	very slow	
	64	0-200	heavy clay	wet			59	mod. rapid	
	67	0-195	clay	wet			7-11	slow	
PlA2	199	0	clay	wet	<1	very slow			
PlA3	28	0	clay loam	dry	224-387	very rapid			cracks
		70-100	clay	dry			44	mod. rapid	cracks
		100-190	clay				12-19	mod. slow	
	32	0-120	clay	dry			1-2	slow	
		120-195	clay				<1-7	slow	
	between 81 and 87	0	clay	dry	150-252	very rapid			cracks to 55 cm
		50- 95	clay				34-60	mod. rapid	
		100-200	clay				30-36	moderate	
PlA4	100	0	clay	wet	15-118	mod. slow to very rapid			
		50-200	clay				<1-2	very slow	
	115	15- 50	clay	wet			<1	very slow	
		60-148	clay	moist			<1	very slow	
	118	30-100	clay	moist			10-19	mod. slow	
		100-200	clay				14-28	mod. slow to moderate	
	133	0	clay	wet	4-28	slow to mod. rapid			
		10-200	clay	moist			1-3	very slow	
PlA5	155	0- 80	clay	moist			<1	very slow	
		80-150	clay				<1-3	very slow	
	156	0- 80	clay	moist			32-62	mod. rapid	cracks
		80-200	clay				<1	very slow	
	180	0	clay	moist	1-4	slow			
		0- 80	clay				<1	very slow	
		80-120	clay				<1	very slow	

APPENDIX VI: DETAILED SOIL MAPS, SCALE 1:2 500, OF THE 4 AREAS

A1 Wasare area (2 sheets)

B1 Awach Kano area (2 sheets)

C1 Kore areas (2 sheets)

D1 Maugo area (4 sheets)