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LAND RESOURCE SURVEY AND EVALUATION FOR AGRICULTURAL PROJECTS

- Training Manual for technical staff of agricultural organizations engaged in preparation of investment projects

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FOREWORD

A single, most important factor responsible for failure in achieving the envisaged objectives of many agricultural projects in the world is the inaccurate collection or improper interpretation/use of land resource data for project preparation. This may be attributed partly to low capability of the consultants entrusted with land resource survey and evaluation but mainly to the difficulties faced in comprehending the data by most personnel concerned with planning and implementation of the projects. In a typical project study, which essentially involves the services of a Soils Expert, an Agronomist, an Agricultural Engineer and an Economist, the Soils Expert carries out survey of the soils and other land attributes relevant to the development objectives and evaluates the project land for various promising land use alternatives, the Agronomist provides necessary agronomic data about the prospective land use types, the Agricultural Engineer plans the required land development works (e.g. vegetation clearance, levelling/ terracing, irrigation and drainage systems, field lay-out, etc.) and the Economist works out the project costs and benefits and socio-economic implications of the project implementation etc. Activities of the last three experts are strongly related to, and are chiefly determined by, the land resource data collected by the Soils Expert, that is to say that the land resource data occupies a pivotal position in preparation and implementation of virtually all agricultural projects. This explains why inaccurate land resource data or its wrong interpretation could lead to unexpected results while implementing a project.

Lack of understanding for the terminology used and the procedures involved in land resource survey and evaluation have kept many national and international experts little concerned with what a Soils Expert describes in his report and they are often found reluctant to discuss anything about the soils, consequently relying on other sources of information which are generally imprecise or rather impractical to apply for project preparation. For instance, the engineers would make use of mainly the topographic information of the available maps for land development purposes, the agronomists would recommend the same land use types as prevalent in the adjoining areas and the economists would make their calculations of costs and benefits on the basis of the development works proposed by the engineers and the land use patterns suggested by the agronomists, assuming that all project land would give similar response to the application of suggested land use types. The role of a Soils Expert is commonly considered as minor, only to the extent of knowing whether the project land, in general, is suitable for development or not, while the variations in characteristics or suitability of different tracts of land in the project area are almost completely disregarded.

The common notion that a report prepared by the soils expert only describes the physical and chemical characteristics of the soils of a project area, and that random collection of soil samples from different parts of a project area and their laboratory analyses to characterize the soils would serve the purpose of soil survey, must now be cursed and it should be clearly borne in mind that, firstly, a standard soil survey, which may rather be termed as land resource survey, encompasses all such attributes of land which could, directly or indirectly, influence the performance of a certain land use type whereby the soil is only one of these attributes and, secondly, the laboratory can provide only a back-up service for testifying some of the field determinations or making a few additional determinations not made in the field but, in no case, can substitute the field studies; in fact, most of the basic and vitally important land resource characteristics can be studied only in the field and never in the laboratory.

If properly understood, the data contained in a wisely prepared land resource survey report would effectively serve the purposes of selecting the promosing land use alternatives, devising appropriate cropping patterns, estimating crop yields, identifying land development requirements, calculating irrigation water needs, planning irrigation and drainage systems, prescribing land management practices and assessing the sustainability of the proposed land use systems etc. Much of the costs involved in topographic surveys or land development activities in the unwanted areas can be eliminated by judicious and timely use of the information contained in the land resource survey reports.

This brief manual, intended for inservice training of the soils experts, agronomists/plant scientists, ecologists, agricultural engineers, agricultural economists, foresters, livestock/range management experts, etc. of various FAO/UNDP-assisted organizations concerned with preparation of soil/land resource inventories, land use planning, project preparation and irrigation development etc., outlines some principles and procedures followed for carrying out land resource surveys and evaluating the land of any project area for agricultural purposes. Its main objective is to promote the use of land resource data in preparation and implementation of the agricultural projects but it may serve to develop a certain level of expertise among the amature soil scientists enabling them carry out systematic land resource survey of different project areas under the guidance of a competent soils expert; undertaking the surveys independently would nevertheless require a long-term field experience under a constant supervision.

I do realize that some deficiencies remain in the book, especially due to inadequate illustrations and exercises, which may limit its utility towards capability development of the related staff. But that has been for want of ample time in its preparation. I expect that some future deliberation would do away with such deficiencies.

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1.1 General

The term **"Land resource survey and evaluation"** implies field investigation of soils and other important land attributes of a certain area in order to show the variability of land characteristics and distribution of different land units on a map, and to describe, classify and evaluate these units for certain purposes of use in the form of a report. Whereas the **"Soils"** form the prime agricultural land resource, the other land attributes including **climate, hydrology, geology, vegetation and organisms** (including man, animals and micro-organisms) etc. play a significant role in determining the response of soils to a specific use. Consequently the same kind of soil would be evaluated differently under different environments.

Major objective of land resource survey and evaluation is to assess the potential and limitations of the resources and predict their response under different kinds of use and management. Such information is of vital importance in developing land use plans and alternatives involving specific land management systems, as well as in assessing and predicting the short-term and long-term effects of a proposed land use alternative.

Systematic survey and objective evaluation of the land resources of an area form a basis for preparation as well as successful implementation of any kind of agricultural development project. The survey is essential for many economical and technical reasons. Firstly, the high costs generally involved in the implementation of most agricultural projects, especially those related to irrigaton development, must be fully justified by prior assessment of the land development requirements in terms of costs, risks involved and benefits envisaged, which are chiefly determined by the land characteristics. Secondly, the implementation of a project itself can not be successfully effected without an accurate knowledge of its land resources as, for example, the design of an irrigation scheme can not be finalized unless the data on characteristics of the soils to be irrigated are at hand. Thirdly, the selection of representative sites to conduct specific research or to execute a pilot project for devising appropriate methods for, or assessing the consequences of, the implentation of a large-scale project can not be justifiably made without a proper land resource data base.

1.2 Applications of land resource surveys

The important areas in which the need for a systematic land resource survey is realized include the following:

- Selection of areas which are suitable for development of agriculture, forestry, range management, wildlife preservation, recreation, urbanization or industrial establishments etc.

- Selection of promising land use alternatives and suitable crops for different parts of a project area, and formulation of appropriate cropping patterns

- Prescription of land management recommendations commensurate with maximum agricultural outputs and optimal conservation of the land resources

- Prediction of crop yields and agricultural productivity of an area or region under given sets of management and input levels and long-term planning of regional or national food and fibre needs

- Prediction of possible changes or environmental hazards like soil erosion, drought, salinization, waterlogging and soil fertlity depletion. with the proposed development of an area or with future changes in land use

- Selection of representative sites for agricultural research stations/experimental farms and pilot projects

- Field application of agricultural research and findings of the pilot projects

- Estimation of land development requirements and costs of a selected project area and formulation of the land development projects

- Implementation of agricultural and land development projects

- Estimation of the expected income and net financial benefits from implementation of an agricultural project

- Determination of water requirements for irrigation of a project area

- Rational distribution of irrigation water resources

- Land appraisal for consolidation, exchange, agricultural taxation and advancement of agricultural credits

- Planning for rehabilitation of degraded lands i.e., the lands affected by soil erosion, soil salinity/ acidity, waterlogging, etc.

- Alignment and designing of roads, railway lines, irrigation canals, drainage channels and flood protection embankments etc.
- Site selection for irrigation dams, air strips, dumps for industrial wastes, etc.
- Siting of agro-based industries
- International coordination in agricultural research and land management technology
- Acquisition of development funds from international aid-giving agencies for agricultural projects

1.3 Kinds of land resource surveys

Depending on the attributes of land studied, various kinds of land resource surveys recognized include the following.

a) Soil surveys:

These surveys focus on investigations related mostly to soils and their pedogenetic relationships with landforms, parent materials, relief, climate, hydrology and vegetation etc. The primary map produced is that of "soils" or "Soils and Landforms" which is then interpreted for various purposes, specifically to produce the land suitability maps.

b) Land use surveys:

These surveys consider investigation and mapping of different major and minor kinds of land use including arable (irrigated or rainfed) land, forest or brush land, rangeland, bare land, urban or built-up land, mines, glaciers, lakes, canals, roads etc.

c) Vegetation surveys:

These surveys are concerned with investigation and mapping of various types of natural vegetation occurring in a project area, which includes trees, bushes, shrubs, forbs and grasses etc., along with the density and distribution of each type. A general relationship of the vegetation with climate, landforms, geology, hydrology and important kinds of soils is commonly established but the soils are not generally mapped or systematically described.

d) Water resource (or hydrological) surveys:

These surveys take into consideration the mapping of surface and ground water resources of an area along with their quantity and quality. The investigations include watersheds, flooding regimes, depths of groundwater tables and irrigation and drainage systems etc. General relationships of the water resources or groundwater tables with the geological formations are commonly established.

e) Geological surveys:

In this kind of surveys, field investigations and mapping are concentrated on various geological formations, landforms, rock types, mineral resources, oil resources, rock structure (folds, faults, fractures), volcanic activity, etc. Some hydrological investigations related to specific geological formations are also covered by these surveys (sometime referred to as hydro-geological surveys).

f) Integrated surveys:

These are multi-purpose surveys intended to map the total physical enviroment of an area. The mapping units are "land systems" which are defined as the areas with recurring patterns of genetically related land facets (the units within which the environmental conditions of topography, geology, soils, climate, land use, vegetation and hydrology etc. are considered uniform for all practical purposes). Landforms are the main basis for definition of the map units (land systems). Such surveys are carried out by a multi-disciplinary team of experts.

1.4 General levels of land resource surveys

Based on the intensity of field investigations and the scales of mapping, as decided by the purpose of survey, six general levels of land resource surveys are recognized which are described below. It may be pointed out that a range of field observation densities, though specified for each level of survey, it is mentioned only for general guidance of an average surveyor; in fact, no strict limits need be imposed since these are to be decided by the degree of land variability in the project area and the level of knowledge and experience possessed by the surveyor. It should also be kept in mind that the scale of the base map used for field observations should generally be about twice as large as the publication scale.

a) Very detailed (or very high-intensity) surveys:

These surveys require field observation and recording of data for almost every hectare of a project area. Average observation density varies from 1 to 2 per hectare. These are very high-cost and time consuming surveys conducted only for special areas like agricultural research stations and field experimental sites where precise information for every small part of land is vital. The base maps used for these surveys are large-scale topographic sheets with adequate details of all field boundaries, ground features and small (<1m) contour intervals. All important variations in land characteristics are identified and delineated as individual map units. The publication map scale ranges from 1:10,000 to 1:1,000.

b) Detailed (or high-intensity) surveys:

These surveys, involving field observations and data recording with an average density of one per 5 to 10ha (occasionally one per 2 to 5ha), are carried out for:

i) execution of land development projects,
ii) feasibility study of high-investment agricultural projects and
iii) intensive agricultural (or urban) development planning at village or catchment level, which includes layout of farms and irrigation or drainage systems.

These are high-cost surveys but are much less expensive than the very detailed ones. The base maps used for field investigations are either very detailed topographic map sheets or the latest large-scale air-photos. All important land variations are identified and mostly delinetated separately in the form of simple map units having predominantly one kind of soil and the associated land characteristics. A few map units, being comprised of two or more kinds of soils which occur in complex patterns, may be recognized as compound. The publication scale of map varies from 1:10,000 to 1:25,000.

c) Semi-detailed (or medium-intensity) surveys:

For these surveys, field observations are made with an average density of one per 20 to 100ha. These are conducted mainly for:

i) pre-feasibility study of high-investment land development projects,
ii) feasibility study of relatively low-investment land development projects,

iii) execution of range and forestry development projects
iv) community development planning.

These are medium-cost surveys which can be completed in relatively short time but still with enough details to serve many a different purpose. The base maps for field investigations generally consist of medium to large-scale air-photos, rarely the topographic map sheets. Interpretation of the air-photos plays an important role in delineation of the land units. Although most of the important land variations are identified, it is rarely possible to delineate these individually so that map units are generally compound representing two or more kinds of soils or other land attributes grouped together, of course with defined patterns and proportions; some of the units mapped may be simple having little or insignificant variations in their major part. The published map scale varies from 1:25,000 to 1:100,000.

d) Reconnaissance (or low-intensity) surveys:

These are the surveys conducted generally with an average field observation density of one per 200 to 500ha. These surveys are required for:

i) preparation of national or regional land resource inventories,
ii) identification of promising areas of development and preparation of project proposals for their feasibility/pre-feasibility study,
iii) providing a basis for detailed and semi-detailed surveys and
iv) regional agricultural development planning.

These are the lowest costing systematic surveys which can be completed in a short time. The base maps exploited for these surveys are the small-scale, generally 1:40,000 to 1:50,000, air-photos which need not be recent ones; for some investigations, the older photos may be preferred over the recent ones, while for some others, the latest ones are required. Other remote sensing data, like MSS imageries, are occasionally used as complement to the air-photos. The delineation of map units is largely based on air-photo interpretation. Major land variations are identified but can not be delineated individually. The map units are compound representing two or more kinds of soils grouped together in defined patterns and proportions. The publication scale of map is generally small varying from 1:100,000 to 1:250,000.

e) Exploratory surveys:

These are non-systematic surveys carried out mainly to select areas for systematic surveys and to have a general idea about the major variations in landforms, soils and other land characteristics for planning of systematic surveys in the selected areas. The field observation density is generally very low, varying as one observation per about 5 to 20 sq. km. The base maps for field investigations include small-scale (1:40,000 to 1:50,000) air-photos, satellite imageries or general topographic maps, or a combination thereof. Mapping is accomplished through air-photo/satellite image interpretation and the publication map scale varies from 1:250,000 to 1:1,000,000.

f) Syntheses:

These are not actual surveys but are rather the compilations of reconnaissance and exploratory survey maps in the form of national or provincial maps, generally at a scale of 1:1,000,000 or smaller. No field observations are made. These are merely the indicative maps prepared for teaching purposes or as wall maps giving very generalized information about certain aspects of the land resources.

2. COLLECTION OF LAND RESOURCE DATA

The land resource surveys require collection of data on various aspects of land, the most important of which, from agricultural point of view, are the physiography, the soils, the climate, the water and land use/natural vegetation. Most of these data are to be collected from the field, some acquired from the relevant agencies/offices and some determined in laboratories; part of the field data is to be backed up by laboratory determinations. These aspects are dicussed one by one in the following, while the latest FAO **specifications their description are given under Annex II.**

2.1 Physiography

The term **"Physiography"** refers to the landforms and topography of an area and plays a key role primarily in determining the nature of soils formed and their present and potential use and finally in overall land assessment. A clear understanding about the physiography of an area is, therefore, a basic requirement for any kind of land resource surveys, especially for mapping of soils.

The physiographic component **Landform** describes the geomorphology of an area and may be defined as a three-dimentional landscape having characteristics due to natural genetic proceeses effected by the combined interaction of its internal and environmental factors such as geology, relief, climate, vegetation, hydrology and the organisms, as well as by the time. It covers the characteristics of not only the land surface but of all what is below the surface.The "landform" differs from "landscape" in that the latter refers to only the land surface features discernable in a certain field of view without visualising the subsurface characteristics and that a landscape may represent more than one landforms or only a part of one landform.

A landform is generally composed of two or more different **Land elements** having own specific characteristics in addition to those common to the others in the landform. Some special studies, especially those relating to research on soil genesis, entail further division of a land element on the basis of minor geomorphological differences into what may be termed as **"Minor land elements"**. An overview of important types of landforms and land elements encountered in different parts the world is presented under Annex I.

A description of **Physiographic position**, which implies the position of a certain observed site in relation to the adjoining area (summit, valley bottom, upper parts of a fan, lower footslopes, middle part of a basin, peripheral parts of a basin, margin of a swamp, island within a basin, etc.) with that of the landform and land element is of vital importance for extrapolation of the data collected to other relevant parts of a project area.

The component <u>**Topography**</u> refers to the configuration of land surface with respect to its ups and downs. For the purpose of this manual, it includes <u>**Slope**</u>, which is decribed in terms of **gradient** (inclination from the horizontal axis, in %), **length** (in metres), **form** (straight, concave or convex) and **aspect** (the facing direction; important only for mountainous areas). The slope gradient is generally given as a range, or that of the steepest aspect, and measured using a "clinometer" which gives direct readings in both percent and degrees. The slope length, for general purposes, may not be measured physically (using a long metric tape, as done in very detailed surveys) but may only be estimated by visual observation.

The description of topography here would also include <u>**Macro-relief**</u> and <u>**Micro-relief**</u> **(or Micro-topography)**; the former refers to the major differences in the height (elevation) of different elements occurring within a landform while the latter implies minor undulations and irregularities of the land surface within one element (differences of height between the crests and the troughs, the micro-ridges and micro-knolls or the flat surface and the mounds etc.).

Accurate knowledge and description of topography of an area is a prerequisite for judicious estimation of land development costs and assessment of land suitability for a given type of use.

2.2 Climate

The **"Climate"** is basically a product of temperature, light and moisture regimes which can be interpreted in many a different way. It is an important land resource determining the major and minor types of agricultural land use in an area. The data on various parameters of climate is collected from the local meteorological offices or related agencies. These parameters include:

- <u>Temperature</u> (where possible, average values of daily maximum and minimum temperatures (in °C) for each 10-day period should be acquired; otherwise, the average 11monthly of the daily maximum and minimum may be used)

- <u>Precipitation</u> (the amount of precipitation in the form of both rain and snow (in mm) should be acquired, where possible, by 10-day intervals clearly marking the break of dry and wet spells; otherwise, average monthly and annual may be used; the amount of **effective precipitation** i.e., the amount which will actually penetrate the soil after allowing runoff, may be estimated from physiographic and soil characteristics)

- Elevation (the elevation (in metres) should be recorded in relation to the mean sea level; the effects of elevation are, though manifested principally in the form of differences in precipitation and temperature already discussed above, different elevations also imply different atmospheric pressures and oxygen availability, and rather a quite different ecology)

- Radiation (data should be obtained on mean daily number of sunshine and day length hours for each 10-day period, where possible; otherwise, mean daily of the total monthly hours may be used)

- Relative humidity (average values for each 10-day period; otherwise mean monthly values may be used)

- Evapotranspiration (data on pan evaporation or evapotranspiration of a reference crop should be acquired as mean daily of each 10-day period, if available; otherwise mean monthly rates may be used)

- Winds (data should be obtained on **wind speed, wind direction** and **frequency of windstorms** as mean of each 10-day periods or mean monthly but with clear indication of maximum speed recorded for any windstorm during the period)

- Hail storms (incidence of hail storms should be described on average monthly basis in terms of **frequency, intensity** and **duration**, if it applies)

2.3 Hydrology

Most data on **"Hydrology"** or **water resources** of an area is acquired mainly from the relevant national organizations but partly through field investigations which is primarily a job of the Hydrologist or Agricultural Engineer. Such data, however, are mostly pertinent to the projects related to irrigation development and include the following.

a) Groundwater resources: The available **quantity, depth** of occurrence and **quality** of the aquifer, as well as the the **overlying material** (rock or soil) should be investigated/recorded if the groundwater is to be exploited for irrigation. The data on depth and quality of the groundwater may be obtained in some areas by directly measuring from the existing open wells, tubewells/bore holes or hand pumps and water sampling for laboratory tests.

The checking of water quality has been noticed as the most critical step to decide whether the groundwater should be developed for irrigation or not, but it is not generally looked into seriously. A rapid check of water quality may be made in the field by measuring pH and EC by means of pH and EC meters but detailed analysis would require carrying of water samples (generally in plastic bottles which should be thoroughly cleaned with distilled water and rinsed with the respective water before sampling) to the laboratory. It may be pointed out that many waters which are regarded suitable due to low EC and a good taste may prove to be too detrimental to the crops as well as to the soils because of high SAR (sodium adsorption ratio) or RSC (residual sodium carbonate) effecting slow sodication of soils. The SAR and RSC can, however, be tested only in the laboratory. Furthermore, some waters may be safely used on rapidly permeable soils but may prove disasterous if used on soils with slow permeability. The soil characteristics must, therefore, be given a high weightage while rating the irrigation waters for a certain area.

a) Surface water resources: The data on available surface water resources such as rivers, lakes, springs etc. of an area, though generally obtained from the related national organizations, should be verified in the field especially with respect to their **location and position** in relation to the area proposed for development and the **irrigation structures** required, as well as to **water quality** in context of the nature of soils to be irrigated as has been discussed above.

2.4 Geology

The geological data important for land resource studies are those related to the **underlying rock or bedrock** which may affect the use or conservation of land in any way, especially when it occurs within about 3 metres depth, such as:

- by restricting the downward water flow which would:
    a) impede soil drainage,
    b) disallow leaching of excess salts from soils,
    c) encourage soil erosion,
    d) allow long storage of water in the reservoirs,
    e) reduce percolation losses of water from irrigation channels and fields,
    f) provide a stable foundation for certain structures like dams and bridges, etc.;

- by adding salts to the soils through solution; etc.

The data on geology are generally acquired from the related national organizations but most of these are in very generalized forms. The details required for study in a small project area may not be available, which would entail field investigations. Where possible, the bedrock should be identified and described in terms of **type** (sandstone, limestone, slate, gneiss, basalt, marl, lava flow, etc.) and **depth of occurrence** (in cm from the surface).

In certain areas, occasional volcanic erruptions may cause surface sedimentaion of ash or cinders etc. which may significantly interfere with the use of land. Such situations should be clearly described.

2.5 Present land use and vegetation

The data to be collected on present land use and natural vegetation, if the land is not being cultivated, should be such that it satisfies the requirements of both the land evaluation and the land development. Most of the data is obtained through physical observation on the site but some of it requires interviewing the local people. Information on the following aspects is of special importace.

a) Present land use: At the first instance, Major kind of land use (rainfed farming, irrigated farming, flood-watered farming, shifting cultivation, forestry, range, recreation, etc.) should be distinguished. Then the relevant major kind of use is to be specified in terms of land use types stating essentially the crops or trees/grasses grown (wheat, cotton, rice, teff, coffee, orange, eucalyptus, short grass etc.) as well as the management practices followed and the inputs made if known. The **crop condition** (very good, good, fair or poor) should also be assessed and the data on **normal** and **maximum yields** of the respective crops should be obtained, where possible, by interviewing the farmer for the particular site and kind of soil on which observation is made and it should be properly recorded.

b) Natural vegetation: The natural vegetation, if present, should be described in terms of **type** (trees, bushes, shrubs or grass) along with its **species** if known, **cover** (in per cent of land surface occupied, by each vegetation type) and **condition** (very good, good, fair or poor) with the **average trunk size** (dia. in cm) and **height** (in metres) by each species when important (for land clearance or fuel/timber extraction etc.).

If possible, the data on both the present land use and the natural vegetation should be acquired on a map of standard scale in order to correlate them with the other land resource data.

2.6 Soils

The term **"Soils"** refers to the collection of all natural bodies occupying the uppermost part of earth's crust, supporting or capable of supporting plants and having properties different from the underlying rock material as a result of the interaction between parent material, climate, living matter and relief over a certain period of time. The soils differ from place to place, in characteristics as well as response to different kinds of use, due to the differences in any one or more of these interactive factors.

Soils are dynamic, three-dimentional natural entities that continue to change over time, though the rate of change is so slow that it can hardly be visualized by man in his short life span. Under the natural environments, a significant change in soils would occur only after several decades. The developed soils that we cultivate now were formed from its raw material generated from rock weathering (called **"Parent material"**) through natural processes continued over thousands of years. Both the good and the poor quality soils were formed from the same parent material, depending on the direction the soil forming proceeded. An outline of the general trends of soil development under different soil forming processes is given in Fig 1.

2.7 Field study of soils

The field study of soil resources implies collection of data on soils as they occur in nature i.e., at the place where they are found. It must be borne clearly in mind that a **"soil sample", however large it may be, does not represent a "soil"** just like a piece of flesh taken out from the body of man can not represent the man as a whole. Only a few of the soil characteristics important for soil classification and land evaluation can be studied from the soil samples in the laboratory while most of them must be studied in the field, not only from within the soil body but also in context of its physical environments.

The soil characteristics to be studied fall in two major categories i.e., **External** and **Internal** which are discussed in the following.

2.7.1 External characteristics:

The external soil characteristics are those which relate to the soil surface and are studied without opening a soil profile. While some of these are easily measured or observed, a few ones may require confirmation from the local people or offices. These characteristics, along with the methodologies in vogue and instruments used, if necessary, for their measurement, are as follows.

PARENT MATERIAL

↓

(Deposition by water, wind, ice or gravity)

↓

STRATIFIED SOIL (Undeveloped)

NORMAL SOIL FORMATION PROCESSES	ABNORMAL SOIL FORMATION PROCESSES
1. Homogenization, addition of organic matter and formation of biological pores	1. No homogenization, little addition of organic matter and almost no formation of biological pores
2. Formation of structural peds	2. No structure development
3. Moderate weathering of mineral particles to release nutrients	3. Little weathering to release nutrients; or excessive weathering
4. Leaching of excess salts; little leaching of nutrients	4. Accumulation of salts (salinization); or execessive leaching resulting in loss of nutrients
5. Illuviation of clay and organic matter; stabilization of structure	5. Little illuviation; infilling of open spaces with silt or salts
6. Free drainage; bright coloration of the soil material	6. Impeded drainage; dark coloration or mottling of the soil material
7. Stable aggregation of surface soil particles controlling soil erosion	7. Little aggregation of surface soil particles favouring soil erosion
8. Dominance of adsorbed calcium on clay particles	8. Dominance of adsorbed aluminium or sodium on clay particles
9. No pan formation	9. Formation of clay, iron, lime or gypsum pans in the profile
10. No fresh sedimentation at surface	10. Frequent surface sedimentation
11. No human disturbance except for establishment of vegetation or control of erosion/sedimentation	11. Significant human disturbance like vegetation clearance, excavation, compaction, ponding, dumping of industrial wastes, irrigating with poor-quality water
↓	↓
GOOD QUALITY SOILS	POOR QUALITY SOILS

Fig 1: Formation of good and poor quality soils from the same parent material

i) PRESENCE OF ROCK OR ROCK FRAGMENTS: The exposure of bedrock (or rock outcrop) or the presence of discrete pieces of rock/rock fragments (large stones and boulders) is an important factor affecting land development costs, hindering cultural operations and reducing the extent of agricultural land area. When present at the soil surface, these are described in terms of **size** (in cm, largest axis) and **proportion** (in vol %age of the area occupied or in metres of spacing range between the individual rocks/fragments).

ii) EVIDENCE OF EROSION/SEDIMENTATION: The Soil erosion leads to depletion of plant nutrients and reduction of effective soil depth, along with many other allied detrimental effects on agricultural lands. It is generally evidenced by removal of the soil surface (appearance of brighter colours which match some lower part of a normal soil occurring nearby, exposure of lime/iron/manganese segregations), smoothened surface pointing out to water movement and/or presence of rills or gullies etc.) and is described in terms of its **type** (by water, wind or ice; sheet, rill or gully if by water) and **degree** (severity).

The Sedimentation (or Deposition), if significant, is harmful in the sense that it temporarily seals the soil surface, if silty or clayey, or may bury the germinating seed. It is indicated by the presence of a laminated layer, or by scattered pieces of such layer if ploughed. The sedimentation may be estimated from the thickness of the laminated surface layers in light of the prevalent land use but must be supported by the information acquired from local people. It is des-described in terms of **type** (deposited by water or wind), **degree** (severity) and **frequency** (number of times occurring during the year).

iii) EVIDENCE OF FLOODING OR PONDING: The term Flooding implies spilling of water from the rivers or drainage ways and its flow over the soil surface. Whereas the flooding reduces aeration of the plant roots, its main detrimental effect is of hindering the cultural operations. The data about this aspect is generally obtained by interviewing the local people but a fair estimation can be made from the surface sedimentation and air-photo patterns.It is described in terms of **frequency** (number of times occurring during the year), **depth** (cm of water flowing over land surface), **duration** (length of periods during which water flows) and **time** (months) when it occurs.

Ponding here implies stagnation of runoff or flood water at land surface for significantly long periods. Unlike flooding which reduces the oxygen supply to plant roots only to a degree that most plants can survive, ponding would practically create anaerobic conditions not tolerated by most of the plants. It is described in the same terms as flooding.

iv) PRESENCE OF CRACKS: The **Cracks** i.e., linear breakage of soil surface upon drying, point out to the swelling and shrinking properties of soils which do not suit certain types of land use as well as affect the land and water management techniques. These are measured and described in terms of **width** (or size in cm), **depth** (in cm to which the cracks extend) and **abundance** (frequency of occurrence) or **spacing** (distance between the cracks).

v) SURFACE CRUSTING: The term **Surface crusting (or sealing)** implies appearance of a very thin (generally <2mm), nearly continuous, dense layer at the soil surface. The "crust", which has a very slow permeability and hinders in infiltration of water and exchange of air in the soil, thus adversely affecting the growth of most plants, is commonly formed due to surface flow of water in soils high in silt or very fine sand fraction and low in organic matter, especially when the exchangeable sodium is also high. It may not be easily noticed except from smoothening of some parts of the surface. When observed, crusting is described in terms of **thickness** (in mm), **consistence** (relative hardness), **intensity** (the degree to which surface has been sealed) and **continuity** (whether continuous or interrupted by cracks, clods etc.).

vi) HUMAN INFLUENCE: It describes any evidence of man's activity (ploughing, excavation, addition of organic matter/ fertilizers, irrigation etc.). No specific terms are defined for this description.

2.7.2 Internal or profile characteristics:

The internal or profile characteristics of soils are described from a vertical section of a soil (called **Soil profile**) cut through its depth to the parent material or bedrock, or to the lower end of plant root activity. The soil profile shows different, horizontally oriented layers which have specific characteristics differing significantly from the overlying and underlying layers. A genetically developed layer is referred to as a **Soil horizon** while an undeveloped one is simply called as **Soil layer**. The soil profile studies involve systematic collection of data on physical, chemical, biological and hydrological characteristics of each soil horizon or layer one by one. These characteristics, as discussed below, are studied for each soil horizon/layer, except that a few of them (soil depth, drainage and infiltration rate) have to be decided by a combination of all the horizons/layers.

a) <u>Physical characteristics</u>:

i) PARENT MATERIAL: It refers to the unconsolidated mineral material (weathered rock or other material detached from an older land surface) or organic materials in which the soils are formed. Although it would no longer exist after being transformed to soils, it is generally identified from the "unaltered" loose material underlying the **solum** (the developed part of the soil). The soil parent material gives sufficient clue to the inherent soil properties unless intensely influenced by climate. It is described in terms of **nature** (sandy, silty, calcareous, etc.), **origin** (how formed; alluvium, till, colluvium, loess, etc.) and, where possible, **parent rock** (the rock type from which derived).

ii) EFFECTIVE DEPTH: The term **"Effective soil depth"** implies total thickness of the soil material which can be effectively exploited by plant roots. The root limiting strata considered are all the nonsoil materials including bedrock, clean gravel, clean sand, and continuous, dense compacted layers. The root penetration may, however, be restricted by temporary mechanical barriers (pans breakable by special implements like chisels), chemical factors (salts, lime, gypsum, or too acidic/alkaline media) or excessive wetness etc. but such factors do not affect the soil depth. While the effective soil depth determines the room available for development of the plant roots, it is a measure of the reservoir of food and water for the plants and, consequently, decides the length of period after which the soils would need recharging with water before the plants start wilting. It is measured directly from the soil pit or auger hole by means of a steel tape and described in terms of **depth classes** with defined ranges in cm.

iii) COLOUR: The inter-horizon and intra-horizon colour variations in soils are indicative of certain important characteristics including the stage/degree of development, drainage conditions, depths of groundwater fluctuations, organic matter content, etc., though the colour has little bearing of its own on the land assessment. In general, a uniform bright coloration reflects higher degree of soil development, good drainage conditions with very deep groundwater table, if any, or low organic matter content. Contrarily, dark soil colours indicate lower degree of soil development, impeded drainage conditions or high organic matter content. In certain cases, however, the colours are due to the parent material and may indicate none of the above, which should be investigated. The colour is described in standard colour names and notations of the **Munsell's soil color Charts** (a book) by comparing a clod of the soil sample taken out by means of knife from the respective horizon/layer with the colour chips of the Charts. Each colour chip is described by three colour components i.e., the **"Hue"** which represents the spectral light wavelength, the **"Chroma"** which stands for purity or strength of the spectral light and **"Value"** which is the degree of lightness or darkness in relation to a neutral grey scale. The colour is noted for each different segment of a horizon/layer if more than one colours are observed. Both the **moist** and **dry** colours are described. A page of Munsell's Soil Colour Charts showing colour names and notations for hue "10YR" is presented in Fig 2.

Impeded drainage or fluctuating water tables tend to create spots of different colours, called Mottles, on the surface and/or within the soil peds. The mottles,when present, are described in terms of **abundance** (%age of the surface area occupied), **size** (diameter), **contrast** (degree of colour difference from the main soil colour), **boundary** (sharpness of the outline) and **colour** (in standard names).

iv) TEXTURE: The **Soil texture** refers to the relative proportion of different sized soil particles i.e., **sand** (0.05-2.0mm dia), **silt** (0.002-0.05mm dia) and **clay** (<0.002mm dia) in the **fine earth fraction** (the soil material smaller than 2mm in diameter). It is the most important soil characteristic which plays a principal role in determining many other compound land characteristics or qualities; these include drainage, permeability, available water capacity, nutrient availability, workability, bearing capacity, erodibility, crack formation, etc. In general, a sandier soil texture indicates better drainage, higher permeability, lower available water capacity and nutrient availability, better workability, higher bearing capacity, lower erodibility and no or fewer cracks. The clayey textures have just the reverse effects, while "loamy" ones (with moderate mixture of sand, silt and clay) behave normally. These effects are,however, modified considerably by "soil structure" discussed later.

In the field, texture is determined by working with a fully wetted soil sample; it is rubbed between the fingers and thumb, felt for its stickiness or slipperiness and observed on the rubbed surface for its smoothness. An alternate method of testing by trying to form a whip or a ring of the wet sample is in vogue but used only by amature surveyors. The texture is described in terms of standard **textural classes** which may be grouped in different categories of coarse, medium and fine as follows. The range of proportions of the three particle sizes (called the **"soil separates"**) in each class, as well as the sand subclasses, is indicated in Fig 3.

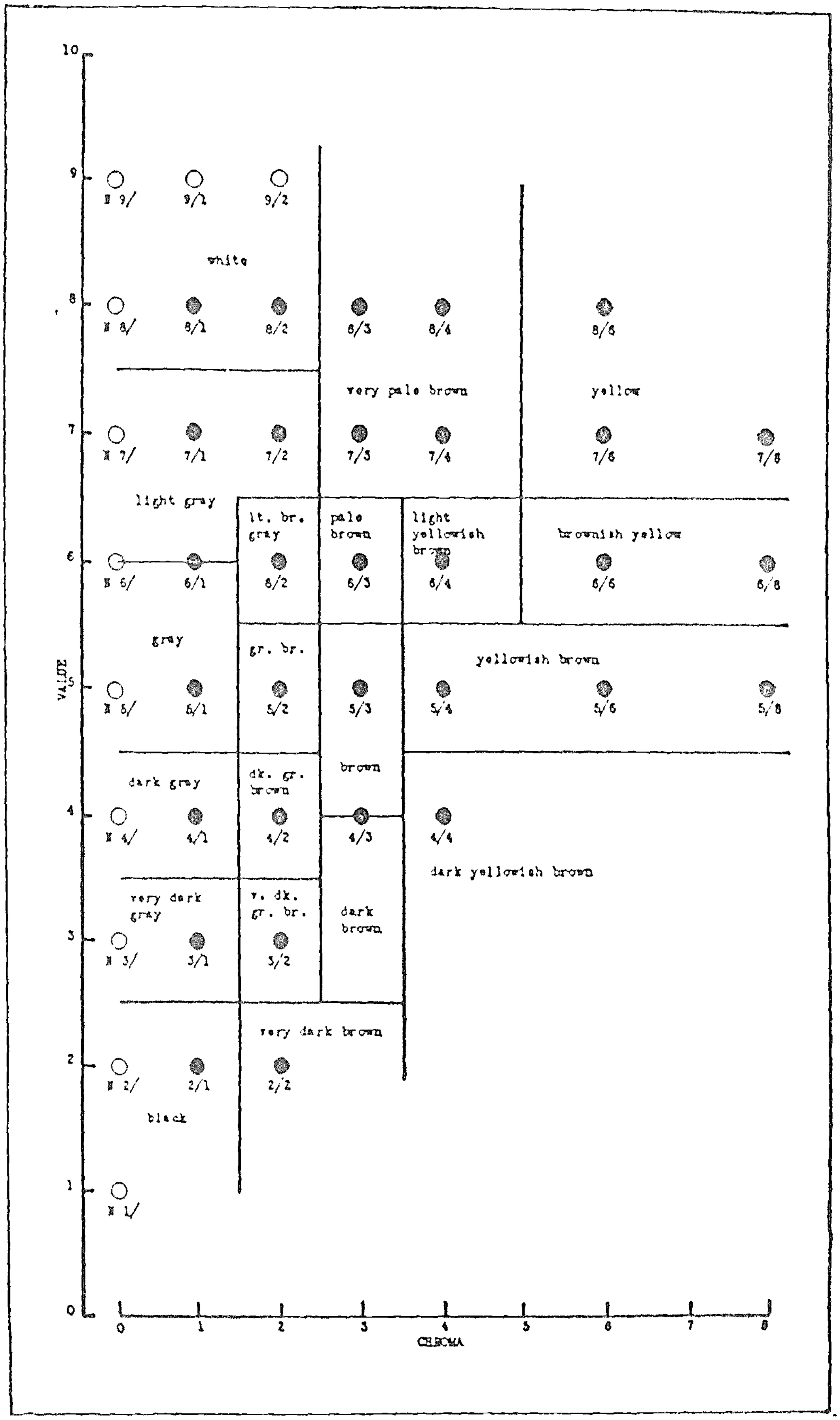


FIGURE 2: —Soil color names for several combinations of value and chroma and hue 10YR.

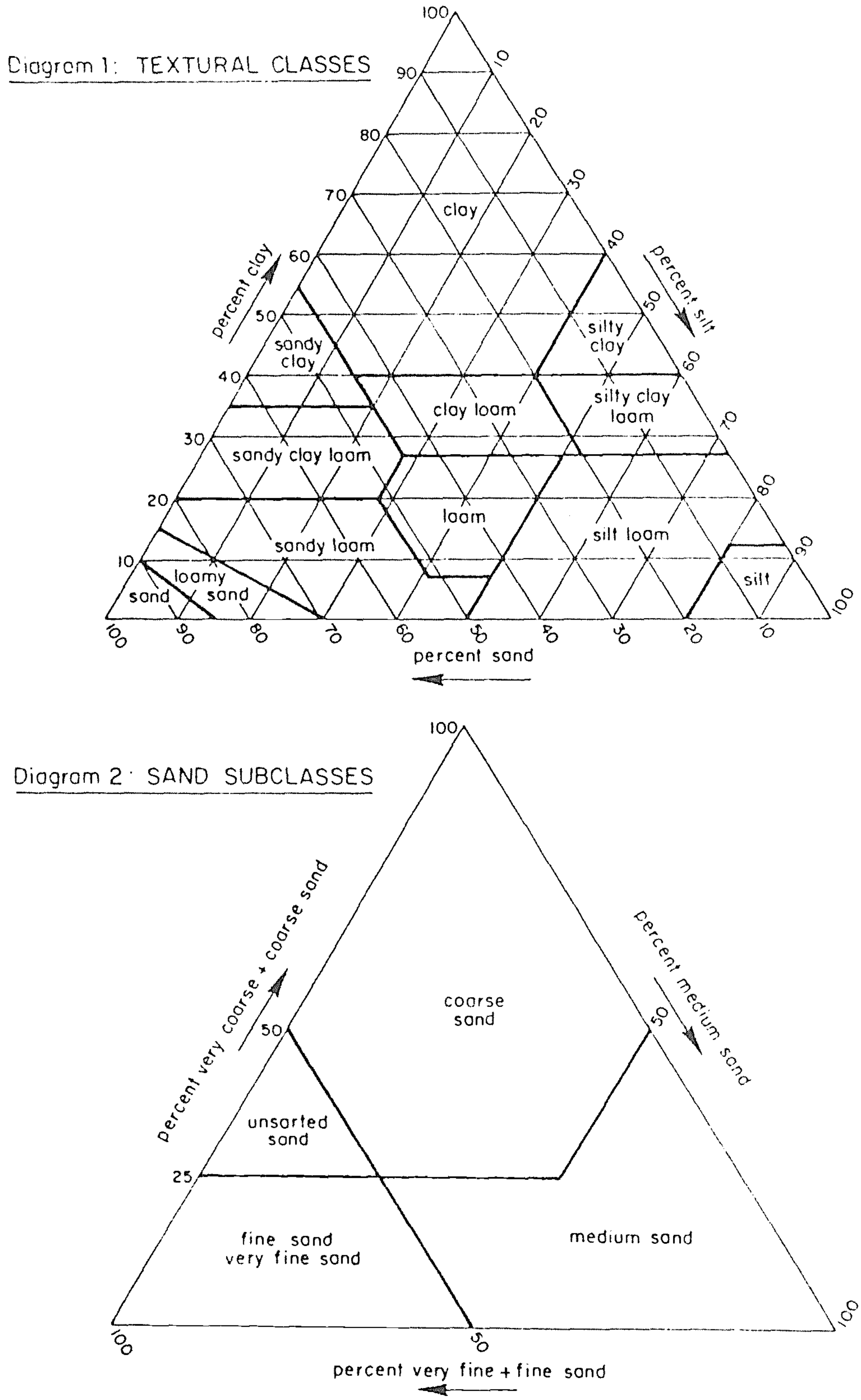


Figure 3: Soil Textural Classes and Sand Classes

a) Coarse textures: sand (with coarse, medium or fine sand fraction), loamy sand (with coarse, medium or fine sand fraction)

b) Moderately coarse textures: coarse sandy loam, sandy loam (with medium sand fraction), fine sandy loam, very fine sand, loamy very fine sand

c) Medium textures: loam, very fine sandy loam, silt, silt loam

d) Moderately fine textures: sandy/fine sandy clay loam, clay loam, silty clay loam

e) Fine textures: sandy/fine sandy clay, silty clay, clay

The textural class names used for organic soils are Peat (consisting of mainly raw, undecomposed organic material) and Muck (consisting of mainly decomposed organaic material); the term **mucky peat** is used if the material lies in between the two. In case the mineral soil material has enough organic matter, placing it in between the "mineral soil" and "organic soil", the **modifier** "Mucky" is used with textural class name.

v) ROCK FRAGMENTS: The presence of **Rock fragments** i.e. the pieces of rocks or minerals which are larger than 2mm in diameter, which include **gravel** (2mm-6cm dia.), **stones** (6-20cm dia.) and **boulders** (>20cm dia.), are described in two different ways i.e., as a qualifier with the textural class or as an independent characteristic. It is, however, recommended that only the "gravel", which can not be separated from the fine earth fraction in any practical way, should only be used as qualifier with the textural class name (slightly gravelly, gravelly, very gravelly or extremely gravelly according to the proportion of the gravel). The larger fragments, which can be removed from the soils and form relatively temporary soil constituents, should be described separately in standard terms of **abundance** (%age of total material), **shape** (flat,angular, rounded or subrounded), **nature** (type of rock/mineral), **size** (for largest axis) and **weathering status** (fresh or weathered).

vi) STRUCTURE: The term **Soil structure** refers to the natural arrangement or organization of soil particles into aggregational units, called **Peds**, of specific forms. It has its specific role in, firstly, determining the degree of soil development and, secondly, contolling the soil environments for development of plant roots, water movement, aeration and supply of plant nutrients. It is observed in the field by gently breaking a large, moist clod detached from a freshly cut wall of the soil pit so that breaking occurs only along the natural lines of weakness and individual peds get separated. The soils may be classified as **Structureless** if no peds are formed, **Simple structured** if only large peds are formed each of which is an entity or **Compound structure** if larger peds break into smaller ones. The soil structure is described in terms of **grade** (degree of development), **size** (of longest axis) and **shape** (specific form). Different "shapes" of soil structure are illustrated in Fig 4.

vii) SPECIAL STRUCTURAL FEATURES: The special features to be observed and described include the following.

Cutans, referring to thin, oriented coatings of translocated clay or mineral compounds, are found in structured soils along ped faces, around mineral grains or rock fragments and along the walls of pores/channels. Whereas they are indicative of the degree of soil development, the cutans determine the stability of soil structure and serve as a rich source of the plant nutrients. They are named after the kind of the coating material as **argillans** (also as clay cutans, clay skins or clay films) when formed from clay, **ferrans** (or iron coatings) when from iron oxides, **manganans** (or manganese coatings) when from manganese oxide, **organan** (or organic matter coatings) when formed from organic matter, etc.

Clay bridges, implying the linkages of mineral grains or rock fragments by means of translocated clay, are generally found in coarse or moderately coarse textured soils and are indicative of a high degree of soil development and structural stability of such soils.

Silt coatings which refer to non-uniform coatings of silty material formed by downward movement of material from the surface with irrigation or rain water and commonly found along the ped faces and walls of the cracks, are the characteristics of some silty soils. These are indicative of relatively unstable surface low in organic matter or high in exchangeable sodium.

Salt or lime coatings. These are the coatings formed by accumulation of salts or lime along the ped faces or around the rock fragments and point out to soil salinity.

Stress surfaces. These refer to the shiny ped surfaces which are not formed due to the presence of cutans but by the mutual pressure of peds exerted while swelling upon wetting - a characteristic of clayey soils.

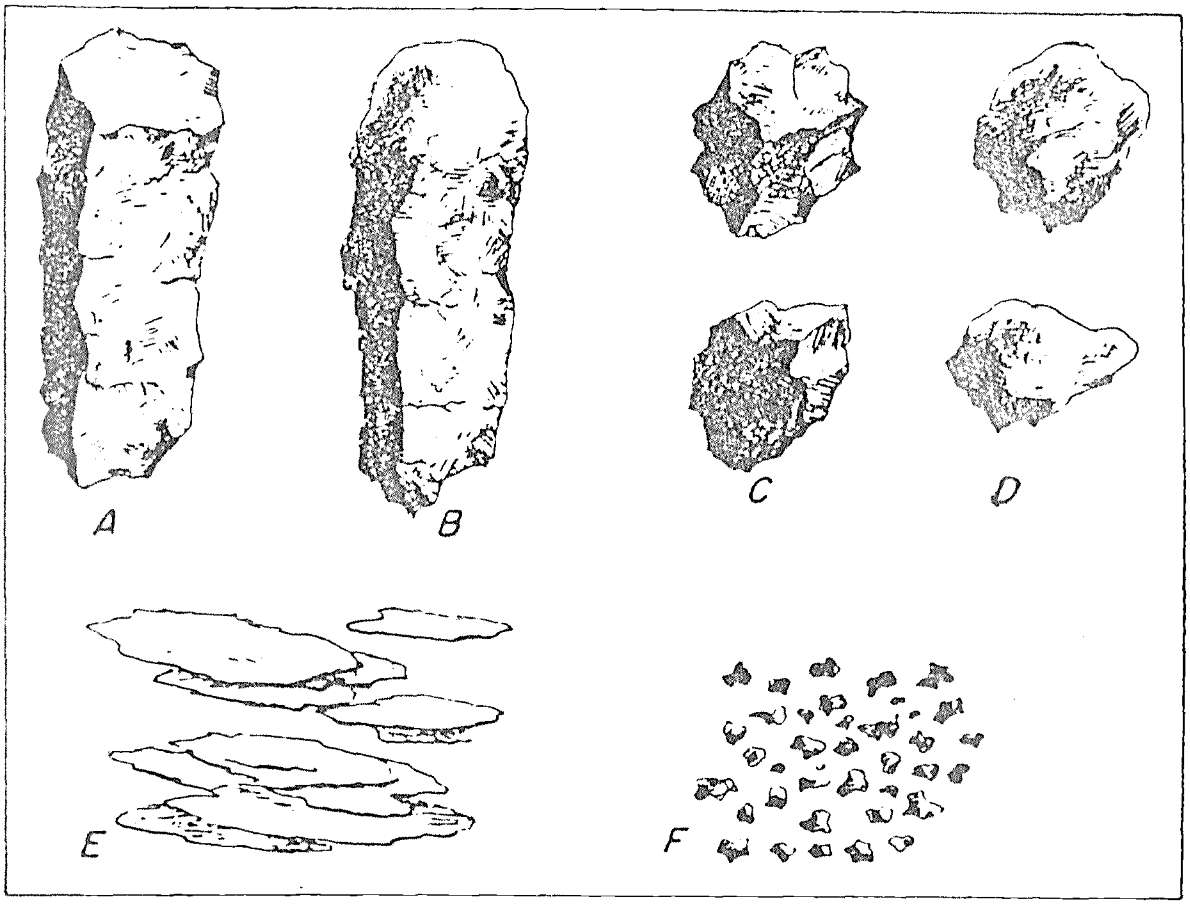


FIGURE 4.—Drawings illustrating some of the types of soil structure: *A*, prismatic; *B*, columnar; *C*, angular blocky; *D*, subangular blocky; *E*, platy; and F, granular.

