INSTITUTE OF AGRICULTURAL RESEARCH

A SURVEY OF STUDIES CONDUCTED ABOUT SOIL RESOURCES APPRAISAL AND EVALUATION FOR RURAL DEVELOPMENT IN ETHIOPIA

BY

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Addis Ababa

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# CONTENTS

1. INTRODUCTION ................................................................. 1

2. PHYSICAL CHARACTERISTICS .................................................. 2
   2.1 GEOLOGY .................................................................. 3
   2.2 GEOMORPHOLOGY & HYDROGRAPHY ................................. 4
   2.3 CLIMATE .................................................................. 7
   2.4 VEGETATION ............................................................ 10
   2.5 LAND USE .................................................................. 11

3. SOILS .............................................................................. 12
   3.1 SOILS OF ETHIOPIA ..................................................... 12
   3.2 SOILS STUDIES - COMPLETED OR IN PROGRESS - BY
       CONSULTANTS ............................................................ 16
       3.2.1 The Blue Nile River Basin .................................... 16
       3.2.2 The Awash River Basin ........................................ 20
          322.1 Initial Surveys .................................................. 20
          322.2 Melka Sadi - Ambara ...................................... 23
          322.3 The Lower Awash Plains .................................. 24
          322.4 Tibila ............................................................. 25
          322.5 Ancelele - Bolhano .......................................... 25
       3.2.3 The Wabi Shebelle River Basin ............................... 26
       3.2.4 Setit Humera Soil Study ...................................... 27
       3.2.5 Land Resource Study of the Rift Valley
            Lake Zone ................................................................ 30
            325.1 Gidabe Basin Morpho Pedo Logical
                 Survey ................................................................ 31
            325.2 Chamo-Babya Western Basin Morpho
                 Pedo logical Survey ............................................ 32
            325.6 Tigrai Rural Development Study ....................... 32
            325.7 Gambella Agricultural Development Project ... 33
   3.3 SOIL & EVALUATION STUDIES BY THE INSTITUTE OF
       AGRICULTURAL RESEARCH ............................................. 33
       3.3.1 Detailed Soil Survey of Gode Agricultural
            Research Station - Bale Administrative Region 33
       3.3.2 Detailed Soil Survey of Holetta Agricultural
            Research Station - Shoa Province Administrative
            Region .................................................................. 34
       3.3.3 Detailed Soil Survey of Jimma Agricultural
            Research Station, Kaffa Administrative Region .......... 36
       3.3.4 Detailed Soil Survey of Bako Agricultural
            Research Station, Wollega Administrative
            Region .................................................................. 38
       3.3.5 Land Resource & Evaluation Study of Wollenkomi
            Addis Ababa Region ............................................... 40
       3.3.6 Land Resource & Evaluation Study of Sendafa
            Debre Zeit Region .................................................... 42
   3.4 THE FUTURE OF SOIL SURVEY AND LAND EVALUATION IN
       ETHIOPIA .................................................................. 44

Appendix I - Definition of Diagnostic Horizontal Properties 45
Appendix II - Definition of Soil Units ................................. 59
1. INTRODUCTION

This paper is a revised and updated version of the Ethiopian country report that was prepared jointly by Mr. L.H.J. Octhman and myself for presentation at the first Meeting of the Eastern African Soil Correlation and Land Evaluation which was held from 11 to 16 March 1974 in Nairobi, Kenya.

In Ethiopia, as in most African countries, agriculture is the major economic activity accounting for 55% of the total gross domestic product and more than 90% of the country's exports. Approximately 85% of the population are engaged in subsistence agriculture. The most important cash crop is coffee which contributes 10% to the total agricultural production and 63% to the agricultural exports. Other main agricultural products are cereals (34%), livestock (29%) and oil seeds (5.4%).

Practically all tropical and temperate zone crops can be grown somewhere in the country. The greatest climatic limitation is the amount and distribution of rainfall, both of which are extremely variable from one part of the country to another. Within the constraints imposed by available water, the altitude determines the types of crops grown. The inaccessibility of vast areas limits the possibilities of agricultural development through the introduction of modern technology.

Agricultural research in Ethiopia is very young. Small scale agricultural experiments were initiated by the Ethiopian Government in 1952 with the help of foreign experts. In 1955 an Agricultural Experiment Station was established at Debre Zeit, 50 km S.E. of Addis Ababa. This was incorporated with the College of Agriculture at Alemaya in Harerge Administrative Region when the latter was started a year later. Most of the earlier recent research work was carried out by these two organizations which are still active in this field.

In 1966 the Institute of Agricultural Research (IAR) was set up with UNDP/FAO assistance to conduct and coordinate agricultural research at a national level. At present it runs 7 regional experiment stations, 22 substations and conducts studies at 15 other locations in different agro-ecological regions.

The Soil Survey and Land Evaluation Section of IAR was not established until late in 1971 with the purpose of providing relevant soil and land evaluation data as an aid to agricultural research, agricultural development regional planning, and as well as the conservation of land and water resources. Another task of the section is to assist and advise the Government in the preparation of terms of reference for foreign consultants undertaking soil and land evaluation studies in the country, and ensure a coordinated approach in matters of soil taxonomy and land classification.
Soil Survey and Land Evaluation studies have mostly been undertaken either by foreign technical aid agencies or by private consultants. This is because of the fact that establishment of a soil survey institution and training of staff for the purpose has been a neglected field in the development plans of the country. Even today, eight years after emergence, the unit in the IAR remains very small and has only one qualified person.

Development without the proper knowledge of the available resources is meaningless as it will not have scientific basis. Ethiopia spent millions of Birr for the studies of:
- Blue Nile River Basin
- Awash River Basin
- Wabi Shebelle River Basin
- Rift Valley Lakes Zone
- Setit Humera area
- Tigré Rural Development Project
- Gambella Agricultural Development Project etc.

However, most of these studies are at such a small scale that they are of no practical use for development planning.

An investment worth a fraction of these expenses for the training of the necessary staff could have accumulated the now much wanted land resources information, could have helped develop a system of appraisal and evaluation, could have saved the country a substantial sum of money for other development purposes above all, it could have been self-reliant by now. Contracts with private consultants will undoubtedly continue for some time to come until it is realized by the concerned higher authorities that this approach is very expensive and unreliable, and thereby train staff and establish an appropriate institution.

2. **PHYSICAL CHARACTERISTICS**

2.1 **GEOLOGY**

For the sake of simplicity, Ethiopian geology can be grouped into:
- Precambrian basement complex
- Mesozoic mantle sediments, and
- Cover deposits

The Precambrian basement complex includes various grades and types of dominant schists and gneisses, and to a lesser extent unaltered sedimentary rocks and igneous intrusions. Within these, a tentative separation into an older, more metamorphosed group and a younger, weakly metamorphosed group is sometimes made. Being of Precambrian age, no fossil bearing rock is found in this complex.
<table>
<thead>
<tr>
<th>Era</th>
<th>Period</th>
<th>Epoch</th>
<th>Age in millions before present</th>
<th>Distinctive Features of Plant &amp; Animal life</th>
</tr>
</thead>
<tbody>
<tr>
<td>CENOZOIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quaternary</td>
<td>Recent</td>
<td>10,000</td>
<td>Rise of Civilization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pleistocene</td>
<td>1 million</td>
<td>Development of man. Extinction of large mammals.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pliocene</td>
<td>3 million</td>
<td>Early evolution of man. Dominance of elephants, horses, and large carnivores</td>
</tr>
<tr>
<td></td>
<td>Tertiary</td>
<td>Miocene</td>
<td>25 million</td>
<td>Development of whales, bats, monkeys.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oligocene</td>
<td>36 million</td>
<td>Rise of Anthropods</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eocene</td>
<td>58 million</td>
<td>Development of primitive mammals. Rise of grasses, cereals, fruits.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paleocene</td>
<td>53 million</td>
<td>Earliest horses</td>
</tr>
<tr>
<td></td>
<td>Cretaceous</td>
<td>Eocene</td>
<td>50 million</td>
<td>Extinction of dinosaurs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jurassic</td>
<td>135 million</td>
<td>Development of flowering plants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Triassic</td>
<td>180 million</td>
<td>Culmination of dinosaurs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>First birds appear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pennsylvanian</td>
<td>310 million</td>
<td>Widespread forests of coal forming, spore bearing plants. First reptiles, abundant insects.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mississippian</td>
<td>345 million</td>
<td>Spread of sharks. Culmination of crenoids.</td>
</tr>
<tr>
<td></td>
<td>Devonian</td>
<td>Silurian</td>
<td>405 million</td>
<td>First amphibians. Many corals. Earliest forests spread over lands</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ordovician</td>
<td>423 million</td>
<td>First land plants and air breathing animals. Development of fishes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cambrian</td>
<td>500 million</td>
<td>Life only in seas. Spread of mollusks. Culmination of trilobites.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Precambrian</td>
<td>600 million</td>
<td>Trilobites predominant. Many marine Invertebrates.</td>
</tr>
</tbody>
</table>

**Source:** After A.N. Strabler (1960), Physical Geography, John Wiley and Sons, New York.
It is intensively foliated, faulted and peneplained to a level surface. On this surface Mesozoic rocks lie unconformably. Characteristically, rocks of Paleozoic age are not found in Ethiopia.

The Mesozoic mantle sediments are rocks deposited during a transgression in the upper Triassic to upper Jurassic when the sea engulfed the country from the south-east the sequence being Adigrat sandstone, shale, gypsum and Antalo limestone. The regression during the upper Jurassic to Cretaceous produced Antale limestone, gypsum, shale and upper sandstone.

The up-swell of the Arab-Ethiopian Massif during Eocene to early Oligocene was followed by enormous out-pourings of flood basalts and faulting of the Rift System started in Oligocene. This flood basalt rests on the Mesozoic sediments and now forms the Ethiopian plateau surfaces including the floors of the Rift System. It is referred to as the Trap Series. As rifting continued in Miocene, Pliocene and again renewed in Quarternary, continuing till the present, volcanism accompanied it and the basic lavas that emanated from the Rift-centered volcanoes are referred to as the Aden Series. With the exception of the few very locally occurring superficial deposits including aeolian, fluviatile, lacustrine, glacial and galciofluvial sediments, the present surface of the country consists largely of rocks of Aden and Trap Series in which basalt and its associates, including trachyte, are dominant.

The Precambrian basement complex remnants are exposed in the northern, western and southern parts of the country, along the plateau fringes. The Mesozoic cover deposits are found in the south-east, while the flood basalts occur on the Central Highlands and in the Rift System.

2.2 GEOMORPHOLOGY AND HYDROGRAPHY

The geomorphology of Ethiopia is intimately related to its underlying geology. Except where deeply dissected by subsequent denudation and apart from the volcanic piles of the Trap Series, The Ethiopian plateau shows a flat horizontal surface which expresses the presence of a peneplained Precambrian rock basement.

The Rift System divides the uplifted Ethiopian Massif into two units, the Western Plateau and the Eastern Plateau (Fig. 2.1). The former includes all the highlands between the Rift scarps in the east and the Sudan border scarps in the west. On both sides, this plateau has been subject to erosional recession starting from the original tectonic scarps. Except for the major river valleys, the whole of this region lies above 1000 m. and about half of it reaches altitudes above 2000 m. The very great elevations of the Western Plateau above sea level induced deep canyon carving by the rivers through the sub-horizontal strata which are now strongly dissected. Many of the greatest
heights of this plateau occur along the scarp facing the Rift System, although there are also a few in the interior, such as the Semien Mountains. The Semien massif is a Hawaiian type volcanic pile now bounded by gigantic erosional precipices on almost all sides. Within this massif the highest peak in the country Ras Dashan 4520 m, is found.

The rivers on the Western Plateau generally flow westwards, most of them tectonically controlled. The dip of the strata, being only 1° or less towards the Sudan, is not the major factor. Major rivers from north to south are:

- Anseba and Barka: flowing into the Red Sea
- Nereb, Tekeze, Atbara, Abai (Blue Nile), Baro and Akobo: joining the Nile.
- Omo: flowing into Lake Rudolf

The Eastern Plateau shows a much more appreciable tilt towards the south-east and the dip of the strata is clearly reflected in the physiography. It has no clearly defined margin to the southeast but slopes gradually through Somalia and beneath the Indian Ocean. The main summits again lie close to the Rift scarp and are composed of Trap Series lavas with altitudes of over 2000 m. The rivers on this plateau have been influenced by the south-easterly surface dip but canyons, so characteristic of the Western Plateau are only found close to the Rift scarp. Further down-stream all the rivers flow sluggishly in shallow U-shaped valleys across the featureless, flat desert plateau towards the Indian Ocean.

Separating the aforementioned two plateaux, a relatively sunken, faulted, complex Rift Valley runs generally SSW - NNE from Lake Rudolf to the Red Sea. The Ethiopian Rift floor, characterised by several lake basins, rises irregularly from less than 400 m around Lake Rudolf basin to over 1800 m, north of Lake Zwai, and descends northwards in a much more regular fashion. It finally falls below sea level before reaching the Red Sea coast.

While the large scale geomorphology of Ethiopia is dominated by tectonics, such factors as denudation by rivers, volcanic structures, lava flows, etc., are important, though on a smaller scale.

Exposures of the Precambrian schists and gneisses of the paleozoic peneplain in the north, west and south form smoothly undulating countrysides. The gigantic intrusions of siliceous rocks into these are more resistant and hence appear as sharply up-standing inselbergs.
The Mesozoic sandstones and limestones give rise to flat plains, except where affected by denudation, resulting in the formation of steep cliffs. Caves and pot-holes develop in limestone and gypsum, though vegetation is sparse on gypsum.

The Tertiary basalts of the Highlands are generally characterised by a rugged topography leading into plains that extend from them.

2.3 CLIMATE

In Ethiopia areas between 1300 m and 2100 m have temperate climate with maximum temperatures rarely rising above 25-28°C. However, temperatures over the country, where altitudes vary greatly, have a very wide range, and do not always coincide with the rainfall regions (Fig. 2.2 and 2.3). At and above these altitudes, the daily maxima & minima in periods of clear weather, may differ by as much as 22°C or more, while during the rains this range may be as low as 6°C. In most years night frosts occur between November and February at altitudes above 1300-2100 m. Frosts coincide with a low relative humidity of 20-30%. Hail may also occur, sometimes even at 1000 m.

When the Central Highlands are generally cool and daily averages less than 16°C, the border areas on all sides are warm to hot, particularly at the Red Sea coast which is also very humid.
Between October and May dry conditions prevail in most of the country due to the strong influences of two anticyclones centered one over the Sudan and the other over Arabia, both of which send dry subsiding air currents over Ethiopia. Between late June and early October these high pressure centers are replaced by cyclonic circulations. During this period two warm, moist currents move over Ethiopia; the south-westerlies from the South Atlantic coming over the humid Congo basin; and the southeasterlies from the Indian Ocean. Upon ascending the Ethiopian plateau both of these moisture laden currents yield the "Big Rains". Between October and May, occasional cold bursts from northern latitudes, penetrate south-wards and coupled with the Inter-tropical Convergence Zone's normal migration produce the "Small Rains". Over the central Highlands those rains are not very reliable but are quite consistent in the southwestern part of the country. This being the overall pattern, actual conditions depend largely on the latitude, longitude and altitude of the place in question, and local topography contributes its own effect.

2.4 VEGETATION

Marked climatic and topographic differences exist in Ethiopia and the vegetation associations follow suit. Heavy deforestation, intensive cultivation and expanding Eucalyptus plantations have left little of the original aspects of the highlands. At present the vegetation varies from scarce desert shrubs to alpine plant association as shown in the following grouping:

The coastal and desert vegetation of the Red Sea coast area reflects a high salt concentration in the soil; the Danakil Depression is roughly similar.

The sub-desert steppe includes the areas of the northwestern, northeastern and southeastern border regions with herbs, grasses and shrubs.

The tree and shrub steppe of the southeast, south, the Rift Valley, Kobar basin, the northwest and the eastern lower slopes are characterized by semi-arid trees and grasses.

The Savannas cover a great part of northern Ethiopia, the northern, western and southeastern slopes of the Central Highlands and the alluvial plains around Lake Tana. In the degraded savanna in the north resulting from deforestation, extensive cultivation and over-grazing, only a sparse cover of grasses and trees is found.

The woodlands from which the evergreen thickets of the eastern Central Highlands are derived represent a typical slope vegetation of fairly dense grasses and shrubs. The mountain grasslands, also derived from the woodlands, vary in appearance from treeless, open undulating country to scattered tree savanna. They are dominated by a herbaceous vegetation with scattered trees.
The swamp and riparian formations include such vegetation as is normally associated with rivers, lakes and swamps.

