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Major professor

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CHARACTERIZATION AND PEDOGENIC CLASSIFICATION OF THE
SOILS OF THE CENTRAL AGRICULTURAL RESEARCH STATION,
AFGOI, SOMALI DEMOCRATIC REPUBLIC

By

Omer Haji Dualeh Abdulla

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ABSTRACT

CHARACTERIZATION AND PEDOGENIC CLASSIFICATION OF THE SOILS OF THE CENTRAL AGRICULTURAL RESEARCH STATION, AFGOI, SOMALI DEMOCRATIC REPUBLIC

By

Omer Haji Dualeh Abdulla

As agronomic research intensified at the Central Agricultural Research Station, Afgoi, the need for classifying the station's soils became very important. Researchers require soil classification and soil maps for planning the layout of experiments, interpretation of results and cultural management. This study was to characterize the soils and to prepare detailed soil maps.

To prepare the soil maps auger observations were made in a grid pattern. Soil samples from these observations were analyzed for total salts. Five representative pedons were selected for detailed analyses. Samples were analyzed for particle size distribution, hydraulic conductivity, soluble salts, CaCO_3 equivalent, pH and saturation percentage. The soils were classified according to Soil Taxonomy and the FAO/UNESCO system.

Dominant soils are Udic Chromusterts which are very fine or fine in particle size class. They are calcareous in all depths and are slightly to moderately alkaline. In general no salinity or alkali problem exists in these soils and permeability is good.

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INTRODUCTION

The Central Agricultural Research Station (CARS) has been a major experimental center in Somalia for the past thirteen years. Even though a substantial amount of agronomic research has been carried out at the station no soil map has ever been made for it and no classification of its soils attempted.

The importance of classifying soils has now been recognized by researchers and other field workers. Researchers make various uses of soil classification including the planning of the layout of experiments in the field, interpretation of experimental results and cultural management.

In order to make an effective extension recommendation a researcher or extension agronomist needs to consider both the types of soils at the station on which trials were run as well as the soils of the area for which the recommendation is intended.

As a result of the demand for a soil survey of the area this study was initiated. The objectives of this study on the soils of CARS are:

1. To characterize the landforms and surface features.
2. To characterize the soil morphology in the field.
3. To analyze representative soil samples in the laboratory for selected chemical and physical properties.
4. To classify the station's soils according to the United

States Soil Taxonomy System and the FAO/UNESCO soil classification system.

5. To prepare a soil map for the station.

LITERATURE REVIEW

The basis of soil classification is an understanding of soil forming factors. For this reason soil forming factors are reviewed here both for Somalia as a whole and for the Central Agricultural Research Station area.

The fundamental equation of soil forming factors (Jenny, 1941), which is given below, perhaps gives the best definition of soil as a natural body. The equation states

$$S = f(cl, o, r, p, t)$$

that soil (S) is a function of climate (cl), organisms (o), topography (r), parent materials (p) and time (t). The magnitudes and interactions of these variables result in the formation of a particular soil type.

Soil Forming Factors in Somalia

Time

In considering time as a soil forming factor both the age of the rocks and the age of soil surfaces will be discussed. It was not possible to find detailed information on the age of soil surfaces in Somalia. The stratigraphy of the country has been summarized by Furon (1963). From Jurassic times to the Lower Eocene times the country underwent alternating coverage by the sea and regression of the sea at different periods. Since Upper Eocene times most of

the country has been above the sea. In the Oligocene and Miocene times the sea covered only relatively small areas near the present coasts and in the Quaternary even smaller areas were covered. This resulted in the deposition of marine, lagoonal as well as continental sedimentary deposits. Rock ages vary from Precambrian igneous and metamorphics to recent alluvial and aeolian deposits.

The present state of the country particularly in the Northern Regions is a legacy of the Pleistocene (Macfadyen, 1950). During the East African Pluvial times in the Pleistocene tremendous erosion took place. This according to Macfadyen explains the little or no soil cover on large areas of the great northern scarp and the deep alluvial deposits in the valleys. Many of these surfaces had no more than 5000 years to recover from the effects of the pluvial times.

In the South Pleistocene to recent deposits include the coastal dune province and the alluvial plains of the Juba and Shabelle Rivers (Ahrens, 1951). From the landform descriptions of FAO (1968) many of the southern plains particularly in Upper Juba appear to be old surfaces but no detailed information is available.

Parent Materials

Parent materials vary within the country and will be discussed by regions (Fig. 1). A map showing the distribution of parent materials in Somalia is given (Fig. 2).

Northern Somalia. Much of the eastern part of this region is underlain by Eocene limestones and anhydrite (Hunt, 1951). Other smaller formations include Precambrian (Basement Complex) granites,

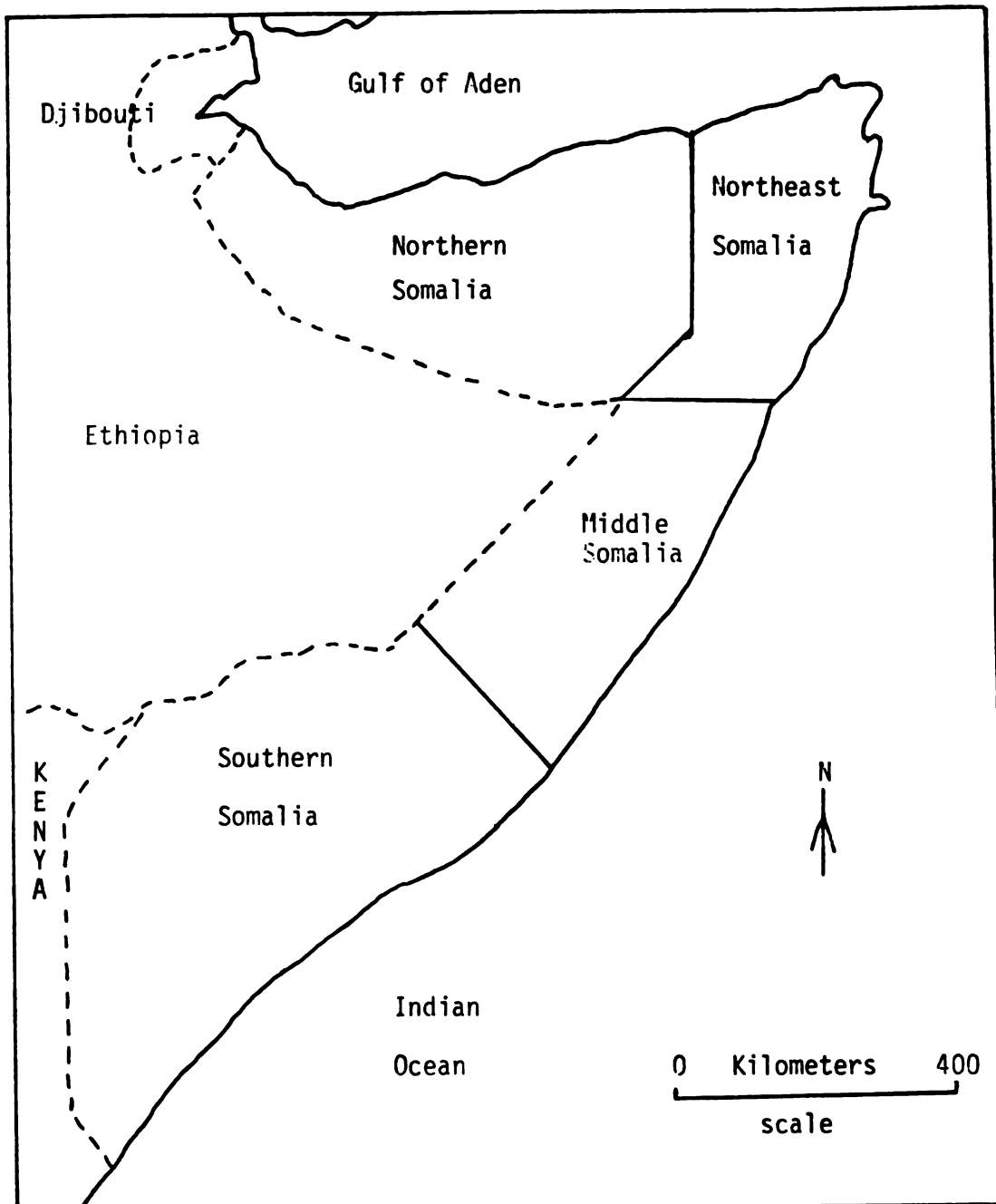


Figure 1. Map of Somalia showing different regions discussed in the Literature review

Figure 2: Legend Explanation:

<u>Map Symbol</u>	<u>Explanation</u>
1	Precambrian granites, dioritic gneisses and schists.
2	Jurassic and Cretaceous limestones, sandstones, gypsum, marl and mudstones.
3	Tertiary limestones, gypsum, anhydrite, sandstones and marl.
4	Pliocene to recent alluvian, colluvium, eluvium, aeolian and marine sediments.
5	Tertiary volcanic rocks, undifferentiated.

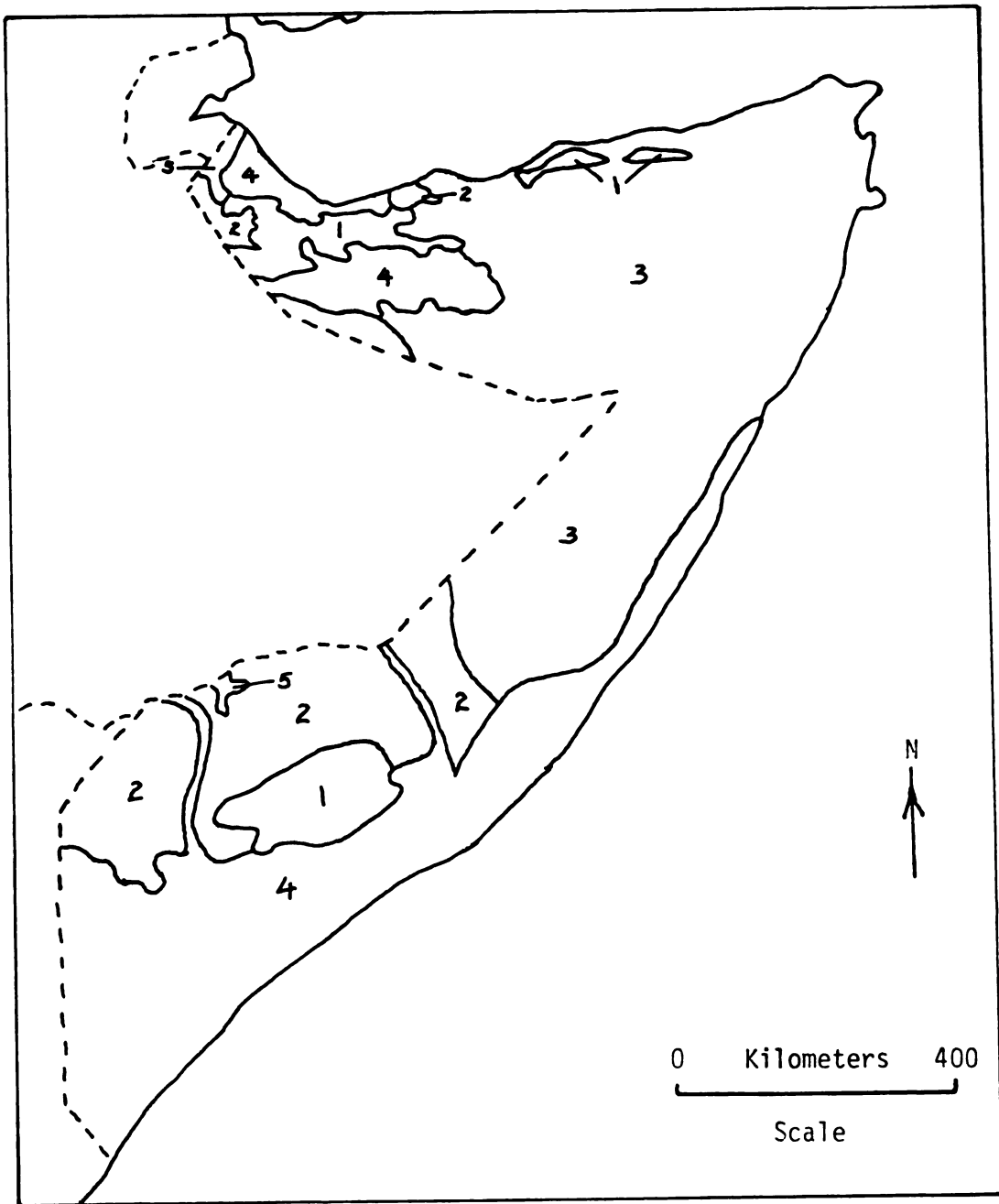


Figure 2. A general stratigraphic and lithological map of Somalia.
After Hunting Technical Services Ltd., 1976

dioritic gneisses and schists. On the coastal plains and some inland areas eluvium and colluvium of Pliocene to Recent age are encountered. The major areas in the central and western parts of the region are underlain by Precambrian granites, dioritic gneisses and schists and by Pliocene to recent eluvium and colluvium (Fig. 2). Other minor formations in the area include Cretaceous and Eocene limestones, gypsum and anhydrite. Dune sands cover very limited areas mainly along the coast. Volcanics probably of Tertiary age underlie some areas in the extreme west.