Slickensides, referring to polished, striated or grooved surfaces of peds or blocks of soil produced while upward sliding of one soil mass past another with extremely high pressure exerted by the soil mass upon swelling when wet. These point out to very clayey nature of soils and swelling/cracking types of clays.

When present, the "cutans" and "coatings" are described in terms of **abundance** (%age of ped surface covered), **contrast** (relative difference in colour with the soil matrix), **colour** (simple colour names), **nature** (type of material) and **location** (where found), in the same sequence. The "clay bridges" are described in terms of **grade** (strength, reflected by thickness of the bridging material). The "stress surfaces" and "slickensides" are described in terms of their **abundance** (frequency of occurrence) and **contrast** (degree of difference from normal surfaces).

viii) CONSISTENCE: It is an expression of the response of soil material to the applied force or pressure at different moisture levels. It allows predicting the behaviour of soils against their disturbance or various cultural practices, especially with respect to ploughing and seedbed preparation. It is determined in the field by feeling or working with fingers and thumb under dry, moist and wet conditions. It is described in terms of **stickiness** (the degree to which the soil sticks to the implements) by working with a wet soil sample, **plasticity** (ability to get moulded in different forms) by observing while making a wire and a small ring of the wet sample, **friability** (ability to get shattered into small particles/aggregates) by pressing a moist clod of the soil, and **hardness** (resistence against breakage) by trying to break a dry clod of the soil.

ix) POROSITY: The **Soil pores** or **Voids** refer to the open spaces occurring within the soil body. The **Porosity** implies the total volume of open space occurring in the soil. This charateristic is extremely important for plant life since the pores serve as respiratory organs and movement spaces for the plant roots, reservoirs of water available to the plants and facilitators of the soil drainage. The pores are identified in the field by visual observation (with naked eye or with the help of a hand lens) of the profile as well as of different large-sized clods detached from the profile. They are described with respect to **abundance** (number of voids per square dm), **size** (in mm of dia. or width if linear) and **type** (shape or form in which they occur).

On the basis of **"type"**, the pores or voids may be divided as:

- Vesicles or vesicular pores which are spherical or elliptical, closed voids (chambers) formed by compressed air like gas bubbles;

- Interstitials which refer to irregular spaces left between the soil particles/aggregates due to their mutual packing, also called as **textural voids** or **packing voids**;

- Bio-pores or channels which represent tube-shaped voids of varying diameter, extending vertically or horizontally for quite long distances (continuous), also called as **tubular pores**;

- Vughs which are irregular, generally large-sized, voids mostly formed by soil animals; and

- Planes which are linear openings occurring along ped faces or formed by cracking of the soil mass.

x) CEMENTATION OR COMPACTION: The term Cementation implies forceful binding together of the soil material by some chemical compound like lime, silica, iron oxides etc. while Compaction means tight packing of the soil particles effected by some mechanical operation. The cemented or compacted layers are called pans which differ in consistence and stability and are classified accordingly. The pans serve as barriers for development of plant roots as well as for movement of water and air in the soil. When present, the pans should be described in terms of **thickness** (in cm, if forming a part of any soil horizon/layer), **continuity** (whether continuous or broken), **structure** (platy, nodular, vesicular etc.), **nature** (kind of cementing agent or compacting activity) and **degree** (the degree to which cemented).

b) Chemical characteristics:

i) REACTION (pH): The term **Soil reaction** refers to the degree of acidity or alkalinity of soil material, which is expressed in terms of **pH** (i.e., negative log of Hydrogen ions concentration). The pH value of a soil is a good indicator of base saturation and degree of weathering that has occurred in the soil material, as well as it determines the availability of many major and micro- nutrients and response to the added fertilizers. It also gives clue to the presence of certain plant-toxic substances in the soil. The soil pH is described in terms of numerical values at a scale of 0 to 14. The soils with pH between 6.5 and 7.5 are generally regarded as **neutral** while those falling above this range (pH >7.5) as **alkaline** and those below the range (pH <6.5) as **acidic**.

In the field, soil pH is measured by one of the following two common methods:

a) Colorimetric method i.e., treating the soil sample with an appropriate **pH indicator** (e.g., Cresol red for neutral or acidic soils, Thymol blue for alkaline soils, Universal indicator for a larger pH range from acidic to alkaline) in a white porcelain spot plate and comparing the changed colour of the indicator with different chips of the relevant standard pH colour chart.

b) Electrometric method i.e., using a portable electric **pH meter** in a 1:2.5 or 1:5 soil-water or soil-KCl(1M) suspension prepared in a plastic tube or a beaker; whatever solution and ratio are used to prepare the soil suspension must be mentioned along with the description as the pH values vary with the methods used. The portable pH meters are also available in combination with the electric conductivity meters (dicussed later), which allows both determinations to be completed in shorter time.

ii) CALCAREOUSNESS: It is a measure of the quantity of carbonates and bicarbonates (commonly called as **lime**) present in the soil material. It is indicative of the kind of material in which the soil was formed and of the degree to which leaching has occurred in the soil but more important is its role in affecting the availability of various nutrients and micronutrients to the plants. The soil calcareousness is estimated in the field by adding a few drops of 10% HCl on a clod of soil and observing its effervescence.Its quantitative measurement is, however, done in the laboratory. It is described in terms of **calcareousness classes** defined by the degree of effervescence or by the amount of carbonates/bicarbonates in the field and in the laboratory repectively.

The presence of powdery lime (in the form of pockets or thread-like fomations called "lime pseudo-mycelia") or **lime concretions** (irregularly shapped, generally hard, segregations of lime mixed with the soil material) should be described separately in terms of **abundance** (%age by volume of the total soil material), **size** (mm of longest axis) and **hardness** (soft or hard).

iii) SALINITY: The **Soil salinity** refers to the presence of soluble salts in the soil in excessive amounts so as to affect the growth of most plants adversely. The plant growth is restricted mainly due to reduced water availability (by effecting increased osmotic pressure), salt toxity and an imbalanced intake of nutrients by the plants. The salinity may be observed in the field from **appearance of salts** at the soil surface in the form of whitish patches, generally with no or very few stunted plants growing on, or on the soil pit wall when the latter is exposed in moist condition and left open to dry for two or three days. A more objective approach is to measure the **electrical conductivity (EC)** with the help of an **EC meter** in 1:2.5 or 1:5 soil-water suspension. It is described in terms of **salinity classes** defined by the degree of salt appearance if observed visually and by ranges of EC if measured by the EC meter.

iv) GYPSUM CONTENT: The gypsum or $CaSO_4$ in soils occurs in the form of crystals, powdery substance or nodules and is generally a characteristic of the severely saline soils part of which have recently lost their excess salts by leaching. The presence of gypsum as such is not much harmful for the plants but its occurrence in the form of **cemented layers or pans** would limit the plant rooting depth and/or restrict the drainage. If found in sodic or saline-sodic soils, it would rather facilitate their leaching and reclamation process. Its presence is determined in the field by taking the filtrate from 1:5 soil-water suspension in a test tube and adding a few drops of acetone to it; if gypsum is present, a white precipitate is formed, otherwise the solution remains transparent. Its quantitative measurement, however, has to be done in the laboratory.

v) SPECIAL CHEMICAL FORMATIONS: As a result of repeated oxidation, reduction and other chemical processes, as well as through segregation and physical translocation of some soil constituents, certain **chemical formations** are encountered at varying depths in the soils. Such formations include nodules or concretions of **lime, gypsum, manganese oxides, iron oxides and iron-manganese oxides** etc. In the filed, these formations are identified by careful looking and testing, after crushing/breaking with the help of nails, a knife or a hammer, and with hydrochloric acid (for lime). These are described in terms of **abundance** (%age of total soil material), **size** (mm of largest axis), **shape** (spherical, cylindrical, platy or irregular etc.) and **composition** (substance from which formed).

vi) WEATHERABLE MINERALS: These refer to the minerals or rock material which would be easily weathered to release a significant amount of nutirents for sustained agriculture. These include feldspars, micas, basalt, shale, limestone, marl and sandstone etc. The presence of weatherable minerals and rock fragments is important only for highly weathered soils like those of the humid tropics but has little importance for less weathered soils and almost all soils of the desert and semi-desert regions. These are described specifically for the highly weathered soils in terms of **abundance** (%age of total soil material), **size** (mm of largest axis), **shape** (flat, angular or rounded etc.), **weatheing status** (fresh or weathered) and **nature** (type of mineral/rock).

c) Biological characteristics:

i) ORGANIC MATTER CONTENT: The term "**Organic matter**", when applied to mineral soils, implies all that material of animal or plant origin which has been fully decomposed and completely mixed with the mineral matter (generally reffered to as **humus**). The content of organic matter in soils can not be quantitatively measured in the field but can be estimated from the related characteristics including specifically the colour, structure and consistence. The soils having very dark colours, granular or crumb structure and very friable (moist) consistence are generally high in organic matter content while the ones having light colours, massive or platy structure and firm (moist) or very hard (dry) consistence have a low organic matter content. This should not, however, be misinterpreted for some special cases as, for instance, the soils formed in volcanic ash which have black colours may have low organic matter while some soils formed in limestone may have light colours but still with high organic matter. The description of organic matter content, wherever estimable, may be added under the "inferred soil characteristics" in qualitative terms along with an estimated range in percent of total soil material. The organic matter content is to be determined quantitatively later in the laboratory.

In case of organic soils, all the decomposed, the semi-decomposed and the undecomposed organic materials should be taken into consideration and the description should include the **stage** of decomposition.

ii) ROOT DISTRIBUTION: The movement and distribution of roots in the soil profile is an indicator of the soil environments as related to the root development. If carefully studied and related to specific indicator plant species, this characteristic alone can lead to a fair assessment of land for agricutural use. It is studied in the field from the soil pit wall carefully prepared so that all roots get exposed. The roots are described in terms of **abundance** (%age of surface area) and **size** (mm of dia.). The **root behaviour** towards penetrating or spreading just above specific horizons/layers (like calcic or petrocalcic horizon, sulfuric horizon, plinthite, very clayey layer, sandy/gravelly layer, etc.) should be mentioned along with the root description.

iii) SPECIAL BIOLOGICAL FEATURES: These features include those which evidence any kind of past or present **biological activity** in the soil. The presence of such features serves as a proof that the soil has such physical and chemical characteristics as liked by the plants and animals, depending on the degree of acvtivity. These features include krotovinas (irregular tubular infillings of animal burrows or large holes left by decayed plant roots), <u>decayed plant roots</u>, <u>insect casts</u> (small spherical or cylindrical excreta of earthwoRms and droppings of other like insects), <u>termite colonies</u> (pockets of termite dwellings) and <u>snail shells</u> etc. The biological activity is described in terms of **abundance** (%age by volume) and **size** (in cm).

iv) <u>ARTEFACTS</u>: The term **"Atrefacts"** refers to the pieces of charcoal, pottery, bones, flint tools, etc. which provide an evidence of human influence on soils, long periods of cultivation or different levels/stages of material deposition. The presence of such artefacts should be described in terms of **abundance** (%age of soil material), **size** (cm, longest axis) and **kind** (type of artefact).

d) <u>Hydrological characteristics</u>:

i) <u>DRAINAGE</u>: The term **Soil drainage** may be defined in two different ways i.e.,

- The soil conditions reflecting the availability of oxygen in the root zone; or
- The soil conditions reflecting the rate or ease with which excess water is removed naturally from the soil surface as well as from the root zone.

This chatracteristic is inferred in the field from the profile morphology. The soil characteristics such as reduced colours (especially when accompanied with mottling), presence of iron/manganese nodules, presence of wet horizons/layers, high groundwater table and presence of pans or slowly permeable layers, all imply impeded drainage conditions. The soil drainage is commonly defined in qualitative terms of **drainage classes** defined under Annex 2. Where possible, it should be described for both the present conditions and the conditions prevailing over the year.

ii) <u>DEPTH OF GROUNDWATER TABLE</u>: From the soil use point of view, **Groundwater table** may be defined as the upper boundary of water-saturated layer or **capillary fringe** while "true water table" (the level of water in a hole after it is left open for long enough to bring the lateral water flow in near equilibrium state) may be lower or, in some cases, higher. Where possible, depths of both boundaries should be described in cm from the soil surface. The water saturated conditions restrict the root development of most plants due to reduced or no oxygen supply and, hence, the groundwater table virtually determines the rooting depth of soils. The information on fluctuations of water table during the year (generally estimated from mottled or reduced layers/horozons, or obtained by interviewing the local people) should be collected where possible.

In certain cases, the water saturation may occur at much higher levels than it should nomally be in the region, possibly due to rain water (or irrigation water) accumulation in some layers overlying an impermeable or slowly permeable layer, while the soil below the latter is unsaturated. Such conditions should be explored and identified as **Perched water tables**.

iii) INFILTRATION RATE: It refers to the rate at which water enters the soil from its surface under given soil moisture conditions. This characteristic is helpful in designing of irrigation systems, estimation of water recharge by a certain rain storm and assessment of soil erodibility. It can be fairly estimated from other soil characteristics which include texture, porosity and structure. In the field, it is measured only for benchmark soils generally by using the **Double-ring infiltrometer** method which is presented under Annex IV as an extract from the Booker Tropical Soil Manual (Landon, 1984). It is defined in terms of **Basic infiltration rates** (i.e., the rates after the tests reach near equilibrium states) similar to hydraulic conductivity or permeability discussed in the following section.

iv) HYDRAULIC CONDUCTIVITY: The term **Hydraulic conductivity or Permeability** refers to the rate of water movement, vertical as well as horizontal, within the soil or within a soil horizon/layer as related to the hydraulic gradient. It is a measure of the ease with which the water as well as the dissolved nutrients can be tranmitted from one part of a soil to the other and, hence, facilitates plant nutrition. The soil horizon/layer having the lowest rate of water transmittance determines the overall hydraulic conductivity of the whole soil. Its too high values, however, imply loss of water and nutrients through percolation/leaching. The hydraulic conductivity of a soil may be estimated roughly from its texture, structure and porosity but its quantitative measurement is done by using the **Auger-hole** method (for layers/horizons below watertable) or **Inverse Auger-hole** method (for layers/horizons above water table) as described under Annex IV as an extract from the Booker Tropical Soil Manual (Landon, 1984). It is described in terms of **hydraulic conductivity or Permeability classes** defined under Annex 2 (See under Internal drainage under the Annex).

2.8 Laboratory study of soils

Some of the soil characteristics studied in the field, as dicussed in the previous section, need backing up by the laboratory through analyses of soil samples collected for that purpose, while a few others have to be studied exclusively in the laboratory. A write-up of the methodologies adopted for various laboratory determinations is beyond the scope of this manual. However, a list of the data to be acquired from the laboratory is presented below for general guidance.

a) Laboratory determinations required to back up field data

Physical characteristics:

- Texture (Mechanical analysis for particle size distribution with propotions of different sized sand, and occasionally of fine clay)

- Cutans (Identified through micromorphological studies)

- Weatherable minerals (Identified through micromorphological studies)

Chemical characteristics:

- pH (From saturated soil extract and in soil-water or soil-KCl suspension as required, by electrometric method)

- Lime content or cacareouness (%age of calcium & magnesium carbonte/bicarbonte; the %age does not include the lime present in the form of hard concretions since these are generally removed from the soil sample before laboratory analyses)

- Electrical conductivity or salinity (From saturated soil extract and in soil-water or soil-KCl suspension as required)

- Gypsum content (%age of calcium sulphate; gypsum present in nodular or concretionary form is not counted as it is generally removed from the soil samples before laboratory analyses)

Biological characteristics:

- Organic matter content (%age of organic carbon and organic nitrogen; the undecomposed organic matter is generally removed from the soil samples before laboratory analyses)

b) **Extra laboratory determinations required**

Physical characteristics:

- Bulk density (i.e., weight per unit volume of the soil; determined from core samples or unbroken clods)

- Clay mineralogy (Identified through crystallography)

Chemical characteristics:

- Soluble cations and anions (i.e., soluble Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4, NO_3; determined through chemical analysis of saturated soil extract)

- Exchangeable cations (i.e., the positively charged ions adsorbed on the surfaces of clay and organic matter particles which can be exchanged with the positive ions present in solution, including Ca, Mg, Na, NH_4, Al, Fe, Cu, Mn, etc.; determined, after extraction with appropriate solution, through chemical analysis or spectrophotometry)

- Cation exchange capacity or CEC (i.e., capacity of soils to hold cations, or plant nutrients, in exchangeable form, guarding them against loss through leaching; determined by adding all exchangeable cations or directly (after replacing all exchangeable cations with NH_4) through chemical analysis or spectrophotometry)

- Exchangeable sodium percentage or ESP (i.e., %age of clay surface area occupied by adsorbed Na; calculated as:

  ESP = 100 x Exch Na / CEC ;

  a high ESP implies low stability of soil structure)

- Base saturation or BS% (i.e., %age of clay surface area occupied by adsorbed bases/positively charged ions including Ca, Mg, K and Na but excluding H and Al; calculated as:

  BS% = 100 (Exch. bases)/CEC ;

  a high base saturation implies a high soil fertility unless the soil is saline)

- Available nutrients (i.e., the nutrients present in the soils in plant available forms, which include NH_4-N, NO_3-N, K, PO_4, Fe, Cu, Zn, Mn, Mo, S, etc.; determined through chemical analysis or spectrophotometry by using appropriate extractants)

Hydrological characteristics:

- Available water capacity or AWC (i.e., the maximum amount of water that can be retained by the soil in available forms for the plants after the free water is fully drained, generally expressed in mm of water per dm of soil column; determined by measuring the water content of soils at 300cm (0.3 atm.) and 15 atm. negative hydraulic pressure or suction, the difference of the two being regarded as AWC; a high value of AWC implies long periods of drought tolerance by plants grown on the soils and vice versa)

3. USE OF REMOTE SENSING DATA FOR LAND RESOURCE SURVEYS

3.1 Forms of remote sensing data

The term **Remote sensing** implies acquisition of data about an object (or earth feature) by means of an instrument which is placed far away from the object. Since all the earth features either reflect or emit electromagnetic energy, which ranges in wavelengths from as small as $<10^{-7}$um to as large as 10^{8}um or 100m (Fig 5), the data acquisition is effected by sensing or recording specific forms of the energy by different means. The reflected energy i.e., the **light**, is recorded on a photographic films by a process called as **Photography** while the emitted energy is generally recorded on a magnetic tape by means of electronic devices by a process called **Scanning**. While the photographic process is completed by a single snap of the whole scene to be recorded on the film, the scanning involves continuous movement of the field of view of the device along certain lines perpendicular to the direction of flight (Fig 6).

Depending on the portion of the electromagnetic spectrum sensed and the sensing device or base material used, the important forms of remote sensing are:

a) **Aerial photography:** Sensing the reflected energy (light) in in wavelengths of 0.3um to 0.9um (1.3um in special cases) by means of a camera on a photo-sensitive film; the product is called as **"Air-photo"** or **"Aerial photograph"**

b) **Aerial thermography:** Sensing the thermal infrared energy (Thermal scanning) in wavelengths of about 3um to 14um through electronic devices (scanners) on a magnetic tape; transferable onto a photographic film; the product is called as **"Thermogram"** or **"Thermal imagery"**

c) **Microwave sensing:** Sensing the reflected and emitted (Radar scanning) energy in wavelengths of 1mm-1m by means of electronic devices (radar) on a special film; the product is called as **"Radar imagery"**

d) **Multispectral:** Sensing the reflected and thermal **scanning (MSS)** infrared energy in wavelengths of about 0.3um to 14um in the form of a multitude of different bands through electronic devices on a magnetic tape which can be transferred onto photographic films; the product is called as **"MSS imagery"** specified with the band in which imaged

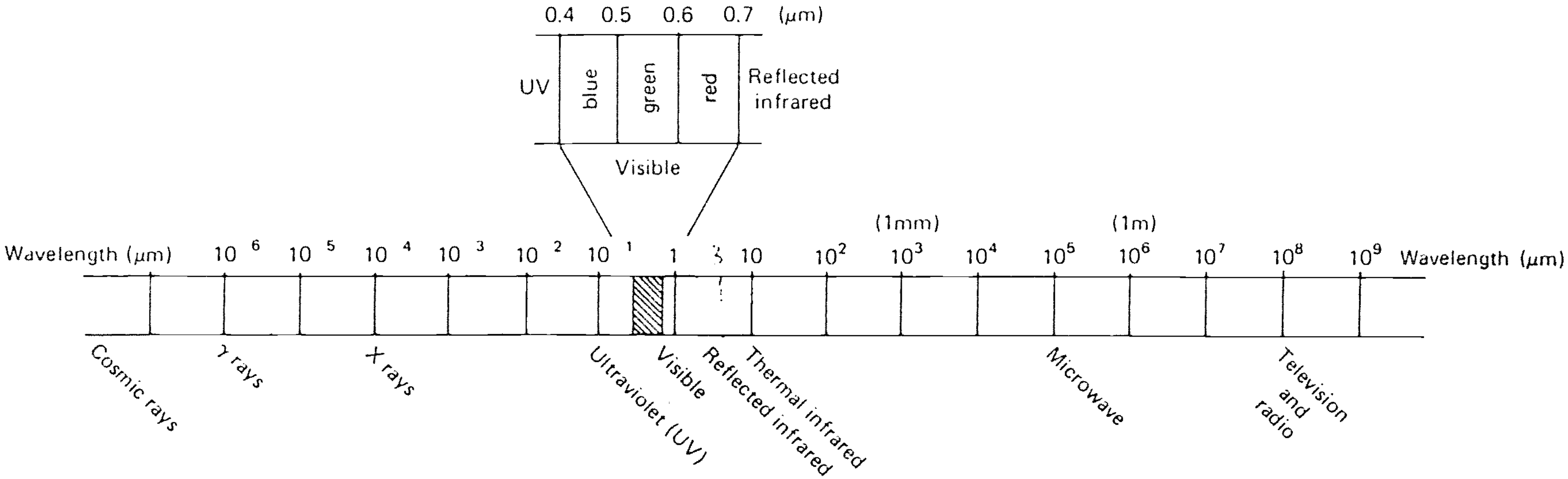


Figure 5: The electromagnetic spectrum.

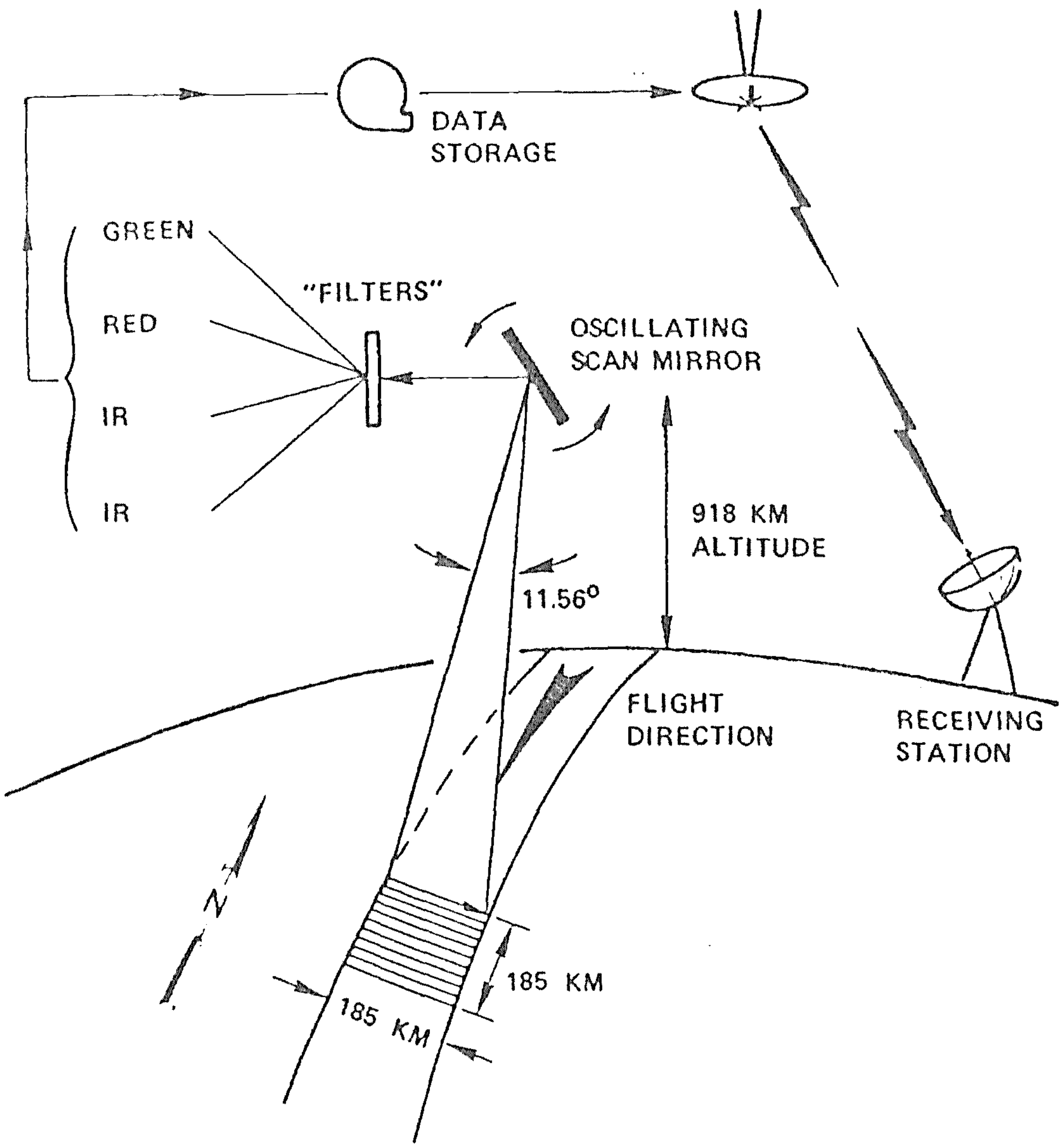


FIGURE 6
Landsat multispectral scanner. For each terrain scene, four images are transmitted to a receiving station. From NASA (1976, Figure 2-4).

The other forms of electromagnetic energy that can be sensed include **radio/TV waves, ultravoilet rays, X-rays,** etc.

The most important scanning systems are the U.S. space satellite Landsat's **Multispectral Scanner or MSS** and **Thematic Mapper or TM** which record data in multilpe spectral bands. The three MSS bands most commonly used for general interpretations are defined below with respect to their spectral ranges:

MSS band	Spectral range	Energy
Band 4	0.5 - 0.6um	Green
Band 5	0.6 - 0.7um	Red
Band 7	0.8 - 1.1um	Ref IR

Although the MSS data is recorded by the Landsat in a 185km wide continuous strip scanned at any one time, the **scenes** (images obtained on the recording films) are framed so as each scene covers an area of 185 x 185km^2. The MSS images have a **ground resolution** (the minimum size of the ground feature recognizable on the image) of 79m. Every point on earth is imaged by one Landsat system after every 18 days which implies 20 images of every point on earth in a year. The multi-temporal images so obtained afford the study of changes over short periods in the earth's dynamic systems.

Latest developments in remote sensing from space satellites have introduced the **Spot images** being sent by the French "Spot Satellite" which have a ground resolution of only 30m.

3.2 Air-photos vs other forms of remote sensing data

A quick look at the electromagnetic spectrum (Fig 5) reveals that the photographic part i.e., the reflected portion, of the electromagnetic energy which can be sensed by a photographic film, is extremely small while a wide scope exists for its sensing in other portions of the spectrum; the latter, though requires the use of electronic devices, has several advantages over the photographic detection as follows:

i) The aerial photography is dependent on light and can be done only during day time while having problems of over-exposue or under-exposure associated with differences in the intensity of light and quality of film etc.; the electronic sensors perform well under all types of atmospheric conditions

ii) The air-photos have problems of scale variations, figure distortions and relief displacement (discussed later in this chapter) which are almost non-existent in the images produced by electronic sensing

iii) The data is recorded by electronic detectors on magnetic tapes which can be computer processed for interpretation and mapping purposes; that abjective can not be normally achieved if the air-photos are used

Despite a few shortcomings in their use, the air-photos are recognized as the most common, versatile and economic form of remote sensing data which can be used for many different purposes.

3.3 Procedure of aerial photography

The air-photos are generally taken by means of a frame camera mounted on an airplane flying in planned straight lines (**Flight Lines or Flight Strips**) at certain known elevations with the camera aperture opening at controlled intervals. The photo coverage of an area is completed by a multiple of flight lines parallel to each other, leaving no gaps but with an overlapping by about 60 percent between the successive photographs (**End Lap**) and by about 30 percent between the adjoining flight lines (**Side Lap**). The ground trace of the line of aircraft movement (**Nadir Line**) should ideally be straight but is seldom so and a **Drift** in the photography may occasionally occur due to lateral displacement of the aircraft flight by winds etc. Another defect in the air-photos, caused by intentional tilting of the aircraft flight axis by the pilot in an effort to counteract the wind effects, termed as **Crab**, generally results in disfiguration of the objects. The procedure of aerial photography and ground coverage of the air-photos is illustrated by figures 7 to 9.

The final product of aerial photography is the strips or blocks of overlapping photos which are systematically arranged and numbered from one end of the flight line to the other (commonly in the west to east direction). Several blocks of photos may be combined together in the form of one large photo (called **Photo-mosaic**) by eliminating the overlapping parts. The photo-mosaics are useful in providing a general view of large areas. The location of each air-photo in any country or project area is indicated on specially prepared **Photo-index Maps** which help in sorting out the air-photos of any project area and their acquisition from the national mapping agencies.

3.4 Role of air-photos in land resource surveys

The scientific methods of mapping soils and other land features important for land resource assessment, problem identification and agricultural planning necessarily entail the use of air-photos as complementary to ground observations. In fact, correct delineation of the variations in land characteristics can not be

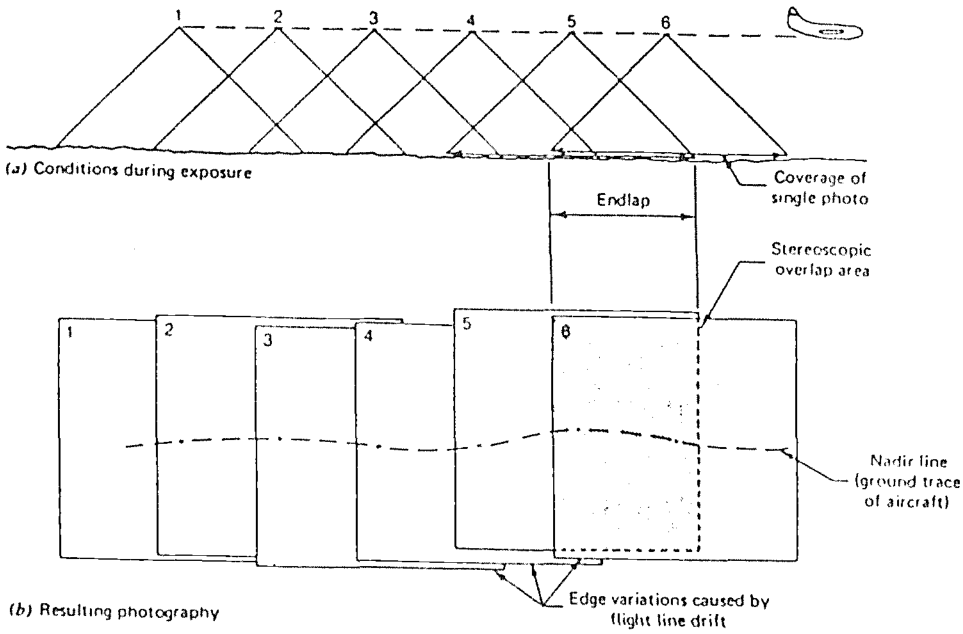


Figure 7a Photographic coverage along a flight strip.

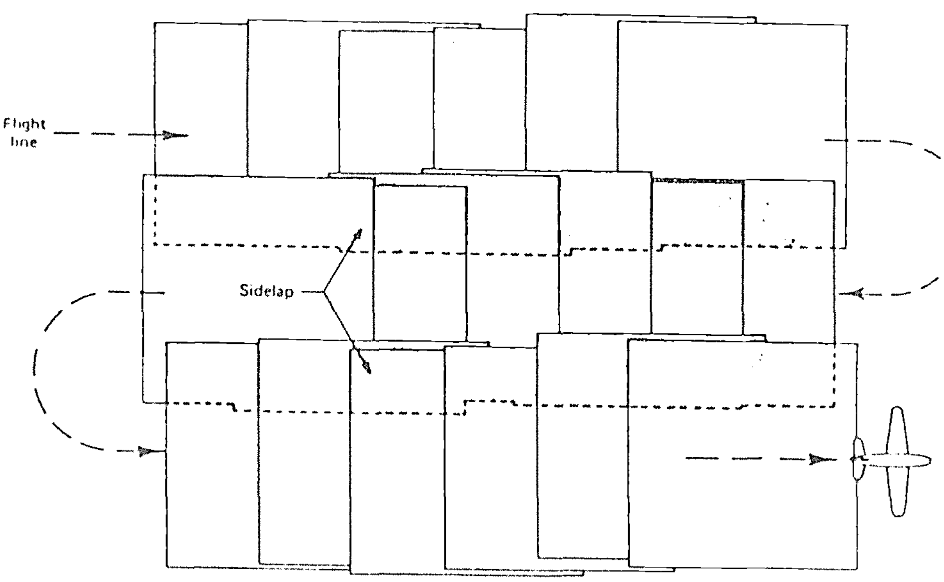


Figure 7b Adjacent flight lines over a project area.

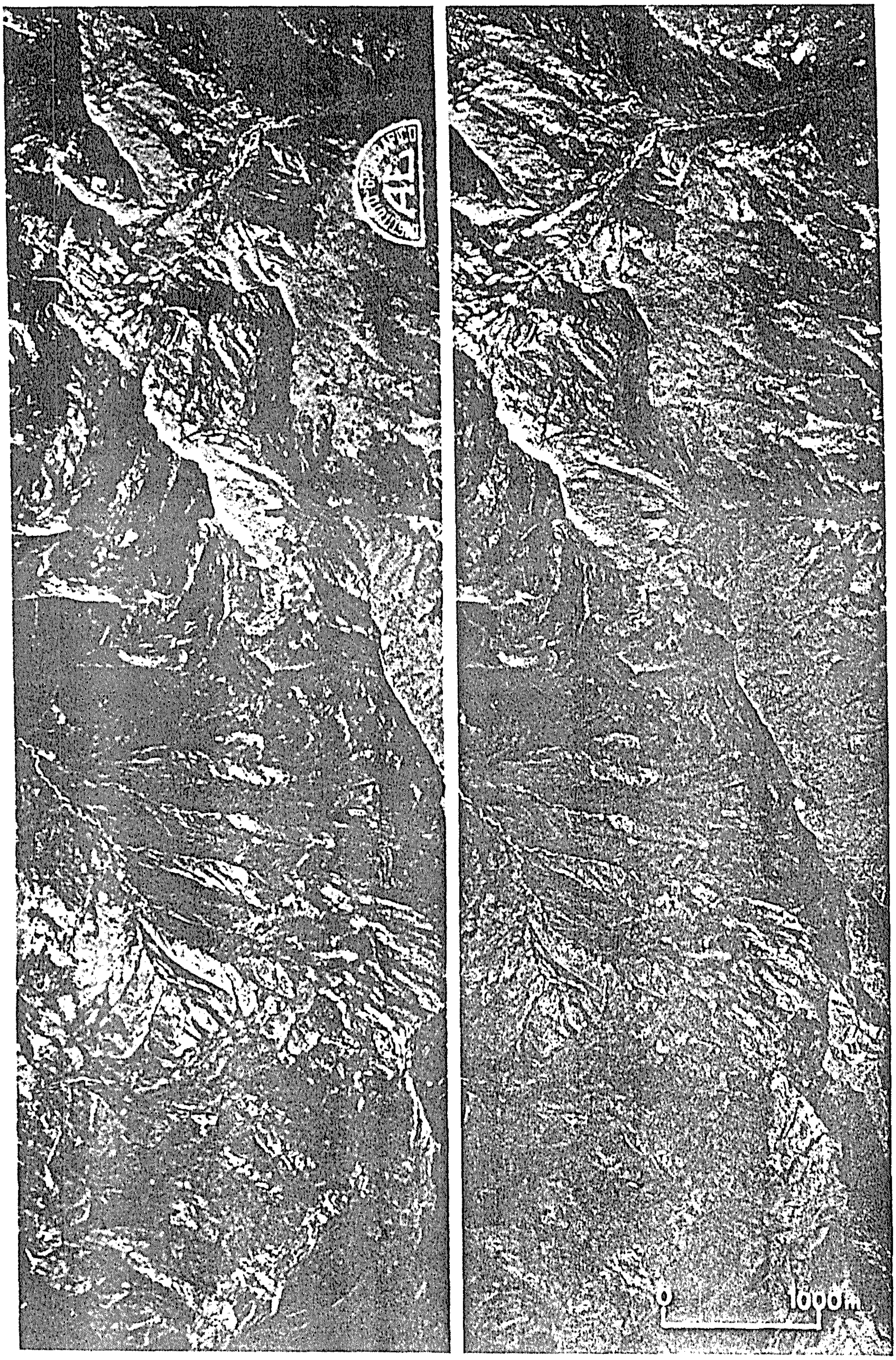


Fig. 8 Stereogram showing an area with complex relief in the Eastern Andes. (Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

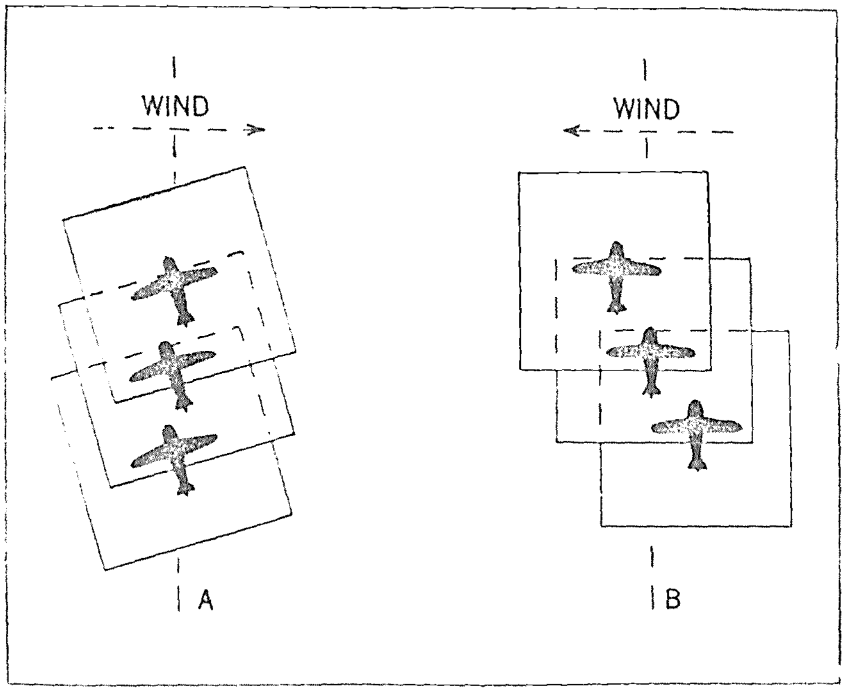


FIGURE 9a—Sketches showing irregularities in aerial photographs: *A*, from crabbing; *B*, from drift.

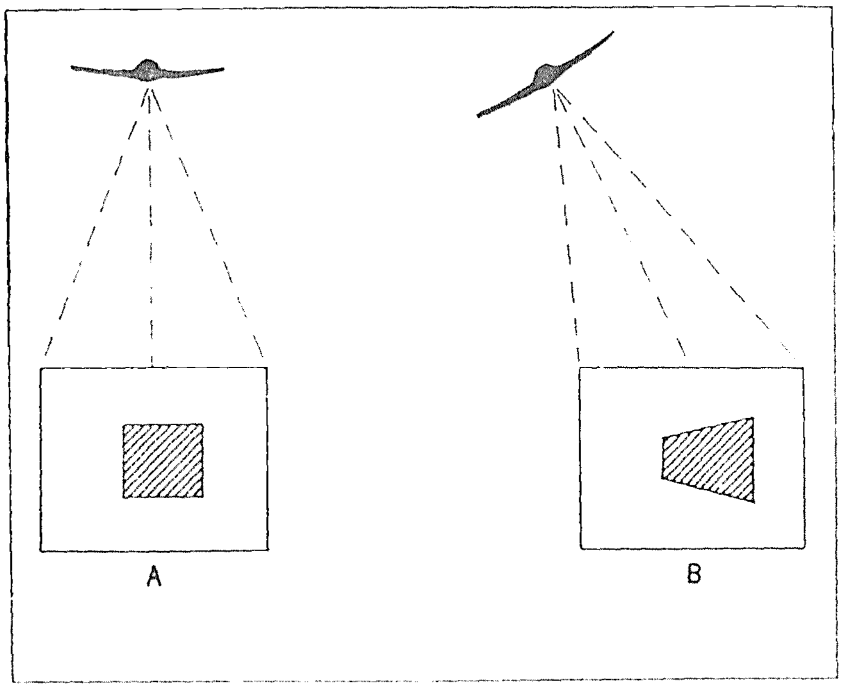


FIGURE 9b-Sketches showing distortion of a square in an aerial photograph because of tilt: *A*, normal; *B*, with tilt.

conceived in the absence of air-photos, except when extremely detailed large-scale maps are available which is impractical to obtain for large project areas; even with such maps, several times more ground observations and time would be required to reach the same degree of accuracy as with the use of air-photos. The fact is that the maps, however detailed they may be with respect to topo-raphic and other information, would remain blind in terms of the much vital information like the micro-relief, slope breaks, soil change, surface cover and moisture conditions etc., which reduces their utility for precise mapping. In contrast, there generally exist sharp differences in tones and patterns of an air-photo wherever there are changes in any of the above and many other features, which makes it much convenient and precise to delineate them separately.

The use of air-photos not only facilitates and expedites land resource mapping but also affords many other advantages even over on-site observations which include:

i) an improved vantage point allowing observation of the earth surface features in their spacial context,

ii) a synoptic view of the terrain,

iii) an increased spacial resolution and geometric fidelity helping in accurate measurement of the features and

iv) a broader spectral sensitivity of the air-photos which allows detection of some invisible features.

The above facts should not be misunderstood to imply that the use of air-photos would eliminate the need for ground observations. Although maps can be produced by interpreting the air-photos alone, at least a few observations on the ground are necessary to make the results of air-photo interpretation reliable.

The air-photos can be effectively used to accomplish various types of land resource studies which include:

- geological surveys,
- soil surveys,
- land use and vegetation surveys,
- forest type classification,
- rangeland surveys,
- crop assessment,
- urban and rural settlement,
- alignment of roads and railways and
- recreational use of lakes and rivers etc.

- hydrological investigations such as:
    - watershed assessment,
    - reservoir site selection,
    - wetland mapping,
    - alignment and designing of flood protection embankments,
    - drainage planning,
    - irrigation planning,

Specific techniques of air-photo interpretation are to be employed for different kinds of studies.

3.5 Types of air-photos and photographic films used

Depending on the position of the camera or the direction of the camera lens kept during photography, the air-photos are classified as:

a) Vertical when the camera lens is directed towards the earth's centre of gravity and

b) Oblique when the camera is intentionally inclined so as to keep the direction of its lens away from the earth's centre of gravity.

Virtually, most of the air-photos classified as vertical are seldom truly so since they generally have 1^0 to 3^0 tilt.

The oblique photos are divided on the basis of the degree of tilt as follows;

i) **High Oblique** -highly tilted photos which show up the horizon

ii) **Low Oblique** -Less tilted photos not showing up the horizon

The various types of photographic film used for aerial photography include:

a) **B&W Panchromatic** -Black and white films with spectral sensitivity of 0.3 to 0.7um

b) **B&W IR-sensitive** -Black and white films with spectral sensitivity of 0.3 to 0.9um (special films upto 1.3um)

c) Normal **Colour** -Colour films with spectral sensitivity of 0.4 to 0.7um

d) **Colour Infrared** -Colour films with spectral sensitivity of 0.4 to 0.9um (special films upto 1.3um); also called as **CD** (Camouflage Detection) films or **False Colour** films

The appearance of colours on the positive prints of the Normal Colour and Colour IR (CD) films is as follows:

Reflected energy of the original scene	[Blue]	[Green]	[Red]	[IR]
Normal Colour photo	[Blue]	[Green]	[Red]	[Black]
Colour IR (CD) photo	[Black]	[Blue]	[Green]	[Red]

The surface cover of healthy green vegetation, which can not be easily differentiated from the wet areas on a B&W panchromatic film because of dark photo tones given by both, is best identified on an IR-sensitive film due to high reflectance by chlorophyll and low reflectance of wetness in the Reflected IR wavelengths of energy.

The signatures (colour impressions) of various forms of vegetation and other important features on Normal Colour and Colour IR films are generally as in Table 1.

Table 1: Signatures of various terrain features on Normal Colour and Colour IR films

Object	Normal colour	Colour IR film
Healthy vegetation:		
Broad-leaf	Green	Red to magenta
Coniferous	Green	Red. brown to purple
Stressed vegetation:		
Previsual stage	Green	Dark red
Visual stage	Yell. green	Cyan
Autumn leaves	Red to yellow	Yellow to white
Clear water	Bluish green	Dark blue to black
Silty water	Light green	Light blue
Shadows	Blue with most details visible	Black with only few details visible
Red rock outcrops	Red	Yellow
Boundary between land and water	Poorly marked	Excellently marked

3.6 The photo scale

The photo scale (S) is defined as a ratio of the distance between two points on the photograph to that on the ground i.e.,

$S = d/D$ where d = Distance on the photo (m)
and D = Distance on the ground (m)

The scale can also be calculated as:

$S = f/(H-h)$ where f = Focal length of the camera (m)
H = Flying height of the plane (m)
and h = Elevation of the terrain (m)
H-h = Flying height of the plane above the terrain (m)

For most frame cameras, 'f' is generally 152mm. A photo scale of 1:50 000 would then imply that the photos were taken from an average height of about 7 500 metres above the terrain.

Since the air-photos present a perspective view of the earth surface features, these **do not have a true scale**. The objects or parts of an object placed at higher elevations lie closer to the camera and, therefore, have a larger scale than those placed at lower elevations. In case of a flat terrain, the photo scale varies so that it is largest at the central part and smallest along the margins. The scale given for a certain air-photo represents an average of its different parts. The differences in the photo scale can be rectified by means of a stereo-plotter; the resultant photo (called as **"Orthophoto"**) would then have a uniform scale, which is used for production of accurate topographic maps.

3.7 Basic characteristics of air-photos

The basic photographic characteristics which help in identification of objects or earth features include:

a) Shape — General form and configuration of the object as it appears on the air-photo (square, rectangular, rounded, oval, triangular, irregular etc.)

b) Size — Area occupied by the object on the air-photo in relevance to the photo scale (large, medium, small, very small etc.)

c) Pattern — Spacial arrangement of the objects in a specific environment (criss-cross, transverse, jumble, parallelly aligned, dotted, irregular, etc.)

d)	**Tone**	Relative brightness or darkness of the image (bright, light grey, dark grey, black etc.)
e)	**Shadow**	Dark shades and their shapes in relation to the objects falling around
f)	**Texture**	Frequency of tonal change on the air-photo; in fact, it is a product of the individual shapes, sizes, patterns, shadows and tones of all the objects around (fine, medium, coarse etc.)
g)	**Location** (Site)	Placement or position of an object in relation to the features or objects around (top of hill, foothill, stream bank, riverbed, adjacent to lake, within built-up land etc.)
h)	**Colour**	Colour of the object in relevance to the type of photographic film; important only for colour photos.

3.8 <u>Reflectance properties of earth features</u>

The earth features have varying capabilities of reflecting light which result in producing different tones on the air-photos and thus lead to their identification. A higher reflectance implies lighter tone and a lower reflectance means darker tone on the air-photos. The same object would reflect more if placed in a higher position than if occupying a lower position and would have correspondingly lighter or darker photo tone - a fact that allows depth perception even while studying the air-photos visually.