2.5 LAND USE

The highlands with their temperate climate contain the bulk of arable and pasture lands which are cropped once or twice a year. In the extensive Central Highlands, however, there are small areas which allow crop growth all year round. The cultivated crops include cereals, oilseeds, pulses, 'enset' (false banana) and coffee. In the lower warmer regions sorghum, cotton, groundnut, sugar cane, etc. become more prevalent. (Table 2.1)

Table 2.1 CROPPING OF CULTIVABLE LAND IN ETHIOPIA AFTER WUNDERLICH AS QUOTED BY HUFFMACEL (1961)

<table>
<thead>
<tr>
<th>Type of Land</th>
<th>Km²</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural land cropped</td>
<td>95,000</td>
<td>8.1</td>
</tr>
<tr>
<td>Coffee forests</td>
<td>5,000</td>
<td>0.6</td>
</tr>
<tr>
<td>Grazing grounds</td>
<td>330,000</td>
<td>28.0</td>
</tr>
<tr>
<td>Closed forest</td>
<td>40,000</td>
<td>3.4</td>
</tr>
<tr>
<td>Open woodland</td>
<td>34,000</td>
<td>2.9</td>
</tr>
<tr>
<td>Open brush &amp; scrub</td>
<td>295,000</td>
<td>25.0</td>
</tr>
<tr>
<td>Deserts</td>
<td>370,000</td>
<td>31.0</td>
</tr>
<tr>
<td>Lakes &amp; Rivers</td>
<td>11,000</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,180,000</td>
<td>100.0</td>
</tr>
</tbody>
</table>
3.1 SOILS OF ETHIOPIA

The first attempt to map the soils of Ethiopia in a very general manner was made by Shantz and Marbut in 1923 at a scale of 1:25 million, as part of their publication "The Vegetation and Soils of Africa", in which they differentiated Chernozems, Tropical Prairie Soils, Laterites and other Red Tropical soils. In 1964 D’Hoore published a soil map of Africa at a scale of 1:5 million in which he mapped 10 major groups/associations in Ethiopia. A few generalized, small scale maps which included Ethiopia, were also produced by various authors and organisations.

The most recent map is the "Soil Map of Africa" produced by the UNESCO/FAO "Soil Map of the World" project at a scale of 1:5 million. Though this map contains a considerable amount of detail, it has some inaccuracies as there is very little factual information available to support it. However, since it applies the recent UNESCO/FAO Soil Classification, the Institute of Agricultural Research decided to use it as a base map on which further improvements and corrections can be made to produce a generalised soil map of Ethiopia. For this purpose the section of the map which covers Ethiopia has been enlarged to a scale of 1:2 million, superimposed on a topographic base (Fig 3.1).

This map distinguishes 13 major groups of soil associations and an area of salt flats (Table 3.1). Here only the most relevant mapping units will be discussed.

On the Western Plateau, with altitudes above 1000 meters, vast areas of soil associations in which Cambisols are dominant, occur. In the western section of this plateau they are largely Humic Cambisols associated with Acrisols, whereas northwards they are mostly Eutric Cambisols associated with Luvisols. The rainfall pattern (Fig. 2.3) appears to be largely responsible for this trend; the high rainfall in the west decreases northwards. As most of the lands are subject to appreciable erosion, the Cambisols occur in all those areas where the A horizon is possible eroded, leaving a cambio B at the surface. Truncated soils are very common in the Ethiopian Highlands and consequently from the large areas of Nitosols shown on the map one gets the impression that their extent may be exaggerated, for there is not sufficient evidence yet of the presence of an argillic B. Therefore in many places on the plateau, the Nitosols may be Cambisols as well.

The Xerosols and Xermosols are common on and along the semi-arid to xeric fringes of both the Eastern and Western Plateau, as well as in vast stretches of the Rift Valley. Often they occur side by side with the Vertisols, which are frequently either of a colluvial-alluvial origin or alternatively occur in places where drainage water from adjacent areas passes or accumulates. Vertisols are also observed on the Plateau in areas of impeded drainage.
TENTATIVE
SOIL MAP of ETHIOPIA
Subject to Revision
(For Internal Use Only)
Fig. 3.1

NOTE - This map was reproduced from the tentative SOIL MAP of AFRICA, Soil Map of the World UNESCO/FAO Scale 1:5,000,000, 1971.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Dominant</th>
<th>Associated with</th>
<th>Inclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Acrisols</td>
<td>Cambisols</td>
<td>Fluvisol, Xerosol Solonchaks</td>
</tr>
<tr>
<td>B</td>
<td>Cambisols</td>
<td>Acrisols, Luvisols, Vertisols, Lithosols, Xerosols</td>
<td>Solonchaks</td>
</tr>
<tr>
<td>Fp</td>
<td>Ferasols</td>
<td>Lithosols</td>
<td>Nitosols, Vertisols</td>
</tr>
<tr>
<td>I-R</td>
<td>Lithosols, Regosols</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>Fluvisols</td>
<td>Solonchaks, Regosols, Yermosols, Vertisols</td>
<td>Histosols, Lithosols</td>
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<tr>
<td>N</td>
<td>Nitosols</td>
<td>Vertisols, Cambisols, Andosols</td>
<td>Luvisols, Lithosols</td>
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<tr>
<td>O</td>
<td>Arenosols</td>
<td>Cambisols, Lithosols</td>
<td>Fluvisols</td>
</tr>
<tr>
<td>R</td>
<td>Regosols</td>
<td>Lithosols, Fluvisols, Cambisols, Xerosols, Arenosols</td>
<td>Vertisols, Acrisols Solonchaks</td>
</tr>
<tr>
<td>T0</td>
<td>Andosols</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Vertisols</td>
<td>Xerosols, Solonchaks, Luvisols, Fluvisols, Cambisols, Acrisols</td>
<td>Lithosols, Gleysois, Solonchaks, Histosols</td>
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<tr>
<td>X</td>
<td>Xerosols</td>
<td>Fluvisols, Andosols, Regosols, Vertisols, Lithosols</td>
<td>Solonchaks</td>
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<tr>
<td>Y</td>
<td>Yermosols</td>
<td>Vertisols, Lithosols, Solonchaks, Xerosols</td>
<td>Regosols, Fluvisols</td>
</tr>
<tr>
<td>Zo</td>
<td>Solonchaks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-F</td>
<td>Salt flat</td>
<td></td>
<td></td>
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</tbody>
</table>

Scale 1:10,000,000
Table 3.1 continued

<table>
<thead>
<tr>
<th>Soil Unit</th>
<th>Sub unit</th>
<th>Map Symbol</th>
<th>Area</th>
<th>Hectares</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Km²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andosols</td>
<td>Orthic Andosols</td>
<td>To</td>
<td>9,057</td>
<td>905,700</td>
<td>0.74</td>
</tr>
<tr>
<td>Vertisols</td>
<td>Chromic Vertisols</td>
<td>Vc</td>
<td>37,397</td>
<td>3,739,700</td>
<td>3.06</td>
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<tr>
<td></td>
<td>Pellic Vertisols</td>
<td>Vp</td>
<td>10,362</td>
<td>1,036,200</td>
<td>0.85</td>
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<td>Xerosols</td>
<td>Haplic Xerosols</td>
<td>Xh</td>
<td>92,245</td>
<td>9,224,500</td>
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<td></td>
<td>Calcic Xerosols</td>
<td>Xk</td>
<td>31,277</td>
<td>3,127,700</td>
<td>2.56</td>
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<tr>
<td></td>
<td>Luvic Xerosols</td>
<td>XI</td>
<td>3,124</td>
<td>312,400</td>
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<td>Yermosols</td>
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<td>22,119</td>
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<td>7,637,900</td>
<td>6.25</td>
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<td></td>
<td>Gypseic Yermosols</td>
<td>Yy</td>
<td>18,614</td>
<td>1,861,400</td>
<td>1.52</td>
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<td></td>
<td>Calcic Yermosols</td>
<td>Yk</td>
<td>26,118</td>
<td>2,611,800</td>
<td>2.14</td>
</tr>
<tr>
<td>Solonchaks</td>
<td>Orthic Solonchaks</td>
<td>Zo</td>
<td>2,629</td>
<td>262,900</td>
<td>0.22</td>
</tr>
<tr>
<td>Salt (Plats)</td>
<td></td>
<td>-</td>
<td>3,293</td>
<td>329,300</td>
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<td>Lakes</td>
<td></td>
<td>-</td>
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<td>702,600</td>
<td>0.58</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1,222,453</td>
<td>122,245,300</td>
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<table>
<thead>
<tr>
<th>Soil Units</th>
<th>Sub units</th>
<th>Map Symbol</th>
<th>Area Km²</th>
<th>Area Hectares</th>
<th>%</th>
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<tr>
<td>Acrisols</td>
<td>Ferric Acrisols</td>
<td>AF</td>
<td>34,823</td>
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<td></td>
<td>Orthic Acrisols</td>
<td>Ao</td>
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<td></td>
<td>Dystric Cambisols</td>
<td>Bd</td>
<td>25,906</td>
<td>2,590,600</td>
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<td>Eutric Cambisols</td>
<td>Be</td>
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<td>Humic Cambisols</td>
<td>Bh</td>
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<td>Bk</td>
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<td></td>
<td></td>
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<tr>
<td>Ferralsols</td>
<td>Plinthic Ferralsols</td>
<td>Fp</td>
<td>7,110</td>
<td>711,000</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lithosols</td>
<td></td>
<td>I-C</td>
<td>425</td>
<td>49,500</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Lithosols + Calcari Regosols</td>
<td>I-Ca</td>
<td>325</td>
<td>32,500</td>
<td>0.03</td>
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<tr>
<td></td>
<td>Lithosols + Eutric Regosols</td>
<td>I-Re</td>
<td>85,746</td>
<td>8,574,600</td>
<td>7.02</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluvisols</td>
<td>Calcaric Fluvisols</td>
<td>Jc</td>
<td>11,185</td>
<td>1,118,500</td>
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</tr>
<tr>
<td></td>
<td>Eutric Fluvisols</td>
<td>Je</td>
<td>3,562</td>
<td>356,200</td>
<td>0.29</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitosols</td>
<td>Eutric Nitosols</td>
<td>No</td>
<td>169,443</td>
<td>16,944,300</td>
<td>13.87</td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Arenesols</td>
<td>Cambic-Arenesols</td>
<td>Qc</td>
<td>28,437</td>
<td>2,843,700</td>
<td>2.33</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regosols</td>
<td>Calcaric Regosols</td>
<td>Rc</td>
<td>212,591</td>
<td>21,259,100</td>
<td>17.40</td>
</tr>
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<td></td>
<td>Dystric Regosols</td>
<td>Rd</td>
<td>623</td>
<td>62,300</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Eutric Regosols</td>
<td>Re</td>
<td>67,063</td>
<td>6,706,300</td>
<td>5.43</td>
</tr>
</tbody>
</table>
Finally, the vast areas of Regosols and Lithosols, which may well occupy much vaster areas than actually exhibited on the map at present deserve attention. One has only to appreciate the almost dramatic dimensions of active soil erosion on both the Western and Eastern Plateau, in order to realise that the intricate soil patterns on the steep mountain, hill and valley slopes are largely Regosols and Lithosols. In addition there are other vast areas in southeastern Ethiopia where Calcaric Regosols are particularly common on the late Jurassic limestone formations, where arid conditions prevail at present. These lands are subject to denudation by wind and water. The appreciable extent of Lithosols in central east Ethiopian coincides with the northeastern extension of the Rift Valley towards the Red Sea. This region is largely occupied by exposed basalts, lava flows and related spatter cones of Miocene-Pleistocene age. In most places the surface is just rock with little soil in between.

As regards the soils of the country at large it is evident that no more than a broad picture can be given and even then it is not a very reliable one, because basic data are still lacking. At this juncture it is worth mentioning the work of Murphoy who has made an appreciable contribution in collecting, a nation-wide scale, data on soils situated along the then existing main roads. It can be stated that this is the only inventory of the soils of the country. However, since it is limited only to the road side observations and does not provide information on the extent of these soils it cannot be used for nation wide planning purposes.

3.2 SOIL STUDIES - COMPLETED OR IN PROGRESS - BY CONSULTANTS

Systematic soil survey and land classification studies were not undertaken until the late 1950's.

In all the studies undertaken since then aerial photographs have been used invariably both in pre-field work analysis and interpretation and also during field mapping.

Some 11 major surveys have been conducted in five areas shown in Fig. 3.2. These are discussed in a chronological order in the following sections.

3.2.1 The Blue Nile River Basin

The Blue Nile river basin study, covering an area of 20,400,000 ha, was undertaken between 1958 and 1963 by the Bureau of Reclamation, US Department of Interior. Within this general project the soil study was done between 1958 and 1962. The survey was geared to identify and to classify irrigable areas within the river basin. However, as the basin was too vast for a complete survey within the allotted time, an initial selection based on aerial photo studies and low altitude helicopter flights, was made and this yielded 17 promising areas which were studied at sub-reconnaissance level. (Table 3.2).
ETHIOPIA
LOCATION of SOIL SURVEY & LAND EVALUATION STUDIES
Fig. 3.2
(See legend next page)
ETHIOPIA
LOCATION of SOIL SURVEY & LAND EVALUATION STUDIES
Fig. 3.2
(Cont.)

LEGEND

River basin studies

<table>
<thead>
<tr>
<th>Legend</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>MNDB</td>
<td>Blue Nile river basin: 17 project areas (1:250,000) mapped at approx. 1:100,000 — 1959-62</td>
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<tr>
<td>ARB</td>
<td>Awash river basin: 1:1,000,000,000 — 1961</td>
</tr>
<tr>
<td></td>
<td>General reconnaissance, Middle Valley (MV)</td>
</tr>
<tr>
<td></td>
<td>Lower plains (LP) 1:250,000 — 1961-64</td>
</tr>
<tr>
<td></td>
<td>Semi-detailed, Middle Valley — Lower Plains 1:100,000 — 1961-64</td>
</tr>
<tr>
<td></td>
<td>Detailed 1:20,000</td>
</tr>
<tr>
<td></td>
<td>a. Melka Sadi-Ambar — 1968-69</td>
</tr>
<tr>
<td></td>
<td>b. Lower Plains — 1972-73</td>
</tr>
<tr>
<td></td>
<td>c. Tiffila — 1972-73</td>
</tr>
<tr>
<td></td>
<td>d. Añgelito — Bathama — 1973-74</td>
</tr>
<tr>
<td>WSRB</td>
<td>Wabi Shebeta river basin: exploratory survey 1:1,000,000 — 1969</td>
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<tr>
<td></td>
<td>Semi-detailed Lower Valley 1:50,000 — 1969-70</td>
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</table>

Other studies

<table>
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<th>Description</th>
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<tbody>
<tr>
<td>SH</td>
<td>Setit Humera: Semi-detailed 1:100,000 — 1972-73</td>
</tr>
<tr>
<td>RVLZ</td>
<td>Rift Valley Lakes Zone land resource study 1:500,000 — 1973</td>
</tr>
<tr>
<td></td>
<td>Ghano — Abaya</td>
</tr>
<tr>
<td></td>
<td>Gidado</td>
</tr>
<tr>
<td></td>
<td>Gambella</td>
</tr>
<tr>
<td></td>
<td>Tigrai</td>
</tr>
<tr>
<td>IAR</td>
<td>Wellenkom — Addis Ababa (IAR) land resource study 1:100,000 — 1973</td>
</tr>
<tr>
<td>IAR 2</td>
<td>Sendago — Debre Zeit (IAR) land resource study 1:50,000 — 1974</td>
</tr>
</tbody>
</table>

Holetto Agricultural Research station (IAR) detailed survey 1:5,000 — 1973

Gode Agricultural Research station (IAR) detailed survey 1:10,000 — 1973

Jimma Agricultural Research Station (IAR) detailed survey 1:2,500

Bako Agricultural Research Station (IAR) detailed survey 1:5,000
Within the 17 selected areas only lands suitable for irrigation were mapped according to the U.S.B.R. standards, thus:

Class 1: arable, highly suitable for irrigation
Already under irrigation 136,353 ha
20,069 ha

Class 2: arable, moderately suitable for irrigation, but all well adapted to it. 355,398 ha

Class 3: arable, marginally suitable for irrigation, but least desirable for it. 595,160 ha

Total 1,106,880 ha

The study in the rest of the areas was only of a cursory nature that practically no information was gathered to allow any meaningful conclusion. Hence these areas were left unclassified.

Breadly, two groups of soils were identified in the basin:

Latesols:

These are:

- Best for irrigation, but difficult to develop because of the steep, rolling topography on which they occur.

- Clay textured with permeability and friability similar to the medium textured soils.