Northeastern Somalia. The largest part of this area is underlain by Upper Eocene limestones (Ahrens, 1951). Other areas are underlain by sandstones, marls, gypsum and anhydrite of Miocene age. Smaller areas are covered by aeolian sands and other formations.

Middle Somalia. The major portion of this area is underlain by Lower Eocene anhydrite and gypsum. Cretaceous limestones and sandstones cover the southwestern parts of the region. The coastal areas on the Indian Ocean form a relatively broad strip of Quaternary aeolian and marine deposits (Ahrens, 1951).

Southern Somalia. This area was covered by the FAO (1968) reconnaissance soil survey which also describes the parent materials. Parent materials include two main groups, that is, residual and transported. Residual parent materials include Jurassic and Cretaceous limestone materials and coquina, Precambrian or crystalline rock formations and gypsiferous beds of the Cretaceous limestones. Transported materials include fine textured older river alluvium, coarse textured river alluvium and fine textured recent river alluvium. They also include very recent river alluvium as well as

eluviated materials, marine deposits and sandy aeolian deposits.

Topography

The general elevation of the country is shown in Fig. 3. Most of the country from the southern borders to the 9th parallel north of the equator is composed of plains varying in elevation from sea level to 1000 meters above sea level (a.s.l.). On the northern parts, topography is varied and is composed of plains and mountainous areas ranging in elevation from sea level to 2400 meters above sea level.

North and Northeastern Somalia. The topography of this area is dominated by the great northern scarp which was uplifted due to rift faulting in the Gulf of Aden in the Upper Eocene times (Macfadeyen, 1950). The scarp has elevations of 1500 meters to 2400 meters a.s.l. The terrain is often rugged and mountainous and forms the main watershed of these areas. Slopes in these highlands range from 0 percent to greater than 30 percent (FAO/UNESCO, 1973). Water erosion is severe (Hunt, 1951). Numerous drainage ways run from the northern slopes of the highlands to the Gulf of Aden. On the southern slopes drainage ways end inland at the foot of the hills. The coastal plain on the Gulf of Aden is very narrow in the east but widens in the west. It is mostly level to gently undulating with slopes in the range of 0 to 8 percent but some areas have slopes as steep as 30 percent (FAO/UNESCO, 1973). The plains south of the mountain area are generally level to rolling with hilly areas. Slopes range mostly from 0 to 8 percent but can go as steep as 30 percent in some places. Internal drainage basins are common

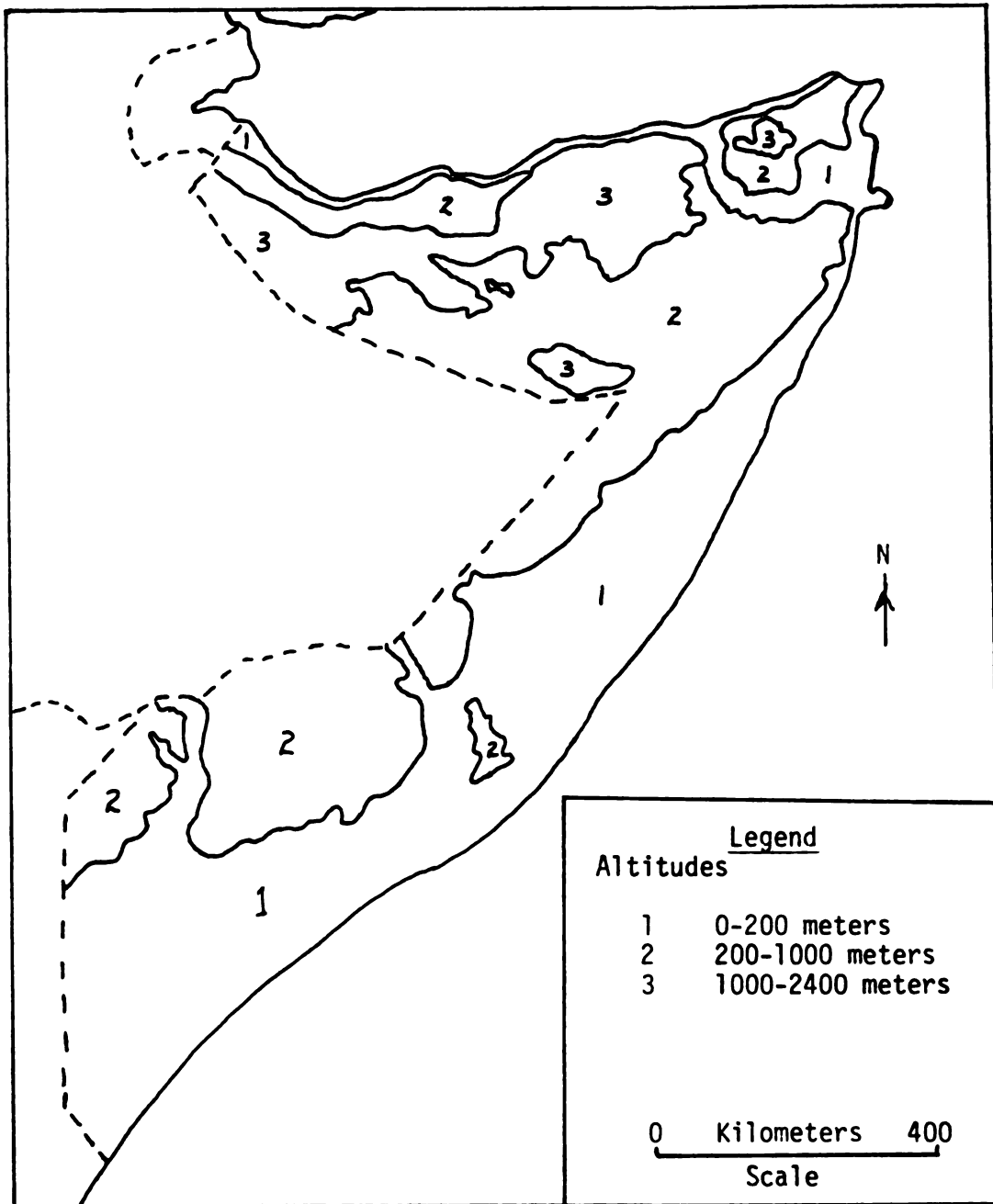


Figure 3. Elevation map of Somalia. After Thrower, 1975

particularly in areas underlain by gypsum and anhydrite (Macfadyen, 1950).

Middle Somalia. The entire middle Somali area is composed of level to rolling plains. Slopes are generally 0 to 8 percent and sometimes are more but almost always below 30 percent (FAO/UNESCO, 1973). Large internal drainage basins and poorly developed channels are common in the area (Ahrens, 1951).

Southern Somalia. The largest portion of Southern Somalia is composed of level to undulating topography with slopes of 0 to 8 percent. Other areas are rolling to hilly with slopes of 8 to 30 percent (FAO, 1968; FAO/UNESCO, 1973). Steeply dissected lands with slopes greater than 30 percent are relatively minor in extent.

Nearly all soils are well drained in Somalia. Areas subject to prennial flooding are minor and are located in lower Shabelle and Juba flood plains. Swampy areas occur in the lower Shabelle flood plain.

Climate

The climate of Somalia is arid to semi arid with erratic rainfall (CCTA, 1964). According to Papadakis (1975) there are 3 climatic types in Somalia. The first one is semi arid tropical which covers the southern Indian Ocean coast and adjacent inland areas. The second type is hot tropical desert which covers most of the remainder of the country. The last type is marine tropical desert which occurs in the highlands of Northern Somalia. At higher altitudes the highlands are cooler and are semi arid.

Mean annual rainfall ranges from 50 to 500 mm and its

distribution in the country is shown in Fig. 4. Rainfall generally occurs in two main seasons, April - May and October - November (Hunt, 1951; CARS, 1978; Veredchenko and Gusenkov, 1965). Winds blow in the northern parts of the country from the southeast from mid May to the end of September and from the northeast from October to April. In the South winds blow from the northeast from late April to late October. Mean annual air temperature ranges from 20°C to 30°C in the country. Mean annual air humidity ranges from 37 percent to 76 percent. Data on evapotranspiration is scarce, however Papadakis (1961) has calculated some values for six locations in the south, middle and northeast of the country and these range from 98 cm to 225 cm per annum.

Using the United States Department of Agriculture classification (USDA, 1975), the soil moisture regimes are either ustic or aridic throughout the country. Soil temperature regimes are isohyperthermic with the exception of few areas. The Gulf of Aden Coast is hyperthermic and the higher parts of the northern highlands are thermic.

Geological evidence indicates climates different from the present prevailed in the past (Macfadyen, 1950). Wetter periods occurred during the East African pluvial periods in the Pleistocene. The last one probably ended as recently as 5,000 years ago.

Vegetation

A general classification of Somalia's vegetation is given in Figure 5. Wooded and grass steppes and subdesert steppes cover most of the country while relatively moist woodlands and savannas cover a

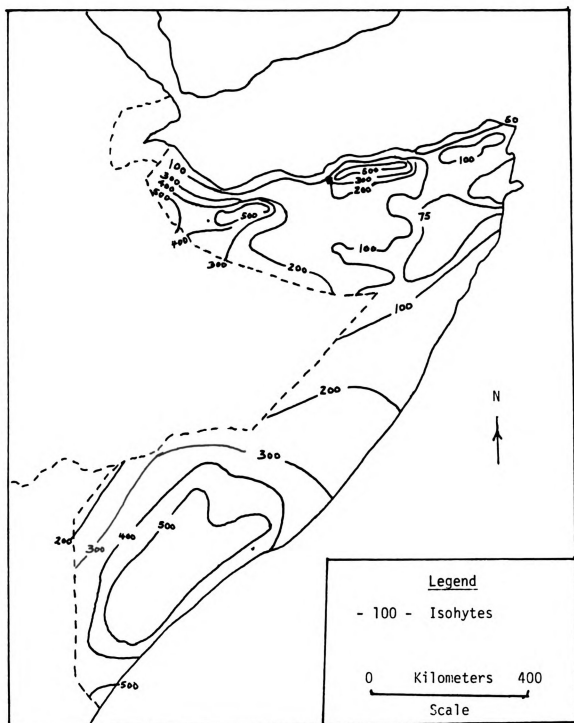


Figure 4. Mean annual rainfall distribution in Somalia. After Hunting Technical Services Ltd., 1976.

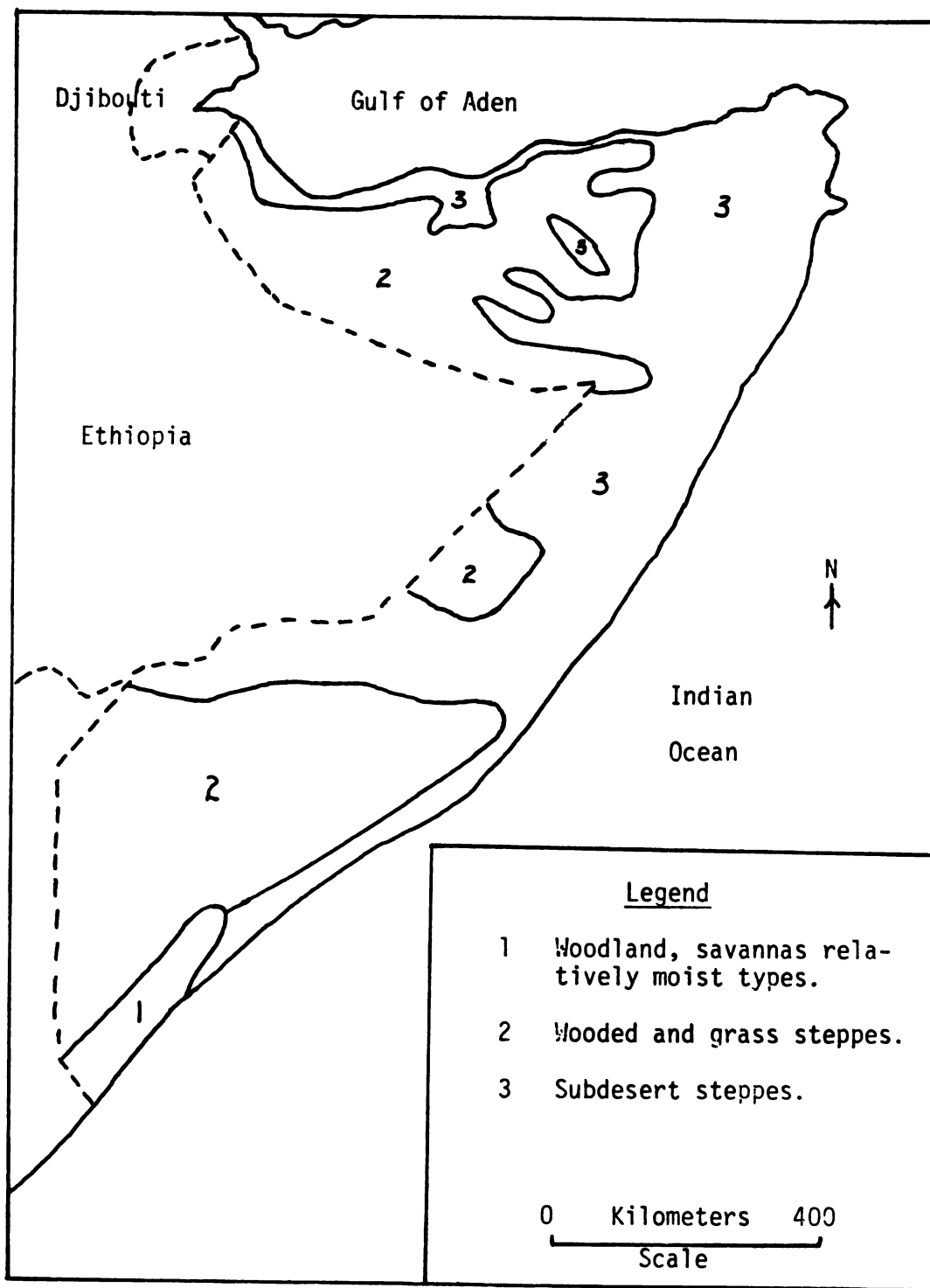


Figure 5. Vegetation map of Somalia. After CCTA, 1964.

small portion in the southernmost part of the country. Most of the literature on vegetation accessible to this writer is confined to the discussion of only portions of the country.