The specific reflectance properties of soils (soil or rock surface without vegetation cover), water and vegetation (with adequate density) in different wavelengths of electromagnetic energy are roughly sketched in Fig 10 and briefly described as follows:

<u>Soils</u>:

The reflectance of soils varies with various factors as discussed below:

a)	**Moisture status**	- Higher reflectance with lower moisture content and vice versa
b)	**Texture**	- Sandy soils have a lower reflectance than clayey soils when dry; the reverse is true when wet; may have same reflectance when just moist; loamy soils lie in intermediate position in either case

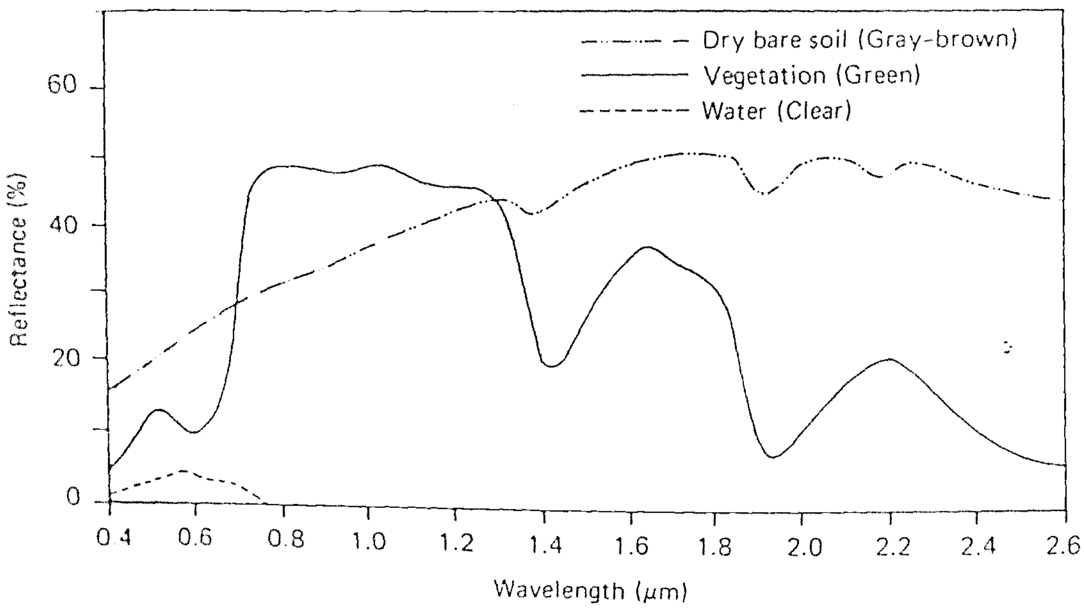


Figure 10 Typical spectral reflectance curves for vegetation, soil and water.

c) **Salinity**	- Saline soils have highest reflectance when dry and moderate when moist
d) **Organic matter content**	- Soils with higher organic matter content have lower reflectance and vice versa
e) **Surface roughness**	- Relatively rough or uneven surface gives lower reflectance as compared to a smooth surface

Vegetation:

The vegetation differs in reflectance in various portions of the electromagnetic spectrum. Healthy dark green vegetation has a low reflectance in its visible portion but high reflectance in the reflected IR portion. The dry vegetation, however, behaves like dry bare soils.

Water:

The water generally has a low reflectance in all portions of the electromagnetic spectrum. The least reflectance, however, occurs in the reflected IR wavelengths, so that it imparts almost black tone on the IR photos. But the reflectance of the bottom or suspended material, even in deep water, commonly manifests itself to modify the photo tones.

3.9 Air-photo interpretation

3.9.1 Basic concept and principle

The air-photo interpretation implies recognition and identification of objects or earth features on the air-photos and their objective description. The main principle controlling the air-photo interpretation is that each terrain feature has a certain shape and area (breadth and width) as well as depth or height and occurs in a specific pattern and tone on the air-photos, and that the differences in surface appearance of the features are related to the differences in their subsurface characteristics. Different land features can be delineated on the air-photos by correlating the differences in their subsurface characteristics with the changes in landscapes which are reflected on the air-photos.

3.9.2 Visual interpretation

Most earth features can be identified through visual study of the air-photos since each feature has a specific appearance on the photo due to its shape, size, pattern of occurrence, photo tone (determined by its reflectance properties), location or colour (on colour photos) relevant to the other features. Some refrence material is, however, often needed to ascertain their identification. Ground checking may be necessary for that purpose in certain cases. The information collectd from the ground checking would then serve as the reference material for delineation of similar objects on the air-photos. The features which are relatively easy to identify with naked eyes include artificial structures (roads, railway lines, canals, drainage channels, air strips, towns), lakes, rivers, swamps, playas, fans, sand dunes, forests, grasslands, cultivated fields and bare land etc.

The minimum size of the earth features which can be clearly identified on an air-photo - the **Photographic Resolution**, depends much on the quality of photography. But, in general, visual identification of certain small objects on a small-scale photo is quite difficult, especially when there is little difference in its photo tone. Problems in identification of objects may also arise due to **Distortions** - i.e., disfiguration of the objects with high relief or due to tlted image. The **Vertical relief displacement**, which implies appearance of the tops of high or very steep objects away from their bases on the air-photos, is another factor posing difficulties in visual identification, especially in a terrain of rugged topography.

A major drawback in studying the air-photos with the naked eye is that the third dimension (depth or height) of objects remains obscure so that the features like hills, mounds, escarpments, depressions, slopes, gullies and relative heights of different landscapes etc., can not be correctly visualized and measured.

3.9.3 Stereo-interpretation

One of the most effective way of air-photo interpretation is by correlating the surface topographic differences of the earth features with their subsurface characteristics. Appreciation of the topographic differences on the air-photos is possible by using an instrument called as **Stereoscope"**. This instrument allows simultaneous view of the objects from two different (adjoining) air-photos (called **stereo-pair**) placed under it side by side. The view thus obtained is three-dimentional, which is based on the principle that the same object on the two adjoining air-photos is imaged from two different angles and while each eye sees the object through stereoscope with a different perspective, the difference is synthesised by the human mind to provide a depth perception or three-dimensional view of the object.

In general, the third dimensional view under the stereoscope is quite exaggerated i.e., the height (or depth) of objects in relation to the length and width appears more than the actual one when viewed through the stereoscope so that relatively gentle slopes may be misunderstood as steep ones. Only a good experience of stereo-interpretation of air-photos would thus lead to right conclusions about the object heights and slopes. In principle, the less the overlapping between the adjoining air-photos, the greater the depth perception. To have complete photo coverage of an area for stereoscopic study, however, at least 50 percent end lap is necessary. It should be well understood that a pair of photographs taken from the same angle or that from two different angles but widely different elevations (thus having different scales) can not give a clear three-dimensional view.

Systematic stereo-interpretation of the air-photos of a project area is initiated by delimiting the areas of study on each photo with **"Match lines"** -the lines which bisect the endlaps and sidelaps into approximately two halves each. For flat terrains, it is more convenient and practical that the match lines are drawn on alternate photos. For stereoscopic study, two adjoining photos of the same flight line (called as **stereopair or stereogram**) are taken at any one time by aligning them under the stereoscope about 5 to 15cm apart (depending on one's eye base which differs from person to person) along an approximately straight horizontal line passing through the **Principal points** (cross marks at the centre) and **Fiducial points** (marks dividing the photo margins into two equal halves on all sides) of the two photos. The photos are kept flat by pressing their margins by means of steel bars or by inserting them into a specially constructed frame. For convenience, any three or four sharp points identified on both the photos may be marked with a colour pencil. The air-photos are then viewed through the stereoscope so that the right eye looks at the right-hand photo and the left eye at the left-hand one. While looking under the stereoscope, orientation of the photos may have to be slightly adjusted so that all the marked points (or some clearly distinguishable features) on one photo get exactly superimposed over the same points/features on the other photo. Concentrated look at various features will then enable one discern the relief differences of the terrain. Wherever these differences are considered important, depending on the purpose of studies, lines are drawn to delimit various map units so that all lines are continuous and extend to the match lines unless joining the other map unit lines. Readjustment of the photos is generally required while moving to other parts of the photos after studying one part; this readjustment is avoided if a scanning type of stereoscope is used.

Several factors may affect the three-dimentional view of terrain features, which include:

i) incorrect orientation of the photos,

ii) reversal of the sequence of photos (this act may give a view of inverted relief),
iii) coverage of the features by deep shadows or clouds,
iv) differences in the scales of the two photos,
v) distorted image (due to tilt),
vi) too much uniformity in colours or tones and
vii) unrelated marks on the photos (scratches, ink blots) etc.

3.10 Methods of air-photo analyses

Although no specific method is generally adhered to by experienced air-photo interpretors, except for special studies, the following three general methods of air-photo analyses may be differentiated.

a) Element analysis: In this method each element (land use, vegetation, landform, slope, drainage, erosion, soils etc.) is studied separately with respect to its type, shape, size, pattern, photo tone, etc. and individual maps are prepared for each element; all maps are then superimposed and integrated to arrive at the final map of land units or soils.

It is a relatively easy method and is good for the biginners.

b) Pattern analysis: In this method, major landscape units are first delineated on the air-photos and then characterised on the basis of patterns of occurrence; the pattern elements are landforms, drainage, erosional features, vegetation, cultural features and photo tones.

This method requires adequate reference material and thorough knowledge about landforms of the area under study.

c) Physiographic analysis: This method involves study and description of the land elements with special consideration of the factors and processes responsible for genesis of the landforms, and of the relationships between the landforms (physiography) and soils or other land features.

It is the most advanced and scientific approach to air-photo analyses for land resource studies but is appropriate only for the expert pedologists.

3.11 Preparation of air-photo interpretation legend and map

The objective of air-photo interpretation is to delineate different land features or elements and prepare a preliminary map of land units, which forms a basis for systematic field studies. Prior to delineation of the land units on the air-photos, a tentative legend is constructed which describes the main characteristics of the units as recognized from the air-photos. The legend consists of a list of sequentially arranged symbols which are defined in terms of the identified characteristics. The legend is refined time and again as the air-photo interpretation proceeds.

The land features or elements which are important for general land resource assessment and can be easily identified and delineated precisely on the air-photos include the following.

a) Landform: All important major and minor landforms/land elements to be identified as, for examples:

Mountainous land: Ridge top, plateau, colluvial slope, scree slope, escarpment, alluvial fan, cone, gully side, valley bottom, rock outcrop, snow cap, lake, glacier, glacial trough, moraine ridge, etc.

Alluvial plains: Bar, levee, level plain, channel, basin, back swamp, oxbow lake, braided riverbed, lake bed, playa, delta, spill flat, etc.

Sand plains: Sandy ridges, inter-ridge valleys, barchans, shifting sand dunes, interdunal flats, playas, rock outcrops, etc.

b) Topography: To be identified with respect to simple or complex slopes as:

Simple slopes: Flat,almost flat, gently sloping, sloping, moderately steep or very steep

Complex slopes: Almost flat, gently undulating, undulating, rolling, hilly, steeply dissected or mountainous

c) Erosion features: Important erosion features include rills and gullies, to be identified with respect to density, shape and size as follows:

Density: Low, medium, high
Shape: V-shaped, U-shaped or _/-shaped
Size: Small-sized, medium-sized, large-sized

d) Drainage: To be described in terms of both pattern and conditions as follows:

Drainage pattern: Dendritic, rectangular, trellis, radial (centipetal or centrifugal), deranged etc. (see Fig 11 for main drainage patterns)

Drainage conditions: Excessively, somewhat excessively, well, moderately well, imperfectly, poorly or very poorly drained

e) Soils: To be identified, where possible, with respect to the following:

Texture: Sandy, loamy, clayey, stony or bouldery

Depth: Shallow, deep, very deep (mention if no soil cover expected)

Salinity: Nonsaline, slightly saline (in patches), moderately saline or severely saline

f) Land use/vegetation cover: The following major kinds of land use can be differentiated:

Forest: Bush forest or tree forest; thin (or open), moderately thick or very thick; broad-leaf or coniferous

Grassland/pasture: Patchy, moderately thick or very thick vegetation cover

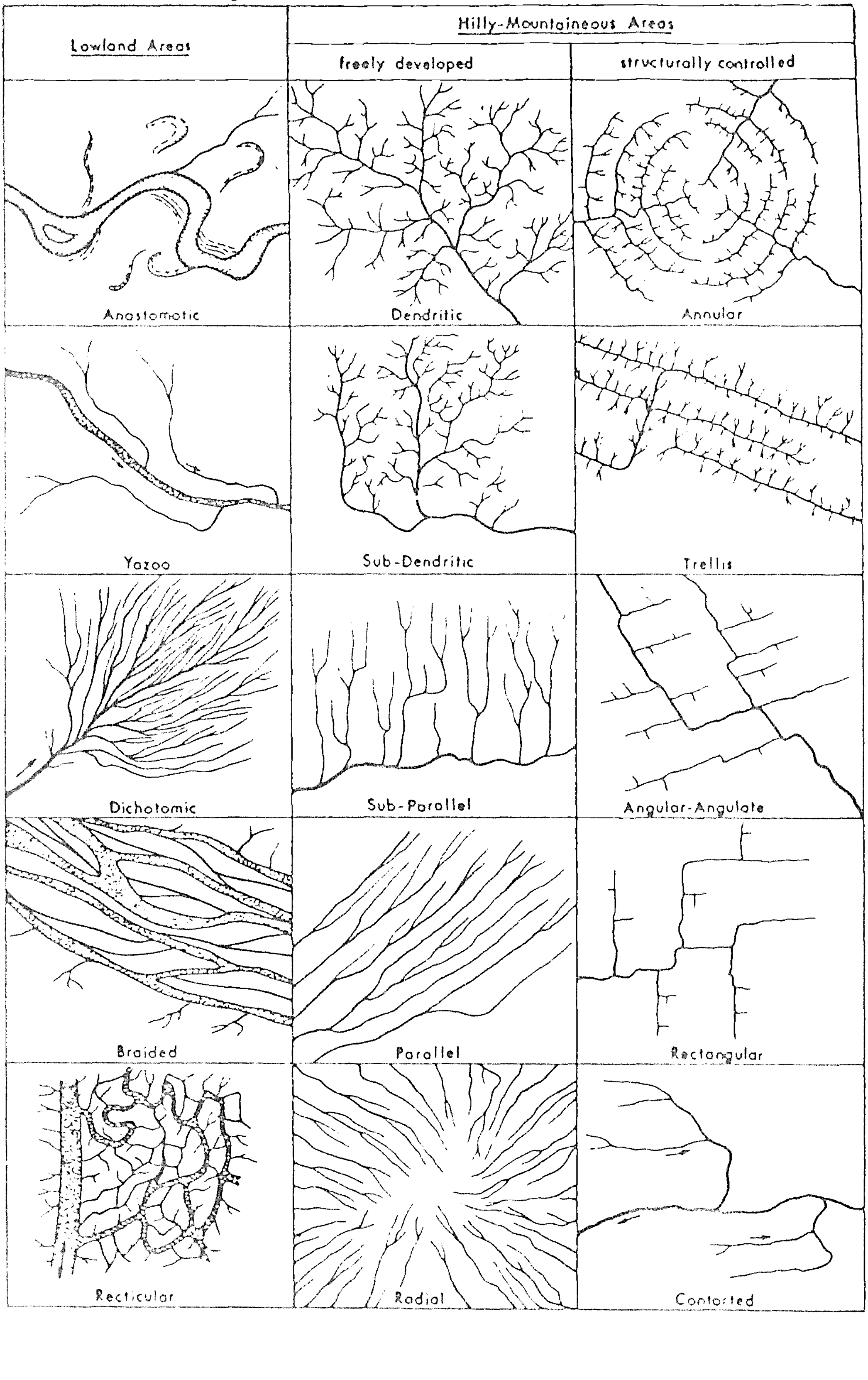
Arable land: General cropping, mainly rice (or teff) or orchards; rainfed or irrigated; currently cropped or fallow

Bare land: Scattered bushes/trees or no vegetation

g) Artificial structures: The easily identified artificial structures, to be sketched on the air-photo interpretation map, include **roads, railway tracks, towns/villages and other built-up areas, grave-yards, brick kilns, querries, air strips, canals, embankments, ponds, lakes or dams etc.**

The choice of the symbols to be used for the air-photo interpretation map and its legend rests on the interpretor. Both the number and the letter symbols may be used, exclusively or in combination. However, for artificial structures, conventional signs instead of numerical or letter symbols are generally used. The legend may represent an individual land feature or a combination of two or more features.

Fig.4: MAIN DRAINAGE PATTERNS



An example of the legend representing landforms and topography is:

I. Mountainous land:

Ia. Mountainous land, ridge top
Ib. Mountainos land, plateau remnant
Ic. Mountainous land, colluvial slope

Ia3. Mountainous land, gently sloping ridge top
Ib2. Mountainous land, almost flat plateau remnant
Ic5. Mountainous land, moderately steep colluvial slope

Examples of a legend representing land use/vegetation cover are:

F. Forest:

Ft. Tree forest
Fb. Bush forest

Ft2. Moderately thick tree forest
Fb3. Thick bush forest

Ft3c. Thick coniferous tree forest
Fb1 . Open bush forest

A. Arable land:

A2. Arable land mainly under rice
A3. Arable land mainly under orchards

A2i. Arable land, mainly under irrigated rice
A2d. Arable land, mainly under rainfed orchards

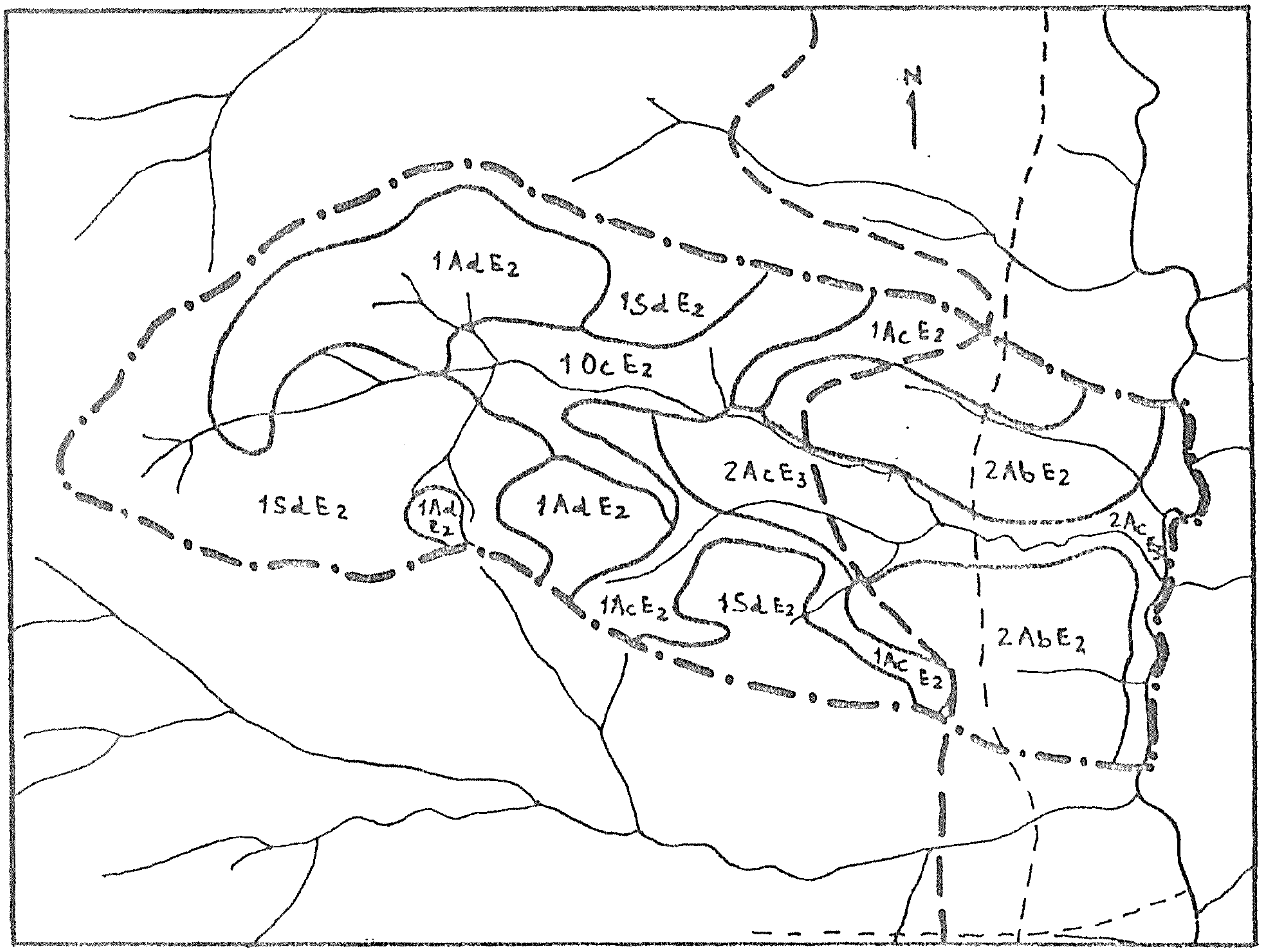
Af. Arable land, currently fallow

A typical air-photo interpretation map prepared for a sample study area for the Highland Soil and Water Conservation Project in Gojam Region of Ethiopia is presented on Map 1.

3.12 Photogrammetry

The photogrammetry implies measurement and mapping of the earth surface features with the help of aerial photographs. The important measurements that can be made and the maps that can be produced with the help of air-photos include the following.

Map 1



AIR-PHOTO INTERPRETATION

DABI SAMPLE AREA

Scale 1:20,000

L E G E N D

Landforms:

1 Colluvial slopes and terracette
2 Piedmont alluvial plains

Land use/vegetation cover:

A Arable land
O Open forest
S Scrub

Slope:

b Gently sloping to undulating
c Moderately steep
d Steep to very steep

Erosion:

E2 Moderate rill and gully erosion
E3 Severe gully and streambank erosion

3.12.1 Measuring horizontal ground distance and angles

The straight horizontal distances between any two points are measured by using a divider placed on the two points and then measured on a ruler, followed by calculations according to the photo scale using the relation:

Distance on the ground (m) = Distance on the photo (m)/ Photo scale

The distance along a zigzag route may be measured either by dividing the routes into different small, nearly straight sections and adding them together or by using a fine inelastic thread placed exactly throughout the route and then measuring the covering thread length with the help of a ruler, followed by calculations with the above procedure.

EXERCISE : Two points P and Q are located 8cm apart on a vertical air-photo taken from an elevation of 1,800m amsl by means of a frame camera having 10mm focal length. If the terrain lies 300m amsl, what will be the ground distance between the two points?

Solution:

$$H-h = 1800-300 = 1500m = 15x10^2m$$
$$f = 10mm = 10^{-2}m$$
$$S = f/(H-h) = 10^{-2}m/(15x10^2m) = 1/15x10^4m$$

1cm on A.P. = 1.5km on ground

10cm on A.P. = 1.5x8 = 12km on ground

3.12.2 Measuring object heights and terrain elevation

a) From relief displacement:

The magnitude of relief displacement is related to the flying height of the aircraft, height of the object and placement of the object in relation to the principal point of the air-photo (see Fig 12). This relation is expressed as:

$d = rh/H$ where d = Relief displacement of the object from its base,
r = Radial distance on the air-photo from its principal point (p) to to the top of the object
h = Height of the object from its base
H = Flying height of the aircraft from the base of the object
(all parameters expressed in the same units)

The height (h) of the object can be calculated by rewriting this relation as: $h = dH/r$

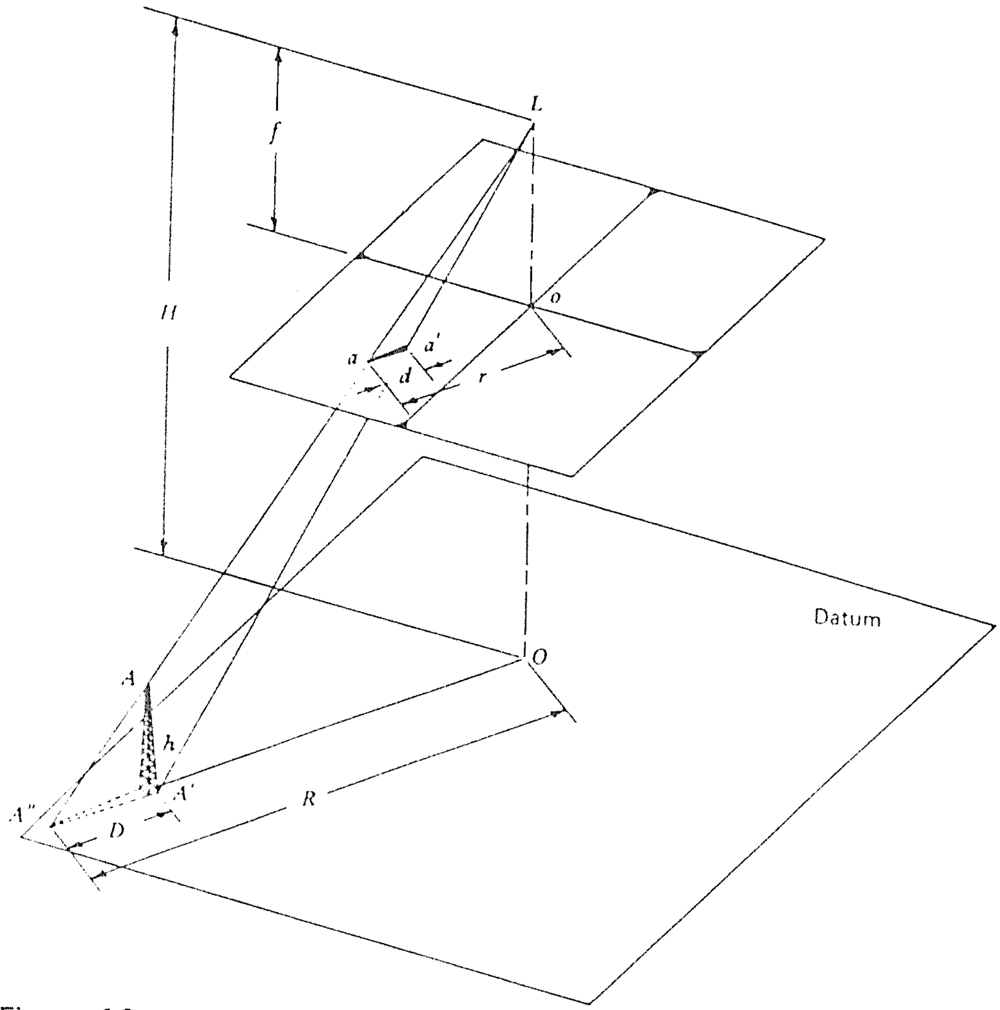


Figure 12 Geometric components of relief displacement.

b) <u>From image parallax:</u>

The relative position of the earth features changes from photo to photo,more so at higher elevations; this change, termed as **Parallax**, is measured by means of a micrometer (parallax bar) and used for height measurements. A few accurately located points (called as "Control points") are used to callibrate these photographic measurements.

In Fig 13a and 13b which represent two adjoining air-photos of the same flight line (a stereopair) with their principal points (indicated by + sign) located at o and o' respectively, the photos are set up in straight direction of the flight line to view under the stereoscope. Relative elevations of the points 1 and 2 (Fig 13a), or the height of an object from point 1 to point 2 (Fig 13b), can be calculated from the difference of parallax by directly measuring with a scale and using the following relations:

Parallax, $p = D-d$

where D = Distance between the two principal points of the stereopair (in mm)
d = Distance between the two images of the same point on the stereopair (in mm)

The difference ($\triangle h$) in elevation of the two points 1 and 2 is calculated as:

$$h = \triangle p . H/(b+\triangle p)$$

where $\triangle p$ = Parallax difference i.e., the difference between the parallaxes of the two points ($p1=D-d1$, $p2=D-d2$; $\triangle p=p1-p2$) (mm)
H = Height of aircraft above the terrain (m)
b = Photo air-base of the stereopair (mm)

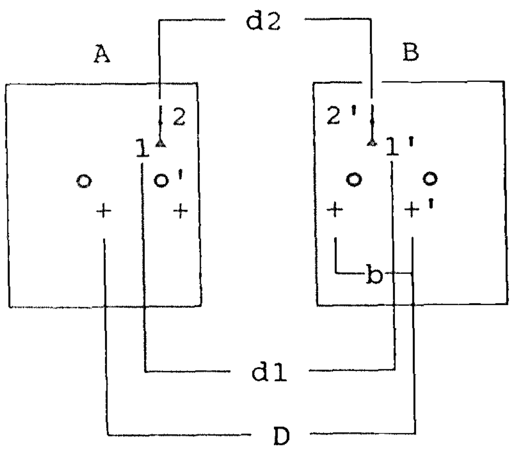


Fig 13b

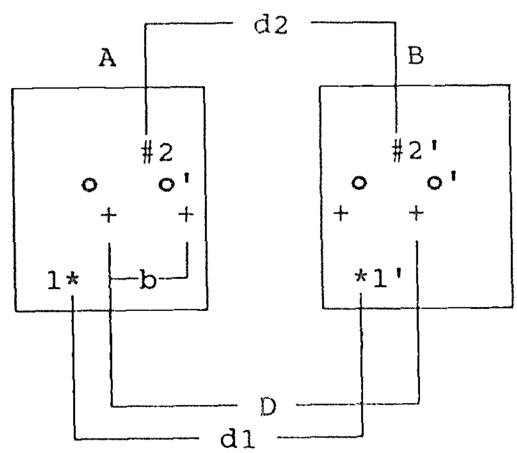


Fig 13a

3.12.3 Generation of orthophotos and topographic maps

The differences in photo scales and distortions in the aerial photographs can be rectified by means of a stereo-plotter. The resultant photograph would then have a uniform scale and would be called as **Orthophoto.** The orthophotos form a standard base for the production of accurate topographic and other maps.

4. DETAILED SOIL DESCRIPTION AND CLASSIFICATION

4.1 The soil profile and the soil horizon

The term Soil profile refers to a vertical section of the soil through its depth to the parent material or bedrock, showing all its genetically developed and undeveloped layers. The Soil horizon is "a layer of soil or soil material approximately parallel to the land surface, having properites due to soil genetic processes and differing from its upper and lowe genetically related layers in physical, chemical and biological characteristics". The term Soil layer is generally given to that section of the soil profile which is not genetically developed and which differs in characteristics from the overlying and underlying layers or horizons. The soil profile may consist of a single layer/horizon or may have a number of layers/horizons, or a combination thereof.

4.2 Methods of studying the soil profiles

Most of the soil profile characteristics are observed and described by one of the following three general methods.

i) By excavating a Soil pit, with rough dimentions of 1m width, 1.5m length and 1.5-2.0m depth (in case of soils with depth less than 2m, the pit is exposed to the underlying parent material or bedrock), in a way that its walls are nearly vertical except that a few steps may be provided on one side (for easy entry into and coming out of the pit). One of the pit walls is then smoothened and carefully dug into with a knife so as to expose all the structural peds and other visually recognizable features. The wall is divided into different soil horizons/layers each of which is then studied individually by sampling it by means of knife and testing with the help of different instruments/chemicals etc. mentioned with the respective characteristic in the following.

ii) By making a Mini-pit of rough dimentions 50cm x 50cm x 50cm and studying it in the manner described above, followed by boring in the centre of the mini-pit by means of an auger and testing each auger sample to a depth of about 1.5 to 2.0 metres.

iii) By boring with Auger immediately from the surface and testing each auger sample in the manner described above to a depth of 1.0 to 1.5 metres.

4.3 The Master horizons

The main horizons and layers used to describe a soil profile of any kind are seven in number and are designated as **H, O, A, E, B, C** and **R.** These horizons are called as the "Master Horizons". Each of these horizons has specific characteristics which differ from those of the others. These characteristics are described as follows.

H: An organic horizon or layer formed from accumulation of undecomposed or partially decomposed organic materials deposited on the surface under prolonged water saturated conditions, which may now be artificially drained.

O: An organic horizon or layer formed from accumulation of undecomposed or partially decomposed litter on the surface, which has not been saturated with water for prolonged periods.

A: A mineral horizon formed at surface or below an O horizon in which all or most of the original rock structure has been oblitrated and has one or more of the following:

- shows an accumulation of humified organic matter which is intimately mixed with the mineral fraction.
- has properties resulting from cultivation, pasturing or similar kinds of disturbance.
- has a morphology acquired by soil formation but lacks the properties of E and B horizons described below.

E: A mineral horizon showing a concentration of sand and/or silt fractions high in resistant minerals, resulting from a loss of silicate clay, iron or aluminium, or some combination of these.

B: A mineral horizon formed below an **A, E, O or H** horizon in which all or much of the rock structure has been oblitrated and is characterized by one or more of the following features:

- an illuvial concentration of silicate clay, iron, aluminium or humus, alone or in combination;
- evidence of removal of carbonates;
- a residual concentration of sesquioxides relative to the source materials;
- coatings of sesquioxides without apparent illuviation of iron;

- an alteration of material from its original condition to the extent that silicate clays are formed, oxides are liberated, or both, or a granular, blocky or prismatic structure is formed;

- brittleness.

C: A mineral horizon or layer of unconsolidated material which is little affected by pedogenetic processes and lack the properties of any other master horizon.

R: Hard bedrock underlying the soil, which is sufficiently coherent to make hand digging with a spade impracticable; the rock may contain cracks but too few and too small for significant root development; the gravelly and stony material which allows root development is considered as C horizon.

4.4 The transitional horizons

The soil horizons having properties of two Master horizons are referred to as the **Transitional horizons** and are designated by a combination of the two symbols representing the relevant Master horizons. The first symbol should belong to that Master horizon which is most similar to the transitional horizon. For instance, a horizon having properties similar to both B and C horizons but being closer to C horizon than B will be designated as CB.

The soil horizons which have intermingling of separately distinguishable Master horizons are designated with the symbols of the two relevant Master horizons separated by a virgue (/), the dominating one coming first. For example, a B horizon having an intrusion or tonguing of O horizon which constitutes less than 50 percent but considerable amount of the total soil material will be designated as B/O.

4.5 Subdivision of the Master horizons

The horizons may be divided vertically on the basis of significant difference in characteristics. These divisions are indicated by using an **Arabic number suffix** with the symbols of the Master or transitional horizons. For instance, three sections of a C horizon differing from each other in texture will be designated as C1, C2 and C3 respectively.

The horizons are qualified with respect to the special characteristics possessed by them. For that purpose, **Small letter suffixes** are used. The suffix letters qualifying the horizons are defined as follows:

b Buried genetic soil horizon (e.g., AB, Btb)

c Containing concretions or nodules:
- the suffix used in combination with another suffix indicating the nature of the concretionary material (e.g., Bck, Ccs)

f Frozen soil horizon/layer (e.g., Cf1)

g Gleyed or mottled horizon reflecting variations in oxidation and reduction processes (e.g., Bg, Cg)

h Showing accumulation of humus or organic matter; used only for mineral horizons (e.g., Ah, Bh)
- The suffix **h** is used with the A horizon only if there has been no disturbance or mixing from ploughing, pasturing or other activities of man (the suffixes p and **h** are mutually exclusive)

j Having jarosite i.e., sulphur mottles (Btj)

k Showing accumulation of calcium carbonate or lime (e.g., Bck, Cck)

m Strongly cemented, consolidated or indurated;
- The suffix is commonly used in combination with another one indicating the cementing material (e.g., Cmk, Bms)

n Showing accumulation of exchangeable sodium (e.g., Btn)

o Showing residual accumulation of sesquioxides; differs from s which indicates illuvial accumulation of organic matter and sesquioxide complexes (e.g., Bo)

p Disturbed by ploughing or other tillage practices (e.g. Ap)

r Strongly reduced as a result of groundwater influence (e.g., Cr, BCr)

s Showing illuvial accumulation of sesquioxides i.e., iron and aluminium oxides (e.g., Bs)

t Illuvial accumulation of clay (e.g., Bt)

v Occurring in the form of a plinthite (iron-rich and humus-poor material hardening irreversibly upon drying)

w Showing weathering or alteration in situ as reflected by colour or structure, or both; not used for a transitional horizon (e.g., Bw)

x Showing the characteristics of a fragipan (e.g., Btx) y Showing accumulation of gypsum (Cy, BCy)

z Showing accumulation of salts more soluble than gypsum (e.g., Az, Bkz)

In case when a normal sequence of soil material is disturbed by a contrasting layer, the boundary between these two horizons or layers is called as "lithological discontinuity". Such discontinuity is indicated by assigning an **Arabic number prefix**, so that the first discontinuity will be indicated by a prefix 2 as the first sequence of material is understood to be 1. For example, if a loam textured Bt horizon is immediately underlain by a clay textured C layer, the C layer will be designated as 2C.

4.6 Horizon boundaries

The boundaries between two adjacent soil horizons have specific nature because of differences in depositional patterns of the soil material, mode of soil formation and degree of soil development. The horizon boundaries should be traced all along their courses within the pits and should be described in terms of their **distinctness** (the width through which the horizon change occurs) and **topography** (smoothness or depth variations of lower limits of the horizon).

4.7 Systematic field description of land characteristcs and soil profile

Before starting description of a soil profile on any observation point or a pit, it is necessary that the important landscape characteristics (see previous section) are properly described. The first job the surveyor has to do after getting into the soil pit for description is to expose a fresh surface of the profile carefully with the help of a "profile knife" so that the soil structural peds break along their lines of weakness rather than being cut through. This process should start from the soil surface and end at the bottom of the pit. The exposed surface will then show various horizons or layers showing differences in colour, structure, consistence (felt while working with the knife) and some other features like presence of mottles, concretions, krotovinas, gravel/stones, etc. The horizon boundaries are drawn with the help of knife all along the pit wall on the basis of such visible differences. Each of these horizons is then studied and tested in detail at its various sections (with 10-15cm vertical subdivisions) for all important soil physical, chemical, biological and hydrological characteristics (see previous section). New horizon boundaries are marked and the depth of each horizon measured (range in depths if boundaries are not smooth) by means of a 2m steel tape. The each horizon is defined using an appropriate symbol according to its characteristics and is described one by one systematically.

The general sequence of describing characteristics for each horizon is as follows:

1. Colour moist and colour dry;
2. Mottling;
3. Texture;
4. Rock fragments;
5. Structure, and secondary structure if compound;
6. Consistence: when wet, when moist and when dry;
7. Porosity;
8. Cutans, pressure faces, slickensides, etc;
9. Cementation or compaction;
10. Chemical formations or mineral nodules;
11. Roots;
12. Special biological features and artefacts;
13. Calcareousness;
14. Content of gypsum;
15. Salinity (electrical conductivity);
16. Horizon boundary;
17. pH;
18. Sample number if taken for laboratory analysis;
19. Special remarks, if any.

4.8 Computerization of soil resource data

The FAO, in collaboration with the International Soil Reference and Information Centre (ISRIC) of Wageningen, the Netherlands, has developed a soil database package (SDB) for computerized data storage and processing. The software for the system is available with FAO as well as with ISRIC (already installed on hard disk of the computer under use by Agricultural Projects Service of Development Project Studies Authority, Addis Ababa, Ethiopia; Directory C:\DOS\SDB) and the instructions regarding its use are published in the FAO World Soil Resources Report 64; FAO-ISRIC Soil Database (SDB), 1989. The latest revision regarding coding of various land parameters/characteristics is made in FAO's "Guidelines for Soil Profile Description", Revised 1990. The following data sets can be stored in the SDB:

a) Field descriptions; information on site and profile characteristics (stored in the coded format)

b) Standard soil chemical analytical results

c) Soil physical analytical results including water infiltration and water retention data

It is recommended that the standard SDB soil description forms, inserted at the end of this chapter, should be used in the field to facilitate the data processing in the computer.

4.9 Soil correlation and classification

After the soil profile description is completed, the soil is identified and classified, by correlation of the soil characteristics, to a **soil series** (defined later in this chapter) which may be one of those already established or a new one to be recognized and named for the project area. The **phase** (also defined later) of the identified soil series, if it is not a normal one, should also be mentioned.

The soil series identified from the pit may be classified to higher categories of FAO and/or USDA soil classification system, whichever is followed. This is generally done by using a **Soil classification key** which is systematically organized in such a manner that a common scientist who is familiar with the terminology of **diagnostic horizons** and other important **diagnostic properties** can easily end in a correct soil classification. The Soil classification key devised for the FAO/UNESCO's Soil Map of the World is presented at Annex III, while a brief account of the "diagnostic horizons" and "diagnostic properties" employed for this classification follows later in this chapter.

4.10 The soil classificational units or "Taxa"

The soils vary in characteristics so frequently that no two soil profiles in the world, however closely located these may be, are exactly the same. These may, nevertheless, resemble in certain genetically related characteristics. If grouped on the basis of these characteristics, we do find the same kinds of soils extending over sizable areas which can be delineated and shown on a map. Such characteristics which are fairly stable over long periods of time are selected for classification of soils and are referred to as the Differentiating criteria. These criteria vary with the category of classification considered for mapping. The classificational (or taxonomic) unit used is called as **Taxon** (plural **Taxa**).

4.11 Soil series - the basic soil classification unit

The **Soil series** is the basic category of soil classification used for standard soil surveys, which is defined as a group of soils which are similar in a certain set of characteristics (called the Soil series differentiating criteria). The characteristics selected for differentiating a soil series are those which remain virtually unchanged for a reasonable period, say about 50 years, not being significantly affected by normal manipulation of soils by man as, for instance, minor levelling, irrigation, cultivation, addition of fertilizers, removal of surface stones, etc. and which are strongly related with the soil genetic processes. For the same purpose, the changeable characteristics of the surface soil are not taken into consideration.

The **soil series differentiating criteria** include:

a) Kind, thickness and arrangement of horizons; and
b) for each horizon:
   i) Structure
   ii) Texture (except of the topsoil)
   iii) Colour
   iv) Reaction
   v) Consistence
   vi) Content of carbonates and other salts
   vii) Content of humus (organic matter)
   viii) Mineralogical composition

The dissimilarity in any one or more of the above-listed characteristics implies a different soil series. The variable soil characteristics, especially those related to the surface soils, are recognised as variations at **"phase"** level discussed in the following section. The soil series are named after the place where it is first identified. For instance, a series first identified near Lake Zwai will be named as "Lake Zwai series" or preferably "Zwai series".

4.12 The soil phases

In addition to the characteristics used for differentiation of soil series or other taxa, there are characteristics to be studied in the field which further differentiate the soils within a taxa. Such variation within a soil taxa are called as the **Soil Phases**. The characteristics considered for soil phases are those important for use and management of the soils rather than soil classification and include those related to both the soils and the other important environmental factors, as listed below.

i) Surface texture
ii) Surface deposition (overblown, overwash, hummocky, etc.)
iii) Presence of rock fragments (gravelly/cherty, stony, bouldery or rocky, etc.
iv) Surface slope
v) Soil depth (shallow, moderately deep, deep or very deep)
vi) Substratum material (clayey, sandy, silty, gravelly, calcareous, gypsiferous, lacustrine, shaly, till, marly, etc.)
vii) Drainage or water table depth (high water table, mod. deep water table, poorly drained, wet, ponded, drained, etc.)
viii) Salinity (nonsaline, slightly saline, moderately saline or severely saline)
ix) Sodicity (sodic surface, slightly sodic, nonsodic, etc.)
x) Physiography (benched or terraced, depressional, convex surface, fan, karst, ridgy, dissected, etc.)
xi) Erosion (eroded, slightly eroded, truncated, etc.)

xii) Flooding (seasonally flooded, frequently flooded, occasionally flooded, etc.)
xiii) Land use (cultivated, reclaimed, forested, etc.)
xix) Any other important characteristic

The corresponding phase names are added to the name of the soil series or other taxa as, for example, Zwai ponded, Mekki moderately deep over gravel, sandy loams, etc.

4.13 Soil classification categories of the USDA's Soil Taxonomy

In addition to the "soil series", there are other higher categories of soil classification, which are used for lower intensity surveys. The differentiating criteria for the higher categories are correspondingly fewer. The hierarchy of soil classification categories adopted by the USDA Soil Conservation Service in their "Soil Taxonomy", along with the main differentiating criteria of each category, except for those of the "soil series" already listed above, is as follows:

Level	Category	Main Differentiating criteria
1	Soil Order	Soil parent materials and genetic soil development The following 10 Soil Orders are recognized: HISTOSOLS ENTISOLS VERTISOLS INCEPTISOLS ARIDISOLS MOLLISOLS ALFISOLS SPODOSOLS ULTISOLS OXISOLS
2	Soil Suborder	Divisions of Orders based on differences in soil moisture regime, soil temperature regime or specific soil physical/chemical properties
3	Great Soil Group	Subdivisions of Suborders on basis of soil morphology, soil moisture/temperature regime or specific soil physical/chemical properties
4	Soil Subgroup	Further division of Great Groups on basis of minor deviations from the central concept of the Great Group

5 **Soil Family** Division of Subgroups based on the differences in any one or more of the following:

- Particle size class
- Mineralogy class
- Calcareousness and reaction class
- Soil temperature regime
- Soil depth class
- Soil slope class
- Soil consistence class
- Coatings (on sand grains) class
- Classes of surface cracks

6 **Soil Series** Already discussed above

An example of classification in the USDA's "Soil Taxonomy" is:

Soil Order:	Aridisols
Soil Suborder:	Argids
Great Soil Group:	Natrargids
Soil Subgroup:	Aquic Natrargids
Soil Family:	Fine-silty, mixed, calcareous, hyperthermic, deep Aquic Natrargids

4.14 The FAO soil classification system

The FAO/UNESCO produced **"Soil Map of the World"** (1971-1981) at a scale of 1:5,000,000 by compiling soil information from various sources of mainly reconnaissance and partily exploratory soil survey. In that "sytheses" level of mapping, it was not possible to adopt the "soil series" as the basic taxonomic unit. There were only two categories of the taxonomic units used viz., the **Major Soil Groupings** and the **Soil Units**, the latter representing divisions of the 26 "Major Soil Groupings" recognized for whole world, along with their various phases.

The "Legend" for Soil Map of the Wrold has recently (1988) been revised to make it more comprehensive and capable of being used for soil survey and land evaluation in the countries which have not yet adopted any specific system of classification, one of their own or of any developed country.

The hierarchy of higher soil classification categories used by FAO for the revised legend (1988) of the **FAO-UNESCO Soil Map of the World**, along with their main differentiating criteria, is as under:

Level	Category	Main Differentiating criteria
1	**Major Soil Grouping**	Soil parent materials, genetic soil development, soil morphology, soil depth and specific soil physical/chemical properties
2	**Soil Unit**	Divisions of Major Soil Groupings based on minor morphological, physical or chemical properties
3	**Soil Subunit**	Subdivisions of Units on basis of the properties which either are common to two Major Groupings or Units or were not considered in the definitions of Major Groupings or Units

These categories correspond roughly to the "Great Soil Group", "Soil Subgroup" and "Soil Family", respectively, of the USDA's Soil Taxonomy and are discussed further in the next section.

The new Legend, which has been constructed with three soil classification categories (discussed above) has **28 Major Soil Groupings** and **153 Soil Units.** Any comprehensive listing of the **Soil Subunits**, which are subdivisions of soil Units, has not as yet been prepared at a global scale and these may be recognized according to the needs of a country/region under certain conditions.

The **Major Soil Groupings** recognized are listed, along with their specific mapping symbols, under different headings reflecting their geographical or evolutionary background as follows.

a. Soils that are not related to any specific region or climatic condition

FL FLUVISOLS GL GLEYSOLS

RG REGOSOLS LP LEPTOSOLS

b. Soils having dominant characteristics due to the parent material

AR ARENOSOLS AN ANDOSOLS VR VERTISOLS

c. Soils with weakly expressed soil horizons (other than those listed under 'a')

CM CAMBISOLS

d. Soils of the arid/semi-arid regions having morphology characterized by accumulation of salts

CL	CALCISOLS	SN	SOLONETZ
GY	GYPSISOLS	SC	SOLONCHAKS

e. Soils having surface accumulation of base-saturated organic matter

KS	KASTANOZEMS	PH	PHAEOZEMS
CH	CHERNOZEMS	GR	GREYEMS

f. Soils having illuvial accumulation of clay, sesqui-oxides and/or organic matter in the subsoil

LV	LUVISOLS	PD	PODSOLUVISOLS
PL	PLANOSOLS	PZ	PODZOLS

g. Soils of tropical and subtropical regions expressing intense weathering

LX	LIXISOLS	AL	ALISOLS	AC	ACRISOLS
NT	NITISOLS	PT	PLINTHOSOLS	FR	FERRALSOLS

h. Soils formed in organic soil material (organic soils)

HS HISTOSOLS

i. Soils having characteristics modified by man

AT ANTHROSOLS

Each of the Major Soil Grouping is divided into different **Soil Units** by adding a qualifying name before the Major Soil Grouping name, like Calcaric Fluvisols, Andic Gleysols, Haplic Solonetz and Luvic Phaeozems. A Soil Unit is indicated on Soil Map of the World by using a small letter suffix like FLc, GLa, SNh and PHl respectively for the above-named Units. The **Soil Subunits** are formed by adding another qualifying name with the Soil Unit name, the two being joined together by means of a hyphon, such as Niti-Haplic Acrisols, Andi-Humic Ferralsols and Ferri-Albic Lixisols, and are indicated on the Map by using another small letter suffix after that of the Soil Unit as, for example, AChn, FRha and LXaf for the above-stated Subunits. Spotting characteristics of the Great Soil Groupings and the Soil Units are described in the "Key" presented under Annex III.

