LECTURE NOTE

SOS 518

SOIL SURVEY AND LAND USE PLANNING

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Soil Forming minerals and rocks

Soil Morphological Characteristics

BASIC PRINCIPLES OF CLASSIFICATION

Why classify?

The purpose of any classification is so to organize our knowledge that the properties of objects may be remembered and their relationships may be understood most easily for a specific objective. The process involves formation of classes by grouping the objects on the basis of their common properties or characteristics. In any system of classification, groups about which the greatest number, most precise, and most important statements can be made for the objective serve the purpose best.

Classification helps us deal with complexity. There are too many objects to consider individually. If we can find some common properties or behaviour between them, we can make meaningful classes to help us organize our knowledge and simplify our decision-making.

We classify individual objects, for example soil profiles, by grouping them into classes, or example soil series. These classes then form other objects that can in turn be classified into still more general classes, for example, reference soil groups. This is a hierarchical classification, and is common in soil science.

• Types of objects

– Individuals

– Populations

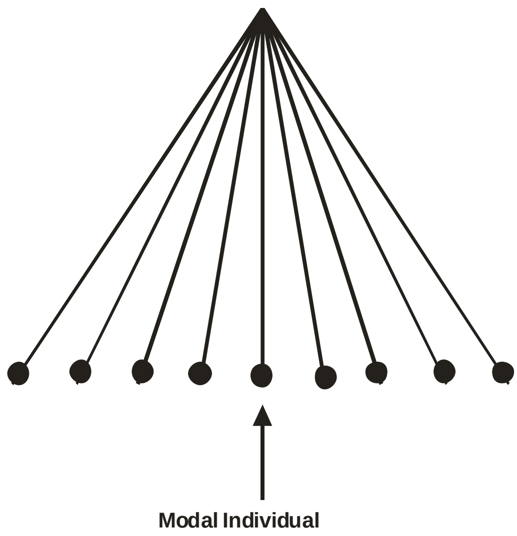
– Sub-populations (strata)

Key concepts of classification

Individual objects make up a population. A class is a group of individual or other classes similar in selected properties and distinguished from all other classes of the same population by differences in these properties. There is diversity in the degree of differences among classes. These diversities make classes of natural object grade by small step into other classes (differences are gradational).

Within every class, there is a central core or nucleus to which other individual members of the class are related in varying degree. This central individual is referred to as the **modal individual**. The modal individual, who is at the centre, typifies the modal properties of the class. In the immediate vicinity of the modal individual are many individuals held by bond of resemblance and similarity so strong that no doubt can exist as to their relationship with the modal individual. At the margins of the group are many individuals less strongly held by bond of resemblance but strongly held by similarity to the modal individual than to that of any other class.

The test of proper placement of any marginal individual is its relative degree of similarity to the modal individuals of different classes.



Differentiating Characteristics

The property chosen as the basis of grouping is called the differentiating characteristic. It serves to differentiate among classes. If the basis of grouping is good, the differentiating characteristics should be associated with a number of co-varying properties or accessory characteristics. For example, soil texture affects cation exchange capacity (CEC), bulk density and hydraulic conductivity. A well conceived grouping is based upon differentiating characteristics that:

- Is important for the objective of classification and
- Carry the greatest possible co-varying or accessory characteristics that are also important for the objective of classification.

Category

A category is a series of classes, collectively formed by differentiation within a population on the basis of **a single set of criteria**. A category must include individuals of the population and groups within a category are classes at a defined level of abstraction.

In any multiple category system, regardless of the number of categories, the properties that are homogenous in a given class consist of the accumulated differentiating and accessory characteristics of that category and all other categories above it. The greatest number of statement can be made about classes of the lowest categories and the least number of statements can be made about units of the higher category.

Formation of classes at a lower categorical level in their final form, pre-supposes knowledge of the population adequate enough to complete all categories above it. As the body of knowledge about any phenomena increases, attempt to effect a complete natural system of classification must pass through a series of approximations or adjustments.

Principles of differentiation as they affect classes

The properties of differentiating characteristics that would meet the conditions of natural system of classification as laid down by Cline (1949), Smith (1963) and Arnold and Eswaran (2003) are as follows:

- A differentiating characteristic must be important for the objective.
- A differentiating characteristic must be a property of the things classified or a direct interpretation for the objective.
- The differentiating characteristics should carry as many accessory properties as possible for the objective.
- The class interval of a differentiating characteristic must provide classes homogenous for the objective. When differentiation is based upon the degree of expression of an attribute, the limiting value of that property between classes of a continuous series may be placed arbitrarily at any point in the series. Not all points within such a series are equally pertinent for a given objective, however, and the establishment of the class interval for the most useful grouping is not arbitrary. Soil classification must rely on data of the observation and experiment for establishment of the significant limiting values of classes.

Principles of differentiation as they affect relationship among categories

- Differentiating characteristics must classify all individuals in any single population. This is what Nikiforrof calls the principle of wholeness of taxonomic categories. Every category must include all existing individuals of the population, therefore, the differentiating characteristics of each category must apply to all individuals or some individuals will remain unclassified.
- Greatly different "kingdoms" require different differentiating characteristics at the same level of abstraction. This principle rest upon the concept of degree of differences among groups of things at different levels of abstraction. Within natural phenomena called soil, there may be populations that have so few important common properties that a single differentiating characteristic at a given level of abstraction would not frame the important classes in each. The breach between organic and inorganic soil may be that order of magnitude.

- All classes of the same category of a single population should be based on the same characteristic. To differentiate on different properties at the same categorical level complicates the problem of visualizing relationships.
- A differentiating characteristic in one category must not separate like things in a lower category. Every characteristic has a ceiling of independence above which it cannot be used to differentiate without separating like things in categories below it. Differentiation at a higher categorical level on any basis must separate on the same basis throughout all lower categories; consequently the properties to be used to differentiate at higher level of generalization must be more important for the objective than those used at lower levels. The importance of a differentiating characteristic must be commensurate with the level of abstraction at which it is used.

Principles of soil classification

What is different about soils?

- There is really no soil '**individual**' as a self-standing object.
- Therefore, the emphasis is on defining **mappable** classes rather than on optimal classification of individuals.
- There is no true **inheritance** or genetics as it is understood in biology

Concept of the pedon as a discrete object within the soil continuum (Soil individuals)

The dimension of the ultimate individuals of the soil population are fixed vertically by the thickness of the soil profile and horizontally by the practical limits of space required for its observation. Vertically, the soil unit must extend from the surface into the parent material; any lesser depth would divide the complete natural body. Horizontally, the limit are not sharply defined; the unit must extend in two directions far enough to allow sampling and accurate determination of the properties that can be observed in the field. It must also be large enough to permit the observation of relationships of the horizons to the rooting of plants. What is a pedon?

The major difficulty in defining soil individuals or basic entities follows from the existence of soil as a continuum. However, the term **pedon** has been proposed as a collective noun for a small basic soil unit that can be regarded as the basic soil entities or soil individual. As a generic term, pedon would thus be parallel to the word 'tree' as a collective noun covering mahogany, pines, leguminous trees, oaks etc. The pedon is in a sense an abstraction or soil unit that is a creation of the mind (Marburt, 1941). According to the terminology of Knox (1965), the pedon is an artificial rather than a natural individual. Each pedon consist of a small volume of soil that is a part of the continuum mantling the land surface. Each pedon begins at the surface and extend downward to include the full set of horizons or to some arbitrary depth corresponding to the vertical dimension of a set of horizons. The upper boundary of pedon is clear enough, but the lower boundary remains vague as a rule. The perimeter is gradational from one pedon to its neighbours.

A pedon consists of a small volume of soil which includes the full solum and the upper part of the unconsolidated parent material. It is usually less than two metres (2m) in depth, and has a lateral cross-section that is roughly circular or hexagonal in shape and between $1m^2$ and $10m^2$ in area. The smallest of these lateral dimensions is proposed for use in most soils, while the larger dimension up to the maximum of $10m^2$ is proposed for uses where needed to cover the full amplitude of one circle in the arrangement of horizons (Simonson and Gardner, 1960).

Source of criteria for soil classification.

For most part, the criteria used to classify soil are those that can be observed or determined rapidly by simple tests on the field. Until techniques are developed that will allow rapid chemical determinations on the field, one should expect homogeneity of chemical properties of soil units only to the extent that these chemical properties are accessory to the observed characteristics used to classify the soils.

Controlled experiments establish relationships that enable selected criteria to which many properties that cannot be observed are accessory. For example, soil colour can tell much about the drainage property of the soil as well as probable level of iron and aluminum oxide in the soil as well as the soil organic matter content.

Criteria for soil classification.

Soil classification is passing through a series of approximations in which the system is being built from the lowest category upward by a process of reducing homogeneity in each successive higher category. Our choice of differentiating characteristic in the higher categories is limited by our knowledge not only of soil properties but also of the relationship among soil properties.

Marbut (1932) proposed the following properties for differentiating soils at the level of soil type:- [What is a soil type?]

1. Number of horizons in the profile
2. Colour of various horizons with special emphasis on the surface one or two
3. Texture of each horizon
4. Structure of the horizons
5. Relative arrangement of horizons
6. Thickness of horizons
7. Thickness of the true soil (profile)
8. Chemical composition of horizons
9. Character of the soil material [alluvial, loess, sand]
10. Geology of the soil material [parent material]

Each of the 10 factors listed varies narrowly in a soil type within the limitation of precision of their measurement. It would be sheer accident if any property could be found to differentiate at higher categorical level than soil type, which is not either a characteristic listed by Marbut or a characteristic to which the properties listed by Marbut are accessory. Therefore, the properties listed by Marbut are accessory characteristics of those attributed whose ceiling of independence are high enough to justify their use in higher categories.

The first step in the selection of differentiating characteristics of higher categories, therefore, is to define the characteristics to which the properties listed by Marbut are accessory. Most of the properties listed are characteristics of individual horizons. All of them, collectively, plus inferences from them, however, define the whole soil, not only in terms of all its horizons but also in terms of relationships among horizons.

Criteria used in Higher Category of soil taxonomy (Classification)

The criteria used in the classification of soils in the higher categories are obtained from the different horizons that make up the pedon or soil individuals. These include the morphology, chemistry, physical and mineralogical properties of the soils. The morphology and some physical properties are observable properties that can be determined rapidly on the field, while the chemical and mineralogical properties are measurable in the laboratory, and their figures could be correlated with corresponding morphological descriptions.

A soil horizon may be defined as a layer within a soil that is approximately parallel to the soil surface and that have properties that are produced by soil forming processes but differs from the adjacent genetically related soil layers in terms of physical, chemical and biological properties, such as colour, structure, texture, consistence, kind and population of organisms, presence or absence of mottles, concretions, bulk density etc. A set of horizons within a single pit constitutes a soil profile. Thus a profile is a vertical section of the soil through all its horizons and extending to the parent material. Agriculturally, the depth of horizon is arbitrarily set at a depth of not more than two metres (2m).

SOIL PROFILES AND HORIZONS

MASTER HORIZONS

Horizontal layers of soil called horizons can be described by their different morphological characteristics. Capital letters designate master horizons, which are further subdivided by Arabic numerals. Master horizons are used to describe similar appearing soil layers and should not be confused with diagnostic horizons used to classify soils.

O Horizon

O horizon is an organic horizon. It is a surface layer characterized by accumulation of organic matter which may be dominated by partially decomposed or undecomposed organic material. An O horizon may be found below the surface if it has been buried. Predominantly found in forested regions, the O horizon is composed of leaf litter in various stages of decay. If the clay content of any horizon is more than 50%, the organic matter content of the horizon must be more than 20% before the horizon can be regarded as O horizon.

There are two types of organic horizon. These are Oi and Oa. Oi is an organic horizon in which the original features of the organic matter are still visible to the naked eye. For example, if the O horizon is from vegetation, the vegetation can still be seen. They are not fully decomposed. In Oa horizon however, the features of the original organic material is no longer visible to the naked eye because they have been totally decomposed. When the O horizon has been partially buried, they are designated as Oe.

A Horizon

The A horizon is the uppermost mineral layer. It may lie below the O horizon. An A horizon has a high concentration of humus and is not dominated by the migration of clay, humus, aluminum, or iron into or out of the horizon. It is transitional between the B and E horizons, but in many soils, the amount of eluviations that has taken place is so small that we hardly have an E horizon. Since it is formed on or adjascent to the soil surface, it is darker in color than the underlying horizon because of the organic matter accumulation.

E Horizon

The E horizon is an elluvial surface horizon. It has experience the loss of clay, organic matter, iron and aluminum oxides with the resultant accumulation of quartz and other resistant minerals. It is also characterized by bleached appearance because of loss of materials. The remaining material tends to be light colored and coarse textured. The E horizon is normally found below an O or an A horizon and above a B horizon. However, it may separate sections of a B horizon. It should be noted however, that E horizon is not common in Nigerian soils.

B Horizon

The B horizon is a subsurface mineral horizon showing evidence of one or more of the following processes:

1. illuvial accumulation of alumino-silicate clay, iron, aluminum, gypsum, or silica;
2. carbonate removal;
3. residual concentration of sesquioxides and silicate clay;
4. coating of sesquioxides, which makes the horizon conspicuously lower in color value, higher in chroma, or redder in hue without apparent illuviation of iron than that found in the overlying and underlying horizons;

5. alteration of materials from its original condition i.e. lots of pedogenic processes are taking place. Formation of silicate clay or liberation of oxides, or both, and formation of granular, blocky, or prismatic structure if volume changes accompany changes in moisture context; or
6. brittleness.

It should be noted that there are no universal diagnostic properties that can be taken as satisfactorily for identifying all B horizons. The development of B horizon is an indication of soil maturation.

C Horizon

The C horizon is a layer of minimal alteration. Material may be similar to or unlike that from which the other horizons formed. C horizons lack the properties of O, A, E or B horizons, and can include coprogenous earth (sedimentary peat), diatomaceous earth, saprolite, unconsolidated bedrock, and other uncemented geologic materials or materials soft enough for excavation with moderate difficulty.

R Layer

An R layer refers to hard consolidated bedrock. Material is cemented and manual excavation is impossible. Intrusive soils can be found in rare cracks in the bedrock. Examples of R layer material include: granite, basalt, quartzite, indurated limestone, or sandstone. The R layer is presumed to be the material from which the overlying horizons are developed. But if it is a different material from that of the overlying mantle, it is represented by IIR, indicating what is called LITHOLOGICAL DISCOUNTINUITY. The roman figure (II) placed before R, is to indicate that the parent material is different from that of the overlying mantle.

TRANSITIONAL HORIZONS

Transitional horizons are dominated by properties of one master horizon but have the subordinate properties of another. These are designated by two capital letters, for example, AB, EB, BE, or BC. The first letter represents the dominant horizon characteristics; the second indicates the weaker expressed characteristics.