The southern equatorial area which includes the Juba Valley is composed mainly of savannas except for a 2 to 3 kilometer strip along the River Juba which is heavily forested (ECA, 1961; Veredchenko and Gusenkov, 1965). The forested area along the river is composed of very dense trees 8 to 10 meters high intertwined with lianas. The savanna area is made up of trees 3 to 5 meters high, which are mainly of Acacia spp., associated with grasses, herbs and succulents.

Generally speaking as one moves from the southern equatorial area to the northeast vegetation becomes less dense. The major vegetation is grass steppes, savannas and bush (Ahrens, 1951). Some areas are nearly barren.

In the north vegetation distribution is controlled by altitude, soil type and rainfall (Hunt, 1951). Salty areas along the coast and gypseous valleys inland are covered by salt loving plants such as Fruticosa, Limmonium spp. and Statice cylindrica. Juniper forests grow on the mountains at altitudes above 1500 meters. At lower altitudes in the mountains Buxus hildebrandtii in association with grasses and other evergreen plants grow. The areas covered by the juniper and Buxus hildebrandtii are relatively small limited by rainfall and altitude. The major portions of the north are covered by woodland, bush and grass steppes. Many areas have little vegetative cover. Trees in the area are mainly acacias mixed with other types. Predominant acacia species include Acacia etbaica,

A. bussei, A. mellifera, A. arabica and A. spirocarpa. Other trees and bush include Zizyphus spp., euphorbi, Delonix spp., Albizzia spp., eucalyptus spp. Balanites spp., Boswellia spp., Cordeauxia edulus, Hyphaene thebatica, Phoenix reclinata and many more. Associated grasses include Chrysopogon aucherii, Sporobolus spp., Penisetum dichotomum, Panicum turgidum, Eragrostis spp., Aristidia spp., Andropogon spp. and others. Aloe spp. are common.

The anhydrite plains in the north do not support trees except for occasional scrub but are covered by grass (Macfadyen, 1950). On the other hand adjacent plains underlain by limestone support a relatively thick cover of trees, bush and grasses.

Large areas of northern Somalia's semi arid plains have an arc like vegetation pattern, the cause of which has not been determined so far (Macfadyen, 1950; Boaler and Hodge, 1964). Relatively thickly vegetated areas alternate with barren areas over very short distances. This happens whether the vegetation of the area is trees, scrub or grass. On aerial photographs the vegetated areas show as arcs. The Somali word for these vegetated areas is kob.

In general the density of vegetative cover is decreasing throughout the country mainly due to overgrazing but also due to clearing of land for agriculture, cutting of trees for building materials, charcoal and other needs of man. Decrease in vegetative cover has led to serious erosion in many places. In the north where steep slopes are common water erosion is serious (Hunt, 1951). In the south dune encroachment is a major problem. According to FAO (1968) over 100,000 hectares had been lost to dunes alone. As overgrazing progresses less desirable plants are taking over the

rangelands. Aside from these man made causes certain areas are losing their vegetative cover due to natural causes. The extent of these areas is not great. An example is one noted by Hunt (1951) and observed by this author near the town of El Afwein. Thick woodlands of Acacia bussei still stand but all the trees are dead. Whether this was caused by disease, lowering of water tables, climatic changes or some other cause is not clear.

Existing Soil Maps in Somalia

Soil maps covering the entire country include one given in the soil map of Africa by the Commission for Technical Cooperation in Africa (CCTA; 1964) and another given in the Soil Map of the World (FAO/UNESCO, 1973). Each organization used its own classification system and mapping units. A soils map of Somalia taken from the soil map of Africa is shown in Figure 6. Six major groups of soils were classified which in turn were subdivided into lower categories. The soils mapped and their important properties are discussed below.

1. Raw mineral soils. There is essentially no soil development in this class. They are composed of rocks and rock debris and desert pavement. This class is very minor in extent. One mapping unit could not be shown in Figure 6 because of the reduced scale. That unit is rocks rich in ferromagnesian minerals.
2. Weakly developed soils. The main characteristic of this group of soils is poor development of the profile. This may be due to the presence of coherent hard rock within the upper 30 cm (lithosols), or moisture deficiency as

Figure 6: Legend

- Ap Desert pavement (regs) residual.
- Bd Lithosols, not differentiated.
- Bf Subdesert soils.
- Bo Juvenile soils on riverine and lacustine alluvium.
- Bq Juvenile soils on windborne sands.
- Ca Rendzinas and Brown Calcareous Soils.
- Cc Soils containing more than 15% gypsum.
- Da Vertisols of lithomorphic origin, derived from rocks rich in ferromagnesian minerals.
- Dj Vertisols of topographic depressions.
- Gb Brown Soils of arid and semi arid tropical regions. Not differentiated.
- Ja Ferruginous Tropical soils on sandy parent materials.
- Jd Ferruginous tropical soils. Not differentiated.
- Db Vertisols of lithomorphic origin, derived from calcareous rocks.

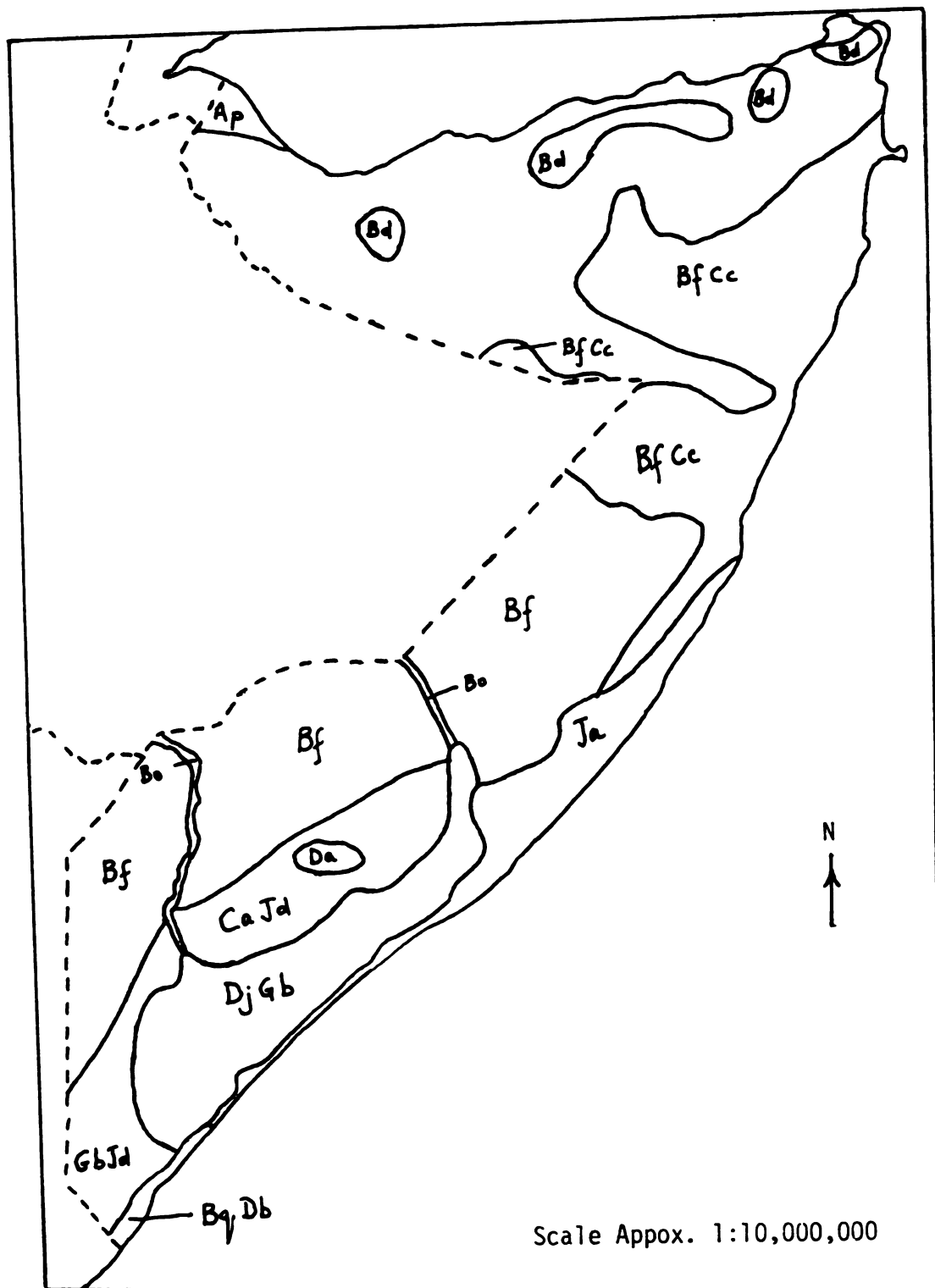


Figure 6. Soil map of Somalia. After CCTA, 1963.

in subdesert soils or lack of adequate time for development such as soils developed on recent alluvial, aeolian and lacustrine deposits. The most extensively mapped soils in Somalia in this group are the subdesert soils. Subdesert soils are characterized by low organic matter, slight differentiation of horizons and may have accumulations of carbonates or soluble salts. One mapping unit of this group of soils is not shown in Figure 6. These are Juvenile soils on fluvio-marine sediments.

3. Calcimorphic Soils. These are soils which have high amounts of free calcium carbonate throughout the profile and high content of bivalent ions in the exchange complex or have greater than 15% gypsum.
4. Vertisols. The general definition of vertisols in the soil map of Africa is given in the soils of the area section. They have been subdivided according to lithological origin, that is, whether they were derived from rocks rich in ferromagnesian minerals, calcareous rocks or sediments in topographic depressions.
5. Brown soils of arid and semi arid tropical regions. The profile in these soils is darkened by organic matter. They have a textural, structural or color B horizon. They are high in reserve weatherable minerals and usually high in 2:1 lattice clay minerals. Cation exchange capacity is medium to high and more than 50 percent saturated with bases in the B and C horizons.
6. Ferruginous Tropical Soils. These soils have an A B C

profile with an A2 and a textural B horizon. Usually a separation of free iron oxides is evident. Clay is mostly kaolinite and the cation exchange capacity is low.

The main soils mapped by FAO/UNESCO (1973) in Somalia are shown in Figure 7. The original FAO/UNESCO map contains more detail than Figure 7. The main soils mapped by FAO/UNESCO and some of their major properties are given below. Detailed definitions of these soils can be found in the FAO/UNESCO (1974) publication. Important diagnostic properties not mentioned here means they are lacking.

Calcaric Regosols. These soils have developed on unconsolidated materials excluding recent alluvium. They have no diagnostic horizons and are calcareous at least between 20 and 50 cm from the surface.

Lithosols. These are shallow soils having a continuous hard rock within 10 cm from the surface.

Calcaric fluvisols. These soils have developed on alluvial, locustrine or colluvial sediments. They have no diagnostic horizons except an ochric epipedon. They are calcareous at least between 20 and 50 cm from the surface.

Cambic Arenosols. These soils lack diagnostic horizons other than an ochric epipedon and have developed on coarse textured unconsolidated material excluding recent alluvium. They have a coloring or alteration characteristic of a cambic B horizon.

Chromic Vertisols. These are vertisols with moist color chromas of 1.5 or more dominant in the soil matrix throughout the upper 30 cm.