4.15 The soil phases of Soil Map of the World

Depending on significant differences in the surface or subsurface features of land, which are important from the land use point of view, any of the FAO's soil classification categories may be divided into two or more **Phases**. Various soil phases recognized for the Soil Map of the World are briefly defined with respect to the special soil characterisitcs expressed, as follows:

Anthraquic phase: the phase indicative of long-term ponding or surface waterlogging conditions

Inundic phase: flooding for periods longer than 10 days

Phreatic phase: occurrence of groundwater table within 5m depth, not significantly affecting soil morphology

Yermic phase: presence of low (<0.6%) organic carbon in the surface soil

Duripan phase: presence of a strongly cemented silica pan in the subsoil

Fragipan phase: presence of a slightly cemented loamy pan in in the subsoil

Petroferric phase: occurrence of a thick, continuous layer strongly cemented with iron in the subsoil

Placic phase: presence of a thin iron pan in the subsoil

Rudic phase: stony/bouldery or rocky surface, impractical for tillage with mechanical implements

Skeletic phase: presence of >40% coarse fragments in subsoil

Lithic phase: underlying bedrock shallower than 50cm depth

Salic phase: presence of salinity within 100cm depth

Sodic phase: presence of exchangeable sodium by >6 percent in some horizon/layer within 100cm depth

Gilgai phase: presence of gilgai micro-relief (surface marked with microbasins and microknolls or micro-ridges and micro-valleys)

Takyric phase: presence of polygonal cracks and platy/massive surface crust (in clayey soils)

Gelundic phase: formation of polygonal structure at surface due to frost heaving

4.16 The diagonstic soil horizons and properties

The differentiation between various Major Soil Groupings and Soil units is based on the presence or absence of specific soil horizons and/or properties called as the **Diagnostic horizons** and **Diagnostic properties** respectively. These horizons and properties are briefly discussed below. For further details, the reader is referred to the Legend of FAO-UNESCO Soil Map of the World (FAO, 1988).

a) Diagnostic horizons

Histic H horizon: An organic surface horizon containing 16 percent or more organic carbon if mineral fraction has >60% clay and 8 percent or more of it if it has no clay, and corresponding carbon content for intermediate clay percentage

Mollic A horizon: A dark coloured inorganic surface horizon containing 0.6 percent or more organic carbon in the upper 18cm, when mixed, and having 50 percent or more base saturation

Umbric A horizon: like Mollic A horizon but having <50 percent base saturation

Fimic A horizon: A man-made surface layer 50cm or more thick containing artefacts

Orhric A horizon: A light coloured surface horizon with low (<0.6%) organic carbon content

Argic B horizon: A subsurface horizon having illuvial accumulation of clay and less than 15 percent exchangeable sodium

Natric B horizon: An argic horizon having 15 percent or more exchangeable sodium

Spodic B horizon: A subsurface horizon having illuvial accumulation of, and continuous cementation by, organic matter plus iron and/or aluminium, and sandy or coarse loamy texture

Ferralic B horizon: A highly weathered subsurface horizon having cation exchange capacity of <16 cmol/kg of clay

Cambic B horizon: An altered subsurface horizon having a weak degree of soil formation and not having properties of any above-described horizons

Calcic horizon: A horizon characterized by accumulation of calcium carbonate

Petrocalcic horizon: A cemented calcic horizon

Gypsic horizon: A horizon with accumulation of gypsum (calcium sulphate)

Sulphuric horizon: An acidic horizon with pH <3.5 formed due to the oxidation of sulphides as a result of artificial drainage

Albic E horizon: A light coloured (bleached) eluvial horizon depleted in clay and iron oxides and dominated by washed primary silt/sand particles due to excessive leaching.

b) <u>Diagnostic properties</u>

Continuous hard rock: Coherent and hard material underlying the solum

Abrupt textural change: An increase in clay content by 20 per cent or more within 5cm vertical distance

Andic properties: The properties diagnostic of volcanic soil material

Smeary consistence: Soil material that changes from a plastic solid into a liquefied state and back to solid condition under pressure or by rubbing; applies only to Andosols

Calcareous: Showing strong effervescence with 10% HCl

Calcaric: Calcareous throughout between 20 and 50cm depth

Fluvic properties: Properties diagnostic of fluviatile, marine or lacustrine sediments i.e., irregularity in organic carbon distribution and stratifications

Gleyic properties: Reduced colours and/or mottles/evidence of iron segregation due to high, stagnant groundwater table

Stagnic properties: Reduced colours and/or mottles/evidence of iron segregation due to water stagnation at surface

Organic soil materials: Soil materials having 18 percent or more organic carbon if saturated with water or 20 percent or more of it if never saturated

Strongly humic: Soil material containing more than 1.4 percent organic carbon to a depth of 100cm

Permafrost: Soil temperatures perennially below $0^{o}C$

Nitic properties: Clayey soil material with a strong blocky structure with shiny ped faces

Ferralic properties: The subsoil material having CEC of <24 cmol/kg of clay; only for Cambisols and Arenosols

Ferric properties: Having red mottles or red, iron-coated and cemented nodules; only applies to Luvisols, Alisols, Lixisols and Acrisols

Plinthite: An iron-rich, humus-poor mixture of clay with quartz and other diluents, irreversibly hardening on exposure to repeated wetting and drying

Geric properties: Having exchangeable bases less than 1.5 cmol/kg

Salic properties: Soil material having ECe of >15 dSm^{-1} within 30cm depth if pH is <8.5; otherwise ECe of >4 dSm^{-1}

Sodic properties: Soil material having 15 percent or more exchangeable sodium or 50 percent or more exchangeable sodium+magnesium

Gypsiferous: Containing 5 percent or more gypsum

Soft powdery lime: Translocated/segregated calcium carbonate in powdery or soft nodular form

Sulphidic materials: Waterlogged mineral or organic soil materials containing 0.75 percent or more sulphur (dry weight) and a pH >3.5

Tonguing: Penetration of an Albic E horizon into an Argic B horizon, which are horizontally more than 5mm (if B is clayey) to 15mm (if B is loamy) and have more depth than width

Interfingering: Penetrations of an Albic E horizon into the the underlying Argic or Natric B horizon, not wide enough to qualify for tonguing

Slickensides: Polished, grooved/striated ped surfaces produced by one mass sliding past another in clayey soils

Vertic properties: Soils showing cracks, slickensides, wedge-shaped or parallelipiped structural aggregates not sufficiently expressed to qualify for Vertisols

Weatherable minerals: Minerals which are unstable under a humid climate e.g., quartz, 1:1 lattice clays, and those liberating plant nutrients and iron/aluminium such as clay minerals, silt- and sand-sized minerals including feldspars, glasses, micas, etc.

4.17 How to classify soils

The soils described in the mannner discussed under section 5 may be classified to the "Soil Units" for the FAO/UNESCO's Soil Map of the World by using the **"Key to Major Soil Groupings and Soil Units"** presented under Annex III. Before their classification, however, the "Diagnostic horizons" and "Diagnostic properties" must be differentiated for each soil.

The key is constructed in such a way that one has first to check the Major Groupings one after the other by correlating the diagnostic horizons/properties stated in a specific sequence and then to check, within the applicable Major Grouping, for the Soil Units which are also orderly arranged. If significant deviations occur from the central concept of the most closely resembling Unit, a relevant qualifying prefix is added to recognize the Subunit.

SOIL DESCRIPTION FORM - FAO-ISRIC SOIL DATABASE PROFILE CODE

status date author unit

loc elev

sheet grid lat lon

FAO 89 74 phase ST
grp subg txt mi re

soil climate soil moisture/temperature regime

topography landform land element position

slope clss form micro topo flood freq/dur

land use type crops

vegetation type species grass cover

parent material over derived from

stones rockoutcrops erosion/dep
ab si ab di hi int ty int ty

sealing/crust

drainage watertable
clss int ext obs mi ma type

moist cond eff.soil depth human
dpt dpt dpt

Remarks

DESIGN	DPT up/ lo	COLOUR				MOTTLES					TEXTURE		STRUCTURE				CONS			
		hue	val	chr	mo	a	s	c	b	co	>2mm	% C	gr	si	ty	>	dry	moi	sti	pla

CUTANS				CEM/COM				PORE		ROCK FRAGM					NODULES							CA	BIOL		ROOT		BND		PH	SAMPLES
q	c	na	lo	c	s	g	n	a	si	a	si	s	w	na	a	k	s	s	h	n	co		a	ki	a	si	w	t		

SOIL PROFILE DESCRIPTION | Profile: PA0001 | Unit: L25B1 | Status: 2

Sheet/Grid: 1825A4/LX360742
Location : Kakulwane Seloko (N. Plain), traverse 5 0.9 km W.
Author(s) :

Coord : S 18-19-06 E 025-26-57
Elevation: 1070 m
Date : 03/04/84

Classification FAO: Pelli-Calcic Vertisol(1989) Pellic Vertisol (1974)
ST : Typic Pellustert
Soil Climate: aquic isohyperthermic
Topography : flat
Element/Pos.: intermediate part
Flooding : annually
Land Use : none-
Vegetation : medium tall grassland
Species :

Land Form: lacustrine plain
Slope : 0.1 -0.3%
Micro Top: high gilgai
Grasscover: 30-70%

Parent Material: lacustrine deposits - derived from basalt
Rock Outcrops : nil -
Erosion: nil

Surface Stones : few fine gravel
Sealing/Crusting: nil

Drainage : poor, internal drainage: very slow, external drainage: ponded
Watertable: not observed (0-25cm / > 150cm) - fresh
Moist Cond: moist 0 - 25 , wet 25 - 220cm
Human Infl: ploughing

Eff. Soil Depth: > 150cm

Remarks: After recent rains few cracks in topsoil, cracks in B hor. 3cm wide, less from 80cm. One month earlier many wi
surface cracks. Augering from 100cm, photo.

Samples: A: 0- 10 B: 10- 25 C: 30- 50 D: 80-100 E: 140-160 F: 190-210

A1 0 - 3 cm 10YR 3/0.5 (moist) and 10YR 3.5/0.5 (dry), clay, strong medium granular structure, hard (dry),

A2 3 - 10 cm 10YR 3/0.5 (moist) and 10YR 3.5/0.5 (dry), clay, moderate fine to coarse subangular blocky structure, very hard (dry), friable (moist), many fine pores, slightly calcareous, many fine roots, clear smooth boundary.

A3 10 - 25 cm 10YR 3/0.5 (moist) and 10YR 3.5/0.5 (dry), clay, moderate medium and coarse subangular and angular blocky structure, extremely hard (dry), very firm (moist), common fine-medium pores, very few fine and medium rounded chert rock fragments, moderately calcareous, many fine roots, gradual smooth boundary.

B1 25 - 65 cm 10YR 3/0.5 (moist) and 10YR 3.5/0.5 (dry), clay, moderate very coarse prismatic parting into strong coarse and very coarse angular blocky structure, extremely hard (dry), very firm (moist), few slickensides, few fine-medium pores, very few medium and coarse rounded chert rock fragments, very few fine hard calcareous white nodules, moderately calcareous, few fine roots, diffuse smooth boundary.

B2 65 - 175 cm 10YR 3.5/0.5 (moist) and 10YR 4/0.5 (dry), clay, moderate very coarse prismatic parting into strong coarse and very coarse wedge shaped angular blocky structure, extremely hard (dry), very firm (moist), common intersecting slickensides, few fine pores, very few medium and coarse rounded chert rock fragments, few fine angular hard calcareous white nodules, moderately calcareous, very few fine roots, diffuse smooth boundary.

Bk 175 - 220 cm 10YR 4/0.5 (moist) and 10YR 4/0.5 (dry), clay, extremely hard (dry), very firm (moist), very few medium and coarse rounded chert rock fragments, common fine hard calcareous white nodules, moderately calcareous,

Print Date: 23/03/89

S O I L A N A L Y S E S R E S U L T S

PROFILE: PA0001

	DEPTH		pH H2O	pH X	EC mS/cm	P ppm	C weight %	N weight %	CaCO3 Total %	CaCO3 Act. %	CaSO4 %	CEC	Ca	Mg	K	Na (meq/100gr soil)	PBS %	K fixed
A	0	10	6.9	6.4	0.0	3	0.60	0.00	0.0	0.0	0.0	45.1	26.7	21.5	0.5	0.6	100	0.0
B	10	25	6.7	6.3	0.0	3	0.50	0.00	0.0	0.0	0.0	50.9	28.3	33.2	0.6	1.1	100	0.0
C	30	50	7.5	7.1	0.5	2	0.40	0.00	0.0	0.0	0.0	55.6	31.0	33.5	0.9	2.6	100	0.0
D	80	100	7.9	7.5	0.6	1	0.40	0.00	0.0	0.0	0.0	56.8	27.7	35.8	1.1	7.4	100	0.0
E	140	160	8.4	7.7	0.4	2	0.20	0.00	0.0	0.0	0.0	58.2	34.5	37.0	1.1	9.0	100	0.0
F	190	210	8.3	7.7	0.4	2	0.20	0.00	0.0	0.0	0.0	54.5	42.9	36.1	1.0	9.1	100	0.0

	Particle size (weight %) vcS	cS	mS	fS	vfS	cSi	fSi	Clay	CECclay meq/100gr	METHODS 123456789
A	0	3	17	16	4	1	4	54	79	H
B	0	3	13	10	3	1	4	65	75	H
C	0	3	10	8	3	2	5	69	79	H
D	1	3	11	9	0	1	4	68	81	H
E	1	2	6	5	2	2	3	78	73	H
F	1	2	5	4	2	1	2	83	65	H

Print date: 23/03/89

PROFILE: PA0001 SOLUBLE SALTS

	DEPTH		pH	EC mS/cm	Ca	Mg	K	Na	B	CO3	HCO3	Cl	SO4	NO3 (meq/100gr soil)	SAR	METHODS 1234567
A	0	10	99.9	99.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	999.9	TEST
B	10	25	99.9	99.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	999.9	TEST
C	25	50	99.9	99.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	999.9	TEST
D	80	100	99.9	99.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	999.9	TEST
E	130	150	99.9	99.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	999.9	TEST

Print date: 23/03/89

S O I L P H Y S I C A L P R O P E R T I E S

PROFILE: G 0901

INFILTRATION (cm/hr) METHOD:

1 999.9
2 999.9
3 999.9

SURFACE STRUCTURE STABILITY INDEX: 9.99

	DEPTH (cm)		BULK DENSITY (g/cc)	WATER CONTENT (weight %) 0.03bar	0.05bar	0.1bar	0.3bar	1.0bar	3.0bar	5.0bar	15.0bar	METHOD
A	0	33	1.66	13.43	12.26	9.27	7.26	5.9	4.3	4.0	3.9	
B	33	69	1.55	15.02	13.80	10.21	7.93	6.8	5.6	6.2	6.0	
C	69	138	1.54	17.66	15.51	13.43	11.18	8.9	7.4	6.9	6.4	

5. LAND RESOURCE SURVEY AND MAPPING

5.1 Soil mapping units

A **"soil mapping unit"** may be defined as the named areas which are delimited on a soil map and defined in terms of their components of soils and/or miscellaneous land types. Each soil mapping unit differs in some respect from all others recognized in a survey area and is uniquely identified on a soil map. Each individual area of a unit is termed as a delineation.

It is rather difficult, time-consuming and extremely costly that the areas occupied exclusively by any one soil series or any other taxon are delineated on the map; it is more so if the phase of a taxon is considered for delineation. Such is done when conducting very high intensity surveys; still inclusions to the extent of about 10 to 15 percent of other minor kinds of soils or taxa are allowed in order to save the undue labour and time to be spent on relatively unimportant deliberation, and to keep the size of the mapping unit above a ceratin minimum (generally about 1 cm^2 on the map). The low to medium intensity (exploratory) reconnaissance and semi-detailed) surveys, or even often the high intensity (detailed) surveys, entail grouping together of two or more taxa in order to show them on a small-scale map. The grouping is, however, done only of the taxa which are geographically and genetically related. The different kinds of soil grouping are named and defined differently as below:

a) **Soil Association.** It is the grouping of two or more dissimilar taxa occurring in a systematic, repetitive pattern and in definite proportions so that the major taxa components can be separated on a large-scale map through detailed (high-intensity) surveys; the units are named after the major taxa, separated by a hyphon, so that the taxon with higher proportion in the map unit comes first, followed by the word "association" e.g., Zwai-Awassa association; phase names may also be attached with the association names as, for example, Zwai-Awassa sandy loams, moderately deep, eroded.

b) **Soil Complex.** It is a kind of association of which the major taxa components are not separable even through detailed (high-intensity) surveys; named similarly as the soil associations.

c) **Undifferentiated Soil Group.** It is a grouping of two or more taxa which have no consistent geographic relationships but have to be mapped together because of having similar land use and management or behaving similarly under a common use; the units are named by using the word "and" between the major component taxa if these are only two, or between the last two if these are more, the previous being separated by using commas (,), and followed by the word "soils"; the word "soils" may be omitted if the phase name relative to the surface texture is used; other phases can also be combined with this group name; examples are: i) Addis and Zeit soils, ii) Addis and Zeit silty clays, moderately well drained, iii) Addis, Zeit and Burhan soils, undulating, eroded.

d) Soil Consociation. It is a kind of grouping in which a single taxon dominates, covering more than 50 percent (generally more than 75%) of the total unit area, while most of the other soil components are also similar in use and management to the dominating taxon; the unit is named after the major taxon followed by the surface texture, and other phase names if they are the same for most soils as, for example, "Gojam silt loam" or "Gojam silt loam, 5-8 percent slopes, eroded", etc.

The above-defined map units are illustrated in terms of their composition in Fig 14.

5.2 Selection of base maps for survey

The first step involved in undertaking the land resource survey of any project area is the selection and acquisition of proper base maps which are needed for:

- delimitation of the project area,
- have general impression of the area about its physiography and geographical setting in relation to the surrounding landscapes,
- planning of field studies,
- accurate location and plotting of field observation points
- delineation of the map unit boundaries and preparation of various land resource maps.

Depending on the nature and detail of studies required, the following three main kinds of base materials are generally used for land resource surveys, singly or in combination:

a) Topographic or specially prepared reference maps of appropriate scale, showing all important ground features and detailed contour lines

b) Vertical air-photos of appropriate scale; may be B&W or colour, panchromatic or IR (see chapter 3) as the purpose may require

c) MSS or TM imageries of appropriate bands, in the form of diapositives and/or colour composites (see chapter 3)

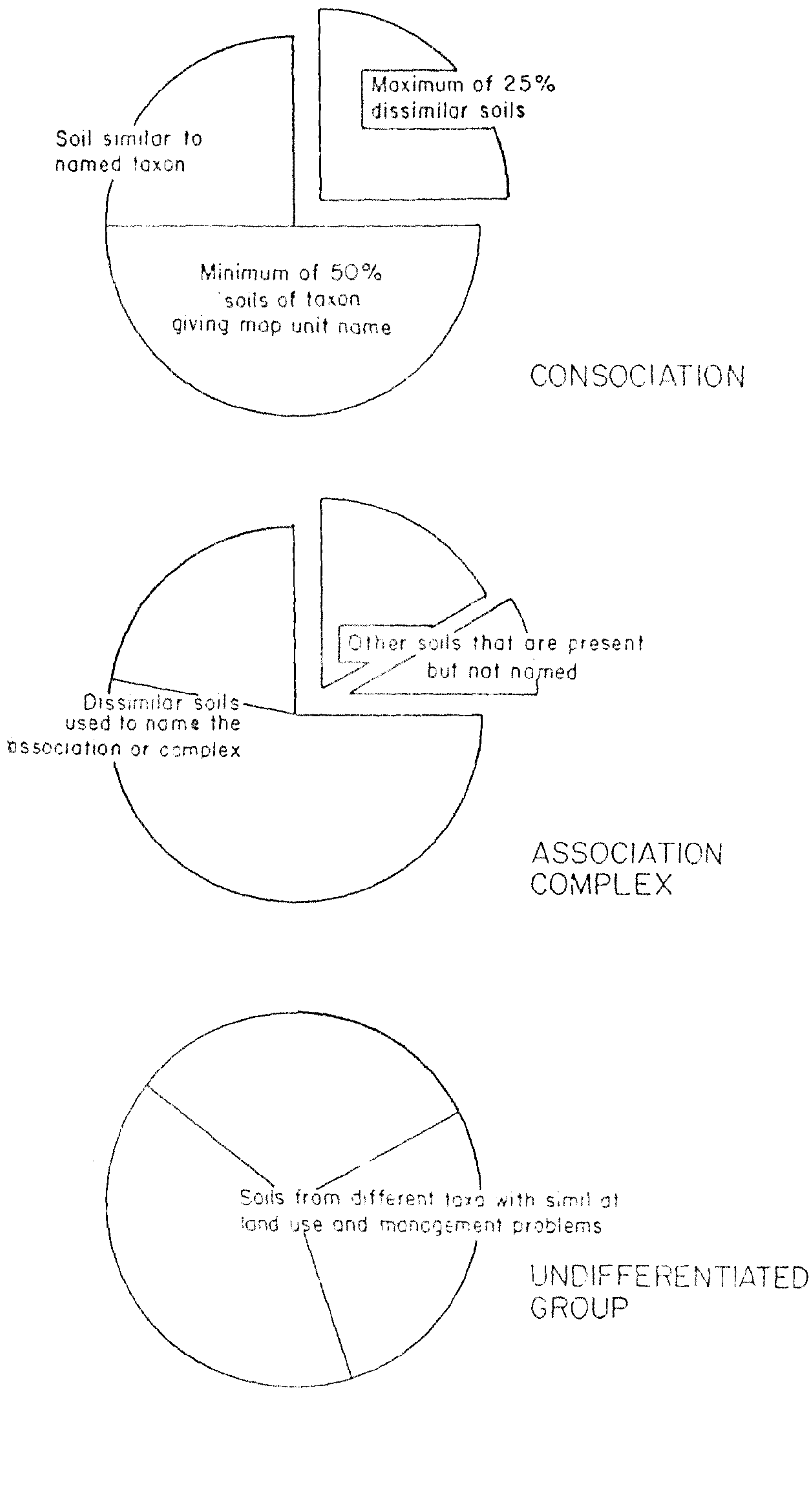


Figure 14: Soil Mapping Units Composition

The scale of the base map to be selected for field investigations should be at least twice that of the map to be published. Good-quality air-photos generally serve as the most versatile and general-purpose base maps and should be preferred over the others. For very large areas to be surveyed in a short time (exploratory or reconnaissance surveys), the purpose is best served by using the MSS or TM images. The MSS/TM images are also commonly used as complementary to the air-photos, especially for updating the land use/ vegetation and hydrological conditions. In any case, however, the topographic maps will be required for orientation of the air-photos or MSS/TM images during desk and field studies as well as for final production of the maps.

The procedure of survey described hereafter is based on the use of air-photos as the base maps for field investigations as well as for interpretation and delineation of the map units, and that of the topographic maps as the reference maps and base maps for final map production. It considers reconnaissance level of surveys requiring selection of sample areas for detailed field investigations and basic mapping, followed by air-photo interpretation, field checking and mapping in other parts of the project area. For detailed or semi-detailed surveys, the procedure described for study of the sample areas should be applied to the whole project area.

5.3 Preliminary desk studies and air-photo interpretation

The preliminary desk studies required for any level of land resource surveys include:

- Demarcation of the project area boundary on the topographic maps and air-photos (the boundarry should also be marked on the Photo-mosaics if available);

- Delimiting the "effective area" by drawing match lines on the relevant air-photos;

- Visual study of broad photo patterns from an array of the photo-mosaics or blocks of air-photos put together systematically and identification of major landforms, variability of land conditions within each landform and their mutual relationships;

- Systematic stereo-interpretation of the air-photos for the whole project area, first using small-scale (1:50,000 or 1:40,000) photos and then larger scale (1:20,000 or 1:10,000 etc. depending on the detail of mapping required), and preparation of a general air-photo interpretation (API) map alongwith its legend; and

- Selection of sample areas for detailed field investigations which represent each unit delineated on the API map, keeping regard of accessibility and size.

5.4 Rapid field reconnaissance or exploratory survey

5.4.1 Objectives

After the desk studies, a short field trip is arranged to have a sharp look at the project area and collect general data on the physiography, kinds of soils, soil parent materials and other factors determining the soil variability, present land use and natural vegetation cover etc. Such information is required to:

- identify the important kinds of soils and other variable land parameters, along with their degree of variability;
- recognize major diagnostic criteria for soil classification
- establish soil-landform relationships;
- correlate the API map units with the physical landscape units and develop perspectives for mapping of soils on the basis of recognized landscape patterns;
- develop a tentative soil map legend;
- finalize the selection of sample areas; and
- determine the general level of observation density required for field investigation of the sample areas.

5.4.2 Procedure

The first job a surveyor has to do while in the field is to orient himself in the true direction and at the right place in relation with the landscape and the field map (air-photo), which may be achieved by using a compass or aligning the identified geographical features shown on topographic maps and photos with the ground features. Then he has to locate and mark on the field map the exact point where he wants to make an observation. The location is indicated on a specially devised **"Field description form"** (See chapter 4) by observation site No. along with a reference of the air-photo or map on which marked and, where possible, with distance and direction (magnetic bearing) from a prominent and permanent point. Following that, information is recorded on the form regarding physiography, geology and soil parent material, climate (only elevation), present land use, vegetation and external soil characteristics as discussed under chapter 2.

The internal soil (or soil profile) characteristics are studied by one of the methods described under chapter 4, to such depths as the purpose requires, and properly recorded on the form. Except for irrigation studies which need observations to about 2 metres depth with occasional augerings to about 3 metres depth, the normal depth of observation during the rapid reconnaissance should be regarded as 1.5 metres. A deep soil pit is generally necessitated wherever new kind of soil is encountered or visualized due to marked differences in physiography, elevation, hydrology, vegetation or surface soil characteristics; otherwise, augering with mini-pits would be adequate. The procedure for describing the soil profile is given under chapter 4.

Depending on the detail of mapping intended, only a few (about 10% of the total to be made in the whole project area) observations are required for the rapid field reconnaissance. The surveyor must be capable of deciding the appropriate observation site for which a basic knowledge of the factors determining the variations in soils and other landscape characteristics is essential. The distance between any two observations is rather unimportant in these studies and must be decided on the basis of any significant change speculated within a certain part of the area. While at some places the distance may be as small as 100 metres, at others it can be over 5 kilometres if the area is large.

Making observations at appropriate physiographic sites, as well as their correct marking on the field map, is the single major factor determining the usefulness of these preliminary field studies. A sufficient number of deep soil pits should be exposed to have detailed soil descriptions, study the soil genetic processes and identify the major diagnostic criteria for soil classification and mapping. Soil samples may be collectd for laboratory analyses only from the soil profiles which differ considerably from each other in important characteristics (The sampling procedure is described later in this chapter). The selection of sample areas for detailed field investigations is also finalized at this stage.

5.4.3 Construction of map legend

The data generated by the rapid field reconnaissance is analysed to develop a tentative **Map legend** which comprises the following two parts:

a) **Soil (or land) identification legend** i.e., a short and orderly list of the soil (or land) classificational units and their various phases prepared according to their physiographic relationships and briefly described with respect to their important characteristics. An example of **Soil identification legend** is as follows.

A. Old dissected plateau:

Aj Anjene series: Very deep, well drained, brown to dark reddish brown, noncalcareous silty clay loams having moderate angular blocky structure; occupying gently sloping top parts of the highest plateau surfaces

Ajt Anjene stony surface (many stones and boulders at surface; occurring on sloping margins of rivers/deep gullies)

Ajw Anjene moderately well drained (profusely mottled below 75-100cm and underlain by silty clay; occupying relatively flat parts of the plateau tops)

Yc Yechereka series: Very deep, moderately well drained, dark reddish brown, noncalcareous clay loams that change to clays at lower depths, with weak subangular blocky structure; occupying gently sloping top parts of the lower plateau surfaces

Ycr Yechereka shallow (less than 50cm thick, underlain by bedrock; occurring at footslopes of the rock outcrops)

B. Old alluvial plains:

Jg Jiga series: Very deep, well drained, dark reddish brown, noncalcareous clay loams that change to clays at lower depths, with angular to subangular blocky structure; occupying higher, flat cultivated terraces

Jge Jiga eroded (with eroded surface; gently sloping margins of terrace, mostly under grass cover)

Fs Finote Selam series: Very deep, mod. well to imperfectly drained, yellowish grey to olive black, noncalcareous clays showing deep and wide cracks when dry; occupying shallow broad basins, mostly under grass cover

Fsw Finote Selam poorly drained (gleyed, with water table within 50cm depth; commonly ponded; lower parts of basins mostly under reed and sedges)

b) Map unit identification legend i.e., an organized list of the map units to be delineated on the map, which includes the symbols representing each map unit as well as its major and minor components. The map units may be identified on the map by using letter symbols or arabic numerals, or a combination of both as the surveyor may decide. An example of the **map unit identification legend** is given below.

1. Old dissected plateau

1.1 **Anjene association** (Aj=40%, Ajw=15%, Yc=20%, Ajt=10%, Ro=10%, Gu=5%)

1.2 **Yechereka complex** (Yc=35%, Yce=20%, Ro=15%, Rb=10%, Jm=10%, Kr=5%)

4. Old alluvial plains

4.1 **Jiga association** (Jg=60%, Jge=30%, Fs=10%)

4.2 **Jiga-Finote selam association** (Jg=40%, Fs=30%, Jgw=15%, Fsw=10%, Ow=5%)

The "map legend" is continually revised with the progress of field investigations as the new facts are being disclosed.

5.5 Field investigations in sample areas

5.5.1 Objectives

The field investigations in sample areas are intended to:

- recognize minor variations in the identified soils, identify new soils if occurring in the project area and improve the soil/land identification legend;
- recognise new map units, if necessary and improve the map unit identification legend;
- finalize the map unit composition by detailed study of different physiographic positions within the relevant landforms;
- correct the API map unit boundaries to remodel them as the soil/land map unit boundaries; and
- map the unsurveyed part of the area by extrapolation with the help of air-photos.

5.5.2 Methods of survey

The sample areas may be studied by one of the commonly recognized three **methods of survey**, the choice of which depends on experience and expertise of the surveyor, kind and quality of the base maps available and nature and accessibility of the terrain. These methods are discussed briefly as follows and illustrated in Figs 15 to 17.

i) **Grid survey:** In this method, the area of study is first divided by equally spaced, horizontal and vertical grid lines, the spacing being decided by the density of observations required. The field observations are then made at fixed intervals irrespective of the soil or landform boundaries which may occur in between any two observation points. The maps are then prepared by delineating the similar observation points together.

Although correct boundaries of soils or landforms can seldom be drawn by this method, it may be the best choice when:

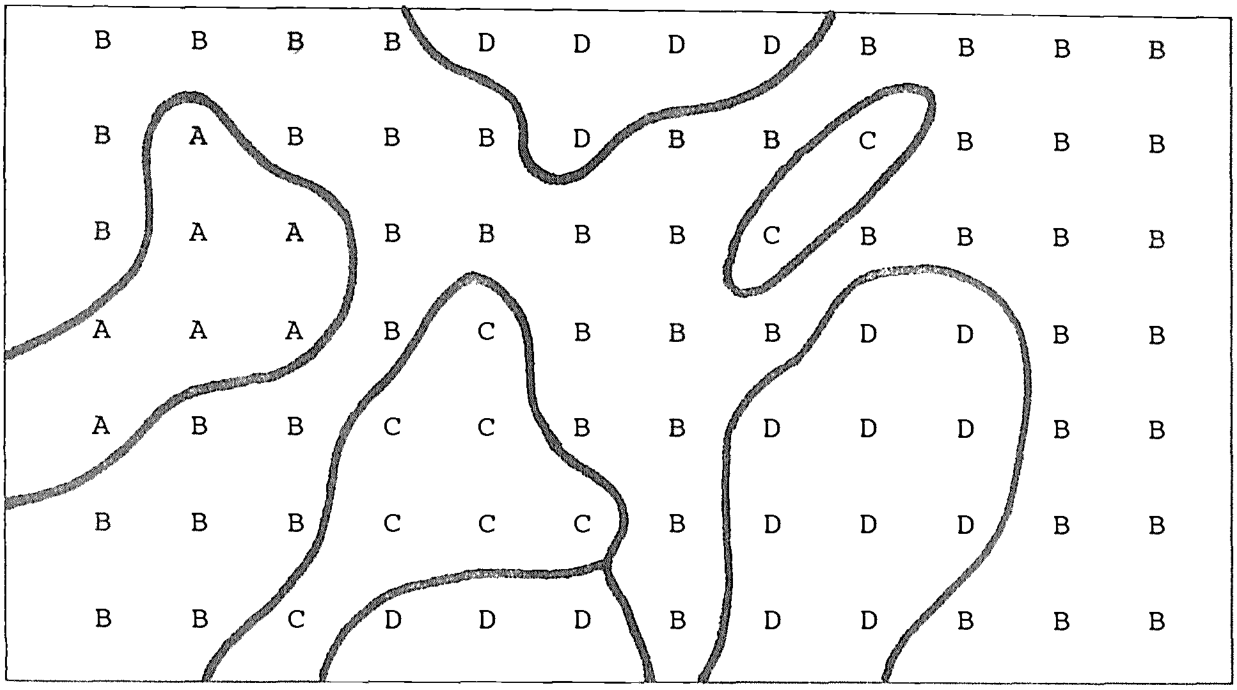
a) the surveyor is relatively amature/inexperienced; or

b) the project area has no distinct terrain features for precise location of the observation points or on-site marking of map unit boudaries; or

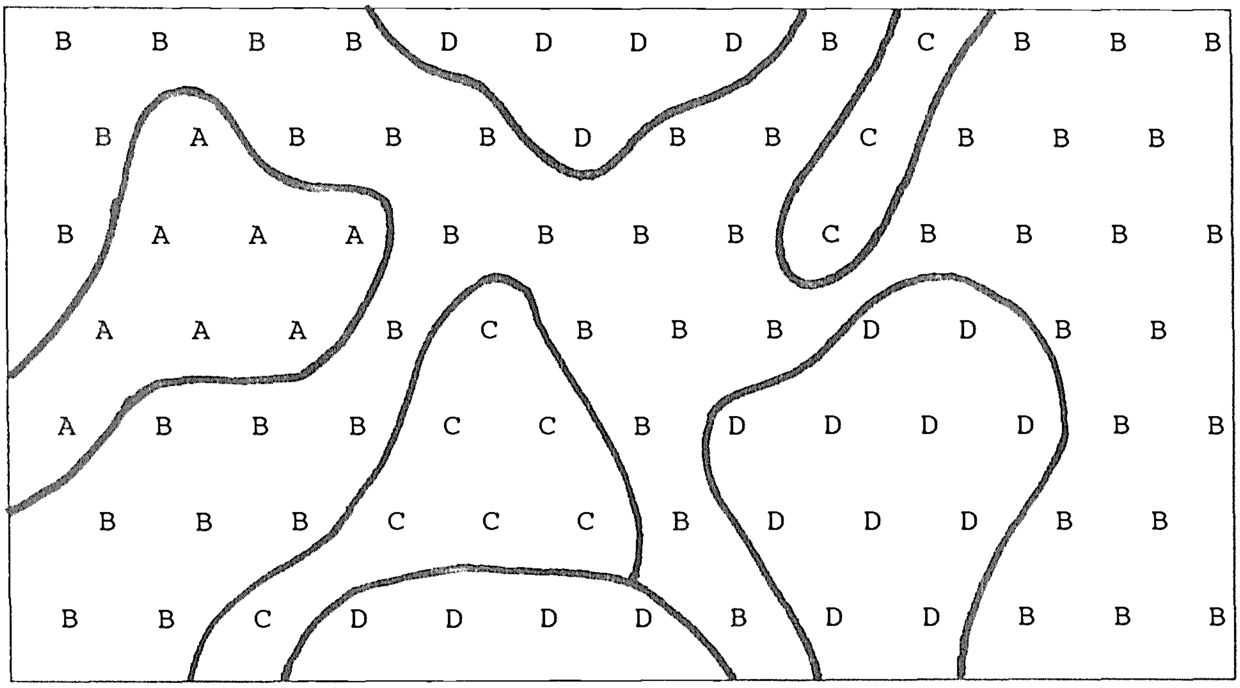
c) the air-photos or fairly detailed topographic maps are not available.

In order to have a standard level of accuracy by this method, a relatively high density of observations (about twice that in the other methods) needs be maintained. The accuracy level of this method can, however, be improved to some extent by an improved method of selecting the grids as shown in Fig 15b.

ii) **Traverse survey:** In this method, specific routes or traverses are marked for field investigations with the help of air-photos or detailed topographic maps in a way that they cut across the physiographic units, keeping appropriate distances which depend on the complexity of the area and the level of survey. The observations are then made along these traverses at carefully selected points which are generally located at regular intervals if the surveyor is less experienced but the intervals may be significantly variable if the surveyor has enough experience to decide the location of points on the basis of soil and physiographic variations and mark them accurately on the field map (air-photos). The map units are then delineated by extrapolation of the field data to similar physiographic units/positions through stereo-interpretation of the air-photos.



a) <u>Normal grid method</u>



b) <u>Improved grid method</u>

Fig 15: <u>Grid method of survey</u>; (A, B, C and D are different types of soils identified in the area, delineated together; compare the map unit boundaries with those correctly drawn through Traverse and Free surveys (Figs 16 and 17)

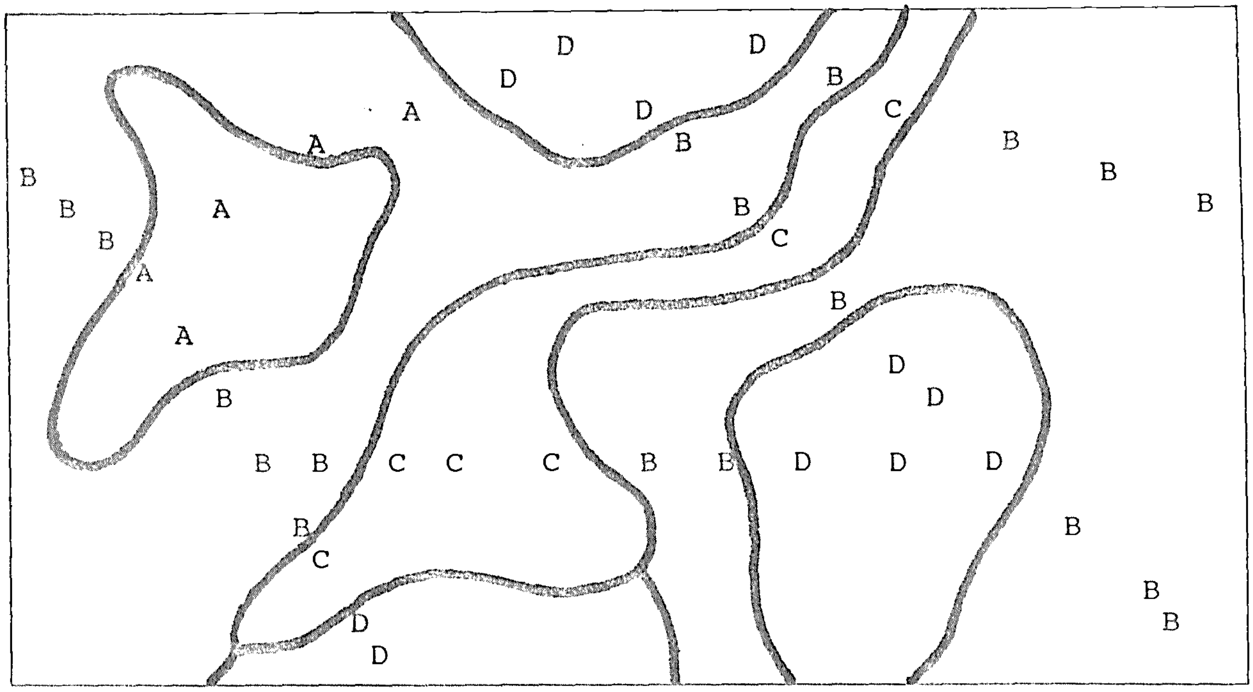


Fig 16: Traverse method of survey

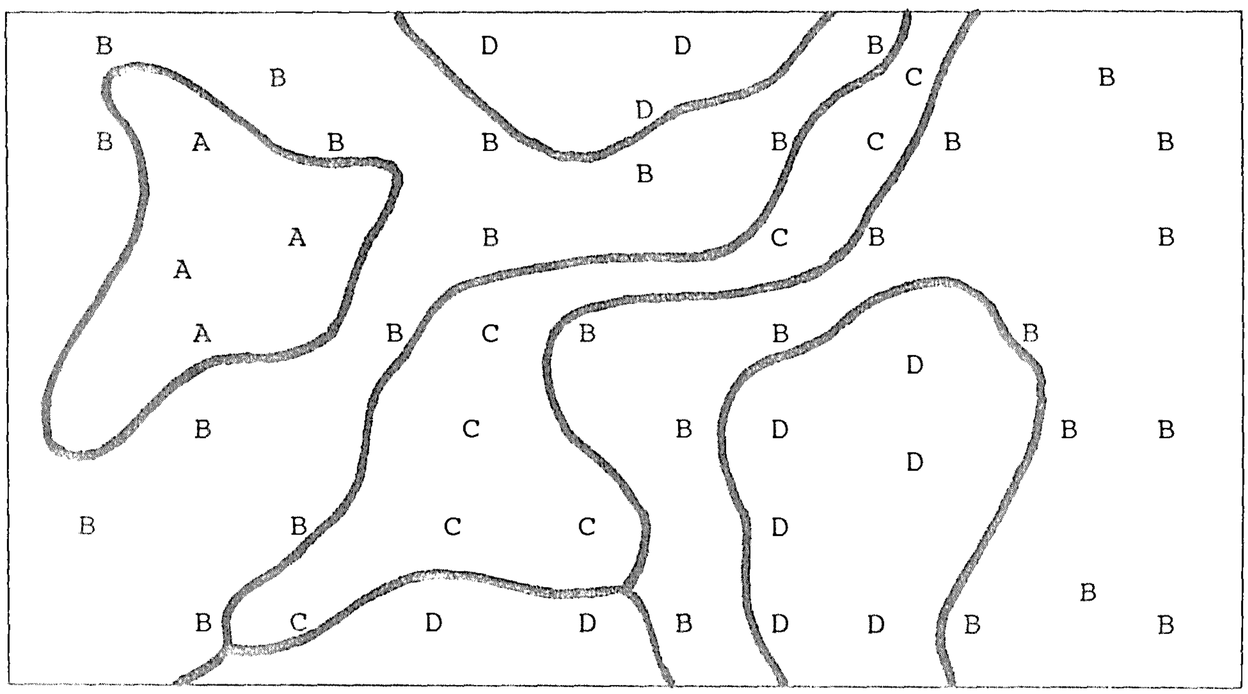


Fig 17: Free method of survey

It is a very reliable and scientific method but requires high skill of the surveyor, firstly in selection of the traverses, secondly in precise location of the observation sites, especially in areas having dense vegetation cover or in featureless terrain, and thirdly in extrapolation of field data to unsurveyed parts. However, more accuracy can be attained by this method with much less number of field observations as compared to the "Grid" method.

iii) Free survey: This method involves making field observations without pre-marking of grids or traverse lines. The location of observation sites is decided in the field by the changes in photo patterns and tones and discernable physiographic, soil or other variations within a certain API map unit. The routes along which field observations are made need not be straight but most commonly the available tracks are followed to facilitate accurate marking of the observation points except where other reference points may serve the purpose. Each map unit is to be checked repeatedly and, where possible, delineated while in the field making use of the visible natural boundaries. The map unit delineations are, however, finalized and the field data extrapolated to the unsurveyed parts through stereo-interpretation of the air-photos.

As in case of the "Traverse" method, this method requires a high skill of the surveyor who is fully familiar with the landform-soil relationships and soil forming processes operative in the area of study, is convenient only for an open country where both the access and visibility are unrestricted and is only successful when high-quality air-photos or very detailed topographic maps are available. It is a quite scientific, efficient and economic method of survey and requires fewer field observations, like those for the Traverse method, as compared to the Traverse method.

5.5.3 Survey procedure:

It is advisable that the air-photos of each selected sample area are got enlarged to a suitable scale before initiating their detailed studies. The soil studies in the sample areas are performed by making observations mainly with auger to about 1.5 metres depth. Preparation of "mini-pits" of about $50x50x50cm^3$ dimentions prior to augering, to study some basically important soil characteristics such as structure, porosity, mottling, roots, etc. which can not be judiciously studied from auger samples, is preferred for general studies but necessitated for special studies, particularly in areas where significant differences in such characteristics occur at short intervals. The observation intervals in any area are decided by complexity of the landscape with respect to physiographic and soil changes, visibility of the terrain and level of survey being conducted. The sample areas are, however, generally studied at detailed to semi-detailed level for which the following average spacing may be maintained:

Detailed or high-intensity surveys	= 200-300 metres
Semi-detailed or medium-intensity surveys	= 300-500 metres

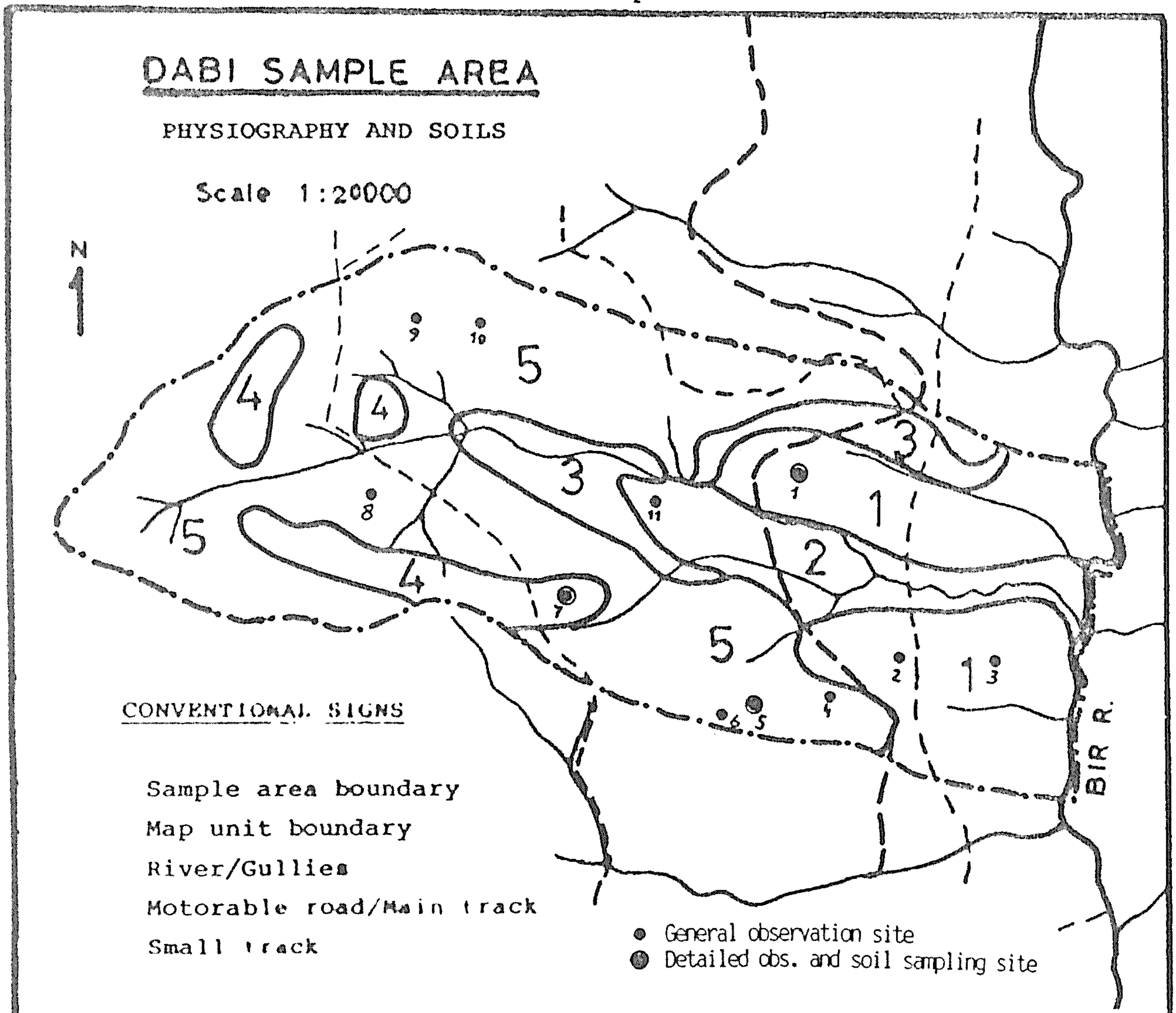
While travelling through the area, the map unit boundaries are drawn on the field map where observed along the route and extended as far as depictable on the ground. The ground features which are generally related to the map unit boundaries include:

- a break in slope gradient
- a change in slope form (such as from convex to concave)
- a change in the surface soil colour
- a margin of swamp or too dry land
- a change in natural vegetation cover (such as grassland to forest or bare land)
- a change in land use (such as from dry-farmed to irrigated; rice crop to cotton crop; or teff crop to maize crop etc.)
- a change in crop stand (i.e. crop condition)
- an edge of a sandy, gravelly or stony area
- a change in surface moisture conditions

During these investigations, a keen search is made to find out the major and minor components and determine the relative proportion of each component within the area delineated for each recognized map unit. Meanwhile due corrections are made in the map unit boundaries where necessary and the "map unit identification legend" updated accordingly. New kinds of soils, if encountered, added to the list in "Soil identification legend" for updating the latter.

An example of a "Physiography and Soils" map produced through semi-detailed survey by "Free" method for a sample study area of the Highland Soil and Water Conservation Project in Gojam Region of Ethiopia, using the Map 1 (fixed in Chapter 3) as the field map, along with the indication of observation sites and the map legend, is presented as Map 2.

Map 2



LEGEND

Subrecent piedmont alluvial plains

1 Dabi claya, gently undulating
2 Dabi clays, sloping
3 Dabi clays, stony surface, moderatly steep

Alluvial terracettes and colluvil slopes:

4 Genet stony loams, moderately steep
5 Genet stony loams, steep to very steep, dissected

5.5.4 Soil sampling

By the time that field investigations in the sample areas approach near completion, representative sites are selected for all important soils to excavate deep pits. Detailed description of the soil profiles exposed in the pits are then recorded and samples are collected from all major horizons/layers for physical and chemical analyses as well as moisture determinations in the laboratory; for the former purpose, **Disturbed soil samples** (in the form of crushed soil mass) are taken in sufficiently strong polythene bags each of which should be identified with a tag describing the observation site number, project number, approximate location, sampling depth, date of collection and name of the collector; in the latter case, **Core soil samples** (undisturbed samples maintaining their natural aggregation in the form of structural peds, voids and the related physical soil characteristics) are taken in standard cylindrical containers, called "cores" or "rings" each of which should be labelled with indelible ink on its outside, as well as on the upper lid, for site number, project number and sampling depth.

