An overview of micropedological features of different soil orders

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Genesis, development, morphology and micropedological features of Ultisols

The word "Ultisol" is derived from "ultimate", because ultisols were seen as the ultimate product of continuous weathering of minerals in a humid, temperate climate without new soil formation via glaciations.

Introduction

Soil is the thin layer covering the entire earth's surface, except for open water surfaces and rock outcrops. The properties of soil are determined by environmental factors. Five dominant factors are often considered in the development of the various soils: (a) the climate, (b) parent materials (rocks and physical and chemical derivatives of same), (c) relief, (d) organisms (fauna and flora), and (e) the time factor. There are a large number of different soils, reflecting different kinds and degrees of soil forming factors and their combinations. Although many soil classification systems exist; However, two systems are widely used: The USDA Soil Taxonomy and the FAO/UNESCO legend. The French system (ORSTROM) is also commonly used in France and in Francophone Africa. The classification of soils starts with examination of soil profiles. Morphologically, soils are composed of a series of horizons. Soil horizons are layers of different appearance, thickness, and properties which have arisen by the action of various soil forming processes. The horizons are normally parallel to the surface. Collectively, the horizons make up what is called the soil profile or soil "Pedon". A soil profile is defined as a vertical section of the soil to expose layering. There are six levels in the hierarchy of categories: Orders (the highest category), suborders, great groups, subgroups, families and series (the lowest category) (USDA, 1978). There are ten orders, differentiated on gross morphological features by the presence or absence of diagnostic horizons or features which show the dominant set of soil forming processes that have taken place.

Ultisol is one of the 12 soil orders in the U.S. soil taxonomy. Ultisols are reddish, clay-rich, acidic soils that support mixed forest vegetation prior to cultivation. They are naturally suitable for forestry, can be made agriculturally productive with the application of lime and fertilizers, and are stable materials for construction projects. Occupying just over 8 percent of the nonpolar continental land area on earth they are found in humid temperate or tropical regions, including the south-eastern United States and China and in the humid tropics in South America and Africa. Ultisols vary in colour from purplish-red, to a bright reddish-orange, to pale yellowish-orange and even some subdued yellowish-brown tones. They are typically quite acidic, often having a pH of less than 5. The red and yellow colours result from the accumulation of iron oxide (rust) which is highly insoluble in water. Major nutrients, such as calcium and potassium, are typically deficient in ultisols, which means they generally cannot be used for sedentary agriculture without the aid of lime and other fertilizers, such as superphosphate. They can be easily exhausted, and require more careful management than alfisols or mollisols. However, they can be cultivated over a relatively wide range of moisture conditions. The Ultisols of the humid region is one of the major soils that are extensively cultivated for various root, tuber and vegetable crops. Just like most tropical soils that are derived from the acidic parent materials which are poor in nutrients reserves, the Ultisols are strongly weathered, leached soils that are low in organic matter, total nitrogen and cation exchange capacity (Bationo and Mokwunye, 1991 and Egbuchua, 2007). They also belong to the acid low fertility group of soils (Sanchez and Logan, 1992). The low nutrient contents of the soil reflect its Kaolinitic, Fe and Al clay mineralogy. Because of the high extractable aluminium associated with ultisols, they are acidic in nature and nutrient impoverished (FMANR, 1996). The need to ensure high crop productivity and increased yield in an ultisols can only be made possible through the use of external inputs from different sources –organic and inorganic (Busari *et al.*, 2004 and Rameshi *et al.*, 2009).

Environmental Conditions for development of a Ultisols

Climate

Ultisols are formed in climatic regions, where precipitation exceeds potential evapotranspiration during some periods each year. Also, the precipitation amount has to exceed the water storage capacity of the soil for some time of the year to allow water to percolate through the soil. This is essential to maintaining the low base status. Ultisols are found in tropical areas, where they tend to have somewhat finer textured E horizons, containing more organic matter and iron, than do the majority of Ultisols formed in temperate climate. Ultisols also may form in frigid soil temperature regimes. Xeric, perudic, udic, ustic, and aquic soil moisture regimes are present in various Ultisols.

Vegetation

Many Ultisols are formed under forest vegetation (e.g. mixed hardwood, pine, oak, hickory forest) although savannah or even swamp vegetation is possible. Because of their low base status most Ultisols are used for timber production but they are also used in agriculture, where liming and fertilization is important to decrease acidity and incease soil fertility. Where adequate agricultural management is applied these Ultisols are quite productive.

Relief

There are no limitations for relief where Ultisols might form. They may occupy hillslopes or level upland areas. The position they occupy is controlled by the relationship between geomorphology and other factors of formation and the resulting rates and degree of expression of pedogenic processes.

Parent Material

Common parent materials for the development of Ultisols contain few basic cations such as siliceous crystalline rocks (e.g. granite) or sedimentary material that is relatively poor in bases (e.g. highly weathered coastal plain sediment). Most of geologically old landscapes are covered by parent material rich in silica but poor in bases. There are some Ultisols formed in parent material with higher base status and less weathered material (e.g. volcanic ash, basic ignenous or metamorphic rocks). Rapid leaching of bases can occur where precipitation amounts are high to form Ultisols.

Time

Time periods involved in development of Ultisols depend on other factors of soil formation and the rate of specific pedogenic processes. A Pleistocene or older age is assigned most parent materials where Ultisols occur. The geologic age of parent materials, however, serves only to fix an absolute maximum on possible periods of time involved in soil formation. The actual time periods involved may be, and generally are, much less.

Geographic distribution

Ultisols occurs intermittently in a global band that lies almost entirely between latitudes of 40 ºN and 40º S. They occupy extensive areas in south in the eastern United States, east central Africa, north-east India, south west china, the island of south East Asia, and north eastern Australia. About 5.6% (730 million hectare) of the earth total length area is ultisols. In the United States, Ultisols comprises approx. 13% of the land area and are located in 3 widely separate regions.

Historical development

Pedologists, geologists, and geographers recognized long ago that red colors characterize the soil covers of the Mediterranean basin (Ramann 1911). Prior to the 1900's, systems of classifying soils were basically technical grouping designed for limited purposes and lacked categories that reflect a concept of soils comparable to Ultisols. The yellow and red earth described by Ramann (1911) and the laterites, red earths and yellow earths included highly weathered soils in Glinka's classification (1914) are the earliest examples of categories that included highly weathered soils with characteristics of many Ultisols. Somewhat latter, the red, yellow, laterite, grey brown podzolic and glay soils (Marbut, 1935) included most of the Ultisols of soil taxonomy. Additional information will lead to further refinement and redefinition of Ultisols, particularly as they relate to oxisols and Inceptisols.

Definitions

Soil taxonomy defines the Ultisols as mineral soils that:

Don't have tongues of albic material in the argillic horizon that have vertical dimensions of as much as 50 cm, if there is > 10% weather able minerals in the 20-200μm fractions; but have one of the following combinations of characteristics.

a) Have an algrillic horizon but not a fragipan and have base saturation (by sum of cations) of < 35%.

b) has in some part a hue of 5YR or yellower or a color value, moist of four or more or a color value dry, that is more than one unit higher than the value, moist the shallowest of the following:

i) 1.25 m bellow the upper boundry of argillic horizon,

ii) 1.8 m below the surface of the soil; or

iii) Immediately above a lithic or para litthic contact

Genetic implications

Percentage base saturation and depth at which it is determined are arbitrary in the genetic sense, but do serve to segment the theoretical Alfisol- Ultisol pedogenic succession. Soils that meet other criteria for Ultisols but are excluded because of the glossic features and weatherable mineral percentage combinations in requirement classify as Alfisols. Ultisols are restricted to a MAST of 8ºC or higher. This serves to limit them to relatively warm climates but is of only general genetic significance. Illuviation of clays and accumulations of organic matter are order-wide pedogenic processes that can be inferred with certainty. Although the low base status depicts highly weathered and leached soils, these conditions may have existed in the initial parent materials (Daniels and Amos, 1981). Five suborder s of Ultisols are recognised. The Humults have relatively large accumulations of Organic matter extending into the argillic horizons and are freely drained. Similar accumulations of organic matter do not occur in the other suborders with comparable drainage. The Aquults, Udults, Ustults and Xerults are defined on the basis of soil moisture regimes or characteristics indicative of soil-moisture conditions.

The characteristics used as a criteria for differentiating great groups and sub-groups have some genetic implications. The Albic, Pale and Haplic great groups primarily reflect the nature and degree of expression of translocation of clays, leaching, or weathering processes. Weathering and leaching are indicated at the order level even though, in some cases, a low base status and highly weathered condition may be inherited from parent material. Thus, processes that can operate in various combinations to develop the variety of soil in the order are inherited.

Relationship with other orders

There is marked similarity between certain taxa in Ultisols and Alfisols. The low base saturation status of Ultisols is the primary characteristic differentiating them from most Alfisols. Four of the five suborders, seventeen of the twenty four great groups and thirty eight of the ninety seven subgroups in Ultisols have similar taxa in Alfisols. The absence of an argalic horizon and the absence of argilic horizon above an oxic horizon in Inceptisols and Oxisols, respectively, are the chief criteria used to distinguish them from Ultisols. At the subgroup level, about one-fifth of the Ultisols taxa are, except for these characteristics, similar to taxa in the Inceptisols and about one- tenth in the Oxisols. Ultisols or Ultisol like soils thst indicate a need for new or revised taxa have since been described by several pedologists, most of which work in tropical areas (Sindhu *et al.*, 2014; Pal *et al.*, 2012).

Exact equivalents of Ultisols at any level of classification are not known in the order soil taxonomic systems. However, most systems that is similar to all or parts of certain Ultisols taxa. Correlations of taxa have been prepared for comparison by Soil Survey Staff (1975) and Costa de Lemos (1978) among others.

Classification

As Sanchez and Logan (1992) noted, there are two general ways to consider soils: (1) on the basis of the nature of its properties; and (2) on the basis of specified functions or use of soil. A set of facts are commonly used to characterize objects of interest. Relationship among the measured facts provides a basis for classification. The ideas and concepts that the human mind to perceive order and casual relations are, therefore, the basis for arbitrarily defining and naming parts of the real world and for developing classifications that assists in consolidating such information the requirements to qualify as an Ultisols are:

- Low base saturation (< 35 %) at 125 cm below the top of the argillic horizon or 180 cm below the surface, providing there are no intervening lithic or paralithic contacts.
- Diagnostic features: Presence of an argillic or kandic horizon, i.e., a zone of accumulation of clays

The major requirements, an argillic horizon and low base status, may develop simultaneously or sequentially with either preceding the other.

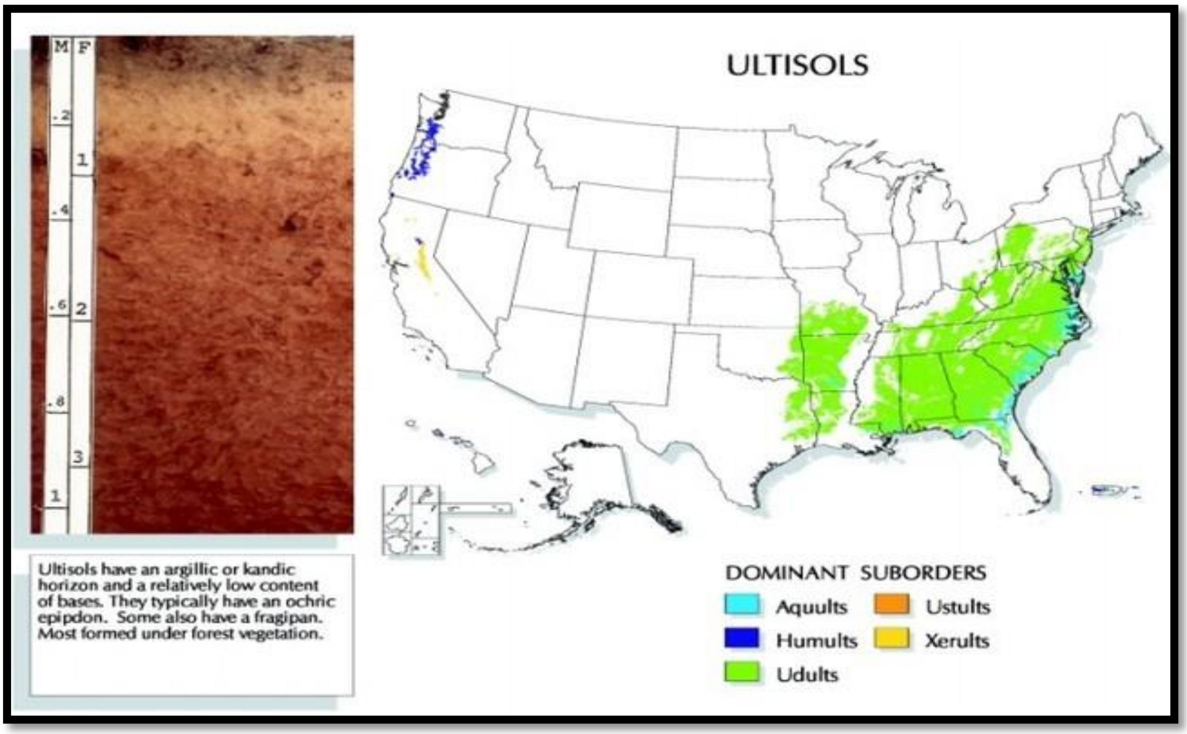


Figure 2: Ultisols and its dominant suborders

A distinct E horizon is not required in Ultisols. Ultisols occupy extensive areas in the south-eastern United States, east central Africa, northeast India, southwest China, and north-eastern Australia.

There are 5 suborders in the Ultisol order, whereas soil moisture regime and organic matter are used to distinguish the suborders:-

Aquults

They are saturated with water at some period of the year or are artificially drained. Aquic conditions form redoximorphic features.

Ustults

Ultisols formed in ustic soil moisture regime are classified as Ustults. Although moisture is limiting, it is seasonally available in adequate amounts for at least one crop per year.

Humults

They have high organic matter contents but do not have other characteristics of wetness. Humults are found in Hawaii, eastern California, and Washington.

Udults

Ultisols formed in humid regions, where dry periods are short are classifed as Udults. Their organic matter content is low. For short periods of time there might be a high water table in the solum but Udults do not show distinct redoximorphic features. For example, Udults extend from the east coast (Maryland to Florida) and beyond the Mississippi River Valley and are the most extensive soils in the humid southeast.

Xerults

Ultisols formed in xeric soil moisture regimes.

In Soil Taxonomy (key of soil taxonomy, 1957) the content and distribution of organic matter together with soil-drainage characteristics are definitive criteria for Humic, Umbric, and Sombric taxa. A sombric horizon is a subsurface horizon of illuvial accumulation of organic matter, which is not found under an albic horizon (e.g. Sombrihumults, Sombric Kandiudults). They are not known to occur in the U.S. and have been reported only in cool, moist, high plateau and mountain areas in intertropical regions. Organic matter in sombric horizons is not associated with large quantities of Al to the extent it is in spodic horizons. Umbric, i.e., the presence of an umbric epipedon is considered at subgroup level (e.g. Umbric Fragiaquults). Humic Ultisols show either an Ap horizon, or an A horizon 15 cm or more thick, that has a color value, moist, of 3 or less and a color value, dry, of 5 or less, which indirectly describes the presence of humus (e.g. Humic Hapludults).

Several soil moisture regimes are considered at sugroup level ranging from dry to wet conditons: Xeric (e.g. Xeric Kandihumults), aridic (e.g. Aridic Aridic Kandiustults), udic (e.g Udic Kandiustults), ustic (e.g. Ustic Kandihumults), and aquic (e.g. Aquic Paleudults). The fragipan horizon is diagnostic for fragic great groups and subgroups in Ultisols (e.g. Fragiaquults, Fragic Paleudults, Fragic Hapludults). Soils that meet the fragipan criteria are common in the eastern part of the United States. Ultisols with a plinthic diagnostic horizon are, for example, Plinthquults, Plinthic Paleaquults.

In some Ultisols spodic characteristics are present (e.g. Spodic Paleudults), i.e., an illuvial accumulation of sequioxides and/or organic matter. It is suggested that the spodic horizon developed in a thick, sandy eluvial horizon of an existing Ultisol. Simultaneous formation and expression of argillic and spodic horizon characteristics are essentially mutually exclusive phenomena. Continued development of the spodic horizon should eventually result in either destruction of the argillic horizon or its translocation to a greater depth. Typically spodic horizons are found in the Spodosol order.

Ultisols in Vertic subgroups (e.g. Vertic Paleudults, Vertic Albaquults) do have appreciable shrink-swell capacities and extensive cracks can be observed in the B horizon during dry season. They developed in clayey sediment, for example, in Puerto Rico and the south eastern United States. A low weatherable mineral content in the non-clay fraction is considered essential to their development. Bases lost through leaching are not replenished by weathering and a low base saturation can develop in relatively short time periods.

Ultisols developed in volcanic ash or other pryoclastics are classified as 'Andic'. They have significant quantities of highly reactive allophane or similar amorphous aluminosilicate materials. Their bulk density is low (<= 1.0 g/cm^3) but they show high water-retention capabilities (e.g. Andic Kandihumults, Andic Kanhaplustults). Such soils can be found in Hawaii.

Soil texture is used to define 'Arenic' (soils that have a sandy or sandy-skeletal particle-size class throughout a layer extending from the mineral soil surface to the top of an argillic horizon at a depth of 50 to 100 cm) and

'Psammentic' (soils that have a sandy particle-size class throughout the upper 75 cm of the argillic horizon, or throughout the entire argillic horizon if it is less than 75 cm thick) (e.g. Arenic Paleaquults, Psammentic Rhodudults).

Ultisols with a soil color that have 50 percent or more chroma of 3 or more in one or more horizons between either the A or Ap horizon or a depth of 25 cm from the mineral soil surface, whichever is deeper, and a depth of 75 cm are defined as 'Aeric' (e.g. Aeric Paleaquults). Ultisols which show a red color are defined by 'Rhodic' (a hue of 2.5YR or redder; and a value moist of 3 or less; and a value dry no more than 1 unit higher than the value moist) (e.g. Rhodic Kandiudults).

Shallow Ultisols are defined as 'Lithic' (e.g. Lithic Kanhaplohumults, Lithic Haplustults).

Ultisols which are grouped as 'old soils' are denoted by 'Pale' (e.g. Palehumults, Palexerults). They are not allowed to have a densic, lithic, paralithic, or petroferric contact within 150 cm of the mineral soil surface. Other limitations to qualify for a Pale subgroup within the Ultisol order are texture changes or skeletans on the faces of peds.

Typical morphology

The gross morphology of the most Ultisols is dominated by horizons of eluviations and Illuviation of clays. A typical horizon sequence is A, E, BE, Bt, BC, C. Common textures are sandy loams, loamy sands, silty clay loams, or clays in the argillic horizon. Clay contents increases regularly from A, E or upper B horizons to maximum in the upper part of argillic horizon, the decreases regularly from depth in to the C horizons. Thickness of solum is generally 1.5 to 2.0 m. Boundaries are abrupt or clear for A and E, clear or gradual for BE and Bt, and gradual or diffuse for BC horizons. The A horizons are commonly less than 15 cm thick with grayish-brown or dark grayish-brown colours and weak or moderate granular structure. E horizons are comparable in thickness and have weak structure or mostly structure less and may meet the criteria set for albic horizon (Lin, 2011). However, E horizon colours seldom have chromas as low or values as high as a cursory examination leads theoretical Alfisol – Ultisol- Oxisol pedogenic succession predominate. In association with Oxisols, they typically occupy landscape positions that are younger or less stable than positions occupied by Oxisols. In association with Alfisols, Ultisols occupy the more stable positions of the same age or older surfaces.