Solonchaks. These soils are characterized by high salinity. Soils formed from recent alluvium are not included even though they may have high salinities. Solonchaks have no diagnostic horizons

Figure 7. Legend:

<u>map symbol</u>	<u>soils</u>
1	calcaric regosols
2	calcaric regosols and fluvisols
3	lithosols and calcaric regosols
4	Lithosols
5	Lithosols and orthic solonchaks
6	Calcaric fluvisols
7	Cambic arenosols
8	Chromic vertisols
9	Orthic solonchaks
10	Orthic solonetz
11	Calcic yermosols
12	Haplic yermosols
13	Gypsic yermosols
14	Calcic Xerosols
15	Calcic xersols and haplic yermosols
16	Gypsic xerosols
17	Calcic cambisols and lithosols
18	Ferric and chromic luvisols
19	Eutric nitosols and chromic vertisols

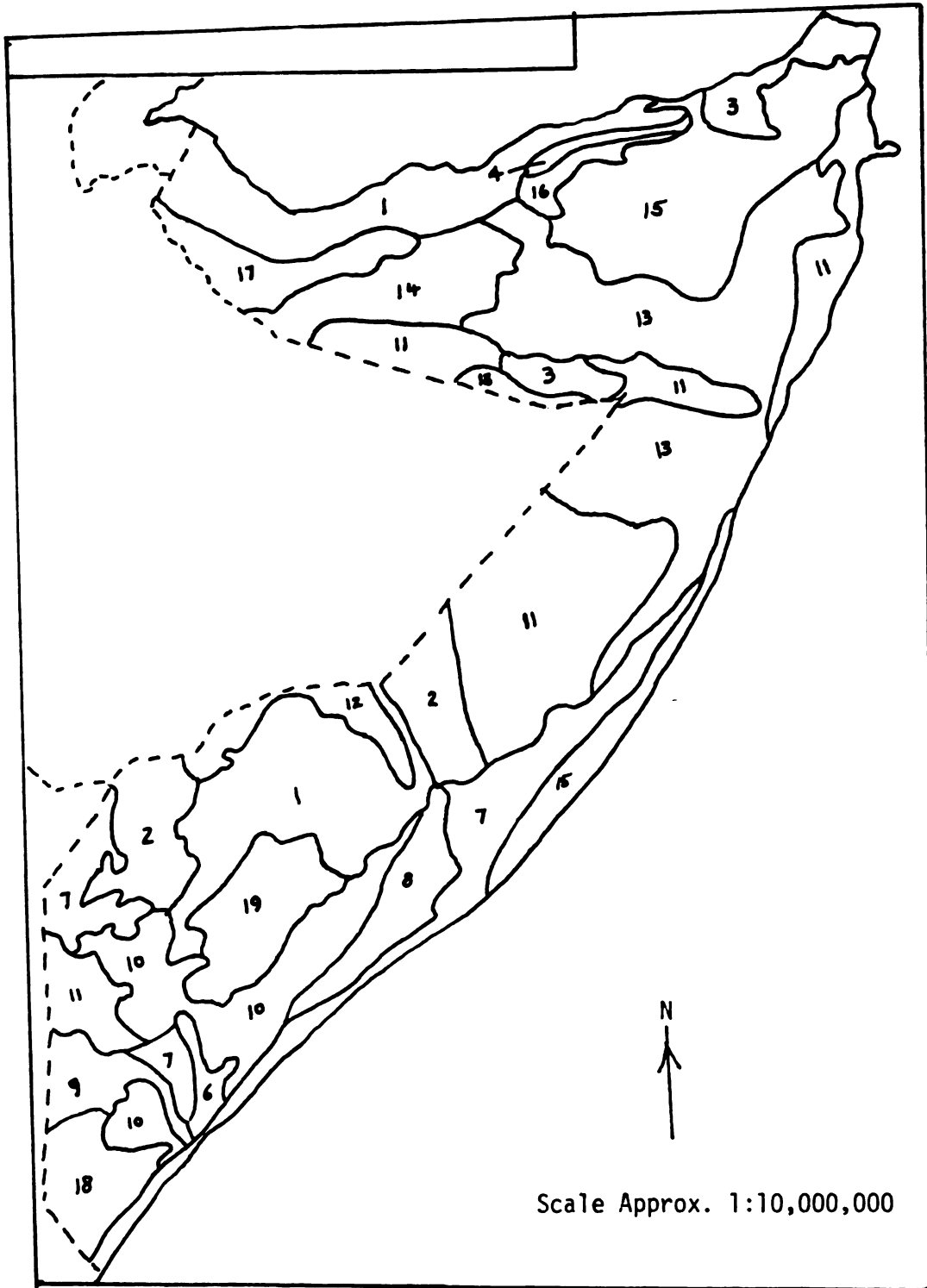


Figure 7. Soil map of Somalia. After FAO/UNESCO, 1973.

other than A horizon, a cambic B horizon, a calcic or gypsic horizon or a histic horizon.

Solonetz. The main feature in a natric B horizon.

Yermosols. These soils occur under an aridic moisture regime. They have a very weak ochric A horizon and one or more of these horizons: A cambic B, an argillic B, a calcic or a gypsic horizon. If they have only a very weak A horizon and no other diagnostic horizons they are haplic yermosols. If a calcic horizon is present within 125 cm from the surface they are calcic yermosols. If a gypsic horizon is present within 125 cm they are gypsic yermosols.

Xerosols. These soils are essentially similar to yermosols except they have a weak ochric A horizon instead of a very weak one.

Calcic cambisols. These soils have a cambic B horizon. They have no diagnostic horizons other than an ochric A horizon and one or more of the following: a calcic horizon, a gypsic horizon or concentrations of soft powdery salts. They are calcareous at least between 20 and 50 cm from the surface. They lack an aridic moisture regime.

Luvisols. These soils have an argillic horizon with base saturation of 50% or more in the B horizon. They also lack an aridic moisture regime. Chromic luvisols have a strong brown to red argillic B while ferric luvisols show ferric properties.

Nitosols. These have an argillic B horizon with a clay distribution where the percentage of clay does not decrease from its maximum amount by as much as 20% within 150 cm of the surface. They also lack an aridic moisture regime. Eutric nitosols have a base saturation of 50% or more throughout the argillic B horizon.

FAO (1968) carried out a soil survey and mapped 20,860,000 hectares in the country. This is approximately the southernmost 1/3 of the country. Eighty one soil map sheets of this area exist. Sixty six soil types and land types were mapped. Soil types are composed of 10 groups. These include latosolic soils, Solonetz and Solonchak, Brown subarid, Terra rosa, Grumosols, Reddish brown calcic, Brown calcic, Reddish brown ferruginous, Regosol-Lithosol and Recent alluvial.

Grumosols are further subdivided into brown, grey brown, grey and reddish brown. The importance of grumosols is illustrated by the FAO (1968) land classification. About 9 percent of the area surveyed is classified as class A land with no serious limitations for cultivation. Grumosols cover most of the class A land. In addition to the class A land 3 other land classes were identified. About 27 percent of the area was classified as marginal for cultivation because of limitations including erosion, droughty conditions, low natural fertility, presence of salts and sodium in the profile and low rainfall. About 10 percent of the area was classified as soils unsuitable for cultivation mostly because of high salt and sodium content in the profile. About 53 percent of the area is classified as unsuitable for cultivation or intensive grazing because it has little or no soil cover.

Although soils in the survey area differ widely in their characteristics some generalizations can be made. Organic matter is less than 2 percent in all soils and often less than one percent. Soil reaction is slightly to moderately alkaline and calcareous profiles are common in the area.

ECA (1961) has done soil classification work in Lower Juba. The area has been resurveyed by FAO (1968) and they have incorporated the earlier findings with some changes into their publication.

Apart from the aforementioned soil surveys and soil maps the only other literature available concerns farm size or project size areas. Veredchenko and Gusenkov (1965) mapped and characterized the Jilib project area. They identified 3 soil types: 1) Grey compact soils of the savanna formed on the terrace above the flood plain and on the delta plain, 2) soils of the Gallery forests formed on young deposits on the flood plain and characterized by less compactness and 3) red soils formed on ancient sandy loam - sandy river bed ridges.

FAO (1969) mapped and characterized the Balad and Mordile irrigation project areas. Soils in the area were classified according to the USDA 7th approximation system (USDA, 1960). Soils in the area include the subgroups of vertisols Udic Chromusterts, Udorthentic Chromusterts and Udorthentic Pellusterts and the entisol subgroup Typic Ustorthent.

The entisols have developed on channel remnants in the flood plain (levee). Their texture is coarse to medium. The vertisols are medium to fine in texture and have developed on flood plain meander or slack water landforms. Clay content for all soils ranges from 6 to 74 percent. Total carbonates range from 6 to 31 percent but predominantly range from 15 to 25 percent. Total nitrogen ranges from 0.04 to 0.11 percent and organic carbon from 0.35 to 1.06 percent. Available phosphorous ranges from low (less than 5%) to marginal (10%). The various mapping units and their characteristics are given in Table 1.

Table 1: Mapping Units of Balad and Mordile Soils (FAO, 1969).

<u>Chromusterts</u>			
<u>Udic Chromusterts (Fpm Recent Alluvial)</u>			
Mapping Unit	Color Hue	Texture	Electrical Conductivity
G1 1a 11	10 YR	medium/fine over coarse/medium	< 4
G1 1a 21	10 YR	medium/fine over fine	< 4
G1 1a 22	10 YR	"	> 4
G1 1a 31	10 YR	medium/fine over stratifications	< 4
G1 1b 11	7.5 YR	medium/fine over coarse/medium	< 4
G1 1b 21	7.5 YR	medium/fine over fine	< 4
G1 1b 31	7.5 YR	medium/fine over stratifications	< 4
<u>Udic Chromusterts (Fpm Old Alluvial)</u>			
Mapping Unit		Texture	E.C.
Sr 111		medium/fine over fine	> 4
Sr 112		"	< 4
<u>Udorthentic Chromusterts (Fpm Recent Alluvial)</u>			
Mapping Unit		Texture	E.C.
Gid 211		Medium/fine over coarse/medium	< 4
G1 221		Medium/fine over fine	< 4
<u>Udorthentic Chromusterts (Fpm Old Alluvial)</u>			
Mapping Unit		Texture	E.C.
Sr 211		medium/fine over fine	< 4
Sr 212		"	> 4

Table 1: (Continued)

<u>Udorthentic Pellustert (FPm Old Alluvial)</u>		
Mapping Unit	Texture	E.C.
G 311	Medium/fine over fine	< 4
<u>Udorthentic Pellustert (FPs1)</u>		
Mapping Unit	Texture	E.C.
Sc 111	Medium/fine over fine	< 4
<u>Typic Ustorthent (FP cr)</u>		
Mapping Unit	Texture	E.C.
C 111	coarse/medium	< 4
C 121	coarse/medium over fine	< 4
C 131	coarse/medium over stratifications	< 4

Soil Forming Factors at CARS

Climate

The Central Agricultural Research Station (CARS) is in a semi-arid region (Papadakis, 1975; CCTA, 1964). Mean annual rainfall is about 536 mm and mean annual air temperature is about 27°C (Table 2). The mean monthly variation in temperature from the annual mean is less than 2°C. Rainfall occurs mainly in April-August and October-November. Mean annual air humidity is 71.6 percent and does not vary much throughout the year. Wind blows from the southwest from late April to late October and from the northeast from late November to early

Table 2: Meteorological Data for CARS, Afgoi (Mean Values)*

	JAN	FEB	MAR	APR	MAY	JUN	JUL
Rainfall (mm) (1953-1976)	2.3	2.4	5.5	84.4	104.4	51.6	65.0
Number of rainy days (1953-1976)	0.5	0.3	0.7	6.9	7.7	8.3	9.9
Temperature in °C (1953-1976)	27.4	27.8	28.8	28.6	27.3	26.0	25.2
Max. Temp. °C (1953-1976)	33.6	34.3	34.6	34.2	31.7	30.2	29.2
Min. Temp. °C (1953-1976)	20.4	20.8	22.0	22.6	22.4	21.4	20.6
Humidity % (1953-1976)	69.0	66.3	66.3	69.8	73.9	75.2	76.9
Hours Sunshine (1957-1958)	275	288	312	252	222	209	275
Evaporation (mm) (1972-1976)	320	324	383	274	248	220	217
Windspeed m/sec. (Oct 1975-June 1977)	3.6	4.1	4.6	2.5	2.6	3.8	3.7

Table 2: (Continued)

	AUG	SEPT	OCT	NOV	DEC	YEAR
Rainfall (mm) (1953-1976)	22.4	13.3	51.5	104.4	29.1	536.3
Number of rainy days (1953-1976)	5.2	1.7	4.0	8.3	2.6	57.1
Temperature in °C (1953-1976)	25.5	26.4	26.9	26.7	27.1	27.0
Max. Temp. °C (1953-1976)	29.9	31.0	31.7	31.7	32.8	32.1
Min. Temp. °C (1953-1976)	20.6	21.1	21.2	21.0	20.6	21.2
Humidity % (1953-1976)	74.9	72.3	71.8	73.9	70.8	71.6
Hours Sunshine (1957-1958)	281	288	260	228	229	3118
Evaporation (mm) (1972-1976)	240	278	266	213	262	3245
Windspeed m/sec (Oct 1975-June 1977)	4.3	3.9	3.3	2.7	3.3	3.5

*CARS unpublished data, 1978.

March. Monthly mean wind speeds range from 2.5 m/sec to 4.6 m/sec.

The area is likely to suffer a partial or complete crop failure of one rain grown crop due to inadequate rainfall in two out of every five years (FAO, 1969).

Using the USDA classification system (USDA, 1975) the soil moisture regime is ustic and the temperature regime isohyperthermic. Table 2 summarizes the meteorological records collected at Afgoi Town and CARS.

Topography

The central agricultural research station is situated on the flood plain of the Shabelle River. The area has slight microrelief and slopes gently away from the river towards the dunes of the coast (FAO, 1968). The soils are well drained.