Table 3.2 BLUE NILE SURVEY

Details of 17 areas studied

<table>
<thead>
<tr>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Under irrigation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ha</td>
<td>ha</td>
<td>ha</td>
<td>ha</td>
<td>ha</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Angar</td>
<td>1,450</td>
<td>24,910</td>
<td>19,900</td>
<td>56,260</td>
</tr>
<tr>
<td>Arjo</td>
<td>80</td>
<td>22,735</td>
<td></td>
<td>22,815</td>
</tr>
<tr>
<td>Azona-Fettam</td>
<td>44,666</td>
<td>49,830</td>
<td>19,113</td>
<td>130,490</td>
</tr>
<tr>
<td>Beles</td>
<td>5,700</td>
<td>35,000</td>
<td>67,200</td>
<td>107,900</td>
</tr>
<tr>
<td>Birr</td>
<td>22,767</td>
<td>8,577</td>
<td>36,240</td>
<td>69,772</td>
</tr>
<tr>
<td>Cheye</td>
<td>3,400</td>
<td></td>
<td></td>
<td>3,400</td>
</tr>
<tr>
<td>Debana</td>
<td>7,050</td>
<td>2,110</td>
<td></td>
<td>9,160</td>
</tr>
<tr>
<td>Dabus</td>
<td>1,380</td>
<td>16,420</td>
<td>12,200</td>
<td>30,000</td>
</tr>
<tr>
<td>Diddessa</td>
<td>12,360</td>
<td>8,665</td>
<td></td>
<td>22,025</td>
</tr>
<tr>
<td>Dinder-Rahad</td>
<td>31,500</td>
<td>127,000</td>
<td>228,500</td>
<td></td>
</tr>
<tr>
<td>Finchaa</td>
<td>22,921</td>
<td>11,262</td>
<td></td>
<td>34,183</td>
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<tr>
<td>Lake Tana</td>
<td>58,030</td>
<td>67,020</td>
<td>160,560</td>
<td>285,620</td>
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<tr>
<td>Nekomte</td>
<td>7,025</td>
<td>11,510</td>
<td></td>
<td>18,535</td>
</tr>
<tr>
<td>Upper Diddessa</td>
<td>1,560</td>
<td>4,800</td>
<td></td>
<td>6,360</td>
</tr>
<tr>
<td>Upper Guder</td>
<td>2,110</td>
<td>27,980</td>
<td>30,090</td>
<td></td>
</tr>
<tr>
<td>Upper Mugar</td>
<td>250</td>
<td>8,450</td>
<td>8,740</td>
<td></td>
</tr>
<tr>
<td>Wama</td>
<td>23,665</td>
<td>19,465</td>
<td></td>
<td>43,130</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>116,353</td>
<td>355,398</td>
<td>595,160</td>
<td>1,106,980</td>
</tr>
</tbody>
</table>

======================================================================================================
- Suitable for a wide range of crops and easy to farm because of good permeability and drainage characteristics.

- Of low natural fertility but respond well to fertilizers.

Grumusols (Vertisols):

- Usually occur on smooth topography, are fairly easy to develop for irrigation but difficult to manage.

- Severely cracking clay with very slow permeability; irrigation must wet the soil laterally after water fills the cracks rather than by normal infiltration.

- High in fertility but machinery is desirable for better exploitation of their potential.

### 3.2.2 The Awash River Basin

#### 3.2.2.1 Initial Surveys

The Awash basin, in contrast to most of the other major catchments in Ethiopia, is in many parts relatively open. Over much of its extent it has a limited amount of rainfall which is confined to one part of the year. However, its lands include considerable areas of high potentialities. As a preliminary step to a fuller exploitation of the basin, the Ethiopian Government requested the U.N. Special Fund for assistance in carrying out land and water resource appraisal studies and the preparation of development plans for the area. The executing agency, FAO, sub-contracted to Hunting Surveys Ltd., London, the aerial photography and to SOGFAH, Grenoble, the actual study, which was completed during the period 1961-64.

The soil and land appraisal was undertaken in three stages:

1. A general aerial reconnaissance of the entire basin, followed by ground checks. In this, 7 million hectares of land were mapped at a scale of 1:1 million and areas likely to be suitable for development under irrigation were selected, in which the following soils were distinguished:

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>% of Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvial soils (young soils on alluvial deposits)</td>
<td>24.4</td>
</tr>
<tr>
<td>Vertisols</td>
<td>15.2</td>
</tr>
<tr>
<td>Vertisols associated with Lithosols</td>
<td>19.1</td>
</tr>
</tbody>
</table>


- 24 -

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>% of Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-arid brown soils</td>
<td>12.6</td>
</tr>
<tr>
<td>Saline and saline-alkali soils inc.</td>
<td>6.4</td>
</tr>
<tr>
<td>including Regosols</td>
<td></td>
</tr>
<tr>
<td>Hydromorphic soils</td>
<td>3.0</td>
</tr>
<tr>
<td>Regosols (eroded soils in arid regions)</td>
<td>15.9</td>
</tr>
<tr>
<td>Lithosols</td>
<td>25.4</td>
</tr>
</tbody>
</table>

This initial investigation led to the selection of certain areas in the Middle Valley and the Lower Plains for further study.

2) A reconnaissance soil survey of selected lands of about 1,121,000 ha in the Middle Valley and 826,000 ha in the Lower Plains, was conducted at a scale of 1:250,000 to locate irrigable areas more specifically. The soils were differentiated as follows:

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>% of Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Soils on recent alluvia</td>
<td>16.2</td>
</tr>
<tr>
<td>Alluvial soils</td>
<td></td>
</tr>
<tr>
<td>Vertisols</td>
<td>9.0</td>
</tr>
<tr>
<td>Hydromorphic soils</td>
<td>3.2</td>
</tr>
<tr>
<td>Organic hydromorphic soils</td>
<td>1.3</td>
</tr>
<tr>
<td>Alkaline hydromorphic soils</td>
<td>2.5</td>
</tr>
<tr>
<td>II. Soils on old alluvia and colluvia</td>
<td>42.0</td>
</tr>
<tr>
<td>Vertisols on calcareous materials</td>
<td>7.3</td>
</tr>
<tr>
<td>Vertisols on calcareous materials in the run-off zones</td>
<td>0.7</td>
</tr>
<tr>
<td>Semi-arid brown soils</td>
<td>15.7</td>
</tr>
<tr>
<td>Saline soils on calcareous materials</td>
<td></td>
</tr>
<tr>
<td>Saline-alkali soils on calcareous</td>
<td></td>
</tr>
<tr>
<td>materials</td>
<td>2.6</td>
</tr>
<tr>
<td>Saline-alkali soils on calcareous</td>
<td></td>
</tr>
<tr>
<td>materials</td>
<td>4.8</td>
</tr>
<tr>
<td>Regosols resulting from erosion</td>
<td>8.2</td>
</tr>
<tr>
<td>Saline soils and regosols on non-</td>
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</tr>
<tr>
<td>differentiated materials</td>
<td>3.3</td>
</tr>
<tr>
<td>III. Skeletal soils on volcanic</td>
<td>41.7</td>
</tr>
<tr>
<td>materials</td>
<td></td>
</tr>
<tr>
<td>IV. Soils on sandy deposits</td>
<td>0.1</td>
</tr>
</tbody>
</table>
The lands were then evaluated in terms of present suitability for development under irrigation, according to three classes, i.e.:

Class A - arable lands suitable for development under irrigation

Class B - arable land, non-irrigable in its present state except under certain special conditions.

Class C - non-arable, non-irrigable land.

Summarizing the land classification gave the following results:

<table>
<thead>
<tr>
<th>Class</th>
<th>Middle Valley</th>
<th>Lower Plains</th>
<th>Total</th>
<th>% Total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>125,000 ha</td>
<td>75,000 ha</td>
<td>200,000 ha</td>
<td>10.2</td>
</tr>
<tr>
<td>Class B</td>
<td>601,000 ha</td>
<td>125,000 ha</td>
<td>726,000 ha</td>
<td>37.1</td>
</tr>
<tr>
<td>Class C</td>
<td>395,000 ha</td>
<td>636,000 ha</td>
<td>1,031,000 ha</td>
<td>52.7</td>
</tr>
</tbody>
</table>

TOTAL 1,121,000 ha 836,000 ha 1,957,000 ha 100

A semi-detailed soil survey of selected irrigable lands in the Middle Valley (262,000 ha) and in the Lower Plains (240,000 ha) was then conducted and mapped at a scale of 1:100,000 for the identification of possible development projects.

The differentiation of soil mapping units followed largely the pattern described for the reconnaissance soil survey under (2) but with further sub-divisions, which are not discussed here.

For the land classification the following specifications of U.S. Bureau of Reclamation, adapted to local conditions where necessary, were used:

Class I - good irrigable land
Class II - moderately good irrigable land
Class III - marginal irrigable land
Class IV - not irrigable, except under special conditions
Class V - Undetermined suitability for irrigation
Class VI - permanently non-irrigable land

The lands were differentiated into the following class:

<table>
<thead>
<tr>
<th>Class</th>
<th>Middle Valley</th>
<th>Lower Plains</th>
<th>% total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Class II</td>
<td>56,600 ha</td>
<td>30,000 ha</td>
<td>17.2</td>
</tr>
<tr>
<td>Class III</td>
<td>30,000 ha</td>
<td>39,000 ha</td>
<td>17.2</td>
</tr>
<tr>
<td>Class IV</td>
<td>40,000 ha</td>
<td>33,000 ha</td>
<td>14.6</td>
</tr>
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<td>Class V</td>
<td>5,900 ha</td>
<td>15,000 ha</td>
<td>5.0</td>
</tr>
<tr>
<td>Class VI</td>
<td>97,400 ha</td>
<td>123,000 ha</td>
<td>42.9</td>
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</tbody>
</table>
The above study indicated, at both the reconnaissance and the semi-detailed stages, the presence of class A (reconnaissance) and class II and III lands (semi-detailed) around Hella Sadi and Amibara, an area in the Middle Awash Valley, in which the Government was interested to a start irrigation development. During late 1968 to early 1969 a detailed soil survey and land classification was carried out by Italconsult, Rome, covering an area of 23,543 ha and mapped at a scale of 1:20,000.

The project area lies in the Rift Valley region at an approximate altitude of 740 m with an annual rainfall of 500-600 mm. It extends over both the recent alluvial plain and old fluvial terrace of the Awash River.

The soil mapping units have been differentiated into the following groups:

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soils on very recent alluvium - Fluvents</td>
<td>2,704</td>
</tr>
<tr>
<td>Vertisols on recent alluvium - Orthents and Usterts</td>
<td>2,362</td>
</tr>
<tr>
<td>Non-calcareous Vertisols on recent alluvium - Usterts</td>
<td>2,035</td>
</tr>
<tr>
<td>Hydromorphic Vertisols - Usterts</td>
<td>2,710</td>
</tr>
<tr>
<td>Usterts</td>
<td>3,504</td>
</tr>
<tr>
<td>Arid brown soils on terrace alluvium Orthids</td>
<td>5,303</td>
</tr>
<tr>
<td>Sodic and alkali soils on recent alluvium - Aquents</td>
<td>4398</td>
</tr>
<tr>
<td>Calcareous soils on gravelly terrace Alluvium - Orthids</td>
<td>451</td>
</tr>
</tbody>
</table>

Subsequently, the lands were classified according to their suitability for irrigated land use as specified by the U.S. Bureau of Reclamation. The following land classes were distinguished:

<table>
<thead>
<tr>
<th>Class</th>
<th>Type</th>
<th>Area (ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Arable (good)</td>
<td>965</td>
<td>3.4</td>
</tr>
<tr>
<td>2</td>
<td>Arable (moderate)</td>
<td>12,124</td>
<td>46.0</td>
</tr>
<tr>
<td>3</td>
<td>Arable (marginal)</td>
<td>6,230</td>
<td>21.8</td>
</tr>
<tr>
<td>4</td>
<td>Limited arable</td>
<td>757</td>
<td>1.6</td>
</tr>
<tr>
<td>6</td>
<td>Non-arable</td>
<td>7,763</td>
<td>27.2</td>
</tr>
</tbody>
</table>
Land class 5 with undetermined suitability under existing conditions pending further special study was omitted at this stage. The land sub-classes indicated their specific major limitations.

322.3 The Lower Awash Plains

The semi-detailed survey of the Lower Awash Plains by SOGEMAH (322.1-3) revealed the availability of adequate promising areas to justify a more specific formulation of a development plan. Sir Alexander Gibb & Partners, London, were requested to conduct a feasibility study of the area, which included a detailed soil survey of an area of about 17,000 ha. Hunting Technical Services provided the soil survey team, which carried out the field work in 1972-73. The final soil and land classification maps were produced at a scale of 1:20,000. The area lies at an altitude of 250 m and has an annual rainfall of 150 to 200 mm.

The Awash River is confined to the Rift Valley. It does not reach the sea, but after crossing the Tendaho-Asayita plain it enters the area occupied by the lakes Camari, Afembo and Bario none of which have an outlet. It is building up a delta projecting into this through and gradually filling it with alluvium. As a result of the delta formation, the course of the Awash has changed frequently, currently draining into Lake Camari.

In the Tendaho-Asayita basin and the present lake area, there are vast lacustrine and littoral sediments associated with the presence of an extensive lake in early Holocene times, dated from 10,000 to 5,000 years BP. Following the drying-up of the lake, the Awash eroded a meander belt through the lake-bed sediments and filled it up with riverine alluvium, which in places was uplifted. In the immediate vicinity of the Asayita basin basaltic lava flows form outcrops from which alluvial fans stretch into the survey area. In a few locations fumaroles occur.

The soil mapping units in close relationship with their geomorphology and parent material have been differentiated into:

- Soils developed on riverine alluvium
- Soils developed on colluvial material
- Soils developed on lacustrine sediments in situ
- Dune sands
- Soils developed on lava ridges
- Soils affected by fumarole activity

Among the above soil groups the first is the most common in the survey area; it has been divided into 9 mapping units.
The land classification follows the U.S. Bureau of Reclamation specifications for irrigated land use. This study distinguishes only land classes 1, 2, 3 and 6 corresponding with good, moderate, marginal arable and non-arable respectively. A further distinction in sub-classes indicated the nature of major limitations within each class, but the details of these are not presented here.

<table>
<thead>
<tr>
<th>Class</th>
<th>Area, ha</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>4,671</td>
<td>23.7</td>
</tr>
<tr>
<td>Class 2</td>
<td>7,701</td>
<td>42.4</td>
</tr>
<tr>
<td>Class 3</td>
<td>1,206</td>
<td>6.6</td>
</tr>
<tr>
<td>Class 4</td>
<td>1,768</td>
<td>9.7</td>
</tr>
<tr>
<td>Class 5</td>
<td>2,193</td>
<td>11.6</td>
</tr>
</tbody>
</table>

Tibila

Tibila is an area in the Upper Awash Valley which has also been selected for a feasibility study. This was done by E.D.P.A., Paris. The investigation included a soil survey and land classification at scale 1:20,000, and was carried out in the period between late 1972 and early 1973. It covered an area of 18,000 ha, lying at an altitude of 1200-1350 m, with an annual rainfall of 600-700 mm.

At Tibila, the Awash River, flowing northwestwards, has incised a relatively narrow and shallow valley with young terraces. The project area is on the southern bank and consists largely of an old upper terrace formation, with a few alluvial fans and a narrow zone of colluvial material along the foot of the mountain scarp in the south. The mountains are mainly composed of ignimbrites, welded tuff and occasionally pumice. Farther northeast, where the plain narrows, protruding basaltic lava flows are common.

The most common soils in the area are medium to fine textured xerosols. Vertisols occur in places, while fluvisols are found on the young terraces along the Awash.
Angelele and Bolhamo plains in the Middle Awash Valley are yet another place in which the Government is interested to develop irrigated agriculture. Bolhamo area is situated on the west bank of the Awash and Angelele on the east bank, more or less opposite each other, just downstream of Amibara (322.2). These project areas are at an altitude of about 750 m, and have an annual rainfall of 500-600 mm. The total area of about 14,000 ha was mapped at a scale of 1:20,000. The land classification, according to the U.S. Bureau of Reclamation specifications for irrigated land use, differentiates land classes 1, 2, 3 and 6.

3.2.3 The Wabi Shebelle River Basin

The study of the Wabi Shebelle catchment, started in 1969 by ORSTOM-BIPA, Paris, was meant as a land resource inventory of the entire basin in order to select promising areas for which more specific development plans could be formulated.

The initial general reconnaissance which was basically similar to that of the Blue Nile River Basin study, covered about 18 million ha and revealed appreciable stretches of irrigable land in the Lower Valley, between Imi and the Somalia border. A semi-detailed soil survey and land classification of this stretch was required for the preparation of a development plan. This survey covered 382,000 ha, mapped at a scale of 1:50,000 and was completed at the end of 1970. The rest of the area was ignored and the information about the soils there is very scanty.