Regional variations are demonstrated by the occurrence of Ultisols in the highly weathered landscape positions are predominantly Ultisols with soils having higher base status on younger upland surfaces and stream terraces. Relief and other geomorphic factors can affect where Ultisols occur in association or close proximity with soils of other orders. Vertisols and aridisols can occur in close proximity to Ultisols in areas where Ultisols adjoined arid climates (Soil Survey Staff, 1975).

Ultisols and Alfisols share the presence of argillic diagnostic horizons but the low base status of Ultisols is the primary characteristic differentiating them from most Alfisols. Most Ultisols are more highly weathered and acidic than Alfisols but generally Ultisols are not as acid as Spodosols.

The absence of an argillic horizon and the absence of an argillic horizon above an oxic horizon in Inceptisols and Oxisols, resprectively, are the criteria used to distinguish them from Ultisols. To distinguish between Ultisols and Oxisols - there are still some weatherable minerals found in Ultisols compared to Oxisols. If base saturation < 35 %, a kandic horizon is present, and less than 40 % clay is found in the surface 18 cm the soil is classified as an Ultisol. In contrast, similar soils with more than 40 % clay in the surface are recognized as distinctive great groups of Oxisols.

Mollisols may occupy drier less leached positions, wetter positions, where leaching has been retarded and/or secondary enrichment with bases has occured. In areas with coarse-textured parent material, Spodosols may develop in low, poorly drained landscape positions with Ultisols on the better-drained sites. Histosols may develop in flat, depressional or poorly drained areas surrounded by Ultisols. Entisols can develop in association with Ultisols in very poorly drained areas or on steep rapidly eroding areas. Aridisols and Vertisols can occur in close proximity to Ultisols in areas where Ultisols adjoin arid climates. Inceptisols form on less stable landscape positions (steep slopes) and at higher elevations in mountainous areas or on floodplains (e.g. Fluvaquents). Soils associated with Ultisols are Psamments in areas of extremely sandy material.

Properties of a typical Ultisols

Generally, an ochric epipedon and an argillic or kandic diagnostic horizon is found in Ultisols. In some Ultisols there are umbric or mollic epipedons. Most Ultisols are formed in weathered parent rock thus the subsurface horizons are underlain by a saprolite zone. A major characteristic of Ultisols is low base saturation throughout the soil profile with slightly higher base contents in the upper soil horizon due to bio-cycling (Staff, NBSS&LUP (2002). The low base saturation status is mainly due to formation in parent material high in silica but low in bases. In some soils, the low base status results from intense leaching of parent material initially high in content of weatherable minerals, while in others, a low base status and small quantities of weatherable minerals were initial parent material characteristics. Typically, the cation exchange capacity (CEC) is low with slightly higer CEC in the upper horizon due to biocycling of nutrients. In many Ultisols there are continuous losses of bases through leaching and erosion, therefore, the CEC remains low. In poorly drained Ultisols, such as the Umbraquults, the base content is slightly higher than in typical Ultisols. Abrupt decreases in base saturation are frequently associated with plinthite, fragipans, or other zones that are saturated for prolonged periods.

Associated with low base (low nutrient) content is a high soil acidity. Surface horizons rarely have pH values less than 5.0 or greater 5.8. In general, the pH values decrease with depth to a minimum of 4.0 to 5.5 in the argillic horizon. In highly weathered and leached Ultisols a decreasing pH is evident throughout the solum.

In most Ultisols organic matter is restricted to the light-colored ochric epipedon. This can be attributed to high decomposition rates by aerobic micro-organisms under warm climates and free soil-drainage. Most of the annual increments of added organic residues are on the surface, where the oxygen and nutrient status of Ultisols are most suitable for high populations of micro-organisms. Organic matter content and thickness of the surface horizon increase in most Ultisols with decreasing internal soil drainage and aeration and umbric epipedons can form under these conditions. Ultisols with high organic matter are typified by the Humic taxa. The organic matter content found in many Ultisols is low compared to other soil orders such as Mollisols or Alfisols.

Clays in Ultisols are usually of the 1:1 type (kaolinite) or gibbsite - there are less clays of the 2:1 type. Therefore, the cation exchange capacity and water holding capacity is relatively low in most Ultisols. These limitations can be overcome by the application of lime to decrease acidity and fertilizers to add bases to the soil but Ultisols are commonly not as productive as Mollsiols or Alfisols. Clay content increases regularly from A, E or upper B horizons to a maximum in the upper part of the argillic horizon, then decreases regularly with depth into the C horizon.

Iron oxides, released from other minerals through weathering or inherited as such from the parent material, are important pedogenic and taxonomic indicators in Ultisols. Goethite is the dominant crystalline form in most Ultisols and commonly associated with lesser quantities of hematite, maghemite, and magnetite. The amounts of hematite are generally greater in Ultisols developed from basic rocks and are more abundant in tropical then temperate regions. This accounts for the red color in well-drained tropical Ultisols compared to other rgions. The red or yellow colors found in the argillic horizon and underlying materials in many Ultisols are due to iron oxides. In most Ultisols, various proportions of the soil are comprised of reddish and grayish or light-colored mottles. This condition is normally associated with segregation of Fe-oxides by alternating oxidation and reduction. Reduction forms relatively soluble Fe^{2+} which may migrate to more oxidizing locations before reoxidization or reoxidize and precipitate in situ on existing Fe^{3+} compounds. Repetitions of the cycle result in development of zones with high and low free iron contents corresponding to the reddish and grayish colors. The behavior of Mn in oxidizing and reducing environments is analogous to that of Fe. Through continued segregation and concentration of oxides by alternating oxidizing and reducing conditions plinthite or fragipans are formed. Plinthite are humus-poor but sequioxide-rich horizons that hardens irreversibly to ironstone hardpans or aggregates with repeated wetting and drying. When sesquioxide-rich features are found on the soil surface or exposed in a cut bank, they are commonly called 'laterite'. It is assumed that the formation of plinthite is associated with a seasonally fluctuating water table and the translocation of sesquioxides. The consequence of plinthite is impeded drainage and waterlogging. In Soil Taxonomy 'plinthite' is used for characterization of Ultisols when > 5 % of the volume of a soil horizon is occupied by plinthite. Fragipans form in similar environmental settings and fragipans and plinthite can occur in the same soil. Fragipans are layers of high bulk density, brittle when moist, and hard when dry. Many fragipans in Ultisols are associated with either, or both, lithologic or chronological discontinuities in the parent material (Soil survey staff, 1975). It has been postulated that many fragipans in Ultisols are a result of pedogenic processes, i.e., the precipitation of silica, clays, and/or sequioxides, which result in high bulk densities. The brittleness is attributed to binding of amorphous material and the formation of aluminosilicate binding agents.

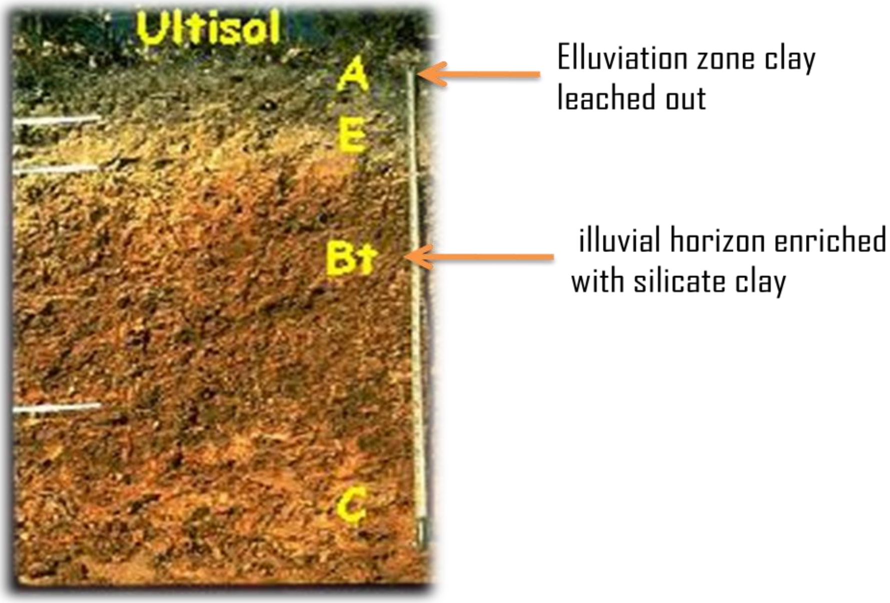
A typical sequence in an Ultisol profile could be characterized by a distinct E horizon that thickens upward into the overlying argillic and downward into the fragipan, such as A, E, BE, Bt, BC, and C horizons.The A horizons are commonly less than 15 cm thick with (dark) grayish-brown colors and weak or moderate granular structure. E horizons are comparable in thickness and have a weak structure or are structureless and may meet the criteria set for albic horizons. Chromas of 3 to 5 and values of 4 to 6 are common in most E horizons. Colors of the B horizon are generally 10YR or redder hue with values of 4 to 6 and chromas 6 to 8. The structure of the B horizon is typically moderate, medium subangular blocky and becomes weaker and coarser with increasing depth. The underlying C horizon has weaker and coarser structure or is structureless. Colors are less red and clay contents lower.

Pedogenesis

The kind, content and distribution of minerals present have a major influence on the morphology and other characteristics of Ultisols. Mineralogical composition and mineral weathering and alteration processes in the solum are among the most important factors in the development of Ultisols. The highly weathered and leached condition and long periods of time generally required in formation results in limited suites of minerals in most Ultisols. Associated primary accessory minerals may include kyanite, rulite, zircon, anatase and magnetite. The small percentages of weatherable minerals are generally K-feldspars and dioctahedral micas. Pyroxenes, amphiboles and other readily weatherable components are rare. Accessory secondary minerals include goethite is usually dominated by kaolinite or inter layered 2:1 phyllosilicates. Secondary oxides are typically the most abundant clay- size accessory minerals (Soil survey staff, 1975).

Mineral weathering and pedogenic processes in Ultisols result in an overall desilication, a conversion or enrichment with respect to sesqui- oxsides and an increase in water content of the mineral fraction. Simultaneous enrichment in quartz and de-silication through loss of combined silica are not incompatible processes in soils developed in quartz rich parent materials; because of the low solubility of the material, this can be expected in environments where losses of combined silica, bases and other constituents exceed the gain in water content of newly formed secondary minerals. Formation of quartz from solution phase constituents is reported in some areas with highly weathered soil (Staff, NBSS&LUP (2002).

When you look at an Ultisols we see…



Ultisols (Red Earth soils) developed from granitic rock under mid-tropical conditions in Belize, Central America were studied. The long-term weathering processes have produced a reddish solum overlaying reddish C horizons which grade into saprolitic material. Although the chemical data indicated that both profiles were strongly weathered, illite was relatively stable and kaolinite contents increased towards the soil surface. The kaolinite content was markedly higher and quartz and feldspars were lower in the older soil (Profile 1). The goethite and hematite contents increased upwards and Al substitution was greater for geothite than hematite in both profiles.

Micro-morphological analyses showed that mica has survived as muscovite rods in sepic and mosepic plasmic fabrics, plagioclase grains disintegrated along micro-cracks and quartz grains developed a craze joint planes pattern before breaking down into fine individual particles. The presence of void, grain and embedded cutans were evidence of in situ weathering of mica and other weatherable minerals. No apparent sign of illuviation could be found in the B horizons; however, void argillans were clear evidence of illuviation within the saprolite zone. A high amount of plasma in the solum suggests that most of the secondary products of weatherable minerals remain in the soil and there is a considerable loss of Si from quartz and other silicates, since the amounts of Si are very high in the parent materials (Hua, 2011).

Translocation and accumulation of clays

The content and distribution of clays, together with Fe-oxides and organic matter, essentially determine the morphology of Ultisols. Soil taxonomy requires that Ultisols have a zone of secondary accumulation of clays developed by processes of eluviations and Illuviation and that meet certain minimum requirements. The zone of Illuviation is normally an argillic horizon but may be fragipan that meets the requirements of an argillic horizon or has thick argillans. The argillic horizon is more clayey, has a higher percentage of < 0.2 um clay and generally has a similar suite of clay minerals when compared to adjacent horizon. Peds, pores and sometimes sand grains, in all or part of the horizon, have coatings of silicate clays oriated with their C-axis normal to the surfaces.

Minor pedogenic processes

Andeptic, Spodic and Vertic subgroups of Ultisols are based on subordinate expression of characteristics prominent in other orders. Soils in these subgroups are not extensive and have not been reported.

Spodic and Arglic horizon

Simultaneous formation and concomitant expression of argillic and spodic horizon characteristics are essentially mutually exclusive phenomena. Continued development of the spodic horizon should eventually result in either destruction of the subjacent argillic or its translocation to a greater depth. Changes that result in a more poorly drained condition might be particularly effective in initiating a new pedogenic cycle thet results in formation of a spodic horizon.

Soil inversion

Pronounced changes in volume with changes in moisture content are the antithesis of processes normally associated with Ultisols. Ultisols in Vertic subgroups do have appreciable shrink-swell capacities and extensive cracks can be readily observed in the B horizon during dry seasons. The typical horizon sequence is A,E,Bt, C. A and E horizons normally do not exeed 15 cm in combined thickness. Slickensides are sometimes identifiable in B and C horizons at depths below 1m. And field morphology indicates that the Bt horizons may qualify as argilic horizons bethought clay films (Lin, 2011). Bases lost through leaching and a low base saturation can develop in relatively short time periods.

Amorphous material accumulations

Significant quantities of highly reactive allophone or similar amorphous alumina silicate materials are present in andeptic subgroups of Ultisols identification little is known, however, about the quantities, composition and behaviour of these materials in most Indian Ultisols.

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Alfisols

Introduction

The Alfisol is defined by soil survey staff, 1975 in soil taxonomy, as soils with argillic horizons, ochric epipedon and high base status (more than 35%). The principle feature of Alfisol is an argillic horizon, a sub surface zone of clay enrichment formed by clay translocation from horizons above. The zone between the soil surface and the top of the argillic horizons is called an ochric epipedon . This zone typically contains most of the organic matter in soil and is depleated of clay compared to its original clay content. A number of other diagnostic horizaon in Alfisols may also occur in Alfisols e.g., fragipans, duripans, natric horizons, petrocalcic horizons, and plinthite may occur. In Alfisol subject to seasonal water logging, both argillic horizons, and ochric epipedons may possess features characteristic of low oxygen environment.

Micromorphology has palyed an important part in the characterization of Alfisol, more so than in any other order. This reviews focus on the contribution of micromorphology so for and assesses the future of micromorphological investigation of Alfisols, related to this more emphasis is given to the micromorphology of argillic horizons and ochric epipedons.

Micromorphological expression of argillic horizons

The micromorphological expression of argillic horizons depends greatly upon the overall partical-size distribution of the soil because this not only determines the size of particles available for transport, but also influences the size of pores through which illuviated particles move. Three general cases are distinguished: sandy, loamy and clayey textured soils (Bullock and Thompson, 1985).

Sandy textured soils

In argillic horizons of such soils, the grains are coated and more or less bridged by illuvial clay. In most instances, these coatings will have a strong birefringence, but in some soils the coating may be a mixture of particles with a resultant lower birefringence. For example, Fedoroff (1973) quoted an example from the Millevaches Pleatu, France, of a soil developed on weathered granite, in which the coating consist of small mica particles covering fragments of sand and gravel size. The clay in which strongly oriented clay particles coat and bridge mineral grains in coarse textured materials is a clearly identifiable example of an argillic horizon. Often, all the clay present in subsurface horizons appears illuvial in origin. There is a gradiation in most argillic horizons in sandy materials between grains with thin coatings without bridges, through grains with both coats and bridges, to more or less infillings of intergranular voids with illuvial clay. Thus, a range of fabrics can occur. Commonly, there are several parts of the range within each sandy argillic horizon, and its important in sampling micromarphological study that this is taken in account.

Loamy textured soils.

The concept of the argillic horizons has been shown to fit well for many medium textured soils of humid-temperate regions. The soils most examined include those in loess in Europe and North America and those in medium-textured till, again mainly in eastern North America and in Western Europe. It's within this textural range that translocated clay is most identifiable in the field as coating on ped surfaces. Unlike in sandy soils, coatings in medium-textured soils are mainly associated with ped faces or, in the absence of peds, with the edges of channels or planes.

In medium-textured soils, the contrast in particle size distribution between the clay coats and the adjacent matrix is often striking, and this, coupled with the well-expressed birefringence of the coats, makes them easily identifiable. The deposition of the coats may be brought about by (a) percolating water being drawn into dry peds, (b) the sieving action of fine pores, and (c) In soils in which the structure is dynamic, by the partial closing of some voids. All the classical features of clay coatings- strong orientation, strong textural contrast, sharp boundaries with the adjacent matrix, and laminated appearance- are characteristic of the clay coatings of argillic horizons, of medium textured soils. As in sandy argillic horizons, coating and deposits of illuvial clay are rarely uniformly distributed.

Because many argillic horizons in medium textured soils are also subjected to biological activity and other forms pedoturbation (usually wetting and drying, shrinking and swelling), disruption of coatings is a common feature. Disrupted coatings, though difficult to identify in the field, are usually clearly identifiable in thin sections by birefringence and textural contrast. They can occasionally be confused with plasma separation associated with shrink-swell if striated birefringence fabrics (bullock et.al 1985) are present. Disrupted coatings have been termed embedded argillans and papules by Brewer (1964), irregular clay concentration and linear clay concentrations (bullock and Murphy, 1979) and intercalations (bullock et.al 1985).

Clay textured soils

Clay coatings in soils of this textural class are difficult to identify in the field and under the microscope. There is no doubt that clay translocation can take place in these soils, but it is difficult to identify for one or more of the following reasons; (a) because the matrix is clayey, it is often difficult if not impossible to detect a contrast between illuviated clay and the adjacent matrix, (b) because of shrinking and swelling, clayey soils normally have a more or less dynamic structure so that coating have a short life before being integrated in the matrix, (c) Once in the matrix, argillans are difficult to distinguish because many clayey soils have strongly developed plasma separations (striated birefringence fabrics; bullock et.al 1985) that resemble embedded coatings, and (d) slickenside coatings (stress coatings) along planes may resemble void coating of illuvial clay.

Thus, the identification of translocated clay in some clayey soils is difficult or, at times, impossible. To determine whether translocation is active, horizons deeper than the level of maximum pedoturbation should be examined. At this depth, clay coatings tend to be more stable and remain on ped faces because of the lower structural dynamism

Microscopic identification of argillic horizons

Identification of argillic horizons in the field is often difficult**.** Clearly, in the course of soil mapping, decisions on the presence or absence of argillic horizons have to be taken without recourse to laboratory support. The main field criteria are the presence of an eluvial horizon over a blocky, fine-textured B horizons and coating of clay on the ped faces and around larger pores in the B horizons. Difficulties arise where the E horizon has been mixed by cultivation, where the presence of a lithological discontinuity is suspected or known, or where there is a large amount of pedoturbation or biological activity. One or more of these occur in many Alfisols (Bullock and Thompson, 1985).