A second type of transitional horizon has two distinct parts with recognizable properties of the two master horizons indicated by the capital letters. Parts of one surround the other. This type of transitional horizon is designated by a capital letter for the part with the greatest volume, followed by a slash and another capital letter for the secondary part (for example, E/B, B/E, or B/C).

SUBORDINATE DISTINCTIONS

Master horizons are further divided by subordinate characteristics, which usually do not apply to transitional horizons. Subordinate distinctions are identified by lower-case letters, called suffix symbols. In some cases, they describe an accumulation of material.

This means that the so-designated horizons contain more of the material in question than is presumed to have been present in the parent material. For example, Bt refers to a B horizon with more clay than normal. The symbols and their meanings are as follows:-

- ***a .*** *highly decomposed organic material.* Used with O to indicate the most highly decomposed organic materials, which have rubbed fiber content of less than 17 percent of the volume.
- ***b*** . *buried genetic horizon.* Used in mineral soils to indicate identifiable buried horizons with major genetic features that were developed before burial. Genetic horizons may or may not have formed in the overlying material, which may be either like or unlike the assumed parent material of the buried soil. This symbol is not used in organic soils or to separate an organic from a mineral layer.
- ***c .*** *concretions or nodules.* Indicates a significant accumulation of concretions or nodules. Cementation is required, but the cementing agent is not specific, except that it cannot be silica. The symbol is not used if the concretions or nodules consist of dolomite or calcite, or more soluble salts. It is used if the nodules or concretions are enriched with minerals that contain iron aluminum, manganese, or titanium.
- ***d*** . *physical root restriction .* Indicates root-restricting layers in naturally occurring or man-made unconsolidated sediments or materials, such as dense basal till, plow pans, and other mechanically compacted zones.
- ***e*** . *organic material of intermediate composition.* Used with O to indicate organic materials of intermediate composition with rubbed fiber content between 17 and 40 percent (by volume).
- ***f*** . *frozen soil.* Indicates permanent ice content in a horizon or layer. The symbol is not used for seasonally frozen layers or for so-called dry permafrost (material that is colder than 0º but does not contain ice).
- ***g*** . *strong gleying.* Indicates either that iron has been reduced and removed during soil formation, or that saturation with stagnant water has preserved it in a reduced state. Most of the affected layers have a chroma of 2 or less, and many have redox concentrations. The low chroma can represent either the color of reduced iron or the color of uncoated sand and silt particles from which the iron has been removed. The symbol *g* is not used for materials of low chroma that have no history of wetness, such as some shales or E horizons. If g is used with B, pedogenic change in addition to gleying is implied. The horizon is designated Cg if no other pedogenic change besides gleying has occurred.
- ***h*** . *illuvial accumulation of organic matter.* Used with B to indicate the accumulation of illuvial, amorphous, dispersible organic-matter-sesquioxide complexes if the sesquioxide component is dominated by aluminum but is present only in small quantities. The organo-sesquioxide material

coats sand and silt particles. In some horizons, these coatings have coalesced, filled pores, and cemented the horizon. The symbol *h* is also used in combination with *s*, as in Bhs, if the amount of sesquioxide component is significant but the color value and chroma of the horizon when moist is 3 or less.

- ***i***. *slightly decomposed organic matter.* Used with O to indicate the least decomposed of the organic materials. Its rubbed fiber content is 40 percent or more (by volume).
- ***k***. *accumulation of carbonates.* Indicates an accumulation of alkaline-earth carbonates, commonly calcium carbonate. It is usually found in arid or dry region.
- ***m***. *cementation or induration.* Indicates continuous or nearly continuous cementation. The symbol *m* is used for horizons that are more than 90 percent cemented, although they may be fractured. The cemented layer is physically root-restrictive. The predominant cementing agent (or the two dominant cementing agents) may be indicated by using defined letter suffixes, singly or in pairs. Following are some suffix combinations and what they indicate:
  - *km* . cementation by carbonates;
  - *qm* . cementation by silica;
  - *sm* . cementation by iron;
  - *ym* . cementation by gypsum;
  - *kqm*. cementation by lime and silica; and
  - *zm* . cementation by salts more soluble than gypsum.
- ***n*** . *accumulation of sodium.* Indicates an accumulation of exchangeable sodium.
- ***o***. *residual accumulation of sesquioxides*
- ***p*** . *tillage or other disturbance.* Indicates a disturbance of the surface layer by mechanical means, pasturing, or similar uses. A disturbed organic horizon is designated Op. A disturbed mineral horizon is designated Ap, even though it is clearly a former E, B, or C horizon.
- ***q*** . *accumulation of silica.* Indicates an accumulation of secondary silica.
- ***r*** . *weathered or soft bedrock.* Used with C to indicate root-restrictive layers of saprolite, such as weathered igneous rock, or of soft bedrock, such as partly consolidated sandstone, siltstone, and shale. Excavation difficulty is low to high.
- ***s*** . *illuvial accumulation of sesquioxides and organic matter.* Used with B to indicate an accumulation of illuvial, amorphous, dispersible, organic-matter-sesquioxide complexes if both organic-matter and sesquioxide components are significant, and if color value and chroma of the horizon when moist is 4 or more. The symbol is also used in combination with the symbol *h*, as in Bhs, if both the organic-matter and sesquioxide components are significant, and if the color value and chroma, moist, is 3 or less.

- ***ss*** . *presence of slickensides.* Indicates the presence of slickensides. Slickensides result directly from the swelling of clay minerals and shear failure, commonly at angles of 20 to 60 degrees above horizontal. They are indicators that other vertic characteristics, such as wedge-shaped peds and surface cracks, may be present.
- ***t*** . *accumulation of silicate clay* Indicates an accumulation of silicate clay that has either formed and subsequently been translocated within the horizon or has been moved into the horizon by illuviation, or both. At least some part of the horizon should show evidence of clay accumulation either as coatings on surfaces of peds or in pores, or as lamellae or bridges between mineral grains.
- ***v*** . *plinthite.* Indicates the presence of iron-rich humus-poor reddish material that is firm or very firm when moist and hardens irreversibly when exposed to the atmosphere and to repeated wetting and drying.
- ***w*** . *development of color or structure.* Used with B to indicate the development of color and structure, or both, with little or no apparent illuvial accumulation of material. It should not be used to indicate a transitional horizon.
- ***x*** . *fragipan character.* Indicates a genetically developed layer with a combination of firmness, brittleness, and commonly a higher bulk density than adjacent layers. Some part of the layer is physically root-restrictive.
- ***y*** . *accumulation of gypsum*
- ***z*** . *accumulation of salts more soluble than gypsum*

DIAGNOSTIC HORIZONS:

Master horizons describe a soil profile, while diagnostic horizons are used to classify soils. Whereas master horizons are based on appearance, diagnostic horizons are based on soil formation processes. These two classification schemes are not complementary. Diagnostic horizons can contain all or part of more than one master horizon.

Diagnostic horizons are horizons mainly used for soil classification. Although they are supposed to be identified on the field, many cannot be surely identified on the field particularly in the tropics. Therefore, laboratory analysis are use to confirm and establish the field identification.

There are two types of diagnostic horizons. These are surface (epipedon) and subsurface horizon.

EPIPEDONS

An epipedon is the surface, or uppermost soil horizon. They are not synonymous to the A horizon. They may be thinner than the A horizon, or include the E or part or the entire B horizon. Epipedons derived from bedrock lack rock structure and are normally darkened by organic matter.

Histic epipedon

This organic horizon is water saturated long enough for reduced conditions to occur unless artificially drained. It is 40 to 60 cm thick and has a low bulk density often less than 1 g cm-3. The actual organic matter content is dependent on the percent clay. If the soil has not been plowed, it must contain between 12 percent and 30 percent organic carbon with no clay and 18 percent or more organic carbon with 60 percent or more clay. When the soil has been plowed, the organic carbon content is from 8 percent with no clay to 16 percent with 60 percent or more clay.

Melanic epipedon

This thick, black surface horizon with a high organic matter content formed in volcanic ejecta. It has a minimum thickness of 30 cm, contains 6 percent or more organic carbon, and has volcanic mineral-like allophane throughout.

Mollic epipedon

This epipedon is a soft dark grassland soil. Its organic carbon content is 0.6 percent or more resulting in a color value of 3 or less moist, 5 or less dry. Its base saturation is 50 percent or more. It measures a minimum of 18 cm thick if not directly above a petrocalcic horizon, duripan, or a lithic or paralithic contact, and contains less than 250 ppm P_2O_5. Moist three months or more each year, it cannot have both hard consistence and massive structure.

Anthropic epipedon

While similar to the mollic epipedon, the anthropic epipedon contains greater than 250 ppm citric acid soluble P_2O_5 with or without a 50 percent base saturation and requires that the soil is moist three months or more over 8 to 10 years. It is commonly found in fields cultivated over long periods of time.

Ochric epipedon

Ochric epipedon is light in colour and low in organic matter and too thin to be any of the other five epipedons. This epipedon does not meet the definitions of any other surface horizon. It does not have the thickness, percent organic carbon, or color to be a mollic or umbric epipedon. The ochric epipedon extends to the first illuvial (B) horizon. Ochric epipedon is the most common epipedon in Nigeria.

Plaggen epipedon

This man-made horizon is 50 cm or more thick and has resulted from centuries of accumulation of sod, straw, and manure, for example. It commonly contains artifacts such as pottery and bricks.

Umbric epipedon

Mollic-like in thickness, organic carbon content, color, P_2O_5 content, consistence, and structure, this epipedon has less than 50 percent base saturation.

DIAGNOSTIC SUBSURFACE HORIZONS

Diagnostic subsurface horizons can be categorized as weakly developed horizons, as horizons featuring an accumulation of clay, organic matter, or inorganic salts, as cemented horizons, or as strongly acidic horizons.

Agric

The agric horizon is an illuvial horizon that has formed under cultivation and contains significant amounts of illuvial silt, clay, and humus. It is usually formed after prolonged years of cultivation.

Albic

Albic (L. *albus*, white) materials are soil materials with a color that is largely determined by the color of primary sand and silt particles rather than by the color of their coatings. This definition implies that clay and/or free iron oxides have been removed from the materials or that the oxides have been segregated to such an extent that the color of the materials is largely determined by the color of the primary particles. Clay, humus, and other coatings have been leached from this eluvial horizon, leaving light-colored sand and silt particles.

Argillic

An argillic horizon is normally a subsurface horizon with a significantly higher percentage of phyllosilicate clay than the overlying soil material. It shows evidence of clay illuviation. The argillic horizon forms below the soil surface, but it may be exposed at the surface later by erosion.

This illuvial horizon of mostly high-charged layer silicate clay has clay films on the faces of peds or some indication of clay movement. It is at least one-tenth the thickness of all overlying horizons. If the overlying horizon has less than 15 percent clay, the argillic has 3 percent more clay than the eluvial horizon above. If the overlying horizon has 15 to 40 percent clay, the argillic has 1.2 times that amount. If the overlying horizon has over 40 percent clay, the argillic has 8 percent more clay.

Calcic

The calcic horizon is an illuvial horizon in which secondary calcium carbonate or other carbonates have accumulated to a significant extent.

Measuring 15 cm or more thick, this horizon is not indurated or cemented, and has evidence of calcium carbonate movement. It has a 15 percent or more $CaCO_3$ equivalent unless there is below 18 percent clay, and then the requirement is a 5 percent or more CaCO3 equivalent. If the horizon is cemented, it is classified as petrocalcic.

Cambic

This horizon shows some evidence of alterations but is very weakly developed between A and C horizons. The cambic horizon has less illuviation evidence than found in the argillic and spodic horizons.

Kandic

The Kandic horizon is a vertically continuous subsurface horizon that underlies a coarser textured surface horizon. The minimum thickness of the surface horizon is 18 cm after mixing or 5 cm if the textural transition to the kandic horizon is abrupt and there is no densic, lithic, paralithic, or petroferric contact within 50 cm of the mineral soil surface. The kandic is a horizon with an illuvial accumulation of 1:1 (kaolinite-like) clay. It has a clay increase of 4 percent or more within 15 cm of the overlying horizon if the surface has less than 20 percent clay; 20 percent or more if the surface has 20 to 40 percent clay; or 8 percent or more if the surface has greater than 40 percent clay. The horizon is 30 cm thick unless there is a lithic, paralithic, or petroferric contact, in which case minimum thickness is 15 cm.

Has an apparent CEC of 16 cmol(+) or less per kg clay (by 1N NH4OAc pH 7) and an apparent ECEC of 12 cmol(+) or less per kg clay (sum of bases extracted with 1N NH4OAc pH 7 plus 1N KCl-extractable Al) in 50 percent or more of its thickness between the point where the clay increase requirements are met and either a depth of 100 cm below that point or a densic, lithic, paralithic, or petroferric contact if shallower. (The percentage of clay is either measured by the pipette method or estimated to be 2.5 times [percent water retained at 1500 kPa tension minus percent organic carbon], whichever is higher, but no more than 100). It has a regular decrease in organic-carbon content with increasing depth, no fine stratification, and no overlying layers more than 30 cm thick that have fine stratification and/or an organic-carbon content that decreases irregularly with increasing depth.

Natric

The natric horizon is similar to the argillic horizon with the additional characteristics of columnar structure. It has an exchangeable sodium percentage of 15 percent or more.

Oxic

The oxic horizon contains highly weathered 1: 1 clays and sesquioxides. It is 30 cm or more thick and has a CEC of less than 16 - 24 $cmol_c$ kg-1 of clay (by NH_4OAC method). Less than 10 percent of the minerals are weatherable. Within a distance of 15 cm, there is an increase in clay of 4 percent or less if the surface horizon contains less than 20 percent clay; less than 20 percent if the surface contains 20 to 40 percent clay; or 8 percent or less if the surface contains 40 percent or more clay.

Glossic

This transitional horizon has parts of an eluvial horizon and the remnants of a degrading argillic, kandic, or natric horizon.

Gypsic

An illuvial horizon, the gypsic is 15 cm or more thick with 5 percent or more gypsum and at least 1 percent by volume of visible gypsum than the underlying horizon. It is a horizon of accumulation of calcium sulphate. If the horizon is cemented, it is classified as petrogypsic.

Placic

This subsurface horizon is cemented by iron, iron and manganese, or iron and organic matter.

Salic

Measuring 15 cm or more thick, the salic horizon contains at least 2 percent soluble salt. A 1:1 soil to water extract has an electrical conductivity of 30 dS/m-1 (decisiemens per meter) or more.

Sombric

The sombric horizon has an illuvial accumulation of humus that is not associated with aluminum (spodic) or sodium (natric).

Spodic

This illuvial horizon contains high pH dependent charge material. A sandy-textured horizon, it has an accumulation of humus with aluminum and/or iron.

Sulfuric

The sulfuric horizon forms as a result of draining soil with a high sulfide content that is oxidized to sulfates, drastically reducing the pH. It is at least 15 cm thick and has a pH of 3.5 or less. This type of horizon is common in acid-sulfate soils.