About 40 km north of Imi the Wabi Shebelle leaves the mountains and meanders into an alluvial plain which is a few kilometers wide. Between Imi and Kalafo the river has incised its bed some five meters into the alluvial plain. However, downstream from Kalafo a wide braided river flood plain, in places with permanent papyrus swamps, is formed.

The climate is semi-arid with an annual rainfall of about 300 mm, concentrated into two-monthly periods, April-May and October-November.

The soils of the Lower Valley have been tentatively differentiated as follows:

- Undeveloped soils on colluvia
- Weakly developed soils
  i) Xerosols: on the limestone plateau and its colluvia,
    - on the sandstone plateau,
    - on the gypsiferous lower hills and their colluvia,
    - on large gypsiferous alluvial flats,
    - on basalt hills and their colluvia.
ii) Weakly developed soils derived from alluvia of the Ogaden limestone plateau:
- on hillocks in the alluvial fans,
- on the lower alluvial fans,
- on recent alluvia of small streams,
- on recent alluvia of larger streams.

iii) Weakly developed soils on alluvia-colluvia from Ogaden limestone and Perefer gypsum.

iv) Weakly developed soils on Wabi Shebelle alluvia.

v) Weakly developed soils on Wabi Shebelle alluvia over Ogaden limestone colluvia.

Vertisols:
- on alluvia from Ogaden limestone
- on alluvia from basalts
- on Wabi Shebelle alluvia

Hydromorphic soils, organic
Sodic soils with salt efflorescence

As the consultant's report has not been published yet, one can only guess what these soils would be in the UNESCO/FAO Soil Classification. It seems that between Imi and Kalafo, Vertisols and Regosols are most common, while in the braided river flood plain below Kalafo Fluvisols, Gleysols and Solonchaks are predominant.

The lands have been classified in three classes:

Class I - very suitable for irrigation
Class II - low suitability for irrigation
Class III - unsuitable for irrigation

The land Classes I and II have been divided into sub-classes according to their suitability for various cropping systems and each of which is then graded according to the nature and severity of major land limitations. Land Class III is sub-divided with respect to the nature of major limitations only.

It has been tentatively estimated that about two thirds of the land would come into Class I, while the rest would be class II and III land.

3.2.4 Setit Humera Soil Study

The Setit Humera survey area is situated in the North-West low lands of Ethiopia adjoining the Sudanese border at 13° 02'N -
14° 35'N and 36° 20' - 37° 03'E.
The climate is influenced by the Inter-Tropical Convergence Zone movements and altitude. Rainfall ranges from 500 mm in the northwest to 1000 mm in the southeast and temperature from 28°C to 28°C. The difference between the absolute maxima and minima is of the order of 40°C.

The geology includes precambrian schists and granite intrusions covered by mesozoic sediments, most of which occur Trap Series basalts from which the soils are actually derived.

With the altitude ranging from 550 m in the north to 1000 m in the southeast, five sets of geomorphological units are distinguished:

1. Low river terrace - discontinuous and up to 400 m wide along main rivers.
2. Terrace escarpment - degraded clay plain between 1 and 3
3. Medium terrace - extensive aggradation clay plain up to 30 km away from rivers.
4. Eroded parts of high terrace - degraded clay plain between 3 and 5.
5. High terrace - plateau remnants occurring in 3 or at the end of it.

An area of 1,000,000 ha was studied on 1:20,000 scale aerial photographs from which 77 mosaics were compiled and reduced to 1:100,000 scale; all information was transferred onto these mosaics. An area of 702,000 ha was selected for systematic study and within this key locations were chosen for more detailed work.

Except for the non-arable lands, the largest portion of the area is taken up by Vertisols. Although small in area coverage, Entisols and Alfisols are also present - Table 3.3.

Table 3.3  

<table>
<thead>
<tr>
<th>Series</th>
<th>Order</th>
<th>Subgroup</th>
<th>Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humera</td>
<td>Vertisol</td>
<td>Typic Chromustert</td>
<td>Fine, montmorillonitic isohyperthermic</td>
</tr>
<tr>
<td>Xhadra</td>
<td>Vertisol</td>
<td>Typic Chromustert</td>
<td>Fine, montmorillonitic, isohyperthermic</td>
</tr>
<tr>
<td>Lugdi</td>
<td>Vertisol</td>
<td>Entic Pellustert</td>
<td>Very fine, montmorillonitic, isohyperthermic</td>
</tr>
<tr>
<td>Karzinab</td>
<td>Vertisol</td>
<td>Typic Chromustert</td>
<td>Very fine, montmorillonitic, isohyperthermic</td>
</tr>
<tr>
<td>Rubassa</td>
<td>Vertisol</td>
<td>Entic Pellustert</td>
<td>Very fine, montmorillonitic, isohyperthermic</td>
</tr>
<tr>
<td>Setit</td>
<td>Entisol</td>
<td>Typic Ustifluvent</td>
<td>Loamy, mixed, calcareous, isohyperthermic</td>
</tr>
<tr>
<td>Tebeldi</td>
<td>Alfisol</td>
<td>Udic Haplustalf</td>
<td>Loamy, mixed, isohyperthermic</td>
</tr>
</tbody>
</table>
Broad correlation between climate, natural vegetation and soils exist. Accordingly three ecological zones termed A, B and C are distinguished - Table 3.4.

Table 3.4 ECOLOGICAL ZONES AND THEIR CHARACTERISTICS

<table>
<thead>
<tr>
<th>Eco-zones</th>
<th>Area, ha</th>
<th>Rain mm period</th>
<th>Vegetation</th>
<th>Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>133,890</td>
<td>570, June-Oct.</td>
<td>Acacia Hellifera</td>
<td>Humera clay Thorn Land</td>
</tr>
<tr>
<td>B</td>
<td>135,600</td>
<td>570-800; May</td>
<td>Acacia Seyal- Khadra-Ludgdi Balanites Savanna clay</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>512,510</td>
<td>800-1000; May</td>
<td>Anorgeissu. Harzinab-Rubasea Nov.</td>
<td>Combretum Savanna Woodland</td>
</tr>
</tbody>
</table>

Three land types exist in the area—arable and cultivated; arable and not cultivated, and non-arable lands each making the following respective percentages of the total area: 39, 15 and 46 table 3.5. The crops grown include: sesame (45); sorghum (35), cotton (12), and other crops, millet, maize, peppers (8).

Table 3.5 SETIT HUMERA SURVEY Land types in each eco-zone

<table>
<thead>
<tr>
<th>Eco-zone</th>
<th>Cultivated</th>
<th>Cultivable</th>
<th>non-cultivable</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ha</td>
<td>%</td>
<td>ha</td>
<td>%</td>
</tr>
<tr>
<td>A</td>
<td>78,150</td>
<td>10.0</td>
<td>24,000</td>
<td>3.1</td>
</tr>
<tr>
<td>B</td>
<td>85,220</td>
<td>10.9</td>
<td>8,000</td>
<td>1.0</td>
</tr>
<tr>
<td>C</td>
<td>140,755</td>
<td>18.0</td>
<td>85,000</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Total 304,125 38.2 117,000 15.9 360,875 46.1 782,000 100.0

Figures in brackets refer to % of cultivated land covered by the respective crops.
3.2.5 Land Resources study of the Rift Valley Lakes Zones

This study is meant to assess the resources and development opportunities of the whole of the Rift Valley Lakes zones in sufficient detail to subdivide the region into discrete development areas. The project area of 5.5 million hectares stretches from Lake Zwai in the north to Lake Stefanie (Chew Bahr) near the Kenyan border in the south. A team of specialists from the Land Resources Division, Overseas Development Administration of the British Government Foreign and common Wealth Office started operations in early 1973.

In the study area two patterns of rainfall can be discerned. From Lake Abaya southward the main rains occur during the period March to May (when 45% of the annual total falls at Arba Minch) and a secondary peak follows in September or October. This pattern is similar to that of Northern Kenya. North of Lake Abaya, the main rains are from July to September, often with a secondary peak in March or April. In this northern area, the rainfall pattern is more typical of the Ethiopian plateau. The annual rainfall varies from 300-550 mm in the valley floor to 1600-2000 mm on the surrounding, plateau. Frost is extensive generally at above 2000 m altitude (could also occur at 1600 m) while hail may occur even at 1000 m.

In the whole area four ecoclimatic zones have been recognised. On the basis of ecological, economical and administrative criteria the area was divided into 33 land regions with the help of aerial photo analysis. Within and across these regions the study identified:

- 8 Regional development areas
- 10 local development areas
- 3 special development areas.

Each of these development areas are defined in more detail in terms of land resources and development potential accompanied by maps at a scale of 1:100,000. The soils have been classified in broad associations according to the recent UNESCO/FAO Soil Classification System (The Legend).

As a follow-up of the main broad study the team undertook a feasibility study of the three special development areas in appreciably greater detail and mapped them at a scale of 1:50,000. These areas are:

- Dilate River Basin
- Lake Awassa Catchment (136,000 ha)
- Lake Zwai Hinterland (95,000 ha, 45,000 of this is lake surface).
3.2.5.1 Gidabo Basin Morphopedological Survey

A reconnaissance survey of 330,000 ha area of the Gidabo Basin (in the Rift Valley Lakes Zone) was conducted in November 1976 and the maps accompanying the report published at a scale of 1:100,000.

The area, which is located at the following approximate geographical coordinates, is bordered by Lake Awasa in the north, Bilate River Basin in the west, Gelana and Canale in the south and Dawa in the east.

Latitude: 6°15'N - 6°55'N
Longitude: 37°55'E - 38°40'E

Within this area the altitude ranges from 1200 m at Lake Abaya to 3000 m on the eastern plateau. Climate also roughly follows altitude and varies from semi-arid (rain 500 mm, temperature 22.5°C) in the Rift to Afro-subalpine (rain 1500 mm, temperature 12.8°C) over the Eastern Plateau.

Four major geomorphological units and six subunits are identified with further subdivision of some of the subunits into still smaller units. For these descriptions of geology, land form, soils erosion, hydrological regions, vegetation, land use and major constraints are given. Some of these are summarized below:

<table>
<thead>
<tr>
<th>Geomorphological Unit</th>
<th>Geology</th>
<th>Landform</th>
<th>Soils</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highlands</td>
<td>Rhyolites</td>
<td>Hilly</td>
<td>Cambisols</td>
<td>Frost</td>
</tr>
<tr>
<td>Rift Escarpment</td>
<td>&quot;</td>
<td>Mountainous</td>
<td>Claysoils</td>
<td></td>
</tr>
<tr>
<td>Structural Basaltic</td>
<td>Basalts</td>
<td>Sediments</td>
<td>Nitosols</td>
<td>Topography</td>
</tr>
<tr>
<td>Reliefs</td>
<td>&quot;</td>
<td></td>
<td>Cambisols</td>
<td></td>
</tr>
<tr>
<td>Rift Valley</td>
<td>Ignimbrites</td>
<td>Hilly</td>
<td>Rhyolites fault</td>
<td>Planosols</td>
</tr>
<tr>
<td></td>
<td>&quot;</td>
<td>Sediments</td>
<td>Cinerites zone</td>
<td>Regosols</td>
</tr>
<tr>
<td></td>
<td>Sediments</td>
<td></td>
<td>Lithosols</td>
<td></td>
</tr>
</tbody>
</table>

- Soils: Cambisols, Claysoils, Nitosols, Cambisols, Vertisols, Gleysols, Regosols, Lithosols, Histosols, Fluvisols, Planosols, Planosols.
3.2.5.2 Chamo-Abaya Western Basin Morphopodological Survey

A reconnaissance survey of 370,000 ha of this area has been done following the same lines as for Gidabo Basin study. However, the report of this one is not published yet.

3.2.6 Tigrai Rural Development Study

The area studied under this project (by Hunttings) is 1,257,000 ha of Central Tigrai Comprising mainly a central plateau of 2000-3000 m altitude and a lowland plains, below the eastern escarpment, of about 1000 m altitude.

The geology, climate and topography of the area have strongly influenced the development of the soils which vary from these typical of semi-desert regions in the eastern lowlands (Rift Valley) to those typical of more temperate zone in the southern volcanic highlands which have subalpine environment above 3500 m a.s.l.

Most of the central plateau soils are base rich, fine textured clays derived from basalts, dolerites, calcareous shales, marls and limestones. In the north the sandstones have given rise to soils which are coarser textured on the surface but have heavier textured sandy subsoils. Alluvial soils occur widely in small pockets on the plateau and are most extensive in the eastern lowlands.

Soil erosion is the major threat to the successful continuation of agriculture in Tigrai and is universally severe on the steeper slopes of the central plateau. As a result virtually all top soil layers and in many places the subsoil as well have been removed leaving bare rock or a litter of surface stones.

Seven use classes of land were defined on the basis of soil depth, land slope and intensity of conservation measures needed for sustained use. On this basis some 40% of the area is considered cultivable. However, much of the land is of poor quality as centuries of erosion have removed virtually all the top soil.

Within the broad area of the above 1,257,000 ha, 174,000 ha of land (90,000 ha around Hekelo and 84,000 ha around Hawzen) are studied at detailed reconnaissance level and land suitability classes defined on the basis of soil depth, land slope, soil texture, surface stoniness, susceptibility to water logging and existing erosion status.

Over the whole area the following taxonomic soil units have been identified:

- Cambisols
- Lithosols
- Arc soils
- Rendzinas
- Luvisols
- Regosols
- Gleysols
- Vertisols
- Fluvisols
- Xerosols
3.2.7 Gambella Agricultural Development Project

As described by TAMS in 1974, the Gambella plain is a relatively flat area of about 1,000,000 ha (about 800,000 ha of which is subject to flooding) in the Southwest of Ethiopia. Although at first sight physiographically homogeneous, it has an intricate pattern of higher and lower-lying areas (with difference in elevation of 2-4 meters) often with extensive creek and gully system.

As the main clay material developed in the area will be montmorillonite soils will tend to be vertisolic dependent on clay content. However, the freely drained levees may have a larger illite and kaolinite component.

The potential suitability of the land for Agriculture is believed to be moderate to good.

3.3 SOIL AND LAND EVALUATION STUDIES BY THE INSTITUTE OF AGRICULTURAL RESEARCH

As mentioned in the introductory chapter, it was not until late 1971 that a soil survey and land evaluation section was established within the I.A.R. Financial and man-power resources are limited and only a small unit has been set up. At present this consists of one Research Officer, one Assistant Research Officer both university graduate, two field technical Assistants, and one draftsman. Laboratory analyses for soils are undertaken by the Analytical services Section of the Institute.

It has been decided to restrict operations of the section to the preparation of detailed soils maps of the I.A.R. research stations and to a land evaluation study of an area of 100,000-200,000 ha surrounding each station, in order to determine the representativeness of the station location and to evaluate the applicability of its research findings to the areas concerned (Fig. 3.2). The study may also detect possible significant agricultural research problems which deserve to be taken up by the I.A.R.

Of the six survey projects undertaken the analytical results of only Gode and Holetta are available. When the reports of letter are completed all the others are still pending and for the time being these are compiled in tentative maps pending the completion of analyses when final maps and reports can be prepared.

3.3.1 Detailed Soil Survey of Gode Agricultural Research Station

Gode Agricultural Research Station of 450 ha, is situated in the Wabi Shebelle Valley, a warm semi-arid region in southeastern Ethiopia at approximately 43°E and 6°N and an altitude of 300 metres. The annual rainfall about 320 mm is concentrated into two-monthly periods, April-May and October-November. The station covers some 450 ha of which 200 have been opened and canalized. A detailed soil survey was undertaken in early 1972 and mapped at a scale of 1:10,000. The detailed soil survey and irrigability land classification reports and maps are completed and issued.
The Wabi Shabelle has incised a wide valley in the Eastern Plateau, which consists largely of Gypsiferous Antalo Limestone. The station is situated on the river alluvial plain with clearly visible, silted-up, former meander branches and levees. This is a lower terrace in which the river incised its present bed some five meters deep. The plain is practically level with a slope gradient of only 0.07%.

The water of the river is of reasonably good quality during the main irrigation seasons. The groundwater is of very high salinity (4-7 mmhos/cm) though of low sodium hazared. It occurs at 5 to 10 m depth and needs to be closely watched.

The soils have been differentiated broadly as follows:

i) Chronic Vertisols of the former back-swamps - 62% of the area.

ii) Calcaric Fluvisols, alongside the former levees, often forming a transition towards the Chronic Vertisols; the clay layer is not thick enough to qualify as Vertisols - 14% of the area.

iii) Calcaric Fluvisols of the former levees - 20% of the area.

iv) Calcaric Fluvisols of the silted-up, former meanders - 4% of the area.

3.3.2 Detailed soil survey of Holetta Agricultural Research Station Shoa Administrative Region

Holetta Agricultural Research Station is situated in the Central Highlands of the Western Plateau at approximately 38°30'E and 9°N and an altitude of 2400 meters. It serves the rainfed highland areas growing mainly cereals with pulses and oil seeds as secondary crops. Livestock is also important. The station, which covers 300 ha was surveyed in detail in mid 1972 and mapped at a scale of 1:5,000. The detailed soil survey and land suitability classification for a number of agricultural land use alternatives is completed and the draft is being processed for issuing.