In a study by McKeague et al.(1981), semi quantitative counts of oriented, apparently illuvial clay in thin sections of B horizons showed that only 32 of the 54 horizons designated Bt in the field had at least 1% apparently illuvial clay and this may be due to clay coating being difficult to distinguish from pressure faces at ped surfaces, or incorrect microscopic identification of illuvial clay in some soils.

Problems in the microscopic identification and measurement of illuvial clay

It is clear that micromorphologist may not agree among them on what constitute illuvial clay in thin section. McKeague et al. (1981) found that different micromorphologist may make significantly different estimates of illuvial clay when analyzing the same thin section. In their study, compatibility of the results varied between samples, but prior consultation among the analysts resulted in closure agreement. Murphy (1983) showed that there was even marked variation in replicate point counting's of illuvial clay by a single operator, attributing this to difficulties in identifying illuvial clay consistently and to orientation and variability of soil material.

Quantitative estimates of illuvial clay

Even if illuvial clay where readily identifiable in thin section, quantifying the amount present would still pose a challenge. A number of different techniques have been used by soil scientist; most of the techniques based on Andersons and Binnie's (1961) proof that area measurements in thin sections are reasonable estimates of volume measurements in the whole soil. To measure the area of illuvial clay in essentially two-dimensional thin sections, investigators have used trace-cut-and-weigh techniques (Boul and Hole, 1961); ribbon transects (Smeck et al 1968); grid counts (McKeague et al., 1978); points counts (Miedema and Slager, 1972); and automatic image analysis (Hill,1981). McKeague et al. (1981) have explored the approach of making estimates based on a few minutes of scanning of a section after study of reference sections. They conclude that, if accepted values could be achieved for illuvial clay in reference thin sections, micromorphologists could learn to make adequate estimates of illuvial clay in thin sections by rapid scanning.

Quantification may still be useful on a relative basis. For example, Eswaran (1968) used point-counting techniques to identify zone of maximum illuviation in a Belgian Alfisol. Similarly, Kwaad and Mucher (1979) and Bullock and Murphy (1979) substantiated their identifications of buried argillic horizons with quantitative estimates of illuvial clay.

Ochric epipedon

Most Alfisols have ochric epipedons, i.e., horizons formed at the soil surface. Ochric epipedon may consist of A horizons, with or without E horizons. A horizons are largely mineral material but with significant amounts of colloidal organic matter, and E horizons are characterized by loss of organic matter, clay, and iron. O horizons, which are surface accumulations of organic debris, may occur in unplowed Alfisols. These horizons are also considered in this section (Bullock and Thompson, 1985).

Micromorphology of O horizons

Accumulation of litter to any considerable thickness is not generally a feature of Alfisols except in some Boralfs and Aqualfs where the rate of microbial decomposition is slowed by cool temperature or low oxygen availability. Udalfs usually have a thin-litter layer, but the rate of turnover normally keeps pace with the rate of addition. Some O horizons in Boralfs, in particular, show a vertical sequence of decomposition stages from fresh litter through highly humified organic matter and would correspond to moder horizon in the European literature. Some Udalfs may also have moder surface horizon, but most commonly in Alfisols there is little or no litter layer, and the humus form corresponds to a mull (Bullock and Thompson, 1985).

Micromorphology of A horizons

Under natural and semi-natural vegetation where the base status is reasonably high, the A horizon of Alfisols is, in effect, a mull humus. This may have a very thin-L layer but below there normally is a fine aggregate structure with the fine material in the form of a clay-organic matter complex. In thin section, the horizon is porous with few recognizable plant fragments other than living roots. Most of the structure appears faunal in origin, with common experiments of earthworms, potworms, and under forest, in particular, springtails and mites. There is an undifferentiated birefringence fabrics with any birefringence of the clay particles masked by organic matter. Most well developed mulls have a spongy to crumb microstructure.

Many of the worlds Alfisols are cultivated, and the previously natural A horizons have been converted into Ap horizons. Although resembling mull in a low content of plant fragments, an organo-clay complex, and undifferentiated birefringence fabrics, Ap horizons differ from A horizons in the artificial microstructure that is created by from A horizons in the artificial microstructure that is created by cultivation.

Micromorphology of E horizons

Structure in Alfisol E horizons is commonly platy; thus elongated planar pores may be seen in thin section. In some soils subject to freezing, the fine material is concentrated in horizontal bands (0.1 to 1mm thick), which are roughly parallel to planar pores. Dumanski and St. Arnaud (1966) and Mermut and St. Arnaud (1981) have described such bands in E horizons of a number of Saskatchewan soils, including some Alfisols. The planar pores are attributed to ice lenses, and the banding is thought to reflect segregation of fine material as water is drawn to a freezing front. Banded fabrics are, however, not a universal feature of Alfisols (Luvisolic and Podzolic) E horizons in Canada (McKeague et al., 1974). In many E horizons, freeze-thaw cycles do not affect porosity patterns because water is absent from pores during freezing or because subsequent bioturbation destroys the fabrics. Finally E horizons in many Alfisols may be expanding downward due to decomposition of argillans.

Future micromorphological studies of Alfisols

Although micromorphology is the surest means of identifying illuvial clay and the amounts present in argillic horizons, there still are several developments needed to improve its use for this purpose.

First, it has been clearly demonstrated that there is little consistency between operators in recognizing and quantifying illuvial clay, and more standardization is needed. Better guidelines are necessary for the identification of illuvial clay. This could be achieved in part by the establishment of a reference collection of well- characterized thin sections, with descriptions agreed upon among a number of experienced micromorphologists. The thin sections and descriptions could be made available for short-term study. A further possibility is to encourage workshops on micromorphological techniques at which soil scientists could work together to standardize identification of pedological features under the microscope.

There should also be standardization concerning how measurements of illuvial clay are expressed. Until now, most amounts of illuvial clay have been expressed on the basis of the total area of soil material in the thin sections. Despite the significant amount of research pertaining to Alfisols, there are still major gaps in understanding clay translocation and the formation of argillic horizons. The few experimental approaches that have been developed have been promising and need to be extended to a wider range of soil material and conditions. Conditions necessary for clay neoformations in Alfisols, the influence of fluctuating Eh and pH conditions on argillic horizon morphology, and the genesis of structure in E horizons are other topics needing for further investigation.

Finally, increasing use of incident beams other than light in studies of Alfisol micromorphology is desirable. Coupling use of instruments like the image-analyzing computer, scanning electron microscope (SEM), transmission electron microscope, and energy-dispersive x-ray analyzer to traditional microscopy will allow the identification of and evaluation of of pedological features with greater accuracy (Bisdom,1981). These techniques also have wide application in studies of soil behavior. The ways in which Alfisols respond to contemporary manipulation (tillage, drainage, compaction, etc.) is likely to be an important future emphasis for micromorphologists.

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Pedological approach and Micromorphological area of Andisols

Introduction of Andisols (From Japanese, black soil)

Andisols were first recognized in Japan and were named as Volcanic ash material. They are typically of dark colour, low bulk denisity soils that do not have an albic horizon, but must have andic properties. The typical characteristics of these soils are the high content of allophane which gives them a very low bulk density and fluffiness, especially in the B-horizon. The low bulk density and high fertility of these soils make them easy to cultivate. In India, such soils are expected in the Islands of Andaman and Nicobar where volcanic activity is observed often (ISSS).

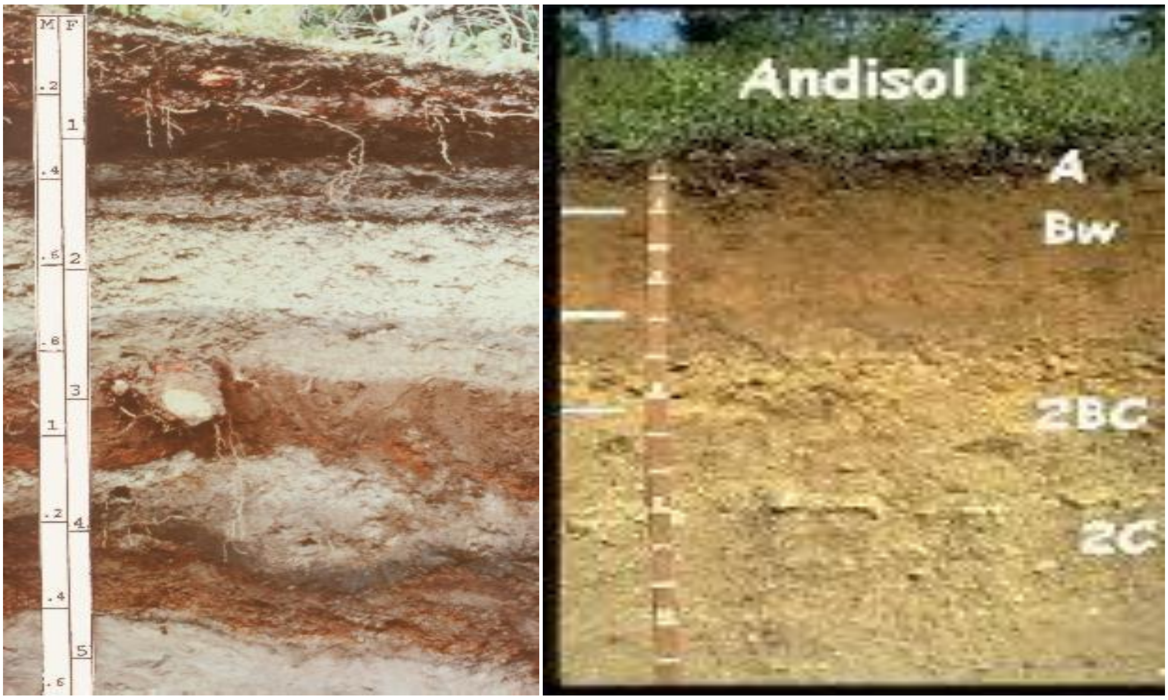


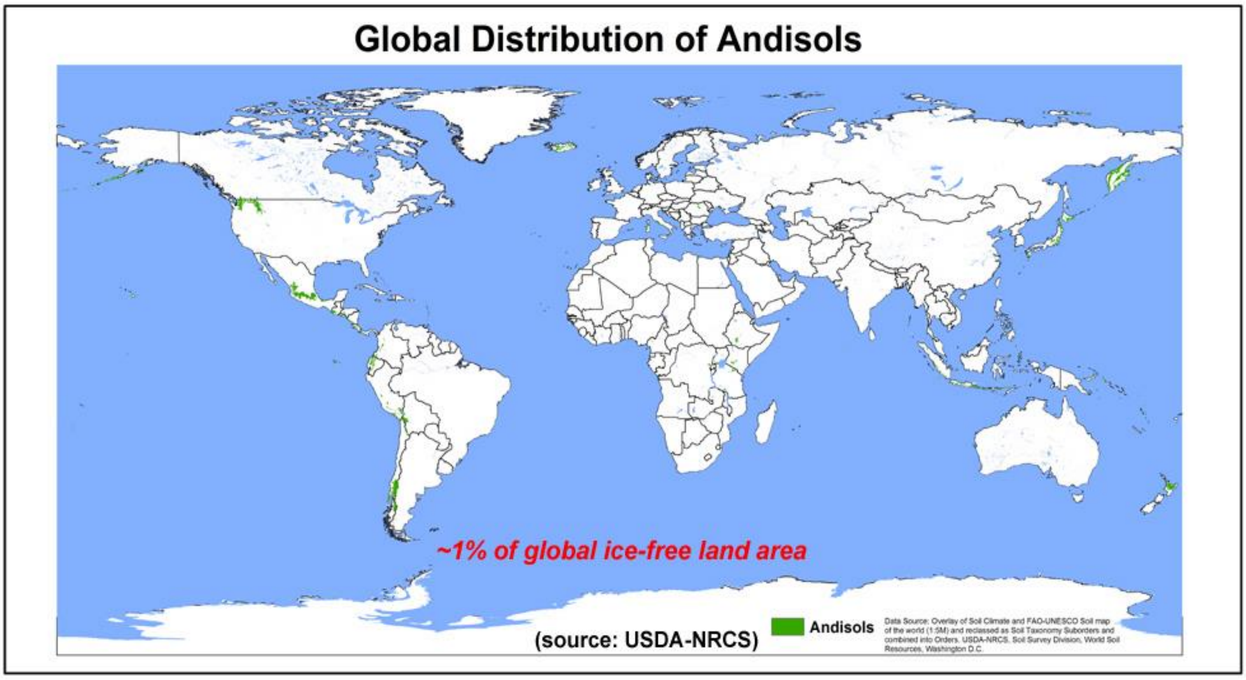
Fig:- Andisols Order and Horizon development

Classification:-

They are keyed out after Histosols in the Soil Taxonomy. The Andisols have been recently defined in Soil Taxonomy (Soil Survey Staff, 1999) in the form of a newly introduced soil Order, viz. Andisols. These soils were earlier grouped under Andepts. Based generally on the soil moisture regimes, the Andisols are divided into eight suborders, viz.:

- **Aquands** - Andisols with a water table at or near the surface for much of the year.
- **Gelands** - Andisols of very cold climates (mean annual temperature <0°C).
- **Cryands** - Andisols of cold climates.
- **Torrands** - Andisols of very dry climates.

- **Ustands** - Andisols of semiarid and sub humid climates.
- **Udands** - Andisols of humid climates.
- **Xerands** - temperate Andisols with very dry summers and moist winters.
- **Vitrands** - relatively young Andisols that are coarse-textured and dominated by glass.



Global distribution of Andisols:-

They are generally quite young, Andisols typically are very fertile except in cases where phosphorus is easily fixed (this sometimes occurs in the tropics). They can usually support intensive cropping, with areas used for wet rice in Java supporting some of the densest populations in the world. Other Andisol areas support crops of fruit, maize, tea, coffee or tobacco. In the Pacific Northwest USA, Andisols support very productive forests. Andisols occupy **~1%** of the global ice-free land area. Most occur around the Pacific Ring of Fire, with the largest areas found in central Chile, Ecuador, Colombia, Mexico, Northwest USA, Japan, Java and NewZealand's North Island. Other areas occur in the Great Rift Valley, Kenya, Italy, Iceland and Hawaii. Fossil Andisols are known from areas far from present-day volcanic activity and have in some cases been dated as far back as the 1.5 billion years ago.

Summary description of Andisols:-

- Connotation: Black soils of volcanic landscapes; from Japan.
- Parent material: Mainly volcanic ash, but also tuff, pumice, cinders and other volcanic ejecta.
- Environment: Undulating to mountainous, humid, arctic to tropical regions with a wide range of vegetation types.
- Profile development: AC- or ABC-profile. Rapid weathering of porous volcanic material resulted in accumulation of stable organo-mineral complexes and short-range-order minerals such as allophane, imogolite and ferrihydrite.
- Use: Many Andisols are intensively cultivated with a variety of crops, their major limitation being their high phosphate fixation capacity. In places, steep topography is the chief limitation.

Characteristics of Andisols:-

Morpho-Genetic characteristics:-

- The 'typical' Andosol has an ABC profile with a dark Ah-horizon, 20 to 50 cm thick on top of a brown B- or C-horizon.
- Topsoil and subsoil colours are distinctly different; darker in humid, cool regions than in tropical climates.
- The average organic matter content of the surface horizon is about 8%t but the darkest profiles may contain as much as 30% organic matter.
- The surface horizon is very porous, very friable, and has a crumb or granular structure.
- In some Andisols the surface soil material is smeary and feels greasy or unctuous; it might become almost liquid when rubbed as a consequence of sol-gel transformations under pressure ('thixotropy).

Pedological and Micropedological characteristics:-

- These soils have volcanic ash, ferromagnesian minerals (olivine, pyroxenes, amphiboles), feldspars and quartz in the silt and sand fractions of Andosol material.
- Some of the mineral grains may have acquired a coating of volcanic ash when the temperature was still high.
- The mineral composition of the clay fraction of Andisols varies with many factors.**eg.** genetic age of the soil, composition of the parent material, pH, base status, moisture regime, thickness of overburden ash deposits, and content and composition of soil organic matter.
- The clay fraction of Andisols contains typical 'X-ray amorphous materials' such as allophane and imogolite.
- Allophane/imogolite and Al-humus complexes may occur together even though the two groups have conflicting conditions of formation.
- Besides primary minerals, ferrihydrite, halloysite and kaolinite, gibbsite and various 2:1 and 2:1:1 layer silicates and intergrades can be present.

Physical characteristics:-

- The good aggregate stability of Andisols and their high permeability to water make these soils resistant to water erosion.
- Exceptions to this rule are highly hydrated types of Andosol that dried out strongly, e.g. after deforestation.
- The surface soil material of such Andisols crumbles to hard granules ('high mountain granulation) that are easily removed with surface run-off water.
- The difficulty to disperse Andosol material gives problems in texture analysis; caution should be taken when interpreting such data.
- The bulk density of Andosol material is low (0.3 Mg/m^3 to 0.9 Mg/m^3) hydrated Andisols and bulk density does not change much over a suction range of 15bar (limited shrink and swell).
- Therefore, the bulk density in the field-moist condition can in practice be substituted for the bulk density at ‘field capacity’, which is diagnostic for identifying an ‘andic’ horizon.

The moisture content at 15bar suction ('permanent wilting point') is high in most Andisols; the quantity of 'available water' is generally greater than in other mineral soils. Excessive air-drying of Andosol material will irreversibly worsen its water holding properties, ion exchange capacity, soil volume, and ultimately the cohesion of soil particles. In the extreme case these fall apart to a fine dust that is very susceptible to wind erosion.

Chemical Characteristics:-

Andisols have highly variable exchange properties.

- The hydrolysis of volcanic glass is favoured by well drained, slightly acidic to moderately- alkaline (pH 5.5 to 8.5)
- The charge is strongly dependent on pH and electrolyte concentration.
- Charge is also the case with some other soils, e.g. Ferralsols, but the overriding difference is that the negative charge of Andisols can reach much higher values because of the high contents of soil organic matter and allophane.
- Andosol components, the variation in charge as a function of pH (Halloysite and Montmorillonite, having a dominantly permanent charge).
- With charge properties variable, base saturation values are also variable. Base saturation values are generally low because of strong leaching, except in some very young Andisols and in Andosols in dry regions.

X-ray amorphous compounds:- The strong chemical reactivity of Andisols has long been attributed to X-ray amorphous compounds. It is more appropriate, however, to ascribe this Andosol characteristic to the presence of 'active aluminium' which may occur in various forms:

- In short-range-order or paracrystalline aluminosilicates such as allophane and imogolite.
- As interlayer Al-ions in 2:1 and 2:1:1 layer silicates.
- In Al-humus complexes,
- As exchangeable Al-ions on layer silicates.

- The role of active iron may often not be ignored but is generally considered of less importance than that of active aluminium.