Age and Character of the Parent Materials

The area is underlain by a thick deposit of recent alluvium (Ahrens, 1951). During the Pleistocene the Shabelle River drained into the Indian Ocean near Mogadiscio and cut a much deeper channel than the present one. Dunes encroached into the delta of the river changing its course westward and parallel to the Indian Ocean Coast. Because of the higher elevations of its new course the gradient of the river was changed increasing its tendency towards aggradation. This aggradation continues to this day. The source of the great silt load of the river are the Cretaceous limestones upstream in the drainage basin which is mostly in Ethiopia. These rocks which probably also supply most of the river's base floor are known to give saline waters (Ahren, 1951). The thickness of the alluvium in the

Afgoi zone exceeds 100 meters and probably overlies Miocene littoral and lagoonal deposits (Faillace, 1964). Static groundwater levels range from 50-55 meters deep, although perched water tables are encountered at times at depths of 5 to 12 meters. The parent material of the present soils is a fine textured Recent alluvium (FAO, 1968).

Soils of the Area

In the soil map of Africa (Figure 6) the soils of the area have been mapped as Vertisols of Topographic Depressions. The definition of Vertisols and of Vertisols of Topographic Depressions according to CCTA (1964) is quoted below.

General definition of Vertisols:

Soils with an A1 horizon at least 20 cm thick and dark in color even though organic matter content is usually low. Calcareous accumulations are frequent. Permeability is slow and internal drainage is poor, at least at some depth even though external drainage may be favorable. Profiles show the effect of mechanical reworking such as dry season cracks, slickensides, and often by gilgai microrelief. The structure is prismatic or coarse blocky throughout most of the profile. The surface horizon sometimes has a fine structure (self mulching).

The reserve of weatherable minerals is high. The clay fraction usually consists of mainly 2:1 lattice clays, especially montmorillonite and mixed layer minerals. The cation exchange capacity of the complex is high and is generally more than 50% saturated, mostly with bivalent cations (normal ammonium acetate at pH 7).

Definition of Vertisols of Topographic Depressions is:

These soils are found in topographic depressions where external drainage aggravates the effects of inherently poor internal drainage. They seem to develop only under climates where potential evaporation is high during part of the year and on parent materials (often sediments) enriched in insoluble constituents derived directly or indirectly from surrounding high land. Accordingly they are more commonly associated with soils having sodic, calcic or gypsic horizons than are vertisols of lithomorphic origin.

In the FAO/UNESCO soil map of the world (Fig. 7) the area soils

have been mapped as Chromic Vertisols with Eutric Fluvisols and Pellic Vertisols as minor associated soils. Chromic Vertisols are vertisols having moist chromas of 1.5 or more dominant in the soil matrix throughout the upper 30 cm. Chromic Vertisols correspond to chromuderts, chromusterts, chromixererts and torrerts in the United States Soil Taxonomy (USDA, 1975).

In the FAO (1968) reconnaissance soil survey the area was mapped as a brown grumosol and included in the Goluen soil type. The Goluen soil type developed on younger alluvium and is fine textured. It has soft mulch and surface cracks. The profile is composed of dark brown clay to clay loam surface underlain by dark brown to brown clay materials. Slickensides occur in the subsurface and subsoil horizons. Calcium carbonate and salts are found in the subsoil. The top soil has no salt hazard while the subsoil has low to medium salt hazard and mostly no sodium hazard.

Soils of CARS

No soil classification has been done on CARS soils in the past. However some data on previous soil samplings give some of the chemical and physical characteristics. According to early reconnaissance sampling (CARS, 1964) soil texture is medium to heavy. Clay content ranges from 32 percent to 80 percent. The top soil has no salinity hazard, i.e. electrical conductivity is less than 4 mmhos/cm. The subsoil in some places has a slight salinity hazard where electrical conductivities range from 4 to 5.8 mmhos/cm. Organic matter is less than 2 percent. Hydraulic conductivity values on disturbed samples are usually high and sometimes excessive. It is rarely below 1 cm/hr.

More recent determinations were carried out on 40 hectares of irrigated land (CARS, 1968). Water infiltration rates varied from 4 cm/hr to 16.5 cm/hr for the first hour and final infiltration ranged from 0.25 to 0.5 cm/hr. The field capacity was 35-40 percent and the wilting point 21.5 percent. Fertility trials (CARS, 1973) indicate response to nitrogen, marginal response to phosphorus and no response to potassium in cereal crops. According to a study (CARS, 1973) carried out from 1968 to 1972, salts are accumulating very slowly as well as moving downwards due to irrigation. The changes in salt content occurring over these five years were considered too small to affect crop yields. The waters of the Shabelle River which are used for irrigation are high to medium in total salt content but have no sodium hazard (CARS, 1973).

MATERIALS AND METHODS

General Nature of CARS

Location

CARS is located about 33 kilometers northwest of Mogadiscio and just 3 kilometers east of Afgoi. The geographical coordinates of Afgoi are Lat. $02^{\circ} 08' 20''$ N, Long. $45^{\circ} 07' 35''$ E. Its altitude above sea level is 85 meters. The station covers about 400 hectares in the area (Fig. 8). The area is L shaped. It starts about 500 meters away from the River Shabelle and extends towards dunes, then turns toward the Afgoi-Mogadiscio Road ending at the old railway line bed.

Land Use

The area is one of the relatively old agricultural areas in the country. Prior to the Italian occupation peasants cultivated the land for an unknown period. During the Italian administration Italian farmers owned and cropped the land. The Somali government expropriated the land in 1963 for public use and started the Central Agricultural Research Station in 1965. Presently about 80 hectares have been developed of which some 60 hectares are used intensively under irrigation for experimental purposes. The rest of the station land is used for rainfed agriculture mainly by private peasants. Crops grown under irrigation include maize, rice, cotton, peanuts, cowpeas, citrus, sesame, and vegetables. The main crops grown under

rainfed conditions are maize and sesame. Many other types of crops are grown under experimentation at the station.

Field Methods

Base Maps. No suitable aerial photographs could be found to serve as base maps. A single aerial photograph at least sixteen years old and having an approximate scale of 1:30,000 was found. It was used to identify landforms. Base maps were drawn based on a 1963 Ministry of Finance map which shows the total area allotted to the station and the original irrigation plan of the presently developed area. A map was drawn for the developed area. Another map was drawn for the whole area.

Landform Identification

The area was traversed on foot to determine landforms in the area. Topography and nature of deposits especially texture and surface color were used as the main guidelines. A number of auger holes were dug to confirm surface observations. The aerial photo proved useful in supporting ground evidence with respect to channel remnants in the area.

Field Soil Characterization

The Developed Area

Auger observations were made over the entire area (D in Fig. 8) at maximum intervals of 100 meters. Field examinations were made on color, texture, reaction to 10 percent HCl, profile arrangement and the presence of concretions and salt precipitates. Samples were collected from these borings for later determination of soluble salt content.

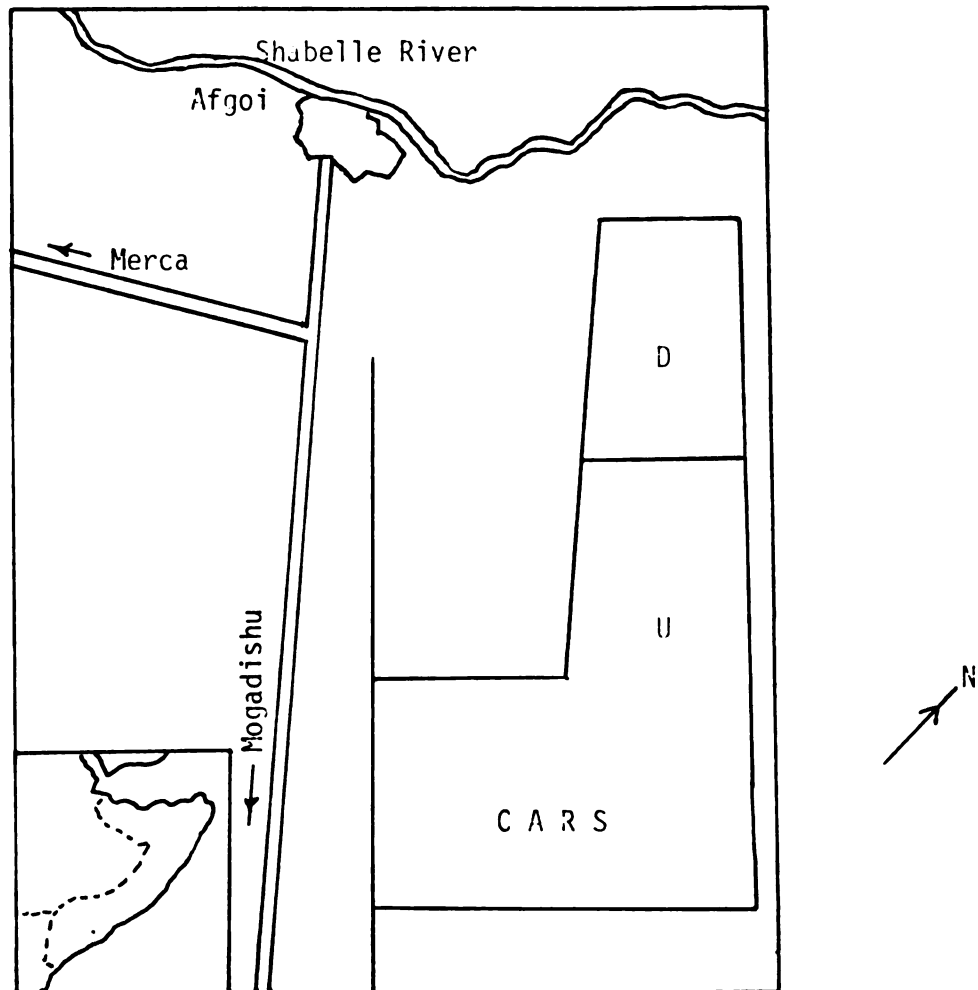


Figure 8. Map showing location of cars.

From these observations, sites were chosen to dig pits to characterize representative profiles. Seven pedons were described in the field. The descriptions followed the Soil Taxonomy (USDA, 1975). Descriptions included site features such as topography, land use and surface structural features of the pedon. Descriptions of profile features included depth of horizons or layers, color, texture, structure, consistence, roots, pores, reaction to 10 percent HCl, boundary and any other important soil feature encountered. Each pit was described to 2 meters.

Laboratory samples were collected from each pit for analysis in the laboratory.

Soil boundary lines were interpolated between observation points.

The Undeveloped Area

The density of observations was less in this area (U in Fig. 8). Auger borings were made at intervals of 200 to 250 meters in a grid pattern. Closer observations were made to separate contrasting soils. No new soils were encountered in the area so boundaries were delineated according to the legend made for the developed area.

Laboratory Methods

Most of the methods used in the laboratory analysis of soil samples were those given in USDA agriculture Handbook No. 60 (U.S.S.L. Staff, 1954). The pH of the saturated paste was determined electrometrically (Method 21a). Electrical conductivity was determined on the saturation extract (Method 4b). Calcium and magnesium in the extract were determined by complexometric titration with EDTA (Method 7) and sodium by flame photometer (Method 10a). Hydraulic

conductivity was determined on disturbed samples (Method 34b) and saturation percentage from saturation paste (Method 27b). Particle size analysis was done by the hydrometer method (Day, 1965). The calcium carbonate equivalent was determined by acid neutralization (Method 23c) with some modifications; 2 grams of soil were used instead of 25 grams and 0.4 N solutions were used for both the HCl and NaOH instead of 0.5 N solutions.

Final Classification of Soils

Following the completion of both field and laboratory characterization of soils a final classification of soils was made and soil maps prepared according to the United States Soil Taxonomy System (USDA, 1975) and FAO/UNESCO system (FAO/UNESCO, 1974).

RESULTS AND DISCUSSION

Types of Landforms

Landform designations used are those of FAO (1968). Two landforms exist in the area. Flood plain meander which covers the bulk of the area and flood plain channel remnant which covers only a small part. The flood plain meander landform is composed of level to very gently sloping plain covered with fine textured deposits. The channel remnant land form is composed of an old levee of an ancient channel of the Shabelle River which meandered through the area in the past. The channel bed and other channel features except the levee have been obliterated by later deposition and erosion in the vicinity. Channel remnant deposits are mostly silty clays and silt loams and the color of the material is lighter than those of the flood plain meander.

Soils in the whole area are well drained and are not subject to flooding. The general slope trend is towards the dunes (away from the river) at a very gentle gradient.

Soil Characterizations

Pedon descriptions of the five representative pedons in the area are given below:

Pedon 1 (P1)

Location: Field 3

Date: Feb., 1978



Figure 9. A landscape photograph of CARS.

Topography: Level, slope < 1%

Land Use: Cropland, irrigated

Surface Features: cracks 1.5-2 cm wide

Ap 0-30 cm: Dark reddish brown (5YR 3/3) dry, and dark reddish brown (5YR 3/2) moist. Clay. massive to weak coarse subangular blocky structure. Hard, very firm, sticky, plastic. Common fine roots, common coarse roots. Few very fine pores. Violent reaction to 10% HCl. Moderately alkaline. Abrupt smooth boundary.

A12 30-60 cm: Dark reddish brown (5YR 3/3) dry, and dark reddish brown (5YR 3/2) moist. Clay. Moderate coarse angular blocky structure, hard, very firm, sticky, plastic, common very fine roots, common coarse roots, few fine pores, strong reaction to 10% HCl, mildly alkaline, clear smooth boundary.