The climate is characterized by a cool dry season with frequent night frosts from October to February, followed by a period of light rains in March and April. May is dry and warm, while from June to September the main rainy season occurs. The mean annual temperature is 13.6°C and the annual rainfall 1056 mm Fig. 3.3

The station forms part of a degraded middle plateau on alkali olivine basalt of the Trap Series, which is of Paleocene-Oligocene-Hocene age.
Fig. 3.3 HOLETTA CLIMATE DIAGRAMS 1969-75
On the basis of field observations and laboratory data, the soils are differentiated as follows:

i) Nito-Luvic phaeozems of the lava plateau remnants - 37% of the area.

ii) Chromic Vertisols of the degraded plateau footslopes - 42% of the area.

iii) Haplic Phaeozems of the Holetta River former flood plain - 19% of the area.

iv) Rocky and stony lands and marsh land - 2% of the area.

In the absence of data regarding economic and land quality information in general, an attempt was made to evaluate the suitability of the land for the various land use alternatives on the basis of only the physical land characteristics such as climate, soil conditions, relief and special endemic conditions. The opinions of the researchers in other disciplines were taken into consideration when designing this empirical approach for the highlands which is left open for criticisms and suggestions for the planned subsequent revisions.

3.3.3 Details Soil Survey of Jimma Agricultural Research Station, Kaffa Administrative Region

A detailed soil survey of Jimma Research Station of about 150 ha area was carried out in March - April 1974.

The Station is located eight kilometers West, Southwest of Jimma and has the following approximate coordinates:

Latitude : 7°40'N
Longitude : 36°45'E

Its altitude varies from 1795 on a.s.l on the plateau remnants to 1724 m in the valley floors.

The six years meteorological data collected at the station indicate the following pattern.
Table 3.6 Climatic data of Jimma Research Station

<table>
<thead>
<tr>
<th>Element</th>
<th>J</th>
<th>F</th>
<th>H</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>Y</th>
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</thead>
<tbody>
<tr>
<td>Rainfall mm</td>
<td>31.2</td>
<td>59.2</td>
<td>100.5</td>
<td>116.3</td>
<td>186.8</td>
<td>193.2</td>
<td>248.4</td>
<td>217.4</td>
<td>203.2</td>
<td>91.9</td>
<td>64.2</td>
<td>15.3</td>
<td>17.27.7</td>
</tr>
<tr>
<td>Rel. Hum., %</td>
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<td>61</td>
<td>63</td>
<td>63</td>
<td>69</td>
<td>73</td>
<td>80</td>
<td>80</td>
<td>77</td>
<td>69</td>
<td>62</td>
<td>56</td>
<td>—</td>
</tr>
<tr>
<td>Evap., mm/day</td>
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<td>5.2</td>
<td>5.4</td>
<td>4.6</td>
<td>3.9</td>
<td>3.0</td>
<td>3.0</td>
<td>2.9</td>
<td>3.9</td>
<td>4.3</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>Sunshine, hrs/day</td>
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<td>7.2</td>
<td>6.3</td>
<td>6.9</td>
<td>6.4</td>
<td>5.4</td>
<td>3.6</td>
<td>4.1</td>
<td>5.6</td>
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<td>7.9</td>
<td>8.8</td>
<td>6.2</td>
</tr>
<tr>
<td>Abs. Max. Temp., °C</td>
<td>30.1</td>
<td>33.6</td>
<td>32.5</td>
<td>33.7</td>
<td>30.5</td>
<td>28.0</td>
<td>28.8</td>
<td>28.7</td>
<td>28.8</td>
<td>28.4</td>
<td>27.8</td>
<td>28.5</td>
<td>—</td>
</tr>
<tr>
<td>Mean Max. Temp., °C</td>
<td>26.6</td>
<td>27.8</td>
<td>27.2</td>
<td>27.1</td>
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<tr>
<td>Abs. Min. Temp., °C</td>
<td>18.2</td>
<td>18.9</td>
<td>19.9</td>
<td>20.2</td>
<td>19.5</td>
<td>18.2</td>
<td>17.8</td>
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<td>16.0</td>
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<tr>
<td>Mean Min. Temp., °C</td>
<td>9.7</td>
<td>9.9</td>
<td>12.5</td>
<td>13.2</td>
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<tr>
<td>Abs. Min. Temp., °C</td>
<td>2.5</td>
<td>2.6</td>
<td>5.5</td>
<td>3.5</td>
<td>8.0</td>
<td>6.5</td>
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<td>7.5</td>
<td>4.0</td>
<td>1.6</td>
<td>0.0</td>
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</tbody>
</table>

In the surroundings of Jimma basaltic flood lava of oligocene - Miocene age (Ashangai group) occurs, as well as the younger Upper Miocene - Pleistocene (Magdala group) basaltic lavas. These rocks form the plateaus which are now strongly dissected by erosion. In between the plateau remnants silted-up river alluvial plains are common. These alluvial materials include basaltic of trachytic ignimbrite volcanic ashes at various depths.

The landscape as a whole is characterized by dendric drainage pattern and the crops grown here are commonly maize, sorghum, tef, root crops and coffee.

The soils developed in the above described landscape have three clear distinctions. These are:

- the dark, reddish brown, clay soils of the hills and ridges are developed in situ from the underlyiing basaltic formation. These are classified as Eutric Nitosols and are separated into nine phases on the basis of slope and occurrence of gravel in the profile.

- The faintly stratified, dark reddish brown, clay soils of the hill valleys developed largely Colluvial materials washed down from the adjacent slopes. These are classified as chrombic cambisols and separated into two phases on the basis of their slope.

- the dark brown, heavy clays of the valley floors developed from alluvial materials. They are classified as verti-Dystric Fluvisols (intergrades) and separated into two slope phases.
As the laboratory data was not available yet the differentiation and classification of these soils was on the basis of only the field observation.

3.3.4 Detailed soil survey of Bako Agricultural Research Station, Wollega Administrative Region

Though some work still remains unfinished, most of the detailed soil survey field work of Bako Research Station was done in June-July 1977.

The station is located about 10 kilometers southwest of Bako and has the following approximate geographic coordinates:

Latitude : 06°06'N
Longitude : 37°03'E

The altitude of the area varies from 1580 m a.s. near the river in the south to 1630 m at the barn in the north.

The 5-17 years meteorological data collected at and near the station shows the following pattern.
Table 3.7 Climatic Data of Bako Research Station

<table>
<thead>
<tr>
<th>Element</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>N</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall, mm</td>
<td>10.7</td>
<td>18.5</td>
<td>41.5</td>
<td>69.1</td>
<td>152.1</td>
<td>197.7</td>
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</tr>
<tr>
<td>Rel. Hum., %</td>
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<td>48</td>
<td>49</td>
<td>47</td>
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<td>Sunshine, hrs/day</td>
<td>7.0</td>
<td>7.9</td>
<td>7.1</td>
<td>6.7</td>
<td>6.5</td>
<td>5.0</td>
<td>3.8</td>
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<td>8.0</td>
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<tr>
<td>Mean Max. Temp., °C</td>
<td>29.0</td>
<td>30.0</td>
<td>31.1</td>
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<td>Mean Min. Temp., °C</td>
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<td>13.5</td>
<td>13.0</td>
<td>12.8</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Plateaus, plateau footslopes and plains occur in the Bako area. The plateau and the upper part of the plateau footslope are built of basalts and the associated basic rocks, the lower part of the plateau footslope from granitic gneisses, and the plains from colluvial and alluvial deposits.

The Research Station occurs mainly on the lower plateau footslopes and plains and the subdivisions of these. The plateau footslopes include the sloping area that stretches from the plateau level to the plains. It is an area of partially deforested system of semi-parallel ridges that are separated from each other by numerous old gullies and streams, the tributaries of Gibe River. With the aid of aerial photographs this area is subdivided into the upper plateau footslopes, the lower plateau footslopes and forested old gullies.

The upper plateau footslopes lie on the plateau side of the slope and have steeper overall slopes and are more intensively cultivated. In many parts of it there are isolated step-like natural terraces, probably resulting from soil creep. Of the remnant natural vegetation oak, Cordia africana and Syzygium guineense are the most conspicuous. On the whole basaltic rocks, from which strong and boulders, reddish brown, clay soils called Luvic Phaeozems and Chromic Luvisols, are common.

The lower plateau footslopes have more clearly defined ridges (oriented roughly E-S) and thicker vegetation cover with relatively more tree component such as oak, Cordia africana, Syzygium guineense, and Gardenia lutca. The most common undergrowth of these are viscum and Snowdonia. The Landscape is developed predominantly from granitic gneiss basement complex rocks which include numerous veins of quartzite. The soils formed from these rocks are predominantly reddish brown, sandy clays classified as chromic Luvisols, Luvic Phaeozems and Chromic Vertisols that has few inclusions of Felic Vertisols. Some of the Luvisols and Phaeozems have quartz gravel at some depth, often below 100 cm.
The forested old gullies have incised deep valley in the plateau footslopes. Although the soils there are seen to be generally shallow no systematic observations have been carried out in them to warrant proper description and classification. These areas are built of either colluvial or alluvial materials.

The colluvial plains are included in the areas that occur at the lower end of the lower plateau footslopes and forming a sort of an apron around the lower fringes of it. The soil developed here are commonly chromic Vertisols and is often associated with Pollic vertisols. The alluvial plains are built of sediments brought there by streams and rivers and could be separated into levees and backswamp areas. During the rains these areas are wet and soggy and surface water is common for some time. As enough number of observations have not been made yet no description and classification of the soils can be given.

The grouping and classification of the soils given here is only tentative pending the acquisition of the laboratory data.

As a follow-up of the detailed surveys summarised above a land resource and evaluation study was made of the surrounding area of Holetta station, which is reported on below.

3.3.5 Land Resource and Evaluation Study of Wollenkomi-Addis Ababa Region.

This land resource and evaluation study concerns an area of nearly 200,000 ha, between 38°15' E to 38°50' N to 9°10' N, extending roughly 30 km westwards and eastwards and 15 km northwards to 25 km southwards of Holetta Station. The fieldwork was done during 1973.

The climate is in general the same as for the station. The altitudes vary between 3400 m at Wachacha Mountain summit and 1950 m in the "lowlands".

The lands have been differentiated according to geomorphological land types, sub-divided where relevant into topographically more homogenous land units, which in fact form the basic mapping units. For each mapping unit the geology, topography soils, drainage conditions, erosion status, vegetation and land use are described. If significant differences in climate can be detected these will be indicated. Finally, a synthesis incorporating the limitations and hazards would be produced. The final map is being prepared at a scale of 1:100,000. The collection of the land resource data has not been done by a multi-disciplinary team. The interpretation of this information
and especially the evaluation of various land utilization types, however, will be undertaken in consultation with specialists in, among other disciplines, agronomy, animal production, range management and farm management. The interpretation and evaluation phase of this study had to be delayed until the laboratory data was available. It is envisaged that the "Background Document" for the 1972 FAO sponsored expert consultation will be followed as a general guide.

A general appraisal of the land resources in the area is given below:

i) Mountains and hills, altitude 2100-2400 m.
- commonly on basalt and trachyte, in places on rhyolite of ashes.
- Moderately steep to very steep and often moderately dissected; gently sloping footslopes.
- Upper slopes: Phaeozems and Cambisols.
- Middle slopes: Regosols and Lithosols.
- Lower slopes: Cambisols.
- Major limitations and hazards: topography, soil depth and stoniness, erosion.

ii) Upper plateaux and their remnants, altitudes 2600-2750 m
- commonly on basalt and trachyte.
- Gently sloping, undulating, slightly dissected.
- Cambisols dominant, Vertisols in shallow depressions.
- Major limitations and hazards: erosion.

iii) Degraded middle plateaux, altitude 2000-2500 m
- commonly on basalt, in places on trachyte.
- Gently sloping, undulating, slightly or moderately dissected.
- Cambisols dominant, Vertisols on gentle lower slopes.
- Major limitations and hazards: erosion.

iv) Degraded lower plateaux, altitude 2100-2200 m
- commonly on basalt.
- Gently sloping, slightly undulating and slightly dissected.
- Vertisols.
- Major limitations and hazards: erosion and soil damage.

v) Piedmont alluvial plains - altitude 1950-2100 m.
- Colluvial-alluvial from basalt and trachyte.
- Almost level, gilgal, slightly dissected.
vi) River alluvial plains — altitudes 2000-2150 m.
- River alluvium from basalt and trachyte.
- Almost level, in places very slightly undulating due to remnants of former levees, etc.
- Vertisols, Cambisols, Fluvisols.
- Major limitations and hazards: drainage, in places seasonal flooding.

In the absence of analytical data the taxonomic classification of the soils is tentative. For example, some of the Cambisols could well be Urtisols as indicated on the soil map of Africa for this particular region.

A common hazard in this region is seasonal night frost which is a widespread hazard for most mapping units. A few units are unaffected, such as the mountain slopes, large exposed valley slopes, etc. There is, however, an appreciable lack of climatic data in the region. Besides Addis Ababa and Holetta which produce detailed meteorological data, only a few rain stations exist in this area.

Land use varies considerably between the mapping units, largely due to altitude, topography and soil differences.

3.3.6 Land Resources and Evaluation Study of Sendafa-Debre Zeit Region.

This area is located immediately east of Addis Ababa between longitudes 38°45' E and 39°00' E and latitudes 9°45' N and 9°12' N. It covers an area of about 126,000 ha with an altitude range of 1850 to 3200 m. The climate is humid temperate. The main rainy season is between June and September. Mean annual temperature varies from 15°-19°C in Addis to 18,8°C at Debre Zeit in the southeast. In the high lying areas, night frost may occur after the rainy period. From the aerial photo analysis the whole area is divided into five major geomorphological land types within which subdivision of smaller units are made on the basis of degree of dissection, slope, vegetation cover, land use etc. The homogeneous land units so delineated total 36. For these descriptions of soils, geology, vegetation, and land use are given. The field mapping scale was 1:50,000 and this may be reduced to 1:100,000 scale during the final publication.

The major geomorphological units identified are:

1) Mountains: These rise to appreciable heights above the surrounding areas either as single units, groups of units or as interconnected chains. They generally have cool temperatures and higher rainfalls. The main characteristics are:

- Basalts, trachytes, rhyolites, and consolidated ashes of basic composition.
Summit areas are flat to gently sloping while the entire slopes with numerous interfluvial ridges are moderately steep to very steep with convex upper slopes and concave footslopes. The transversal slopes are steeper than the longitudinal.

Very shallow to moderately deep soils include stony and rocky varieties of Lithosols, Regosols and Phaeozems (Entisols, Inceptisols and mollisols). In most parts the soils are less than 20 cm deep, often being only about 10 cm deep Lithosols.

Sparses grass cover and few trees and bushes.

Most parts are cultivated with barley and lentils (50% fallow) while the remainder is left for grazing and hay harvesting. Forested lands make less than 10% and even these are limited to narrow belts along the streams the surroundings of Addis Ababa.

Hills: These also rise to significant heights above the surrounding area but to a lesser extent than the mountains. They are either remnants of mountains, strongly dissected plateaus or plains or are cones produced by volcanic activity. As seen from the aerial photos they appear largely similar to the mountains with respect, to geology, soils, vegetation and land use.

Plateaux: These include the slightly undulating to rolling landscapes with gently sloping to flat interfluvial ridges. Only small areas are found in the survey area.

- Lasalt and its associates,
- Gently undulating to rolling with steep peripheral slopes referred to as plateau footslopes.

Reddish brown soils of high clay content that may qualify as Cambisols, Phaeozems, Mollisols (Inceptisols, Molisols, Alfisols) and in places Vertisols.

- Dominantly grasses of various types and few scattered eucalyptus trees. On the footslopes where the soils are shallow, stony and rocky, bushes are common.

- Largely cultivated with barley, wheat, beans and peas. The remaining area is reserved for grazing and hay.
iv) Plains: These are areas extending from the foot of mountains, hills or plateaux with gentle to very gentle slopes. They can be of two types - erosional such as piedmont plains or depositional such as pyroclastic and alluvial plains. Only the latter are identified in the survey area.

- Basalt, consolidated to semi-consolidated ashes of basic composition (trachytic) and alluvium.

- Generally gently sloping but locally moderately steep, particularly along rivers and fault scars.

- Mostly Vertisols (Pellusterts) while Fluvisols, Cambisols and Phaeozems (Entisols and Hollosols) may be found along rivers and eroded areas.