PEDOLOGICAL FEATURES

Fragipan

A fragipan is a brittle horizon situated at some depth below an eluvial horizon. It has a low organic matter content, lower bulk density than overlying horizons, and hard or very hard consistence when dry.

Duripan

This subsurface horizon is cemented by silica in more than 50 percent of its volume. It dissolves in concentrated basic solution or alterating acid and then basic solutions, but does not slake in HCl.

Plinthite

Plinthite (Gr. *plinthos*, brick) is an iron-rich, humu spoor mixture of clay with quartz and other minerals. It commonly occurs as dark red redox concentrations that usually form platy,polygonal, or reticulate patterns. Plinthite changes irreversibly to an ironstone hardpan or to irregular aggregates on exposure to repeated wetting and drying, especially if it is also exposed to heat from the sun. The lower boundary of a zone in which plinthite occurs generally is diffuse or gradual, but it may be abrupt at a lithologic discontinuity.

Generally, plinthite forms in a horizon that is saturated with water for some time during the year. Initially, iron is normally segregated in the form of soft, more or less clayey, red or dark red redox concentrations. These concentrations are not considered plinthite unless there has been enough segregation of iron to permit their irreversible hardening on exposure to repeated wetting and drying. Plinthite is firm or very firm when the soil moisture content is near field capacity and hard when the moisture content is below the wilting point. Plinthite does not harden irreversibly as a result of a single cycle of drying and rewetting. After a single drying, it will remoisten and then can be dispersed in large part if one shakes it in water with a dispersing agent.

In a moist soil, plinthite is soft enough to be cut with a spade. After irreversible hardening, it is no longer considered plinthite but is called ironstone. Indurated ironstone materials can be broken or shattered with a spade but cannot be dispersed if one shakes them in water with a dispersing agent.

Slickensides

Slickensides are polished and grooved surfaces and generally have dimensions exceeding 5 cm. They are produced when one soil mass slides past another. Some slickensides occur at the lower boundary of a slip surface where a mass of soil moves downward on a relatively steep slope. Slickensides result directly from the swelling of clay minerals and shear failure. They are very common in swelling clays that undergo marked changes in moisture content.

Gilgai

Gilgai

Lithic Contact

A lithic contact is the boundary between soil and a coherent underlying material. Except in Ruptic-Lithic subgroups, the underlying material must be virtually continuous within the limits of a pedon. Cracks that can be penetrated by roots are few, and their horizontal spacing is 10 cm or more. The underlying material must be sufficiently coherent when moist to make hand-digging with a spade impractical, although the material may be chipped or scraped with a spade. The material below a lithic contact must be in a strongly cemented or more cemented rupture-resistance class. Commonly, the material is indurated. The underlying material considered here does notinclude diagnostic soil horizons, such as a duripan or a petrocalcic horizon.

A lithic contact is diagnostic at the subgroup level if it is within 125 cm of the mineral soil surface in Oxisols and within 50 cm of the mineral soil surface in all other mineral
soils. In organic soils the lithic contact must be within the control section to be recognized at the subgroup level.

Paralithic Contact

A paralithic (lithiclike) contact is a contact between soil and paralithic materials (defined below) where the paralithic materials have no cracks or the spacing of cracks that roots can enter is 10 cm or more.

Paralithic Materials

Paralithic materials are relatively unaltered materials (do not meet the requirements for any other named diagnostic horizons or any other diagnostic soil characteristic) that have an extremely weakly cemented to moderately cemented rupture resistance

class. Cementation, bulk density, and the organization are such that roots cannot enter, except in cracks. Paralithic materials have, at their upper boundary, a paralithic contact if they have no cracks or if the spacing of cracks that roots can

enter is 10 cm or more. Commonly, these materials are partially weathered bedrock or weakly consolidated bedrock, such as sandstone, siltstone, or shale. Paralithic materials can be used to differentiate soil series if the materials are within the series

control section. Fragments of paralithic materials 2.0 mm or more in diameter are referred to as pararock fragments.

Petroferric Contact

A petroferric (Gr. *petra*, rock, and L. *ferrum*, iron; implying ironstone) contact is a boundary between soil and a continuous layer of indurated material in which iron is an important cement and organic matter is either absent or present only in traces. The indurated layer must be continuous within the limits of each pedon, but it may be fractured if the average lateral distance between fractures is 10 cm or more. The fact that this ironstone layer contains little or no organic matter distinguishes it from a placic horizon and an indurated spodic horizon (ortstein), both of which contain organic matter.

Several features can aid in making the distinction between a lithic contact and a petroferric contact. First, a petroferric contact is roughly horizontal. Second, the material directly below a petroferric contact contains a high amount of iron (normally 30 percent or more Fe2O3). Third, the ironstone sheets below a petroferric contact are thin; their thickness ranges from a few centimeters to very few meters. Sandstone, on the other hand, may be thin or very thick, may be level-bedded or tilted, and may contain only a small percentage of Fe2O3. In the Tropics, the ironstone is generally more or less vesicular.

Lithologic discontinuities

Lithologic discontinuities are significant changes in particle size distribution or mineralogy that represent differences in lithology within a soil. A lithologic discontinuity can also denote an age difference. For information on using horizon designations for lithologic discontinuities, see the *Soil Survey Manual*
(USDA, SCS, 1993).

Not everyone agrees on the degree of change required for a lithologic discontinuity. No attempt is made to quantify lithologic discontinuities. The discussion below is meant to serve as a guideline.

Several lines of field evidence can be used to evaluate lithologic discontinuities. In addition to mineralogical and textural differences that may require laboratory studies, certain observations can be made in the field. These include but are not limited to the following:

1. Abrupt textural contacts.—An abrupt change in particle-size distribution, which is not solely a change in clay content resulting from pedogenesis, can often be observed.

2. Contrasting sand sizes.—Significant changes in sand size can be detected. For example, if material containing mostly medium sand or finer sand abruptly overlies material containing mostly coarse sand and very coarse sand, one can assume that
there are two different materials. Although the materials may be of the same mineralogy, the contrasting sand sizes result from differences in energy at the time of deposition by water and/or wind.

3. Bedrock lithology vs. rock fragment lithology in the soil.—If a soil with rock fragments overlies a lithic contact, one would expect the rock fragments to have a lithology similar to that of the material below the lithic contact. If many of the rock fragments do not have the same lithology as the underlying bedrock, the soil is not derived completely from the underlying bedrock.

4. Stone lines.—The occurrence of a horizontal line of rock fragments in the vertical sequence of a soil indicates that the soil may have developed in more than one kind of parent material. The material above the stone line is most likely transported, and the material below may be of different origin.

5. Inverse distribution of rock fragments.—A lithologic discontinuity is often indicated by an erratic distribution of rock fragments. The percentage of rock fragments decreases with increasing depth. This line of evidence is useful in areas of soils that have relatively unweathered rock fragments.

6. Rock fragment weathering rinds.—Horizons containing rock fragments with no rinds that overlie horizons containing rocks with rinds suggest that the upper material is in part depositional and not related to the lower part in time and perhaps in lithology.

7. Shape of rock fragments.—A soil with horizons containing angular rock fragments overlying horizons containing well rounded rock fragments may indicate a discontinuity. This line of evidence represents different mechanisms of transport (colluvial vs. alluvial) or even different transport distances.

8. Soil color.—Abrupt changes in color that are not the result of pedogenic processes can be used as indicators of discontinuity.

9. Micromorphological features.—Marked differences in the size and shape of resistant minerals in one horizon and not in another are indicators of differences in materials.

Use of Laboratory Data

Discontinuities are not always readily apparent in the field. In these cases laboratory data are necessary. Even with laboratory data, detecting discontinuities may be difficult. The decision is a qualitative or perhaps a partly quantitative judgment. General concepts of lithology as a function of depth might include:

1. Laboratory data—visual scan.—The array of laboratory data is assessed in an attempt to determine if a field designated discontinuity is corroborated and if any data show evidence of a discontinuity not observed in the field. One must sort changes in lithology from changes caused by pedogenic processes. In most cases the quantities of sand and coarser fractions are not altered significantly by soil-forming processes. Therefore, an abrupt change in sand size or sand mineralogy is a clue to lithologic change. Gross soil mineralogy and the resistant mineral suite are other clues.

2. Data on a clay-free basis.—A common manipulation in assessing lithologic change is computation of sand and silt separates on a carbonate-free, clay-free basis (percent fraction, e.g., fine sand and very fine sand, divided by percent sand plus silt, times 100). Clay distribution is subject to pedogenic change and may either mask inherited lithologic differences or produce differences that are not inherited from lithology. The numerical array computed on a clay-free basis can be inspected visually or plotted as a function of depth.

Another aid used to assess lithologic changes is computation of the ratios of one sand separate to another. The ratios can be computed and examined as a numerical array, or they can be plotted. The ratios work well if sufficient quantities of the two fractions are available. Low quantities magnify changes in ratios, especially if the denominator is low.

Soil Moisture Regimes

The term “soil moisture regime” refers to the presence or absence either of ground water or of water held at a tension of less than 1500 kPa in the soil or in specific horizons during periods of the year. Water held at a tension of 1500 kPa or more is not available to keep most mesophytic plants alive. The availability of water is also affected by dissolved salts. If a soil is saturated with water that is too salty to be available to most plants, it is considered salty rather than dry. Consequently, a horizon is considered dry when the moisture tension is 1500 kPa or more and is considered moist if water is held at a tension of less than 1500 kPa but more than zero. A soil may be continuously moist in some or all horizons either throughout the year or for some part of the year. It may be either moist in winter or dry in summer or the reverse. In the Northern Hemisphere, summer refers to June, July, and August and winter refers to December, January, and February.

Normal Years

In the discussions that follow and throughout the keys, the term “normal years” is used. A normal year is defined as a year that has plus or minus one standard deviation of the long-term mean annual precipitation. (Long-term refers to 30 years or more.) Also, the mean monthly precipitation during a normal year must be plus or minus one standard deviation of the long term monthly precipitation for 8 of the 12 months. For the most part, normal years can be calculated from the mean annual precipitation. When catastrophic events occur during a year, however, the standard deviations of the monthly means should also be calculated. The term “normal years” replaces the terms “most years” and “6 out of 10 years,” which were used in the 1975 edition of *Soil taxonomy* (USDA, SCS, 1975).

Soil Moisture Control Section

1. The intent in defining the soil moisture control section is to facilitate estimation of soil moisture regimes from climatic data. The upper boundary of this control section is the depth to which a dry (tension of more than 1500 kPa, but not air-dry) soil will be moistened by 2.5 cm of water within 24 hours. The lower boundary is the depth to which a dry soil will be moistened by 7.5 cm of water within 48 hours. These depths do not include the depth of moistening along any cracks or animal burrows that are open to the surface. If 7.5 cm of water moistens the soil to a densic, lithic, paralithic, or petroferric contact or to a petrocalcic or petrogypsic horizon or a duripan, the contact or the upper(1) from 10 to 30 cm below the soil surface if the particle-size class of the soil is fine-loamy, coarse-silty, fine-silty, or clayey;
2. (2) from 20 to 60 cm if the particle-size class is coarse-loamy;
3. and (3) from boundary of the cemented horizon constitutes the lower boundary of the soil moisture control section. If a soil is moistened to one of these contacts or horizons by 2.5 cm of water, the soil moisture control section is the boundary or the contact itself. The control section of such a soil is considered moist if the contact or upper boundary of the cemented horizon has a thin film of water. If that upper boundary is dry, the control section is considered dry.

The moisture control section of a soil extends approximately

30 to 90 cm if the particle-size class is sandy. If the soil contains rock and pararock fragments that do not absorb and release water, the limits of the moisture control section are deeper. The limits of the soil moisture control section are affected not only by the particle-size class but also by differences in soil structure or pore-size distribution or by other factors that influence the movement and retention of water in the soil.

Classes of Soil Moisture Regimes

The soil moisture regimes are defined in terms of the level of ground water and in terms of the seasonal presence or absence of water held at a tension of less than 1500 kPa in the moisture control section. It is assumed in the definitions that the soil supports whatever vegetation it is capable of supporting, i.e., crops, grass, or native vegetation, and that the amount of stored moisture is not being increased by irrigation or fallowing. These cultural practices affect the soil moisture conditions as long as they are continued.

Aquic moisture regime.—The aquic (L. *aqua*, water) moisture regime is a reducing regime in a soil that is virtually free of dissolved oxygen because it is saturated by water. Some soils are saturated with water at times while dissolved oxygen is present, either because the water is moving or because the environment is unfavorable for micro-organisms (e.g., if the temperature is less than 1 ^{oC}); such a regime is not considered aquic.

It is not known how long a soil must be saturated before it is said to have an aquic moisture regime, but the duration must be at least a few days, because it is implicit in the concept that dissolved oxygen is virtually absent. Because dissolved oxygen is removed from ground water by respiration of microorganisms, roots, and soil fauna, it is also implicit in the concept that the soil temperature is above biologic zero for some time while the soil is saturated. Biologic zero is defined as 5 ^{oC} in this taxonomy. In some of the very cold regions of the world, however, biological activity occurs at temperatures below 5 ^{oC}. Very commonly, the level of ground water fluctuates with the seasons; it is highest in the rainy season or in fall, winter, or spring if cold weather virtually stops evapotranspiration. There are soils, however, in which the ground water is always at or very close to the surface. Examples are soils in tidal marshes or in closed, landlocked depressions fed by perennial streams.

Such soils are considered to have a peraquic moisture regime.

Aridic and torric (L. *aridus*, dry, and L. *torridus*, hot and dry) moisture regimes.—These terms are used for the same moisture regime but in different categories of the taxonomy. In the aridic (torric) moisture regime, the moisture control section is, in normal years:

1. Dry in all parts for more than half of the cumulative days per year when the soil temperature at a depth of 50 cm from the soil surface is above 5 ^{oC}; *and*
2. Moist in some or all parts for less than 90 consecutive days when the soil temperature at a depth of 50 cm is above 8 ^{oC}.

Soils that have an aridic (torric) moisture regime normally occur in areas of arid climates. A few are in areas of semiarid climates and either have physical properties that keep them dry, such as a crusty surface that virtually precludes the infiltration of water, or are on steep slopes where runoff is high. There is little or no leaching in this moisture regime, and soluble salts accumulate in the soils if there is a source.

The limits set for soil temperature exclude from these moisture regimes soils in the very cold and dry Polar Regions and in areas at high elevations. Such soils are considered to have anhydrous conditions (defined earlier).

Udic moisture regime.—The udic (L. *udus*, humid) moisture regime is one in which the soil moisture control section is not dry in any part for as long as 90 cumulative days in normal years. If the mean annual soil temperature is lower than 22 ^{oC} and if the mean winter and mean summer soil temperatures at a depth of 50 cm from the soil surface differ by 6 ^{oC} or more, the soil moisture control section, in normal years, is dry in all parts for less than 45 consecutive days in the 4 months following the summer solstice. In addition, the udic moisture regime requires, except for short periods, a three-phase system, solid-liquid-gas, in part or all of the soil moisture control section when the soil temperature is above 5 ^{oC}.