Hydrological characteristics:-

Most Andisols have excellent internal drainage because of their high porosity and their occurrence in predominantly high terrain positions. Gleyic soil properties develop where groundwater occurs at shallow depth; stagnic properties are particularly prominent in paddy fields on terraced volcanic slopes, e.g. on Java and Bali (Indonesia).

Pedogenesis process of Andisols:-

Andisols are characterised by the presence of either an andic horizon or a vitric horizon. Andic horizons are rich in allophanes or aluminium-humus complexes whereas the vitric horizon contains an abundance of 'volcanic glass'. Andosol formation depends essentially on rapid chemical weathering of porous, permeable, fine-grained mineral material in the presence of organic matter. Hydrolysis of the primary minerals 'micro-cline' and 'augite' may serve to illustrate this type of weathering.

$KAlSi_3O_8 + 2\ H_2O\ =\ K^+ + Al^{3+} + 3\ SiO_2 + 4\ OH^-$ (Microcline)

$CaFeSi_2O_6 + 2\ H_2O\ =\ Ca^{2+} + Fe^{2+} + 2\ SiO_2 + 4\ OH^-$(Augite)

$Fe^{2+} =\ Fe^{3+} + e^-$

$Fe^{3+} + 3\ H_2O\ =\ Fe(OH)_3 + 3\ H^+$ (Ferrihydrite)

The liberated Fe^{2+} and Al^{3+} ions are tied up in stable complexes with humus. The ferrous iron is first oxidised to the ferric state after which it precipitates for the greater part as ferrihydrite.

1. Allophanes are non-crystalline hydrous aluminosilicates with Al/Si molar ratios typically between 1 and 2 (the Al/Si ratio of kaolinite is 1). They consist of hollow spherules with a diameter of 3.5 - 5nm and have a very large specific surface area.

2. Ferrihydrite represents the short-range-order hydrous iron oxides previously termed amorphous ferric oxide or iron oxide gel. Ferrihydrite is the dominant iron oxide mineral of most volcanic soils and some of the properties

ascribed to allophane may in part be caused by ferrihydrite. Recent evidence suggests that much, if not all, organically bound iron (as extracted by pyrophosphate) is ferrihydrite-Fe.

Aluminium protects the organic part of Al-humus complexes against bio-degradation. The mobility of these complexes is rather limited because rapid weathering yields sufficient Al and Fe to produce complexes with a high metal/organic ratio that are only sparingly soluble. This combination of low mobility and high resistance against biological attack promotes accumulation of organic matter in the topsoil culminating in the formation of a 'melanic' surface horizon that has an intense dark colour and a high content of organic matter. The fate of the liberated silica depends largely on the extent to which aluminium is tied up in Al-humus complexes. If most or all aluminium is 'fixed', the silica concentration of the soil solution increases and while part of the silica is washed out, another part precipitates as opaline silica. If not all aluminium is tied up in complexes, the remainder may co-precipitate with silicon to form allophanes of varying composition, often in association with imogolite. Note that formation of Al-humus complexes and formation of allophane associations are mutually competitive. This is known as the 'binary composition' of Andisols. It seems that allophane (and imogolite) are stable under mildly acid to neutral conditions (pH>5) whereas Al-humus complexes are dominant in more acid environments. If there is still aluminium available under the latter conditions, this may combine with excess silicon to form 2:1 and 2:1:1 type phyllosilicate clay minerals (e.g. chlorite), often found in association with Al-humus complexes.

Example:- Imogolite is a paracrystalline aluminosilicate consisting of smooth and curved threads with diameters varying from 10 to 30 nm and several thousands of nm in length. The threads consist of finer tube units of 2 nm outer diameter; their outer wall consists of a gibbsite (Al) sheet and the inner wall of a silica sheet. The Al/Si molar ratio is 2. changeable Al, which is not found on allophane. The stability conferred on the organic matter by aluminium is no less in the presence of allophane. This suggests that the activity of aluminium in allophone is high enough to interact with organic molecules and prevent bio-degradation and leaching. The competition between humus and silica for Al is influenced by environmental factors:-

The 'Al-humus complex + opaline silica + phyllosilicate clay' association is most pronounced in acidic types of volcanic ash that are subject to strong leaching. In practice, there is a continuous range in the binary composition of

Andisols, from a pure Al-humus complexes association ('non-allophanic) to an allophane/imogolite association, in which the extremes are rare. This variation occurs both within one profile and between profiles.

After the very early stage of Andosol formation, complete inactivation of aluminium by organic matter may constrain the formation of allophane under humid temperate conditions. Only when humus accumulation levels off will aluminium become available for mineral formation. This explains why B-horizons in Andisols are usually much richer in allophane and imogolite than A-horizons: the weathering of primary minerals proceeds but the supply of organic matter is limited so that little aluminium is tied up in Al-humus complexes.

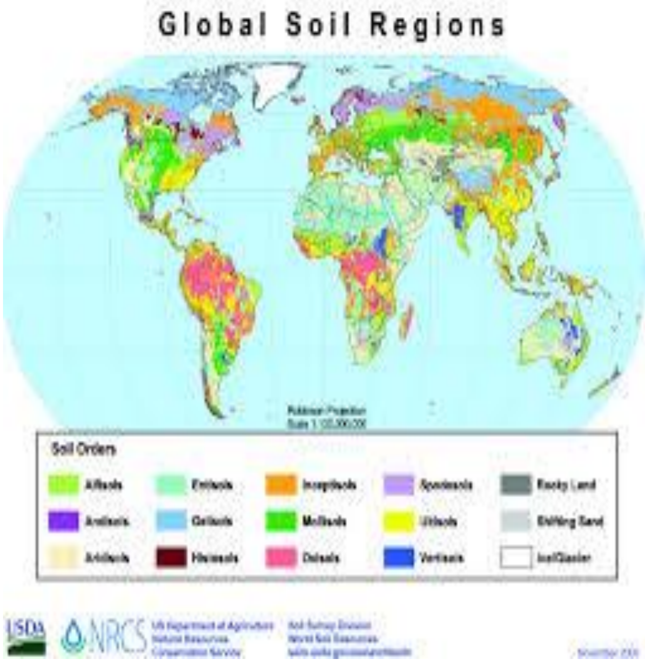
The total pore fraction of the soil material increases greatly in the course of weathering, typically from some 50 volume percent to more than 75 percent. This is explained by leaching losses and stabilization of the residual material by organic matter and weathering products (silica, allophane, imogolite, ferrihydrite). The genesis of Andisols is further complicated where there is repeated deposition of fresh ash. Thin ash layers may just rejuvenate the surface soil material whereas thicker layers bury the soil. A new profile will then develop in the fresh ash layer while soil formation in the buried A-horizon takes a different course in response to the suddenly decreased organic matter supply and the different composition of the soil moisture.

The clay assemblage of Andisols changes over time, particularly that of the subsoil, as allophane and imogolite are transformed to halloysite, kaolinite or gibbsite (depending on the silica concentration of the soil solution). Aluminium from the Al-humus complexes will gradually become available and ferrihydrite will eventually turn into goethite. All these processes are strongly influenced by such factors as the rate of rejuvenation, the depth and composition of the overburden, the composition of the remaining material and the moisture regime. Eventually, an Andosol may grade into a 'normal' soil, e.g. a podzolized soil, or a soil with ferric properties, or with clay illuviation.

Regional distribution of Andisols:-

In India, such soils are expected in the Islands of Andaman and Nicobar where volcanic activity is observed often. Low-activity clay soils on old planation surfaces of the tropics are generally considered as stable end points of soil formation. It is therefore surprising to find Andisols on them. We characterized the properties of six profiles representative of these soils in the western part of the Nilgiri Hills (2000–2500 m above mean sea level), Southern

India, where the present climatic conditions are cool (mean annual temperature 15°C) and humid (mean annual rainfall 2500 mm). Thick (50–80 cm) dark-reddish brown topsoil overlies strongly desilicated yellowish-red materials. This horizon has andic properties to a sufficient depth and the carbon content requirement of the melanic epipedon to place these soils in the Andisol order. Our data as well as the history of the Nilgiri Hills suggest that the formation of these non-allophanic Andisols resulted from the succession of two main steps. First, a 'lateritic' weathering cycle led to the relative accumulation of secondary Al and Fe oxides. Later, the accumulation of organic matter favoured by a more recent climatic change induced complexation by organic acids of Al and Fe oxides, and the production of enough metal–humus complexes to give rise to andic properties. Such soils, in which secondary Al and Fe oxides, generally considered as indicators of an advanced weathering stage, are involved in a new cycle of soil formation, are original Andisols (Caner *et al.* 2000).



Associations with other Soil Groups:-

Andisols are azonal soils occurring in all climates and at all altitudes. Consequently they occur together with almost any other Soil Group. A typical configuration on mountain slopes would have Andisols at the higher end of the slope, Cambisols and Luvisols at mid-slope positions and Vertisols (basic volcanic materials) or Acrisols (acidic materials) near the foot of the slope. In tropical highlands, e.g. in Kenya and Ethiopia, Andisols are often associated with Nitisols.

Management and use of Andisols

Andisols have a high potential for agricultural production but many of them are not used to their capacity. By and large, Andisols are fertile soils, particularly Andisols in intermediate or basic volcanic ash and not exposed to excessive leaching. The strong phosphate fixation of Andisols is a problem. Ameliorative measures to reduce this effect include application of lime, silica, organic material and 'phosphate' fertilizer. Andisols are easy to cultivate and have good rootability and water storage properties. Strongly hydrated Andisols are difficult to till because of their low bearing capacity and their stickiness. Andisols are planted to a wide variety of crops including sugarcane, tobacco, sweet potato (tolerant of low phosphate levels), tea, vegetables, wheat and orchard crops. Andisols on steep slopes are perhaps best kept under forest. Paddy rice cultivation is a major landuse on Andisols in lowlands with shallow groundwater. Elsewhere, continued paddy rice production has resulted in formation of a dense hardpan over accumulation layers of iron and manganese oxides; these hardpans reduce percolation losses of water.

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Micromorphology of Aridisols

Aridisols (L. Aridus, meaning dry) aremineral soils of dry places (arid and semi-arid) and areas having high ground water table.During most of the time when the soils are warm enough for plants to grow, soil water is held at potentials less than the permanent wilting point or has a content of soluble salts great enough to limit the growth of plants other than halophytes, or both. There is no period of 90 consecutive days when moisture is continuously available for plant growth. The concept of Aridisols is based on limited soil moisture available for the growth of most plants. In areas bordering deserts, the absolute precipitation may be sufficient for the growth of some plants. Because of runoff or a very low storage capacity of the soils, or both, however, the actual soil moisture regime is aridic. Soil moisture and to a lesser extent soil temperature regimes control processes in soils. In the other soil orders, soil moisture regimes are used at the suborder level or the lower categories, but in the Aridisols they are used to define the order category. The result is a rather homogeneous class in the sense that additions, removals, transfers, and transformations within the soils are strongly influenced by the lack of moisture. Aridisols require a minimum degree of soil formation. This is commonly expressed as a cambic horizon. Because the soil moisture regime is the single most important constraint in the utilization of these soils, this order delineates geographic areas that have relatively uniform useBecause of an extreme imbalance between evapotranspiration and precipitation, many Aridisols contain salts. The dominant process is one of accumulation and concentration of weathering products. The accumulation of salts is the second most important constraint to land use. Many soluble precipitates may be eliminated or changed in concentration through irrigation. In Aridisols, however, the availability of adequate quality irrigation water is a fundamental problem. Together with irrigation, a mechanism for evacuation of the soluble precipitates must be provided or there is a rapid buildup of salinity and/or sodicity. Irrigation and drainage systems must be well maintained to keep the soils from reverting to their original state. The classification of Aridisols must include consideration of these constraints or performance restrictive qualities at a high categoric level. Some Aridisols are also situated on geologic evaporites. It is frequently difficult to bring these substratum conditions into a classification system, but care must be taken to evaluate these deep-seated salt accumulations, particularly in irrigation projects. Some Aridisols have inherited features, such as an argillic horizon, that may be attributed to past wetter paleoclimatic conditions. There is evidence, however, that clay illuviation has also occurred during the Holocene. These attributes, and specifically an argillic horizon, significantly affect the use and management of the soils. In the definition of suborders, emphasis is given to the redistribution of soluble materials and their accumulation. Four of the seven suborders are defined on the basis of the composition and accumulation of the soluble fraction. Weathering and clay translocation also take place in Aridisols. Two suborders reflect these processes.

The seven suborders are:

1. Cryids—Aridisols in cold areas

2. Salids—accumulation of salts more soluble than gypsum

3. Durids—accumulation of silica

4. Gypsids—accumulation of gypsum

5. Argids—accumulation of clay

6. Calcids—accumulation of carbonates

7. Cambids—translocation and/or transformation of material The great group level reflects the degree of expression of the horizons of accumulation

1. Unlike Inceptisols and Entisols, Aridisols have:

a. An aridic soil moisture regime; and

b. An ochric or anthropic epipedon; and

c. One or more of the following with the upper boundary within 100 cm of the soil surface: a cambic horizon with its lower boundary at a depth of 25 cm or more; a cryictemperature regime and a cambic horizon; a calcic, gypsic, petrocalcic, petrogypsic, or salic horizon; or a duripan; or

d. An argillic or natric horizon; or

e. A salic horizon; and

(1) Saturation with water in one or more layers within 100 cm of the soil surface for 1 month or more in normal years; and

(2) A moisture control section that is dry in some or all parts at some time in normal years; and

(3) No sulfuric horizon that has its upper boundary within 150 cm of the mineral soil surface;

2. Unlike Histosols, Aridisols do not have organic soil materials that meet one or more of following:

a. Overlie cindery, fragmental, or pumiceous materials and/or fill their interstices and directly below these materials have either a densic, lithic, or paralithic contact; or

b. When added with the underlying cindery, fragmental, or pumiceous materials, total 40 cm or more between the soilsurface and a depth of 50 cm; or

c. Constitute two-thirds or more of the total thickness of the soil to a densic, lithic, or paralithic contact and have no mineral horizons or have mineral horizons with a total thickness of 10 cm or less; or

d. Are saturated with water for 30 days or more in normal years (or are artificially drained), have an upper boundary within 40 cm of the soil surface, and have a total thickness of either:

(1) 60 cm or more if three-fourths or more of their volume consists of moss fibers or if their bulk density, moist, is less than 0.1 g/cm3; or

(2) 40 cm or more if they consist either of sapric or hemic materials, or of fibric materials with less than three-fourths (by volume) moss fibers and a bulk density, moist, of 0.1 g/cm3 or more;

3. Unlike Gelisols, Aridisols do not have:

a. Permafrost within 100 cm of the soil surface; or

b. Gelic materials within 100 cm of the soil surface and permafrost within 200 cm of the soil surface;

4. Unlike Spodosols, Aridisols do not have either:

a. A spodic horizon and an albic horizon in 50 percent ormore of each pedon; or

b. An Ap horizon containing 85 percent or more spodicmaterials;

5. Unlike Andisols, Aridisols do not have andic soil properties in 60 percent or more of the thickness between either the mineral soil surface or the top of an organic layer with andic soil properties, whichever is shallower, and a depth of 60 cm or a densic, lithic, or paralithic contact, a duripan, or a petrocalcic horizon, whichever is shallower;

6. Unlike Oxisols, Aridisols do not have within 150 cm of the mineral soil surface either an oxic horizon or a kandic horizon that meets the weatherable-mineral requirements for an oxic horizon and also do not have 40 percent or more clay in the surface 18 cm after mixing;

7. Unlike Vertisols, Aridisols do not have all of the following:

a. A layer 25 cm or more thick, with an upper boundary within 100 cm of the mineral soil surface, that has either slickensides or wedge-shaped aggregates that have their long axes tilted 10 to 60 degrees from the horizontal; and

b. A weighted average of 30 percent or more clay in the fine-earth fraction either between the mineral soil surface and a depth of 18 cm or an Ap horizon, whichever is thicker, and 30 percent or more clay in the fine-earth fraction of all horizons between a depth of 18 cm and either a depth of 50 cm or a densic, lithic, or paralithic contact, a duripan, or a petrocalcic horizon if shallower.

8. Unlike Alfisols and Ultisols, Aridisols have an aridic soil moisture regime;

9. Unlike Mollisols, Aridisols do not have a mollicepipedon.

1. Argids

These are the Aridisols that have an argillic or nitric horizon but do not have a duripan or a gypsic, petrocalcic, petrogypsic, or salic horizon within 100 cm of the soil surface. The low water flux and high concentration of salts in many Aridisols hinder clay illuviation. The presence of an argillic horizon commonly is attributed to a moister paleoclimate, although there is evidence that clay illuviation occurred during the Holocene in arid soils. Where the soil moisture regime grades to ustic or xeric, evidence of clay translocation commonly is more readily established. Most of the Argids occur in North America. A few have been recognized in the deserts of North Africa or the Near East.

Argids are the Aridisols that:

1. Have a natric or argillic horizon;

2. Have a soil temperature regime warmer than cryic;

3. Do not have a duripan or a gypsic, petrocalcic, petrogypsic, or salic horizon that has its upper boundary within 100 cm of the soil surface.

- PetroargidsArgids that have a duripan or a petrocalcic or petrogypsic horizon that has its upper boundary within 150 cm of the soil surface,
- NatrargidsOther Argids that have a natric horizon. Other Argids that do not have a densic, lithic, or paralithic contact within 50 cm of the soil surface and have either:

1. A clay increase of 15 percent or more (absolute) withina vertical distance of 2.5 cm either within the argillic horizon or at its upper boundary

2. An argillic horizon that extends to 150 cm or more from the soil surface, that does not have a clay decrease with increasing depth of 20 percent or more (relative) from the maximum clay content, and that has, in 50 percent or more of the matrix in some part between 100 and 150 cm, either:

a. Hue of 7.5YR or redder and chroma of 5 or more; or

b. Hue of 7.5YR or redder and value, moist, of 3 or less and value, dry, of 4 or less.-Paleargids,

- Gypsiargids- Other Argids that have a gypsic horizon that has its upper boundary within 150 cm of the soil surface.
- Calciargids- Other Argids that have a calcic horizon that has its upper boundary within 150 cm of the soil surface

Subgroup of argids

Calciargids

These are the Argids that, below the argillic horizon, have acalcic horizon within 150 cm of the soil surface. These soilshave been recharged with calcium carbonate from dust. Calciargids are commonly on late-Pleistocene erosional surfaces or on gentle to steep slopes. Before the International Committee on Aridisols (ICOMID) was established, these soils were classified as Haplargids.Calciargids are the Argids that:

1. Have a calcic horizon that has its upper boundary within 150 cm of the soil surface;

2. Do not have a natric horizon

3. Do not have a duripan or a gypsic, petrocalcic, or petrogypsic horizon that has its upper boundary within 150 cm of the soil surface;

4. Have a densic, lithic, or paralithic contact within 50 cm of the soil surface; or a. A clay increase of less than 15 percent (absolute) within a vertical distance of 2.5 cm either within the argillic horizon or at its upper boundary.

Lithic Calciargids—Calciargids that have a lithic contact within 50 cm of the soil surface.