- Except for the very few scattered eucalyptus trees nearly all areas are cultivated with few grazing areas. Crops grown include wheat, barley, teff (Eragrostis tef), bean, pea, lentil, chick pea, vetch and 'mow' (Guizota abyssinica). The remaining area left for grazing and hay is usually poorly drained land.

Although the field work of this area was completed in January 1975 the laboratory data is still not available to allow report writing. However, consolidation of the field data has revealed that there are at least 25 kinds of soils in the total survey area. When the laboratory data becomes available these may further be subdivided into more kinds.

3.4 THE FUTURE OF SOIL SURVEY AND LAND EVALUATION IN ETHIOPIA

From the above it is clear that soil survey and land evaluation work in Ethiopia is still in its initial stage. Except for the few reconnaissance surveys of some river basins and minor semidetailed studies, no important national scale surveys have been conducted so far. However, the demands for this type of study is great by the various organizations and institutions of the Government. These include the Soil and Water Conservation Division (SWCP), Extension and Project Implementation Division (EPID), Valleys Development Authority (VDA), National Water Resources Commission (NWRC), Arsi Rural Development Unit (ARDU), Wolaita Agricultural Development Unit (WADU), Ministry of Agriculture and Settlement, College of Agriculture, State Farms Authority and others who either undertake some of these studies or require data of this nature. The IAR is not yet ready to cater for the various demands, though it does render assistance and advice whenever possible. For the time being, close cooperation with the other organizations offers the best opportunity to satisfy the urgent needs.
As soil survey activities expand, there should be more joint studies, particularly with the Soil Fertility Section of IAR, EPID, SPA, ARNU, HADU, and SWCD as a contribution to establishing land evaluation criteria for various parts of the country. This work would benefit from Ethiopia's participation in the FAO-sponsored Eastern African Soil Correlation and Land Evaluation Committee as the experiences of other countries would be made use of.

As the College of Agriculture at Almaya and the Junior Agricultural Colleges of Jimma, Ambo, Debre Zeit and Awassa have not established soil science departments and are not offering enough courses in the subject, they are not yet producing the required personnel. Therefore, the building up of a cadre of qualified soil scientists is currently a very slow process. As a result, the expansion of soil survey and land evaluation work in Ethiopia is the foreseeable future can proceed only at even a slower pace.

Hence, unless something is done to strengthen the Agricultural Colleges so that they would be able to produce the required staff and unless the government establishes a soil survey institute immediately and send substantial numbers of people for specialized studies in foreign countries, at least until the Agricultural Colleges are strengthened, we would not be out of the dilemma for a long time to come. Therefore, I plea to the Government to take steps towards that goal. People in the planning and programming sections should be aware of this critical situation.
APPENDIX I

DEFINITION OF DIAGNOSTIC HORIZONS AND PROPERTIES

Soil horizons that have a set of quantitatively defined properties which are used for identifying soil units are called "diagnostic horizons". Since the characteristics of soil horizons are produced by soil-forming processes, the use of diagnostic horizons for separating soil units ensures that the classification system is based on general principles of soil genesis.

Objectivity is secured, however, in that the processes themselves are not used as criteria but only their effects, expressed quantitatively in terms of morphological properties that have identification value.

The definitions and nomenclature of the diagnostic horizons used here are drawn from those adopted in Soil Taxonomy (U.S. Soil Conservation Service, 1974). The definitions of these horizons have been summarized and sometimes simplified in accordance with the requirements of the FAO/UNESCO Legend. Reference is made to soil taxonomy for additional information on the concepts underlying the definitions of the diagnostic horizons and for detailed descriptions of their characteristics. Where there was compatibility between horizons designations and diagnostic horizons the ABC terminology has been combined with the diagnostic qualification.

1. HISTIC H. HORIZON

The histic H horizon is an H horizon which is more than 20 cm but less than 40 cm thick. It can be more than 40 cm but less than 60 cm thick if it consists of 75 percent or more, by volume, of sphagnum fibres or has a bulk density when moist of less than 0.1.

A surface layer of organic material less than 25 cm. thick also qualifies as a histic E horizon, if after having been mixed to a depth of 25 cm it has 28 percent or more organic matter and the mineral fraction contains more than 60 percent clay, or 14 percent or more organic matter and the mineral fraction contains no clay, or intermediate proportions of organic matter for intermediate contents of clay. The same criteria apply to a plough layer which is 25 cm or more thick.

A histic H horizon is eutric when it has a pH (H_2O, 1:5) of 5.5 or more throughout; it is deptric when the pH (H_2O, 1:5 is less than 5:5 in at least a part of the horizon.

2. MOLLIC A HORIZON

The mollic A horizon is an A horizon which, after the surface 18 cm are mixed, as in ploughing, has the following properties:

-
1. The soil structure is sufficiently strong, so that the horizon is not both massive and hard or very hard when dry. Very coarse prisms larger than 30 cm in diameter are included in the meaning of massive if there is no secondary structure within the prisms.

2. Both broken and crushed samples have colours with a chroma of less than 3.5 when moist, a value darker than 3.5 when moist, and 5.5 when dry; the colour value is at least one unit darker than that of the C (both moist and dry). If a C horizon is not present, comparison should be made with the horizon immediately underlying the A horizon. If there is more than 40 percent finely divided lime, the limits of colour value dry are waived - the colour value, moist, should then be 5 or less.

3. The base saturation is 50 percent or more (by the NH\textsubscript{4}OAc method).

4. The organic matter content is at least 1 percent throughout the thickness of mixed soil, as specified below. The organic matter content is at least 4 percent if the colour requirements are waived because of finely divided lime. The upper limit of organic carbon content of the mollic A horizon is the lower limit of the histic H horizon.

5. The thickness is 10 cm or more if resting directly on hard rock, a petrocalcic horizon, a pterogypsic horizon or a duripan; the thickness of the A must be at least 18 cm and more than one third of the thickness of the solum where the solum is less than 75 cm thick, and must be more than 25 cm where the solum is more than 75 cm thick.

6. The content of \(\text{P}_{2}\text{O}_{5}\) soluble in 1 percent citric acid is less than 250 ppm, unless the amount of \(\text{P}_{2}\text{O}_{5}\) soluble in citric acid increases below the A horizon or when it contains phosphat nodules, as may be the case in highly phosphatic parent materials. This restriction is made to eliminate plough layers of very old arable soils or kitchen middens. Such a horizon is an anthropic A horizon. Because of the scale of the map it has not been possible to use it as a diagnostic horizon.

3. **UMBRIC A HORIZON**

   The requirements of the umbric A horizon are comparable to those of the mollic A horizon in colour, organic matter and phosphorus content, consistency, structure and thickness. The umbric A horizon, however, has a base saturation of less than 50 percent (by the NH\textsubscript{4}OAc method). The restriction against a massive and hard or very hard or very hard horizon when dry is applied only to those A horizons that become dry. If the horizon is always moist, there is no restriction on its consistency or structure.

   Horizons which have acquired the above requirements through the slow addition of materials under cultivation are excluded from the umbric A horizon. Such horizons are plaggen A horizon. Because of the scale of the map it has not been possible to separate soils which are characterized by such man-made surface layers.
4. **OCHRIC A HORIZON**

An ochric A horizon is one that is too light in colour has too high a chroma, too little organic matter, or is too thin to be mollic or umbric, or is both hard and massive when dry.

In separating Yermosols from Xerosols a distinction is made between very weak and weak ochric horizon:

1. A very weak ochric A horizon has a very low content of organic matter with a weighted average percentage of less than 1 percent in the surface 40 cm if the weighted average sand/clay ratio for this depth is 1 or less; or less than 0.5 percent organic matter if the weighted sand/clay ratio is 13 or more; for intermediate sand/clay ratios the organic matter content is intermediate. When hard rock, a petrocalcic horizon, a petrogypsic horizon or a duripan occur between 18 and 40 cm, the contents of organic matter mentioned above are respectively less than 1.2 and 0.6% in the surface 18 cm of the soil.

2. A weak ochric A horizon has a content of organic matter which is intermediate between that of the very weak ochric A horizon and that required for the mollic A horizon.

5. **ARGILLIC B HORIZON**

An argillic B horizon is one that contains illuvial layer-attic clays. This horizon forms below an eluvial horizon, but it may be at the surface if the soil has been partially truncated. The argillic B horizon has the following properties:

1. If an eluvial horizon remains, the argillie B horizon contains more total and more fine clay than the eluvial horizon, exclusive of differences which may result from a lithological discontinuity. The increase in clay occurs within a vertical distance of 30 cm or less:

   a) if any part of the eluvial horizon has less than 15 percent total clay in the fine earth (less than 2 mm) fraction, the argillie B horizon must contain at least 3 percent more clay (for example, 13 percent versus 10 percent);

   b) if the eluvial horizon has more than 15 percent and less than 40 percent total clay in the fine earth fraction, the ratio of the clay in the argillie B horizon to that in the E horizon must be 1.2 or more;

   c) if the eluvial horizon has more than 40 percent total clay in the fine earth fraction. The argillie B horizon must contain at least 8 percent more clay (for example, 50 percent versus 42 percent).
2. An argillie B horizon should be at least one tenth the thickness of the sum of all overlying horizons, or more than 15 cm. thick if the eluvial and illuvial horizons are thicker than 150 cm. If the B horizon is sand or loamy sand, it should be at least 15 cm thick; if it is loamy or clayey, it should be at least 7.5 cm thick. If the B horizon is entirely composed of lamellae, the lamellae should have a thickness of 1 cm or more and should have a combined thickness of at least 15 cm.

3. In soils with massive or single grained structure the argillie B horizon has oriented clay bridging the sand grains and also in some pores.

4. If peds are present, an argillie B horizon either:

   a) Shows clay skins on some of both the vertical and horizontal ped surfaces and in the pores, or shows oriented clays in 1 percent or more of the cross-section;

   b) if the B has a broken or irregular upper boundary and meets requirements of thickness and textural differentiation as defined under 1 and 2 above clay skins should be present at least in the lower part of the horizon.

   c) If the B horizon is clayey with kaolinitic clay and the surface horizon has more than 40 percent clay, there are some clay skins on peds and in pores in the lower part of that horizon having blocky or prismatic; or

   d) if the B horizon is clayey with 2 to 1 lattice clays, clay skins may be lacking, provided there are evidences of pressure caused by swelling, or if the ratio of fine to total clay in the B horizon is greater by at least one third than the ratio in the overlying or the underlying horizon, or if it has more than 8 percent more fine clay; the evidences of pressure may be occasional slickensides or wavy horizon boundaries in the illuvial horizon, accompanied by uncoated sand or silt grains in the overlying horizon.

5. If a soil shows a lithologic discontinuity between the eluvial horizon and the argillie B horizon, or if only a plough layer overlies the argillie D horizon, the horizon need show clay skins in only some part, either in some fine pores or, if peds exist, on some vertical and horizontal ped surfaces. Thin sections should show that some part of the horizon has about 1 percent or more of oriented clay bodies, or the ration of fine clay to total clay should be greater by at least on third than in the overlying or the underlying horizon.

6. The argillie D horizon lacks the set of properties which characterize the natric B horizon.

6. CABRIC B HORIZON

   A cabric B horizon is one altered horizon lacking properties that meet the requirements of an argillie, natric or spodic B horizon; lacking the dark colours, organic matter content and structure of the histic A, or the mollic and umbric A horizon; showing no cementation, induration or brittle consistence when moist, having the following properties:
1. Texture that is very fine sand, loamy very fine sand or finer.

2. Soil structure or absence of rock structure in at least half the volume of the horizon.

3. Significant amounts of weatherable minerals reflected by a cation exchange capacity (by NH₄OAC) of more than 16 meq per 100 g clay, or by a content of more than 3 percent weatherable minerals other than muscovite, or by more than 6 percent muscovite.

4. Evidence of alternation in one of the following forms:
   a) higher clay content than the underlying horizon;
   b) stronger chroma or redder hue than the underlying horizon;
   c) evidence of removal of carbonates (when carbonates are present in the parent material or in the dust that falls on the soil) reflected particularly by a lower carbonate content than the underlying horizon of calcium carbonate accumulation, if all coarse fragments in the underlying horizon are completely coated with lime, some in the cambic horizon are partly free of coatings; if the coarse fragments are coated only on the underside, those in the cambic horizon should be free of coatings;
   d) evidence of reduction processes or of reduction and segregation of iron reflected by dominant moist colours on ped faces; or in the matrix if peds are absent, is as follows:
      i) chromas of 2 or less if there is mottling,
      ii) if there is no mottling and the value is less than 4, the chroma is less than 1; if the value is 4 or more the chroma is 1 or less,
      iii) the hue is no bluer than 10 y if the hue changes on exposure to air.

5. Enough thickness that its base is at least 25 cm below the soil surface.

8. OXIC B HORIZON

The oxic B horizon is a horizon that is not argillic or matric and that:

1. Is at least 30 cm thick
2. Has a fine-earth fraction that retains 10 meq of less ammonium ions per 100 g clay from an unbuffered NH₄Cl solution, or has less than 10 meq of bases extractable with NH₄OAC plus aluminium extractable with KCl per 100 g clay.

3. Has an apparent cation-exchange capacity of the fine earth fraction of 16 meq or less per 100 g clay by NH₄OAC unless there is an appreciable content of aluminum-interlayered chlorite.
4. Does not have more than traces of primary aluminosilicates such as feldspars, micas, glasses, and ferromagnesian minerals.

5. Has texture of sandy loam or finer in the fine earth fraction and has more than 15 percent clay.

6. Has mostly gradual or diffuse boundaries between its subhorizons.

7. Has less than 5 percent by volume showing rock structure.

9. CALCIC HORIZON

The calcic horizon is a horizon of accumulation of calcium carbonate. The accumulation may be in the C horizon, but it may also occur in a B or in an A horizon.

The calcic horizon consists of secondary carbonate enrichment over a thickness of 15 cm or more, has a calcium carbonate equivalent content of 15 percent or more and at least 5 percent greater than that of the C horizon. The latter requirement is expressed by volume if the secondary carbonates in the calcic horizon occur as pendants on pebbles, or as concretions or soft powdery forms, if such a calcic horizon rests on very calcareous materials (40% or more calcium carbonate equivalent), the percentage of carbonates need not decrease with depth.

10. GYPSIC HORIZON

The gypsic horizon is a horizon of secondary calcium sulfate enrichment that is more than 15 cm thick, has at least 5 percent more gypsum than the underlying C horizon, and in which the product of the thickness in centimeters and the percent of gypsum is 150 or more. If the gypsum content is expressed in me per 100 g of soil, the percentage of gypsum can be calculated from the product of the me of gypsum per 100 g of soil and the me weight of gypsum, which is 0.006. Gypsum may accumulate uniformly throughout the matrix or as nests of crystals; gravelly material gypsum may accumulate as pendants below the coarse fragments.

11. SULFURIC HORIZON

The sulfuric horizon forms as a result of artificial drainage and oxidation of mineral or organic materials which are rich in sulfides. It is characterized by a pH less than 3.5 (H₂O, 1:1) and jarosite mottles with a hue of 2.5 or more and a chroma of 6 or more.

12. ALBIC E HORIZON

The albic E horizon is one from which clay and free iron oxides have been removed, or in which the oxides have been segregated to the extent that the colour of the horizon is determined by the colour of the primary sand and silt particles rather than by coatings on these particles.
An albic E horizon has a colour value moist of 4 or more, or a value dry of 5 or more, or both. If the value dry is 7 or more, or the value moist is 6 or more, the chroma is 3 or less. If the parent materials have a hue of 5YR or redder, a chroma moist of 3 is permitted in the albic E horizon where the chroma is due to the colour of uncoated silt or sand grains.

An albic E horizon may overlie a spodic B, an argillic or natric B, a fragipan, or an impervious layer that produces a perched waterable.

**Diagnostic properties**

A number of soil characteristics which are used to separate soil units cannot be considered as horizons. They are rather diagnostic features of horizons or of soils which when used for classification purposes need to be quantitatively defined.

13. **ABRUP T TEXTURAL CHANGE**

An abrupt textural change is a considerable increase in clay content within a very short distance in the zone of contact between an A or an E horizon and the underlying horizon. When the A or E horizon has less than 20 percent clay, the clay content of the underlying horizon is at least double that of the A or E horizon within a vertical distance of 8 cm or less. When the A or E horizon has 20 percent clay or more the increase in clay content should be at least 20 percent (for example, from 30 to 50 percent clay) within a vertical distance of 8 cm or less, and the clay content in some part of the underlying horizon (B horizon or impervious layer) should be at least double that of the A or E horizon above.

14. **ALBIC MATERIAL**

Albic materials are exclusive of E horizons, and have a colour value moist of 4 or more, or a value dry 5 or more, or both. If the value dry is 7 or more, or the value moist is 6 or more, the chroma is 3 or less. If the parent materials have a hue of 5YR or redder, a chroma moist of 3 is permitted if the chroma is due to the colour of uncoated silt or sand grains.