The udic moisture regime is common to the soils of humid climates that have well distributed rainfall; have enough rain in summer so that the amount of stored moisture plus rainfall is approximately equal to, or exceeds, the amount of evapotranspiration; or have adequate winter rains to recharge the soils and cool, foggy summers, as in coastal areas. Water moves downward through the soils at some time in normal years.

In climates where precipitation exceeds evapotranspiration in all months of normal years, the moisture tension rarely reaches 100 kPa in the soil moisture control section, although there are occasional brief periods when some stored moisture is used. The water moves through the soil in all months when it is not frozen.

Such an extremely wet moisture regime is called perudic (L. *per*, throughout in time, and L. *udus*, humid). In the names of most taxa, the formative element "ud" is used to indicate either a udic or a perudic regime; the formative element "per" is used in selected taxa.

Ustic moisture regime.—The ustic (L. *ustus*, burnt; implying dryness) moisture regime is intermediate between the aridic regime and the udic regime. Its concept is one of moisture that is limited but is present at a time when conditions are suitable for plant growth. The concept of the ustic moisture regime is not applied to soils that have permafrost or a cryic soil temperature regime (defined below).

If the mean annual soil temperature is 22 ^{oC} or higher or if the mean summer and winter soil temperatures differ by less than 6 ^{oC} at a depth of 50 cm below the soil surface, the soil moisture control section in areas of the ustic moisture regime is dry in some or all parts for 90 or more cumulative days in normal years. It is moist, however, in some part either for more than 180 cumulative days per year or for 90 or more consecutive days.

If the mean annual soil temperature is lower than 22 ^{oC} and if the mean summer and winter soil temperatures differ by 6 ^{oC} or more at a depth of 50 cm from the soil surface, the soil moisture control section in areas of the ustic moisture regime is dry in some or all parts for 90 or more cumulative days in normal years, but it is not dry in all parts for more than half of the cumulative days when the soil temperature at a depth of 50 cm is higher than 5 ^{oC}. If in normal years the moisture control section is moist in all parts for 45 or more consecutive days in the 4 months following the winter solstice, the moisture control section is dry in all parts for less than 45 consecutive days in the 4 months following the summer solstice.

In tropical and subtropical regions that have a monsoon climate with either one or two dry seasons, summer or winter seasons have little meaning. In those regions the moisture regime is ustic if there is at least one rainy season of 3 months or more. In temperate regions of subhumid or semiarid climates, the rainy seasons are usually spring and summer or spring and fall, but never winter. Native plants are mostly annuals or plants that have a dormant period while the soil is dry.

Xeric moisture regime.—The xeric (Gr. *xeros*, dry) moisture regime is the typical moisture regime in areas of Mediterranean climates, where winters are moist and cool and summers are warm and dry. The moisture, which falls during the winter, when potential evapotranspiration is at a minimum, is particularly effective for leaching. In areas of a xeric moisture regime, the soil moisture control section, in normal years, is dry in all parts for 45 or more consecutive days in the 4 months following the summer solstice and moist in all parts for 45 or more consecutive days in the 4 months following the winter solstice.

Also, in normal years, the moisture control section is moist in some part for more than half of the cumulative days per year when the soil temperature at a depth of 50 cm from the soil surface is higher than 6 ^{oC} or for 90 or more consecutive days when the soil temperature at a depth of 50 cm is higher than 8 ^{oC}. The mean annual soil temperature is lower than 22 ^{oC}, and the mean summer and mean winter soil temperatures differ by 6 ^{oC} or more either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact if shallower.

SOIL TEMPERATURE REGIMES

Classes of Soil Temperature Regimes

Following is a description of the soil temperature regimes used in defining classes at various categoric levels in this taxonomy.

Cryic (Gr. *kryos*, coldness; meaning very cold soils).— Soils in this temperature regime have a mean annual temperature lower than 8 ^{oC} but do not have permafrost.

1. In mineral soils the mean summer soil temperature (June, July, and August in the Northern Hemisphere and December, January, and February in the Southern Hemisphere) either at a depth of 50 cm from the soil surface or at a densic, lithic, or

paralithic contact, whichever is shallower, is as follows:

a. If the soil is not saturated with water during some part of the summer and

(i) If there is no O horizon: lower than 15 ^{oC}; *or*

(ii) If there is an O horizon: lower than 8 ^{oC}; *or*

b. If the soil is saturated with water during some part of the summer and

(i) If there is no O horizon: lower than 13 ^{oC}; *or*

(ii) If there is an O horizon or a histic epipedon: lower than 6 ^{oC}.

2. In organic soils the mean annual soil temperature is lower than 6 ^{oC}.

Cryic soils that have an aquic moisture regime commonly are churned by frost.

Isofrigid soils could also have a cryic temperature regime. A few with organic materials in the upper part are exceptions.

The concepts of the soil temperature regimes described below are used in defining classes of soils in the low categories.

Frigid.—A soil with a frigid temperature regime is warmer in summer than a soil with a cryic regime, but its mean annual temperature is lower than 8 ^{oC} and the difference between mean summer (June, July, and August) and mean winter (December, January, and February) soil temperatures is more than 6 ^{oC} either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower.

Mesic.—The mean annual soil temperature is 8 ^{oC} or higher but lower than 15 ^{oC}, and the difference between mean summer and mean winter soil temperatures is more than 6 ^{oC} either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower.

Thermic.—The mean annual soil temperature is 15 ^{oC} or higher but lower than 22 ^{oC}, and the difference between mean summer and mean winter soil temperatures is more than 6 ^{oC} either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower.

Hyperthermic.—The mean annual soil temperature is 22 ^{oC} or higher, and the difference between mean summer and mean winter soil temperatures is more than 6 ^{oC} either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower.

If the name of a soil temperature regime has the prefix *iso*, the mean summer and mean winter soil temperatures differ by less than 6 ^{oC} at a depth of 50 cm or at a densic, lithic, or paralithic contact, whichever is shallower.

Isofrigid.—The mean annual soil temperature is lower than 8 oC.

Isomesic.—The mean annual soil temperature is 8 ^{oC} or higher but lower than 15 ^{oC}.

Isothermic.—The mean annual soil temperature is 15 ^{oC} or higher but lower than 22 ^{oC}.

Isohyperthermic.—The mean annual soil temperature is 22 ^{oC} or higher.

SOIL CLASSIFICATION

This is a process whereby soils are grouped on the basis of their properties. These properties include among others, the epipedon and diagnostic subsurface horizon, the nature of the profile, the soil texture, structure, mineralogy and the nature of the climate including rainfall, temperature and relief.

The reasons for classifying soils are the same as enumerated under the general principles of classification.

Major ways of classifying soils

There are various ways to organise a soil classification. A major distinction is between **natural** and **technical** approaches:

• **Natural** soil classifications group soils by some intrinsic property, behaviour, or genesis of the soils themselves, without reference to use

• **Technical** soil classifications group soils by some properties or functions that relate directly to a proposed use or group of uses.

Natural classifications:

• Group by **ecologic region**, e.g. "prarie soils", "boreal soils". Geographically-compact but may have diverse properties and function.

• Group by **presumed genesis**, i.e. the development pathway of the soil profile. These are called **genetic** soil classifications. The soil individual is considered as a natural body with its own history and ecology. This depends on the interpretation of landscape and soil genesis.

• Group by **similar properties**, working **bottom-up** from a set of individuals, to a set of classes, and then grouping the classes into super-classes. This can be done by:

– Subjective judgment of the classifier

– Numerical classification, usually multivariate

Technical classifications:

• Hydrologic response

• Suitability classes (FAO Framework for Land Evaluation)

• Land Use Capability (USDA LCC)

• Fertility Capability Classification (FCC)

• Engineering group

It would be very nice if the groups formed in these ways corresponded. For example, it might be expected that soils that had similar genesis would have similar properties and behaviour. The early soil classifiers thought that soils in an ecological region all had the same genesis and properties. But that is not always so.

International Soil Classification Systems

There are two major world soil classification systems. These are the United State Department of Agriculture (UDSA) taxonomic system and the World Food and Agricultural Organization (FAO) World Reference Base System (USDA, 2003; FAO, 2006). These are systems designed for universal application. They should classify any soil, and serve to **correlate** experiences on similar soils all over the world.

USDA SYSTEM OF SOIL CLASSIFICATION

As the name implies, this classification system was original developed for America. Its origin can be traced back to 1938 by Marbut. From Marbut the system has undergone series of approximations. The 7th approximation was published in 1960. The 2003 edition is the 9th approximation. Although the system was developed for American soils, it has become an internationally accepted system of classification been used all over the world.

The USDA classification system is a multi**-** categorical and hierarchical system. Thus the classes in the highest categories are divided into smaller classes in the lower one and continue to the lowest level, which is the soil series.

Soil Order: There are twelve orders namely Alfisols, Andisols, Aridisols, Entisols, Gelisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, and Vertisols. The most common soil orders in Nigeria are Alfisols, Entisols, Inceptisols, Oxisols and Ultisols. These soil orders are differentiated from each other on the basis of diagnostic horizons and pedogenic processes that are responsible for the soil formation. The formative name for each order is usually a two or three letter prefix use in combination with other prefixes from the different category level to form the soil name. The prefixes are: Alfisols = ALF, Andisols = AND, Aridisol = ID, Entisols = ENT, Gelisols = EL, Histosils = IST, Inceptisols = EPT, Mollisols = OLL, Oxisols = OX, Spodosols = OD, Ultisols =ULT, Vertisols = ERT.

Alfisols:

Alfisols refers to soils with either an argillic B or textural B horizon, kandic, or natric horizon and with a base saturation by sum of cation greater than 35%. It also does not have a plaggen epipedon and may contain fragipan that has clay films 1 mm or more thick in some part.

Inceptisols:

Soils with cambic B horizons and with textures finer than loamy fine sands *or more* of the following:

- A cambic horizon with its upper boundary within 100 cm of the mineral soil surface and its lower boundary at a depth of 25 cm or more below the mineral soil surface; *or*
- A calcic, petrocalcic, gypsic, petrogypsic, or placic horizon or a duripan with an upper boundary within a depth of 100 cm of the mineral soil surface; *or*
- A fragipan or an oxic, sombric, or spodic horizon with an upper boundary within 200 cm of the mineral soil
- surface; *or*
- A sulfuric horizon that has its upper boundary within 150 cm of the mineral soil surface; *or*
- A cryic temperature regime and a cambic horizon; *or*

2. No sulfidic materials within 50 cm of the mineral soil surface; *and both*:

- In one or more horizons between 20 and 50 cm below the mineral soil surface, either an *n* value of 0.7 or less or less than 8 percent clay in the fine-earth fraction; *and*
- *One or both* of the following:

(1) A salic horizon or a histic, mollic, plaggen, or umbric epipedon; *or*

(2) In 50 percent or more of the layers between the mineral soil surface and a depth of 50 cm, an exchangeable sodium percentage of 15 or more (or a sodium adsorption ratio of 13 or more), which decreases with increasing depth below 50 cm, *and* also ground water within 100 cm of the mineral soil surface at some time during the year when the soil is not frozen in any part.

Oxisols

They are soils with oxic B horizon. Usually they are highly weathered and lacking minerals other than quartz, kaolinite and sesquioxides. They may also be defined as stated below

(1) An oxic horizon that has its upper boundary within 150 cm of the mineral soil surface and no kandic horizon that has its upper boundary within that depth; *or*

(2) 40 percent or more (by weight) clay in the fine-earth fraction between the mineral soil surface and a depth of 18 cm (after mixing) *and* a kandic horizon that has the weatherable-mineral properties of an oxic horizon and has its upper boundary within 100 cm of the mineral soil surface.

Ultisols

These are soils with argillic B horizons but with base saturation by sum of cation less than 35% at one of the following depths:

(a.) If the epipedon has a sandy or sandy-skeletal particle size class throughout, *either*:

1. 125 cm below the upper boundary of the argillic horizon (but no deeper than 200 cm below the mineral soil surface) or 180 cm below the mineral soil surface, whichever is deeper; *or*

2. At a densic, lithic, paralithic, or petroferric contact if shallower; *or*

(b.) The shallowest of the following depths:

(1) 125 cm below the upper boundary of the argillic or kandic horizon; *or*

(2) 180 cm below the mineral soil surface; *or*

(3) At a densic, lithic, paralithic, or petroferric contact; *or*

(2.) A fragipan and *both* of the following:

a. Either an argillic or a kandic horizon above, within, or below it or clay films 1 mm or more thick in one or more of its sub horizons; *and*

b. A base saturation (by sum of cations) of less than 35 percent at the shallowest of the following depths:

(1) 75 cm below the upper boundary of the fragipan; *or*

(2) 200 cm below the mineral soil surface; *or*

(3) At a densic, lithic, paralithic, or petroferric contact.

Vertisols

Vertisols are heavy clay soils containing swelling and shrinking montmorillonite or smectite type of clay. The common feature of this soil is cracking but these cracks must be as wide as 1cm and must progress as far as 50cm depth to qualify as a true vertisol. Other noticeable features of vertisols are gilgai and slickensides.

Aridisols

Aridisols are primarily soils of the arid region occurring in area where there is no water in the soil as long as 90 consecutive days when soil temperature is greater than 6°C.

Entisols

They are young soils recently developed and their main characteristic is the lack of any diagnostic horizon.

Histosols

These are soils with high organic matter containing between 20% to 30% organic matter within 80cm of the soil surface.

<u>Assignment</u>

Write short notes on

1. Mollisols
2. Spodosols
3. Gelisols
4. Andisols

Sub-Order: The sub-orders are the next categories to the soil order and are differentiated from each other within the order on basis of characteristics of great generic significance. These include moisture and temperature regimes, diagnostic surface horizon (epipedon), parent material, drainage and vegetation effects. Formative elements used at the sub-order level includes: - UD = udic moisture regime; UST = ustic moisture regime; XER = Xeric moisture regime; AQU = aquic moisture regime, HUM= presence of humus etc. Example ustalf = UST + ALF; ALF= Alfisol, UST = Ustic moisture regime; Ustalf= Alfisol under ustic moisture regime.

Great Group: Sub orders are divided into great groups on the basis of characteristics affecting the whole profile. It includes the following main characteristics and other accessory properties.

(a) Close similarities in the kind, arrangement and degree of expression of horizon.

(b) Close similarities in soil temperature and moisture regimes.

(c) Similarities in the base status.

Common formative element used at the level of great group includes: Plinth = Plinthite, Cry = cryic temperature regim, Dur = Duripan, Natr = Natric horizon, etc. Example Plinthaqualf = PLINTH + AQU + ALF = Plinthite + Aquic moisture regime + Alfisol. Thus plinthaqualf is an alfisol under aquic moisture regime and has a plinthic horizon.