Having proper moisture conditions during the time of soil description and sampling from the pits is an imxortant factor to determine the accuracy of description and quality of the amples. If possible, such operations are performed when the soil is neither too dry nor too wet; it should ideally be in slightly moist condition. The "disturbed soil samples" are collected starting from the lowermost horizon/layer, then its upper one and so on that the topmost one is sampled in the last; the purpose of so sampling is to avoid contamination by the soil material falling from the upper parts. The size of each disturbed soil sample should be at least 2kg so that it can be used for all laboratory determinations. The "core samples" are generally collected from each major horizon/ layer starting from the topsoil to a depth of about 100cm, using a specially prepared instrument called "Core sampler". An utmost care should be taken to avoid disturbance of the soil's structure and to fill up the rings completely. Two core samples i.e., one by pushing the ring in the horizontal direction and the other in vertical direction are preferred to interpolate for average values of the soil moisture characteristics and accuracy. An extra core sample is necessitated if determination of bulk density is also intended.

It must be clearly borne in mind that the collection of soil samples from surface alone, whether simple or composite, or from some preplanned depths without keeping regard of the horizon boundaries has little meaning for soil classification or mapping. Soil sampling by means of auger is also not advisable unless it is imperative due to shortage of time or having no arrangements for digging of pits in the field; in the latter case, the profile is first studied carefully from each bucket sample which is piled separately on a clean place, noting the depths of all soil changes, and then the samples are collected by augering again at a new closest spot from the identified different horizons/layers.

5.5.5 Hydrological investigations

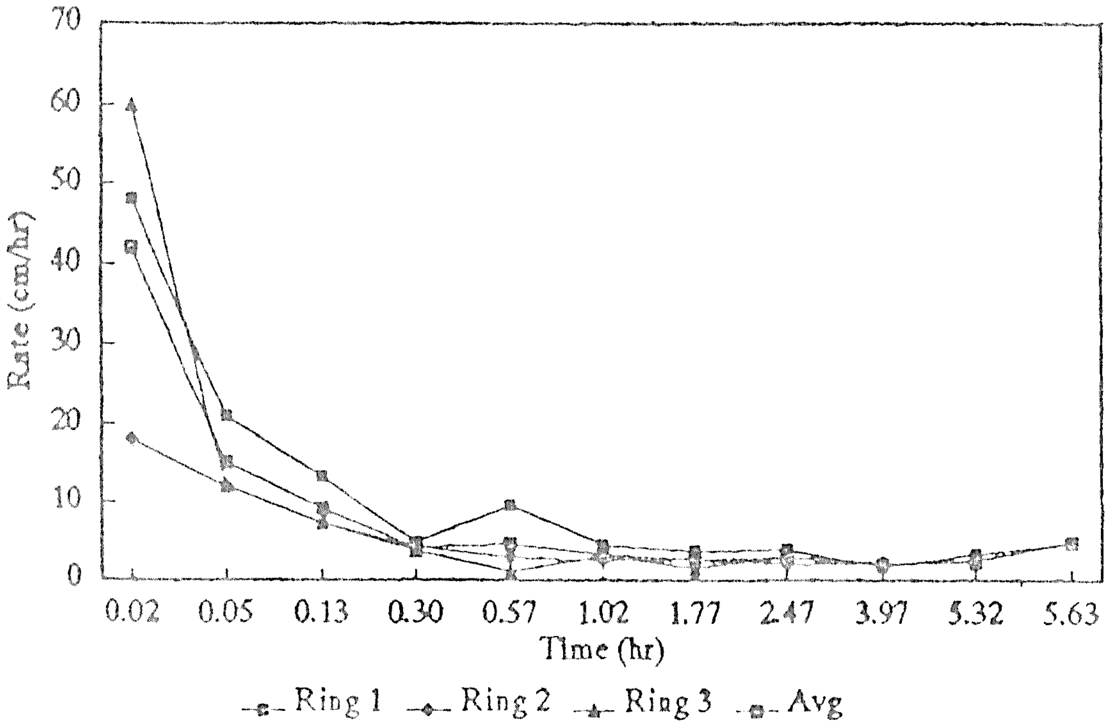
While the profiles of important soils occurring in the sample areas are described in detail and sampled from the pits, some hydrological investigations need to be made in the field; these include "Infiltration tests" and determination of "Hydraulic Conductivity or Permeability". The most practical method of carrying out infiltration tests is the **Double-ring Infiltrometer method**, the procedure for which is described under Annex IV. These tests are carried out in triplicate only for very important soils (i.e. those occurring in considerable extent) around their most representative pits, while the results obtained from the tests can be extrapolated to estimate the rates of relatively unimportant soils. The sites of all infiltration tests should be excavated immediately after the test to study the wetting depths and trends of water movement. The wetted profiles so exposed should be sketched on a graph paper. An example of an infiltration curve obtained from the test made on a typical soil type in Gojam Region of Ethiopia under the Highland Soil and Water Conservation Project, along with the basic infiltration rate of the soil and the wetted profile sketched, is presented in Fig 18 to 19.

The field determination of hydraulic conductivity may be done only for the horizon/layer which is expected to have the lowest rate since that would represent the hydraulic conductivity of the whole soil profile. For that purpose, a fair estimate can be made from the texture, porosity and structure of the respective soil horizon/layer. The hydraulic conductivity is generally determined by using the **Auger-hole method** if the target horizon/layer occurs below the water table and by the **Inverse Auger-hole method** if it is above it. These methods are described under Annex IV.

5.6 Extrapolation of the sample area studies

After field studies in the sample areas, their relevant air-photos are carefully studied under the stereoscope and the map unit delineations finalized in light of the field data using the revised map legend. If the air-photo enlargements were used for these studies, the delineations are transferred to the small-scale photos covering the whole project area. The photo patterns, tones and other relevant photo characteristics of each established map unit are then compared systematically with those on the rest of air-photos of the project area and, where found similar, the same map units are recognized and delineated in the unsurveyd parts. Some areas in the unsurveyed parts may appear different in some respects from what were studied in the sample areas, for which a special note is made for physical checking in the field.

FIG. 18: WATER INFILTRATION CURVE OF ZEMBELA SERIES (AN ALISOL)



<u>Basic Infiltration Rate (cm/hr)</u>: Replicate 1 = 2.8

Replicate 2 = 2.1

Replicate 3 = 2.1

Average = 2.1

Suitability for surface irrigation: Highly suitable

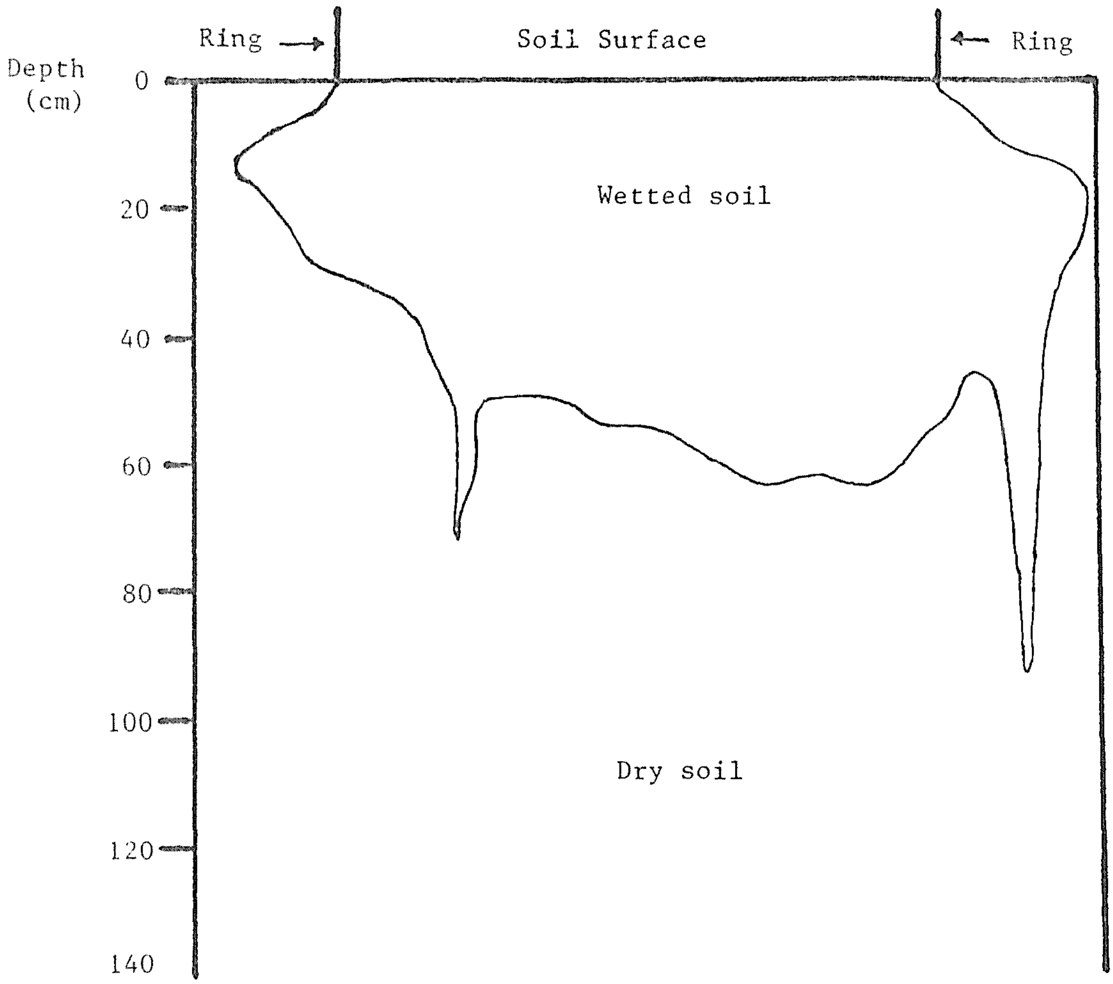


Fig. 19: Wetted soil profile after infiltration test on Dabi series (a vertisol)

5.7 Field investigations outside the sample areas

The map units delineated by extrapolation in unsurveyed part of the project area need to be checked through an adequate number of observations made by augering to a depth of 100-150cm. The observations may be made along the marked traverses (Traverse survey) or at selected sites (Free survey). The density of such observations varies with the scale and precision required for the final map, degree of variation encountered within the sample area studied, degree of change between different sample areas and degree of correlation between physical and photo-interpreted map unit boundaries observed in the sample areas. Average spacings needed for field observations in detailed and semi-detailed surveys have been described previously, while those for the reconnaissance survey range as 500m to 1.0km.

Many new facts may be revealed during these main field investigations such as:

- some new kinds of soils or new phases of the recognized soils are encountered,
- composition of the recognized map units is found different,
- certain soils are found to occur at more than one physiographic positions or in more than one landforms,
- some soils identified to be important while studying the sample areas are actually not quite extensive,
- the land use or vegetation cover of some soils is changing under certain conditions, etc.

All such facts are properly recorded and amendments are made in the map legend accordingly. The map unit boundaries are also reviewed and finalized through a final stereo-interpretation of the air-photos in light of these facts.

While the main field studies in the whole project area are under way and important soil series are finally established, the agronomic and other kinds of land resource data relevant to the assessment of land for the intended purposes of use are collected by interviewing the farmers and local communities, as well as by personal observation from the existing conditions. Such data, which include average and maximum crop yields under defined input levels, current land management practices, infrastructure, constraints and applied land and water conservation measures etc., must be related to the land conditions, especially the kind of soils; otherwise, its usefulness becomes doubtful.

5.8 Preparation of map

The map unit boundaries drawn on the air-photos should be matched between every two adjoining photos and flight lines, recorrecting where necessary, so that no line remains hanging and that every map unit is enclosed except when it extends to the project area boundary. These boundaries are then transferred from the air-photos, one by one, onto a base map (generally a topographic map) of appropriate scale by using a **zoom transferscope or sketchmaster**, or with free hand using a **proportionate divider** and correlating the geographical features seen on the photos with those indicated on the maps. The boundaries trasferred onto the maps often need to be reduced to the publication scale which may be about 2 to 5 times as small as the former. For that purpose, an instrument called as the **pantograph** is used. The reduction from several larger-scaled map sheets may be obtained directly on a single small-scaled map or on different small-sized map sheets which need to be compiled together on a "Permatrace" paper or drafting film before the map boundaries can be transferred to the small-scale base map (or to a film with overprints of geographical features) for final drafting of the land resource map. The map legend is then printed on the map and the map unit symbols are boldly indicated within the area of each unit prior to its reproduction.

5.9 Map units of Soil Map of the World

The mapping units being used for updating the FAO/UNESCO Soil Map of the World with the revised legend, as well as those used for the already printed map, are the **"Associations"** of mainly the "Soil Units" and partly of the "Major Soil Groupings" or of a combination thereof, so that the symbol of the dominant Soil Unit/Major Soil Grouping takes the first place in the mapping symbol which is followed by one or two symbols representing the associated important soils, joined together by means of a hyphons.

The map symbols of the Soil Units or Major Soil Groupings (or of the map units) are identified by one or two Arabic number(s) representing the **"Surface texture"** wherever such information is available. The textural classes represented by various numbers are defined as folows:

1. **Coarse textured** i.e., sands, loamy sands and sandy loams with <15% clay and >70% sand

2. **Medium textured** i.e., Sandy loams, loams, sandy clay loams, silt loams, silt, silty clay loams and clay loams with <35% clay; and <70% sand if clay is >15%

3. **Fine textured** i.e., clays, silty clays, sandy clays, clay loams and silty clay loams with >35% clay

The map symbols also include the **Slope classes** represented by a small letter suffix (two small letter suffixes if the slopes are compound) as follows:

a. **Level to gently undulating** i.e., the dominant slopes ranging between 0 and 8%

b. **Rolling to hilly** i.e., the dominant slopes ranging between 8 and 30%

c. **Steeply dissected to mountainous** i.e., the dominant slopes over 30%.

Symbols of the **"Phases"** indicating the land characteristics not reflected by the soil units or by the composition of the soil associations are to be indicated on the map by **overprints**.

6. LAND EVALUATION

6.1 The concept of Land Evaluation

The term **Land evaluation** refers to the process whereby the suitability of land for specific kind/kinds of use (such as irrigated coffee production, irrigated horticulture, rainfed forestry, spate-irrigatred sorghum, livestock production, etc.) is assessed. The main objective of land evaluation is to select suitable tracts of land for development and to find out the suitable cropping and land management alternatives that would be physically and financially practicable and economically viable. It helps in making decisions as to whether a certain project should be implemented or not, and to fairly estimate what benefits or losses are likely to accrue with its implementation.

The land evaluation is generally presented in the form of land suitability classes which may be defined in qualitative or quantitative terms, depending on the detail of surveys conducted and the availability of economic data. The qualitative land suitability classes represent relative suitability for the specified use, while the quantitative land suitability classes are described in absolute economic terms like "net farm income", "net returns per ha" or "net incremental benefits" etc.

6.2 The FAO Framework for land evaluation

The FAO's Framework for Land Evaluation (FAO, 1976) and the FAO's Guidelines on Land Evaluation Rainfed and Irrigated Agriculture (FAO, 1983 & 1985) recommend land suitability assessment at the following four categorical levels:

a) Land suitability **"Order"**
b) Land suitability **"Class"**
c) Land suitability **"Subclass"**
d) Land suitability **"Unit"**

At the highest level of **"Order"**, the land is classified as:

S: Suitable or **N: Not suitable**

As the second level of **"Class"**, the Order **"S"** is divided into three (or four if need arises) Classes, on the basis of degree of suitability for the defined use. Each Class is identified by using an Arabic number suffix and defined as below in terms of relative degree of limitations posed, if any, to sustained application of a certain land use type and expected reduction in productivity or benefits or increased inputs required to achieve the acceptable level of outputs from the land.

S1: Highly suitable No significant limitation; no significant reduction in productivity/benefits or raising of inputs above an acceptable level

S2: Moderately suitable Moderately severe limitations; considerable reduction in productivity/benefits or input costs raised to the extent that the use, though still attractive, is not as profitable as of **S1** land

S3: Maginally suitable Severe limitations; much reduced productivity/benefits or input costs raised to the extent that the use is only marginally justified

The Order **"N"** is similarly divided into two Classes on the basis of degree of unsuitability for the defined use as:

N1: **Currently not suitable**
N2: **Permanently not suitable**

At the third level of **"Subclass"**, the Classes "S2", "S3" and "N1" (not S1 and N2) are divided into various Subclasses, on the basis of kind(s) of limitation(s) imposed to the defined use, by using small letter suffixes representing the major limitation as, for example:

S2m: Moderately suitable due to low moisture availability
S3d: Marginally suitable due to impeded drainage
S2t: Moderately suitable due to unfavourable topography

In case that two limitations are equally important in affecting the land use, two letter suffixes may be used for differentiation at Subclass level as, for example:

S3wz: Marginally suitable land due to difficult soil workability and salinity hazard

At the lowest level, the land suitability Subclasses are further divided into **"Land Suitability Units"**, on the basis of management requirements, by using Arabic numbers separated with a hyphon as, for example:

S3d-1: Marginally suitable land due to impeded drainage by collection of water during rainy season;

S3d-2: Marginally suitable land due to impeded drainage by high water table; and

S3d-3: Marginally suitable land due to river flooding during summer (The land flooded by river may also be classified separately by using another suffix, say "f").

6.3 Main procedures followed in land evaluation

The main procedures followed for evaluation of a tract of land selected for a development project include:

i) Preliminary study of the existing information, especially that relevant to field appraisals of land conditions and experiences in a fully developed area having physical, climatic and socio-economic conditions similar to the project area;

ii) Selection of the land use alternatives (crops, irrigation methods, soil management technology, etc.) and description of the **"land use types"** (the land use with detailed definition in terms of all important attributes) for evaluation; in some cases, the land use types may be obvious from the outset (e.g., irrigated rice, rainfed sisal, irrigated orchards, rainfed tree crops, etc.); in some others, these may be already defined in the terms of reference;

iii) Preparation of a land resource inventory (from the land resource surveys already discussed) of physiography, climate, geology, hydrology, soils, present land use and vegetation, fauna and socio-economic conditions;

Three sets of data are obtained from the land resource surveys i.e.,

a) Definitions and descriptions of the land units,
b) Maps showing the distribution of these land units and
c) Values of land characteristics of the land units.

The land units are described in terms of all the above characteristics, except for socio-economic conditions for which the data are separately collected by economists;

iv) Listing of land use requirements in terms of the critical limits of land characteristics;

v) Selection of **"Class-determining factors"** (the variables affecting agronomic, management, land development, conservation, and environment or socio-economic conditions, and having influence on the outputs and inputs of a land use type) and specification of critical limits of the values of land characteristics for designating the land suitability categories (levels of suitability for individual land use requirements or limitations, expressed as s_1, s_2, s_3, n_1 or n_2) and the weightage given to each "class determining factor for evaluation;

vi) Matching the values of characteristics of the land units with the critical limits of land use requirements or limitations (land suitability categories) and classification of each land unit to appropriate land suitability subclasses (and further to the land suitability units, if required) considering the weightage of the class determining factors;

vii) Mapping and description of the land suitability subclasses or units, or subclass associations, depending on the level of investigations made.

6.4 Physical vs economic land evaluation

The land suitability classes defined above may be translated into various physical and economic indices or measures of suitability. Three most practical and convenient measures of land suitability which lend themselves to progressive applications as more and more data become available are briefly described below.

i) Land Productivity Index. The **land Productivity Index (LPI)** may be defined as "the physical productivity of land under a specified land use (land use type), relative to that of the best land having similar physical environments". The indices are useful tools to have rough estimates of the potential levels of productivity for comparison with the provisional estimates of land development costs at the level of reconnaissance and prefeasibility studies.

The LPIs may be expressed in terms of **"relative yield"** (the yield per unit area relative to that of the best land as a percentage or fraction) or in terms of **"absolute yields"** (the actual yields e.g., in kg/ha or t/ha). Both the ranges of values and the single values (which may be mid-values or estimated values within the ranges) can be used for that purpose. A well estimated single value within the specific range of the respective land suitability class is preferred in cases when it can be wisely selected by the economist or planner fully conversant with the evaluation procedures; in other cases, the mid-values may be used.

The proposed standards of LPIs for different land suitability classes under conditions prevalent in Ethiopia are as in Table 2.

Table 2: Proposed land productivity indices for Ethiopia

Land suitability class	Land Productivity Index			
	Range		Mid-value	
	Percentage	Fraction	Percentage	Fraction
S1	81-100	0.81-1.0	90	0.90
S2	51-80	0.51-0.8	65	0.65
S3	20-50	0.20-0.5	35	0.35
N1	<20	<0.2	10	0.1
N2	0	0	0	0

The rough initial calculations based on the LPI may also help in the identification of alternative land use types, including the possible cropping/conservation and management systems, and the approximate amounts which can be invested in land development. It is important to note that the land suitability classes into which the given land unit-land use type combinations fall may differ abruptly if the "relative yield" is used as the index unit. It may also be kept in mind that the LPIs do not take into account the prices or the costs of production.

ii) Net Farm Income. The **Net Farm Income** is defined as "the value obtained after subtracting all variable and fixed costs from the gross value of the production got from the land". It is a suitable method to evaluate land for pre-feasibility studies when the common project costs are not generally known, as these are not taken into account in estimating the Net Farm Income. The Net Farm Income may be calculated for both the **'without-project'** and the **'with-project'** situations. It would, however, generally suffice to base the land suitability classification on the 'with-project' Net Farm Income. The land evaluation by this method does not consider the increase of income effected by moving from a 'without-project' to 'with-project' situation. This evaluation would need further refinement for detailed project planning as it would generally include some "marginally suitable lands" that would have to be eliminated by further economic analysis. The further revisions and adjustments in land evaluation may, however, be curtailed significantly by making estimates in terms of "Net Incremental Farm Income" (i.e., **'with-project' Net Farm Income minus 'without-project' Net Farm Income**, which is normally assesed for the year of full development).

iii) **Net Incremental Project Benefits**. The "**Net Incremental Project Benefits**" may be defined as "the increase in net benefits from a unit area of land envisaged with the development under a project plan. It is calculated as:

Net Incremental Farm Income - "**Annual Equivalent Value of Common Costs**" (i.e., the project costs calculated on yearly basis; not including the costs of land improvements like land clearing, drainage, reclamation, levelling etc.) - "**Annual Equivalent Value of Area-specific Land Development Costs**".

The "**Cut-off value**" (the value corresponding to the Net Incremental Project Benefits being zero) used to define the boundary between the "Suitable" and the "Not suitable" lands is virtually that represented by the Annual Equivalent Value of Common Costs, and it should include the project's **Annual Operation and Maintenance Costs**.

6.5 The approaches followed for economic land evaluation

It is generally convenient to follow a two-stage approach to arrive at quantitative (economic) evaluation i.e., a first approximation of land suitability is made on the basis of physical criteria, resulting in a qualitative land suitability classification, and then the economic and social analyses are carried out for each suitability class on the most promising land use alternatives. The other method, the parallel approach, includes the economic criteria throughout the process of matching and land suitability classification and the land classes are based on economic assessment whereby the physical limits are selected to fit the economic limits.

The "two-stage" approach has the advantage of being more straight-forward to follow and having validity of the physical classification made for a long time, so that the final economic evaluation can be easily revised in the light of changing economic conditions. Moreover, it is probably more scientific since it provides a strong basis in the form of land suitability classification arrived at by using more or less permanent land parameters, which can be further used to evaluate the land for some more prospective land use types identified in near future. In comparison, the "parallel" approach directly results in land evaluation which is valid for a relatively short time and entails repetition of the whole process to revise it whenever the changed economic conditions necessitate it. A disadvantage visualized in land evaluation by the "two-stage" approach, however, is that some more promising economic alternatives may be overlooked in the initial physical evaluation.

EXERCISE IN ASSESSMENT OF LAND SUITABILITY FOR AGRICULTURAL PROJECTS

Question:

A project area covering 500 ha is proposed for development to grow irrigated cotton at high inputs level. It comprises three land units mapped as 1, 2 and 3 which occupy 50%, 30% and 20% of the project area respectively and have the following composition with respect to different soil types:

Soil types	Unit 1	Unit 2	Unit 3
A	25%	80%	40%
B	60%	15%	30%
C	15%	5%	30%

The same soil types occurring in a nearby developed area were studied for economic analysis under irrigated cotton cultivation at high inputs level. The yields per ha obtained, with a total of the fixed and recurring costs of EB450/-, were found as follows:

Soil type A = 2.5 tons

Soil type B = 4.2 tons

Soil type C = 3.0 tons

The estimated annual equivalent value of common costs for the installation of irrigation and drainage systems in the project area are EB400/- per ha, while the annual equivalent value of area-specific costs per ha are EB500/-, EB250/- and EB350/- for the soil types A, B and C respectively. The project area is presently used for rainfed cultivation of maize at a low inputs level. The average yield of maize obtained is 1.5 tons/ha with EB150/- per ha worth of average annual inputs. If the farmgate market rates of cotton and maize are EB1,200/- and EB750/- per ton respectively,

i) Estimate the Net Incremental Irrigation Benefits (NIIB) if the whole project area is to be developed;

ii) Evaluate the suitability of the three soil types for irrigation development, assuming the cut-off value at EB1,000/- per ha and the minimum per ha NIIB from S1 and S2 lands as EB2,000/- and EB1,500/- respectively; and

iii) Judge suitability of the project for execution if:
   a) the whole area is developed
   b) only the area under land units 1 and 3 is developed.

Solution:

i) Total project area = 500ha

Area under Unit 1 = 250ha
Area under Unit 2 = 150ha
Area under Unit 3 = 100ha

Area under Soil type A:
Unit 1 = 62.5ha
Unit 2 = 120 ha
Unit 3 = 40 ha
Total = 222.5ha

Area under Soil type B:
Unit 1 = 150 ha
Unit 2 = 22.5ha
Unit 3 = 30 ha
Total = 202.5ha

Area under Soil type C:
Unit 1 = 37.5ha
Unit 2 = 7.5ha
Unit 3 = 30 ha
Total = 75 ha

Annual equivalent value of common costs =
400x500 = EB200,000

Annual equivalent value of area-specific costs:
Soil type A = 500x222.5 = EB111,250
Soil type B = 250x202.5 = EB 50,625
Soil type C = 350x75 = EB 26,250
Total = EB188,125

Without-project fixed and recurring costs = EB150/ha
Without-project gross value of production =
1.5x750 = EB1,125/ha
Without-project Net Farm Income = 1,125-150 = EB975

With-project fixed and recurring costs = EB450/ha
With-project gross value of production =
1200x(2.5x222.5+4.2x202.5+3x75)/500 = EB3,916.2/ha
With-project Net Farm Income = 3,916.2-450 = EB3,466.2/ha

Net Incremental Irrigation Benefits (NIIB) =
3,466.2-975.0 = EB2,491.2/ha

Total NIIB = 500x2,491.2 = EB1,245,600

ii) Land suitability limits:

S1 = NIIB > EB2,000
S2 = NIIB EB1,500 to EB2,001
S3 = NIIB EB1,000 to EB2,000
N = NIIB < EB1,000

NIIB for soil type A = 2.5x1,200-450-975-400-500 = EB 675
NIIB for soil type B = 4.2x1,200-450-975-400-250 = EB2,965
NIIB for soil type C = 3.0x1,200-450-975-400-350 = EB1,425

Land suitabilty assessment:

Soil type A = N
Soil type B = S1
Soil type C = S3

iii)

a) NIIB for the whole project area = EB2,491.2/ha
(from (i) above)

From the limits given above, **the project suitability for development of the whole area is assessed as: S1 or Highly Suitable**

b) NIIB for Unit 1 =
0.25x675+0.6x2,965+0.15x1,425 = EB2,161.5

NIIB for Unit 3 =
0.4x675+0.3x2,965+0.3x1,425 = EB1,587.0

Proportion of unit 1 = 50/70
Proportion of Unit 3 = 20/70

Weighted average NIIB for units 1 and 3 =
2,161.5x5/7+1,587x2/7 = **EB1,997.36**

Project suitability if only units 1 and 3 are developed is assessed as : S2 or Moderately suitable

7. INTERPRETATION AND UTILIZATION OF LAND RESOURCE DATA FOR FEASIBILITY STUDIES

The land resource data provided in the survey reports and maps is not commonly interpreted in the way it deserves and consequently the results presented in the project study reports may occasionally be misleading. The results of the most vital interpretation i.e., land evaluation, which is generally well described in the land resource reports, are often used by some planners/engineers, while preparing the project reports, in such a confusing style that it would significantly influence the land development costs as well as the benefits envisaged from the project implementation. A few brief guidelines on how to justifiably manipulate the land resource data for determining various parameters for the project studies are given in the following.

7.1 Interpretation of climatic data

The climatic data can be interpreted in many a different way according to the purpose. The one adopted by FAO (1978) for the Agro-ecological Zones project leads to classification into **"Major climates"** and **"Length of Growing periods"** as discussed below.

7.1.1 Classification to Major Climate

The **"Major climates"** are broad climatic divisions defined in terms of monthly mean temperatures, seasonality of rainfall and temperature regime during the growing period of a crop. In all, **14** Major climates have been recognized as defined in Table 3.

Table 3: Major Climate classification
(MMT =monthly mean temperatures in °C, corrected to sea level; 24h-MT =24 hour mean temp. regime during the growing period)

Major Climate during the growing period	24h-MT(°C)
a) TROPICAL CLIMATES (MMT all months >18)	
1. **Warm tropics**	>20
2. **Moderately cool tropics**	15-20
3. **Cool tropics**	5/10-15
4. **Cold tropics**	<5

b) <u>SUBTROPICAL CLIMATES</u> (MMT all months >5 but one or more months <18)	
5. **Warm to moderately cool subtropics with summer rainfall**	>20
6. **Warm to moderately cool tropics (summer rainfall)**	15-20
7. **Warm subtropics (summer rainfall)**	>20
8. **Moderately cool subtropics (summer rainfall)**	15-20
9. **Cool subtropics (summer rainfall)**	5/10-15
10. **Cold subtropics (summer rainfall)**	<5
11. **Cool subtropics (winter rainfall)**	5/10-15
12. **Cold subtropics (winter rainfall)**	<5
c) <u>TEMPERATE CLIMATES</u> (MMT one or more months <5)	
13. **Cool temperate**	5/10-15
14. **Cold temperate**	<5

7.1.2 Determining the growing period

The climatic data can be interpreted in terms of **"Growing periods"** for specific crops, which is determined mainly by **water availability** and **temperature regime** but should take into consideration the **radiation regime, humidity, winds** and **hail** which may have considerable influence on the growth or yield of crops in certain parts of the growing period. On the basis of **water availability**, the period is defined as the one during which effective precipitation (P) exceeds half the potential evapotranspiration (0.5PE) of a crop, plus the period required to evapotranspire the available moisture stored in the soil (crop root zone) from an excess of precipitation if occurred; for the sake of simplicity and as first approximation, the available moisture stored from the excess preci-pitation is assumed as 100mm unless a lower precipitation disallows such assumption. On the basis of **temperature regime**, it is defined as the period during which the mean daily temperature equals or exceeds 5°C; the days when the temperature remains below 5°C are discounted to calculate the lengths of **Normal growing periods.**

For rainfed conditions, the **"Growing period"** is defined as "the period of a year when both the water availability and the temperature regime are favourable for growth of the respective crop". For irrigated conditions, however, the condition of water availability is waived and it would be defined as "the period of a year when the temperature regime is favourable for growth of the respective crop".

Based on **water availability**, the following three **"Types"** of growing periods are differentiated:

a) Humid period: the period when there is an excess of effecive precipitation over the potential evapotranspiration; rainfed crops can be grown successfully with little moisture stress

b) Intermediate (or subhumid) period: the period when effective precipitation is less than potential evapotranspiration but exceeds half of the latter; rainfed crops can be grown but would experience moisture stress require supplemental irrigation for high yields

c) Dry period: the period when the precipitation is less than half of the potential evapotranspiration; crops can be grown only with irrigation during this period

Furthermore, the growing period should be assessed with respect to both the **"Length"** and the **"Quality"**; the former term implies "number of days for which the growing period lasts, not counting for the days when the crop may remain dormant due to too low temperatures" while the latter means "relative degree of suitability of the growing period considering together the moisture (especially the regularity in precipitation) and the temperature regime, as well as radiation, humidity, winds and hail etc. which may have differential effects on the crop performance or cultural operations".

The procedure followed to estimate the length of growing period is as follows:

i) Analyse the temperature data to divide it into 10-day periods during which the mean daily temperatures are more than or equal to 5°C

ii) The **beginning of growing period** is counted from the first 10-day period selected as above wherein the precipitation equals or exceeds half the potential evapotranspiration of the considered crop

iii) The **end of growing period** is marked by a time when, after a period with precipitation less than half of potential evapotranspiration has passed, the stored soil moisture would be expected to have been used up by the crop; the latter is estimated from the available moisture capacity of soils and the water balance.

Although the division of growing periods on the basis of **quality**, though yet to be considered for further refinement in the agro-ecological zonation, it is proposed that each of the "Humid" and "Intermediate (or Subhumid)" growing periods should be further graded as **"Regular"** and **"Erratic"** depending on whether the precipitation received during the period is well distributed or erratic, or the factors like "radiation", "humidity", "winds", "hail", etc. would have favour-able or adverse effects on crop performance, respectively. Such grading would help in assessment of the crop yields nearest to the facts.

7.1.3 Calculation of irrigation water requirements

The data on precipitation, temperature and evapotranspiraion can be interpreted to calculate the **"irrigation water requirements** for cultivation of different crops and hence in designing of the surface water reservoirs, the groundwater pumping systems and the irrigation channels etc. The detailed procedure of how to estimate the water requirements for irrigation is described in FAO Irrigation and Drainage Paper 24 and the main steps followed are outlined below.

i) Set out a cropping calendar of 10-day or weekly periods for all cultural operations (land preparation, seeding, harvesting, etc.)

ii) Select a reference crop and calculate its evapotranspiration (ETo) for each 10-day or weekly period using the relevant climatic data as described in the above-cited FAO paper, or obtained from some local research station if available

iii) Calculate maximum evapotranspiration (ETm) of the crop for its different stage of growth by multiplying ETo with the relevant crop coefficients (Kc) listed in the cited FAO paper or obtained from some local research station

iv) Estimate:

a) the amount of water needed to wet the soil, if initially dry,
b) water losses from run-off, seepage and percolation and
c) leaching requirements, if any

v) Estimate the amount of water to be added through run-on or capillarity from groundwater

vi) Add (iii) and (iv) together and subtract (v) from the total to get the irrigation water requirements at farm gate

vii) Add on the conveyance losses from the source to the farm gate to estimate the total water requirements for design of water reservoirs

viii) Decide on the irrigation schedules for the proposed irrigation technique in terms of frequency, rate and duration of water application

ix) Determine peak water requirements in terms of flow rates

x) Match the water supply and the water requirement profiles by review and iteration

7.2 General assessment of land characteristics

The assessment of land characteristics varies with the land use type considered. However, their general assessment for agriculture under an average level of inputs and management may be made as presented as in Table 4. The assessment is given in terms of two values of land characteristics representing "highly suitable land" and "marginally suitable to not suitable land"; for intermediate land suitability classes, it should be estimated between the stated values of the respective characteristics.

Table 4: General assessment of land characteristics

Land characteristics	Values/grades indicative of high land suitability (S1)	Values/grades indicative of low land suitability (S3/N)
a) Physiography:		
Slope	Simple; <2	Compound; >30%
Physiographic position	Flat; no water collection or shedding	Concave (excessive water collection)/Convex (excessive water shedding
b) Climate:		
Length of growing period	>180 days	<60 days

Table 4: General assessment of land characteristics (contd.)

Land characteristics	Values/grades indicative of high land suitability (S1)	Values/grades indicative of low land suitability (S3/N)
Type of growing period	Humid; intermediate for certain crops	Dry
Quality of growing period	Regular	Erratic
c) Hydrology:		
Irrigation water availability/ quality	Adequate and timely supply; good to very good quality	Scanty or irregular supply; marginal or unfit for irrigation
d) Present land use/vegetation cover:		
Land use	Intensively cultivated	Uncultivated or patchy cultivation
Vegetation cover	Dense, uniform	Sparse, non-uniform
e) External soil characteristics:		
Rocks or rock fragments	Absent for arable use; few stones for range or forestry	Frequent, large-sized stones and boulders or rock outcrops
Erosion/ sedimentation	No rills/gullies; no surface sedimentation	Many rills/gullies or frequent deposition of barren material
Flooding/ ponding	No flooding; no or minor, short-duration ponding	Frequent, deep flooding or long-duration ponding
Surface crusting	No surface crusts formed	Frequent crust formation after rains
Human influence	No disturbance by man except cultivation, minor levelling, irrigation or addition of organic matter	Severe disturbance by man by excavation, major levelling operations or surface addition of infertile material

Table 4: General assessment of land characteristics (contd.)

Land characteristics	Values/grades indicative of high land suitability (S1)	Values/grades indicative of low land suitability (S3/N)
f) Soil physical characteristics:		
Effective depth	>150cm	<50cm
Colour	Topsoil: dark colours Subsoil: dark greyish dark brown or reddish brown with no mottles	Topsoil: light grey/red Subsoil: very red or dark grey with mottles or black with mottles
Texture	Loam, silt loam, very fine sandy loam, clay loam, sandy clay loam or silty clay loam	Sand, loamy sand, heavy clay, silt, peat or muck
Structure	Topsoil: granular to crumb Subsoil: fine to med. subangular blocky	Topsoil: rock structure, massive or single grain Subsoil: rock structure, massive, single grain, prismetic/columnar or coarse angular blocky
Cutans/clay bridging	Thin to mod. thick org matter or clay cutans; weak to mod. strong clay bridging in sandier soils	No clay or org matter cutans; no clay bridging in sandy soils
Silt/salt or lime coatings	No or few; no infillings of voids	Many thick infillings in most voids
Stress surfaces/ slickensides	Absent	Common to many in the rooting zone
Consistence	Wet: sl sticky/sticky, sl plastic/plastic Moist: friable to very friable Dry: sl. hard to hard	Wet: very sticky/non-sticky Moist: extremely firm or loose Dry: ext. hard or loose
Porosity	Common to many fine and medium channels in the subsoil	No medium and very few or no fine channels in the subsoil
Pans	Absent within 150cm	Present within 50cm

Table 4: General assessment of land characteristics (contd.)

Land characteristics	Values/grades indicative of high land suitability (S1)	Values/grades indicative of low land suitability (S3/N)
g) Soil chemical characteristics:		
pH	6.0 to 8.0	<5.0 or >9.0
Calcareousness, lime	Noncalc to mod. calc; few or no lime concretions; no powdery lime	Str. calc; many lime concretions and/or abundant powdery lime
Salinity, ECe	Nonsaline; ECe <4 dS/m	Severely saline; ECe >16 dS/m
Sodicity, ESP	Nonsodic; ESP <6 for clayey soils; <15 for loamy soils	Sodic; ESP >30 for clayey soils, >50 for loamy soils
Gypsum content	<5%	>20%
Chemical formations	No or very few fine Fe/Mn concretions; no durinodes	Many Fe/Mn concretions or durinodes
Weatherable minerals	Abundant throughout upto 100cm depth	Absent within 100cm depth
Cation exchange capacity	Medium to high; >20 cmol/kg topsoil and >10cmol/kg of clay	Low; <5cmol/kg soil or <16cmol/kg clay
Base saturation	High; >50%	Low; <5%
h) Soil biological characterisitcs:		
Organic matter content	>1% in topsoil	<0.5% in topsoil
Root distribution	Common to many; well distributed to >1.5m depth; not deformed	Few; unevenly distributed, partly or mostly deformed
Biological activity	Evident in major part to >1.5m depth	Absent
Artefacts	Absent or few	Many to >100cm depth

Table 4: General assessment of land characteristics (contd.)

Land characteristics	Values/grades indicative of high land suitability (S1)	Values/grades indicative of low land suitability (S3/N)
i) Soil hydrological characteristics:		
Drainage	Well drained	Exessively, imprerfectly or poorly drained
Groundwater table	>2m deep	<1m deep
Available water capacity	Rainfed: >200mm Irrigated: >150mm	Rainfed: <75mm Irrigated: <50mm
Infiltration rate/hydraulic conductivity	Moderate; 0.5-1.5cm/h	Rapid/very rapid or slow/very slow; >5cm/h or <0.1cm/h

7.3 Estimating the potential crop yields

Acquiring reliable data on potential yields of different crops under certain agro-ecological environments is a prerequisite to serve as threshold values for quantitative estimation of the yields to be realized from different classes of land at the defined level of inputs and management. The potential crop yields should represent not the highest but the one most frequently obtained at a certain kind of soil. Such data should be collected from the most relevant agricultural research stations and advanced farmers. However, in the less developed/developing countries, acquisition of such data is difficult, mainly because neither the agricultural research is well diversified, nor any proper records are maintained and not the agricultural parcels are generally of standard size.

For guidance in estimating the crop yields in cases when no agricultural research data are available, the indicative yields of some important tropical and subtropical crops, estimated for high and medium input levels, are reproduced in the following Table 5 from the Booker Tropical Soil Manual (Landon, 1984), with some amendments made according to the need of the table and/or personal experience of the author of this manual. The yields are obtainable from a **highly suitable (S1) land** where all agro-ecological conditions are favourable for the respective crops. Mid-values of the yield ranges given in the table may be used for general purpose of having rough estimates of gross returns or net farm income from a tract of land having a certain suitability class, by multiplying with a factor of land productivity index specific to the class as discussed in the following sections.

Table 5: Indicative yields of important tropical and sub-tropical crops under high and medium input levels

Crop	Indicative yield (t/ha)			
	High inputs level		Medium inputs level	
	Irrigated	Rainfed	Irrigated	Rainfed
a) Cereal crops				
Wheat	4-6	2.5-4.0	1.5-2.5	3-5
Maize	6-9	3-5	4-5	1.5-3.0
Sorghum	5-6	3-4	3-4	1.5-2.0
Rice (paddy)	6-8	-	4-5	1.5-2.5
b) Fibre crops				
Cotton	4-5	-	2-3	1.0-1.5
Sisal (fibre)	-	2-3	-	1.5-2.0
c) Sugar crops				
Sugarcane	120-150	-	70-100	-
Sugarbeet	50-60	30-40	40-45	20-30
d) Pulses and oilseed crops				
Beans (dried)	6-8	-	1.0-1.5	0.5-1.0
Soybean	2.5-3.5	1.5-2.5	1.5-2.5	0.8-1.3
Groundnut (unshelled)	3.5-4.5	2-3	1.5-2.0	1.0-2.0
Sunflower	2.5-3.5	1.5-2.5	1.5-2.0	0.8-1.5
Safflower	3-4	1.5-2.5	1.5-2.0	0.8-1.3
e) Vegetable crops				
Onion	35-45	-	10-20	5-10
Pepper (fresh (fruit)	20-25	-	10-15	5-8
f) Stimulent crops				
Coffee (clean hulled beans)	-	1.0-2.0	-	0.5-1.2
Tea (processed)	-	1.5-2.0	-	0.8-1.2
Tobacco (air-cured leaves)	3-4	2.0-2.5	1.5-3.0	1.0-1.5
g) Fruit crops				
Banana	40-60	-	35-50	15-25
Orange	25-40	-	20-30	10-20
Grape	20-30	-	10-15	5-10
Pineapple (fresh (fruit)	40-50	25-35	30-40	20-25
h) Tubers				
Sweet potato	40-50	20-25	12-18	5-10
Cassava	40-60	-	25-35	15-20

7.4 Calculating the extent of map units

The land resource survey reports describe each map unit in terms of the characteristics of major and minor component soils (or land types) along with the areal extent of the map unit within the surveyed area, as well as the proportion of each component soil (or land type) within the map unit. It is, however, rather common that the land resource survey carried out for any land development project covers larger area than which is finally selected for development and that the boundaries of the area surveyed rarely coincide with those of the area to be developed. As a result, the extent of different map units falling within the project area is to be recalculated.

The traditional methods of calculating area with the help of a planimeter or using transparent graph/square or dotted papers gives only rough estimates. An alternate method of weighing the map cuttings of each unit and multiplying the weight with the area per unit weight of the map has been found relatively accurate and convenient. The area per unit weight of the map is obtained by dividing the known area of a square cutting from the map by its weight. For example, a square cutting of 10cm x 10cm from a map of 1:50,000 scale covers an area of 25 sq km and if it weighs, say, 12.5 grams, the area per gram is 0.5 sq km or 50 ha, which would serve as the multiplication factor for all mapping units. The accuracy of the method depends much on the uniformity in thickness and weight of the paper used for the map to be cut and, of course, in precision of cutting and weighing. Generally, a weighted average of two to three squares cut from different parts of the map is taken to minimise the errors caused due to a non-uniform paper. All the map unit and square cuttings should be stored under the same environmental (moisture and temperature) conditions until these are weighed, which should be done at the same time.

7.5 Calculating the physical area of map units for a high-relief terrain

A common problem encountered in calculating the physical (or land surface) area of a map unit in Ethiopia is that almost no extensive tract of land is a flat terrain. The maps are, however, to be constructed on the basis of straight horizontal distances between any two points while the curved surfaces occurring in a non-flat area would always cover more area than the flat surfaces considered for map preparation. For example, a map unit consisting of a ridge which has smooth surfaces forming 60° angles with the horizontal on all sides will cover a distance from its one end to the other opposite end which is about twice that actually measured from the map, while its actual surface area, i.e. the "Physical area" as the term used here, will be roughly four times the "Map area", i.e. the area calculated from the map. It obviously implies that the maps can not be used directly to calculate the "physical area" of a map unit representing a ridgy or hilly terrain. However, the topographic maps showing contour lines at reasonably short intervals may help in arriving at a rough but more appropriate calculation of the area as follows:

i) Calculate the **"Map area"** (the area represented on a map) of the unit by one of the methods discussed above;

ii) Calculate average slope of the map unit by dividing the elevation difference with the distance between the highest and the lowest points separately for its width and length directions;

iii) Considering the slopes as tangents of the slope angles, find out the slope angles by means of a scientific calculator;

iv) Find out cos values of the slope angles determined;

v) Multiply together the cos values obtained for the length and width directions, and divide the "map area" with this factor; this gives the **"Physical area"** of the map unit.

The above may be illustrated by an example as follows:

Suppose a map unit measured 1.2km x 0.5km on the map has an elevation difference, from its two opposite ends to the centre, of 300m in the length direction and of 150m in the width direction. Then the slopes along its length and width directions may be calculated as 300/600=0.5 and 150/250=0.6, converted into slope angles ($\tan^{-1}$ of 0.5 and 0.6) as 27° and 31° respectively. By dividing the calculated "map area" of $0.6km^2$ (or 60ha) with the mutual multiplication of cos27°(=0.89) and cos31°(=0.86), the "physical area" of the map unit will be $0.6/(0.89 x 0.86)=0.8km^2$ or 80ha.

The area calculation from a land resource survey map is, however, relatively easy and would be more accurate since the slope data are already available for each map unit and need not be estimated from the contour lines as above. The map unit composition also allows using the weighted average slopes in case of complex units, which is not possible from the topographic maps. The remaining procedure of calculations remains the same as from the topographic maps.

It may be somewhat cumbersome if every delineation of a map unit is recalculated. A rather straightforward way of doing it would be to take average slopes of the units, or of the project area if it does not differ much for its various map units, and make corrections for the relevant units by making only a few calculations. Such exercise would, however, be necessitated only when the slopes exceed about 10 percent and the project area is very large mapped at a small scale.

EXERCISE IN CALCULATING THE GROUND DISTANCE BETWEEN TWO POINTS LOCATED IN A SLOPING SURFACE FROM A MAP

Question: Two points **A** and **B** having elevations of 4,500m and 4,200m respectively are located 8cm apart on a topographic map of scale 1:15,000. Calculate their actual distance on the ground.

Solution:

Difference in elevation of A and B = 4,500-4,200 = 300m
Map scale 1:15,000 implies that:
1cm on the map = 150m on the ground
Distance measured from the map = 8x150 = 1,200m
Slope (tan of the slope angle) = 300/1,200 = 0.25
Slope angle in degrees = $\tan^{-1}0.25 = 14^{\circ}$
Cos 14° = 0.97
Actual distance on the ground = 1,200/0.97 = **1,237m**

7.6 Calculating the extent of suitable land

It is uncommon, except for very high intensity (very detailed) surveys, that a map unit delineated on any land resource map consists of only one land suitability subclass/unit. Whereas the map units indicated on reconnaissance and semi-detailed survey maps are mainly the associations/complexes or undifferentiated groups (see Section 4 for definitions), those of the detailed surveys also often include a certain proportion of land having different suitability than when their major components have. In any case, the composition of each map unit in terms of different land suitability subclasses (or in terms of different kinds of soils, evaluated for land suitability in a separate table) occurring in any area surveyed for a development project is generally indicated in the survey reports, both as their percentages within a specified map unit and as hectarage within the unit and project area.