15. **ARIDIC MOISTURE REGIME**

The concept of aridic moisture regime is used to characterize Yermosols and xerosols and to separate them from soils, outside arid areas, which have a comparable morphology. In most years these soils have no available water in any part of the moisture control section more than half the time (cumulative) that the soil temperature at 50 cm is above 5°C (the moisture control section lies approximately between 10 and 30 cm for medium to fine textures, between 20 and 60 cm for medium to coarse textures, and between 30 and 90 cm for coarse textures). There is no period as long as 90 consecutive days when there is moisture in some or all parts of the moisture control section while the soil temperature at 50 cm is continuously above 8°C. In most years the moisture, control section is never moist in all parts for as long as 60 consecutive days during 3 months following the winter solstice if mean summer and mean winter temperatures is less than 22°C.
16. **EXCHANGE COMPLEX DOMINATED BY AMORPHOUS MATERIALS**

An exchange complex that is dominated by amorphous material shows the following characteristics:

1. The cation exchange capacity of the clay at pH 8 is more than 150 me per 100 g measured clay, and commonly is more than 500 me per 100 g clay. The high value is, in part, the result of poor dispersion.

2. If there is enough clay to give a 15-bar water content of the soil of 20 percent or more, the pH of a suspension of 1 g soil in 50 ml H NaF is more than 9.4 after 2 minutes.

3. The ratio 15-bar water content to measured clay is more than 1.0.

4. The amount of organic carbon exceeds 0.6 percent.

5. Differential thermal analysis shows a low temperature endotherm.

6. The bulk density of the fine earth fraction is less than 0.85 g per cm$^3$ at 1/3 bar tension.

17. **FERRALIC PROPERTIES**

The term ferralic properties are used in connexion with cambisols and Arenosols which have a cation exchange capacity (from NH$_4$Cl) of less than 24 me per 100 g clay in respectively, at least some subhorizon of the cambic B horizon or immediately underlying the A horizon.

18. **FERRIC PROPERTIES**

The term ferric properties is used in connexion with Luvisols and Acrisols showing one or more of the following: many coarse mottles with hues redder than 7.5 YR or chromas more than 5, or both; discrete nodules, upto 2 cm in diameter, the exteriors of the nodules being enriched and weakly cemented or indurated with iron and having redder hues or stronger chromas than the interiors; a cation exchange capacity (from NH$_4$Cl) of less than 24 meq per 100 g clay in at least some subhorizon of the argillic B horizon.

19. **GILGAII MICRORELIEF**

Gilgai is the microrelief typical of clayey soils that have a high coefficient of expansion with distinct seasonal changes in moisture content. This microrelief consists of either a succession of enclosed microbasins and microknolls in nearly level areas, or of micro valleys and microridges that run up and down the slope. The height of the microridges commonly ranges from a few cm to 1 m. Rarely does the height approach 2 m.
20. **HIGH ORGANIC MATTER CONTENT IN THE B HORIZON**

For Ferralsols and Nitosols of low base saturation the terminology "high organic matter content in the B horizon" refers to an organic matter content (weight average of the fine earth fraction of the soil) of 1.35 percent or more to a depth of 100 cm (exclusive of an O horizon if present); for Acrisols a high organic matter content in the B horizon means one or both of 1.5 percent or more organic matter in the upper part of the B horizon, or an organic matter content (weighted average of the fine earth fraction of the soil) of 1.35 percent or more to a depth of 100 cm (exclusive of an O horizon if present).

21. **HIGH SALINITY**

The term "high salinity" applies to soils which have an electric conductivity of the saturation extract of more than 15 mmhos per cm at 25°C at some time of the year, within 125 cm of the surface when the weighted average textural class of the surface is coarse, within 50 cm for medium textures, within 75 cm for fine textures, or of 4 mmhos within 25 cm of the surface if the pH (H₂O, 1:1) exceeds 8.5.

22. **HYDROMORPHIC PROPERTIES**

A distinction is made between soils which are strongly influenced by groundwater, the Gleysols, and the soils of which only the lower horizons are influenced by groundwater or which have a seasonally perched water table within the profile, the "gleyic" groups. The Gleysols have a reducing moisture regime virtually free of dissolved oxygen due to saturation by groundwater or its capillary fringe. Since hydromorphic processes are dominant, the occurrence of argillic, natric, spodic and oxic B horizons is excluded from Gleysols by definition.

The morphological characteristics which reflect waterlogging differ widely in relation to other soil properties. For the sake of brevity, the expression "hydromorphic properties" is used in the definition of Gleysols and gleyic groups. This term refers to one or more of the following properties:

1. Saturation by groundwater, that is, when water stands in a deep unlined bore hole at such a depth that the capillary fringe reaches the soil surface; the water in the bore hole is stagnant and remains coloured when a dye is added to it.

2. Occurrence of a histic H horizon.

3. Dominant hues that are neutral N, or bluer than 10Y

4. Saturation with water at some period of the year or artificially drained, with evidence of reduction processes or of reduction and segregation of iron reflected by:
4.1 In soils having a spodic B horizon, one or more of the following:

a) Mottling in an albic E horizon or in the top of the spodic B horizon;

b) A duripan in the albic E horizon;

c) if free iron and manganese are lacking, or if moist colour values are less than 4 in the upper part of the spodic B horizon, either:
   i) no coatings of iron oxides on the individual grains of silt and sand in the materials in or immediately below the spodic horizon wherever the moist values are 4 or more and, unless an Ap horizon rests directly on the spodic horizon, there is a transition between the albic E and spodic B horizon at least 1 cm in thickness, or
   ii) fine or medium mottles of iron or manganese in the materials immediately below the spodic B horizon;

d) a thin iron pan that rests on a fragipan or on a spodic B horizon, or occurs in an albic E horizon underlain by a spodic B horizon.

4.2 in soils having a mollic A horizon. If the lower part of the mollic A horizon has chroma of 1 or less, either:

a) distinct or prominent mottles in the lower mollic A horizon, or

b) colours immediately below the mollic A horizon or within 75 cm of the surface if a calcic horizon intervenes, with one of the following:
   i) if hues are 10YR or redder and there are mottles, chromas of less than 1.5 on ped surfaces or in the matrix; if there are no mottles chromas of less than 1 (if hues are redder than 10YR because of parent materials, that remains red after citrate dithionite extraction the requirement for low chroma is waived)
   ii) if the hue is nearest to 2.5Y and there are distinct or prominent mottles, chromas of 2 or less on ped surfaces or in the matrix; if there are no mottles, chromas of 1 or less.
   iii) if the nearest hue is 5Y or yellower and there are distinct or prominent mottles, chromas of 3 or less on ped surfaces or in the matrix, and if there are no mottles, chromas of 2 or less.
   iv) hues bluer than 10Y
v. any colour if the colour results from uncoated mineral grain.

vi) colours neutral N.

If the lower part of the mollic A horizon has chromas of more than 1 but not exceeding 2 either:

a) distinct or prominent mottles in the lower mollic A horizon; or
b) base colors immediately below the mollic A horizon that have one or more of:

i) Values of 4 and chromas of 2 accompanied by some mottles with values of 4 or more and chromas of less than 2.

ii) values of 4 and chromas of less than 2

iii) values of 5 or more and chromas of 2 or less accompanied by mottles with high chroma.

4.3 in soils having an argillic B horizon immediately below the plough layer or an A horizon that has moist colour values of less than 3.5 when rubbed, one or more of the following:

a) moist chromas of 2 or less;

b) mottles due to segregation of iron;

c) iron-manganese concretions larger than 2 mm, and combined with one or more of the following:

i) dominant moist chromas of 2 or less in coatings on the surface of peds accompanied by mottles within the peds, or dominant moist chromas of 2 or less in the matrix of the argillic B horizon accompanied by mottles of higher chroma (if hues are redder than 10YR because of parent materials that remain red after citrate dithionite extraction, the requirement for low chromas is waived).

ii) moist chromas of 1 or less on surfaces of peds or in the matrix of the argillic B horizon.

iii) dominant hues of 2.5Y or 5Y in the matrix of the argillic B horizon accompanied by distinct or prominent mottles.

4.4 in soils having an oxic B horizon:

a) plinthite that forms a continuous phase within 30 cm;

b) if free of mottles-dominant chromas of 2 or less immediately below an A horizon that has a moist colour value of less than 3.5; or if mottled with distinct or prominent mottles within 50 cm of the surface, dominant chromas of 3 or less.

4.5 in other soils

a) in horizons with textures finer than loamy fine sand:
i) if there is mottling, chromas of 2 or less

ii) if there is no mottling and values are less than 4, chromas of less than 1, if values are 4 or more, chromas of 1 or less;

b) in horizons with textures of loamy fine sand or coarser:

i) if hues are as red as or redder than 10YR and there is mottling, chromas of 2 or less; if there is no mottling and values are less than 4, chromas of less than 1, or if values are 4 or more, chromas of 1 or less.

ii) if hues are between 10YR and 10Y and there is distinct or prominent mottling, chromas of 3 or less; if there is no mottling, chromas of 1 or less.

PERMAFROST

Permafrost is a layer in which the temperature is perennially at or below 0°C.

PLINTHITE

Plinthite is an iron-rich, humus-poor mixture of clay with quartz and other detritus, which commonly occurs as red mottles, usually in plagioclase or reticulate patterns, and which changes irreversibly to an ironstone hardpan or to irregular aggregates on exposure to repeated wetting and drying. In a moist soil, plinthite is usually firm but it can be cut with a spade. When irreversibly hardened the material is no longer considered plinthite but is called ironstone.

SLICKENSIDES

Slickensides are polished and grooved surfaces that are produced by one mass sliding past another. Some of them occur at the base of a slip surface where a mass of soil moves downward on a relatively steep slope. Slickensides are very common in swelling clays in which there are marked changes in moisture content.

SMEARY CONSISTENCE

The term "smeary consistence" is used in connexion with Andosols characterized by thixotropic soil material, that is, material that changes under pressure or by rubbing from a plastic solid into a liquidified stage and back to the solid condition. In the liquidified stage the material skids or "smears" between the fingers.

SOFT POWDERY LIME

Soft powdery lime refers to translocated authigenic lime, soft enough to be cut readily with a fingernail, precipitated in place from the soil solution rather than inherited from a soil parent material. It should be present in a significant accumulation.
To be identifiable, soft powdery lime must have some relation to the soil structure of fabric. It may disrupt the fabric to form spheroidal aggregates, or white eyes, that are soft and powdery when dry, or the lime may be present as soft coatings in pores on structural faces. If present as coatings, it covers a significant part of the surface; commonly, it coats the whole surface to a thickness of 1 to 5 mm or more. Only part of a surface may be coated if little lime is present in the soil. The coatings should be thick enough to be visible when moist and should cover a continuous area large enough to be more than filaments. Pseudomycelia which come and go with changing moisture conditions are not considered as soft powdery lime in the present definition.

SULFIDIC MATERIALS

Sulfidic materials are waterlogged mineral or organic soil materials containing 0.75 percent or more sulfur (dry weight), mostly in the form of sulfides, and having less than three times as much carbonates (CaCO₃ equivalent) as sulfur. Sulfidic materials accumulate in the soil that is permanently saturated, generally with brackish water. If the soil is drained the sulfides oxidize to form sulfuric acid; and the pH, which normally is near neutrality before drainage, drops below 3.5. Sulfidic material differs from the sulfuric horizon in that it does not show jarosite mottles with a hue of 2.5Y or more or a chroma of 6 or more.

TAKYRIC FEATURES

Soils with takyric features have a heavy texture, crack into polygonal elements when dry and form a platy or massive surface crust.

TONGUING

As used in the definition of Podzoluvisols, the term tonguing is connotative of the penetration of an albic B horizon into an argillic B horizon along ped surfaces, if peds are present. Penetrations to be considered tongues must have greater depth than width, have horizontal dimensions of 5 mm or more in fine textured argillic horizons (clay silty clay and sandy clay), 10 mm or more in moderately fine textured argillic horizons (silty loams, loams, very fine sandy loams, or coarser), and must occupy more than 15 percent of the mass of the upper part of the argillic horizon.

With chernozems, the term tonguing refers to penetrations of the A horizon into an underlying cambic B horizon or into a C horizon. The penetrations must have greater depth than width, and must occupy more than 15 percent of the mass of the upper part of the horizon in which they occur.

VERTIC PROPERTIES

The term "vertic properties" is used in connection with cambisols and luvisols which at some period in most years show cracks that are 1 cm or more wide within 50 cm of the upper boundary of the B horizon and extend to the surface or at least to the upper part of the B horizon.
Appendix II Definitions of Soil Units

The definitions of soil units given in this section are listed in the order in which they are shown on the legend of the accompanying map. For the sake of brevity the definitions include only a limited number of necessary characteristics, sufficient to separate the different units. The soil diagnostic horizons and diagnostic properties used in this section have been defined in appendix I.

1. The soils defined below have their upper boundary at the surface, or at least 50 cm below the surface when they are covered with a mantle of new material. In other words, horizons buried by 50 cm or more newly deposited surface material are no longer diagnostic for classification purposes.

2. The definitions listed do not express differences in soil temperature and soil moisture unless such differences are also reflected by other soil characteristics which can be preserved in samples. An exception to this rule is made for soils with an aridic moisture regime — Yermosols and Xerosols — since soil moisture in this case is the only characteristic by which these soils can be separated from others with a similar morphology.

3. When two or more B horizons occur within 125 cm of the surface it is the upper B horizon which is determining for the classification, as long as it is sufficiently developed to meet the requirements of the diagnostic horizon.

4. The terminology "having no diagnostic horizons other than" indicates that one or more of the diagnostic horizons listed may be present.

5. For all definitions given, except for the lithosols, it is implied that the soil is not limited in depth by continuous coherent and hard rock within 10 cm of the surface.

6. The analytical data which are used in the definitions are based on laboratory procedures described in "Soil Survey laboratory methods and Procedures for Collecting Soil Samples" (U.S. Soil Conservation Service, 1967).

These soils are defined as follows:

1. Acrisols: (From L. Acris, very acid; connotative of low base saturation). These are soils having an argillie B horizon with a base saturation of less than 50 percent (by NH₄OAc) at least in the lower part of the B horizon within 125 cm of the surface; lacking a mollic A horizon; lacking an albic E horizon overlying a slowly permeable horizon, the distribution pattern of the clay and the tonguing which are diagnostic for Planosols, Nitosols and Podzoluvisols respectively; lacking an aridic moisture regime.
1.1 Ferric Acrisols (from L. ferrugineus soils). Acrisols having an ochric A horizon; showing ferric properties; lacking a high organic matter content in the B horizon; lacking plinthite within 125 cm of the surface, lacking hydromorphic properties within 50 cm of the surface.

1.2 Orthic Acrisols: (from Gr. Orthos, true, right; connotative of common occurrence). As Ferric Acrisols but lacking ferric properties.

2. Cambisols (From late L. Cambiare, change; connotative of changes in colour, structure and consistence resulting from weathering in site).

These are soils having a cambic B horizon and (unless buried by more than 50 cm or more new material) no diagnostic horizons other than an ochric or an umbric A horizon, a calcic or gypsic horizon, the cambic B horizon may be lacking when an umbric A horizon is present which is thicker than 25 cm. Lacking high salinity, lacking the characteristics diagnostic for vertisols or Andosols; lacking an aridic moisture regime; lacking hydromorphic properties within 50 cm of the surface.

2.1 Dystric Cambisols: (from Gr. dys, ill, distrophic, infertile). Cambisols having an ochric A horizon and a base saturation (by NH₂OAc) of less than 50 percent at least between 20 and 50 cm from the surface; lacking ferric properties in the Cambic B horizon; lacking hydromorphic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

2.2 Eutric Cambisols: (from Gr. eu, good, cutrophic, fertile) As Dystric cambisols but having a base saturation (by NH₂OAc) of 50 percent or more at least between 20 and 50 cm from the surface but which are not calcareous within this depth; lacking vertic properties; having a cambic B horizon not strong brown to red.

2.3 Humic Cambisols: (from L. humus, earth, rich in organic matter.) Cambisols having an Umbric A horizon which is thicker than 25 cm when a cambic B horizon is lacking, lacking vertic properties; lacking hydromorphic properties within 100 cm of the surface, lacking permafrost within 200 cm of the surface.

2.4 Calcic Cambisols: (from L. Calxis, lime; connotative of strong accumulation of calcium carbonate.)

Cambisols having an Ochric A horizon and showing one or more of the following: a calcic horizon, a gypsic horizon or concentrations of soft powdery lime within 125 cm of the surface; calcareous at least between 20 and 50 cm from the surface; lacking vertic properties; lacking hydromorphic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.
3. Ferralsols: (from L. ferrum and alluminum, connotative of a high content of sesquioxide.)

These are soils having an oxic B horizon.