Sub-group: Sub-groups are sub – division of the great group. Criteria for differentiating the sub groups are:

(a) presence of diagnostic horizons or features
(b) properties that are subordinate to those used in differentiating great groups
(c) properties that tend towards other great groups

The sub group name is derived from the great group name to which an adjective is attached indicating the major property of the sub group; e.g. calcic Rhodxeralf = Calcic + Rhod + Xer + Alf. Calcic = calcic horizon; Rhod = Red colour (hue 2.5YR or redder); Xer = xeric moisture regime; Alf = Alfisol; Thus, calcic rhoxeralf means a red coloured alfisols having a calcic horizon under xeric moisture regime.

Family: This is a user oriented category. Thus the criteria for separation are soil properties that influence the response of soil to management and manipulation. These include:

(a) particle size distribution
(b) mineralogy of the horizon
(c) temperature regime
(d) the thickness of the soil penetrable by plant root
(e) cation exchange capacity
(f) presence of cutans
(g) presence of vertic property
(h) A few other definitive soil properties.

For example clayey calcic rhodxeralfs means calcic rhodxeralfs with clayey soil texture

Series: It is a sub division of the soil family and is a more user oriented class than the family. Separation of the family into series involves more detailed properties of the soil profile. Soil series is given name after the place where it was first encountered. For example, Ibadan series, Iwo series, Apomu series etc.

FAO/UNESCO CLASSIFICATION SYSTEM

The FAO/UNESCO system was developed by a panel set up by UNESCO for providing the basic unit for the soil map of the world. This classification was compiled from diverse systems in term of category and nomenclature. Therefore the panel has to reconcile and correlate these diverse systems into a unified system with well defined category without ambiguity.

The FAO system has two categories, a higher and a lower one. These categories have not been given name. From their definition, the higher category is equivalent to the great group of the USDA taxonomy while the lower category cannot be fitted into any category of the USDA.

The criteria for classification are similar to those of great group and sub group in the USDA taxonomy and include diagnostic horizon, pedogenic processes, soil depth, drainage characteristics and physical and chemical properties of the soil. However, the definition of diagnostic horizons in the FAO system is different from that of the USDA system, although there are many equivalent definitions. For example, argillic horizon in the USDA is the same as argic horizon in the FAO, while Albic, calcic, cambic, duric, histic, melanic, gypsic and nitric horizons has definition similar to those horizons bearing the same nomenclature in the USDA system. Other diagnostic horizons defined in the FAO system include anthraquic, anthric, cryic, ferralic, ferric, folic, fragic, fluvic, hortic,hydragric, irragric etc.

The following are the soil in the higher category class of the FAO (WRB, 2006) system:- ACRISOLS, ALBELUVISOLS, ALISOLS, ANDOSOLS, ANTHROSOLS, ARENOSOLS, CALCISOLS, CAMBISOLS, CHERNOZEMS, CRYOSOLS, DURISOLS, FERRALSOLS, FLUVISOLS, GLEYSOLS, CYPSISOLS, HISTOSOLS, KASTANOZEMS, LEPTOSOLS, LIXISOLS, LUVISOLS, NITOSOLS, PHAEOZEMS, PLANOSOLS, PLINTHOSOLS, PODZOLS, REGOSOLS, SOLONCKAK, SOLONETZ, STAGNOSOLS, TECHNOSOLS, UMBRISOLS and VERTISOLS. In all there are 32 reference groups in the FAO system. The names of soils are indicated by adding prefix and suffix adjectives from the qualifier lists to the reference group, for example Gleyic Luvisol oxyaquic.

Common group in Nigeria soils are Plinthosols, ferralsols, stagnosols (mangrove soils), alisols (ultisols), acrisols (ultisols), luvisols, lixisols (alfisols), arenosols, cambisols and regosols.

Acrisols

Acrisols are soils that have a higher clay content in the subsoil than in the top soil as a result of pedogenic processes (especially clay migration) leading to an argic (argillic) subsoil horizon. Acrisols have in certain depths a low base saturation and low activity clays. Acrisols correlates with Ultisols with low activity clays (USDA).

Alisols

Alisols are soils that have a higher clay content in the subsoil than in the top soil as a result of pedogenic processes (especially clay migration) leading to an argic (argillic) subsoil horizon. Alisols have in certain depths a low base saturation and high activity clays throughout the argic horizon. They occur predominantly in humid tropical, humid subtropical and warm temperate regions. Alisols correlates with Ultisols with high activity clays (USDA).

Arenosols

Arenosols comprise sandy soils, including both soils developed on residual sand after in situ weathering of usually quartz-rich sediments or rocks, and soils developed in recent deposited sands such as dunes in deserts and beach lands.

Cambisols

Cambisols combine soils with at least an incipient subsurface soil formation. Transformation of parent material is evident from structure formation and mostly brownish discoloration, increase clay percentage, and /or carbonate removal. US taxonomy classifies most of these soils as Inceptisols.

Gleysols

Gleysols are wetland soils that, unless drained, are saturated with ground water for long enough periods to develop a characteristic gleyic colour pattern. This pattern is essentially made up of reddish, brownish or yellowish colours at ped surfaces and/or in the upper soil layer or layers, in combination with grayish/bluish colours inside the peds and/or deeper in the soil. Many of the WRB Gleysols correlate with the aquic suborder in the USDA taxonomy (Aqualfs, Aquents, Aquepts, aquolls etc).

Lixisols

Lixisols comprise of soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenic processes (especially clay migration) leading to an argic (argillic) subsoil horizon. Lixisols have a high base saturation and low activity clays at certain depths. Lixisols correlates with Alfisols with low activity clays (USDA).

Luvisols

Luvisols comprise of soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenic processes (especially clay migration) leading to an argic (argillic) subsoil horizon. Luvisols have high activity clays throughout the argic horizon and a high base saturation at certain depths. Luvisols correlates with Alfisols with low activity clays (USDA).

Local soil classification Systems

A number of soil classification systems exist within the country that is native of the country. These includes:-

(1) Smith and Montgomery (1962)
(2) Moss (1957)
(3) Jungerius (1964)
(4) Klinkenberg and Higgins (1968)

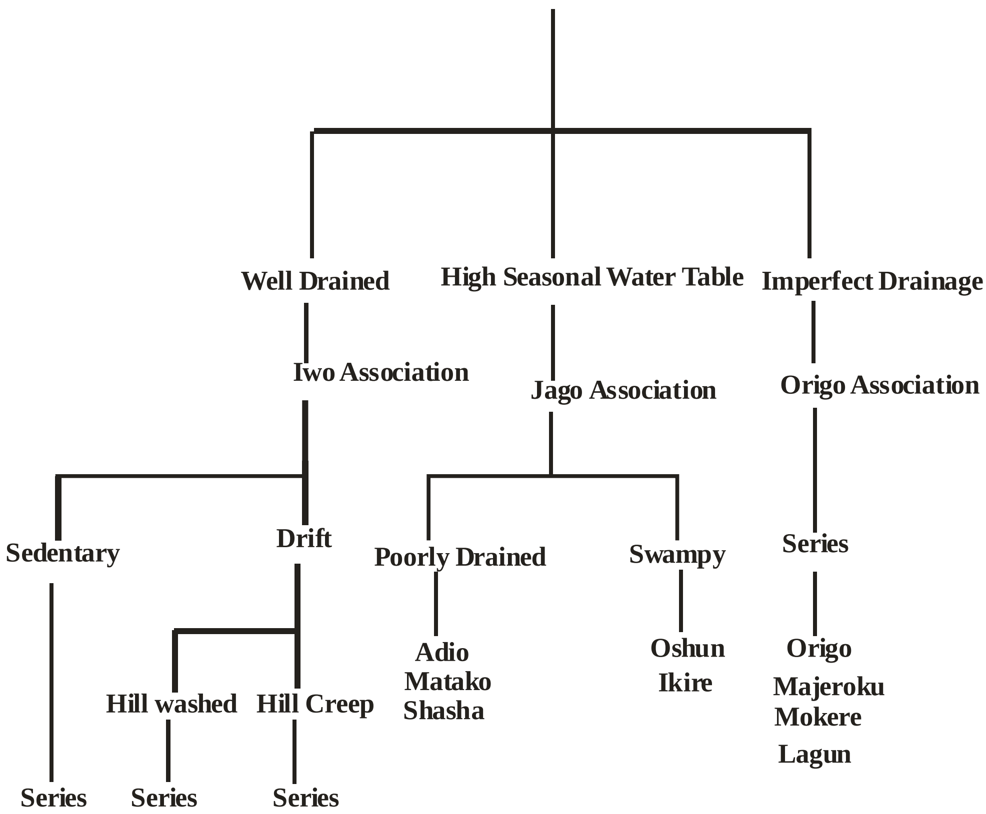
However, non of these classification can be said to be national, i.e. they are not nationally acceptable and cannot be apply to the nation because each of the system was either developed for the soils of a given locality or of a given parent material.

While the classification by Smith and Montgomery was developed for the soils of central southern part of Nigeria that of Moss was for the soils on sedimentary deposits. The classification by Jungerius was for the eastern part of the country while that of Klinkenberg and Higgins was for the northern part of the country.

Soil Classificaation by Smith and Montgomery

All the soils classified by Smith and Montgomery are within the central southern part of Nigeria. These soils are formed from igneous and metamorphic rocks. The classification of Smith and Montgomery was carried out to identify soils within the central southern part of Nigeria that were suitable for the production of cocoa.

In the taxonomic classification, the basic unit of classification is the soil series. However, they had two other categories at the drainage level and the association level. The associations are further broken down on the basis of parent material. The schematic diagramme below depicts the classification pattern adopted by Smith and Montgomery.



In the classification of Smith and Montgomery, the only association that has impeded drainage is the Origo association developed from gneiss.

In the well drained category are Iwo series developed from coarse grained granitic rocks and gneiss; Ondo series developed from medium grained granitic rocks; Egbeda series developed from fine grained biotite, gneiss and schist, while other series like Itagunmodi is formed from amphibiolites; Okemesi from quartz, schist and massive quartzites and Mamu from sericite schist.

The hill washed series in all the association are said to be the same. These are Oba, Iregun and Apomu series.

SOIL SURVEY

Soil survey is a branch of soil science which involves the identification of the different types of soil in a given landscape and the location of their distribution to scale on a map. In addition, soil survey provides information on the quality of the land in terms of their response to management and manipulation.

From this definition, it is clear that soil classification is a branch of soil survey and the unit of classification is the taxonomic unit or mapping unit or pedon. A taxonomic class depicts the properties of a soil profile as given in the profile description and analyses.

Mapping Unit

A mapping unit is a geographical unit and it is an area of land within which the greater proportion is occupied by the taxonomic class after which it is named. For example, if about 85% of the soil within a mapping unit is occupied by a soil whose property is that of Ibadan series, the soil will be named as Ibadan series.

Purity of Mapping

The degree of uniformity or heterogeneity in term of kinds of soils within a mapping unit is a measure of its purity. Purity is the proportion of the mapping unit occupied by the profile class after which it is named. It is usually estimated in percentage and different soil survey organizations have different acceptable purity standards. For example, USDA standard is 85% while the Soil survey of England and Wales is 70%.

In accessing the purity of a map, the point used for mapping cannot be used for estimating purity.

Kind of mapping units

Mapping units have been distinguished based on the amount of inclusion or impurity they contain. Five kind of mapping units have thus been distinguished and these are consociation, association, complex, undifferentiated and miscellaneous/unvisited.

Consociation

A consociation is a mapping unit with very little inclusion or impurity. It is assumed to contain the profile class after which it is named but in practice the purity of such class may range from 70% to 85%.

Association

An association is a mapping unit that contain two or more taxonomic class that are nearly equally represented and in which it is very easy to separate one profile class from the other.

Complex

Complex is a mapping unit where more than two taxonomic classes are equally represented and the components are intricately interwoven so that separation, even at large scale is difficult.

Undifferentiated

This is a mapping unit consisting of a number of taxonomic units that are so intricately interwoven that separation into different units are impossible at any reasonable mapping scale.

Miscellaneous/unvisited

This is a loosely used term by some survey organization. It refers mainly to areas that cannot be mapped because of rock outcrops, thick forests or other impediments.

Principles of soil survey

The principles of survey can be discussed under five points

A soil survey must have an objective

The objective or aim of soil survey must be defined before the commencement of the survey. It may be wide ranging such as to provide a relatively stable data base that will last for many years and be useable for a variety of purposes, or it may be narrow and specific such as to delineate the land suitable for irrigation in a particular area.

A soil survey is not the only basis for decision on land use and management, it is only an aid

Decisions on land management are usually influenced by economic considerations, social and institutional factors, often by existing legal land rights and sometimes by political constraints. Even on the more limited sphere of the physical environment, the soil is only one factor. Slope angle, frequently has a dominant effect on the choice between arable and non-arable use and climate is the main determinant in the choice of crop. The findings of soil survey and land evaluation are usually guides to land use.

Land resources do not consist of soils alone

The potential of land to support crops depends on climate as much as on soils, and whenever soil-water relationship can be advantageously modified. Also, applied ecological surveys are more important than soils as a basis for livestock production and extractive forestry. Landform and characteristics of the deeper regolith are frequently more important to the engineers than the upper 1-2 meters studied by the soil surveyor. Therefore, when commissioning or considering a soil survey, one should bear in mind the other kinds of natural resources information that may be necessary and whether these can be incorporated into the soil survey or will require other specialist's investigations.

A soil map must show soils

The map produced by a survey is a soil map if mapping units are based specifically on soil profile. Many surveys rightly include features of land forms in the description of the mapping units. A map based on classes such as "soil-land form association" is a soil map if it is directed towards showing the distribution of soils; the land forms being used as a means to an end. If on the other hand, it is primarily a map of land form units with soils being added to the legend, then it is a geomorphological map.

Soil map and report are complementary

The products of a soil survey include a soil map and survey report; neither is more important than the other because they are mutually indispensible. The amount of information that can be printed on the face of a map is limited and must be supported by data given in the soil survey memoir or report. The report is however, more than just an amplified legend. It contains in addition, background information on other environmental factors, information on land potential and probable response to various alternative forms of management. And sometimes also land use management recommendation. One soil survey report may serve several map sheets.

Kinds of Soil Survey

Soil survey have been distinguished on the basis of three criteria:- purpose of survey, regularity of observation and scale of mapping (intensity).

Based the purpose of the survey (What do you want to do want to do with the soil survey report?), there are two (2) types of surveys:- special purpose and general purpose surveys.

A general purpose soil survey is one that is done mainly to add to the already existing inventory of soil information. This commonly found in the national survey of each country, e.g. the USDA, FMAWR. The information may not be needed at the time of survey but such a survey is done for record purpose. Such survey usually employs many differentiating properties so that it may be found useful for several purposes that may arise in the future.