Many scientists involved in the feasibility studies regard a soil map unit as consisting of one class or subclass of land suitability and make their calculations on the same basis. While it may be quite practical to consider a map unit as uniform for certain purposes, like estimating the required length of irrigation or drainage channels and farm roads, most calculations like the land levelling and vegetation clearance costs, irrigation water requirements and net returns from the land use (or net farm income) etc., require treatment of each component of the map unit separately. For example, a map unit having 40 percent of the land classified as S1, 30 percent as S2, 10 percent as S3 and the remaining 20 percent as N1 or N2 would be considered suitable for irrigation development, but the land development activities would not be undertaken on the 20 percent N1/N2 land (representing, say, gullied land or rock outcrop) or, if done, would involve exceptional costs. On the other hand, the returns in terms of production would come mostly from 70 percent of the area comprising S1 and S2 lands (since the returns are unassured from S3 land). Furthermore, the returns from S1 and S2 (and S3) lands would be differently calculated due to differences in their input costs and productivty indices. Such factors must be taken into account while estimating the costs and benefits from the development of compound map units.

A simple way to estimate the returns from the use of a compound map unit is to calculate their weighted averages in terms of land productivity indices. Using the mid-values of the indices proposed for Ethiopia under Table 2, the weighted average land productivity index for the map unit quoted as example above would be calculated as in Table 6.

Table 6: Calculation of weighted average LPIs for a map unit

Land suit. class	Percent	L.P. Index (%)	Wtd. Av. LPI (%)
S1	40	90	36 (90x0.4)
S2	30	65	20 (65x0.3)
S3	10	35	3 (35x0.1)
N1+N2	20	0	0 (0x0.2)

Weighted average LPI of the map unit = 36+20+3 = 59% or 0.59

EXERCISE IN CALCULATING THE EXTENT OF SUITABLE LAND AND NET INCREMENTAL PROJECT BENEFITS

Question:

A tract of land covering 250ha is proposed to be developed for commercial production of coffee. The semi-detailed land resource survey of the area resulted in evaluation of the land in the form of three compound land suitability map units recognized as A, B and C. These units cover 40%, 30% and 30% of the project area, respectively, and are described to have the following composition:

Land suit. class	Percent area occupied by: Unit A	Unit B	Unit C
S1	55	10	5
S2	15	50	15
S3	20	25	50
N1	6	10	10
N2	4	5	20

It is proposed that only the map units which comprise more than 50% of moderately and/or highly suitable land would be developed and used for coffee production at a medium level of inputs. An average annual yield of coffee grown on a highly suitable land of the nearby farm at medium level of inputs, with the average annual cost of production being EB850/-, is reported to to be 1.2 tons of hulled clean beans. The estimated annual equivalent value of the common project costs is EB650/ha, while the annual equivalent value of the area-specific costs for map units **A**, **B** and **C** are EB300/ha, EB500/ha and EB800/ha respectively. At present, the average yield from coffee on the prospective development area is 0.4 tons per ha while the average value of inputs made is EB250/ha. Estimate the total Net Incremental Project Benefits for a year of full development after implementation of the project, assuming the local market rate of coffee beans as EB10,000 per ton and using the land productivity indices for the land suitability classes S1, S2 and S3 as 90, 70 and 40 percent respectively.

Solution:

Total project area = 250ha
Area under Unit **A** = 0.4x250 = 100ha
Area under Unit **B** = 0.3x250 = 75ha
Area under Unit **C** = 0.3x250 = 75ha

Map units with >50% component of S1+S2 land:
Unit **A** = 100ha
Unit **B** = 75ha
Total area to be developed = 175ha

Annual equivalent value of common costs =
175x650 = EB113,750

Annual equivalent value of area-specific costs =
100x300+75x500 = EB67,500

Total development costs = 113,750+67,500 = EB181,250

Gross annual value of "with-project" coffee production:

a) from S1 land =
0.9x1.2x10,000x(0.55x100+0.1x75) = EB675,000

b) from S2 land =
0.7x1.2x10,000x(0.15x100+0.5x75) = EB441,000

Total from S1 and S2 lands = EB1,116,000

Total "with project" production costs = 850x175
= EB148,750

"With-project" Net Farm Income = 1,116,000-148,750
= EB967,250

Gross annual value of "without-project" coffee
production = 175x0.4x10,000 = EB700,000

Total "without-project" production costs = 250x175
= EB43,750

"Without-project" Net Farm Income = 700,000-43,750
= EB656,250

Net Incremental Farm Income = 967,250-656,250 = EB311,000

Net Incremental Project Benefits = 311,000-181,250
= EB129,750

7.7 Counting the risk factor

The agricultural production from any class of land is determined, apart from its inherent or modified characteristics and management or input factors, by several unforseen natural as well as human factors such as unusually too wet or too dry weather conditions, hail/wind storms, locust or bird attacks, unexpected low viability of seed, abnormal effects of pesticides, irregularities in the water supply system, etc. To be realistic in estimating the value of agricultural production, such factors must be duly considered. In the newly introduced agricultural systems, as is normally the case with most land development projects, significant reductions in crop yields may be effected due to these factors alone.

Considering the conditions prevalent in Ethiopia, it may be suggested that the yield estimates for one out of every five years be reduced by 50 percent for class S1 lands, 60 percent for class S2 lands and 80 percent for class S3 lands (the risks are commonly higher for lower classes). With these considerations, the 5-year averages of the proposed Land Productivity Indices for different land suitability classes in Ethiopia may be degraded as in Table 7.

Table 7: Degrading LPIs for Ethiopia due to risk factor

Land suitability class	Land Productivity Index			
	Range		Mid-value	
	Percentage	Fraction	Percentage	Fraction
S1	74-90	0.74-0.90	82	0.82
S2	41-73	0.41-0.73	57	0.57
S3	18-40	0.18-0.40	29	0.29
N1	<18	<0.18	9	0.09
N2	0	0	0	0

7.8 Determining the limits of soil cut for land grading

Land grading is the most common requirement for arable land development and soil conservation projects, especially in Ethiopia. In common practice, the nature of soils are overlooked while deciding on the thickness of surface soil to be removed in the process of land grading. Many soils in Ethiopia may be rendered marginal or unsuitable if the topsoil is removed beyond certain limits. These limits vary with the soils. Not only that the agricultural productivity of such lands would be seriously affected but also the soil erosion may be greatly accelerated resulting in exposure of the rock surface and gullying problems.

In case of soils which are deep and more or less uniform in characteristics throughout the profile, which include Nitisols, Ferralsols, Regosols and Anthrosols, an indiscriminate land levelling may not do much harm except when having a mollic or an umbric A horizon. But the soils like Planosols, Plinthosols, Vertisols, Calcisols, Gypsisols and shallow phases of all soils, it may be quite disasterous, resulting in irrepairable damage to them.

The depth to which a certain kind of soil can be safely truncated for the purpose of land grading/levelling should be decided by the thickness of developed (structured) soil material above:

i) a dense or slowly permeable layer;
ii) a hard pan;
iii) bedrock;
iv) sand or gravel; or
v) a chemical barrier like highly alkaline/saline layer or sulphidic material, or a layer with abundant soft powdery lime

The minimum thickness of the developed soil material which should be retained depends on the type of use the land is going to be given to but, as a general rule, it may be regarded as 100cm in normal cases and 50cm in exceptional cases when only small patches are to be affected. In cases when the soil surface must be removed to leave behind a thickness of less than 50cm as, for example, to bring the land under the irrigation command, the land is better left ungraded and put to some alternative use.

8. THE LAND RESOURCES OF ETHIOPIA

This chapter gives a brief account of only a few aspects of the land resources of Ethiopia just to familiarize the reader with general land conditions of the country, especially in respect of its physiography and soils. The elaborated discussions on this subject are beyond the scope of this manual and require a separate publication which may be prepared at some later stage.

8.1 Physiography and geomorphology

The physiography of Ethiopia is described differently by different authors. One common basis adopted for physiographic divisions of the country by all authors is the **"Relief"**. No systematic and comprehensive account of the **"Landforms"** or **"Geomorphology"** is, however, available in the country as far as it relates to the deposition of soil parent material and soil genesis. The latter aspect has been dealt only barely in the FAO/UNDP Working Document (1983) on "Geomorphology and Soils, Ethiopia" prepared by the Land Use Plan-ning and Regulatory Department (LUPRD) of Ethiopian Ministry of Agriculture (MOA) under the project ETH/78/003.

8.1.1 Major physiographic regions

On a very broad basis, Ethiopia may be divided into the following three major regions, here referred to as **"Physiographic regions"**:

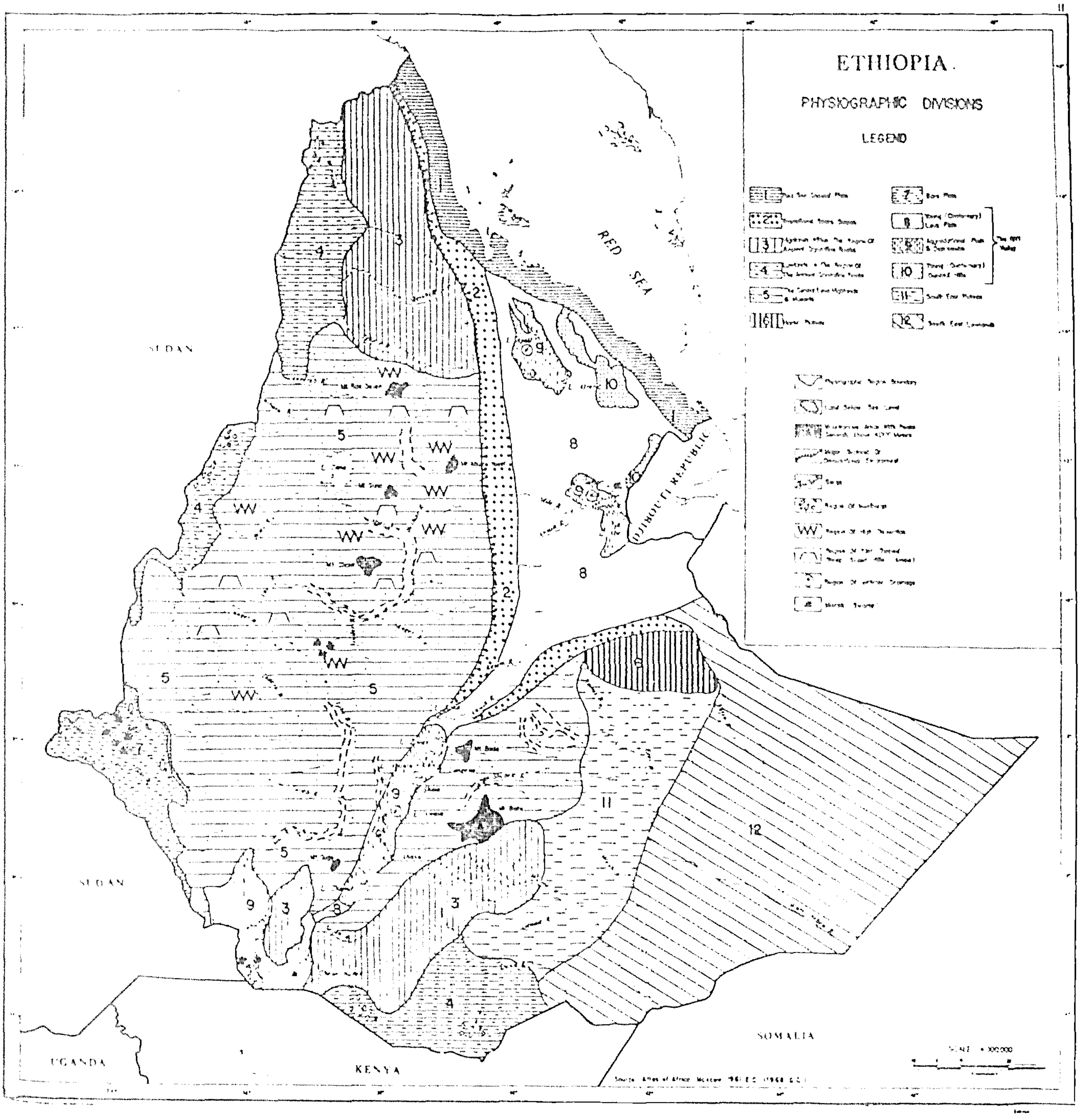
a) **The Plateaux**
b) **The Rift Valley System**
c) **The South-Eastern and South-Western Lowlands**

Whereas detailed divisions on the basis of physiography are sketched by the Ethiopian Mapping Authority (National Atlas of Ethiopia, 1981) as on Map 3, each of the above-listed region is described briefly in the following.

a) THE PLATEAUX. This region represents an uplifted land surface, commonly known as the **"Highlands"**, which covers major part of the Ethiopian territory. It has elevations ranging mostly from 1500m to 3500m (average elevations 2000-2500m) with many summits rising above 4000m and a few ones above 4500m. It occurs in the form of two large units, separated by the Rift Valley, which are discussed below.

i) The Ethiopian plateau or Western Highlands. This unit occupies about two-third of the Plateaux region and and lies towards west of the Rift Valley. It rises abruptly, forming an almost continuous escarpment, along its boundary with the Rift Valley in its eastern part but joins

Map 3


ETHIOPIA.
PHYSIOGRAPHIC DIVISIONS
LEGEND
SUDAN
RED SEA
DJIBOUTI REPUBLIC
SUDAN
UGANDA
KENYA
SOMALIA

the western and south-western lowlands with rather gradual slopes. The Plateau has many subdivisions or blocks made by gorges and steep-sided valleys of various major and minor rivers, the major ones including the **Blue Nile** (locally called as **Abay**), **Tekezze** and **Omo**. Very deep gorges occur generally along the upper courses or tributaries of these rivers. Most spectacular is the gorge of Blue Nile having its bed about 1500m below the general level of the Plateau.

Major part of the Plateau has an undulating to rolling surface but a considerable part is hilly to mountainous with numerous volcanoes and the associated landscapes (craters, vents, lava flows, etc.), rock outcrops/inselbergs and almost parallelly aligned high ridges alternating with fairly extensive alluvial valleys. The plateau is composed mostly of the Tertiary volcanic rocks in its central parts and Precambrian metamorphic rocks in the northern and south-western parts but sizable patches of Quatenary basaltic lava flows and Mezozoic sandstone rocks are also encountered mainly in the central parts. A substantial proportion of the ridges consists of mainly boulders and stones mixed with abundant soil material and gravel, which are postulated to be the Quaternary **glacial sediments.** Quite extensive patches of alluvial plains and terraces with almost flat to gently sloping surface are also encountered, while a few basins also occur, the most important of which is the **Tana Depression** marked with the **Tana Lake** - the largest water body of the country.

ii) The Somalian Plateau or South-Eastern Highlands. This is a relatively small unit of the Plateaux region which lies towards east of the Rift Valley. Similar to the other unit, it rises abruptly along its boundary with the Rift Valley and slopes towards its eastern and southern boundary so that it finally merges with the South-Eastern Lowlands. The Plateau is subdivided into several parts by deep gorges and valleys of various rivers, the most important of which are the **Wabe Shebele** and the **Genale.** The general elevation varies between 1500m and 3000m but exceeds 4000m for a few summits and drops below 1000m along its eastern and south-eastern parts.

The surface topography of the major part of this Plateau is undulating to rolling but becomes hilly to mountainous in some parts, while extensive blocks of almot flat to gently sloping alluvial plains and terraces also occur. The landforms like volcanic cones, rock outcrops/inselbergs and lava flows are found to occur also in this unit. Most of the rocks occurring in this part of the region are identified as Tertiary volcanics. High ridges comprising mainly the boulders and stones mixed with abundant soil material and gravel, which are thought to be the Quaternary **glacial deposits**, are encountered along with their associated alluvial valleys in this part too.

b) THE RIFT VALLEY SYSTEM. This region represents an extensive subsided land surface or **graben**, also recognized as the **"Central Lowlands"**, aligned in north-east to south-west direction but bifurcating towards its north-eastern part where it surrounds an area called **"Afar Triangle"**. Most of its northern part (north of the point of bifurcation) and the southern part lie between 500m and 1500m, but the northernmost being located below 500m and gradually dropping to the sea level. Some very low areas also exist in the northern part which lie below the sea level (some as low as 120m below sea level) and are identified as depressions, the most notable being **"Danakil Depression"** which is now a dried-up lake occurring as a low playa, or "salt flat" as locally described. The middle part of the Valley is relatively high with an elevation of about 1500m to 2000m. The general surface topography of this region is flat to gently undulating. However, a substantial part in the north comprises low to moderately high hills, called as the **"Afar Hills"**, which are associated with numerous deep valleys and some volcanoes rising to an elevation of about 2500m. The The extreme north-eastern part of the Valley adjoining the Red Sea consists of the almost flat Coastal plains which are formed mainly from sandy marine sediments.

The floor of the Valley is formed mainly by recent volcanic (basaltic) material with patches of lava flows and sedimentary rock material, while most of its surface is covered by alluvium consisting of lake-bed deposits (lacustrine plain) and fluvial sediments laid down by the **Awash River** and its tributaries (alluvial plains). In a few but quite extensive patches, the alluvium is found mixed with volcanic ash or ignimbrites.

A substantial part of the Rift Valley is occupied by a number of small to large-sized lakes, the important ones being **Zwai, Abiata, Langano, Shalla, Awassa, Abaya** and **Chew Bahr**. The Valley is also characterized by the presence of many hot water springs.

c) THE SOUTH-EASTERN AND SOUTH-WESTERN LOWLANDS. This region, also called as **"The Outer lowlands"**, includes:

i) The eastward dipping part of the South-Eastern Highlands, known as the **South-eastern lowlands** or **"Ogaden desert"**;

ii) The **Southern lowlands** located south of the South-Eastern Highlands; and

iii) The **South-western lowlands**, which comprise the"**Baro-Akobo basin**" in the upper parts and the "**Omo basin**" in the lower parts, lying towards south-west of the Western Highlands.

This region lies below an elevation of 1500m and has almost flat to gently sloping topography and its surface is marked at places with scattered low hills (outcrops/inselbergs and volcanic cones etc.). It is traversed by a few rivers, the important ones being **Wabe Shebele**, **Genale**, **Weyb** and **Fafen** in the "South-eastern Lowlands", **Dawa** in the "Southern Lowlands" and **Baro**, **Gilo**,, **Akobo** and **Omo** in the "South-Western Lowlands".

The bedrock in extreme eastern part of the South-eastern lowlands belongs mostly to Tertiary sediments and that in its western part comes from the Mesozoic sediments, while the surface of the lowlands is covered mainly by alluvial deposits (alluvial plains) and partly by aolian sediments (aeolian plains). The Southern and South-Western Lowlands comprise mainly the Quaternary alluvial sediments (alluvial plains) of varying thickness. Extensive patches marshes and swamps form a special feature of the SouthWestern Lowlands.

8.1.2 Physiographic classification by LUPRD

The physiographic divisions considered by LUPRD were based mainly on delineation of **Landscape units** (defined as the tracts of land having specific recurrent patterns of landforms, soils and vegetation/land use) by manual/visual interpretation of Landsat imageries. The "landscape units" were then analysed to differentiate various **Significant land facets** (genetically linked, more or less homogeneous, subdivisions of the landscape units), which led to recognition of 12 divisions reflecting the general physiographic character of 'landforms'. Each of these 'landforms' was considered for subdivision, where applicable or possible, on the basis of their genesis. The recognised 'landforms' and their subdivisions used for mapping of "Geomorphology and Soils", as well as the major characteristics and areal extent (in km^2 indicated within parenthesis) of different components of each subdivision, are listed in the following.

1. **Wetland:**

a. Alluvial landforms
- Permanent fresh water swamps and marshes (2,400)

b. Evaporite landforms
- Brackish playa lakes and marshes (3,610)

2. **Seasonal wetland and seasonally waterlogged land:**

a. Alluvial landforms
- Seasonal swamps and marshes (5,200)
- Deltas and lakes (420)
- Basins/depressions (5,820)
- Major rivers and meander belts (9,630)
- Alluvial plains (2,080)
- Seasonally dry river channels (10,240)
- Lacustrine/fluvio-lacustrine plains (1,150)

3. **Plains and undulating sideslopes:**

a. Alluvial landforms
- Alluvial plains (4,050)
- Alluvial/colluvial slopes and fans (67,270)
- Alluvial fans and 'bajadas' (16,880)
- Volcano-lacustrine plains (2,740)
- Lacustrine/fluvio-lacustrine plains (2,130)
- Coastal margin plains (1,730)

b. Volcanic landforms
- Low volcanic plains and piedmont zones (7,390)
- Plains and low plateaux (3,680)
- Lava platforms and plains (14,400)

c. Residual landforms
- Undulating sideslopes and piedmont zones (82,590)
- flat to undulating lowland plains and low plateaux (111,100)
- Uplifted reefs (1,660)

4. **Plains and low plateaux with hills, moderately dissected sideslopes and dissected plains**

a. Alluvial landforms
- Eroded residual landforms and fans (9,710)

b. Volcanic landforms
- Dissected volcanic piedmont plains, lava platforms, cones, vents and craters (12,780)

c. Structural landforms
- Step faulted plains and low plateaux with fault scarps and sags, etc. (2,120)
- Low hills and valleys (270)

d. Residual landforms
- Undulating to rolling lowland plains/ plateaux, partly with dissected lava plains and rock outcrops (85,910)
- Dissected sideslopes and piedmont zones (38,620)
- Undulating plains and low plateaux with low to moderately high hills (43,660)

5. Hills with plains

a. Volcanic landforms
- Volcanic cones, vents and craters etc. (9,190)

b. Structural landforms
- Faulted lava fields and platforms/horsts with infilled grabens (17,180)

c. Residual landforms
- Low to moderately high hills and valleys (52,100)

6. Low to moderate relief hills

a. Structural landforms
- Parallel ridges with valleys & fault sets (9,260)
- Faulted lava platforms (8,550)

b. Residual landforms
- Gently sloping rises and low plateaux (790)
- Low to moderately high hills (42,740)

7. Moderate to high relief hills, severely dissected side-slopes and plateaux

a. Volcanic landforms
- Dissected, steep sideslopes of volcanoes with small cones and vents (4,380)

b. Structural landforms
- Dissected rift margins and fault scarps (1,710)
- Parallel ridges with valleys & fault sets (35,030)

c. Residual landforms
- Dissected sideslopes and piedmont zones (24,650)
- Dissected plateaux with mod. high hills (270)
- Minor river gorges and ravines (5,170)
- Moderate to high hills (102,470)

8. High to mountainous relief hills

a. Volcanic landforms
- Volcanoes and related high-relief forms (27,820)

b. Structual landforms
- Parallel ridges & valleys with fault sets (22,990)
- Major river gorges (2,580)

c. Residual landforms
- Mountainous ridges (55,930)
- Mountainous ridges with sloping valleys (800)
- Major river gorges, canyons and escarpments (104,690)

9. High plateaux

a. Volcanic landforms
- Undulating high plateuax formed on pyroclastic deposits (11,250)
- High volcanic piedmonts and lava plateaux (14,020)
- Volcanic sideslopes and piedmonts (16,190)
- Plateau summits with volcanoes (1,140)

b. Structural landforms
- High benches/terraces/plateaux with major river gorges (1,040)

c. Residual landforms
- Undulating to rolling high plateaux (9,570)

10. Moderately dissected plateaux, plateaux with hills and rolling to hilly plateaux

a. Volcanic landforms
- Dissected volcanic plateaux (2,160)
- Volcanic cones, vents, craters, plugs and piedmont plains etc. (1,510)
- Dissected volcanic sideslopes with other volcanic relicts (13,920)
- High volcanic piedmonts and lava plateaux (4,700)

b. Structural landforms
- Step faulted rift margin plateaux (1,900)
- Linear ridges with parallel valleys (830)

c. Residual landforms
- Rolling to hilly plateaux (29,380)
- High plateaux with hills and seasonal marshlands (3,770)
- Undulating high plateaux with hills (5,130)

11. Rubble land and rock outcrop

a. Volcanic landforms
- Dissected lava and rock outcrops (4,370)
- Young lava flows (11,960)

12. Sand and salt deposits

a. Aeolian landforms
- Sand dunes & salt-encrusted sand deposits (1,910)

b. Alluvial landforms
- Basins with alluvial, colluvial and evaporite deposits (2,340)

c. Evaporite landforms
- Playas and salinas (3,720)
- Evaporite pediments with alluvial/ colluvial deposits (970)

It may be realized that the physiographic divisions made as above can not rightly be called as "landforms" but are rather the "landscape units" of which different landforms (or geomorphic units) are only the components. Whereas the same landforms repeat in different landscape units, their continuity, as well as the continuity of the related soils, is understood to be frequently interrupted by the landscape unit boundaries. But mapping in that fashion was probably the best choice in view of the base map used (Landsat images), the available image interpretation facilities and the adopted small mapping scale.

8.3 Climate

The climate of Ethiopia is strongly dependent on elevation, with respect to both the temperature regimes and the moisture regimes. These two major components of the climate are discussed separately, as described in the "Agroclimatic Resources Inventory for Land Use Planning" by Land Use Planning and Regulatory Department (LUPRD, 1984b), in the following.

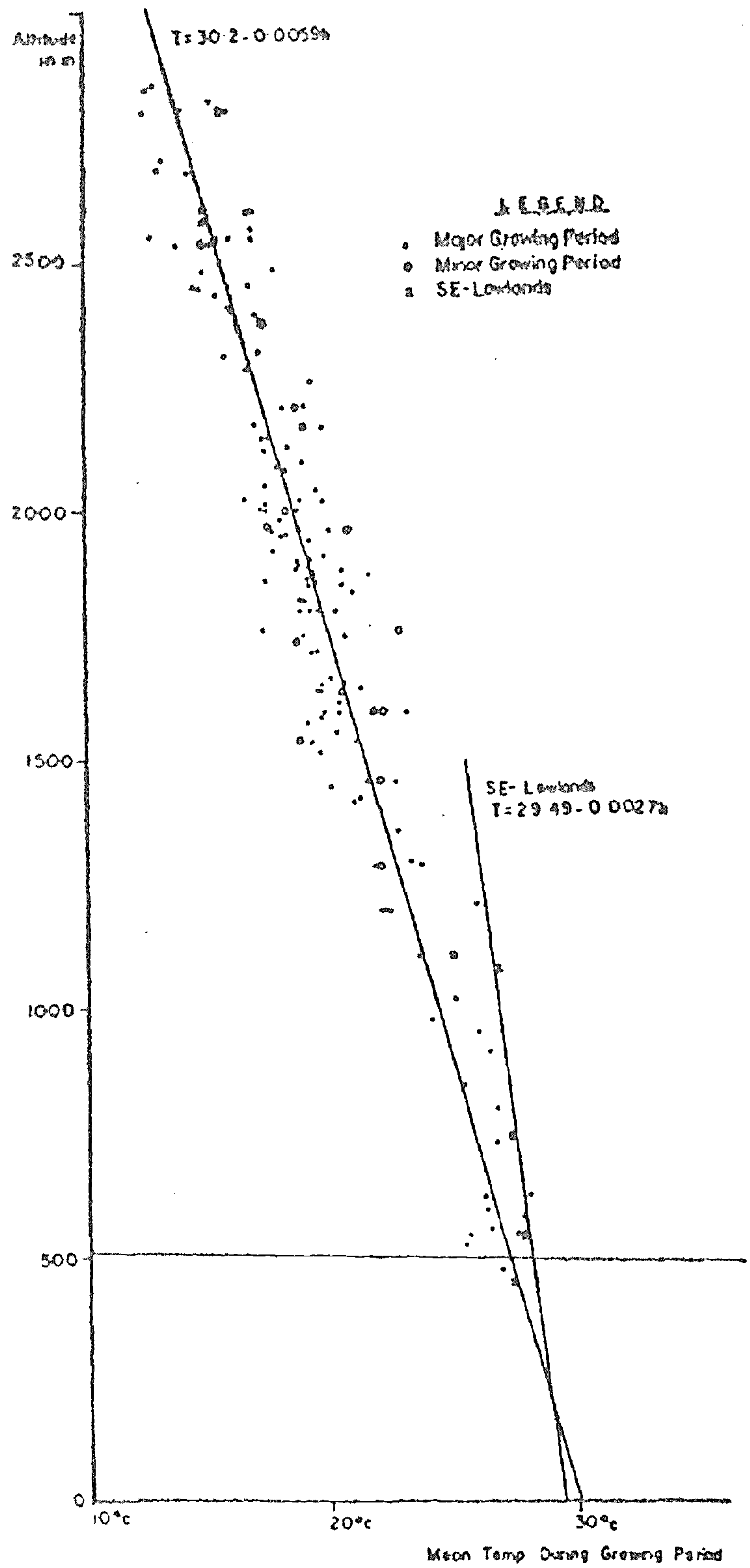
8.3.1 Temperature

An almost direct relationship exists between the elevation and temperature as follows (See also Fig 20:

$T = 30.2 - 0.0059h$ (for all parts of Ethiopia except the South-Eastern Lowlands)

$T = 29.5 - 0.0027h$ (for South-Eastern Lowlands)

FIG. 20: VARIATION OF THE MEAN TEMPERATURE DURING GROWING PERIOD WITH ALTITUDE ASL.



According to variations in temperature, **ten Thermal Zones** are identified as defined below in terms of the mean annual temperature (during the growing period), along with the altitudinal range of each Zone:

Thermal zone	Altitudinal range (metres)		Mean temperature (°C)
	SE Lowlands	Other parts	
Zone 1	150 - 700	150 - 450	> 27.5
Zone 2	700 - 1250	450 - 900	25.0 - 27.5
Zone 3	1250 - 1800	900 - 1300	22.5 - 25.0
Zone 4	-	1300 - 1750	20.0 - 22.5
Zone 5	-	1750 - 2150	17.5 - 20.0
Zone 6	-	2150 - 2600	15.0 - 17.5
Zone 7	-	2600 - 3000	12.5 - 15.0
Zone 8	-	3000 - 3400	10.0 - 12.5
Zone 9	-	3400 - 3850	7.5 - 10.0
Zone 10	-	3850 - 4550	< 7.5

The distribution of these Thermal Zones is indicated on Map 4.

In addition to the "Thermal Zones" defined above, different **Temperature Regimes** have been recognized for a better understanding about the seasonal fluctuations of temperature in the country. The distribution of these temperature regimes is indicated on Map 5 while the various codes used as map symbols are defined as follows:

F Mean temperature drops
R Mean temperature rises
FR Mean temperature drops followed by mean temperature rises
RF Mean temperature rises followed by mean temperature drops

I Temperature change by < 5°C
II Temperature change by 5 - 10°C
III Temperature change by > 10°C

w Dry period warmer than major annual growing period
c Dry period cooler than major annual growing period
d Period with mean temperature < 5°C; regarded as dormant period if occurring within the growing period

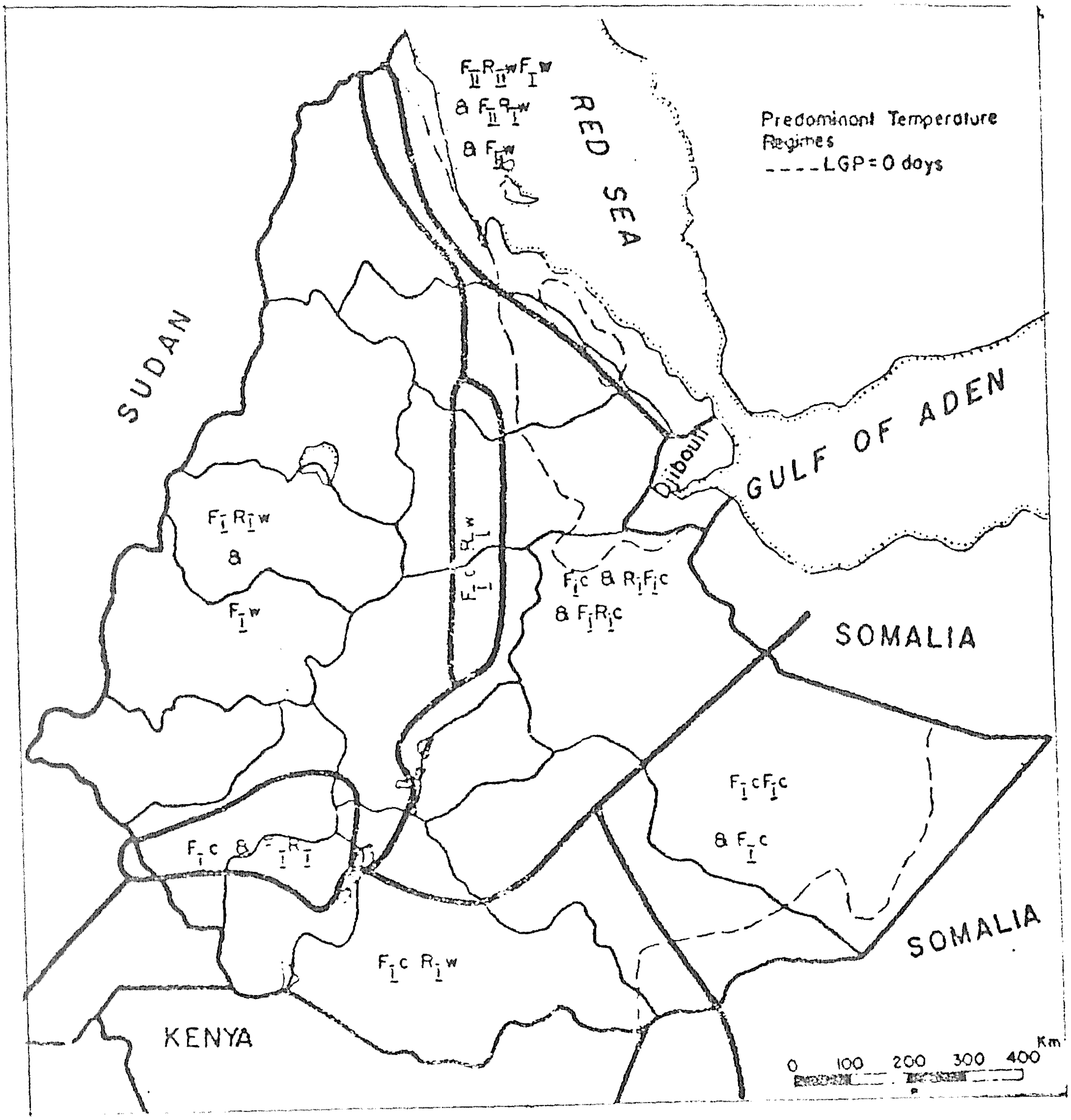
8.3.1 Rainfall

Three different mechanisms are considered to be responsible for bringing rainfall in different parts of Ethiopia i.e., **the summer monsoon, the tropical easterlies** and the **local convergence** in connection with the land-sea-wind systems over the red sea. The detailed discussion about the rainfall petterns is beyond the scope of this manual; the reader is referred to the publication cited above (LUPRD, 1984b) for that purpose.

Map 4


ETHIOPIA
GENERALISED THERMAL ZONES
THERMAL ZONES
10
9
7-8
5-6
3-4
1-2
RED SEA
GULF OF ADEN
DJIBOUTI
SUDAN
SOMALIA
SOMALIA
UGANDA
KENYA

Map 5: DISTRIBUTION OF TEMPERATURE REGIMES IN ETHIOPIA



The annual amount of rainfall in the country varies from less than 200mm in the extreme south-eastern and extreme north-western low land parts to over 2,000mm in the central highland parts lying above about 3,000 metres amsl. The distribution of mean annual rainfall in the country is indicated on Map 6.

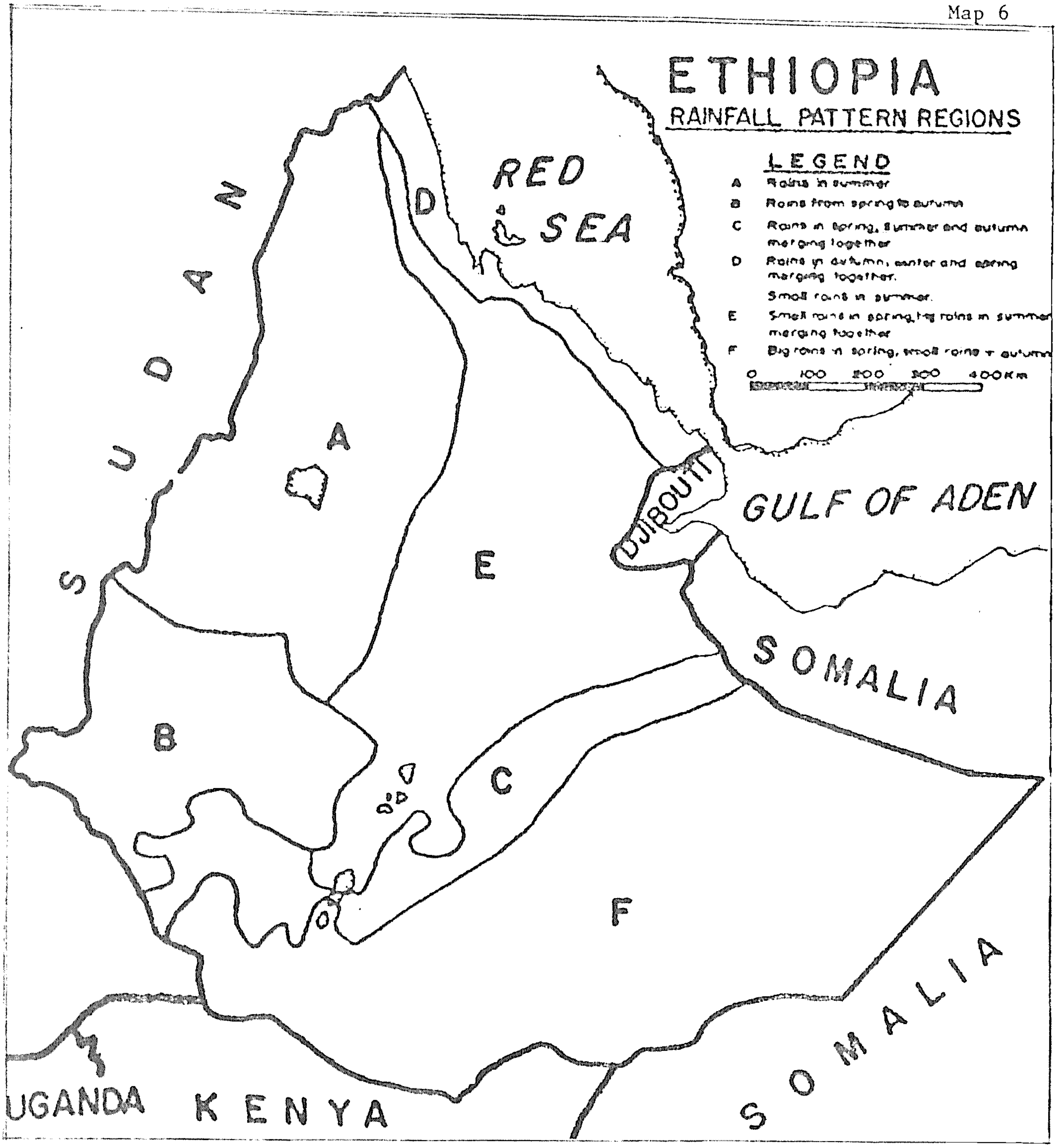
8.3.3 Agroclimatic zones

The Community Forests and Soil Conservation Department of Ethiopia in their publication "Soil Conservation in Ethiopia" (CFSCDD, 1986) have divided the country into **11 Agroclimatic Zones** based on the altitudinal range and rainfall as defined below:

Agroclimatic Zone	Altitudinal Range (masl)	Annual rain-fall (mm)
High Wurch	>3,700	>1,400
Wet Wurch	3,200-3,700	>1,400
Moist Wurch	3,200-3,700	900-1,400
Wet Dega	2,300-3,200	>1,400
Moist Dega	2,300-3,200	900-1,400
Wet Weyna Dega	1,500-2,300	>1,400
Moist Weyna Dega	1,500-2,300	900-1,400
Dry Weyna Dega	1,500-2,300	<900
Moist Kolla	500-1,500	900-1,400
Dry Kolla	500-1,500	<900
Berha	<500	<900

This above zonation is, of course, just too simple and is not presented on any map. It is primarily designed to provide guidance to the Development Agents, generally possessing a low level of technical knowledge, in soil conservation activities undertaken in different parts of the country. It may serve a good purpose to that end; otherwise the climatic variations are significant within the limits of a Zone, which are effected by vegetation cover, land use, slope aspect, wind direction, etc., which must be studies for specific local conditions prevailing in the project areas.

Map 6


ETHIOPIA
RAINFALL PATTERN REGIONS
LEGEND
A Rains in summer
B Rains from spring to autumn
C Rains in spring, summer and autumn merging together
D Rains in autumn, winter and spring merging together.
Small rains in summer.
E Small rains in spring, big rains in summer merging together
F Big rains in spring, small rains in autumn
0 100 200 300 400Km
RED SEA
GULF OF ADEN
DJIBOUTI
SUDAN
SOMALIA
SOMALIA
UGANDA
KENYA
A
B
C
D
E
F

8.4 Soils

The soil resource data reported in the FAO/UNDP Field Document 3 of Project ETH/78/003 titled "Geomorphology and Soils" (LUPRD, 1984) indicates that most of the Major Soil Groupings recognized by FAO occur with varying extents in Ethiopia. The important ones, with a few minor adjustments of renaming according to the Revised Legend of the World Soil Map (FAO,1988), are grouped hereunder in order of their relative values for agriculture, along with their approximate extent (in percent of the total country's area).

a)	Soils with very high agricultural value:	Phaeozems (2%) Andosols (1%)
b)	Soils with high agricultural value:	Nitisols (12%) Cambisols (11.5%) Fluvisols (6%) Luvisols + Lixisols* (6%)
c)	Soils with moderate agricultural value:	Alisols + Acrisols (3%) Vertisols (10%) Calciosols + Gypsisols (3%)
d)	Soils with low agricultural value:	Solonchaks (7%) Regosols + Arenosols(4.5%)
e)	Soils with almost no agricultural value:	Leptosols (18%)

* The Lixisols have a moderate agricultural value but have to be listed together with Luvisols because of the former being a new Major Soil Grouping recognized by FAO, which are understood to have been mapped along with the latter.

The remaining about 26% of the country's area is occupied by minor soils and miscellaneous land types including rock outcrops, volcanoes, lava flows, lakes, rivers, gorges, escarpments, etc.

The main characteristics which are diagnostic for differentiation of these soils are outlined in the following.

Fluvisols: Stratified (undeveloped) soils of the river plains with varying textures and an irregular organic matter distribution

Regosols: Soils formed from loose, loamy to clayey materials with little structural development but showing no fluvic properties and with no diagnostic horizon other than an ochric/umbric A, and lacking salic/gleyic properties

Arenosols: Soils similar to Regosols but formed from coarse textured materials and having no diagnostic horizon except orchric A or Albic E

Andosols: Dark coloured soils formed from volcanic materials, loamy to clayey, mainly with a granular topsoil and a weakly developed profile (a cambic B horizon) with an ochric, mollic or umbric A horizon and no salic horizon

Vertisols: Widely and deeply cracking, tough clayey (with 30% or more clay) soils with a fine to very fine blocky topsoil, showing intersecting slickensides or wedge-shaped/ parallelepiped structural peds; may or may not have gilgai relief

Cambisols: Weakly developed (a cambic B horizon), brown to reddish brown coloured soils of varying textures, mostly sloping and stony/gravelly, with a low (<50%) base saturation, lacking salic/gleyic properties; may have ochric, mollic or umbric A horizon

Calcisols: Brown to dark greyish brown soils with varying textures showing lime accumulation (calcic or petrocalcic horizon) in subsoil and with no other diagnostic horizon except an ochric A and cambic or argic B, and lacking salic/gleyic properties

Gypsisols: Similar to Calcisols but showing accumulation of gypsum instead of lime (gypsic or petrogypsic horizon)

Solonchaks: Saline/severely saline soils having salic but not fluvic properties and no diagnostic horizon except an ochric A, cambic B and calcic or gypsic horizons

Phaeozems: Dark coloured, loamy to clayey soils with a thick granular topsoil (mollic A horizon), no calcic, gypsic, natric or ferralic horizon and with a high (>50%) base saturation

Luvisols: Brown to reddish brown, loamy to clayey soils having accumulation of clay in the subsoil (argic B horizon), having high CEC (24 cmol/kg or more) of clay fraction and high (>50%) base saturation, lacking a mollic horizon, an abrupt textural change and properties diagnostic of Nitisols

Alisols: Soils similar to Luvisols except having a low (<50%) base saturation

Lixisols: Soils similar to Luvisols except having a CEC of less than 24 cmol/kg of clay

Acrisols: Soils similar to Lixisols except having a low (<50%) base saturation

Nitisols: Very deep clayey soils similar to Luvisols but with shiny fine blocky structural peds and no significant (>20%) decrease in clay content from maximum within 150cm depth, having gradual or diffuse horizon boundaries and lacking ferric or vertic properties

8.5 Land resource development strategies

Any systematic land resource inventory which could allow objective assessment of the agricultural land resources of Ethiopia is not currently available. The kinds of soils occurring in the country, though arbitrarily evaluated as in the preceding section, the suitability of any soil for a specific land use type, and even for a major kind of land use, can not in fact be properly assessed without considering some additional characteristics not diagnostic for soil classification at the level of Major Grouping, which include slope, erosion, drainage, stoniness, etc. The soils within each Grouping may vary in suitability from **S1** to **S3**, or even to **N**, when further classified at the levels of Soil Units/Subunits and especially of phases. But detailed discussions about the Ethiopia's soils at these levels is beyond the capacity of this manual.

It may also be pointed out that the soil classification made by LUPRD needs updating, not only beacuse the FAO-UNESCO's Legend for Soil Map of the World has been revised but also that studies conducted by the author in an area covering about half a million hectares of the Ethiopian highlands reveal that soils had not been properly characterised for the previous studies. Whereas most of the said area was mapped as having mainly Nitosols, Vertisols and Cambisols, not a single soil profile out of many studied could qualify for Nitosols (now renamed as Nitisols) and the extent of Vertisols and Cambisols was too little to allow delineation of any one unit on the map of 1:250,000 scale where such soils could be predominent.

The author did have a fair chance to get a general impression about the agricultural development possibilities in the country but in not more than about half a part of it. Unfortunately, the persistent tense political situation throughout his assignment period with FAO kept mobility of the author much restricted, especially to the northern, western and extreme eastern parts. The field experience so far gained while studying various agricultural projects, mostly related to irrigation development, leads the author to part with the following ideas regarding the current strategies adopted for development of the country's land resources through irrigation and soil conservation, and proposals for improvement of investigations to be made and alternative development strategies.

8.5.1 Irrigation development

Despite having an extensive land resource, in respect of both the soils and the climate as well as of the water for irrigation, the country has so far been incapable of being self-sufficient in even the food. Obviously, inefficient use of the resources is the basic reason. A major constraint to their potential use relates to tapping of the huge surface water resource for irrigation purposes. The efforts currently being made in that direction are based on the "engineers approach" in which the selection of areas for irrigation is primarily done by the engineers considering mainly the commandability of the areas with respect to location and topography, supported by some data on present land use, while the suitability of land for sustained irrigated use is either not assessed at all or done at a much later stage when the land development plans have already been finalized and a substantial investment has been made. Virtually all irrigation development plans are decided on the engineers choice. Consequently, most of the land so far selected has at the most a moderate degree of suitabilty for irrigated agriculture and a considerable part of it is either not suitable or only marginally so. It may also be mentioned here that two of the 15 irrigation project areas studied by the author so far, after heavy investments in terms of topographic and dam surveys had already been made in one of the areas, were found unsuitable and had finally to be dropped out of the irrigation plan.

An unfortunate happening with the country is that most of the land area comprising the old alluvial terraces and plains, which is assessed as highly suitable for agricultural development lies just above the level of its commandability by normal river diversions. But there certainly exist the possibilities of bringing a significant part of the areas under irrigation command through small dams, which may timely look to be a much costly affair but has ultimately to pay back many times. A systematic investigation to locate such tracts of land by making use of the remote sensing data should be placed at the highest priority.

8.5.2 Soil conservation

Major part of the Ethiopian territory is constituted by sloping to very steep land having soil cover of varying thickness, and is subject to erosivity of the high-intensity rainfalls. Major part of the land surface, which once used to be covered by thick forest and grass cover, now lies at the mercy of rains due to being deprived of its protective vegetative cover. A substantial proportion of such land has been almost completely denuded and has now reached a point of no return. These parts include mainly two types of land i.e., that which has virtually lost all of its soil cover and can not be rehabilitated by any means, and that which retains thick soil cover but is so intricately dissected by gullies that its protection would not be practical so that any investments made on it would prove futile; in fact, the acceleration of erosion on the latter kind of land would result in the development of very productive alluvial valleys in the bottom land, which should be encouraged by constructing check dams at suitable places rather than trying to stabilize the land by establishing vegetation or terracing etc.