A13 60-90 cm: Dark reddish brown (5YR 3/3) dry, and dark reddish brown (5YR 3/2) moist, clay, coarse to very coarse angular blocky structure. Common slickensides. Hard, very firm, sticky, plastic. Few very fine roots. Common coarse roots. Few very fine pores. Violent reaction to 10% HCl. Mildly alkaline. Gradual wavy boundary.

A14 90-120 cm: Reddish brown (5YR 4/3) dry. Dark reddish brown (5YR 3/2) moist. Many coarse prominent dark grey mottles (7.5YR 4/0) dry. Some charcoal black stainings. Clay. Strong medium to coarse subangular blocky structure. Slickensides common. Very hard, very firm, sticky, plastic. Few very fine roots. Few very fine pores. Violent reaction to 10% HCl. Mildly alkaline. Abrupt smooth boundary.

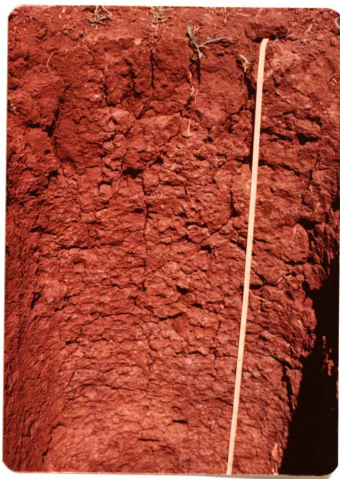


Figure 10. A photograph of Pedon P1 a udic chromostert which is very fine in all depths.

C1 120-135 cm: Brown (7.5YR 5/4) dry. Dark brown (7.5YR 3/2) moist.

Clay. Moderate medium subangular blocky structure. Very hard, firm, slightly sticky, plastic. Few very fine roots. Few coarse roots. Violent reaction to 10% HCl. Gradual wavy boundary.

C2 135-200 cm: Mixed materials. Brown to dark brown (7.5YR 4/2)

moist clay and dark reddish brown (5YR 3/2) moist, clay. Strong medium subangular blocky structure. Very hard, very firm, slightly sticky, plastic. Few very fine roots. Few fine pores. Common gypseous white salt spots and streaks on peds. Violent reaction to 10% HCl. Mildly alkaline.

Cracks start from the surface and end at 160 cm. Width at the surface is 1 to 2 cm. At 50 cm cracks are 1 cm wide and at 150 cm 0.5 cm wide.

Pedon 2 (P2)

Location: Field 11

Date: Feb., 1978

Topography: Level, slope < 1%

Landuse: Cropland, irrigated

Surface features: Cracks 1-1.5 cm wide.

Ap 0-30 cm: Brown (7.5YR 5/4) dry. Dark brown (7.5YR 3/2) moist.

Clay. Massive to weak coarse subangular blocky structure. Hard, firm, sticky, plastic. Common fine roots. Few coarse roots. Few fine pores. Violent reaction to 10% HCl. Mildly alkaline. Abrupt smooth boundary.

A12 30-94 cm: Brown (7.5YR 5/4) dry. Dark brown (7.5YR 3/2) moist.

Clay. Strong very coarse subangular blocky structure. Common slickensides. Hard, very firm, sticky, plastic. Common fine

and very fine roots. Few coarse roots, few fine pores. Violent reaction to 10% HCl. Mildly alkaline, abrupt smooth boundary.

A13 94-107 cm: Brown (7.5YR 5/4) dry. Dark brown (7.5YR 3/2) moist. Clay. Strong medium subangular blocky structure. Hard, very firm, sticky, plastic. Few very fine roots. Few medium vesicular pores. Violent reaction to 10% HCl. Slightly alkaline. Abrupt smooth boundary.

C1 107-120cm: Brown to dark brown (7.5YR 4/2) dry. Dark brown (7.5YR 3/2) moist. Common distinct strong brown mottles (7.5YR 4/6) dry. Clay. Fine moderate subangular blocky structure. Very hard, very firm, sticky, plastic. Few very fine and fine roots. Few vesicular medium pores. Common snail shells. Violent reaction to 10% HCl. Mildly alkaline. Abrupt smooth boundary.

C2 120-128 cm: Yellowish brown (10YR 5/4) moist. Loam. Structureless. Soft, very friable, slightly sticky, slightly plastic. Common fine and very fine pores. Strong reaction to 10% HCl. Mildly alkaline. Abrupt irregular boundary.

C3 128-140 cm: Brown to dark brown (10YR 4/3) moist. Few faint strong brown mottles (7.5YR 3/6) moist. Clay. Strong medium subangular blocky structure. Hard, firm, slightly sticky, plastic. Few very fine roots. Common white calcareous concretions. Violent reaction to 10% HCl. Slightly alkaline. Abrupt wavy boundary.

C4 140-200 cm: Brown to dark brown (7.5YR 4/4) moist. Intermixture of sandy loam and some clay. Overall texture loam.

Structureless. Very friable, non sticky, non plastic. Violent reaction to 10% HCl. Slightly alkaline.

Cracks begin at the surface and go down to 90 cm. They are 1 to 1.5 cm wide at the surface and about 1 cm at 50 cm depth.

Pedon 3 (P3)

Location: Field 17

Date: Feb., 1978

Topography: Level, slope < 1%

Land use: Mostly rainfed cropping. Occasionally irrigated.

Surface features: Cracks 1-2 cm wide

Ap 0-30 cm: Reddish brown (5YR 4/3) dry. Dark reddish brown (5YR 3/2) moist. Clay. Weak to moderate medium subangular blocky structure. Hard, very firm, sticky, plastic. Few very fine and fine roots. Strong reaction to 10% HCl. Moderately alkaline. Abrupt smooth boundary.

A12 30-85 cm: Reddish brown (5YR 4/3) dry. Dark reddish brown (5YR 3/2) moist. Clay. Strong medium subangular blocky structure. Common slickensides. Hard, very firm, sticky, plastic. Few very fine roots. Few fine pores. Strong reaction to 10% HCl. Moderately alkaline. Abrupt wavy boundary.

C1 85-97: Brown (7.5YR 5/4) dry. Brown to dark brown (7.5YR 4/2) moist. Common prominent red mottles (2.5YR 4/6) moist. Clay. Moderate fine subangular blocky structure. Hard, very firm, sticky, plastic. Strong reaction to 10% HCl. Mildly alkaline. Abrupt wavy boundary.

C2 97-107cm: Pink (7.5YR 7/4) dry. Dark reddish brown (5YR 3/2) moist. Many distinct dusky red mottles (2.5YR 3/2) moist. Silt loam. Structureless, massive. Soft, friable, slightly



Figure 11. A photograph of Pedon P3, a udic chromostert, very fine underlain by loamy materials.

sticky, slightly plastic. Few very fine roots. Many white calcareous concretions. Strong reaction to 10% HCl. Moderately alkaline. Abrupt smooth boundary.

C3 107-119 cm: Pink (7.5YR 7/4) dry. Dark reddish brown (5YR 3/2) moist. Many distinct dusky red mottles (2.5YR 3/2) moist. Silt loam. Weak medium subangular blocky structure. Many white calcareous concretions. Hard, firm, sticky, slightly plastic. Few fine roots, few fine pores. Strong reaction to 10% HCl. Moderately alkaline. Abrupt smooth boundary.

C4 119-141 cm: Grey (10YR 5/1) moist. Many distinct dark reddish brown mottles (2.5YR 3/4) moist. Silty clay. Moderate medium columnar structure. Hard, very firm, slightly sticky, plastic. Common snail shells. Many gypseous white salts in peds. Strong reaction to 10% HCl. Moderately alkaline. Abrupt smooth boundary marked by a one centimeter thick black line (7.5YR 2/0) moist.

C5 141-205 cm: Yellowish brown (10YR 5/4) moist. Sandy loam. Structureless. Soft, very friable, non sticky, non plastic. Strong reaction to 10% HCl. Moderately alkaline.

Cracks 1-2 cm wide start at the surface and taper down to 0.5 cm at 75 cm below the surface.

Pedon 4 (P4)

Location: Field 19

Date: March, 1978

Topography: Level, slope < 1%

Land use: Rainfed cropping

Surface features: Soft crust.

Ap 0-25 cm: Reddish brown (5YR 5/3) dry. Dark reddish brown (5YR

C1 50-75 cm: Pink (7.5YR 7/4) moist. Loam. Structureless. Soft, very friable, slightly sticky, non plastic. Few very fine roots. Few medium pores. Strong reaction to 10% HCl. Slightly alkaline. Abrupt smooth boundary.

C2 75-130 cm: Dark reddish brown clayey material (5YR 3/3) dry, (5YR 3/2) moist intermixed with silt loam material, pink (5YR 7/4) dry, reddish brown (5YR 5/3) moist. Overall texture silty clay loam. Moderate fine to medium subangular blocky structure. Hard, firm, slightly sticky, slightly plastic. Few fine roots. Few medium pores. Common powdery white salts as streaks and spots on peds. Violent reaction to 10% HCl. Mildly alkaline. Abrupt smooth boundary.

C3 130-140 cm: Pink (7.5YR 7/4) moist. Silt loam. Structureless. Soft, very friable, non sticky, slightly plastic. Few medium pores. Strong reaction to 10% HCl. Slightly alkaline. Abrupt smooth boundary.

C4 140-200 cm: Dark reddish brown material (5YR 3/2) moist, intermixed with reddish brown material (5YR 5/4) moist. Silt loam. Moderate fine to medium subangular blocky structure. Hard, friable, slightly sticky, slightly plastic. Few fine roots. Few medium pores. Strong reaction to 10% HCl. Moderately alkaline.

Pedons 6 and 7 which represent very minor soils (inclusions) in the area are described in the appendix.

Laboratory Analysis of Soils

Results of laboratory analysis of representative pedons are given in Tables 3 and 4.

All five pedons have A and C horizons only. This can be explained by the relatively young age of the parent materials coupled with an ustic moisture regime and in the case of vertisols the continuous turning over or churning effect. The influence of these factors have resulted in little horizon differentiation. All five pedons are calcareous throughout the profile.

Pedon P1 has a very fine particle size class in all horizons with less than 10% sand. Clay content in the control section is 72%. P2 and P3 are also very fine in the control section with clay contents of 72% and 69% respectively. P2 and P3 however differ from P1 in the lower part of the profile. Below the very fine material P2 is composed of coarse loamy material while P3 is underlain by stratified fine silty, fine and coarse loamy materials. P4 is fine throughout with a clay content of 49% in the control section. P5 is fine loamy in the control section with a clay content of 32%. Below the control section the pedon is composed of stratifications of fine loamy and coarse loamy materials.

Early reconnaissance sampling of CARS soils (CARS, 1964) gave particle size classes of mostly very fine in the control section with clay contents ranging from 52% to 80%. Most values were a little higher than the present data falling between 72% and 80%. Most profiles were very fine in all depths in this study. It is obvious that those samplings missed the soils represented by Pedon 5 and those areas having loamy materials in the lower layers of the pedon. The

Table 3: Particle Size Distribution and Hydraulic Conductivity of Five Representative Pedons

	% Sand	% Silt	% clay	Class*	Hydraulic Conductivity** cm/hr
Pedon P1					
Ap	2	24	74	C	0.58
A12	7	23	70	C	1.09
A13	9	21	70	C	0.80
A14	0	18	82	C	1.32
C1	3	27	70	C	1.38
C2	0	19	81	C	--
Pedon P2					
Ap	7	35	58	C	0.51
A12	0	26	74	C	0.45
A13	4	34	62	C	1.83
C1	7	26	67	C	--
C2	46	36	18	L	--
C3	14	27	59	C	--
C4	38	49	13	L	--
Pedon P3					
Ap	4	28	68	C	1.50
A12	2	25	73	C	0.88
C1	2	35	63	C	2.07
C2	16	62	22	Si1	3.80
C3	4	72	24	Si1	3.90
C4	3	47	50	Sic	--
C5	66	25	9	Sal	3.88
Pedon P4					
Ap	17	39	44	C	1.21
A12	14	37	49	C	0.71
AC	11	39	50	C	1.47
Pedon P5					
A11	18	44	38	Sic1	1.30
C1	43	38	19	L	2.32
C2	14	48	38	Sic1	1.80
C3	27	65	8	Si1	1.56
C4	11	67	22	Si1	1.72

*C - clay, L - loam, Si1 - silt loam, Sic1 - silty clay loam,
Sic - silty clay, Sal - sandy loam.