XererticCalciargids—Other Calciargids that have *both*:

1. *One or both* of the following:a. Cracks within 125 cm of the soil surface that are 5mm or more wide through a thickness of 30 cm or morefor some time in normal years, and slickensides orwedge-shaped aggregates in a layer 15 cm or more thickthat has its upper boundary within 125 cm of the soilsurface; *or*

b. A linear extensibility of 6.0 cm or more between the soil surface and either a depth of 100 cm or a densic, lithic, or paralithic contact if shallower; *and*

2. A moisture control section that is dry in all parts for

- less than three-fourths of the time (cumulative) when thesoil temperature is 5 oC or higher at a depth of 50 cm and a
- soil moisture regime that borders on xeric.

UstericCalciargids

1. One or both of the following: a. Cracks within 125 cm of the soil surface that are 5

mm or more wide through a thickness of 30 cm or more for some time in normal years, and slickensides or wedge-shaped aggregates in a layer 15 cm or more thick that has its upper boundary within 125 cm of the soil surface; or

b. A linear extensibility of 6.0 cm or more between the soil surface and either a depth of 100 cm or a densic, lithic, or paralithic contact if shallower; and

2. A moisture control section that is dry in all parts for less than three-fourths of the time (cumulative) when the soil temperature higher at a depth of 50 cm and a soil moisture regime that borders on ustic.

VerticCalciargids—Other Calciargids that have one or both of the following:

1. Cracks within 125 cm of the soil surface that are 5 mm or more wide through a thickness of 30 cm or more for some time in normal years, and slickensides or wedge-shaped aggregates in a layer 15 cm or more thick that has its upper boundary within 125 cm of the soil surface; or

2. A linear extensibility of 6.0 cm or more between the soil surface and either a depth of 100 cm or a densic, lithic, or paralithic contact if shallower.

AquicCalciargids—Other Calciargids that are either:

1. Irrigated and have aquic conditions for some time in normal years in one or more layers within 100 cm of the soil surface.

2. Saturated with water in one or more layers within 100 cm of the soil surface for 1 month or more in normal years.**ArenicUsticCalciargids**—Other Calciargids that have:

1. A sandy or sandy-skeletal particle-size class throughout a layer extending from the soil surface to the top of an argillic horizon at a depth of 50 cm or more; and

2. A moisture control section that is dry in all parts for less than three-fourths of the time (cumulative) when the soil temperature at a depth of 50 cm is 5 oC or higher and a soil moisture regime that borders on ustic.

ArenicCalciargids—Other Calciargids that have a sandy or sandy-skeletalparticle-size class throughout a layer extending from the soilsurface to the top of an argillic horizon at a depth of 50 cm or
more.

Durinodic Xeric Calciargids— Have one or more horizons, within 100 cm of the soil surface and with a combined thickness of 15 cm or more,that contain 20 percent or more (by volume) durinodes or are brittle and have at least a firm rupture-resistance classwhen moist; *and*

2. Are dry in all parts of the moisture control section for less than three-fourths of the time (cumulative) when the soil temperature is 5 oC or higher at a depth of 50 cm and have a soil moisture regime that borders on xeric.

2. Calcids

Calcids are the Aridisols that:

1. Have a petrocalcic or calcic horizon that has its upperboundary within 100 cm of the soil surface and do not have anargillic or natric horizon with its upper boundary within 100cm of the soil surface, unless a petrocalcic horizon is within100 cm of the soil surface;

2. Have a temperature regime warmer than cryic;

3. Do not have a duripan or a salic, gypsic, or petrogypsichorizon that has its upper boundary within 100 cm of the soilsurface.

TypicHaplocalcids—The Typic subgroup is centered on drysoils that lack the features that define the other subgroups.These soils do not have a lithic contact with its upper boundarywithin 50 cm of the soil surface; a high shrink-swell potential;

AquicDurinodicHaplocalcids—These are theHaplocalcids that are saturated with water for 1 month or more within 100 cm of the soil surface in normal years and have asignificant amount of durinodes or brittleness. These soils donot have a lithic contact within 50 cm of the soil surface or ahigh shrink-swell potential. They are known to occur inCalifornia and Nevada.

AquicHaplocalcids—These are the Haplocalcids that aresaturated with water for 1 month or more within 100 cm of thesoil surface in normal years. These soils do not have a lithiccontact within 50 cm of the soil surface, a high shrink-swellpotential, or a significant amount of durinodes or brittleness.These soils occur in California, Nevada, Idaho, and Utah.

DuricHaplocalcids—These are the Haplocalcids that havea duripan with an upper boundary between depths of 100 and150 cm but do not have a soil moisture regime that borders onxeric. These soils do not have a lithic contact within 50 cm ofthe soil surface or a high shrink-swell potential.

Duric Xeric Haplocalcids—These are the Haplocalcids that have a duripan at a depth of 100 to 150 cm and have a soil moisture regime that borders on xeric. These soils do not have a lithic contact within 50 cm of the soil surface or a high shrink-swell potential. DuricHaplocalcids are not saturated with water for 1 month or more within 100 cm of the soil surface in normal years and do not have a significant amount of durinodes or brittleness. These soils are rare in the world.

DurinodicHaplocalcids—These are the Haplocalcids that have one or more horizons, within 100 cm of the soil surface and with a combined thickness of 15 cm or more, that contain 20 percent or more durinodes or are brittle and have at least a firm rupture-resistance class when moist. They occur in Nevada, California, and Arizona.

Durinodic Xeric Haplocalcids—These are the Haplocalcids that have one or more horizons, within 100 cm of the soil surface and with a combined thickness of 15 cm or more, that contain 20 percent or more durinodes or are brittle and have at least a firm rupture-resistance class when moist.

Lithic Haplocalcids—These are the Haplocalcids that have a lithic contact within 50 cm of the soil surface but do not have a soil moisture regime that borders on either xeric or ustic. These soils occur throughout the deserts of the world.

Lithic UsticHaplocalcids—These are the Haplocalcids that have a lithic contact within 50 cm of the soil surface and a soil moisture regime that borders on ustic. These soils are common in the semiarid regions of the world. In the United States, they occur in Texas, Utah, and Arizona.

Lithic Xeric Haplocalcids—These are the Haplocalcids that have a lithic contact within 50 cm of the soil surface and asoil moisture regime that borders on xeric. In the UnitedStates, these soils occur in Nevada, Utah, and Idaho.

PetronodicHaplocalcids—These are the Haplocalcids that have, in one or more horizons with a combined thickness of 15 cm or more, 20 percent or more nodules and concretions but do not have a soil moisture regime that borders on ustic or xeric.

PetronodicUsticHaplocalcids—These are then Haplocalcids that have, in one or more horizons with a combined thickness of 15 cm or more, 20 percent or more nodules and concretions and that have a soil moisture regime that borders on ustic.

Petronodic Xeric Haplocalcids—These are the Haplocalcids that have, in one or more horizons with a combined thickness of 15 cm or more, 20 percent or more nodules and concretions and have a soil moisture regime that borders on xeric.

SodicHaplocalcids—These are the Haplocalcids that have, in a horizon at least 25 cm thick within 100 cm of the soil surface, an exchangeable sodium percentage of 15 or more during at least 1 month in normal years and have a soil moisture regime that does not border on either ustic or xeric.

UsticHaplocalcids—These are the Haplocalcids that have a soil moisture regime that borders on ustic. These soils do not have, in a horizon at least 25 cm thick within 100 cm of the soil surface, an exchangeable sodium percentage of 15 or more during at least 1 month in normal years and do not have a lithic contact within 50 cm of the soil surface.

VerticHaplocalcids—These are the Haplocalcids that havea high shrink-swell potential. These soils do not have a lithiccontact within 50 cm of the soil surface. They are relativelyrare in the world.

VitrandicHaplocalcids—These are the Haplocalcids thathave a significant amount of volcanic glass, cinders, pumice, orpumicelike fragments throughout one or more horizons with atotal thickness of 18 cm or more within 75 cm of the soilsurface and have a soil moisture regime that does not border on

xeric.

Xeric Haplocalcids—These are the Haplocalcids that have asoil moisture regime that borders on xeric. These soils do nothave, in a horizon at least 25 cm thick within 100 cm of thesoil surface, an exchangeable sodium percentage of 15 or moreduring at least 1 month in normal years and do not have alithic contact within 50 cm of the soil surface; a high shrinkswellpotential

3. Cambids

Cambids are the Aridisols that:

1. Have a cambic horizon that has its upper boundary within

100 cm of the soil surface;

2. Have a soil temperature regime warmer than cryic;

3. Do not have a duripan or an argillic, calcic, natric,petrocalcic, gypsic, petrogypsic, or salic horizon that has itsupper boundary within 100 cm of the soil surface.

TypicAquicambids—TheTypic subgroup is centered onAquicambids that do not have any of the features defined forthe other subgroups. These soils do not have an accumulation

of sodium; durinodes or brittleness.

DurinodicAquicambids—These are the Aquicambids thathave one or more horizons, within 100 cm of the soil surfaceand with a cumulative thickness of 15 cm or more, that contain20 percent or more durinodes or are brittle and have at least afirm rupture-resistance class. These soils do not have, in ahorizon at least 25 cm thick, an exchangeable sodiumpercentage of 15 or more. The soil moisture regime does notborder on xeric.

Durinodic Xeric Aquicambids—These are theAquicambids that have a soil moisture regime that borders on

xeric and have one or more horizons, within 100 cm of the soilsurface and with a cumulative thickness of 15 cm or more, thatcontain 20 percent or more durinodes or are brittle and have atleast a firm rupture-resistance class. These soils do not have, ina horizon at least 25 cm thick, an exchangeable sodiumpercentage of 15 or more.

FluventicAquicambid.—These are the Aquicambids thathave an irregular decrease in content of organic carbon belowthe cambic horizon.

PetronodicAquicambids—These are the Aquicambidsthat have one or more horizons, within 100 cm of the soil

surface and with a combined thickness of 15 cm or more, thatcontain 20 percent or more nodules and concretions. These soilsdo not have a significant amount of sodium, durinodes, orbrittleness.

SodicAquicambids—These are the Aquicambids that have,in one or more horizons at least 25 cm thick within 100 cm of thesoil surface, an exchangeable sodium percentage of 15 or morefor at least 1 month in normal years. These soils occur in NewMexico.

UsticAquicambids—These are the Aquicambids that havea soil moisture regime that borders on ustic. These soils do nothave a significant amount of sodium, durinodes, nodules,concretions, volcanic glass, pumice, cinders, or pumicelikefragments and are not brittle. They also do not have anirregular decrease in content of organic carbon below thecambic horizon.

VitrandicAquicambids—These are the Aquicambids thathave a significant amount of volcanic glass, pumice, cinders, orpumicelike fragments in one or more horizons 18 cm thickwithin 75 cm of the soil surface but do not have a soil moistureregime that borders on xeric.

VitrixerandicAquicambid.—These are the Aquicambidsthat have a significant amount of volcanic glass, pumice,cinders, or pumicelike fragments in one or more horizons 18cm thick within 75 cm of the soil surface and have a soilmoisture regime that borders on xeric. These soils do not havea significant amount of sodium, durinodes, concretions, ornodules and are not brittle.

Xeric Aquicambids—These are the Aquicambids that have asoil moisture regime that borders on xeric. These soils do nothave a significant amount of sodium, durinodes, nodules,concretions, volcanic glass, pumice, cinders, or pumicelikefragments and are not brittle. They also do not have anirregular decrease in content of organic carbon below thecambic horizon.

4. Cryids

Cryids are the Aridisols of cold deserts. Short growingseasons combined with arid conditions limit the use of thesesoils. The soils are characteristically at high elevations,dominantly in the mountain and basin areas in the UnitedStates and Asia and in other parts of the world.

TypicPetrocambids—These are the Petrocambids that donot have a soil moisture regime that borders on ustic or xeric ora significant amount of sodium, volcanic glass, cinders,pumice, or pumicelike fragments.

SodicPetrocambids—These are the Petrocambids thathave, in a horizon at least 25 cm thick within 100 cm of the soil surface, an exchangeable sodium percentage of 15 or moreduring at least 1 month in normal years.

UsticPetrocambids—These are the Petrocambids thathave a soil moisture regime that borders on ustic. These soilsdo not have a significant amount of sodium, volcanic glass,cinders, pumice, or pumicelike fragments.

VitrandicPetrocambids—These are the Petrocambids thathave a significant amount of volcanic glass, cinders, pumice, orpumicelike fragments throughout one or more horizons with atotal thickness of 18 cm or more within 75 cm of the soilsurface and do not have a soil moisture regime that borders onxeric. These soils also do not have a significant amount ofsodium.

VitrixerandicPetrocambids—These are the Petrocambidsthat have a significant amount of volcanic glass, cinders,pumice, or pumicelike fragments throughout one or morehorizons with a total thickness of 18 cm or more within 75 cmof the soil surface and have a soil moisture regime that borderson xeric. These soils do not have a significant amount ofsodium.

5. Durids

Durids are the Aridisols that have a duripan that has anupper boundary within 100 cm of the soil surface. In manyareas the duripan is within 50 cm of the soil surface. Thesesoils occur dominantly on gentle slopes and formed insediments that contain pyroclastics.

TypicArgidurids—TheTypic subgroup of Argidurids isdefined in terms of characteristics that are not evident. It doesnot have the following: a high shrink-swell potential;saturation with water for 1 month or more within 100 cm ofthe soil surface in normal

AbrupticArgidurids—These are the Argidurids that havea significant increase in content of clay within a short distanceeither within the argillic horizon or at its upper boundary butdo not have a soil moisture regime that borders on xeric. Theabrupt increase in content of clay is important to watermovement.

Abruptic Xeric Argidurids.—These are the Argiduridsthat have a significant increase in content of clay within a shortdistance either within the argillic horizon or at its upperboundary and have a soil moisture regime that borders onxeric.

AquicArgidurids—These are the Argidurids that aresaturated with water for 1 month or more within 100 cm of thesoil surface in normal years. These soils are commonlysaturated by runoff from melting snow or from heavy rains.They are dry for most of the year. They do not have a highshrink-swell potential.

ArgidicArgidurid—These are the Argidurids that have aduripan that is strongly cemented or less cemented in all subhorizons and do not have a soil moisture regime thatborders on xeric. These soils do not have a high shrink-swellpotential, saturation with water for 1 month or more within100 cm of the soil surface in normal years, or a significantincrease in content of clay within the argillic horizon or at itsupper boundary. These soils are known to occur in Nevada,Oregon, and California.

HaploxeralficArgidurids—These are the Argidurids thathave a duripan that is strongly cemented or less cemented inall subhorizons and have a soil moisture regime that borders onxeric.

6. Gypsids

Gypsids are the Aridisols that have a gypsic or petrogypsichorizon within 100 cm of the soil surface. Accumulation ofgypsum takes place initially as crystal aggregates in the voidsof the soils. These aggregates grow by accretion, displacing theenclosing soil material. When the gypsic horizon occurs as acemented impermeable layer, it is recognized as thepetrogypsic horizon. Each of these forms of gypsumaccumulation implies processes in the soils, and each presentsa constraint to soil use. One of the largest constraints isdissolution of the gypsum, which plays havoc with structures,roads, and irrigation delivery systems.

Gypsids are the Aridisols that:

1. Have a gypsic or petrogypsic horizon that has an upperboundary within 100 cm of the soil surface

2. Do not have a petrocalcic horizon overlying the gypsic orpetrogypsic horizon;

3. Have a soil temperature regime warmer than cryic;

4. Do not have a duripan or a salic horizon that has an upperboundary within 100 cm of the soil surface.

TypicArgigypsids—These are the Argigypsids that do nothave a lithic contact within 50 cm of the soil surface; a highshrink-swell potential; a calcic horizon above the gypsichorizon; a soil moisture regime that borders on xeric or ustic; asignificant amount of volcanic glass, cinders, pumice, orpumicelike fragments; or a significant amount of durinodes,concretions, or nodules.

Calcic Argigypsids—These are the Argigypsids that havea calcic horizon over the gypsic horizon. These soils do nothave a lithic contact within 50 cm of the soil surface or a highshrink-swell potential. They are known to occur in Arizona.

Lithic Argigypsid.—These are the Argigypsids that have alithic contact within 50 cm of the soil surface. They can have asoil moisture regime that borders on ustic or xeric.

PetronodicArgigypsids—These are the Argigypsids thathave a significant amount of durinodes, nodules, or concretions. These soils do not have a calcic horizon above thegypsic horizon, a lithic contact within 50 cm of the soilsurface, or a high shrink-swell potential.

UsticArgigypsids—These are the Argigypsids that have asoil moisture regime that borders on ustic. These soils do nothave a lithic contact within 50 cm of the soil surface; a highshrink-swell potential; a calcic horizon above the gypsic

SalidsSalids are most common in depressions (playas) in thedeserts or in closed basins in the wetter areas bordering thedeserts. In North Africa and in the Near East, such depressionsare referred to as Sebkhas or Chotts, depending on the presenceor absence of surface water for prolonged periods.

Sub gruop

TypicHaplosalids—These are the Haplosalids that do nothave a calcic, gypsic, or petrogypsic horizon or a duripan withan upper boundary within 100 cm of the soil surface. Before1994, these soils were identified as Torriorthents if a salichorizon was the only diagnostic horizon. These soils occur in

California.

Calcic Haplosalids—These are the Haplosalids that have acalcic horizon that has its upper boundary within 100 cm of thesoil surface. These soils do not have a gypsic or petrogypsichorizon or a duripan with an upper boundary within 100 cm ofthe soil surface. They occur in Arizona.

DuricHaplosalids—These are the Haplosalids that have aduripan with its upper boundary within 100 cm of the soilsurface.

GypsicHaplosalids—These are the Haplosalids that havea gypsic horizon with its upper boundary within 100 cm of thesoil surface. These soils do not have a duripan. They occur inCalifornia.

PetrogypsicHaplosalids—These are the Haplosalidsthat have a petrogypsic horizon that has its upper boundarywithin 100 cm of the soil surface. These soils do not have aduripan.

Reference:

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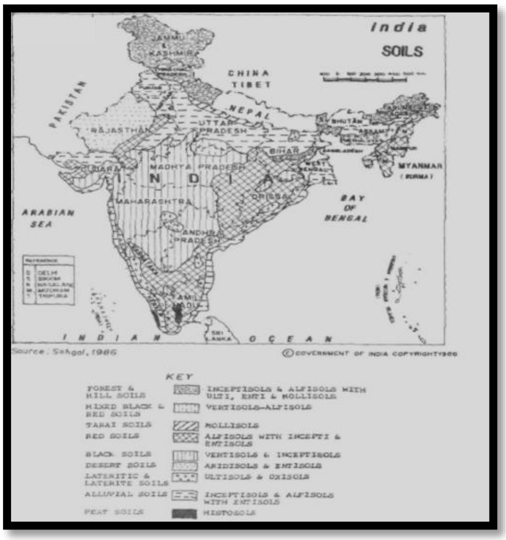
ENTISOLS

Introduction

Entisol, one of the 12 soil orders in the Soil Taxonomy. *Entisols are soils defined by the absence or near absence of horizons (layers) that clearly reflect soil-forming processes*. Occupying under 11 percent of the nonpolar continental land surface of the Earth, they are formed on surface features of recent geologic origin, on underlying material that is highly resistant to weathering, or under conditions of extreme wetness or dryness. Soils in India represent Inceptisols (95.8 m ha), Entisols (80.1 m ha), Vertisols (26.3 m ha), Aridisols (14.6), Mollisols (8.0 m ha), Ultisols (0.8 m ha), Alfisols (79.7 m ha), Oxisols (0.3 m ha) and non-classified soil (23.1 m ha). Typical geographic settings include areas of active erosion or deposition (i.e., steep slopes or floodplains), areas of quartzite bedrock or quartz sand (i.e., major desert and dune regions), and wetlands. They often are associated with urban areas because of the tendency for human settlement to concentrate on river delta or coastal lands. They also can be created by disturbing the land, as in extraction, the moving of earth materials, or the disposal of waste products. Despite their lack of distinct horizons (an optimal condition for agricultural soils), Entisols are commonly arable if given an adequate supply of plant nutrients and water. Entisols differ from mere weathered earth materials (saprolite) by the partial formation of a surface horizon. They differ from Inceptisols, another soil of recent origin, by a lesser subsurface accumulation of transported clay. **Entisols** are soils of recent origin. The central concept is soils developed in unconsolidated parent material with usually no genetic horizons except an A horizon. All soils that do not fit into one of the other 11 orders are Entisols. Thus, they are characterized by great diversity, both in environmental setting and land use.