The need to conserve the soil resources of the country should be most realized for relatively flat areas having a good soil cover and currently being under cultivation. Such areas are, however, being mostly ignored, or not given a priority, under the envisaged soil conservation plans. On the other hand, most severely affected areas are being generally exploited to conceive high investment soil conservation projects. This obviously goes in the interest of engineers but would have little impact on improvement of national economy. It must be realized that a hectare of good land currently producing, say, 8 quintals of maize can produce 4 to 5 tons of it only with a small investment on soil conservation and drainage works and a little improvement in soil management, while a deteriorated hectare of land currently yielding, say, 2 quintals of maize can produce at the best 10 quintals of it with extraordinary high investments. It is clear that the former line of action can bring about major improvements in the economy while the latter one would only be garbing on the economy. It is high time that the situation is duly appreciated and the soil conservation plans are wisely constructed to make best use of the available land resources.

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ANNEX I: GENERAL TYPES OF PARENT MATERIALS AND LANDFORMS

1. The landforms and parent materials

The term **"Landform"** is differently defined and used by different disciplines. A geologist commonly considers it as a land feature created by nature due to various internal and external geological processes and would generally speak of it mostly in context of the rocks which may be found exposed or underlying the soils, and dating back to over a million years. A common man would regard it as a kind of landscape with specific surface features. From the land resource point of wiew, however, it should be looked at for its those internal and external characteristics which are related to the formation of different soils and influencing various kinds of land use. It may, therefore, be objectively defined for agricultural land resource surveys as **a three-dimentional landscape having characteristics due to its specific kind of parent material and the natural genetic processes effected by the combined interaction of its internal and environmental factors such as geology, relief, climate, vegetation, hydrology and organism, as well as by the time.** The term parent material here refers to the unconsolidated mineral matter (inorganic materials) generated through rock weathering or other geological processes (volcanic eruptions, etc.) and the organic materials accumulated from vegetation decays, which act as the base material for soil formation.

The landform differs from the "landscape" in that the former considers both the surface and the subsurface characteristics while the latter refers to only the features which are discernable at the land surface in a certain field of view without visualizing what lies below the surface. A landscape may represent more than one landforms or only a part of one landform, and vice versa.

A clear understanding about the type of landform occurring within an area of study is the basic requirement to understand and map the kinds of soils to be encountered in the area since the two are strongly related. The landforms are also commonly referred as "**geomorphic units**" or "**physiographic units**".

Various kinds of parent materials contributing to the genesis of specific landforms may be grouped into eight main categories as briefly described below. Appropriate subdivisions of the categories are also mentioned where important.

i) **Residuum**: These are the materials accumulated due to the local (in place) weathering of rocks, not transported to any farther place ; a certain degree of movement from its original place of weathering may be allowed as long as it overlies the same type of rock.

The parent rock (the rock from which the residuum was derived) should be distinguished in terms of one or more of the following important **rock types**, as listed in FAO's "Guideline for Soil Profile Description" (FAO, 1990):

a) Acid igneous/metamorphic rocks:

Granite	Gneiss	Quartzite	Schist
Andesite	Diorite		

b) Basic igneous/metamorphic rocks:

Ultra basic	Gabbro	Basalt	Dolerite
Volcanic			

c) Sedimentary rocks:

Limestone	Dolomite	Sand stone	Quartzitic stone
Silt stone	Shale	Marl	Travertine
Conglomerate	Tuff	Pyroclastic	Evaporite
Gypsum			

ii) **Colluvium or colluvial deposits:** These are the materials which got accumulated by downslope transportation of weathered rock material mainly under the influence of earth's gravitational force; may be partly transported by water or ice.

iii) **Alluvium or alluvial deposits:** These are the materials derived from weathered rock material or from some older sediments which were transported and deposited by water. The alluvium deposited by the rivers or local streams is specified as **"Fluvium or fluvial deposits"**.

Depending on the deposition mode or the source of water depositing the material, the alluvium is differentiated as:-

River or general alluvium: the alluvium deposited by river streams originating in the far-off areas and in different types of rocks; the material is generally well sorted and of mixed mineralogy.

Piedmont or local alluvium: the alluvium deposited by the water streams/torrents originating in nearby rocks; the material is partly sorted and generally has specific mineralogy.

Lacustrine alluvium or lacustrine deposits: the material settled out of the still water of lakes at their bottoms; it is generally fine textured and saline.

Marine alluvium or marine deposits: the materials settled out of the sea and reworked by sea tides and currents, or those exposed due to recession of sea or construction of dikes; it also includes the beach or coastal deposits in the form of low ridges of sandy or gravelly textures and the lagoonal deposits occurring beyond them.

iv) **Cover sands:** These are the sandy materials transported and deposited by relaively fast winds; also called as aeolian deposits which may be specified as aeolian sand if the material is coarser than very fine sand.

v) **Loess:** These are the materials dominated by silt-sized particles which are transported and deposited by relatively gentle winds.

vi) **Volcanic ash and ignimbrites:** These are the materials originating from erruption of volcanoes which are transported and deposited by winds; the finer material (<0.05mm) is called as ash (or "fine ash" by some scientists) while the sand-sized material (0.05-2mm) is called as ignimbrites; still coarser material (>2mm) is termed as cinders.

vii) **Glacial deposits:** It is the material detatched from the weathered rock or older sediments which is transported and deposited by ice/glaciers; it is termed as drift when deposited both by the glacial ice and by the water from melting glaciers, and as till when it is deposited solely by the ice; the material is generally a heterogeneous mixture of clay, silt, sand, gravel and stones/ boulders.

viii) **Organic deposits:** These are the plant residues or decomposed/semi-decomposed organic materials accumulated in amounts to be transformed to soils e.g., **peat**, **saprolite** and **littoral deposits**.

There are also several intergrades of the above-described soil parent materials e.g., **glacio-fluvial**, **glacio-lacustrine**, **colluvio-alluvial**, **loesso-alluvial** and **residuo-colluvial deposits** which have mixed characteristics.

2. General types of major and minor landforms

No specific set encompassing all the various types of landforms encountered in different parts of the world has so far been devised. The terminologies used to describe a certain landform may also differ considerably with different scientists. However, in order to achieve the objective of providing a suitable reference material for the users of this manual, especially for those who are not soil scientists, an effort is made in the following text to list most of the important types of landforms found in the world and to briefly describe them in such commonly understood terminologies which could give a fair clue to the general types of soils found within each landform well as to its general agricultural potential.

The following general types of landforms are discussed mainly in relation to their relief, genesis and relationships with the soils and agricultural use. Whereas most of the landforms are being described at three categorical levels, i.e. **Major landform, Minor landform (or landform)** and **Land element**, the appropriate category to be selected for description of a project area depends on the detail of survey undertaken. It may also be pointed out that these categories should not be taken in absolute terms and may be considered only arbitrary and relative to the survey area. A Major Landform recognized on a large scale may may be regarded as a Minor Landform on a very small scale map (e.g., a national map) and vice versa.

2.1 MOUNTAINOUS LAND. This major landform represents steeply dissected to mountainous landscapes with very high relief. The important components of this landform in terms of minor landforms/land elements are:

a) Rock outcrops: The areas with mainly bare rock surface having little or no soil cover, which may include rocky hills or inselbergs (steep-sided, generally bare, low hills or piles of broken rock fragments/ boulders standing out within the flat land/plains), volcanic cones, craters, vents, volcanic tuff and rocky escarpments etc.

b) Colluvial slopes: Relatively gentle slopes occurring at the bases of steep slopes with a cover of the soil material accumulated by movement from the upper parts after weathering of rocks, mainly due to gravity but partly through transportation by water.

c) Residual slopes: Relatively gentle slopes not receiv- any colluvial sediments but having a cover of soils formed in residuum; the soil material is generally gravelly and stony/bouldery.

d) Scree slopes and talus cones: Very steep mountain slopes and sloping cones having a loose, unstable cover of gravel and stones with little soil material.

e) Footslopes: The landforms occurring between the mountain fronts and the valleys or plains, generally having a cover of mixed alluvial and colluvial sediments, but some parts may be completely denuded.

f) Fans and cones: The deltaic or conical formations of stony and bouldery soil material occurring at the base of mountains (cutting through the footslopes) where large gullies/rivers descending from the upper slopes touch the plains; the material is mainly the alluvium but may be mixed with drift/till or colluvium; the upper, steeper and narrower parts are referred to as cones or alluvial cones while the lower, relatively gentle slopes as fans or alluvial fans.

g) Inland valleys: The deep, steep-sided narrow alluvial valleys occurring within the mountainous land.

h) Playas: Closed basins having abundant accumulation of salts due to continual drying of saline water run-on from the adjacent rocks.

2.2 HILLY LAND: This major landform represents hilly to steeply dissected areas of moderately high relief and includes the following important minor landforms/land elements.

a) Rock plains. Hilly to rolling, mostly bare rock surfaces (may have a thin patchy cover of residual/ colluvial material) which include rock outcrops or inselbergs, lava flows, low volcanoes, craters, etc.; generally have a considerable component of almost flat to gently sloping land with alluvial, colluvial or volcanic deposits in the inter-ridge hollows/valleys; a few small fans/cones along the bases of the hills and patches of playas or salt flats may also be found.

b) Covered hill plains: Rolling to hilly ridges having a substantial cover of residual, colluvial, volcanic, alluvial or glacial/glacio-fluvial sediments which are generally mixed with stones and boulders; small fans and cones generally encountered along the bases of the ridges.

c) Moraine ridges: Rolling to hilly high ridges formed from very thick glacial deposits having heterogeneous soil material mixed with boulders, stones and gravel.

2.3 PLATEAUX. These include almost flat to rolling areas lying at high elevations, commonly with a few low hills; it may be partly dissected by gullies. The relatively flat parts of the plateaux having a considerably thick soil cover are often distinguished as terraces. The plateaux, however, may or may not have a soil cover.

This landform is described in accordance with the kind of parent material or soil cover e.g., loess plain (or loess terrace), ash plain, residual plain, alluvial terrace, rock plain (including peneplains - the almost flat to undulating, nearly bare rock surfaces created by the planation process of weathering and erosion forces). In some part of the plateaux, especially in case of loess plains, there often exist tracts of land which have been extremely eroded, leaving behind bizarre pinnacles with nominal tops as remnants of the plateau surface; these parts, where the pinnacles may be associated with some rocky hills, should be distinguished as badland.

2.4 PLAINS. These landforms represent dominantly flat to undulating/rolling areas lying at relatively low elevations. According to the type of parent material, the plains can be divided into various landforms as follows.

Volcanic plains. These are the land surfaces formed by deposition of volcanic material including ash, ignimbrites, cinders, tuff, lava flow, etc. A few low hilly parts of volcanic origin may be found. Most of the sand-sized or finer material has generally been transformed into soils. The following minor landforms/land elements should be distinguished:

a) Ash plains: Almost flat areas having more or less uniform cover of volcanic ash/ignimbrite material.

b) Volcanic footslopes: Gently sloping to steep, generally gullied, areas having varying thickness of the pyroclastic material (volcanic deposits of varying texture).

c) Volcano-alluvial plains: The plains formed by redeposition of volcanic material by water after being eroded from the adjoining ridges, generally with some admixture of alluvium.

Residual plains. These represent reasonably extensive, mountain or plateau surfaces with relatively gentle slopes which are covered (partially or fully) with the soils formed in residuum. Only the plateaux composed of easily weatherable rocks and located in humid or subhumid areas can generally develop into residual plains (The patchy residual materials occurring on the mountain slopes are not regarded as residual plains for this classification. These generally include the following important minor landforms/land elements.

a) Sloping plains: higher lying, flat to gently sloping/ undulating parts acting mainly as shedding or non-shedding and non-collecting sites for rain water and having a relatively thin soil cover.

b) Basins or troughs: Lower lying parts serving as collecting sites for rain water and having a relatively thick soil cover.

c) Rock outcrops: Almost bare rock surfaces, generally occurring in the form of low ridges.

Piedmont alluvial plains. These include gently sloping to flat land surfaces occurring below the mountain foot-slopes and alluvial fans. The plains are formed by deposition of local alluvium; the material generally has specific mineralogical composition, attributed to the local rock types, and is not well sorted. They include the following minor landforms/land elements.

a) Gravelly aprons: Gently sloping, uppermost gravelly parts of the plains formed due to the coalescence of lower parts of fans along the mountain bases; generally intersected by numerous rills and small gullies.

b) Level plains: The intermediate, relatively level parts of the plains having sediments with few or no gravel and almost no gullies but common rills.

c) Basins: The farthest, low-lying areas of the plains where water from mountain washes finally accumulates and dries out, generally depositing fine, nongravelly sediments.

d) Piedmont alluvial terraces: Almost flat to gently sloping areas resting much higher than the present courses of water streams and receiving no more fresh sediments.

River plains. These are almost flat land surfaces, occasionally occurring in the form of multi-stepped terraces, formed from the river alluvial contributed by many tributaries originating in different types of rocks or parent materials. The material is generally of mixed mineralogy and well sorted.

Those parts of the plains where river flooding and deposition is still active or has ceased only recently are commonly referred to as the Floodplains (further divided into Active, Recent or Subrecent floodplains according to the age and Meander or Cover floodplains on the basis whether the various land elements are still recognizable or have almost disappeared), while those being permanently cut off from the flooding regime, mainly due to deep incision of the rivers, are identified as alluvial terraces or river terraces.

The following important minor landforms/land elements are distinguished.

a) Active channels or riverbeds: The courses of currently active water streams; the channels may be straight, meandering (with a serpentine shape) or braided (in the form of many channels frequently separating from and joining the main channel).

b) Abandoned channels: The old courses of river channels, currently inactive but may become occasionally active, generally having sandy or gravelly sediments.

c) Infilled channels: The concave, open basins formed from infilling of old river channels, generally with fine sediments; these may be distinct (traceable by visual observation) or indistinct (traceable only through systematic study).

d) Oxbow lakes: The crescent-shaped remnants of old meandering channels, cut off from the main channel due to the change of its course; generally remaining under water (poorly or very poorly drained).

e) Meander scars: The distinct, infilled cut-off parts of the meandering channels.

f) Levees (or natural levees): The raised parts of channel banks formed from relatively coarse sediments laid down by the spilling water; generally located along both sides of a straight channel and outside the curves in case of the meandering channel.

g) Bars (also called meander bars or point bars): The sandy sediments left by the meandering (or braided) channels towards inside of their curves while cutting along and moving towards the outer curves.

h) Covered bars: The bars (or meander bars) overlain by finer sediments deposited by water.

i) Level plains: Almost flat areas beyond the levees, generally well drained and extensive.

j) Back swamps or basins: The low-lying areas of closed basins located beyond the level plains, continually receiving the left-over spill water as well as run-off water from the surrounding areas; generally having fine sediments with moderately well to poor drainage.

k) River terraces: Almost flat, generally multi-stepped, parts of the old river plains, resting much higher than the flood plains and present courses of rivers, mainly due to deep incision of the latter.

Estuary or delta plains. These plains represent the areas which occur near the sea in the form of almost flat land developed from alluvial deposits of a number of small distributaries of the river effected by their spill-over due to interception of water flow by sea tides; the sediments are generally of fine texture and severely saline.

The important minor landforms/land elements occurring are as follows.

a) Spill channels: The open basins or channels linking the plains with the river; the channels may be active, abandoned or infilled ones as described for the river plains.

b) Levees and spill flats: Almost flat areas lying in between the spill channels with some raised parts (levees) along the channel banks.

c) Basins: Relatively low-lying areas (closed basins) between and at the extremities of the spill channels.

Lacustrine plains. These are almost flat to concave land surfaces exposed from the bottom of lakes due to drying out of the latter; the sediments, being deposited by the still lake water, are generally fine and saline. The important minor landforms/land elements identified are:

a) Basin plains: Almost flat, mainly nonsaline areas, generally with medium to fine textured material.

b) Playas: Concave, severely saline areas marking the deepest parts of the lake beds.

Marine plains and terraces. These landforms represent flat to undulating land surfaces formed by the deposition/exposure of marine sediments along the sea coasts; the sediments are generally saline and have coarse to fine texture, depending mainly on the physiographic position. Relatively low-lying areas, part of which is occasionally influenced by sea tides, are referred to as plains and the high-lying, flat to gently sloping areas are called as terraces. The following minor landforms/ land elements are identified.

a) Coastal dunes: Undulating to rolling areas of sand dunes, mainly occurring along the sea coast.

b) Spill channels: The open basins or sea water channels; may be active, abandoned or infilled ones as described under the "River plains".

c) Lagoons or lagoonal infills: The closed basins formed beyond the coastal dunes; generally imperfectly to poorly drained.

d) Level plains: Almost flat areas of the marine plains formed beyond the coastal dunes and lagoons.

e) Marine terraces: Almost flat to gently sloping areas resting much higher than normal plains, mainly due to the uplift of continental land and partly due to recession of the sea.

Aeolian plains. These landforms occur in the form of undulating to rolling areas of sand ridges/dunes formed from the sandy sediments laid down by winds. The minor landforms/land elements found within the aeolian plains include the following.

a) Sand ridges: The stabilized or semi-stabilized longitudinal (oriented in prevailing direction of winds) to transverse (oriented perpendicular to the prevailing wind direction) ridges of sandy material; the ridges have two distinc facets viz., the relatively stable "**windward face**" and the loose, unstable "**leeward face**"; the longitudinal ridges are also identifed as "Seif dunes".

b) Whalebacks or Sand levees: Flat-topped, semi-stable sand ridges extending parallel to the prevailing winds but lacking any distinct windward or leeward face.

c) Barchan dunes: Crescent-shaped, unstable sand dunes shifting from one place to another.

d) Inter-dunal flats or inter-ridge hollows: The flat to concave areas lying in between the sand dunes/ridges.

e) Sand sheets: The extensive flat surface sand deposits having almost no relief features.

f) Rock outcrops: Rolling to hilly bare rock surfaces, generally composed of limestone, marl, sandstone or gypsum.

g) Salt flats or playas: Flat to concave areas receiving saline water run-off from the adjoining rocks of limestone, gypsum etc.

Loess plains. These are flat to steeply dissected land surfaces formed by the deposition of silty material carried and laid down by winds; a considerable part of these areas presently stands as severely affected by water erosion in the form of pinnacles while the other part is intricately gullied. Most of the loess plains existing in the world today are, located on the Plateaux discussed earlier rather than as the true Plains. The minor landforms/land elements distinguished within these plains include:

a) Loess terraces or terrace remnants: The high-lying almost flat to gently slopping or undulating areas of thick loess deposits, generally dissected to varying degrees by deep gullies.

b) Loesso-alluvial plains: The low-lying, almost flat areas formed from the loess material redeposited by water after eroding from the loess terraces.

Glacial/glacio-fluvial plains. These are almost flat to rolling/hilly landforms developed from the sediments carried and laid down mainly by ice or glaciers upon melting and partly by the streams formed from the melt-water; the sediments are generally stony/bouldery or gravelly with little sorting where deposited by ice, and non-gravelly to gravelly with partial sorting where deposited by melt-water. The important minor landforms/ land elements identified include:

a) Till plains: Gently undulating to rolling, extensive areas of till deposits.

b) Moraine ridges: The drift deposits occurring mainly along the courses of glaciers (Lateral moraine) or along the lower end of the glaciers (End moraine), in the form of irregular, several kilo meters long, high ridges.

c) Drumlins: Long, rounded, cigar-shaped low hills of glacial till deposits.

d) Outwash plains: Almost flat to undulating areas of glacio-fluvial deposits formed below the melting front of glaciers.

e) Glacial lakes: The lakes formed by glacial melt-water.

In addition to the above-described major landforms important for soil studies, the following two other types of major landforms may be identified when studying large areas:-

i) **Glaciers, ice caps and ice sheets**. These landforms represent areas occupied by glaciers, ice-covered mountain peaks and extensive flat to hilly areas having a permanent, thick ice cover and virtually no soil cover.

ii) **Oceans, seas and lakes**. These are the areas occupied permanently by water.

3. Relationship of Landforms with age

Each of the above-described major and minor landforms, as well as the land elements, may be divided on the basis of its age of formation i.e., of the sediment deposits. The differntiation of land surfaces on this basis is extremely important to estimate the degree of soil development and weathering of the soil material, which ultimately decide the soil physical and chemical conditions affecting their agricultural use. The soils occurring in too young landforms generally have more favourable chemical characteristics but less favourable physical characteristics; the reverse is true for the soils of too old landforms. But variations do occur under varying environmental conditions. Such changes are most prominent in case of flat areas occurring under a hot humid moisture regime but may be indistinct in case of sloping soils of desert climates. Under a certain climatic regime, the soils belonging to the same parent material, having the same slope gradient and aspect and occupying the same physiographic position will differ in their degree of development as well as in physical and chemical characteristics only due to differences in the time passed since the deposition of their parent materials.

The period which is important for deposition of parent materials and genesis of soils is rather too short indistict on the geological time scale. It is generally limited from about one million years back (beginning of middle pleistocene, the Quaternary era) to the present time. For general differentiation of landforms on the basis of age, with particular reference to soil formation, these may be classified as:

Old: Those postulated to have got their parent materials deposited earlier than about 10,000 years ago;

Subrecent: Those with parent material deposits of about 300 to 10,000 years before present; and

Recent: Those having their parent material deposited later than 300 years before present.

ANNEX II: FAO SPECIFICATIONS FOR DESCRIBING LAND CHARACTERISTICS

Whereas the terminology used for describing the important land characteristics has been specifically defined by FAO in order to make the descriptions objective and equally understandable in all countries using the FAO standards, various characteristics are classified by specifying the boundaries of their different classes, in quantitative terms as far as practical. These specifications, as well as a complete listing of all the characteristics, along with the coding system recommended for common use and to facilitate data input in the FAO-ISRIC Soil Database (FAO, 1989), are given in the FAO's **Guidelines for Soil Profile Description** (revised 1990, 3rd Edition). The specifications relative to important land characteristics are described under chapter 2 and are presented below for guidance of the user of this manual.

1. Topography:

The general topography of the landscape is classified in terms of percent slope as:

Flat	0 - 0.5%	
Almost flat	0.5 - 2%	
Gently undulating	2 - 5%	
Undulating	5 - 10%	
Rolling	10 - 15%	
Hilly	15 - 30%	
Steeply dissected	> 30%	(<300m relief difference)
Mountainous	> 30%	(<300m relief difference)

The slope gradient for the observation site is also separately classified and the slope forms are distinguished as:

Slope gradient		Slope forms
Flat	0 - 0.2%	Straight
Level	0.2 - 0.5%	Concave
Nearly level	0.5 - 1%	Convex
Very gently sloping	1 - 2%	Terraced
Gently sloping	2 - 5%	Complex (Irregular)
Sloping	5 - 10%	
Strongly sloping	10 - 15%	
Moderately steep	15 - 30%	
Steep	30 - 60%	
Very steep	> 60%	

2. Land use

The present land use types are distinguished as follows:

a) **Settlement, industry:**

- Residential
- Industrial
- Transport
- Recreational
- Excavations

b) **Crop agriculture:**

Annual field cropping	- Shifting cultivation - Fallow system cultivation - Ley system cultivation - Rainfed arable cultivation - Wet rice cultivation - Irrigated cultivation
Perennial field cropping	- Non-irrigated cultivation - Irrigated cultivation
Tree and shrub cropping	- Non-irrigated tree crop cultivation - Irrigated tree crop cultivation - Non-irrigated shrub crop cultivation - Irrigated shrub crop cultivation

c) **Animal husbandry:**

Extensive grazing	- Nomadism - Semi-nomadism - Ranching
Intensive grazing	- Animal production - Dairying

d) **Forestry:**

Natural forest and woodland	- Selective felling - Clear felling
Plantation forestry	

e) **Mixed farming:**

- Agro-forestry
- Agro-pastoralism (cropping and livestock systems)

f) **Extraction and collection:**

- Exploitation of natural vegetation
- Hunting and fishing

g) **Nature protection:**

Nature and game preservation	- Reserves - Parks - Wildlife management
Degradation control	- Without interference - With interference

h) **Not used and not managed**

3. Vegetation:

The commonly used vegetation types are defined as:

Grassland:	Mainly grasses and subordinate forbs; no woody species
Forbland:	Herbaceous plants predominant
Forest:	Continuous tree layer, crowns overlapping; large number of tree and shrub species in distinct layers
Woodland:	Continuous tree layer, crowns usually not touching; understorey may be present
Shrubland:	Continuous layer of shrubs, crowns touching
Savanna:	Grasses with discontinuous layer of trees or shrubs

The grass cover is classified in terms of the percent area of ground surface occupied as:

0: No cover	0%
1: Patchy*	0 - 15%
2: Moderately dense*	15 - 40%
3: Dense*	40 - 80%
4: Very dense*	> 80%

* Not so named by FAO but proposed by the author.

4. Effective soil depth:

The effective soil depth is classified as:

Very shallow	< 30cm
Shallow	30 - 50cm
Moderately deep	50 - 100cm
Deep	100 - 150cm
Very deep	> 150cm

5. Rock outcrops and surface coarse fragments:

The classes of rock outcrops and surface coarse fragments are defined with respect to **percentage of surface area** and **average distance** (between the rock outcrops) as:

Surface area		Distance	
Very few	0 - 2%	1	> 50m
Few	2 - 5%	2	20 - 50m
Common	5 - 15%	3	5 - 20m
Many	15 - 40%	4	2 - 5m
Abundant	40 - 80%	5	< 2m
Dominant	> 80%		

The size classes of surface coarse fragments are defined in terms of the lengths of their greatest dimensions as:

Fine gravel	0.2 - 0.6cm
Medium gravel	0.6 - 2.0cm
Coarse gravel	2 - 6cm
Stones	6 - 20cm
Boulders	20 - 60cm
Large boulders	60 - 200cm

6. Erosion or deposition (sedimentation):

The following general types of erosion or deposition are distinguished:

Water erosion/deposition
- Sheet erosion
- Rill erosion
- Gully erosion
- Tunnel erosion
- Deposition

Wind erosion/deposition
- Wind erosion
- Wind erosion & deposition
- Wind deposition
- Shifting sands

Water and wind erosion

Mass movement (landsliding and similar phenomena)

Salt deposition

The classes of erosion and/or deposition on the basis of area affected are defined as:

1: Very patchy*	0 - 5%
2: Patchy*	5 - 10%
3: Somewhat extensive*	10 - 25%
4: Extensive*	25 - 50%
5: Very extensive*	> 50%

* Not so named by FAO but proposed by the author.

The erosion classes with respect to degree of erosion are defined as:

Slight	Some evidence of damage to surface horizons; original biotic functions largely intact
Moderate	Clear evidence of removal of surface horizons; original biotic functions partly destroyed
Severe	Surface horizons completely removed, subsurface horizons exposed; original biotic functions largely destroyed
Extreme	Substantial removal of deeper subsurface horizons; original biotic functions fully destroyed (badlands)

The following calsses are distinguished on basis of activity of the erosion process:

- Active at present
- Active in recent past (in previous 50-100 years)
- Active in historical times
- Period of activity not known

7. Surface sealing (crusting):

The surface sealing or crusting is classified with respect to thickness and consistence of the crust as:

Thickness		Consistence
Thin	< 2mm	- Slightly hard
Medium	2 - 5mm	- Hard
Thick	5 - 20mm	- Very hard
Very thick	> 20mm	- Extremely hard

8. Surface cracks:

The classes for surface cracks are defined in terms of their width and spacing as:

Width		Spacing	
Fine	< 1cm	Very closely spaced	< 0.2m
Medium	1 - 2cm	Closely spaced	0.2 - 0.5m
Wide	2 - 5cm	Mod. widely spaced	0.5 - 2.0m
Very wide	5 - 10cm	Widely spaced	2 - 5m
Extremely wide	> 10cm	Very widely spaced	> 5m

9. Surface salts:

The surface salinity is defined with respect to cover (percent of the surface area occupied by salts) and thickness of the salt crust as:

Cover		Thicknes	
Low	0 - 15%	Thin	< 2mm
Moderate	15 - 40%	Medium	2 - 5mm
High	40 - 80%	Thick	5 - 20mm
Dominant	> 80%	Very thick	> 20mm

10. Surface cover of bleached sand:

The presence of bleached, loose sand at surface (affecting the reflectance properties of soil surface) is classified in terms of percent of surface area occupied as:

Low	0 - 15%
Moderate	15 - 40%
High	40 - 80%
Dominant	> 80%

11. Drainage:

The following kinds of sites with respect to external drainage are distinguished:

Ponded (run-on or collecting site)
Neither receiving/collecting nor shedding site
Shedding site with slow run-off
Shedding site with moderately rapid run-off
Shedding site with rapid run-off

The classes of (general) drainage are defined as:

Excessively drained: Water is removed from the soil very rapidly; the soils are commonly very coarse textured or rocky, shallow or steeply sloping.

Somewhat excessively drained: Water is removed from the soil rapidly; the soils are commonly sandy or very pervious.

Well drained: Water is removed from the soil readily but not rapidly; the soils commonly retain optimum amounts of moisture and wetness does not inhibit the growth of roots for significant periods.

Moderately well drained: Water is removed from the soil somewhat slowly; the soils are wet for short periods within the rooting depth; they commonly have an almost impervious layer or predictably receive heavy rainfall.

Somewhat poorly (imperfectly) drained: Water is removed from the soil slowly so that the soil is wet at a shallow depth for significant periods; the soils commonly have an almost impervious layer, a high water table, addition of water by seepage or very frequent rainfall.

Poorly drained: Water is removed from the soil so slowly that the soils are commonly wet at a shallow depth for considerable periods; the soils commonly have a shallow water table which is usually the result of an almost impervious layer, seepage or very frequent rainfall.

Very poorly drained: Water is removed from the soil so slowly that the soils are wet at shallow depths for long periods; the soils have a very shallow water table and commonly occur in level or depressed sites or very high rain falls almost every day.

The Internal drainage is classified with respect to **hydraulic conductivity** or **permeability** in terms of cm per hour of water flow as:

Extremely slow	< 0.06cm/h
Very slow	0.06 - 0.2cm/h
Slow	0.2 - 0.6cm/h
Moderately slow	0.6 - 2.0cm/h
Moderately rapid	2 - 6cm/h
Rapid	6 - 20cm/h
Very rapid	> 20cm/h

12. Flooding:

The classes of flooding with respect to duration and depth in terms of number of days and cm of water column above surface, respectively, are as:

Duration		Depth	
Very short*	< 1day	Very shallow	< 25cm
Short*	30 - 90 days	Shallow	25 - 50cm
Long*	90 - 180 days	Moderately deep	50 - 100cm
Very long*	180 - 360 days	Deep	100 - 150cm
Continuous*	> 360 days	Very deep	> 150cm

* Not so named by FAO but proposed by the author.

13. Groundwater:

The classes for depths of groundwater table (existing, minimum and maximum depths during the year) within the soil profile and below the soil profile (termed as the **"Phreatic water"**) are defined as:

Within the soil profile		Below the soil profile	
Very shallow	0 - 25cm	Shallow	2 - 3m
Shallow	25 - 50cm	Moderately deep	3 - 5m
Moderately deep	50 - 100cm	Deep	- 8m
Deep	100 - 150cm	Extremely deep	> 8m
Very deep	> 150cm		

The following types of water are distinguished on the basis of quality:

- Fresh (non-saline)
- Saline
- Brackish
- Polluted
- Oxygenated
- Stagnating

14. Mottles:

The mottles of soil matrix are classified on the basis of abundance and size and defined in terms of the percent of surface area occupied and approx. diameter, respectively, as:

Abundance		Size	
Very few	0 - 2%	Very fine	< 2mm
Few	2 - 5%	Fine	2 - 6mm
Common	5 - 15%	Medium	6 - 20mm
Many	15 - 40%	Coarse	> 20mm
Abundant	> 40%		

On the basis of contrast (colour difference with soil matrix) and boundary (width of interface between soil matrix colour and mottle colour), the mottles are classified as:

Contrast		Boundary	
Faint:	Evident only on close examination	Sharp	<0.5mm
		Clear	0.5 - 2mm
Distinct:	Readily seen but not striking	Diffuse	> 2mm
Prominent:	Quite striking and conspicuous		

15. Particle size:

The particle size or textural classes of fine earth fraction (<2mm dia) are defined in terms of the length of largest axis as:

Clay	< 2um	(<0.002mm)
Fine silt	2 - 20um	(0.002-0.020mm)
Coarse silt	20 - 63um	(0.020-0.063mm)
Very fine sand	63 - 125um	(0.063-0.125mm)
Fine sand	125 - 200um	(0.125-0.200mm)
Medium sand	200 - 630um	(0.200-0.630mm)
Coarse sand	630 - 1250um	(0.630-1.250mm)
Very coarse sand	1250 - 2000um	(1.250-2.000mm)

The **textural classes** recognized are indicated in Fig 3.

16. Rock fragments:

The rock fragments present within the soil profile are classified with respect to abundance in terms of volume percentage as:

Very few	0 - 2%
Few	2 - 5%
Common	5 - 15%
Many	15 - 40%
Abundant	40 - 80%
Dominant	> 80%

The size classes of the rock fragments are defined in terms of the lengths of their greatest dimensions as:

Fine gravel	0.2 - 0.6cm
Medium gravel	0.6 - 2.0cm
Coarse gravel	2 - 6cm
Stones	6 - 20cm
Boulders	20 - 60cm
Large boulders	60 - 200cm

The rock fragments are distinguished on the basis of shape as:

- Flat
- Angular
- Subrounded
- Rounded

With respect to the stage of Weathering, the rock fragments are classified as:

Fresh or slightly weathered: Little or no signs of weathering

Weathered: Partial weathering indicated by discoloration or loss of crystal form in the outer parts only

Strongly weathered: All but very resistant minerals are weathered with whole of the fragment strongly discoloured and so altered as to disintegrate under a moderate pressure

17. Structure:

On the basis of presence or absence of structural peds, soils are first classified as:

Apedal Structureless soils having no peds formed

Pedal Structured soils showing formation of peds

The Apedal or structureless soils are classified on the basis of degree **of coherence among the soil particles** as:

Single grain: Loose, soft or very friable material with >50% of it breaking into discrete mineral particles

Massive: Coherent material not breaking into discrete mineral particles

For Pedal or structured soils, structural classes are defined with respect to grade as:

Weak: Peds barely observable in place and have a weak arrangement of natural surfaces of weakness; when disturbed, soil material breaks into only a few entire peds, many broken peds and much of it without ped faces; ped surfaces differ in some way from the ped interiors; may be subdivided into **very weak** and **weak.**

Moderate: Peds observabe in place and have a distinct arrangement of natural surfaces of weakness; when disturbed, soil material breaks into many entire peds, some broken peds and little of it without ped faces; ped surfaces generally differ from the ped interiors.

Strong: Peds clearly observable in place and have a prominent arrangement of natural surfaces of weakness; when disturbed, soil material separates into entire peds; ped surfaces differ markedly from ped interiors; may be subdivided into **strong** and **very strong**.

The classes of structure with respect to type are defined in terms of shape or form of peds as follows:

Granular: Spheroids or polyhedrons with curved or irregular surfaces which are not casts of the faces of the surrounding peds

Blocky: Nearly equidimensional blocks or polyhedrons with flat or slightly rounded surfaces which are casts of the faces of surrounding peds; subdivided into:
a) **angular blocky** (faces intersecting at relatively sharp angles and
b) **subangular blocky** (faces intersecting at rounded angles.

Prismatic: Ped dimensions limited in horizontal plane and extended in the vertical plane; well defined vertical faces which are casts of the faces of surrounding peds; the faces intersect at relatively sharp angles; distinguished as **columnar** if the peds have rounded caps

Platy: Flat peds with vertical dimension limited; generally oriented on a horizontal plane and overlapping

Rock structure: No peds formed; fine stratifications in unconsolidated sediments and/or pseudomorphs of weathered minerals retaining their position relative to each other and to unweathered minerals in saprolite from consolidated rocks.

If required, these basic structures may be subdivided as, for example, "**subangular prismatic**", "**nutty subangular blocky**", "**angular blocky wedge-shaped**", "**angular blocky parallelipiped**", "**stratified structure**", etc.

Each type of soil structure is separately classified for size of the peds; the size classes refer to the smallest dimentions in case of prismatic, columnar and platy structures but the largest ones in case of blocky and granular structures:

	Platy	Prismatic	Blocky	Granular
Very fine	< 1cm	< 10cm	< 5cm	< icm
Fine	1- 2cm	10- 20cm	5-10cm	1- 2cm
Medium	2- 5cm	20- 50cm	10-20cm	2- 5cm
Coarse	5-10cm	50-100cm	20-50cm	5-10cm
Very coarse	>10cm	>100cm	>50cm	>10cm

18. Cutanic features:

The cutanic features including **clay or mixed-clay/mineral coatings** by illuviation, **slickensides**, **pressure faces**, etc. are classified according to abundance in terms of percentage of the surface area occupied as:

Very few	< 2%
Few	2 - 5%
Common	5 - 15%
Many	15 - 40%
Abundant	40 - 80%
Dominant	> 80%

The classes of cutanic features with respect to contrast are defined in terms of difference in colour, smoothness or any other relevant property of the features with the normal surfaces as:

Faint: Little difference; fine grains are readily apparent; lamellae are <2mm thick

Distinct: Distinctly different; fine grains enveloped but their outlines still visible; lamellae 2-5mm thick

Prominent: Strongly contrasting; outlines of fine grains invisible; lamellae >5mm thick

19. Consistence:

The consistence classes are defined under dry, moist and wet conditions as follows:

a) When dry, the consistence is defined in terms of resistence to the applied pressure against breakage as:

Loose: Non-coherent; no pressure required

Soft: Very weakly coherent and fragile; breaks to powder or individual grains with very light pressure

Slightly hard: Weakly resistant to pressure; breaks easily between thumb and forefinger

Hard: Moderately resistant to pressure; not easily broken between thumb and finger; can be broken in hand with moderate pressure

Very hard: Very resistant to pressure; can be broken in hand only with difficulty

Extremely hard: Extremely resistent to pressure; can not be broken in hand

b) When moist, the consistence classes are defined in terms of the ease with which soil material can be crushed between thumb and forefinger as:

Loose: Non-coherent; crushing not required

Very friable: Crushed very with very gentle pressure

Friable: Crushed easily with gentle to moderate pressure

Firm: Crushed with moderate pressure but resistence is distinctly noticeable

Very firm: Crushed only with strong pressure, barely so done between thumb and forefinger

Extremely firm: Crushable only with very strong pressure and not between thumb and forefinger

c) When wet, the consistence classes are defined with respect to **stickiness** (in terms of adherence of the soil material to thumb and forefinger when pressed in between and the pressure is released and the degree to which it gets stretched when the digits are separated) and **plasticity** (in terms of ability of the soil material to get moulded in the form of a wire of about 3mm dia. and a ring) as follows:

Stickiness	Plasticity
Nonsticky: Practically no adherence	**Nonplastic:** No wire can be formed
Slightly sticky: Soil material adheres but comes off easily and rather cleanly; not stretched appreciably when pulled apart	**Slightly plastic:** Wire can be formed but breaks immediately if bent into a ring; soil material deformed with little force
Sticky: Soil material adheres and pulls apart after tending to get stretched rather than pulling free	**Plastic:** Wire formable but breaks if bent into a ring; soil material deformed with slight to moderate pressure
Very sticky: Soil material adheres strongly and is much stretched when pulled apart	**Very plastic:** Wire formable and can be bent into a ring; soil material defromed only with strong force

20. Porosity (voids):

The size classes of voids (generally used only for channels/ tubular voids) are defined in terms of their diameter as:

Very fine	< 0.5mm
Fine	0.5- 2mm
Medium	2 - 5mm
Coarse	5 - 20mm
Very coarse	20 - 50mm

The abundance classes of voids (channels) are defined in terms of number per square decimeter separately for small and large voids as:

	Very fine/fine	Medium/coarse
Very few	1 - 20	1 - 2
Few	20 - 50	2 - 5
Common	50 - 200	5 - 20
Many	> 200	> 20

The soil porosity classes are defined in terms of percentage of surface area occupied together by all voids as:

Very low	< 2%
Low	2 - 5%
Medium	5 - 15%
High	15 - 40%
Very high	> 40%

21. Cementation and compaction:

The cementation (hardening of soil material to an extent that it does not slake in water after immersion for one hour) or compaction (close packing of soil particles to a firm consistence) in the form of pans or otherwise is classified in terms of continuity as:

Broken: <50% cemented/compacted and having irregular appearance

Discontinuous: 50-90% cemented/compacted, generally with a regular appearance

Continuous: >90% cemented/compacted and only in places may be interrupted by cracks or fissures

On the basis of structure, the cementation or compaction is classified as:

None/Massive: Without any recognizable orientation

Platy: Oriented in horizontal layers

Vesicular: Marked with large, equidimensional voids

Pisolithic: Largely constructed from spherical nodules

Nodular: Largely constructed from irregularly shaped nodules or concretions

On the basis of degree, the classes of cementation/compaction are defined as:

Compacted but not cemented; The soil mass is appreciably hardened but slakes in water

weakly cemented: The mass is brittle and hard but can be broken in hands

Moderately cemented: The mass is discontinuous but can not be broken in hands

Cemented (or strongly cemented): The mass is continuous and can not be broken in hands

22. Mineral nodules or segregations:

The classes of mineral nodules and crystalline, microcrystalline or amorphous segregations of non-organic substances are defined with regard to abundance in terms of the percentage of soil volume occupied and size of the largest dimensions as:

Abundance		Size	
Very few	< 2%	Very fine	< 2mm
Few	2 - 5%	Fine	2 - 6mm
Common	5 - 15%	Medium	6 - 20mm
Many	15 - 40%	Coarse	> 20mm
Abundant	40 - 80%		
Dominant	> 80%		

According to kind, the mineral nodules are classified in terms of the form in which they occur as defined below:

Crystal: specific geometrical form

Concretion: a discrete body with a concentric internal structure, generally cemented

Soft segregation (or accumulation): A non-discrete soft body different from the surrounding soil mass but not easily separated as a unity

Nodule: A discrete body without any internal organization which may or may not be cemented

Residual rock fragment: A discrete, impregnated body still showing rock structure

The mineral nodules and segregations are distinguished with respect to shape and hardness as:

Shape	Hardness
Rounded or spherical	**Hard:** Can not be broken in fingers
Elongate	**Soft:** Can be broken between forefinger and thumb nail
Flat	
Irregular	
Angular	

23. Roots:

The classes of roots on the basis of abundance and size are defined in terms of number per square decimeter and in terms of diameter respectively as:

Abundance		Size	
No roots	0	Very fine	< 0.5mm
Very few	1 - 20	Fine	0.5 - 2mm
Few	20 - 50	Medium	2 - 5mm
Common	50 - 200	Coarse	> 5mm
Many	> 200		

24. Biological features:

The biological features like **krotovinas, termite burrows, insect nests, worm casts or burrows** of large animals etc. are classified in terms of their abundance (few, common and many; not specifically defined) and kind as locally identified. In addition, their specific locations, patterns, size, composition or any other characteristic may be recorded.

25. Carbonates or calcareousnes:

The classes of calcareousness are defined in terms of the intensity of effervescence given by the soil material after testing with 10% HCl as follows:

Non-calcareous:	No detectable effervescence
Slightly calcareous:	Audible but not visible effervescence
Moderately calcareous:	Visible effervescence
Strongly calcareous:	Strong visible effervescence with bubbles forming low foam
Extremely calcareous;	Extremely strong or violent effervescence with thick/high foam formed quickly

26. Horizon boundary:

With repect to distinctness and topography, the horizon boundary classes are defined in terms of width and shape respectively as:

Distinctness		Topography	
Abrupt	< 2cm	Smooth:	Nearly plane surface
Clear	2 - 5cm	Wavy:	Pockets less deep than wide
Gradual	5 - 15cm	Irregular:	Pockets more deep than wide
Diffuse	> 15cm		

ANNEX III: KEY TO MAJOR SOIL GROUPINGS AND SOIL UNITS

Soils having an H horizon, or an O horizon, of 40 cm or more (60 cm or more if the organic material consists mainly of sphagnum or moss or has bulk density of less than 0.1 kg m^3) either extending down from the face or taken cumulatively within the upper 80 cm of the soil; the thickness of the H or O horizon may be less when it rests on fragmental material of which the interstices are filled with organic matter.

HISTOSOLS (HS)

Histosols having permafrost within 200 cm of the surface.
Gelic Histosols (HSi)

Other Histosols having a sulfuric horizon or sulfidic materials at less than 125 cm of the surface.
Thionic Histosols (HSt)

Other Histosols that are well drained and are never saturated with water for more than a few days.
Folic Histosols (HSl)

Other Histosols having raw or weakly decomposed organic materials, the fibre content of which is dominant to a depth of 35 cm or more from the surface; having very poor drainage or are undrained.
Fibric Histosols (HSf)

Other Histosols having highly decomposed organic materials with only small amounts of visible plant fibers and a very dark grey to black colour to a depth of 35 cm or more from the surface, having an imperfect to very poor drainage.
Terric Histosols (HSs)

Other soils in which human activities have resulted in a profound modication or burial of the original soil horizons, through removal or disturbance of surface horizons, cuts and fills, secular additions of organic materials, long-continued irrigation, etc.

ANTHROSOLS (AT)

Anthrosols showing remnants of diagnostic horizons due to deep cultivation.
Aric Anthrosols (ATa)

Other Anthrosols having a fimic A horizon.
Fimic Anthrosols (ATf)

Other Anthrosols showing an accumulation of fine sediments, thicker than 50 cm, resulting from long-continued irrigation or man-made raising of the soil surface.

Cumulic Anthrosols (Atc)

Other Anthrosols having, to a depth of more than 50 cm, an accumulation of wastes from mines, town refuse, fills from urban development, etc.

Urbic Anthrosols (ATu)

Other soils which are limited in depth by continuous hard rock or highly calcareous materials (calcium carbonate equivalent of more than 40 percent) or a continuous cemented layer within 30 cm of the surface or having less than 20 percent of fine earth over a depth of 75 cm from the surface; having no diagnostic horizons other than a mollic, umbric, or ochric A horizon with or without a cambic B horizon.

LEPTOSOLS (LP)

Leptosols which are limited in depth by continuous hard rock or a continuous cemented layer within 10 cm of the surface.

Lithic Leptosols (LPq)

Other Leptosols having permafrost within 200 cm of the surface.

Gelic Leptosols (LPi)

Other Leptosols having a mollic A horizon which contains or immediately overlies calcareous material with a calcium carbonate equivalent of more than 40 percent.

Rendzic Leptosols (LPk)

Other Leptosols having a mollic A horizon.

Mollic Leptosols (LPm)

Other Leptosols having an umbric A horizon.

Umbric Leptosols (LPu)

Other Leptosols having an ochric A horizon and a base saturation (by NH_4OAc) of less than 50 percent.

Dystric Leptosols (LPd)

Other Leptosols. These Leptosols have an ochric A horizon and base saturation of more than 50 per cent.

Eutric Leptosols (LPe)

Other soils having, after the upper 20 cm have been mixed, 35 per cent or more clay in all horizons to a depth of at least 50 cm; developing cracks 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: intersecting slickensides or wedge-shaped or parallelepiped structural aggegates at some depth between 25 and 100 cm from the surface.

VERTISOLS (VR)

Vertisols having a gypsic horizon within 125 cm of the surface.

Gypsic Vertisols (VRy)

Other Vertisols having a calcic horizon or concentrations of soft powdery lime within 125 cm of the surface.

Calcic Vertisols (VRk)

Other Vertisols having a base saturation (by NH_4OAc) of less than 50 percent at least between 20 to 50 cm from the surface.

Dystric Vertisols (VRd)

Other Vertisols.

Eutric Vertisols (VRe)

Other soils showing fluvic properties and having no diagnostic horizons other than an ochric, a mollic, an umbric A horizon, or a histic H horizon, a sulfuric horizon, or sulfidic material within 125 cm of the surface.

FLUVISOLS (FL)

Fluvisols having a sulfuric horizon or sulfidic material, or both, within 125 cm of the surface.

Thionic Fluvisols (FLt)

Other Fluvisols having a mollic A horizon or a eutric histic H horizon.

Mollic Fluvisols (FLm)

Other Fluvisols which are calcareous at least between 20 and 50 cm from the surface.

Calcaric Fluvisols (FLc)

Other Fluvisols having an umbric A horizon or a dystric histic H horizon.

Umbric Fluvisols (FLu)

Other Fluvisols having a base saturation (by NH_4OAc) of less than 50 percent, at least between 20 to 50 cm from the surface.

Dystric Fluvisols (FLd)

Other Fluvisols showing salic properties.

Salic Fluvisols (FLs)

Other Fluvisols.

Eutric Fluvisols (FLe)

Other soils showing salic properties and having no diagnosjtic horizons other than an A horizon, a histic H horizon, a cambic B horizon, a calcic or a gypsic horizon.

SOLONCHAKS (SC)

Solonchaks having permafrost within 200 cm of the surface.

Gelic Solonchaks (SCi)

Other Solonchaks showing gleyic properties within 100 cm of the surface.

Gleyic Solonchaks (SCg)

Other Solonchaks having a mollic a horizon.

Mollic Solonchaks (SCm)

Other Solonchaks having a gypsic horizon within 125 cm of the surface.

Gypsic Solonchaks (SCy)

Other Solonchaks having a calcic horizon within 125 cm of the surface.

Calcic Solonchaks (SCk)

Other Solonchaks showing sodic properties at least between 20 and 50 cm of the surface.

Sodic Solonchaks (SCn)

Other Solonchaks.