A special purpose soil survey is done for specific purpose in mind, e.g. survey for irrigation or survey for citrus plantation. In such survey, the properties (differentiating characteristics) of the land which is important for the purpose are emphasized. Special purpose surveys are usually done at large scale or semi-detailed. This has to be so because the area covered are smaller and also the intensity of observation also need to be higher.

Based on regularity of observation, three kinds of surveys have been distinguished: - free survey, rigid grid and flexible grid.

In **free survey**, there is no rigid pattern of observation. The surveyor uses the field features such as change in vegetation, topography, slope and even change in sound to movement to observe soil and to locate soil boundaries. Usually there is a lot of remote sensing methodology involved in free survey. And in most modern soil survey involving 5000 ha and above, this is usually the type of survey methodology adopted. The advantage is that it is cheaper because there is less number of observation points. However, because it depends largely on the experience of the surveyor, it can be very inaccurate with an amateur, since boundary placement is more difficult.

In **rigid grid survey**, examinations of the soil are done at regular and pre-determined interval. It is normally used when detailed information is required, e. g. mapping the soil of a research station or mapping for irrigation. Usually, the points of observation are at the intersection of the two regularly placed vertical and horizontal lines.

It has an advantage in thickly forested area where visibility of the terrain is poor. It is usually not used or recommended in large areas as it is expensive and the accuracy may not deserve the extra cost. It is the best method of survey for amateurs.

Flexible grid survey method is a compromise between the free and rigid grid methods of survey. In this system of survey, the number of observation is fixed but the location of the observation points are not pre-determined and can be fixed at will.

Based on the scale of mapping, there are seven kinds of surveys:- compilation, integrated survey, exploratory survey, reconnaissance survey, semi-detailed survey, detailed survey and intensive survey.

Compilation: These are soil maps produced by abstraction from other soil surveys. And where they exist they are filled by inferences. The scale is usually at 1: 100,000 or smaller. Many national soil maps of many countries are produced in this way.

Integrated survey: This is also known as land system survey. It is based on mapping the total physical environment and in fact land forms are mapping unit. Soils are an important but usually not a defining property of the mapping unit. The scale is 1: 250,000 or smaller.

Exploratory survey: Exploratory surveys are not survey proper. They are usually rapid road traverse made to provide modicum of information about the area that are otherwise unknown. Scale of exploratory survey varies from 1: 2,000,000 to 1,500,000.

Reconnaissance survey: These are mostly based on remote sensing especially Area Photo Imagery (API). They are the smallest scale of survey where the whole area is still covered. The scale is usually 1:250,000 although smaller scales have been used.

Semi-Detailed survey: In a semi-detailed survey, we have a combination of remote sensing and field work. Mapping units are usually soil association. Scale of mapping varies from 150,000 to 100, 000.

Detailed survey: Detailed surveys are executed through field examination with pre-determined numbers of observation points and or spacing. These kinds of surveys are usually employed for small area and for special purposes. Scale of observation varies between 1: 10,000 and 1: 25,000. Mapping unit are usually soil series.

Intensive survey: Intensive survey rigid grid approach, i.e. number of observation and spacing of observation are pre-determined. Mapping units are soil series and phase of soil series. Scale of mapping varies from 1: 1,000 to 1: 10,000 or even larger. They are usually experimental station surveys.

Producing soil survey report

Soil survey reports take different forms because of the variation in the purpose of the survey and the interest of the client. However, some basic items are common to all soil survey reports. These are:

(a) The physical environment
(b) Methodology of the survey
(c) Description of the soils in terms of mapping unit and classification
(d) Land evaluation

The physical environment

In the physical environment, the aspects usually discussed are the location and extent, the climate, regional and local relief and topography, geology of the parent materials, vegetation and land use pattern (including mining and agriculture).

Location: The location is given in longitude and latitude or the Eastings and Northings (when using GPS). The site is also indicated by small area on a large map where the area of the project is shaded. The approximate area of the land is also given in hectares.

Climate: Full information is given on the climatic condition of the area. Data on Rainfall, temperature, relative humidity, wind speed and direction are collected and presented either as tables or as graphs.

Relief and topography: Because of the influence of relief on soil formation, the information on it is very vital. Beside, it also affects decision on land uses even after survey. For example, the topography or relief of a land can be an important factor in determining the suitability of a land for arable cropping, irrigation agriculture or pastoral agriculture.

Geology or parent material: Knowledge of the parent rock from which the soil is formed is necessary. The difference between geology and parent material become important where the transported material and the geology are different from each other.

Vegetation

Experience has shown that there is a close association between vegetation and kind of soils. Therefore, information on the vegetation of the project area is important. It is therefore necessary to mention the type, subtype and identification of vegetation. For example, the land use and vegetation may be described as grassland with shrub and abundant vegetation cover. Woody species, broad leaves and grasses dominate the vegetation. The woody species occupy about 60% of the total ground surface. The predominant woody species are *Daniellia oliverii* (Iya), *Chloris excelsa* (Iroko), *Anogysus leocarpus* (Ayin), *Terminalia glaucesccens* (Idi); while the dominant broad leaf is *Chromolaena odorata* (Siam weed or Akintola weed).

Land Use

The kind and pattern of land use in the project area must be fully discussed. This include the type of crop cultivated, irrigation practices, area covered, mining activities, constructions if any, and some peculiar characteristics of farming systems e.g. land conservation practices.

Social Economic activities

The social economic environment of the project area also needs to be mentioned. The presence or absence of market and the marketing potentials of the available markets should be described.

Methodology of the survey

Here the method used in carrying out the soil survey is spelt out

The soils

This is the main part of the report. In it a full account of the soils, their properties and distribution over the landscape studied are given. Specifically, the aspect of the soils to be mentioned includes:-

(1) Soil classification: The soil classification systems used are discussed and the criteria of classification are well spelt out. In addition, the categorical level at which the classification was stopped should be mentioned. Any problem or problems encountered should be mentioned here and a summary should be given. This may include both the classification and mapping.

(2) Description of the mapping units: The mapping units are described fully in terms of their extent and major soil properties. Also for each mapping unit, the representative profile class is given and the extent of coverage (purity). The other profile classes mapped as inclusions in the mapping unit must also be indicated and the extent mentioned.

Soil Survey interpretation and land evaluation

Land evaluation is the main point most land users are interested in. This is the stage where the potentials of the soils in that area is accessed and their response to management are accessed. The soils can be grouped into:

1. Capability classes (Land capability classification)
2. Land suitability evaluation classes (FAO framework)
3. Irrigation capability classification (US Bureau of land reclamation)

4. Fertility capability classification

Text figures

Here the legend of the soil map and land evaluation map are presented. Each map must have its own legend and this must correlate with the map.

Appendix

Various information from which the report has been summarized but which are too voluminous to be included in the main report are presented here. The data presented here include data on profile description and analyzed data.

REMOTE SENSING

What is Photogrammetry and Remote Sensing:

Photogrammetry and Remote Sensing is officially defined by the International Society for Photogrammetry and Remote Sensing (ISPRS) as "the art, science, and technology of obtaining reliable information from noncontact imaging and other sensor systems about the Earth and its environment, and other physical objects and processes through recording, measuring, analyzing and representation".

Simply speaking, photogrammetry and remote sensing are sciences concerned with the acquisition of information from images. In photogrammetry the emphasis is acquisition of geometric information through measurement, while in remote sensing the emphasis is on the acquisition of thematic information through interpretation. Both measurement and interpretation could be achieved either manually or automatically.

In remote sensing, a wide range of sensors (sensing devices) is in use to acquire images, sensitive to a large range of wavelengths of the electromagnetic spectrum. On the other hand, imaging cameras are the normal sensors which are sensitive to only the (near-) visible part of the electromagnetic spectrum. Imaging sensors are normally mounted either in a satellite or in an aircraft. Photogrammetry and remote sensing have found wide applications.

Foundations of Remote Sensing

The Electromagnetic Spectrum

The USGS defines the electromagnetic spectrum in the following manner: "Electromagnetic radiation is energy propagated through space between electric and magnetic fields. The electromagnetic spectrum is the extent of that energy ranging from cosmic rays, gamma rays, X-rays to ultraviolet, visible, and infrared radiation including microwave energy."

Electromagnetic Waves

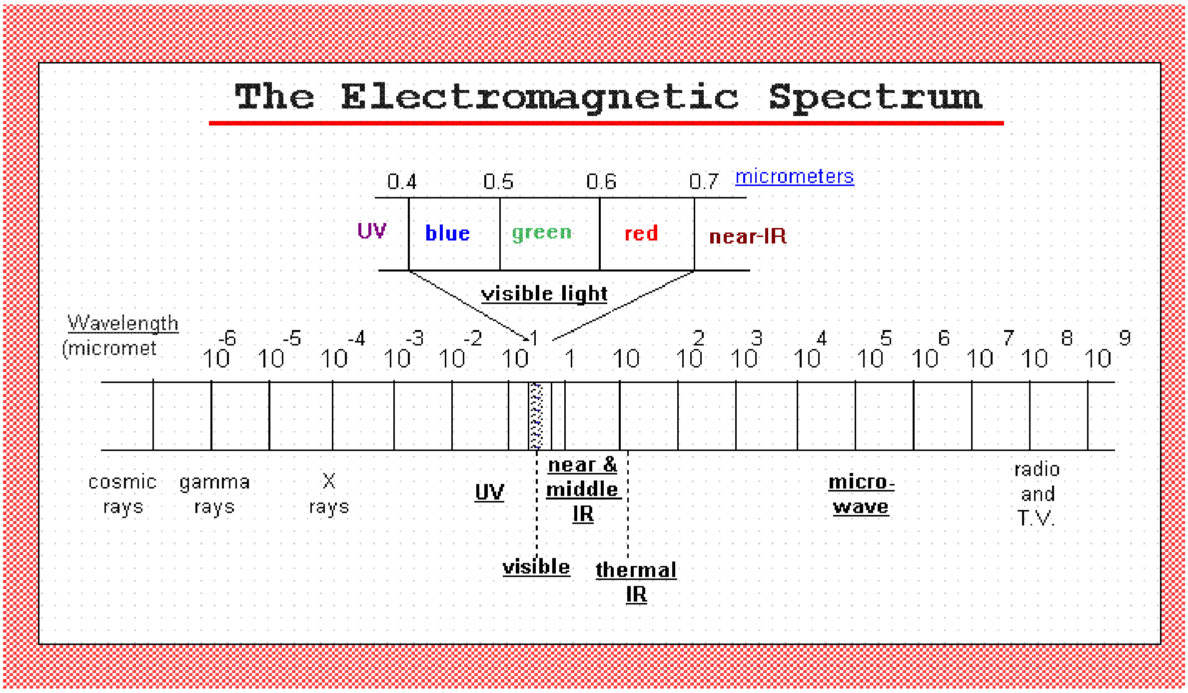
Electromagnetic waves may be classified by FREQUENCY or WAVELENGTH, and the velocity of ALL electromagnetic waves is equal to the speed of light, which we (along with Einstein) will refer to as c.

Wave Phenomena Concepts

Electromagnetic waves are *radiated* through space. When the energy encounters an object, even a very tiny one like a molecule of air, one of three reactions occurs. The radiation will either be reflected off the object, absorbed by the object, of transmitted through the object. The total amount of radiation that strikes an object is referred to as the *incident radiation*, and is equal to:

reflected radiation + absorbed radiation + transmitted radiation

In remote sensing, we are largely concerned with REFLECTED RADIATION. This is the radiation that causes our eyes to see colors, causes infrared film to record vegetation, and allows radar images of the earth to be created.



The electric field and the magnetic field are important concepts that can be used to mathematically describe the physical effects of electromagnetic waves.

The electric field vibrates in a direction transverse (i.e. perpendicular) to the direction of travel of the electromagnetic wave.

The magnetic field vibrates in a direction transverse to the direction of the em wave AND transverse to the electric field.

POLARIZATION: Polarization is defined by the orientation of the electrical field E. It is usually described in terms of HORIZONTAL POLARIZATION and VERTICAL POLARIZATION. Polarization is most important when discussing RADAR applications of remote sensing.

Aerial Photography

Introduction

Aerial photography has two uses that are of interest within the context of this course:

(1) Cartographers and planners take detailed measurements from aerial photos in the preparation of maps.

(2) Trained interpreters utilize aerial photos to determine land-use and environmental conditions, among other things.

Although both maps and aerial photos present a "bird's-eye" view of the earth, aerial photographs are NOT maps. Maps are orthogonal representations of the earth's surface, meaning that they are directionally and geometrically accurate (at least within the limitations imposed by projecting a 3-dimensional object onto 2 dimensions). Aerial photos, on the other hand, display a high degree of radial distortion. That is, the topography is distorted, and until corrections are made for the distortion, measurements made from a photograph are not accurate. Nevertheless, aerial photographs are a powerful tool for studying the earth's environment.

Because most GISs can correct for radial distortion, aerial photographs are an excellent data source for many types of projects, especially those that require spatial data from the same location at periodic intervals over a length of time. Typical applications include land-use surveys and habitat analysis.

This unit discusses benefits of aerial photography, applications, the different types of photography, and the integration of aerial photographs into GISs.

Basic Elements of Air Photo Interpretation

Novice photo interpreters often encounter difficulties when presented with their first aerial photograph. Aerial photographs are different from "regular" photos in at least three important ways:

- objects are portrayed from an overhead (and unfamiliar) position.
- very often, infrared wavelengths are recorded, and
- photos are taken at scales most people are unaccustomed to seeing

These "basic elements" can aid in identifying objects on aerial photographs.

Tone (also called Hue or Color) **--** Tone refers to the relative brightness or color of elements on a photograph. It is, perhaps, the most basic of the interpretive elements because without tonal differences none of the other elements could be discerned.

Size -- The size of objects must be considered in the context of the scale of a photograph. The scale will help you determine if an object is a stock pond or Lake Minnetonka.

Shape -- refers to the general outline of objects. Regular geometric shapes are usually indicators of human presence and use. Some objects can be identified almost solely on the basis of their shapes.

- the Pentagon Building
- (American) football fields
- cloverleaf highway interchanges

Texture -- The impression of "smoothness" or "roughness" of image features is caused by the frequency of change of tone in photographs. It is produced by a set of features too small to identify individually. Grass, cement, and water generally appear "smooth", while a forest canopy may appear "rough".

Pattern *(spatial arrangement)* **--** The patterns formed by objects in a photo can be diagnostic. Consider the difference between (1) the random pattern formed by an unmanaged area of trees and (2) the evenly spaced rows formed by an orchard.

Shadow -- Shadows aid interpreters in determining the height of objects in aerial photographs. However, they also obscure objects lying within them.

Site -- refers to topographic or geographic location. This characteristic of photographs is especially important in identifying vegetation types and landforms. For example, large circular depressions in the ground are readily identified as sinkholes in central Florida, where the bedrock consists of limestone. This identification would make little sense, however, if the site were underlain by granite.