Environmental Conditions

Climate: Entisols may form in a variety of climates. For example, an arid or pergelic climate may limit the amount of soil development to inhibit the formation of other soil orders. A pronounced saturation of the soil profile or even submergence for long enough periods inhibit soil development and soils persist in the Entisol order.

Vegetation: Harsh environments may limit root and plant growth due to consolidated highly resistant bedrock, infertility or toxicity of initial material, submergence, or high erosion rates. When adequately fertilized and their water supply is controlled some Entisols can be used in agriculture (rangeland, grazing land). However, restrictions on their depth, clay content, or water balance limit intensive use of large areas of these soils. Some Entisols are intensively farmed, for example, river alluvium Entisols.

Relief: Entisols may be present on very steep slopes on hard bedrock where soil formation is inhibited. Mass movement may remove material from such an area as fast or faster than most pedogenic horizons form. Other Entisols form on level to gently sloping relief in deposited material such as alluvium or colluvium.

Parent Material: Entisols are on land surfaces that are very young (alluvium, colluvium, mudflows), extremely hard rocks (e.g. Orthents), or disturbed material (e.g. mined land, highly compacted soils, toxic material). They also occur on deep bodies of water and glaciers which are transitions between 'soils' and 'not soils'. Psamments are Entisols formed in sandy material and are found in Alabama and Georgia and used mostly for grazing. They are also typical of the shifting sands of the Thar Desert. Entisols may be associated with bedrock outcrops. Entisols may be also associated with salt flats.

Time: Shortness of time since exposure of initial materials to the active factors of soil formation limits soil development. Fresh lava flows, marine or lacustrine deposits newly exposed by uplift of land or by lake drainage, provide sites for very young soils. Human activity may force the formation of Entisols. Deforestation may induce soil erosion where highly eroded, shallow Entisols remain.

Classification of Entisols

Entisols are divided into 5 suborders: *Aquents*, *Arents*, *Psamments*, *Fluvents*, and *Orthents.*

Aquents - Permentantly or usually wet soils formed on river banks, tidal mudflats etc. Here, general wetness limits development. Aquents, or the wet Entisols, are widely distributed. They dominate some of the delineations along the southern Atlantic and gulf coasts and on the flood plains along the Mississippi River and along other rivers and streams. Some Aquents are forming, mostly in sandy deposits, in other parts of the country. Most of the soils are forming in recent sediments. They support vegetation that tolerates permanent or periodic wetness. They are used mostly as pasture, cropland, forest, or wildlife habitat.

Arents – Anthropogenic soils, diagnostic horizons cannot develop because of deep mixing through ploughing, spading, or other methods of moving by humans. Arents do not have diagnostic horizons because they have been deeply mixed by ploughing, spading, or other methods of moving by humans. They are important soils for irrigated crop production in India. Small areas also occur throughout the country. Arents are used mostly as cropland, urban land, or pasture. Some are used as wildlife habitat.

Fluvents - Alluvial soils where development is prevented by repeated deposition of sediment in periodic floods. Found in valleys and deltas of rivers, especially those with high sediment load. Fluvents are the more or less freely drained Entisols that formed in recent water-deposited sediments on flood plains, fans, and deltas along rivers and small streams throughout the country. Some of the largest areas are on the flood plains along the Ganga River. Most Fluvents are frequently flooded, unless they are protected by dams or levees. Stratification of the materials is normal. Most Fluvents are used as rangeland, forest, pasture, or wildlife habitat. Some are used as cropland.

Orthents – Orthent are shallow or "skeletal soils". Found on recent erosion surfaces or very old landforms completely devoid of weatherable minerals. Orthents are mainly in the Western States. They are commonly on recent erosional surfaces. Orthents are used mostly as rangeland, pasture, or wildlife habitat. In USA soil taxonomy, Orthents are defined as Entisols that lack horizon development due to either steep slopes or parent materials that contain no permanent weatherable minerals (such as ironstone). Typically, Orthents are exceedingly shallow soils. They are often referred to as "skeletal soils" or, in the FAO soil classification, as Lithosols. The basic requirement for recognition of an orthent is that any former soil has been either completely removed or so truncated that the diagnostic horizons typical of all orders other than Entisols are absent. Most Orthents are found in very steep, mountainous regions where erodible material is so rapidly removed by erosion that a permanent covering of deep soil cannot establish itself. Such conditions occur in almost all regions of the world where steep slopes are prevalent. Orthents occur in flat terrain because the parent rock contains absolutely no weatherable minerals except short-lived additions from rainfall, so that there is no breaking down of the minerals (chiefly iron oxides) in the rock.

The steepness of most Orthents causes the flora on them to be sparse shrubs or grassland. In those on ancient, flat terrain, dry grassland, savanna, or, very rarely, rainforest can prevail. Because of their extreme shallowness and, usually, steepness and consequent high erosion hazard, Orthents are not suitable for arable farming. The flora typically supported on them is generally of very poor nutritive value for grazing, so that typically only low stocking rates are practicable. Many Orthents are very important as habitat for wildlife.

Psamments -. In soil taxonomy, a Psamment is defined as an Entisol which consists basically of unconsolidated sand deposits, often found in shifting sand dunes but also in areas of very coarse-textured parent material subject to millions of years of weathering. Entisols those are sandy in all layers where development is precluded by the impossibility of weathering the sand. Formed from shifting or glacial sand dunes. Psamments occur throughout the country. Some of the largest areas are in Rajasthan Punjab, Haryana and Gujrat. These soils are sandy in all layers. They are among the most productive rangeland soils in some arid and semiarid climates. Psamments are used mostly as rangeland, pasture, or wildlife habitat. A Psamment has no distinct soil horizons, and must consist entirely of material of loamy sand or coarser in texture. In the FAO soil classification, Psamments are known as Arenosols. Psamments occur throughout the world, being especially abundant in the deserts of Africa and Australia and in India it is present in Western states as Rajasthan Gujrat, some part of Haryana. Psamments typically have very low water-holding capacities because the sand in the soil is not *graded* so that sands of varying coarseness are constantly mixed right through the soil. Because most sands are highly siliceous, Psamments are also extremely low in all essential nutrients, most especially phosphorus and are highly acidic in all except very arid climates. They are always much less productive than other soils in the same region even when fertilized, and require careful management because the sand is very easily eroded.

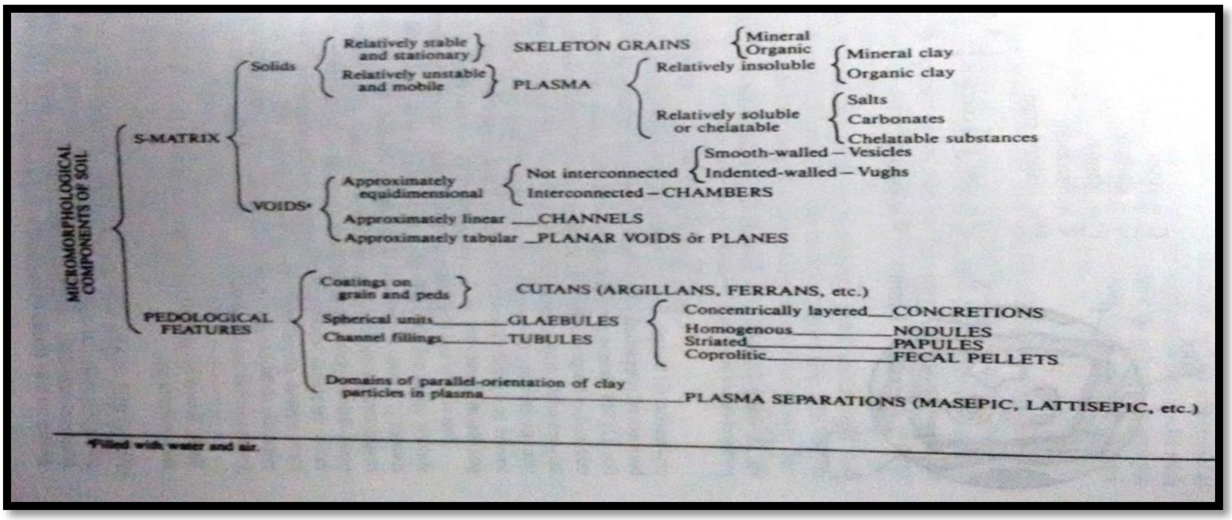
Micro pedological study of Entisol in India

Micropedological study –

Morphological features are to some extent visible to naked eye, but examination with optical aid reveals more detailed features which are helpful in understanding pedogenesis. This is known as soil micropedology. This can be done by hand lens but rigorous examination need preparation of thin section of selected ped. The ped is impregnated with resin, which on drying becomes as hard as rock and can be cut into thin section for examination under petro graphic microscope good deal of information can be gained from micro morphological study of thin section, Viz

1. *Origin of the parent material i.e. insitu weathered rock, sediment colluvium etc.*
2. *Exogenic processes like flooding , aeolian sand, silt deposits or or erosion influencing soil development*
3. *Soil forming processes*
4. *Land use management effect arising from cultivation, irrigation etc.*

Micropedological parameters includes:-



S matrix –S matrix of soil mineral is a material within simplest primary ped, or composing of a pedal material in which pedological feature occur. It consists of plasma, skeleton grain and void. Soil plasma is the material capable of being or having been moved, recognized or concentrated by processes of soil formation. Soil void are spaces between solid soil material.Vugh are unconnected void with irregular shape and irregular wall. Vugh are formed in soil materials that have high proportion of fine textured mineral capable of adhesion and cohesion.

Pedological feature are unit distinguishable from the enclosing or enclosed material for any reason such as origin difference in concentration or arrangement.

Cutan- A modification of the texture, structure, or fabric at natural surfaces in soil materials due to concentration of particular soil constituents or in situ modification of the plasma; cutans can be composed of any of the component substances of the soil material. **Diffusion Cutans-** Concentrations at a surface due to diffusion; usually associated with concentrations within the s-matrix of the soil material that reach a maximum at the cutanic surface.**Illuviation Cutans-**Formed by movement of the cutanic material in solution or suspension and subsequent deposition. **Stress Cutans**- In situ modifications of the plasma due to differential forces such as shearing; they are not true coatings**. Grains Cutans**- Cutans associated with the surfaces of skeleton grains or other discrete units; such as nodules, concretions, etc.**Free Grain Cutans**-Occur on the surfaces of grains which form the walls of voids. **Embedded Grain Cutans-**Occur on surfaces of grains embedded in relatively densely packed plasma. **Ped Cutans**-Associated with the surfaces of peds.**Channel Cutans**- Associated with the walls of channels whether these are of biological origin (worm channels) or not. **Plane Cutans**-Associated with walls of planar voids other than those between peds.**Normal Void Cutans**- Associated with the walls of the normal equant, triaxial, and prolate voids within primary peds or in apedal soil material.

Mineralogical nature of **cutanic** material

Argillan- A cutan composed dominantly of silicate clay minerals. Ferri-argillan- A cutan composed of intimately mixed clay minerals and iron oxides or hydroxides, whose colour depends on the degree of hydration and oxidation of the iron oxides and hydroxides. Organo-Argillan-A cutan composed of clay minerals stained by organic compounds. Sesquan- A cutan composed of a concentration of sesquioxides or hydroxides. Mangan- A cutan containing enough manganese (oxides or hydroxides) to effervesce upon application of hydrogen peroxide. Soluan- A cutan consisting of crystalline salts, such as carbonates, sulfates, and chlorides of Ca, Mg, and Na. Calcan- A cutan composed of carbonates (e.g. calcitans). Gypsum - A cutan composed of gypsum. Halan- A cutan composed of salt (halite). Silan -A cutan composed of silica in its various forms, such as silt or clay size quartz or chalcedony. Skeleton- A cutan composed of skeleton grains adhering to cutanic surfaces. Alban- A cutan composed of materials that have been strongly reduced. Ferran- a cutan composed of a concentration of iron oxides. Matran- A cutan that contains s-matrix skeleton grains within the plasma concentration. Organan-A cutan composed of a concentration of organic matter.

Globules

A three dimensional unit within the s-matrix of the soil material, and usually approximately prolate to equant in shape. Its morphology (size, shape, and/or internal fabric) is incompatible with its present occurrence being within a single void in the present soil material. Concretions- Globules with a generally concentric fabric about a centre which may be a point, a line, or a plane. Nodules- Globules with an undifferentiated internal fabric; in this context undifferentiated fabric includes recognizable rock and soil fabrics.Papules-Galebules composed dominantly of clay minerals with continuous and/or lamellar fabric. Pedodes- Globules with a hollow interior, often with a drusy lining of crystals. Septeria- Globules with a series of radiating cracks crossed by a series of cracks concentric with the margins; the crack pattern is often highly irregular; they are usually spheroidal with sharp boundaries.

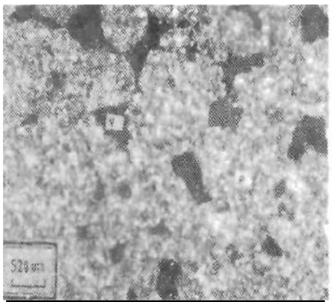
Pedotubules

Pedotubules- A pedological feature consisting of soil material (skeleton grains plus plasma) and having a tubular external form; the external boundaries are relatively sharp. Granotubules -Pedotubules composed essentially of skeleton grains without plasma, or all the plasma occurs as pedological features. Aggrotubules- Pedotubules composed of skeleton grains and plasma which occur essentially as recognizable aggregates within which there is no directional arrangement with regard to the external form. Isotubules - Pedotubules composed of skeleton grains and plasma that are not organized into recognizable aggregates and within which the basic fabric shows no directional arrangement with regard to the external form. Striotubules- Pedotubules composed of skeleton grains and plasma that are not organized into recognizable aggregates but exhibit a basic babric with a directional arrangement related to the external form'.

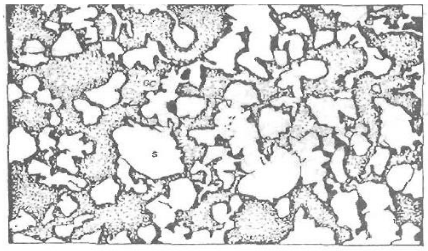
Fabric – Arrangement of materials in thin section. Asepic plasmic fabric - Anisotropic plasma with anisotropic domains with regard to each other resulting in a flecked extinction pattern. Gefuric - The coarser particles are linked up by braces of finer materials.Gefu-chitonic - A region having both gefuric as well as chitonic related distribution in a soil thin section. Monic related distribution - Presence of particles of only one size group or amorphous materials with interstitial voids. Pedal- The void surfaces that are interconnected and intersected to form a small ped. Skelsepic – When plasma separation is alone or around skeleton grain. Vughs - Irregular void surfaces in the soil formed as a result of shrinkage characteristics.

Entisols in Indo-Gangetic alluvium are formed in young river flood plains or on sand dunes or other aeolian deposits and are characterised morphologically either by the absence of diagnostic horizon or have only fragments of diagnostic horizon which are discernible. The dominant Entisols observed are Psamments, Aquents and Fluvents (Dhir *et al.*, 1982; Sehgal *et al.,* 1986). Psamments are soils characterised by <35 per cent rock fragments and have textures coarser than loamy fine sand in all sub-horizons either to a depth of 100 cm or to a lithic, paralithic or petroferric contact whichever is shallower: also may be stratified. Micro morphologically, the Psamments consist of variety of minerals such as quartz, feldspars, micas and carbonates with moderate to slight alteration. The fine material comprises of small carbonate crystals forming coatings around and bridges between coarse mineral grains. Elementary structure is apedal, vughy, with crystic plasmic fabric. The related distribution is gefu-chitonic. Kooistra (1982) reported sedimentary features and mineral infilling in the voids in Thar pedon suggesting aeolian activity. The presence of shells and snails in these soils suggest fluvial action. Ustipsamments common in parts of Rajasthan and Haryana occur on dune slopes, inter dunal areas and recent river deposits. They are characterised by stratification and absence of diagnostic horizon. Textures are loamy fine sand or coarser. The coarse mineral grains in Ustipsamments comprises of variety of minerals with mica showing moderately strong alteration. Elementary structure is apedal, vughy, gefu-chitonic with Asepic to Skelsepic plasmic fabric.

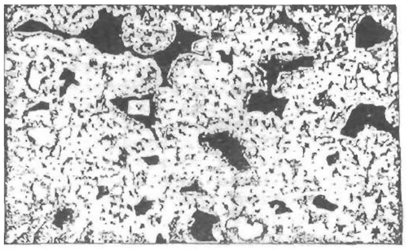
Kooistra (1982) reported thin and discontinuous Ferri-argillan around mineral grains and packing voids formed due to insitu weathering of mica. Generally, the groundmass of an A horizon shows remnants of a geogenetic lamination in which laminae, with higher contents of fine material alternate with laminae practically free of fine material. The instability of the open packing of the coarse textured soil material has resulted loosely packed soil material.



Monic to chitonic related distribution in an (Entisol) with incipient grain cutan and mineral weathering



Monic to Chitonic related distribution (MC); Grain cutan (GC); Skeleton (S)



Stipple-speckled b-fabric (SF); Vughs (V); Plasma (P)

Fluvents

Fluvents are characterised by textures of loamy very fine sand or finer in some sub-horizon, absence of a lithic or a paralithic contact within 25 cm; lack a diagnostic horizon and Monic to chitonic related distribution in an (Entisol) Ustipsamments with incipient grain cutans and mineral weathering; Depth 25- 40 cm; crossed nicols .Monic to Chitonic related distribution (MC); Grain cutan (Ge); Skeleton (5) 23 are not permanently saturated. Fluvents are represented by Torrifluvents and ustifluvents. Torrifluvents with calcareous alluviums derived from Siwaliks occur on old flood plains of Ghaggar valley in Rajasthan (Murthy *et al.* 1982). They have an overlying burden from the strong south westerly sand and dust storms. Torrifluvents comprise of a variety of minerals which are fresh or nearly fresh. Colour of plasma is dark yellowish brown. Elementary structure is weakly pedal, vughy with moderately developed Skelsepic plasmic fabric. Skeleton grains predominate over plasma throughout. Calcium carbonate nodules with crystals ranging from 15 m to 150 m are common (Khadkikar *et al.,* 2000). Kooistra (1982) reported the occurrence of calcitans and neo-calcitans in the lower horizons of Masitawali pedon and considers it to be due to current processes. The presences of white, transparentcrlstals up to 35 m have been identified as salt crystals. Ustifluvents occur in regions of young river alluvium and old levees which are stratified (flood plain region) (Khadkikar *et al.,* 2000).