**Disturbed samples.

Table 4: Some Chemical Properties of Five Representative Pedons

pH		Saturation Extract				SAR	CaCO ₃ Eq. %	SP* %
		E.C. mmhos/ cm	Ca meq/ 100g	Mg meq/ 100g	Na meq/ 100g			
Pedon P1								
Ap	7.9	3.2	0.73	0.31	0.42	2.8	16	52
A12	7.8	1.3	0.24	0.09	0.27	3.1	15	48
A13	7.8	2.1	0.38	0.24	0.28	2.4	27	48
A14	7.8	2.1	0.34	0.14	0.33	3.1	20	48
C1	7.9	0.7	0.13	0.04	0.13	2.1	28	44
C2	7.8	3.2	0.72	0.19	0.44	3.0	--	48
Pedon P2								
Ap	7.8	1.1	0.16	0.08	0.12	1.7	26	40
A12	7.8	1.5	0.29	0.14	0.33	3.3	23	48
A13	7.7	1.4	0.20	0.08	0.19	2.6	10	40
C1	7.8	1.2	0.19	0.09	0.21	2.5	16	48
C2	7.8	0.7	0.09	0.06	0.08	1.6	21	32
C3	7.5	1.6	0.20	0.08	0.24	3.2	20	40
C4	7.4	1.9	0.16	0.09	0.29	4.6	--	32
Pedon P3								
Ap	7.9	0.1	0.14	0.10	0.02	0.3	22	48
A12	8.0	1.8	0.10	0.07	0.62	9.8	20	48
C1	7.8	6.5	0.48	0.24	1.80	15	24	40
C2	7.9	9.5	0.36	0.25	1.96	21	23	28
C3	7.9	10.0	0.60	0.40	2.84	20	32	40
C4	7.9	10.1	1.00	0.70	3.25	16	29	50
C5	8.0	7.0	0.38	0.32	1.44	14	--	32
Pedon P4								
Ap	7.6	1.1	0.13	0.08	0.23	3.5	20	42
A12	7.7	1.6	0.09	0.05	0.60	11	12	46
AC	7.6	5.0	0.43	0.24	1.68	13	29	48
Pedon P5								
A11	7.8	3.2	0.84	0.24	0.20	1.4	20	40
C1	7.6	5.5	1.05	0.45	0.15	1.0	18	30
C2	7.8	10.0	1.12	0.71	0.90	5.4	18	30
C3	7.6	8.5	1.13	1.20	0.54	2.6	18	36
C4	7.8	12.0	1.10	0.68	1.26	8.0	19	28

*Saturation percentage.

Goluen soil type data for particle size classes (FAO, 1968) fall within the ranges found in this study for P1, P2, P3, and P4 as far as the control section is concerned. Clay content ranges from 54% to 68% in the control section while lower parts are mostly very fine.

Hydraulic conductivity of P1, P2, P3 and P4 ranged from 0.51 cm/hr to 3.9 cm/hr in the various horizons. This indicates moderately slow permeability in some horizons to no problems in others. Hydraulic conductivity values of 1 cm/hr or greater indicate that the soil has no permeability problems (U.S.S.L. Staff, 1954). Pedon P5 has hydraulic conductivities greater than 1 cm/hr in all horizons. It can be said that permeability is not a major limiting factor in all five pedons. Hydraulic conductivity data for the Goluen soil type are variable but not very different from the present data. Initial values range from 0.31 to 2.51 cm/hr and final values range from 0.50 to 3.12 cm/hr (FAO, 1968).

Soil reaction in all five pedons is slightly to moderately alkaline (Table 4). pH values range from 7.4 to 8.0 in all horizons but are mostly between 7.6 and 7.9. It is not surprising that the pH values of these soils are on the alkaline side considering the climate and parent materials of the area. The ustic moisture regime's leaching capability is limited. In addition the soils developed on base rich, young deposits derived mainly from limestones.

As mentioned earlier the soils are calcareous in all horizons. Soil reaction in the Goluen soil type (FAO, 1968) is quite similar and pH values are mostly between 7.7 and 8.0 with a range of 7.4 to 8.3.

Total salt content in Pedon P1 and Pedon P2 is negligible (less

than 3.3 mmhos/cm) throughout the profile with no apparent distribution pattern. In Pedon P3 salt content in the upper 85 cm is negligible (less than 1.8 mmhos/cm). Below this depth the pedon has medium to high salinity levels (6 to 10 mmhos/cm). Pedon P4 has very low salinity in the upper 90 cm and has medium salinity below this depth. Pedon P5 has low salinity in the top 50 cm and medium and high salinities at lower depths. Salinity increases with depth in Pedons P3, P4 and P5.

Calcium in the saturation extract ranges from 0.09 to 1.13 meq/100 g while magnesium ranges from 0.04 to 1.2 meq/100 g and sodium from 0.02 to 3.25 meq/100 g in the profiles of all five pedons. Pedon P5 has higher values of both calcium and magnesium than the other pedons (Table 4). Significant increases of sodium levels occur in Pedon P3 below 85 cm, below 90 cm in Pedon P4 and below 140 cm in Pedon P5.

The values determined for soluble calcium, magnesium and sodium in this study fall within the ranges found in the Goluen soil type (FAO, 1968), however some of Goluen profiles have higher values.

Sodium adsorption ratio (SAR) values indicate no sodium hazard in Pedons P1, P2 and P5 throughout the profile. In Pedon P3 there is no sodium hazard in the upper 85 cm. Below this depth the pedon has low to medium sodium hazard. Pedon P4 has no sodium in the upper 90 cm and low hazard below that. The SAR tends to increase with increase in total salts. Previous CARS samples show no sodium hazard throughout the profile (CAR, 1964). The Goluen soil type has mostly no sodium hazard but occasionally it has low levels (FAO, 1968).

Calcium carbonate equivalent ranges from 10 to 32% for all pedons and horizons. There is some increase in total carbonates in

the lower horizons of Pedons P1 and P3. In Pedon 5 carbonate levels are nearly constant throughout the profile. Carbonate levels in earlier studies are generally similar (FAO, 1968; FAO, 1969).

Saturation percent (SP) results seem somewhat low especially for fine textured soils. The soils in this study have SP values of 40 to 50%. Saturation percent values for the Goluen soil type (FAO, 1968) are higher with a range of 42 to 86%.

Separate determinations of total salinity were made on a 100 meter grid sampling over the developed area. The results are summarized in Table 5.

Table 5: Summary of Soil Salinity Analysis Results of CARS Developed Area

Depth in Profile	No. of Samples	E.C. mmhos/cm	
		Range	Mean
Surface 50 cm	108	0.45-5.0	1.65
All horizons in upper meter	186	0.45-10.0	2.26
All horizons in lower meter	101	0.70-16.0	4.61

In the upper meter electrical conductivity readings were less than 4.00 mmhos/cm in 84% of the samples. Fourteen percent of the samples had E.C.s of 4.0-8.0 and about 2% had E.C.'s ranging from 8.1 to 10.0 mmhos/cm. In the lower meter 59% of the samples had E.C.'s less than 4 mmhos/cm, 22% had E.C.'s of 4 to 8 mmhos/cm and 19% ranged from 8.1 to 16.0 mmhos/cm. Salinity increases with depth. Lateral distribution of salinity levels in the upper meter of the fine and very fine soils is scattered with no distribution pattern

which could be mapped. The fine loamy soils, however, have medium salinity levels in the upper meter.

Early CARS samples (CARS, 1964) show little salinity throughout the profile and an increase of salt content with depth. Salinity data on the Goluen soil type (FAO, 1968) is very similar to the findings of this study. Previous salinity data is given in Table 6.

Table 6: Summary of Previous Salinity Data on CARS and the Surrounding Area

Source of Data	Depth in Profile	No. of Samples	E.C. (mmhos/cm)	
			Range	Mean
CARS, 1964	Whole Profile	13	0.9-5.8	2.5
FAO, 1968	Upper 50 cm	20	0.8-4.2	1.58
FAO, 1968	Upper meter	33	0.8-8.0	2.47
FAO, 1968	Lower meter	18	3.0-12.0	6.1

Because of the sampling procedure levels of salinity could not be summarized for different depths in the CARS 1964 data.

Classification of Soils

Classification According to the U.S. Soil Taxonomy System

Morphologically pedons P1, P2, P3 and P4 fall into the order of Vertisols. They satisfy the requirements for the order with respect to clay content, cracks and slickensides. All four pedons fall into the suborder Usterts. Suborder requirements with respect to duration and frequency of crack openings are satisfied. Mean annual

soil temperature is above 22°C and varies by less than 5°C adding another characteristic of the suborder. With respect to color all pedons have moist chromas greater than 1.5. This puts all four pedons in the great group chromusterts. All four pedons fall into the subgroup udic chromusterts. Color values, structure and period of crumb openings limits are satisfied for the subgroup.

At the family level particle size class differences occur between the udic chromusterts. Pedons P1, P2 and P3 have more than 60% clay in the control section. Therefore, they have a very fine particle size class. Pedon P4 has 44-50% clay and therefore has a fine particle size class.

No mineralogical determinations were made on these soils. From the high shrink-swell displayed by these vertisols the mineralogy is most likely montmorillonitic.

Pedon P5 does not have the morphological characteristics which put the four pedons into the order of vertisols. It does not have any diagnostic horizons other than an ochric epipedon. Therefore P5 is an entisol. Profile characteristics show that the pedon is an orthent. Even though its soil moisture is ustic, the profile has electrical conductivities greater than 2 mmhos/cm. This puts it in the great group of Torriorthents. Morphological characteristics, moisture regime and the iso temperature regime puts this pedon into the subgroup Ustic Torriorthents. This is the nearest subgroup for this pedon. Ustic Torriorthents must have an aridic moisture regime that borders on an ustic regime but pedon P5 has an ustic moisture regime. The particle size class is fine loamy.

All five pedons have an isohyperthermic temperature regime.

Soil Classification According to the FAO/UNESCO System

Both in morphology and clay content pedons P1, P2, P3 and P4 are Vertisols. All four pedons have moist color chromas greater than 1.5 therefore they are chromic Vertisols. Pedon P5 classifies as a calcaric fluvisol.

A summary of soil classification of pedons described is given below:

<u>Pedon</u>	<u>U.S. Soil Taxonomy Classification System</u>	<u>FAO/UNESCO Classification System</u>
P1, P2 P3	Udic chromusterts, very fine, isohyperthermic	Chromic Vertisols
P4	Udic chromustert, fine, isohyperthermic	Chromic Vertisol
P5	Ustic Torriorthent, fine loamy, isohyperthermic	Calcaric Fluvisol

It is considered unwise at this stage to carry the classification down to the series level because of the relatively small area (400 ha) involved in the present study. Classification at the series level should be done after further studies are made outside the station.

CCTA (1963) mapped the soils of the area as Vertisols of Topographic Depressions. The vertisols identified here would meet the general criteria defined in the classification for vertisols of topographic depressions. In the soil map of the world (FAO/UNESCO, 1973) the area has been mapped as chromic vertisols with eutric fluvisols and pellic vertisols as minor associated soils. At CARS Chromic Vertisols cover the main portion of the area. Calcaric rather than eutric fluvisols have been identified in this study as the minor associated soils. The soils identified in Balad and Mordile (FAO,

1969) include udic chromusterts which have also been identified at CARS in this study but the other soils classified in these areas are not similar to those of CARS.

Pedons described for the Goluen soil type (FAO, 1968) have morphological, chemical and physical characteristics similar to the vertisols described in this study. Of the three pedons described two are described sufficiently for comparison. These two pedons differ from the udic chromusterts described in this study mainly in moist color value which is greater than 3.5. This would put them into the subgroup udorthentic chromusterts. This is not surprising because the Goluen soil type has been mapped over 237,500 hectares in the surrounding area and therefore probably has quite a number of vertisol subgroups in it.

Landform Soil Type Relations

Soils identified on the flood plain meander landform are primarily Udic Chromusterts while those on the flood plain channel remnant landform are primarily Ustic Torriorthents.

Soil Maps

Figures 12 and 13 are the soil maps for developed areas and for the entire CARS land respectively. Mapping units and map symbols are explained below:

<u>Mapping Unit</u>	<u>Map Symbol</u>	<u>Soils</u>
Mapping Unit 1	MU1	Udic chromusterts, very fine, which are typified by pedons P1, P2 and P3. Minor inclusions are udic chromusterts, fine.
Mapping Unit 2	MU2	Udic chromusterts, fine, which are typified by pedon P4. Minor inclusions