Haplic Solonchaks (SCh)

Other soils, exclusive of coarse textured materials, showing gleyic properties within 50 cm of the surface; having no diagnostic horizons other than an A horizon, a histic H horizon, a cambic B horizon, a calcic or a gypsic horizon; lacking plinthite within 125 cm of the surface.

GLEYSOLS (GL)

Gleysols having permafrost within 200 cm from the surface.
Gelic Gleysols (GLi)

Other Gleysols having a sulfuric horizon within 125 cm of the surface.
Thionic Gleysols (GLt)

Other Gleysols having andic properties.
Andic Gleysols (GLa)

Other Gleysols having a mollic A horizon or a eutric histic H horizon.
Mollic Gleysols (GLm)

Other Gleysols having an umbric A horizon or a dystric histic H horizon.
Umbric Gleysols (GLu)

Other Gleysols having a calcic horizon or a gypsic horizon, or both, within 125 cm of the surface.
Calcic Gleysols (GLk)

Other Gleysols having a base saturation (by NH_4OAc) of less than 50 percent,at least between 20 to 50 cm from the surface.

Dystric Gleysols (GLd)

Other Gleysols.
Eutric Gleysols (GLe)

Other soils showing andic properities to a depth of 35 cm or more from the surface and having a mollic or an umbric A horizon possibly overlying a cambic B horizon, or an ochic A horizon and a cambic B horizon; having no other diagnostic horizons.

ANDOSOLS (AN)

Andosols having permafrost within 200 cm of the surface.
Gelic Andosols (ANi)

Other Andosol showing gleyic properties within 100 cm of the surface.
Gleyic Andosols (ANg)

Other Andosols lacking a smeary consistence, or a texture which is silt loam or finer on the weighted average for all horizons within 100 cm of the surface, or both.
Vitric Andosols (ANz)

Other Andosols having a mollic A horizon.
Mollic Andosols (ANm)

Other Andosols having an umbric A horizon.
Umbric Andosols (ANu)

Other Andosols.
Haplic Andosols (ANh)

Other soils which are coarser than sandy loam to a depth of at least 100 cm from the surface, having no diagnostic horizons other than an ochric A horizon or an albic E horizon.

ARENOSOLS (AR)

Arenosols showing gleyic properties within 100 cm of the surface.
Gleyic Arenosols (ARg)

Other Arenosols having an albic E horizon with a minimum thickness of 50 cm within 125 cm of the surface.
Albic Arenosols (ARa)

Other Arenosols which are calcareous at least between 20 and 50 cm from the surface.
Calcaric Arenosols (ARc)

Other Arenosols showing some clay increase or lamellae of clay accumulation within 125 cm of the surface.
Luvic Arenosols (ARl)

Other Arenosols showing ferralic properties within 125 cm of the surface.
Ferralic Areonosols (ARo)

Other Arenosols showing colouring or other alteration characteristic of a cambic B horizon.
Cambic Arenosols (ARb)

Other Arenosols.
Haplic Arenosols (ARh)

Other soils having no diagnostic horizons other than an ochric or umbric A horizon.

REGOSOLS (RG)

Regosols having permafrost within 200 cm of the surface.
Gelic Regosols (RGi)

Other Regosols having an umbric A horizon.
Umbric Regosol (RGu)

Other Regosols which are gypsiferous at least between 20 and 50 cm from the surface.
Gypsic Regosols (RGy)

Other Regosols which are calcareous at least from 20 to 50 cm from the surface.
Calcaric Regosols (RGc)

Other Regosols having a base saturation (by NH_4OAc) of less than 50 percent, at least from 20 to 50 cm from the surface.
Dystric Regosols (RGd)

Other Regosols.
Eutric Regosols (RGe)

Other soils having a spodic B horizon.

POOZOLS (PZ)

Podzols having permafros within 200 cm of the surface.
Gelic Podzols (PZi)

Other Podzols showing gleyic properties within 100 cm of the surface.
Gleyic Podzols (PZg)

Other Podzols having a B horizon in which a subhorizon contains dispersed organic matter and lacks sufficient free iron to turn redder on ignition.
Carbic Podzols (PCc)

Other Podzols in which the ratio of percentage of free iron to percentage of organic carbon is 6 or more in all subhorizons of the B horizon.
Ferric Podzols (PZf)

Other Podzols lacking or having only a thin (2 cm or less) and discontinuous albic E horizon; lacking a subhorizon within the B horizon which is visibly more enriched with organic carbon.
Cambic Podzols (PZb)

Other Podzols.
Haplic Podzols (PZh)

Other soils having 25 percent or more plinthite by volume in a horizon which is at least 15 cm thick within 50 cm of the surface or within a depth of 125 cm when underlying an albic E horizon or a horizon which shows stagnic properties within 50 cm of the surface or gleyic properties within 100 cm of the surface.

PLINTHOSOLS (PT)

Plinthosols having an albic E horizon.
Albic Plinthosols (PTa)

Other Plinthosols having an umbric A horizon or a dystric histic H horizon and which are strongly humic.
Humic Plinthosols (PTu)

Other Plinthosols having an ochric A horizon and a base satu-saturation (by NH_4 OAc) of less than 50 percent throughout the upper 50 cm of the plinthite horizon.
Dystric Plinthosols (PTd)

Other Plinthosols having an ochric A horizon and a base saturation (by NH_4 OAc) which is more than 50 percent throughout the upper 50 cm of the plinthite horizon.
Eutric Plinthosols (PTe)

Other soils having a ferralic B horizon.

FERRALSOLS (FR)

Ferralsols having plinthite within 125 cm of the surface.
Plinthic Ferralsols (FRp)

Other Ferralsols having geric properties in at least some part of the ferralic B horizon within 125 cm of the surface.
Geric Ferralsols (FRg)

Other Ferralsols which are strongly humic, having an umbric A horizon, or a mollic A horizon and a base saturation (by NH_4OAc) of less than 50 percent in at least a part of the B horizon within 100 cm of the surface.
Humic Ferralsols (FRu)

Other Ferralsols having a red to dusky red B horizon (rubbed soil has hues redder than 5YR with a moist value of less than 4 and a dry value not more than one unit higher than the moist value).

Rhodic Ferralsols (FRr)

Other Ferrasols having a yellow to pale yellow B horizon (rubbed soil has hues of 7.5YR or yellower with a moist value of 4 or more and moist chroma of 5 or more).

Xanthic Ferralsols (FRx)

Other Ferralsols.

Haplic Ferralsols (FRh)

Other soils having an E horizon showing stagnic properties at least in part of the horizon and abruptly overlying a slowly permeable horizon within 125 cm of the surface, and lacking a natric or a spodic B horizon.

PLANOSOLS (PL)

Planosols having permafrost within 200 cm of the surface.

Gelic Planosols (PLi)

Other Planosols having a mollic A horizon or a eutric histic H horizon.

Mollic Planosols (PLm)

Other Planosols having an umbric A horizon or a dystric histic H horizon.

Umbric Planosols (PLu)

Other Planosols having a base saturation (by NH_4OAc) of less than 50 percent in at least a part of the slowly permeable horizon within 125 cm of the surface.

Dystric Planosols (PLd)

Other Planosols.

Eutric Planosols (PLe)

Other soils having a natric B horizon.

SOLONETZ (SN)

Solonetz showing gleyic properties within 100 cm of the surface.

Gleyic Solonetz (SNg)

Other Solonetz showing stagnic properties within 50 cm of the surface.

Stagnic Solonetz (SNj)

Other Solonetz having a mollic A horizon.

Mollic Solonetz (SNm)

Other Solonetz having a gypsic horizon within 125 cm of the surface.

Gypsic Solonetz (SNy)

Other Solonetz having a calcic horizon within 125 cm of the surface.

Calcic Solonetz (SNk)

Other Solonetz.

Haplic Solonetz (SNh)

Other soils having a mollic A horizon with a moist chroma of 2 or less to a depth of at least 15 cm, showing uncoated silt and sand grains on structural ped surfaces; having an agric B horizon.

GREYZEMS (GR)

Greyzems showing gleyic properties within 100 cm of the surface.

Gleyic Greyzems (GRg)

Other Greyzems.

Haplic Greyzems (GRh)

Other soils having a mollic A horizon with a moist chroma of 2 or less to a depth of at least 15 cm; having a calcic horizon, or concentrations of soft powdery lime within 125 cm of the surface, or both.

CHERNOZEMS (CH)

Chernozems having an argic B horizon and showing gleyic properties within 100 cm of the surface.

Gleyic Chernozems (CHg)

Other Chernozems having an argic B horizon; a calcic horizon may underlie the B horizon.

Luvic Chernozems (CHl)

Other Chernozems showing tonguing of the A horizon into a cambic B or into a C horizon.

Glossic Chernozems (CHw)

Other Chernozems having a calcic horizon.

Calcic Chernozems (CHk)

Other Chernozems.

Haplic Chernozems (CHh)

Other soils having a mollic A horizon with a moist chroma of more than 2 to a depth of at least 15 cm; having one or more of the following: a calcic or gypsic horizon, or concentrations of soft powdery lime within 125 cm of the surface.

KASTANOZEMS (KS)

Kastanozems having a gypsic horizon.
Gypsic Kastanozems (KSy)

Other Kastanozems having an argic B horizon; a calcic horizon may underlie the B horizon.
Luvic Kastanozems (KSl)

Other Kastanozems having a calcic horizon.
Calcic Kastanozems (KSk)

Other Kastanozems.
Haplic Kastanozems (KSh)

Other soils having a mollic A horizon; having a base saturation (by NH_4OAc) of 50 percent or more throughout the upper 125 cm of the soil.

PHAEOZEMS (PH)

Phaeozems showing gleyic properties within 100 cm of the surface.
Gleyic Phaeozems (PHg)

Other Phaeozems showing stagnic properties within 50 cm of the surface.
Stagnic Phaeozems (PHj)

Other Phaeozems having an argic B horizon.
Luvic Phaeozems (PHl)

Other Phaeozems that are calcareous at least between 20 to 50 cm from the surface.
Calcaric Phaeozems (PHc)

Other Phaeozems.
Haplic Phaeozems (PHh)

Other soils having an argic B horizon showing an irregular or broken upper boundary resulting from deep tonguing of the E into the B horizon or from the formation of discrete nodules larger than 2 cm, the exteriors of which are enriched and weakly cemented or indurated with iron and have redder hues and stronger chromas than the interiors.

PODZOLUVISOLS (PD)

Podzoluvisols having permafrost within 200 cm of the surface.

Gelic Podzoluvisols (PDi)

Other Podzoluvisols showing gleyic properties within 100 cm of the surface.

Gleyic Podzoluvisols (PDg)

Other Podzoluvisols showing stagnic properties within 50 cm of the surface.

Stagnic Podzoluvisols (PDj)

Other Podzoluvisols having a base saturation (by NH_4OAc) of less than 50 percent in at least a part of the B horizon within 125 cm of the surface.

Dystric Podzoluvisols (PDd)

Other Podzoluvisols.

Eutric Podzoluvisols (PDe)

Other soils having a gypsic or a petrogypsic horizon within 125 cm of the surface; having no diagnostic horizons other than an ochric A horizon, a cambic B horizon or an argic B horizon permeated with gypsum or calcium carbonate, a calcic or a petrocalcic horizon.

GYPSISOLS (GY)

Gypsisols having a petrogypsic horizon, the upper part of which occurs within 100 cm of the surface.

Petric Gypsisols (GYp)

Other Gypsisols having a calcic horizon.

Calcic Gypsisols (GYk)

Other Gypsisols having an argic B horizon.

Luvic Gypsisols (GYl)

Other Gypsisols.

Haplic Gypsisols (GYh)

Other soils having a calcic or a petrocalcic horizon, or a concentration of soft powdery lime, within 125 cm of the surface; having no diagnostic horizons other than an ochric A horizon, a cambic B horizon or an argic B horizon permeated with calcium carbonate.

CALCISOLS (CL)

Calcisols having a petrocalcic horizon, the upper part of which occurs within 100 cm of the surface.
Petric Calcisols (CLp)

Other Calcisols having an argic B horizon.
Luvic Calcisols (CLl)

Other Calcisols.
Haplic Calcisols (CLh)

Other soils having an argic B horizon with a clay distribution which does not show a relative decrease from its maximum of more than 20 percent within 150 cm of the surface; showing gradual to diffuse horizon boundaries between A and B horizons; having nitic properties in some subhorizon within 125 cm of the surface.

NITISOLS (NT)

Nitisols which are strongly humic, having an umbric A horizon, or a mollic A horizon and a base saturation (by NH_4OAc) of less than 50 percent in at least a part of the B horizon within 125 cm of the surface.
Humic Nitisols (NTu)

Other Nitisols having a red to dusky red argic B horizon (rubbed soil having hues redder than 5 YR with a moist value of less than 4 and a dry value not more than one unit higher than the moist value).
Rhodic Nitisols (NTr)

Other Nitisols.
Haplic Nitisols (NTh)

Other soils having an argic B horizon which has a cation exchange capacity equal to or more than 24 cmol(+) kg^{-1} clay throughout, and a base saturation (by NH_4OAc) of less than 50 percent in at least some part of the B horizon within 125 cm of the surface.

ALISOLS (AL)

Alisols having plinthite within 125 cm of the surface.
Plinthic Alisols (ALp)

Other Alisols showing gleyic properties within 100 cm of the surface.
Gleyic Alisols (ALg)

Other Alisols showing stagnic properties within 50 cm of the surface.
Stagnic Alisols (ALj)

Other Alisols which are strongly humic, having an umbric or a mollic A horizon.
Humic Alisols (ALu)

Other Alisols showing ferric properties.
Ferric Alisols (ALf)

Other Alisols.
Haplic Alisols (ALh)

Other soils having an argic B horizon which has a cation exchange capacity of less than 24 cmol(+) kg^{-1} clay in at least some part, and a base saturation (by NH_4OAc) of less than 50 percent in at least some part of the B horizon within 125 cm of the surface.

ACRISOLS (AC)

Acrisols having plinthite within 125 cm of the surface.
Plinthic Acrisols (ACp)

Other acrisols showing gleyic properties within 100 cm of the surface.
Gleyic Acrisols (ACg)

Other Acrisols which are strongly humic, having an umbric or a mollic A horizon.
Humic Acrisols (ACu)

Other Acrisols showing ferric properties.
Ferric Acrisols (ACf)

Other Acrisols.
Haplic Acrisols (ACh)

Other soils having an argic B horizon which has a cation exchange capacity equal to or more than 24 cmol(+) kg^{-1} clay throughout, and a base saturation (by NH_4OAc) of 50 percent or more throughout the B horizon to a depth of 125 cm.

LUVISOLS (LV)

Luvisols showing gleyic properties within 100 cm of the surface.
Gleyic Luvisols (LVg)

Other Luvisols showing stagnic properties within 50 cm of the surface.
Stagnic Luvisols (LVj)

Other Luvisols having an albic E horizon.
Albic Luvisols (LVa)

Other Luvisols showing vertic properties.
Vertic Luvisols (LVv)

Other Luvisols having a calcic horizon or concentrations of soft powdery lime within 125 cm of the surface.
Calcic Luvisols (LVk)

Other Luvisols showing ferric properties.
Ferric Luvisols (LVf)

Other Luvisols having a strong brown to red B horizon (rubbed soil has a hue of 7.5YR and a chroma of more than 4, or a hue redder than 7.5YR).
Chromic Luvisols (LVx)

Other Luvisols.
Haplic Luvisols (LVh)

Other soils having an argic B horizon which has a cation exchange capacity of less than 24 cmol(+) kg^{-1} clay in at least some part and a base saturation (by NH_4OAc) of 50 percent or more throughout the B horizon to a depth of 125 cm.

LIXISOLS (LX)

Lixisols having plinthite within 125 cm of the surface.
Plinthic Lixisols (LXp)

Other Lixisols showing gleyic properties within 100 cm of the surface.
Gleyic Lixisols (LXg)

Other Lixisols showing stagnic properties within 50 cm of the surface.

Stagnic Lixisols (LXj)

Other Lixisols having an albic E horizon.

Albic Lixisols (LXa)

Other Lixisols showing ferric properties.

Ferric Lixisols (LXf)

Other Lixisols.

Haplic Lixisols (LXh)

Other soils having a cambic B horizon.

CAMBISOLS (CM)

Cambisols having permafrost within 200 cm of the surface.

Gelic Cambisols (CMi)

Other Cambisols showing gleyic properties within 100 cm of the surface.

Gleyic Cambisols (CMg)

Other Cambisols showing vertic properties.

Vertic Cambisols (CMv)

Other Cambisols having an umbric A horizon or a mollic A horizon overlying a cambic B horizon with a base saturation (by NH_4OAc) of less than 50 percent.

Humic Cambisols (CMu)

Other Cambisols which are calcareous at least between 20 and 50 cm from the surface.

Calcaric Cambisols (CMc)

Other Cambisols having a cambic B horizon with ferralic properties.

Ferralic Cambisols (CMo)

Other Cambisols having a base saturation of less than 50 percent (by NH_4OAc) at least in some part of the B horizon.

Dystric Cambisols (CMd)

Other Cambisols which have a strong brown to red B horizon (rubbed soil has a hue of 7.5YR and a chroma of more than 4, or a hue redder than 7.5YR).

Chromic Cambisols (CMx)

Other Cambisols.

Eutric Cambisols (CMe)

ANNEX IV: FIELD MEASUREMENT OF HYDRAULIC CONDUCTIVITY AND INFILTRATION TESTS

(Extract from Booker Tropical Soil Manual (Landon, 1979), pages 218-230)

1 Field measurement of infiltration using double-cylinder infiltrometer 1/

1.1 Introduction

Infiltration rate (see Section 6.2) refers to the vertical entry of water into a soil surface. It should not be confused with hydraulic conductivity, or permeability, which is a measure of the ability of a soil to transmit water in all directions, horizontally as well as vertically. Two figures are of interest - the initial intake rate (say in the first hour) and the equilibrium or basic infiltration rate which is the constant rate that develops after several hours.

Infiltration rates can be measured by observing the fall of water within two concentric cylinders driven vertically into the soil surface layer. The use of a double cylinder (colloquially double ring), with measurement confined to the inner ring, minimises error due to non-vertical flow at the edge of the cylinder. If two metal cylinders are not available the outer one can be replaced by an earth bund.

Water of the same quality as will be applied in irrigation should preferably be used, or misleading results may ensue. Quirk (1957), for instance, has demonstrated substantial increases in infiltration rates by increasing the electrolyte concentration of the applied water. The soil sites to be tested should be thoroughly pre-wetted: soaking for a few hours using an earth bund at each site is sufficient for most soils, but dry, fine-textured soils may need several days' soaking. The site should be covered with polythene after soaking to prevent surface drying. This pre-wetting allows the rings to be inserted more easily than in dry soils, and helps to reduce variations in rates caused by differences in initial moisture status (see Turner and Sumner, 1978).

The test should normally be run until the steady state is reached (usually from about 3 to 5 h). The amount of water required depends on soil conditions. One 200 ℓ drum may suffice on impermeable clays whereas sandy soils may take four or five drums. The test does not work well on cracked clays as the water disappears too fast and the results are too variable to be reliable. Where necessary, sample(s) should be taken at depths of 25, 75 and 150 cm to determine the moisture content of the soil before the test commences. The initial water content during soil survey operations is likely to be variable, but the test cannot be done on saturated soil. If there is temporary waterlogging of the site, wait until downwards draining recommences. Evaporation rates are usually too low to be significant, but if the infiltration rate is very low and the weather is hot and dry it is necessary to correct for evaporation.

At least three replicates should be run at each site, preferably close to a sampled profile pit so that complete data on the soil are obtained. The test can be made on bare or vegetated soil, but note that the rate under grass is usually substantially higher than on cultivated land. The vegetation must be clipped down so that it does not break the water surface, and loose material which would float should be cleared off.

1.2 Equipment (for three replicate tests made concurrently)

Three steel cylinder sets, 40 cm high (old oil drums provide ideal material). Seam is ground smooth on inside. One end should be bevelled from outside to inside. For ease of transport replicate cylinders should be of slightly different diameters to allow concentric stacking when not in use: the inner ones should be about 30 cm and the outer ones about 60 cm in diameter; these dimensions allow an old inner tube to be floated in the outer ring to dissipate the force of water during refills.

One hardwood 15 x 15 cm timber (optionally having 0.6 cm steel plate bolted to one side).

1/ Adapted to standard BAI practice from FAO (1979a).

Means of storing and transporting water (water trailer or drums, plus six buckets).

7 kg sledge-hammer, or heavy weight with handle.

Three still wells (20 to 25 cm lengths of 10 cm ID perforated plastic drainpipe) used to reduce movement of water surface caused by refills.

Three floats and scales; three float guides.

Three old inner tubes.

Piece of sacking or plastic sheet.

Auger and shovel.

Knife or shears for cutting vegetation.

Three stop-watches.

Standard observation forms (see Figure B.1) and clipboard (preferably one per replicate).

Graph paper (1 mm squared, Chartwell Ref C14G).

1.3 Procedure

a) Record information on the soil surface at the time of the test, eg the presence of any surface litter, the condition of the soil surface (cultivated, crusted, cracked, etc) and any other conditions which might affect the rate of water intake. Select sites about 10 m apart in areas representative of the soil to be tested, and sample the soil just outside the rings to determine the initial moisture content.

b) Drive cylinders into the pre-wetted soil to approximately 15 cm depth, placing the driving plate over the cylinder with the heavy timber on top. Rotate the timber every few blows and check that penetration is uniform and vertical (alternatively, in very hard soils, cut soil round rim with knife to insert cylinder, and then seal the edges with bentonite). Firm the soil next to the inside and outside of the cylinders. Place sacking or plastic sheet and inner tubes (or similar) over the soil to dissipate the force of the water and reduce turbidity. Get everything ready for all three replicates before starting the test.

c) Fill both cylinders to a depth of about 15 to 20 cm at the first site, and record the time and the height of the water in the inner cylinder, using the floating scale in the still well.

d) Repeat for each replicate. Remeasure the levels after 1, 5, 10, 20, 30, 45, 60, 90, 120 min and each hour for the remainder of the test (more often if the infiltration rate is rapid). Also record levels immediately before and immediately after each refill; if no floating scale is available, levels can be measured from the water surface to the top of the cylinder before and after topping up. The water in the outer cylinder should be kept at approximately the same level as in the inner one to avoid any interaction affecting the inner level. The fall in level should be kept to less than half the maximum depth of water.

e) Record readings on a standard form (see Figure 21) and calculate the rates. The curves of infiltration vs time should be plotted on graph paper and the cumulative amount of water infiltrated also plotted as a check (see Figure 6.1). There is ample time to do this in the field between measurements and it should be done at once so that errors can be rectified. If one cylinder gives a widely different rate from the others (perhaps because of a hidden insect burrow) reject the result when making the averages.

f) After the test period remove the cylinders and dig a cross-section through the centre of the 30 cm cylinder site in order to describe the soil morphology and observe and record the outline of the wetted soil. In some conditions auger borings can be used to delineate the wetted area; in sandy or moist soil the wetting pattern may be too deep or indeterminate to outline. Where field capacity and/or bulk density measurements are to be made, the digging-out process should be left for 48 h until these other measurements are complete.

g) From the graph the values of the maximum initial infiltration rate and the basic rate can be obtained. Measurements should be made at several sites on the same soil series to obtain a reliable average. The infiltration rates for various soils can then be compared, and the diagram of the wetting pattern is helpful in explaining differences between them (for example, claypan soils may have rapid initial intake which soon decreases to very slow, whereas loamy friable soils may have a lower initial intake rate but a higher final rate).

Ring infiltration: worked example of field data sheet | Figure 21

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INFILTRATION RATE MEASUREMENT BAI

Project	Site No
DSS	64

Prewetting	Source/EC of water	Date	Author	Sheet No	Replicate No
44 gal application to 12m² area 72 hr previously	Well 250m SE of site	27 Jul 83	PLS	1	1

Height of zero above soil surface (cm)	Depth of insertion of ring (cm)	Land class
0	15	2s

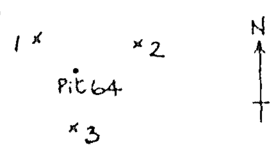
Surface features	Soil
Slight capping 0-2cm (see profile field sheet) No vegetation.	DHO 1

Local time	Interval (mins)	Cumulative time (mins)	Depth of water in infiltrometer (cm)	Intake (cm)	Cumulative intake (cm)	Infiltration rate (cm/hr) Immediate	Infiltration rate (cm/hr) Mean
8 00	0	0	12.0	-	-	-	-
	2	2	9.1 - 10.9	2.9	2.9	87.0	87.0
	3	5	10.1 - 12.1	0.8	3.7	16.0	44.4
	2	7	11.7	0.4	4.1	12.0	35.1
	1	8	11.6	0.1	4.2	6.0	31.5
	4	12	11.1 - 13.5	0.5	4.7	7.5	23.5
	4	16	13.0	0.5	5.2	7.5	19.5
	8	24	12.2	0.8	6.0	6.0	15.0
	8	32	11.5	0.7	6.7	5.25	12.6
	13	45	10.2 - 14.8	1.3	8.0	5.2	10.7
9.00	15	60	13.5	1.3	9.3	5.2	9.3
	15	75	12.2 - 14.5	1.3	10.6	5.2	8.5
	15	90	13.2	1.3	11.9	5.2	7.9
	15	105	12.1	1.1	13.0	4.4	7.4
10.00	15	120	11.0 - 15.1	1.1	14.1	4.4	7.0
	15	135	13.9	1.2	15.3	4.8	6.8
	15	150	12.7	1.2	16.5	4.8	6.6
	15	165	11.6 - 13.3	1.1	17.6	4.4	6.4
11.00	15	180	12.2 - 14.8	1.1	18.7	4.4	6.3
	15	195	13.6	1.2	19.9	4.8	6.1
	15	210	12.5	1.1	21.0	4.4	6.0
	15	225	11.5	1.0	22.0	4.0	5.9
12 00	15	240	10.5	1.0	23.0	4.0	5.8

Diagram/Comments

Moisture penetration to 80cm

Replicate locations:



h) Notes: 1. During filling, care must be taken to avoid puddling or disturbance of the soil surface by using the sacking or plastic sheet. Care should also be taken to prevent the rings becoming undermined and thus allowing seepage to occur.

2. During the experiment, the water in the outer guard ring and inner ring should be kept at the same level by the addition of water to the outer one after topping up the inner.

3. On dry clay soil it is particularly difficult to hammer the rings into the ground. The hard soil surface tends to shatter and it becomes exceedingly difficult to obtain a good seal. If necessary after pre-wetting, the rim should be sealed with bentonite to make absolutely sure there is no leakage.

2 Field measurement of hydraulic conductivity: auger-hole and inverse auger-hole methods 1/

2.1 Introduction

Hydraulic conductivity (see Section 6.3) refers to the subsurface movement of water within a soil, both vertically and horizontally. Measurements are mostly used in connection with the design of drainage systems in wet land and in canal seepage investigations. The most common measurements made involve the combined horizontal and vertical water movements under saturated conditions, although for special investigations unsaturated flows and/or the vertical and horizontal components may be considered separately. Similar remarks to those for infiltration rate (Subsection B.1.1) apply to water quality and pre-wetting when making hydraulic conductivity tests by the inverse auger-hole method, but the quantity of water is very much lower; often only half a 200 ℓ drum will be sufficient.

2.2 The auger-hole method

The auger-hole method is based on a hole bored into the soil to a certain depth below the water-table. When equilibrium is reached with the surrounding groundwater, a volume of water is removed from the hole and the surrounding groundwater allowed to seep in to replace it. The rate at which the water rises in the hole is measured and then converted by a suitable formula to the hydraulic conductivity (K) for the soil. The simplest approach is provided in van Beers (1976) and in FAO (1979a, Appendix B.1) which set out in simple and convenient detail the method and calculations to be used for practical purposes; the experimental set-up is shown in Figure 22, and photographs of the installation are given in van Beers (1976, p 10). For tests made by BAI, note that the pointer is set at ground level, not on a stand, which simplifies the calculation slightly.

The auger-hole method gives the average permeability of the soil layers extending from the water-table to a small distance (a few decimetres) below the bottom of the hole. If there is an impermeable layer at the bottom of the hole, the value of K is governed by the soil layers above this impermeable layer. The radius of the column of soil of which the permeability is measured is about 30 to 50 cm.

The use of this method is limited to areas where a high GWT occurs (at least during part of the year) and to soil where a boring of known shape can be maintained throughout the test. Hence in certain sandy soils it is necessary to use a perforated tube as support for the sides (see notes below). The method is unsuitable for use in very stony or coarse soils because of the difficulty of augering a uniform hole in such materials. It is also unusable when artesian conditions occur, or in soils containing small sand lenses within less permeable material. In general, however, the method is suitable for most agricultural soils.

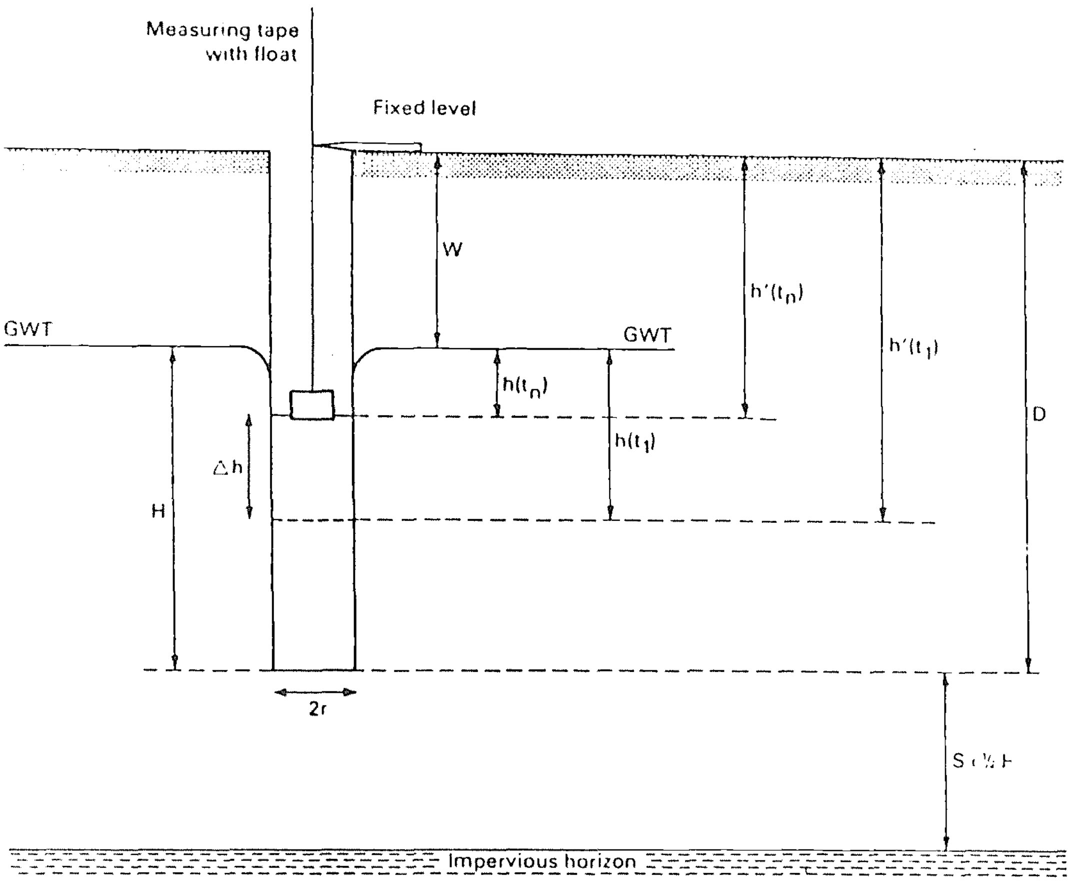
Normally three replicates are run consecutively at each investigation site, since the time involved for each replicate is of the order of half an hour.

2.3 Equipment for auger-hole method

8 cm diameter auger

1/ Much of this section is reproduced from ILRI (1974) by permission.

The auger-hole method for hydraulic conductivity measurement — Figure 22



W =	depth of GWT below fixed level
$H = D - W$ =	depth of the auger hole below water-table
$h'(t_1), h'(t_n)$ =	depth of GWT in the hole below fixed level at the time of the first reading (t_1) and after some readings (at time t_n). Usually about five readings are taken
$\Delta h = h'(t_1) - h'(t_n) = h(t_1) - h(t_n)$ =	the rise of water-level in the hole during the time of measurements
$\bar{h} = h(t_1) - 0.5\,\Delta h$ =	average head during time of measurements
S =	depth of impervious horizon below the bottom of the hole
r =	radius of hole

Source: *Adapted from van Beers (1976)*

Tape measure and holder/pointer

Float (with attachment for tape measure)

Stop-watch

7.5 cm diameter bailer (can be made from a 1 m length of 7.5 cm (3 in.) diameter drainpipe, fitted with a flap valve at the base and rope handle at the other end)

Screen or perforated plastic tube

The tube material should be about 2 mm thick, with perforations of about 0.5 mm diameter spaced about 4 mm apart, in order to cover about 20% of the tube surface. The screen or tube should be cylindrical, 10 cm in outer diameter for a hole with a diameter of 10 cm, and 1 m in length. For drawing the tube out of the borehole a kind of drawhook is useful. A reinforcement with a riveted ring is fitted to each end of commercial screens, and cams for holding a drawhook can be secured to the top of the screen tube.

Side scratcher to clean sides of hole and remove smearing effects

Can be made from a tube approximately 7 cm diameter by 9 or 10 cm long, with nails protruding 0.3 or 0.4 cm. Cylinder should be fitted with coupling to allow connection to auger handle.

Special cutter (to give flat bottom to hole)

Bucket and water supply

Standard observation forms and clipboard

Graph paper (semi-log)

For inverse auger-hole method:

Small piece of sacking (or coarse sand fill) to prevent erosion of bottom of hole.

2.4 Procedure for auger-hole method

a) Select sites (and about 3 to 5 stations at each) as for infiltration tests (see Subsection B.1.1), and record site information (as Subsection B.1.2a).

b) Auger and describe a hole of about 8 cm diameter (or more) to a depth below the water-table, and finish off with a special cutting tool to obtain a flat bottom to the hole; take care to eliminate smearing of the sides of the hole (Smitham, 1970). The hydraulic conductivity is calculated as below using the graphs provided in van Beers (1976) or Maasland and Haskew (1957). If the hole penetrates two or more horizons below the water-table, the hydraulic conductivity of each horizon can be determined approximately using the method described by van Beers (1976). In such heterogeneous profiles, however, the piezometer method may be preferable (see eg Johnson et al, 1952; Luthin and Kirkham, 1949; review by Luthin, 1957; ASAE, 1962).

c) Place the tape holder near the hole so that the steel tape, with float attached, hangs exactly vertically in the hole.

d) Lower the float to the groundwater surface and record this level.

e) Lift the float carefully from the hole and turn the tape holder sideways so that it is clear of the edge of the hole.

f) Bail the water from the hole until the level is reduced by about 20 to 40 cm (this may take one or two bailings), rapidly return the pointer to its former position, and lower the float to the surface of the groundwater. The readings should then be started as soon as possible.

g) Take about five readings at regular intervals of about 5 to 30 sec, depending on the hydraulic conductivity; time between readings should correspond to a rise of about 1 cm in water-level. The steel tape or float may tend to stick to the wall of the cavity, and so should be tapped regularly. All readings, including groundwater level and depth of the hole, are taken at the contact of the tape on the pointer.

h) Measure the depth of the hole.

i) The hydraulic conductivity is calculated as below, or using the graphs provided in van Beers (1976) or Maasland and Haskew (1957).

k) Note: In unstable sandy soils it is necessary to use the perforated tube as a support for the sides. The auger is used up to the point where the hole becomes unstable, then the perforated tube is lowered into the hole. R··

moving the bailer up and down a mixture of sand and water will enter the bailer and the tube can be pushed downwards to the desired depth.

A good rule of thumb is that the rate of rise in mm s^{-1} in an 8 cm diameter hole to a depth of 70 cm below the water-table approximately equals the K value of the soil in m day^{-1}.

Care should be taken to complete the measurements before 25% of the volume of water removed from the hole has been replaced by inflowing groundwater. After that, a considerable funnel-shaped water-table develops around the top of the hole. This increases resistance to the flow around and into the hole. The effect is not accounted for in the formulae or flow charts developed for the auger-hole method and, consequently, it should be checked that $\Delta h < 0.25h(t_1)$.

It often happens that h is relatively large for the first reading, due to water dripping along the walls of the hole directly after bailing. If this occurs, the first measurement should be discarded.

2.5 Auger-hole method: calculation for the single-layer situation

Ernst (1950) found that the relation between the hydraulic conductivity of the soil and the flow of water into the auger hole depends on the boundary conditions; this relation, derived numerically, is given as:

$$K = C \frac{\Delta h}{\Delta t}$$

where K = hydraulic conductivity (m day^{-1})

C = geometry factor = f ($\bar{h}$, H, r, S)

$\frac{\Delta h}{\Delta t}$ = rate of rise of water-level in the auger hole (cm s^{-1})

2.8 Hydraulic conductivity measurement above the water-table: the inverse auger-hole method

The inverse auger-hole method (Kessler and Oosterbaan, 1974; FAO, 1979a, Appendix B.1) is an auger-hole test above the water-table, and is described in French literature as the Porchet method. It consists of augering a hole to a given depth, filling it with water and measuring the rate of fall of the water-level. The experimental arrangement is very similar to that of the auger-hole test, except that water is poured into the hole, rather than removed, and a fall in level is recorded rather than a rise; an example is illustrated in Figures 24 and 25.

Due to the swelling properties of soil, a K value obtained by this method may differ from one obtained if the soil is saturated. If this change of structure is significant, it has to be taken into consideration when the measured K is evaluated. Similarly, the test should not be done on a dry soil but only after saturating the test site, eg by conducting the test immediately after an infiltration measurement.

The calculation is as follows:

For the cylindrical auger hole and its flat base

$$A(t_i) = 2\pi r\, h(t_i) + \pi r^2$$

where $A(t_i)$ = area through which water passes into the soil at time t_i (cm^2)

r = radius of the auger hole (cm)

$h(t_i)$ = water-level in hole at time t_i (cm)

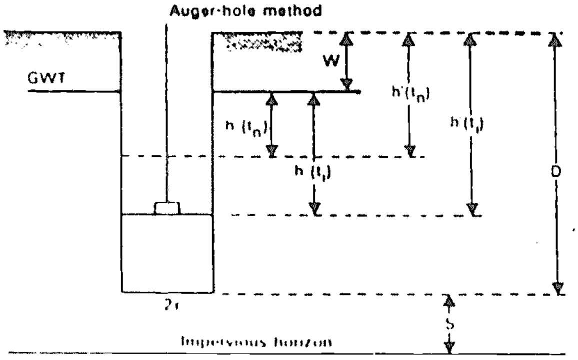
Auger-hole method: worked example of field data sheet — Figure 23

BOOKER AGRICULTURE INTERNATIONAL LTD.
HYDRAULIC CONDUCTIVITY MEASUREMENT — BAI

Project	Replicate No	Site No
CB Estate	1	JRL 1

Date	Author	Soil	Land Class
2 Dec 83	CB	A R	2d

Auger-hole method



Radius of hole, r (cm)	Depth of hole, D (cm)
4	240

Depth of GWT, W (cm): 114

H = D − W (cm)	S (cm)
126	$> \frac{1}{2}H$

Conductivity, K (m/day): 0.7

i	t_i sec	$h(t_i)$ cm	$h(t_i)-h(t_n)$ cm	i	t_i sec	$h(t_i)$ cm	$h(t_i)-h(t_n)$ cm
1	0	145.2	–	10			
2	10	144.0	1.2	11			
3	20	142.8	1.2	12			
4	30	141.7	1.1	13			
5	40	140.6	1.1	14			
6	50	139.6	1.0	15			
7				16			
8				17			
9				18			

Check $\Delta h = h(t_1) - h(t_n) < \frac{1}{4} h(t_1)$ $\quad 5.6 < \frac{1}{4}(145.2 - 114) = \frac{1}{4} \times 31.2 = 7.8$

$\bar{h} = h(t_1) - \frac{1}{2}\Delta h = 28.4$ cm $(31.2 - 2.8)$

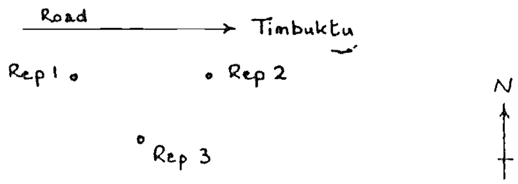
$H/r = 31.5 \quad \bar{h}/r = 7.1 \quad \Delta h/\Delta t = 5.6/50 = 0.11$

$K = C\,\Delta h/\Delta t$ m/day $\quad C = 6.0$ (from Fig. B.4)

$= 6.0 \times 0.11$

$= 0.7 \text{ m day}^{-1}$

Diagram/comments

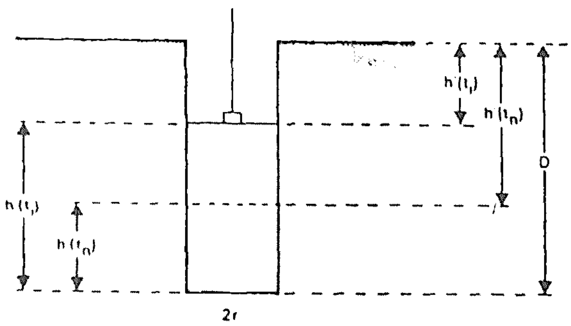


Auger hole possibly slightly smeared

Inverse auger-hole method: worked example of field data sheet   Figure 24

BOOKER AGRICULTURE INTERNATIONAL LTD HYDRAULIC CONDUCTIVITY MEASUREMENT	Project Zangaro River	Replicate No 2	Site No. JRL 2
	Date 2 Jul 79	Author CB	Soil AW (1)	Land class 3sd

Inverse auger-hole method



Radius of hole, r (cm)	4
Depth of hole, D (cm)	100
Source of water	Zangaro River
Prewetting	Soaked twice (48 and 24 h) before test - 4 buckets per soaking. 1 bucket soaking on test day
Depth of GWT (cm)	> 5m (estd)
Conductivity, K (m/day)	0.7

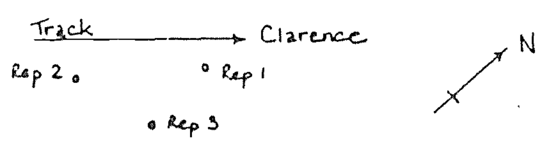
i	t_i sec	$h'(t_i)$ cm	$h(t_i)$ cm	$(ht_i + r/2)$ cm	i	t_i sec	$h'(t_i)$ cm	$h(t_i)$ cm	$(ht_i + r/2)$ cm
1	0	73	17	19	17				
2	40	74	16	18	18				
3	80	75	15	17	19				
4	150	76	14	16	20				
5	250	77	13	15	21				
6	350	78	12	14	22				
7	550	79	11	13	23				
8	750	80	10	12	24				
9	975	81	9	11	25				
10					26				
11					27				
12					28				
13					29				
14					30				
15					31				
16					32				

$$K = 1.15\,r\,\frac{\text{Log}\,(h(t_i) + r/2) - \text{Log}\,(h(t_n) + r/2)}{t_n - t_i}\ \text{cm s}^{-1}\ \times 864 = \text{m/d}$$

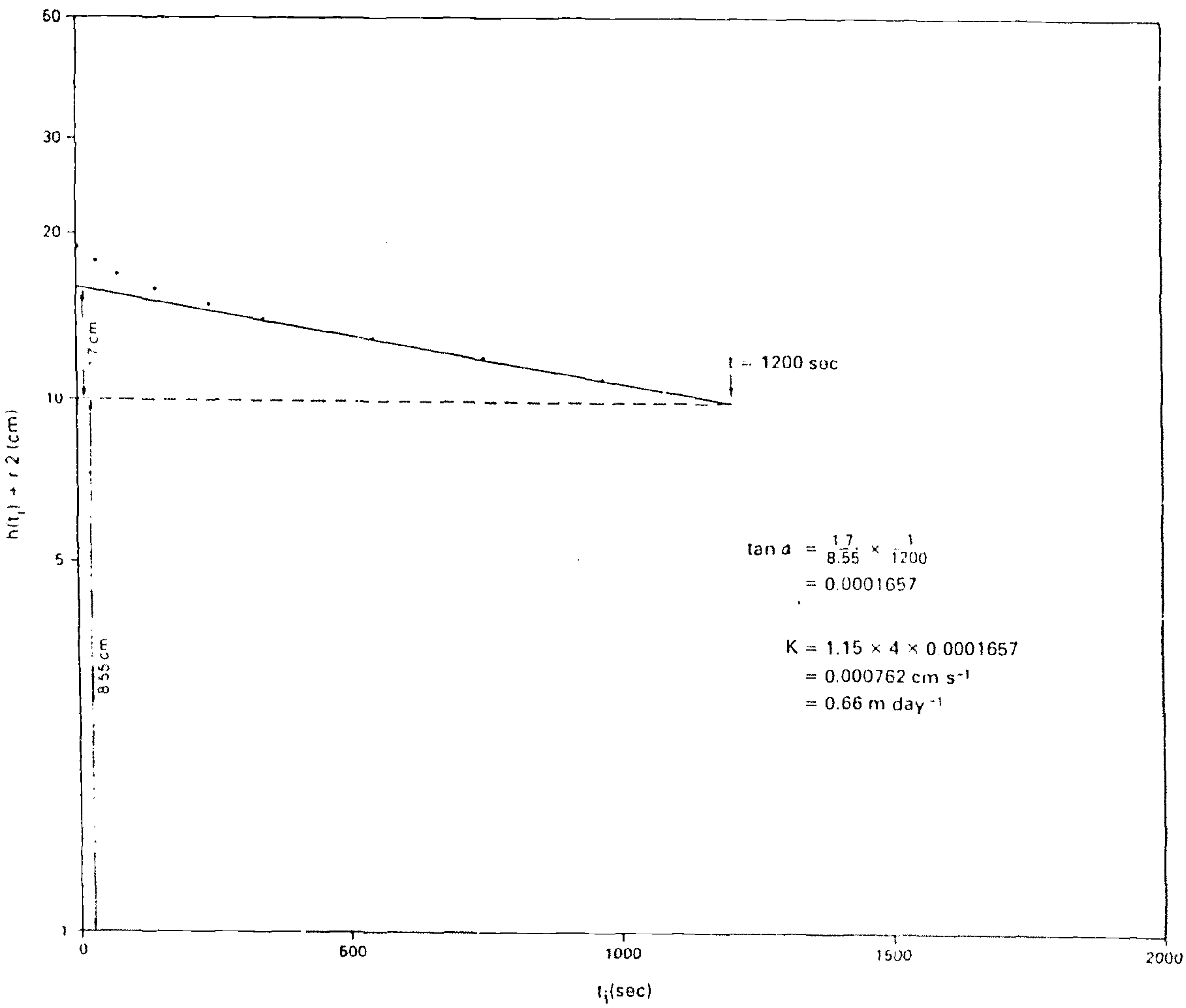
$K = 0.66\ \text{m day}^{-1}$ (from Fig B.9)

A plot of $(h(t_i + r/2)$ against t on semi-log paper gives a straight line with slope α where $K = 1.15\ r \tan \alpha$

Diagram/comments



Inverse auger-hole method: worked example - graph | Figure 25



Graph paper required: 2 cycle logarithmic one way scale (also called semilog paper) 0.1, 0.5 and 1 cm.

A4 size - Chartwell reference No C5521

Supposing that the hydraulic gradient is approximately one, then according to Darcy's Law (Subsection 6.3.2) the volume rate of flow is given by:

$$Q(t_i) = KA(t_i) = 2K\pi r\ (h(t_i) + r/2)$$

where $Q(t_i)$ = volume rate of flow at time t_i ($cm^3\ s^{-1}$)

If during the time interval (dt) the water-level falls over a distance (dh), the volume rate of flow into the soil equals:

$$Q(t_i) = -\pi r^2 \frac{dh}{dt}$$

Combining the last two equations gives:

$$2K\pi r\ (h(t_i) + r/2) = -\pi r^2 \frac{dh}{dt}$$

Integration between the limits

$$t_i = t_1,\ h(t_i) = h(t_1) \text{ and}$$
$$t_i = t_n,\ h(t_i) = h(t_n)$$

gives:

$$\frac{2K}{r}(t_n - t_1) = \ln\ (h(t_1) + r/2) - \ln\ (h(t_n) + r/2)$$

Changing to common logarithms and rearranging gives:

$$K = \frac{1.15r\ [\log\ (h(t_1) + r/2) - \log\ (h(t_n) + r/2)]}{t_n - t_1}$$

$$= 1.15r\ \tan\ \alpha$$

By plotting $(h(t_i) + r/2)$ against t_i on semi-logarithmic paper, a straight line with a slope α is obtained (see Figure B.9). (Note that the slope calculation includes a direct length measurement on the graph paper).

B.2.9 Inverse auger-hole method: constant level methods

In some circumstances it is desirable to maintain the level of water in the hole during an inverse auger-hole test so that the water remains, say, within a particular soil horizon. The hydraulic conductivity is then calculated from readings of the volume of water necessary to maintain the constant level in the hole. The experimental set-up, although somewhat more complex than for the falling-head method, is not difficult to use: full details are given in FAO (1979a, pp 173ff). Note the comments on values obtained as given in Subsection 6.3.5.