They have variety of slightly weathered minerals. The plasma is yellowish brown to grey is brown, that dominates over skeleton grains. Elementary structure is weakly pedal, vughy, Pedotubules, porphyric with Asepic to stipple-speckled fabric. Faunal activity is quite predominant as evide nced by the presence of mineral excrements (Pal *et al*., 2014). The predominance of carbonate mycelia, carbonate nodules and shells and snails in Dham series suggest fluvial action (Kooistra, 1982). The heterogeneity of soil material suggests the material of different origin. Ahuja *et al.* (1983) while studying the pedogenic development and litho logical discontinuities in the landscape of Ghaggar river basin of Haryana and Punjab have identified weak and patchy Argillan in the old basin and not in recent channel bars, relict channels and undifferentiated plains. Ahuja *et al.* (1984) have also observed low degree of development with more litho logical discontinuity in recent landforms (channel courses, and levees) and better development with lesser breaks in the older ones (plains and old basins).

Aquents

Aquents are Entisols that are saturated with water, lack Vughy structure. The occurrence of fluvaquents has been reported from different parts. of the country. However, the micro morphological data is available only for Kanagarh pedon, occurring on old flood plains of river Hooghly, West Bengal (Pal *et al*., 2014). These soils are characterised by hexagonal cracks of 2 to 4 cm wide on the surface extending up to 20 cm depth. The fluvaquents possess variety of minerals and moderately altered mica. The plasmic fabric is maskelsepic with porphyric related distribution. Elementary structure is pedal, vughy and Skelsepic. The sedimentary nature of these soils is characterised by the remnant of sedimentary laminations. Kooistra (1982) suggests small accumulation of sesquioxides with sharp boundaries as a recent formation in these soils.

Phosphate analysis

Phosphorous analysis can be a way for understanding weathering of soil

Weathering Index was the determined as the ratio of active P and occluded P as proposed by Puranik *et al.* (1979).

$$\text{Weathering index (WI)} = \frac{(\%S\text{-}P + \%Ca\text{-}P + \%Al\text{-}P + \%Fe\text{-}P)}{(\%R\text{-}SP + \%Occluded\text{-}P)}$$

Where; S-P: Saloid Phosphate, Ca-P: Calcium Phosphate, Al-P: Aluminium Phosphate, Fe-P: Iron Phosphate, R-SP: Reductant Soluble Phosphate

Soil maturity was examined in terms of profile weight mean of total P and computed Weathering Index (WI) based upon the PWM of inorganic phosphorus fractions.PWM – total P was maximum in Entisol (421.6 mg kg-1) in Chotanagpur Plateau, thereafter decreased gradually down the slope of the toposequence and ultimately attained a minimum of 287.6 mg kg-1 in Inceptisols. Based upon PWM – total P soil maturity was found to follow the sequence as Inceptisols (most matured)> Entisol (least matured) found in that area. With increase in soil maturity the active P content was found to decrease together with increase in RS-P and occluded P and consequently the WI narrowed down with the soil development (Sarkar *et al.,* 2014).

Conclusion -

The micro morphological approach provides an insight into the complex heterogeneous nature of soils which can be resolved to simplicity by studying the soil fabric into its individual organisational units. The importance of this technique in identifying soil features, such as clay coatings, calcitic nodules, infillings, excrements etc. and in solving the soil management, and soil genesis and classification problems has been well recognised. In the past decades, only a few workers used this technique to investigate soil related issues. However, since 1982 it has attracted the attention of many workers. Major The major limitation is, considering the extent of different soils and the complexity in their formation, very few pedon with limited thin sections have been studied. As such the present micro morphological characterisation of soils is in conclusive. Soil taxonomy already in use in India for several years has a limitation of not having micro morphological information of soils. This is very necessary for categorical establishment of soil fabric analysis. As it will provide a clear view of keeping the soil in suitable order.

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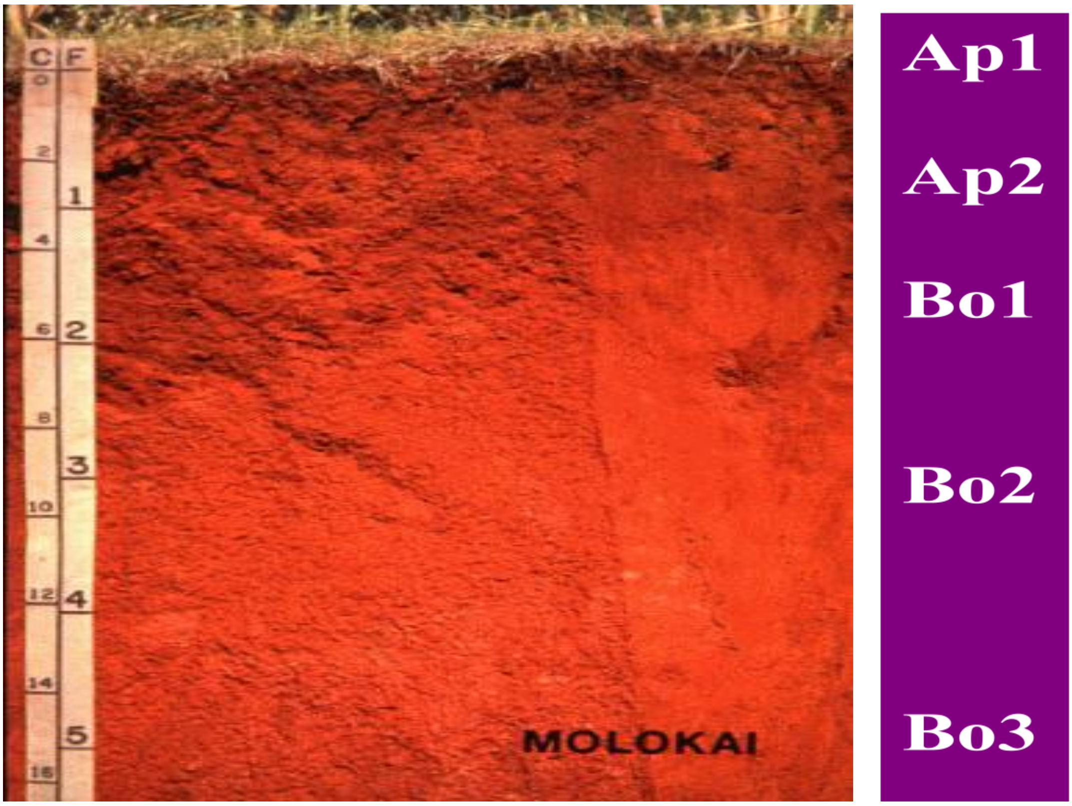
Genesis, development, morphology, taxonomy and micropedology of Oxisols

I. Introduction

1. Concept

Oxisols are the most weathered of the 12 soil orders in the USDA soil classification system. They are composed of the most highly weathered tropical and subtropical soils, and are formed in hot, humid climates that receive a lot of rainfall. Oxisols are located primarily in equatorial regions.

2. Oxisol soil profile



3. Key featurs:

1.The most highly-weathered soils

2. Form in hot, humid climates with high annual rainfall.

3. Commonlyoccur in equatorial latitudes.

4. Highly weathered and leached, dominated by iron and aluminum oxides.

5. Low in natural fertility (basic cations, Ca^{2+}, Mg^{2+}, K^{+}) and high in soil acidity (H^{+}, Al^{3+})

6. Physically stable soils, with low shrink-swell properties and good erosion resistance.

7. these soils require extensive inputs of lime and fertilizers to be agriculturally productive.

II. Typical Characteristics:

1. **Climate**:

Oxisols are the most highly weathered soil order. These soils form under year-round hot, tropical climates. Although climatic pattern may have changed over the course of the soil's history, these soils formed under moist climates.

2. **Mineralogy**:

While the subsurface soil layers contain clay particles, the layer is loaded with hydrous oxides of aluminum and iron. Hydrous oxides are the products of intense weathering of minerals, after much of the silica has leached away from silicate minerals, such as kaolinite.

3. **Physical Traits**:

Highly weathered soils generally resist compaction and allow water to move and drain freely.

4. **Productivity**:

Although these soils generally contain low activity clays, highly weathered, tropical soils are nonsticky and workable. Oxisols form strong aggregates, do not have a shrink and swell potential, and are resistant to erosion. However, nutrient cations, such as calcium, magnesium, nitrate, and potassium, must be added to the soil. Phosphorus may also be limited, because it tends to form strong bonds with the oxides. Organic matter can be added to increase the availability of phosphorus.

III. Oxisols Physico-chemical Properties .

1. Oxisols show an oxic or kandic subsurface diagnostic horizon. An oxic horizon has to be at least 30-cm thick and is sandy loam or finer. It has a high content of low-charge 1:1 clays with an effective cation exchange capacity (ECEC) of <= 12 cmol kg $^{-1}$ clay and a cation exchange capacity (CEC) of <= 16 cmol kg $^{-1}$ clay at pH 7. Weathering and intense leaching have removed a large part of the silica from silicate minerals in this horizon (low nutrient reserve). Although the clay content in Oxisols is often high the CEC is low. This is due to the almost complete weathering of primary minerals and 2:1 type clay minerals to 1:1 type minerals such as kaolinite and gibbsite. Those minerals are not expandable secondary minerals and their CEC is low. The permanent charge of kaolinite and gibbsite is low but they may develop a small but significant pH dependent charge due to their low crystallinity. The most common structure of oxic horizons in soils on old geomorphic surfaces is massive separating into very fine crumbs. The primary aggregates built up of individual particles are held together by clay-sized substances. Bulk densities of the oxic horizon are usually in the range from 1 to 1.3 g cm $^{-3}$. The oxic horizon contains less than 10 % weatherable minerals and has < 5 % by volume rock structure.

2. The oxic horizon is generally very high in clay-size particles dominated by hydrous oxides of iron and aluminum. Most of the sesquioxides are generally goethite or hematite although maghemite may also be present in soils derived from basic rocks. Most clay-size minerals found in the oxic horizon are poorly crystallized. Generally, poorly crystallized Al and Fe-oxides may form more effective bonds between particles compared to better crystallized Al and Fe-oxides,

which are poor cementing agents. This indicate that the composition of sesquioxides is as important as their quantity for structural stability of a soil.

3. Oxisols are classified by the presence of an oxic or a kandic horizon. Kandic horizons show the same ECEC and CEC as oxic horizons but kandic horizons have a clay content increase at its upper boundary of > 1.2 x clay within a vertical distance of < 15 cm, i.e., abrupt or clear textural boundary.

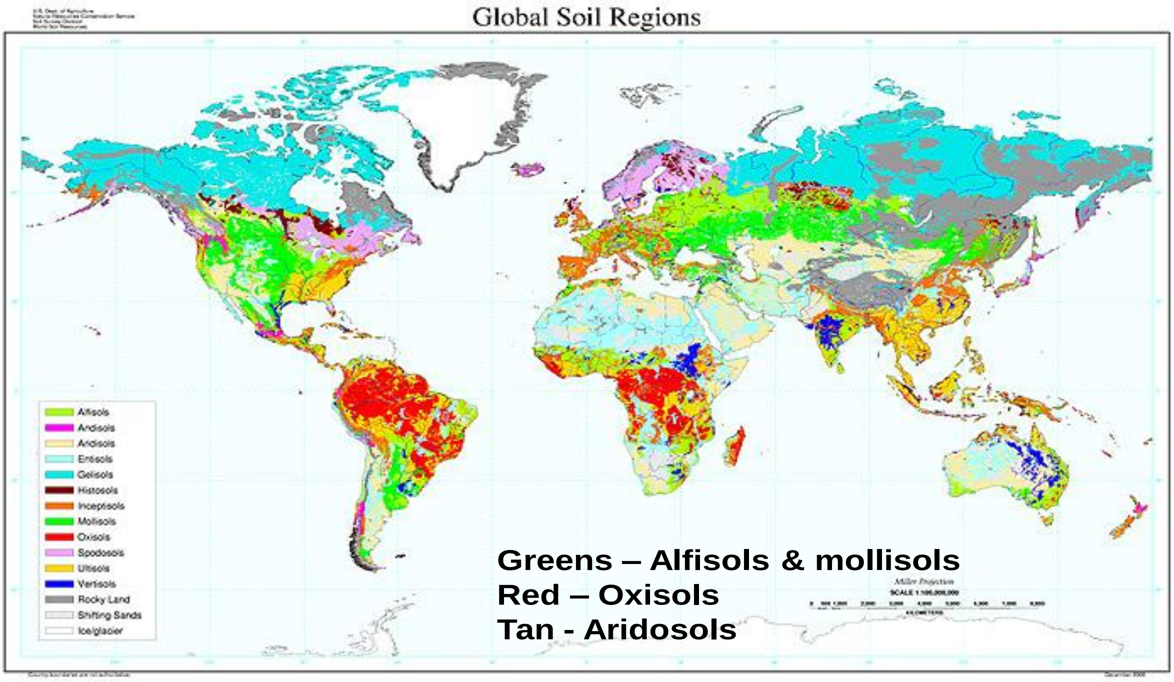
4. A fluctuating water table (alternating oxidation - reduction) in Oxisols may form plinthite consisting of red-and-gray mottled material. In the past this material has been designated as 'laterite' or 'lateritic iron oxide crust'. If subjected to repeated wetting and drying, as in exposure by erosion of overlying material, it becomes indurated to ironstone, which may be subsequently erode and be deposited as ironstone gravel layers in alluvial fans.

5. Infiltration and percolation rates in Oxisols are rapid. Many Oxisols bahave like sandy textured soils with respect to their pF curves, i.e., the water holding capacity is limited.

IV. **Global Extent And Geographic Distribution**

Absence of reliable national maps in many countries of the world prevents an accurate assessment the extent and distribution of Oxisols. The only map available for such assessments is the Soil Map of the World (FAO-UNESCO, 1971-1976) which has been digitized by FAO. This digitized vector map was converted from the FAO legend to Soil Taxonomy units, a process which also involves many sources of errors. The FAO map was developed during the sixties and since then, more reliable information is available for a few countries, specifically for Brazil. As the digital map is vector based, the new information cannot be incorporated unless FAO develops a new vector map. Thus, the area of Oxisols presented here is probably considerably overestimated. It is not only overestimated in Brazil, but also in the northern part of the Southern African Plateau. Finally, in the last two decades both Soil Taxonomy and the Legend of the Soil Map of the World have undergone many revisions, which introduces other sources of errors in the current estimates.

Soil map of world



V. Classification

Suborders:

1. **Aquoxa**: Oxisols that have aquic conditions.

2. Torrox: Other Oxisols that have an aridic soil moisture regime.

3 .Ustox :Other Oxisols that have an ustic or xeric soil moisture regime.

4. Perox: Other Oxisols that have a perudic soil moisture regime .

5. Udox :Other Oxisols.

VI. Land Use And Management

The highly weathered soils of the tropics, specifically the Oxisols, have been perceived as being problematic for management and unproductive. It is true that they have many constraints but under high levels of management and particularly for perennial crops, their productivity is economic and sustainable. They of course share many of the management problems of other soils and in some, such as moisture stress, they are more severely impacted than for example some Alfisols. Under low-input agriculture, productivity is low, risk is high, and potential for resource degradation is also high. In this module, aspects of management are considered with illustrations of how to address some of the more important constraints. Due to inherent difficulties of low-input agriculture, which traditional farmers are usually aware of, Oxisols were not exploited for large scale cultivation until recently. This is despite the fact that the land surface, tillage conditions, and other properties appear attractive for cultivation. In fact, these same features prompted much early research on the management of the soils. There are still many misconceptions of the management properties of these soils, one being that they share similar yield constraining properties of other acid soils. There are a few members of Oxisols which have soil acidity and aluminum toxicity as a dominant constraint. Oxisols in general are not restricted by acidity and few have Al problems. However, that does not mean that they do not respond to liming. The response is due to the amendment and nutritional effect of the calcium and not to neutralizing effect of soil acidity. Thus there are some fundamental differences in management of Oxisols as compared to other soils, and this must be borne in mind.

VII. Sustainable Development Consideration

The humid tropical forest ecosystem, with Oxisols as the dominant soil, is a pristine environment and serves as an enormous reservoir of sequestered carbon, biological diversity with a wide array of plants and animals, in addition to being a resource of food, timber, medicine, and other products for people. Plantation agriculture with localized small farmer use did minimal disturbance to the natural equilibrium. With population increases, the fragility of the ecosystem is being tested. Over 15 million hectares of forests are now being destroyed annually with little or no effort to regenerate. Resilience of such ecosystems is so low that complete regeneration may not be achieved. In addition, some plants and animals adapted to unique niches in this ecosystem are lost permanently when their habitat is destroyed. Although there are many attempts, particularly in the Amazon Basin to understand the system, there are few efforts to develop remedial measures to reduce the negative impacts. The limited resource farmers of the tropics, who are the silent majority in this ecosystem, practice shifting cultivation and their sheer numbers have made the slash-and-burn form of agriculture the most extensive form of agriculture in this ecosystem. The consequence is that forests are decreasing in area, forest resources are decreasing in amount and composition, and in the process of performing this form of agriculture the farmers are not only reducing the quality of the resource base but also impacting the quality of the global environment, primarily through the release of carbon dioxide and other greenhouse gases. The challenge is then to develop a viable alternative to the slash-and-burn form of agricultural system. If successful, the rewards are not only to provide a mechanism for the millions of people to extricate themselves from the poverty trap they are in today but also to ensure the survival of the forest ecosystem and reduce the negative environmental impacts that are already well entrenched.

- The physical properties of soil are being reclaimed, and soil bulk density was a good indicator of soil quality and the physical properties studied showed good relationships with the amount of soil organic matter.
- Reclaimed and managed of oxisol by gypsum and organic mannuring give good productive of soil.

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INCEPTISOLS AND ITS MORPHOLOGY

Inceptisols

[Latin *inceptum, meaning* beginning (from the verb *incipere*) + -sol]

INTRODUCTION

Origin- 1960s

Area covered under soil order in India-**95.8** (Mha). Highest than other order, percent representation cover -**29.13%.**

Soil come under-Forest/Hill, Lateritic, Red, Black, Alluvial soil.