3.1 Plinthic Ferralsols: (from Gr. plinthos, brick; connotative of method clayey materials which harden irreversibly upon exposure.)

Ferralsols having plinthite within 125 cm of the surface.

4. Lithosols: (from Gr. lithos, stone; connotative of soils with hard rock at very shallow depth.)

Soils which are limited in depth by continuous coherent hard rock within 10 cm of the surface.

5. Fluvisols (from L. fluvius, river; connotative of floodplains and alluvial deposits.)

Soils developed from recent alluvial deposits having no diagnostic horizons other than (unless buried by 50 cm or more new material) an ochric or an umbric A horizon, a histic H horizon, or a sulfuric horizon. As used in this definition, recent alluvial deposits are fluviatile, marine, lacustrine, or colluvial sediments characterized by one or more of the following properties:

a) having an organic matter content that decreases irregularly with depth or that remains above 0.35 percent to a depth of 125 cm (thin strata of sand may have less organic matter if the finer sediment below meets the requirements).

b) receiving fresh material at regular intervals and/or showing fine stratification;

c) having sulfidic material within 125 cm of the surface.

5.1 Calcaric Fluvisols: (from L. calcium; connotative of an accumulation of calcium carbonate.)

Fluvisols which are calcareous at least between 20 and 50 cm from the surface; lacking a sulfuric horizon and sulfidic material within 125 cm of the surface.

5.2 Eutric Fluvisols: (from Gr. eu, good, eutrophic, fertile)

Fluvisols having a base saturation (by NH₄Cl) of 50 percent or more at least between 20 and 50 cm from the surface but which are not calcareous at the same depth; lacking a sulfuric horizon and sulfidic material within 125 cm of the surface.

6. Nitosols: (from L. nitidenus, shiny; connotative of shiny ped surfaces.)

Soils having 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 percent within 150 cm of the surface; lacking a molic A horizon; lacking an albic E horizon; lacking the ongoing which is diagnostic for the Podzoluvisols; lacking ferric and vertic properties; lacking plinthite within 125 cm of the surface; lacking an aridic moisture regime.
6.1 Eutric Nitosols: (from Gr. eu, good; eutrophic, fertile.) 
Nitosols having a base saturation of 50 percent or more 
(by NH₄OAc) throughout the argillic B horizon within 125 cm 
of the surface.

7. Arenosols: (from L. Arena, sand, connotative of weakly developed 
coarse - textured soils)
Soils from coarse - textured unconsolidated materials, exclusive 
of recent alluvial deposits, consisting of albic material occurring 
over a depth of at least 50 cm from the surface or showing charac­
teristics of argillic, cambic or oxic B horizons which, however, 
do not qualify as diagnostic horizons because of textural require­
ments; having no diagnostic horizons (unless buried by 50 cm or 
more new material) other than an Ochric A horizon; lacking hydromo­
orphic properties within 50 cm of the surface; lacking high salinity.

7.1 Cambic Arenosols: (from lato L. Cambiare, change, connotative 
of changes in colour, structure or consistence resulting from 
weathering in situ )
Arenosols showing colouring or alteration characteristics of 
a cambic B horizon immediately below the A horizon; lacking 
lamellae of clay accumulation; lacking ferra lic properties.

8. Regosols: (Prom Gr. rhegos, blanket; connotative of mantle of loose 
material overlying the hard core of the earth; soils with weak or 
no development.)
Soils from un consolidated materials, exclusive of recent alluvial 
deposits having no diagnostic horizons (unless buried by 50 cm or 
more new material) other than an ochric A horizon; lacking hydro­
morphic properties within 50 cm of the surface; lacking the chara­
teristics which are diagnostic for Vertisols and Andosols; lacking 
high salinity; when coarse textured lacking lamellae of clay 
accumulation, features of cambic or oxic B horizon or albic material 
which are characteristic of Arenosols:

8.1 Calcaric Regosols: (from L. calcium; connotative of the presence 
of calcium carbonate).
Regosols which are calcareous at least between 20 and 50 cm 
from the surface.

8.2 Dystric Regosols: (from Gr. dys, ill, dystrophic, infertile) 
Regosols having a base saturation (by NH₄OAc) of less than 
50 percent at least between 20 and 50 cm from the surface; 
lacking permafrost within 200 cm of the surface.

8.3 Eutric Regosols: (from Gr. eu, good, eutrophic, fertile) Re­
gosols having a base saturation (by NH₄OAc) of 50 percent or 
more at least between 20 and 50 cm from the surface but which 
are not calcareous within this depth; lacking permafrost within 
200 cm of the surface.
9. **Andosols**: (from Japanese An, dark, and Do, soil; connotative of soils formed from materials rich in Volcanic glass and commonly having a dark surface horizon).

Soils having a mollic or an umbric A horizon possibly overlying a cambic B horizon; having no other diagnostic horizons (unless buried by 50 cm or more new material); having to a depth of 35 cm or more one or both of:

a) a bulk density (at 1/3 bar water retention) of the fine earth (less than 2 mm) fraction of the soil of less than 0.85 gm/cm^3 and an exchange complex dominated by amorphous material;

b) 60 percent or more Vitric Volcanic ash, cinders, or other vitric pyroclastic material in the silt, sand and gravel fractions; lacking hydromorphic properties within 50 cm of the surface; lacking the characteristics which are diagnostic for Vertisols; lacking high salinity.

9.1 **Ochric Andosols**: (from Gr. Ochros, pale)

Andosols having an ochric A horizon and a cambic B horizon having a smearable consistence and/or having a texture which is silt loam or finer on the weighted average for all horizons within 100 cm of the surface.

10. **Vertisols**: (from L. Verto, turn; connotative of turnover of surface soil).

Soils having, after the upper 20 cm have been mixed, 30 percent or more clay in all horizon to a depth of at least 50 cm; developing or cks from the soil surface downward which at some period in most years (unless the soil is irrigated) are at least 1 cm wide to a depth of 50 cm; having one or more of the following: gilgai microrelief, intersecting slickensides, or wedge-shaped or parallel piped structural aggregates at some depth between 25 and 100 cm from the surface.

10.1 **Chromic Vertisols**: (from Gr. Chromos, colour; connotative of soils with a high chroma).

Vertisols having most chromas of 1.5 or more dominant in the soil matrix throughout the upper 30 cm.

10.2 **Pellic Vertisols**: (from Gr. pellos, dusky, lacking colour; connotative of soils with a low chroma).

Vertisols having most chromas less than 1.5 dominant in the soil matrix throughout the upper 30 cm.

11. **Xerosols**: (from Gr. Xeros, dry)

Soils occurring under an aridic moisture regime; having a weak ochric A horizon and one or more of the following: a cambic B horizon, an argillic B horizon, a calcic horizon a gypsic horizon; lacking other diagnostic horizons; lacking the characteristics which are diagnostic for Vertisols; lacking high salinity; lacking permafrost within 200 cm of the surface.)
11.1 Haplic Xerosols: (from Gr. Haplos, simple; connotative of soils with a simple, normal horizon sequence).

Xerosols having no diagnostic horizons other than a weak A horizon and a cambic B horizon.

11.2 Calcic Xerosols: (from L. Calxis lime; connotative of strong accumulation of calcium carbonate).

Xerosols having a calcic horizon within 125 cm of the surface; lacking an argillic B horizon overlying the calcic horizon.

11.3 Luvic Xerosols: (from L. luvii, from Lue, to wash, lessiver; connotative of illuvial clay accumulation).

Xerosols having an argillic B horizon; a calcic or a gypsic horizon may be present if underlying the B horizon.


Soils occurring under an aridic moisture regime; having a very weak ochric A horizon and one or more of the following: a cambic B horizon, an argillic B horizon, a calcic horizon, a gypsic horizon; lacking other diagnostic horizons; lacking the characteristic which are diagnostic for Vertisols; lacking high salinity; lacking permafrost within 200 cm of the surface.

12.1 Haplic Yermosols: (from Gr. haples simple; connotative of soils connotative of soils with a simple, normal horizon sequence. Yermosols having no diagnostic horizons other than a very weak A horizon and a cambic B horizon; lacking takyric features).

12.2 Gypsic Yermosols: (from L. Gypsum)

Yermosols having a gypsic horizon within 125 cm of the surface; lacking an argillic B horizon overlying a gypsic horizon; lacking takyric features.

12.3 Calcic Yermosols: (from L. Calxis, lime; connotative of a strong accumulation of calcium carbonate).

Yermosols having a calcic horizon within 125 cm of the surface; lacking an argillic B horizon overlying the calcic horizon, lacking takyric features.

13. Selonchates (from Russian Sol. Salt)

Soils, exclusive of those formed from recent alluvial deposits, having a high salinity and having no diagnostic horizons other than (unless buried by 50 cm or more new material) an A horizon a histric H horizon, a cambic B horizon, a calcic or a gypsic horizon.

13.1 Orthic Solonchaks: (from Gr. orthos, true, right; connotative of common occurrence).

Solonchaks having an ochric A horizon, lacking takyric features; lacking hydromorphic properties within 50 cm of the surface.
Minerals Stress Features:

Mineral stress phenomena considered here are nutritional deficiencies or toxicities which are inherent to the morphology and chemical composition of the soil and which often represent a serious constraint for crop production and land development.

It should be noted that different species or varieties may react very differently to high or low levels of mineral elements in soils. The relationships described below need, therefore, to be interpreted in terms of specific crops and their nutrient requirements.

I. For these soils, the formation of which is closely linked with the kind of parent material (e.g., Andosols, Arenosols, thionic Fluvisols, Histosols, Nitosols, Rendzinas, and Vertisols), mineral stress features are substratum related and, to a large extent, consistent within each group.

II. For other soils which are not limited to a narrow range of parent materials, mineral stress features may be related to a type of soil-forming process which, when active for a sufficient length of time, has imprinted specific properties on the soil group as a whole (E.g., Acrisols, Ferralsols, Chernozems, Kastanozems, Phaozems, Planosols, Podzols, Solonchaks, Solonetzs, Xerosols and Yermosols).

III. There is a third category of soils in which mineral stress features if they occur, are not consistent with soil classification units at a high level of generalization, mostly for reasons of great variability (E.g., Cambisols, Fluvisols, Lithosols, Luvisols, Podzoluvisols, Rankers, and Regosols). For these soils relationships between soil characteristic, plant nutrient status, and mineral stress features can be established at lower levels of the classification system.

Mineral stress features related to parent material and to soil forming processes are briefly discussed for the soil units listed below.

Acrisols

(From L. acris, vay acid) soils of tropical and subtropical areas with subsurface horizons of clay accumulation, low base status, and low content of weatherable minerals. Mineral stress features in these soils are associated with very strong leaching, strong acidity, depletion of bases, and possible toxicities of aluminum, manganese, and iron. Nitrogen deficiency is a general constraint for crop production on Acrisols. A low cation
exchange capacity, especially in the surface horizon, is often an obstacle to effective fertilization.

**Andosols**

(From Japanese an, dark and do, soil) Weakly developed soils on volcanic ash deposits of andesitic to basaltic nature, with a high proportion of easily weatherable minerals. These conditions lead to the formation of amorphous hydrated oxides which determine mineral stress phenomena because of their very high phosphate – borate –, and molybdate – fixing capacity by which these elements are easily converted into forms unavailable for most plants. A dominance of Mg over Ca may develop from the weathering of ferromagnesian silicates in basaltic volcanic ashes.

**Arenosols**

(From L. arena, sand) soils showing weak horizon differentiation and derived from sands with a large proportion of quartz. Consistent mineral stress phenomena observed in these soils are linked with a general paucity of fertility elements, an unsatisfactory water holding and cation-retaining capacity, and a deficiency in minor elements normally bonded to the clay or organic matter (Zn, Mn, Cu, Fe). Arenosols derived from quartz materials show consistent deficiency in potassium.

**Ferralsols**

(From L. ferrum and aluminum) Strongly weathered soils of tropical regions, consisting mainly of Kaolinite, quartz, and hydrated oxides, and having a low base exchange capacity. Mineral stress problems are mainly related to a low retention capacity and a strong fixation of phosphates by free sesquioxi-des and clay components with high fixing capacity. Specific mineral stress phenomena in ferralsols can be listed as follows:

- deficiency in bases (Ca, Ma, K) and incapability to retain bases are applied as fertilizers or amendments;
- Presence in acid Ferralsols (with pH in water below 5.2) of exchangeable aluminum, an element which is toxic for many plant species and highly active in the fixation of phosphates;
- Presence of free manganese in acid Ferralsols, likewise toxic for a number of species;
- fixation of phosphate on sesquioxide minerals;
- deficiency of molybdenum, especially for the growth of legumes;
- toxicities of iron and manganese shown by paddy rice.
It should be noted that for Ferralsols other than plinthic
Ferralsols, mineral stress is partly compensated by favourable
physical conditions which permit full root penetration and full
utilization of the profile by plant roots in search of moisture
and nutrients.

Eluvisols

(From L. Fluvius, river) weakly developed soils from alluvial
deposits in active flood plains. The great variability of
these soils, related to the wide range of materials from which
they are derived, does not permit the marking of specific stress
features for the group as a whole.

Gleysols

(From Russian Local name gley, mucky soil mass) soils in
which excess of water is a major factor in their formation.
Low oxidation potential reduces nitrification and availability
of manganese. Iron toxicity may occur while an excess of molybdenum
may result from poor drainage.

Nitosols

(From L. nitidus, shiny, lustrous, connotative for shiny
ped faces) Soils of tropical regions showing features of strong
weathering and deeply developed subsurface horizons of clay
accumulation. Mineral stress phenomena of Nitosols are similar
to those of Ferralsols but are much less acute. Base exchange
capacity is low but markedly higher than in Ferralsols. Moderate
phosphate fixation occurs in the presence of hydrated oxides.
Manganese toxicity may occur in the more acid Nitosols. The
favourable physical conditions of these soils, their relatively
good base retention capacity rank these soils among the most
responsive in the tropics.

Phaeozems

(From Greek Phaios, dusky, and Russian Zemlja, earth)
Soils of humid temperate forest - steppes and high grass
prairies, having a strong accumulation of organic matter in
the surface horizons, a high to medium base status, and showing
deep leaching of calcium carbonate. These soils are among
the most fertile in the world and do not, as a group, show
mineral stress features. Molybdenum toxicity may occur in
the more poorly drained members of this group.

Planosols

(From L. Planus, flat, level) Soils generally developed in
level or depressed topography showing strongly textural differentiation
and seasonal surface waterlogging. The growth of plants in
planosols is impeded by alternating periods of water excess
and severe drought. Strong leaching, furthermore, entails a lack
of nutrients combined with a low cation exchange capacity in the surface horizon. In strongly developed Planosols aluminum toxicity may occur.

Solonchaks

(From Russian sol, salt) Soils showing high concentrations of soluble salts which result in high osmotic pressure of the soil solution, moisture stress, and a hinderance to normal ion uptake by plants. Depending on the nature of the salts present, different anions and cations may occur in excess. The presence of boron in irrigation water or the accumulation of boron derived from certain parent materials — E.g. borosilicates present in loess deposits — may cause boron toxicity.

Vertisols

(From L. Verto, turn) Soils developed from swelling clays, showing deep and wide cracks when dry and a turn-over or surface material by self mulching. Stress features in Vertisols are mainly related to their moisture regime, characterized by the very narrow range between moisture stress and excess of water resulting from the very strong clay-water bonds of the expanding-type clay minerals. Base saturation in Vertisols is high with calcium and magnesium prevailing in the sorptive complex. In high pH Vertisols, phosphorus availability is generally low. Shortage of nitrogen may occur as a result of poor surface drainage and relatively low contents of organic matter. Irrigation may promote the formation of sulfides that remain free because of the limited amount of iron present. Sulfides may harm roots.

Xerosols

(From Greek xeros, dry) Soils of semi-arid areas, exclusive of strongly saline and sodium-saturated soils. These soils suffer from drought stress in most years. The lack of water supply is the most serious limiting factor to plant growth. When water is applied, mineral stress phenomena may result from high calcium carbonate content reduced availability of phosphorus, salinity and alkalinity hazards, and acute deficiency of iron and zinc. Xerosols may have high contents of gypsum which, besides causing serious physical problems, may induce magnesium and potassium deficiencies.

Yermosols

(From sp. Yermo, desert, derived from L. eremos, solitary, desolate) Soils of arid areas. Drought stress is a permanent characteristic of these soils. When water is supplied through irrigation, mineral stress features may occur similar to those described for Xerosols.

The mineral stress features reported above refer mainly to the growth of plants. It is equally important, however, to note that certain elements are of importance for plant quality with regard to human or animal nutrition. Selenium toxicity may occur in poorly drained soils; cobalt deficiency is frequent in Podsol and Oxisols; iodine is often lacking in soils with high calcium carbonate content.
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