Association -- Some objects are always found *in association with* other objects. The context of an object can provide insight into what it is. For instance, a nuclear power plant is not (generally) going to be found in the midst of single-family housing.

Advantages of Aerial Photography over Ground-Based Observation

Aerial photography offers an improved vantage point.

Aerial photography has the capability to stop action.

It provides a permanent recording.

It has broader spectral sensitivity than the human eye.

It has better spatial resolution and geometric fidelity than many ground-based sensing methods.

Types of Aerial Photography

Black and White

Color

Color Infrared

In 1903 or 1904 the first reliable black and white infrared film was developed in Germany. The film emulsion was adjusted slightly from regular film to be sensitive to wavelengths of energy just slightly longer than red light and just beyond the range of the human eye. By the 1930s, black and white IR films were being used for landform studies, and from 1930 to 1932 the National Geographic Society sponsored a series of IR photographs taken from hot air balloons.

Throughout the 1930s and 1940s, the military was hard at work developing color infrared film, eager to exploit it for surveillance. By the early 1940s the military was successful in its attempts. It developed a film that was able to distinguish camouflaged equipment from surrounding vegetation. Within months, however, an IR reflecting paint was developed for use on military vehicles, effectively making IR film technology useless to the military. So, they dropped it.

The scientific community, however, has made continuous use of the film technology.

Color infrared film is often called "false-color" film. Objects that are normally red appear green, green objects (except vegetation) appear blue, and "infrared" objects, which normally are not seen at all, appear red.

The primary use of color infrared photography is vegetation studies. This is because healthy green vegetation is a very strong reflector of infrared radiation and appears bright red on color infrared photographs.

LAND USE PLANNING

Concept, Principles and Justification of Land-Use Planning

Decisions on land use have always been part of the evolution of human society. In the past, land use changes often came about by gradual evolution, as the result of many separate decisions taken by individuals. In the more crowded and complex world of the present they are frequently brought about by the process of land use planning. Such planning takes place in all parts of the world, including both developing and developed countries. It may be concerned with putting environmental resources to new kinds of productive use. The need for land use planning is frequently brought about, however, by changing needs and pressures, involving competing uses for the same land.

The function of land use planning is to guide decisions on land use in such a way that the resources of the environment are put to the most beneficial use for man, whiles at the same time conserving those resources for the future. This planning must be based on an understanding both of the natural environment and of the kinds of land use envisaged. There have been many examples of damage to natural resources and of unsuccessful land use enterprises through failure to take account of the mutual relationships between land and the uses to which it is put. It is a function of land evaluation to bring about such understanding and to present planners with comparisons of the most promising kinds of land use.

Land evaluation is concerned with the assessment of land performance when used for specified purposes. It involves the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use. To be of value in planning, the range of land uses considered has to be limited to those which are relevant within the physical, economic and social context of the area considered, and the comparisons must incorporate economic considerations.

The aims of land evaluation

Land evaluation may be concerned with present land performance. Frequently however, it involves change and its effects: with change in the use of land and in some cases change in the land itself.

Evaluation takes into consideration the economics of the proposed enterprises, the social consequences for the people of the area and the country concerned, and the consequences, beneficial or adverse, for the environment. Thus land evaluation should answer the following questions:

- How is the land currently managed, and what will happen if present practices remain unchanged?

- What improvements in management practices, within the present use, are possible?

- What other uses of land are physically possible and economically and socially relevant?

- Which of these uses offer possibilities of sustained production or other benefits?

- What adverse effects, physical, economic or social, are associated with each use?

- What recurrent input levels are necessary to bring about the desired production and minimize the adverse effects? What are the benefits of each form of use?

If the introduction of a new use involves significant change in the land itself, as for example in irrigation schemes, then the following additional questions should be answered:

- What changes in the condition of the land are feasible and necessary, and how can they be brought about?

- What non-recurrent inputs are necessary to implement these changes?

The evaluation process does not in itself determine the land use changes that are to be carried out, but provides data on the basis of which such decisions can be taken. To be effective in this role, the output from an evaluation normally gives information on two or more potential forms of use for each area of land, including the consequences, beneficial and adverse, of each.

Land evaluation and land use planning

Land evaluation is only part of the process of land use planning. Its precise role varies in different circumstances. In the present context it is sufficient to represent the land use planning process by the following generalized sequence of activities and decisions:

i. recognition of a need for change;

ii. identification of aims;

iii. formulation of proposals, involving alternative forms of land use, and recognition of their main requirements;

iv. recognition and delineation of the different types of land present in the area;

v. comparison and evaluation of each type of land for the different uses;

vi. selection of a preferred use for each type of land;

vii. project design, or other detailed analysis of a selected set of alternatives for distinct parts of the area; This, in certain cases, may take the form of a feasibility study.

viii. decision to implement;

ix. implementation;

x. monitoring of the operation.

Land evaluation plays a major part in stages iii, iv and v of the above sequence, and contributes information to the subsequent activities. Thus land evaluation is preceded by the recognition of the need for some change in the use to which land is put; this may be the development of new productive uses, such as agricultural development schemes or forestry plantations, or the provision of services, such as the designation of a national park or recreational area.

Recognition of this need is followed by identification of the aims of the proposed change and formulation of general and specific proposals. The evaluation process itself includes description of a range of promising kinds of use, and the assessment and comparison of these with respect to each type of land identified in the area. This leads to recommendations involving one or a small number of preferred kinds of use. These recommendations can then be used in making decisions on the preferred kinds of land use for each distinct part of the area. Later stages will usually involve further detailed analysis of the preferred uses, followed, if the decision to go ahead is made, by the implementation of the development project or other form of change, and monitoring of the resulting systems.

Principles

Certain principles are fundamental to the approach and methods employed in land evaluation. These basic principles are as follows:

i. Land suitability is assessed and classified with respect to specified kinds of use

This principle embodies recognition of the fact that different kinds of land use have different requirements. As an example, an alluvial flood plain with impeded drainage might be highly suitable for rice cultivation but not suitable for many forms of agriculture or for forestry.

The concept of land suitability is only meaningful in terms of specific kinds of land use, each with their own requirements, e.g. for soil moisture, rooting depth etc. The qualities of each type of land, such as moisture availability or liability to flooding, are compared with the requirements of each use. Thus the land itself and the land use are equally fundamental to land suitability evaluation.

ii. Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land

Land in itself, without input, rarely if ever possesses productive potential; even the collection of wild fruits requires labour, whilst the use of natural wilderness for nature conservation requires measures for its protection. Suitability for each use is assessed by comparing the required inputs, such as labour, fertilizers or road construction, with the goods produced or other benefits obtained.

iii. A multidisciplinary approach is required

The evaluation process requires contributions from the fields of natural science, the technology of land use, economics and sociology. In particular, suitability evaluation always incorporates economic considerations to a greater or lesser extent. In qualitative evaluation, economics may be employed in general terms only, without calculation of costs and returns. In quantitative evaluation the comparison of benefits and inputs in economic terms plays a major part in the determination of suitability.

It follows that a team carrying out an evaluation require a range of specialists. These will usually include natural scientists (e.g. geomorphologists, soil surveyors, and ecologists), specialists in the technology of the forms of land use under consideration (e.g. agronomists, foresters, irrigation engineers, experts in livestock management), economists and sociologists. There may need to be some combining of these functions for practical reasons, but the principle of multidisciplinary activity, encompassing studies of land, land use, social aspects and economics, remains.

iv. Evaluation is made in terms relevant to the physical economic and social context of the area concerned

Such factors as the regional climate, levels of living of the population, availability and cost of labour, need for employment, the local or export markets, systems of land tenure which are socially and politically acceptable, and availability of capital, form the context within which evaluation takes place. It would, for example it will be unrealistic to say that land was suitable for non-mechanized rice cultivation, requiring large amounts of low-cost labour, in a country with high labour costs. The assumptions underlying evaluation will differ from one country to another and, to some extent, between different areas of the same country. Many of these factors are often implicitly assumed; to avoid misunderstanding and to assist in comparisons between different areas, such assumptions should be explicitly stated.

v. Suitability refers to use on a sustained basis

The aspect of environmental degradation is taken into account when assessing suitability. There might, for example, be forms of land use which appeared to be highly profitable in the short run but were likely to lead to soil erosion, progressive pasture degradation, or adverse changes in river regimes downstream. Such consequences would outweigh the short-term profitability and cause the land to be classed as not suitable for such purposes.

This principle by no means requires that the environment should be preserved in a completely unaltered state. Agriculture normally involves clearance of any natural vegetation present, and normally soil fertility under arable cropping is higher or lower, depending on management, but rarely at the same level as under the original vegetation. What is required is that for any proposed form of land use, the probable consequences for the environment should be assessed as accurately as possible and such assessments taken into consideration in determining suitability.

vi. Evaluation involves comparison of more than a single kind of use

This comparison could be, for example, between agriculture and forestry, between two or more different farming systems, or between individual crops. Often it will include comparing the existing uses with possible changes, either to new kinds of use or modifications to the existing uses. Occasionally a proposed form of use will be compared with non-use, i.e. leaving the land in its unaltered state, but the principle of comparison remains. Evaluation is only reliable if benefits and inputs from any given kind of use can be compared with at least one, and usually several different, alternatives. If only one use is considered there is the danger that, whilst the land may indeed be suitable for that use, some other and more beneficial use may be ignored.

Basic concepts

Certain concepts and definitions are needed as a basis for the subsequent discussion. These concern the land itself, kinds of land use, land characteristics and qualities, and improvements made to land.

For the sake of clarity, some definitions are given in the text in simplified form. Formal definitions of terms used in a specialized sense are given in the Glossary.

Land

Land comprises the physical environment, including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use. It includes the results of past and present human activity, e.g. reclamation from the sea, vegetation clearance, and also adverse results, e.g. soil salinization. Purely economic and social characteristics, however, are not included in the concept of land; these form part of the economic and social context.

A land mapping unit is a mapped area of land with specified characteristics. Land mapping units are defined and mapped by natural resource surveys, e.g. soil survey, forest inventory. Their degree of homogeneity or of internal variation varies with the scale and intensity of the study. In some cases a single land mapping unit may include two or more distinct types of land, with different suitabilities, e.g. a river flood plain, mapped as a single unit but known to contain both well-drained alluvial areas and swampy depressions.

Land is thus a wider concept than soil or terrain. Variation in soils, or soils and landforms, is often the main cause of differences between land mapping units within a local area: it is for this reason that soil surveys are sometimes the main basis for definition of land mapping units. However, the fitness of soils for land use cannot be assessed in isolation from other aspects of the environment, and hence it is land which is employed as the basis for suitability evaluation.

Land use

Suitability evaluation involves relating land mapping units to specified types of land use. The types of use considered are limited to those which appear to be relevant under general physical, economic and social conditions prevailing in an area. These kinds of land use serve as the subject of land evaluation. They may consist of major kinds of land use or land utilization types.

Major Kinds of Land Use and Land Utilization Types

A major kind of land use is a major subdivision of rural land use, such as rainfed agriculture, irrigated agriculture, grassland, forestry, or recreation. Major kinds of land use are usually considered in land evaluation studies of a qualitative or reconnaissance nature.

A land utilization type is a kind of land use described or defined in a degree of detail greater than that of A major kind of land use. In detailed or quantitative land evaluation studies, the kinds of land use considered will usually consist of land utilization types. They are described with as much detail and precision as the purpose requires. Thus land utilization typos are not a categorical level in a classification of land use, but refer to any defined use below the level of the major kind of land use.

A land utilization typo consists of a set of technical specifications in a given physical, economic and social setting. This may be the current environment or a future Betting modified by major land improvement e, e.g. an irrigation and drainage scheme. Attributes of land utilization types include data or assumptions on:

- Produce, including goods (e.g. crops, livestock timber), cervices (e.g. recreational facilities) or other benefits (e.g. wildlife conservation)

- Market orientation, including whether towards subsistence or commercial production

- Capital intensity

- Labour intensity

- Power sources (e.g. man's labour, draught animals machinery using fuels)

- Technical knowledge and attitudes of land users

- Technology employed (e.g. implements and machinery, fertilizers, livestock breeds, farm transport, methods of timber felling)

- Infrastructure requirements (e.g. sawmills, tat factories, agricultural advisory services)

- Size and configuration of land holdings, including whether consolidated or fragmented

- Land tenure, the legal or customary manner in which rights to land are held, by individuals or groups

- Income levels, expressed per capita, per unit of production (e.g. farm) or per unit area.

Management practices on different areas within one land utilization typo are not necessarily the same. For example, the land utilization type may consist of mixed farming, with part of the land under arable use and part allocated to grazing. Such differences may arise from variation in the land, from the requirements of the management system, or both.

Some examples of land utilization types are:

i. Rainfed annual cropping based on groundnuts with subsistence maize, by smallholders with low capital resources, using cattle drawn farm implements, with high labour intensity, on freehold farms of 5-10 ha.

ii. Farming similar to (i) in respect of production, capital, labour, power and technology, but farms of 200-500 ha operated on a communal basis.

iii. Commercial wheat production on large freehold farms, with high capital and low labour intensity, and a high level of mechanization and inputs.

iv. Extensive cattle ranching, with medium levels of capital and labour intensity, with land held and central services operated by a governmental agency.

v. Softwood plantations operated by a government Department of Forestry, with high capital intensity, low labour intensity, and advanced technology.

vi. A national park for recreation and tourism.

Some descriptions of land utilization types are given in Chapter 5.

Where it is wished to relate agricultural land utilization types to a general classification, the Typology of World Agriculture of the International Geographical Union may be considered (Kostrowicki, 1974). The role of land utilization types in land evaluation is discussed further in Beek (1975).

Multiple and Compound Land Use

Two terms, multiple and compound land utilization types, refer to situations in which more than one kind of land use is practiced within an area.

A multiple land utilization type consists of more than one kind of use simultaneously undertaken on the same area of land, each use having its own inputs, requirements and produce. in example is a timber plantation used simultaneously as a recreational area.

A compound land utilization type consists of more than one kind of use undertaken on areas of. land which for purposes of evaluation are treated as a single unit. The different kinds of use may occur in time sequence (e.g. as in crop rotation) or simultaneously on different areas of land within the same organizational unit. Mixed farming involving both arable use and grazing is an example.

Sometimes an appropriate land utilization type can be found by making several land mapping units part of the same management unit, e.g. livestock management which combines grazing on uplands in the rainy season and on seasonally flooded lowlands in the dry season.

Land utilization types are defined for the purpose of land evaluation. Their description need not comprise the full range of farm management practices, but only those related to land management and improvement. At detailed levels of evaluation, closely-defined land utilization types can be extended into farming systems by adding other aspects of farm management. Conversely, farming systems that have already bean studied and described can be adopted as the basis for land utilization types.