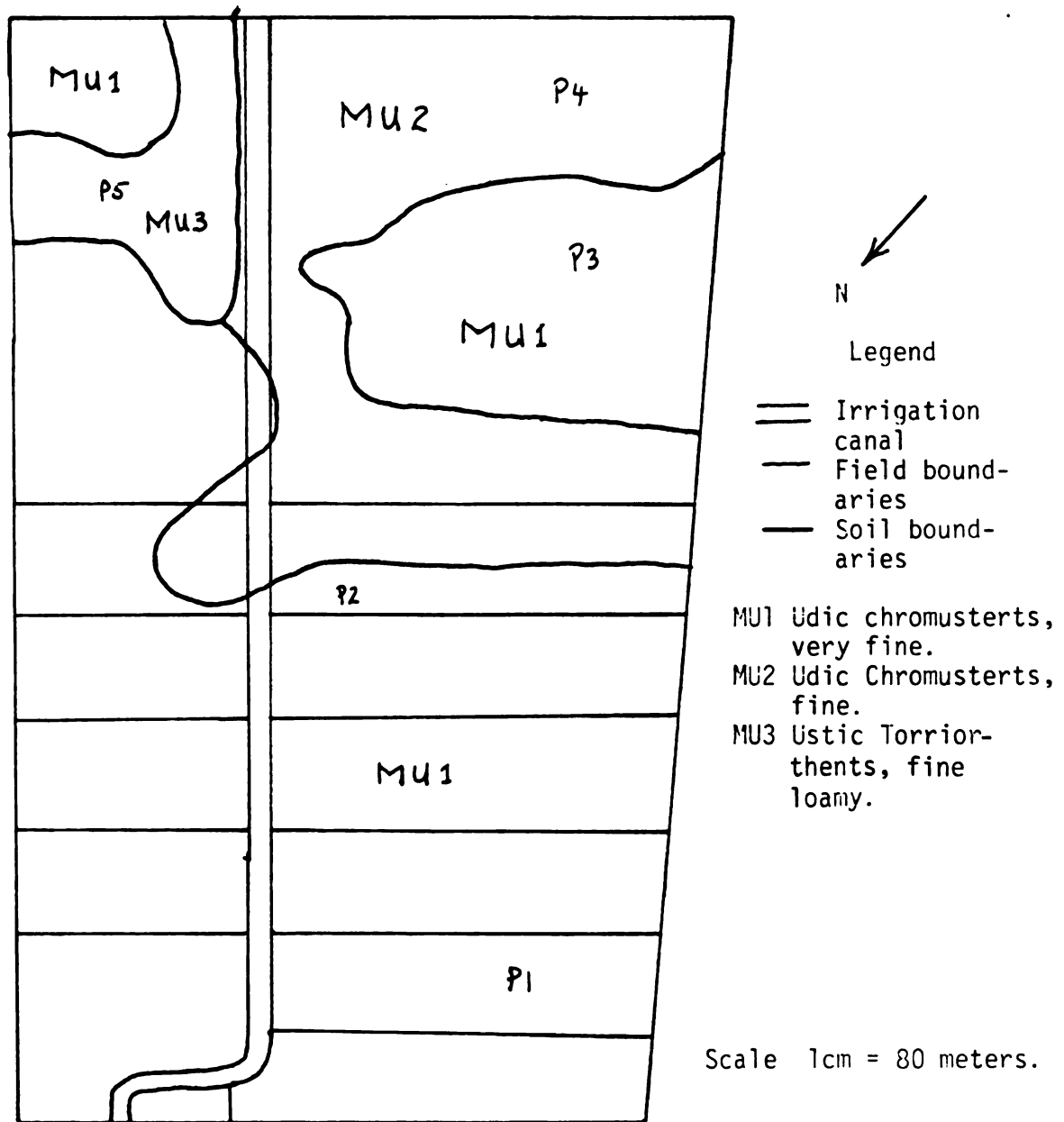


Figure 12. Soil Map of CARS developed area. Locations of Representative Pedons are indicated by P1, P2, P3, P4 and P5.

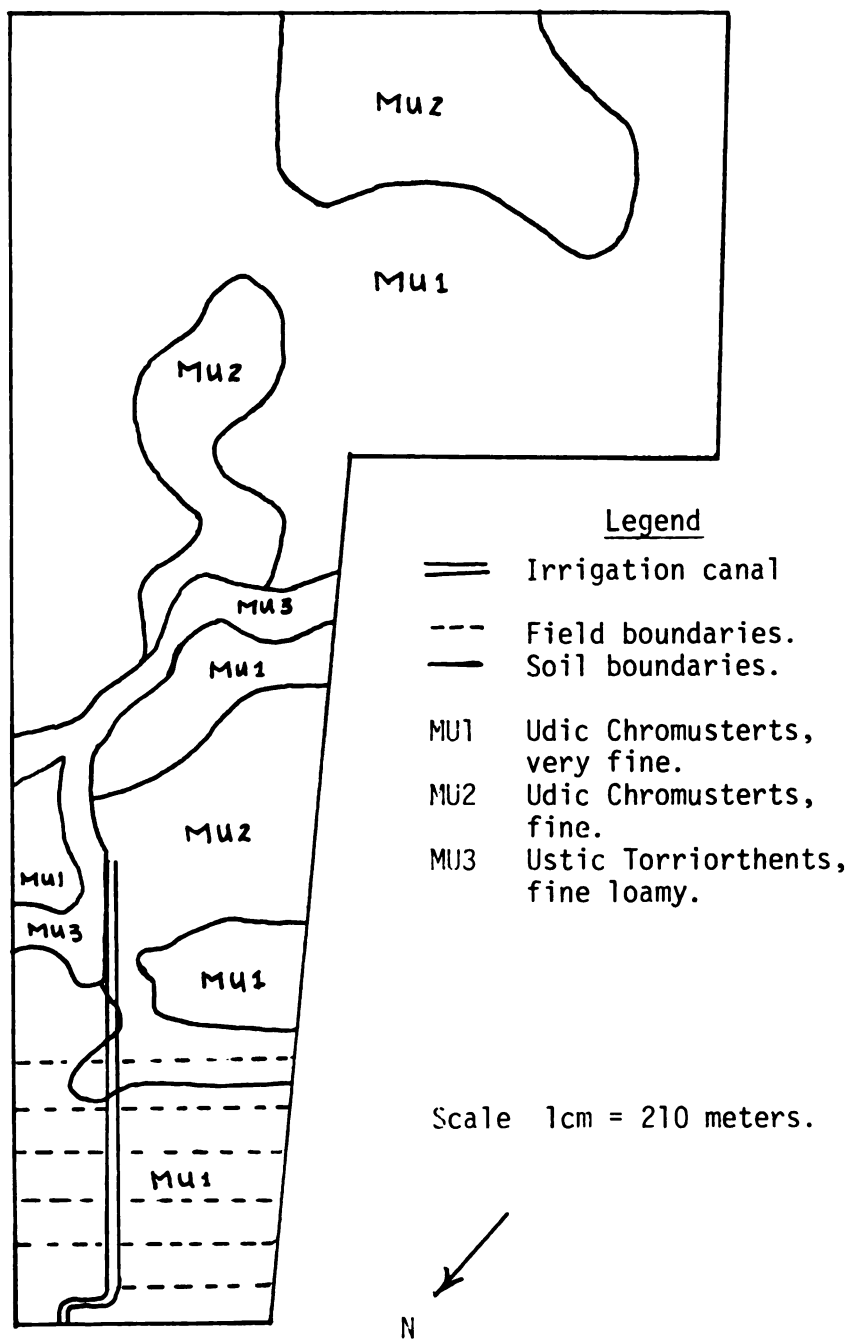


Figure 13. Soil map of CARS.

<u>Mapping Unit</u>	<u>Map Symbol</u>	<u>Soils</u>
Mapping Unit 2	MU2	are udic chromusterts, very fine, typic ustorthents coarse loamy over clayey and ustic torriorthents, fine loamy.
Mapping Unit 3	MU3	Ustic Torriorthents, fine loamy which are typified by pedon P5. Minor inclusions are typic ustorthents, coarse loamy over clayey.

SUMMARY AND CONCLUSIONS

Two subgroups of soils have been identified at CARS. Udic chromusterts compose the major part of the CARS area. A small part is composed of Ustic Torriorthents. At the family level the Udic Chromusterts are either very fine or fine. The Ustic Torriorthents are fine loamy.

The very fine Udic chromusterts are heavy clay with clay percentages of 69 to 72% and are underlain either by very fine material or loamy material. The fine Udic chromusterts have clay contents of 44 to 50%. The Ustic Torriorthents are fine loamy underlain by stratifications of coarse and fine loamy materials. Clay content in the top soil is around 32%.

All the soils are calcareous in all depths. Soil reaction is slightly to moderately alkaline with pH ranges mostly between 7.6 and 7.9.

Salinity levels in the vertisols vary. In general there is no salinity in the upper meter of the profile and mostly no salinity or medium salinity in the lower meter. The Ustic Torriorthents have low salinity in the surface layer and medium to high salinity in lower horizons. Where salt content is appreciable salinity increases with depth.

The soils of CARS have no sodium hazard in the upper meter of the profile and either no sodium hazard or low to medium hazard in

lower layers. In general there is no salinity or alkali problem in these soils.

Permeability varies from moderately slow to good for all soils. Even though high clay contents are common in these soils permeability is not a limiting factor.

Large tracts of homogeneous soils are plentiful ruling out problems with field layout of experiments due to soil differences.

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APPENDIX

APPENDIX

Representative pedons of inclusions are described below:

Pedon No. 6 (P6)

Location: Field 12

Date: Feb., 1978

Topography: Level, slope < 1%

Land use: cropland, irrigated, ploughed at the
time of survey

- Ap 0-25 cm: Light yellowish (10YR 6/4) dry. Brown to dark brown (7.5YR 4/4) moist. Loam. Structureless. Slightly hard, friable, slightly sticky, slightly plastic. Few fine and very fine roots. Violent reaction to 10% HCl. Moderately alkaline. Abrupt smooth boundary.
- C1 25-56 cm: Very pale brown (10YR 7/3) dry. Yellowish brown (10 YR 5/4) moist. Distinct common strong brown mottles (7.5YR 5/8). Sandy loam. Structureless. Soft, very friable, slightly sticky, nonplastic. Common very fine roots. Few tubular medium pores. Strong reaction to 10% HCl. Moderately alkaline. Abrupt smooth boundary.
- C2 56-65 cm: Dark brown (7.5YR 3/2) moist. Sandy clay loam. Strong very fine angular blocky structure. Hard, firm, slightly sticky, slightly plastic. Few fine and very fine roots. Strong reaction to 10% HCl. Moderately alkaline. Abrupt smooth boundary.

C3 65-75 cm: Brown to dark brown (7.5YR 4/4) moist. Sandy loam.

Structureless. Soft very friable, slightly sticky non-plastic. Strong reaction to 10% HCl. Abrupt smooth boundary.

C4 75-90 cm: Very pale brown (7.5YR 7/4) dry. Brown to dark brown (7.5YR 4/4) moist. Sandy loam to sandy clay loam. Structureless. Soft friable, slightly sticky, slightly plastic. Few very fine roots. Common hard clay and mineral concretions. Common snail shells. Strong reaction to HCl. Moderately alkaline. Abrupt smooth boundary.

C5 90-135 cm: Brown to dark brown (7.5YR 4/2) moist. Clay. Fine to medium subangular blocky structure. Hard, firm, slightly sticky, plastic. Few fine and very fine roots. Strong reaction to 10% HCl. Abrupt smooth boundary.

C6 135-200 cm: Stratified silt loam/clay/sandy loam.

Classification

U.S. Soil Taxonomy System Typic ustorthent, coarse loamy over clayey, Isohyperthermic.

FAO/UNESCO System Calcaric fluvisol.

Pedon No. 7 (P7)

Location: Field 16

Date: Feb., 1978

Topography: Level, slope < 1%

Land use: Rainfed cropping

Surface features: soft crust.

Ap 0-25 cm: Brown (7.5YR 5/4) dry. Brown to dark brown (7.5YR 4/4) moist. Clay loam. Weak very coarse granular structure. Slightly hard, firm, slightly plastic. Common fine and very fine roots. Few fine pores. Few fine calcareous concretions.

Violent reaction to 10% HCl. Slightly alkaline. Abrupt wavy boundary.

C1 25-70 cm: Yellowish brown (10YR 7/4) dry. Very pale brown (10YR 5/4) moist. Loam. Structureless. Few fine and very fine roots. Strong reaction to 10% HCl. Slightly alkaline. Abrupt smooth boundary.

C2 70-130 cm: Brown to dark brown (7.5YR 4/2) moist. Clay. Strong fine subangular blocky structure. Hard, very firm, slightly sticky, plastic. Few very fine roots. Common white powdery salts on peds. Few fine horizontal pores. Violent reaction to HCl. Slightly alkaline. Abrupt smooth boundary.

170 cm +: Structureless brown sandy loam.

Classification

U.S. Soil Taxonomy System

Typic ustorthent, coarse loamy over clayey, Isohyperthermic.

FAO/UNESCO System

Calcaric fluvisol.

Table 7: Results of Laboratory Analysis for Pedons 6 and 7

pH	Saturation Extract				SAR	CaCO ₃ Equiv. %	SP** %
	EC mmhos/cm	Ca meq/100g	Mg meq/100g	Na meq/100g			
<u>Pedon 6</u>							
8.1	0.45	0.06	0.03	0.54	1.4	20	32
8.0	1.11	0.13	0.06	0.12	2.2	13	32
7.9	0.75	0.12	0.08	0.09	1.4	11	40
8.0	1.1	0.13	0.08	0.08	1.5	19	32
7.9	0.9	0.09	0.08	0.11	2.2	20	32
7.9	0.7	0.14	0.08	0.12	1.6	11	48
7.9	0.9	0.12	0.08	0.14	2.2	--	40
<u>Pedon 7</u>							
7.6	0.6	0.12	0.40	0.10	2.1	10	40
7.8	1.5	0.19	0.14	0.37	4.2	28	48
7.5	4.8	0.68	0.26	1.81	11.6	20	52

Table 7: (Continued)

Particle Size Analysis				Hydraulic Conductivity cm/hr
% Sand	% Silt	% Clay	Class*	
<u>Pedon 6</u>				
46	32	22	L	2.45
68	24	8	Sa1	3.83
69	10	21	Sa C1 1	3.92
52	47	1	Sa1	--
76	4	20	Sa1/Sa C1 1	4.24
27	19	54	C	--
46	36	18	1	--
<u>Pedon 7</u>				
26	38	36	C1	1.05
44	40	16	1	0.81
28	28	44	C	0.89

*L - loam, Sa1 - Sandy Loam, Sa Cl 1 - Sandy Clay loam,
C - clay, Cl - Clay Loam.

**Saturation percentage.

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