Land characteristics, land qualities and diagnostic criteria

A land characteristic is an attribute of land that can be measured or estimated. Examples are slope angle, rainfall, soil texture, available water capacity, biomass of the vegetation, etc. Land mapping units, as determined by resource surveys, are normally described in terms of land characteristics.

If land characteristics are employed directly in evaluation, problems arise from the interaction between characteristics. For example, the hazard of soil erosion is determined not by slope angle alone but by the interaction between elope angle, slope length, permeability, soil structure, rainfall intensity and other characteristics. Because of this problem of interaction, it is recommended that the comparison of land with land use should be carried out in terms of land qualities.

A land quality is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of use. Land qualities may be expressed in a positive or negative way. Examples are moisture availability, erosion resistance, flooding hazard, nutritive value of pastures, accessibility. Where data are available, aggregate land qualities may also be employed, e.g. crop yields, mean annual increments of timber species.

Table 1 gives an illustrative list of land qualities related to productivity from three kinds of use and to management and inputs. It is not exhaustive, nor is each land quality necessarily relevant for a particular area and type of land use. The qualities listed in B and C are in addition to those of A, which may be relevant to all three kinds of use (based in part on Beek and Bennema, 1972). There may also be land qualities related to major land improvements. These vary widely with the types of improvement under consideration. An example is land evaluation in relation to available supplies of water where irrigation is being considered.

A land quality is not necessarily restricted in its influence to one kind of use. The same quality may affect, for example, both arable use and animal product

There are a very large number of land qualities, but only those relevant to land use alternatives under consideration need be determined. A land quality is relevant to a given type of land use if it influences either the level of inputs required, or the magnitude of benefits obtained, or both. For example, capacity to retain fertilizers is a land quality relevant to most forms of agriculture, and one which influences both fertilizer inputs and crop yield. Erosion resistance affects the costs of soil conservation works required for arable use, whilst the nutritive value of pastures affects the productivity of land under ranching.

Land qualities can sometimes be estimated or measured directly, but are frequently described by means of land characteristics. Qualities or characteristics employed to determine limits of land suitability classes or subclasses are known as diagnostic criteria.

A diagnostic criterion is a variable which has an understood influence upon the output from, or the required inputs to, a specified use, and which serves as a basis for assessing the suitability of a given area of land for that use. This variable may be a land quality, a land characteristic, or a function of several land characteristics. For every diagnostic criterion there will be a critical value or set of critical values which are used to define suitability class limits.

Soil and Land capability classification

Land suitability and land capability

The term "land capability" is used in a number of land classification systems, notably that of the Soil Conservation Service of the U.S. Department of Agriculture (Klingebiel and Montgomery, 1961). In the USDA system, soil mapping units are grouped primarily on the basis of their capability to produce common cultivated crops And pasture plants without deterioration over a long period of time. Capability is viewed by some as the inherent capacity of land to perform at a given level for a general use, and suitability as a statement of the adaptability of a given area for a specific kind of land use; others see capability as a classification of land primarily in relation to degradation hazards, whilst some regard the terms "suitability" and "capability" as interchangeable.

Because of these varying interpretations, coupled with the long-standing association of "capability" with the USDA system, the term land suitability is used in this framework, and no further reference to capability is made.

Land suitability classifications

General

Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses.

In this chapter, the structure of the suitability classification is first described. This is followed by an account of the range of interpretative classifications recognized: qualitative, quantitative and of current or potential suitability. In accordance with the principles given in Chapter 1, separate classifications are made with respect to each kind of land use that appears to be relevant for the area. Thus, for example, in a region where arable use, animal production and forestry were all believed to be possible on certain areas, a separate suitability classification is made for each of these three kinds of use.

There may be certain parts of the area considered, for which particular kinds of use are not relevant, e.g. irrigated agriculture beyond a limit of water availability. In these circumstances, suitability need not be assessed. Such parts are shown on maps or tables by the symbol NR: Not Relevant.

Structure of the suitability classification

The framework has the same structure, i.e. recognizes the same categories, in all of the kinds of interpretative classification (see below). Each category retains its basic meaning within the context of the different classifications and as applied to different kinds of land use. Pour categories of decreasing generalization are recognized:

i. Land Suitability Orders:	reflecting kinds of suitability.
ii. Land Suitability Classes:	reflecting degrees of suitability within Orders.
iii. Land Suitability Subclasses:	reflecting kinds of limitation, or main kinds of improvement measures required, within Classes.
iv. Land Suitability Units:	reflecting minor differences in required management within Subclasses.

<u>Land Suitability Orders</u>

Land suitability Orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders represented in maps, tables, etc. by the symbols S and N respectively.

Order S Suitable:	Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.
Order N Not Suitable:	Land which has qualities that appear to preclude sustained use of the kind under consideration.

Land may be classed as Not Suitable for a given use for a number of reasons. It may be that the proposed use is technically impracticable, such as the irrigation of rocky steep land, or that it would cause severe environmental degradation, such as the cultivation of steep slopes. Frequently, however, the reason is economic: that the value of the expected benefits does not justify the expected costs of the inputs that would be required.

Land Suitability Classes

Land suitability Classes reflect degrees of suitability. The classes are numbered consecutively, by arabic numbers, in sequence of decreasing degrees of suitability within the Order. Within the Order Suitable the number of classes is not specified. There might, for example, be only two, S1 and S2. The number of classes recognized should be kept to the minimum necessary to meet interpretative aims; five should probably be the most ever used.

If three Classes are recognized within the Order Suitable, as can often be recommended, the following names and definitions may be appropriate in a qualitative classification:

Class S1 Highly Suitable:	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
Class S2 Moderately Suitable:	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
Class S3 Marginally Suitable:	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.

In a quantitative classification, both inputs and benefits must be expressed in common measurable terms, normally economic. In different circumstances different variables may express most clearly the degree of suitability, e.g. the range of expected net income per unit area or per standard management unit, or the net return per unit of irrigation water applied to different types of land for a given use.

Where additional refinement is necessary it is recommended that this should be achieved by adding classes, e.g. S4, and not by subdividing classes, since the latter procedure would contradict the principle that degrees of suitability are represented by only one level of the classification structure, that of the suitability class. This necessarily change e the meanings of class numbers, e.g. if four classes were employed for classifying land with respect to arable use and only three with respect to forestry, Marginally Suitable could refer to S4 in the former case but S3 in the latter.

An alternative practice has been adopted in some countries. In order to give a constant numbering to the lowest Suitable class, classes have been subdivided as, e.g. S2.1, S2.2. This practice is permitted within the Framework, although for the reason given in the preceding paragraph it is not recommended.

Suitability Class S1, Highly Suitable, may sometimes not appear on a map of a limited area, but could still be included in the classification if such land is known or believed to occur in other areas relevant to the study.

Differences in degrees of suitability are determined mainly by the relationship between benefits and inputs. The benefits may consist of goods, e.g. crops, livestock products or timber, or services, e.g. recreational facilities. The inputs needed to obtain such benefits comprise such things as capital investment, labour, fertilizers and power. Thus an area of land might be classed as Highly Suitable for rainfed agriculture, because the value of crops produced substantially exceeds the costs of farming, but only Marginally Suitable for forestry, on grounds that the value of timber only slightly exceeds the costs of obtaining it.

It should be expected that boundaries between suitability classes will need review and revision with time in the light of technical developments and economic and social changes.

Within the Order Not Suitable, there are normally two Classes:

Class N1 Currently Not Suitable:	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
Class N2 Permanently Not Suitable:	Land having limitations which appear so severe as to preclude any possibilities Of successful sustained use of the land in the given manner.

Quantitative definition of these classes is normally unnecessary, since by definition both are uneconomic for the given use. The upper limit of Class N1 is already defined by the lower limit of the roast suitable class in Order S.

The boundary of Class N2, Permanently Not Suitable, is normally physical and permanent. In contrast, the boundary between the two orders, Suitable and Not Suitable is likely to be variable over time through changes in the economic and social context.

Land Suitability Subclasses

Land Suitability Subclasses reflect kinds of limitations, e.g. moisture deficiency, erosion hazard. Subclasses are indicated by lower-case letters with mnemonic significance, e.g. S2m, S2e, S3me. Examples are given in Table 5. There are no subclasses in Class S1.

The number of Subclasses recognized and the limitations chosen to distinguish them will differ in classifications for different purposes. There are two guidelines:

- The number of subclasses should be kept to a minimum that will satisfactorily distinguish lands within a class likely to differ significantly in their management requirements or potential for improvement due to differing limitations.

- As few limitations as possible should be used in the symbol for any subclass. One, rarely two, letters should normally suffice. The dominant symbol (i.e. that which determines the class) should be used alone if possible. If two limitations are equally severe, both may be given.

Land within the Order Not Suitable may be divided into suitability subclasses according to kinds of limitation, e.g. N1m, N1me, N1m although this is not essential. As this land will not be placed under management for the use concerned it should not be subdivided into suitability units.

Land Suitability Units

Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. The units differ from each other in their production characteristics or in minor aspects of their management requirement e (often definable as differences in detail of their limitations). Their recognition permits detailed interpretation at the farm planning level. Suitability units are distinguished by arabic numbers following a hyphen, e.g. S2e-1, S2e-2. There is no limit to the number of units recognized within a subclass.

Conditional Suitability

The designation Conditionally Suitable may be added in certain instances to condense and simplify presentation. This is necessary to cater for circumstances where small areas of land, within the survey area, may be unsuitable or poorly suitable for a particular use under the management specified for that use, but suitable given that certain conditions are fulfilled.

The possible nature of the conditions is varied and might relate to modifications to the management practices or the input e of the defined land use (occasioned, for example, by localized phenomena of poor soil drainage, soil salinity); or to restrictions in the choice of crops (limited, for example, to crops with an especially high market value, or resistant to frost). In such instances, the indication "conditional" can avoid the need for additional classifications to account for local modifications of land use or local major improvements.

Conditionally Suitable is a phase of the Order Suitable. It is indicated by a lower case letter c between the order symbol and the class number, e.g. Sc2. The conditionally suitable phase, subdivided into classes if necessary, is always placed at the bottom of the listing of S classes. The phase indicates suitability after the condition(e) have been met.

Employment of the Conditionally Suitable phase should be avoided wherever possible. It may only be employed if all of the following stipulations are met:

i. Without the condition(s) satisfied, the land is either not suitable or belongs to the lowest suitable class.
ii. Suitability with the condition(s) satisfied is significantly higher (usually at least two classes).
iii. The extent of the conditionally suitable land is very small with respect to the total study area.

If the first or second stipulation is not met, it may still be useful to mention the possible improvement or modification in an appropriate section of the text. If the third stipulation is not met, then the area over which the condition is relevant is sufficiently extensive to warrant either a new land utilization type or a potential suitability classification, as appropriate.

As the area of land classed as Conditionally Suitable is necessarily small, it will not normally be necessary to subdivide it at the unit level.

It is important to note that the indication "conditional" is not intended to be applied to land for which the interpretation is uncertain, either in the sense that its suitability is marginal or because factors relevant to suitability are not understood. Use of "conditional" may seem convenient to the evaluator, but its excessive use would greatly complicate understanding by users and must be avoided.

Qualitative and Quantitative Classifications

A qualitative classification is one in which relative suitability is expressed in qualitative terms only, without precise calculation of costs and returns.

Qualitative classifications are based mainly on the physical productive potential of the land, with economics only present as a background. They are commonly employed in reconnaissance studies, aimed at a general appraisal of large areas.

A quantitative classification is one in which the distinctions between classes are defined in common numerical terms, which permits objective comparison between classes relating to different kinds of land use.

Quantitative classifications normally involve considerable use of economic criteria, i.e. costs and prices, applied both to inputs and production. Specific development projects, including pre-investment studies for these, usually require quantitative evaluation.

Qualitative evaluations allow the intuitive integration of many aspects of benefits, social and environmental as well as economic. This facility is to some extent lost in quantitative evaluations. The latter, however, provide the data on which to base calculations of net benefits, or other economic parameters, from different areas and different kinds of use. Quantitative classifications may become out of date more rapidly than qualitative ones as a result of changes in relative costs and prices.

Classifications of Current and Potential Suitability

A classification of current suitability refers to the suitability for a defined use of land in its present condition, without major improvements. A current suitability classification may refer to the present use of the land, either with existing or improved management practices, or to a different use.

A classification of potential suitability refers to the suitability, for a defined use, of land units in their condition at some future date, after specified major improvements have been completed where necessary.

Common examples of potential suitability classifications are found in studies for proposed irrigation schemes. For a classification to be one of potential suitability it is not necessary that improvements shall be made to all parts of the land; the need for major improvements may vary from one land unit to another and on some land units none may be necessary.

In classifications of potential suitability it is important for the user to know whether the costs of amortization of the capital costs of improvements have been included. Where these are included, the assumptions should state the extent to which input e have been costed and the rates of interest and period of repayment that have been assumed.

Classification with amortization is only possible if the repayment of capital costs can be apportioned to identifiable areas of land. If the benefits from major expenditure are not confined to the agricultural sector (as in multipurpose irrigation and power schemes), responsibility for capital repayments is difficult to assess. In these circumstances, amortization costs will usually be excluded from the evaluation.

The distinction between qualitative and quantitative classifications, and between current and potential suitability, do not fully describe the nature of a classification. Two further considerations of importance are treatment of the location factor and of amortization of capital costs, but these by no means exhaust the range of possibilities. They are not distinguished as further specific types of classification. A suitability classification needs to be read in conjunction with the statement of the data and assumptions on which it is based (Chapter 4).

The results of land suitability evaluation

The results of an evaluation will usually include the following types of information, the extent to which each is included varying with the scale and intensity of the study. Some examples are given in Chapter 5.

i. The <u>context</u>, physical, social and economic, on which the evaluation is based. This will include both data and assumptions.

ii. <u>Description of land utilization types or of major kinds of land use</u> which are relevant to the area. The more intensive the study, the greater will be the detail and precision with which these are described.

iii. <u>Maps, tables and textual matter showing degrees of suitability</u> of land mapping units for each of the kinds of land use considered, together with the diagnostic criteria. Evaluation is made separately for each kind of use. Examples of land suitability maps and tables are given in Fig. 2 and Table 3.

iv. <u>Management and improvement specifications</u> for each land utilization type with respect to each land mapping unit for which it is suitable. Again, as the survey becomes more intensive, so the precision with which such specifications are given increases; thus in a semi-detailed survey a need for drainage might be specified, whilst in a detailed survey the nature and costs of drainage works would be given.

v. <u>Economic and social analysis</u> of the consequences of the various kinds of land use considered.

vi. <u>The basic data and maps</u> from which the evaluation was obtained. The results, particularly the suitability classification itself, are based upon much information of value to individual users. Such information should be made available, either as an appendix to the main report or as background documentation.

vii. Information on the reliability of the suitability estimates. Such information is directly relevant to planning decisions. It will also aid any subsequent work directed towards improving the land suitability classifications, by indicating weaknesses in the data and aspects which might repay further investigation.