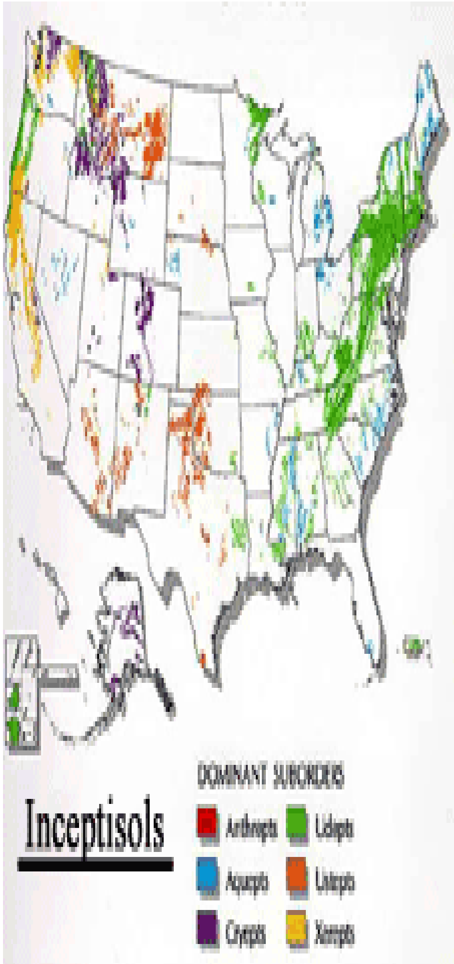
These soils are in the beginning stages of soil profile development. The differences between horizons are just beginning to appear. Some colour changes may be evident between the emerging horizons, and the beginnings of a B horizon may be seen with the accumulation of small amounts of clay, salts, and organic material. These soils show more profile development than Entisols, but have not developed the horizons or properties that characterize other soil orders. Inceptisols are commonly found throughout the world, and are prominent in mountainous regions. The natural productivity of these soils varies widely, and is dependent upon clay and organic matter content, and other edaphic (plant-related) factors.

Inceptisol soil profiles give some indication of clay minerals, metal oxides, or humus accumulating in layers, but such accumulation is not sufficient to classify the soil into an order defined by characteristic surface or subsurface horizons. They commonly are found either with underlying weathering-resistant parent material (for example, quartzite or siliceous sandstone) or in topographic settings conducive to soil erosion or waterlogging.

Inceptisols differ from Entisols in that they exhibit more well-developed soil horizons. By definition, however, they may not form on volcanic-ash parent material (reserved for Andisols), develop in an arid climate (reserved for Aridisols), contain permafrost (reserved for Gelisols), or exhibit seasonal cracking and swelling (characteristic of Vertisols).

Mineral soils containing some developed horizons other than one of illuvial clay. Moisture is available to mature a crop. The horizons of Inceptisols result mostly from slight to moderate alteration of the parent material. These alterations may be expressed by soil structure development, carbonate removal and hydrolytic weathering to produce clay, form iron oxide minerals and accumulate organic matter. Inceptisols are limited in Arizona primarily to subhumid regions. Only the Ochrepts suborder of Inceptisols is officially recognized in Arizona, but soils of the Andepts suborder have been identified (Hendricks and Davis, 1979). The soil texture is finer than loamy sand. The clay fraction of the soil has a moderate to high capacity to retain cations (bases plus aluminium).

Soil Order	Key Characteristics	U.S. Order Distribution Map	Profile Examples

Inceptisols	Inceptisols – Soil Profile Begins		Paxton Series
	• The beginnings of soil profile development • Color differences between horizons starting to show • Prominent in mountainous areas, but occur almost everywhere • Widely variable productivity potential • Extent of world ice-free land area: 10%		 A/C to USDA

CONCEPT

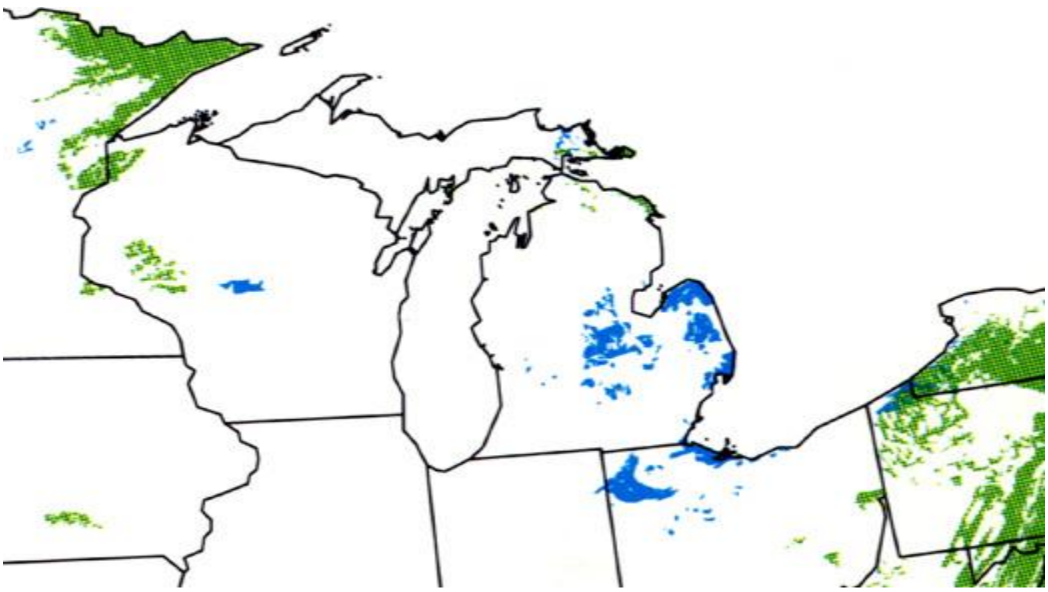
Soil that have no spodic, argillic, nitric, oxic, petrocalcic, plinthite, but have an altered or cambric B. Horizon, or an umbric mollic, or plaggen epipedon.

DISTRIBUTION

Like Entisols, Inceptisol are also widely-distributed soils in all the soil moisture and temperature regimes of the world, exept the arid region (representing aridic/torric moisture region), such as Sahara (North Africa) and Thar (Western India) deserts, central ands southern Australia, Mongolia, Greenland, etc. They are very commonly observedin the zone in the Intertropical zone under all topographic positions. In India, these soils are most comman in all the state, except in the hot and arid region of western Rajassthan (popularly known as the Thar Desert). Haryana, where Entisols and/or Aridisols are predominant.

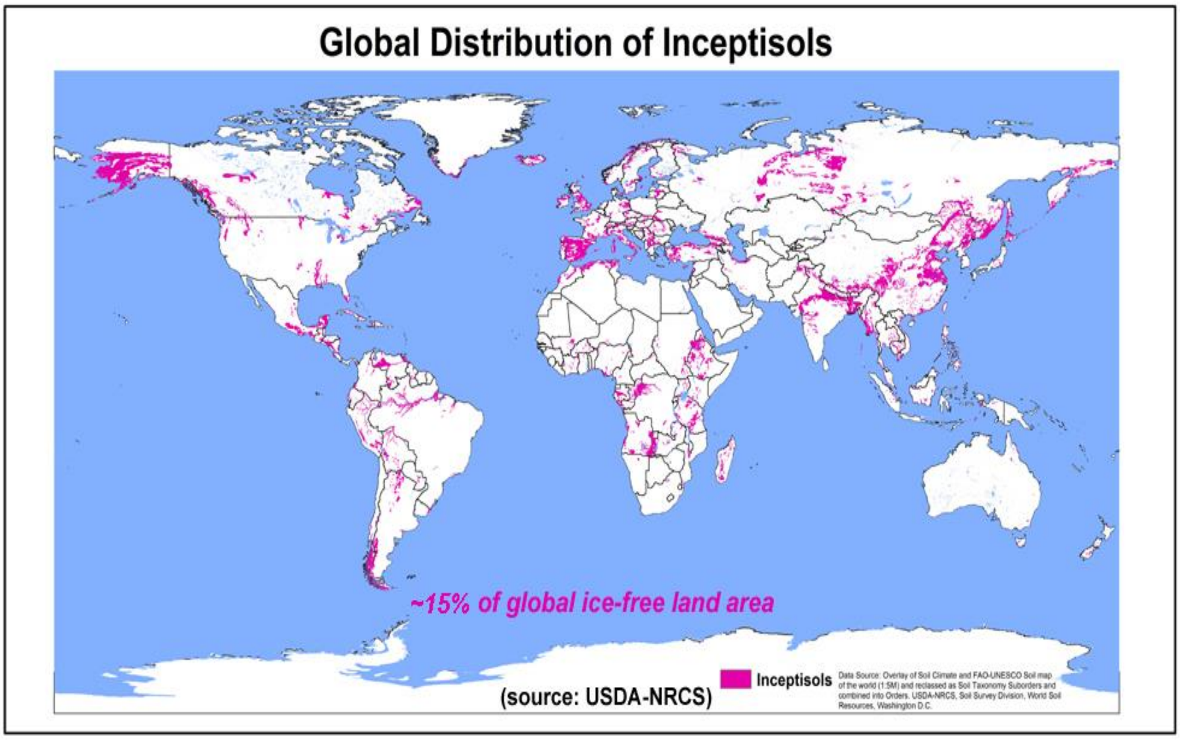
Inceptisol, one of the 12 soil orders in the U.S. Soil Taxonomy. Inceptisols are soils of relatively new origin and are characterized by having only the weakest appearance of horizons, or layers, produced by soil-forming factors. They are the most abundant on Earth, occupying almost 22 percent of all nonpolar continental land area. Their geographic settings vary widely, from river deltas to upland forests to tundra environments. For example, they occur in the Mississippi valley, central Europe, the Amazon region, northeastern India, Indonesia, and Alaska. They are usually arable with appropriate control of erosion or drainage. Inceptisols 15.8% of world, Ochric or Umbric + cambic.

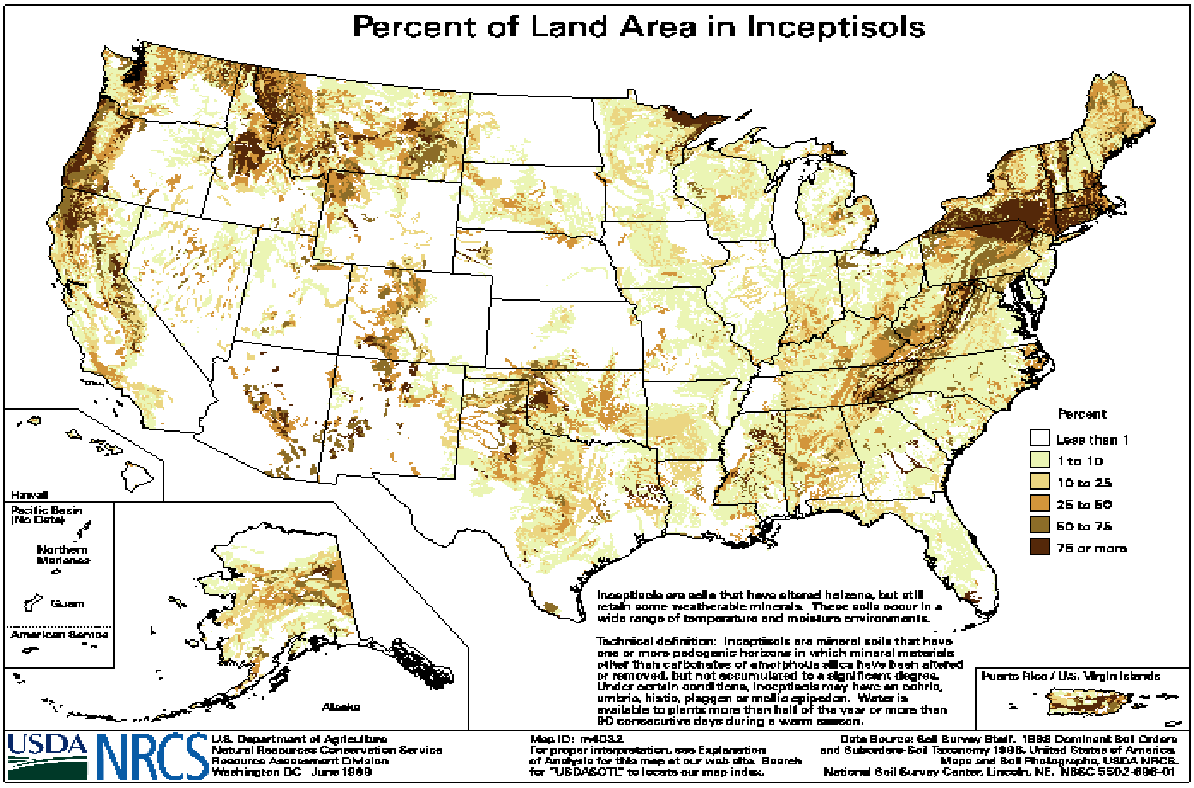
Figure- The map below, which shows the locations of Inceptisols in the Great Lakes region, should also suggest to you that Inceptisols are also found on steep slopes (the Appalachian region) or on rocky landscapes (northern Minnesota). What the map does NOT show is that Inceptisols, like the one shown above, are also found on the rocky landscapes of the western UP.



DOMINANT SUBORDERS

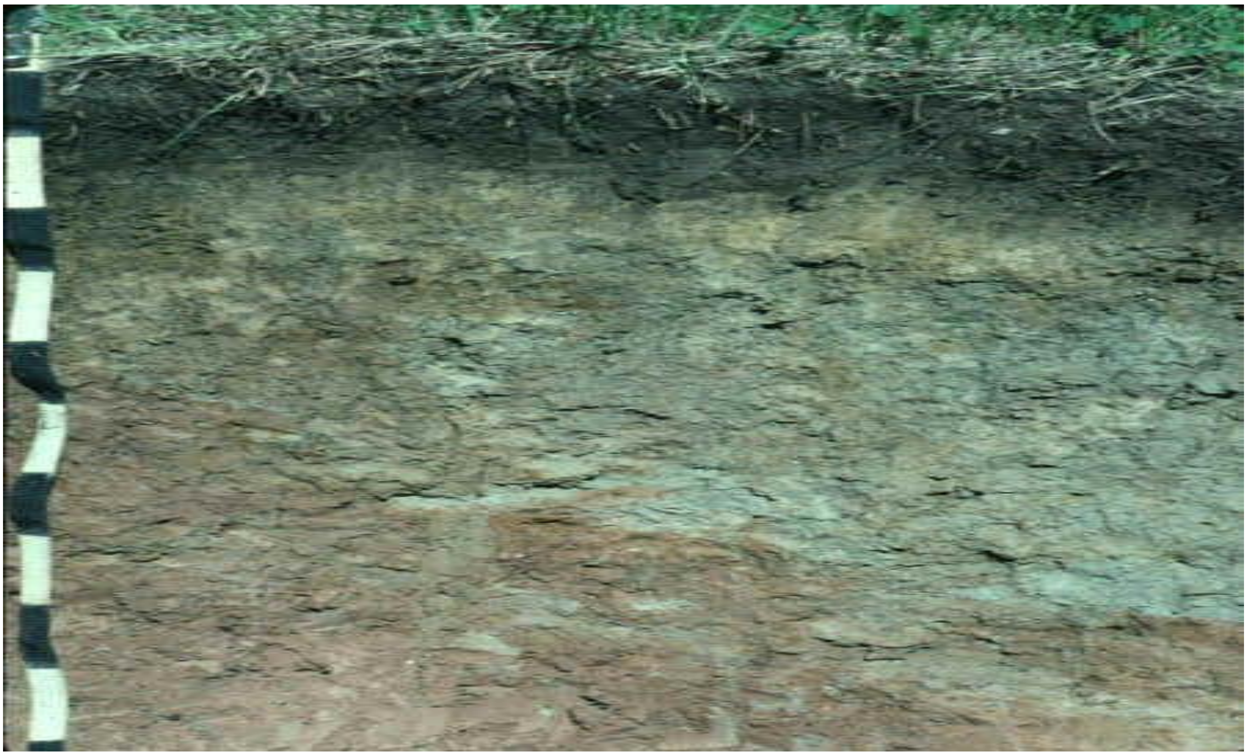
Aquepts   Udepts


Global Distribution of Inceptisols
~15% of global ice-free land area
Inceptisols
(source: USDA-NRCS)


Percent of Land Area in Inceptisols
Percent
Less than 1
1 to 10
10 to 25
25 to 50
50 to 75
75 or more
Hawaii
Pacific Basin (No Data)
Northern Marianas
Guam
American Samoa
Alaska
Puerto Rico / U.S. Virgin Islands
Inceptisols are soils that have altered horizons, but still retain some weatherable minerals. These soils occur in a wide range of temperature and moisture environments.
Technical definition: Inceptisols are mineral soils that have one or more pedogenic horizons in which mineral materials other than carbonates or amorphous silica have been altered or removed, but not accumulated to a significant degree. Under certain conditions, Inceptisols may have an ochric, umbric, histic, plaggen or mollic epipedon. Water is available to plants more than half of the year or more than 90 consecutive days during a warm season.
U.S. Department of Agriculture
Natural Resources Conservation Service
Resource Assessment Division
Washington DC June 1999
Map ID: m4032
For proper interpretation, see Explanation of Analysis for this map at our web site. Search for "USDASOTL" to locate our map index.
Data Source: Soil Survey Staff. 1998 Dominant Soil Orders and Suborders-Soil Taxonomy 1998. United States of America. Maps and Soil Photographs, USDA NRCS. National Soil Survey Center, Lincoln, NE. NSSC 5502-898-01

Inceptisols are soils with weakly developed B horizons, as shown below.

In Michigan, Inceptisols are located primarily in the Saginaw Valley and two areas in the eastern half of the Upper Peninsula. Little eluviation or illuviation has taken place, and the soils are characterized by poor drainage and waterlogging. If drained successfully, they can be productive-as in the navy-bean-producing areas of the Saginaw Valley. The gray colors, in the soil below, are indicative of wet conditions, and are a "give-away" that this soil is an Inceptisol.



In Michigan, most Inceptisols are found on the flat, wet lake plains of the Saginaw Valley, and those near Toledo. Such soils usually have abundant gray (technically: gleyed) colors.

FORMATION

The Inceptisols are usually not dry and have one or more diagnostic horizon. They have developed rather recently owning to the alteration of the parent material to develop soil structure, but without much leaching and/or accumulation of material in their subsoil.

Inceptisols may have higher chromas, or colour or altered-B subsurface horizon, termed cambic. These soil have developed to the extent that relief feature from their parent material may be difficult to observe within the profile; however primary igneous, metamorphic and sedimentary structures normally take some time to be obliterated entirely. The soils have too weak profile development to be called Zonal.

The parent material of Inceptisols is as variable as that of Entisols. Soils formed in volcanic ash, with at least 60% recognizable pyroclastic fragments, that were earlier included in Inceptisols, are now separate to have another Order of Andisols. The Inceptisols develop under varied climatic (semeiarid to humid) and vegetation (from grassland through forest to Tundra) conditions. In humid to subhumid climate, Inceptisols may be develop in a few thousand years; in relatively drier climates. In sequences of alluvial terraces, they occupy intermediate positions b/w Entisols (nearest the stream) and other developed Alfisols (father away from the stream). Soil Formed in colluvial material in mountains of Idaho.

CLASSIFICATION

Inceptisols have been subdivided into seven suborders and each suborder comprises of 2-syllables.

Aquepts - Inceptisols with a water table at or near the surface for much of the year.

Anthrepts - Inceptisols with evidence of human habitation and farming.

Gelepts - Inceptisols of very cold climates (mean annual soil temperature ≤0°C)

Cryepts - Inceptisols of cold climates.

Ustepts - Inceptisols of semiarid and subhumid climates.

Xerepts - temperate Inceptisols with very dry summers and moist winters.

Udepts - Inceptisols of humid climates.

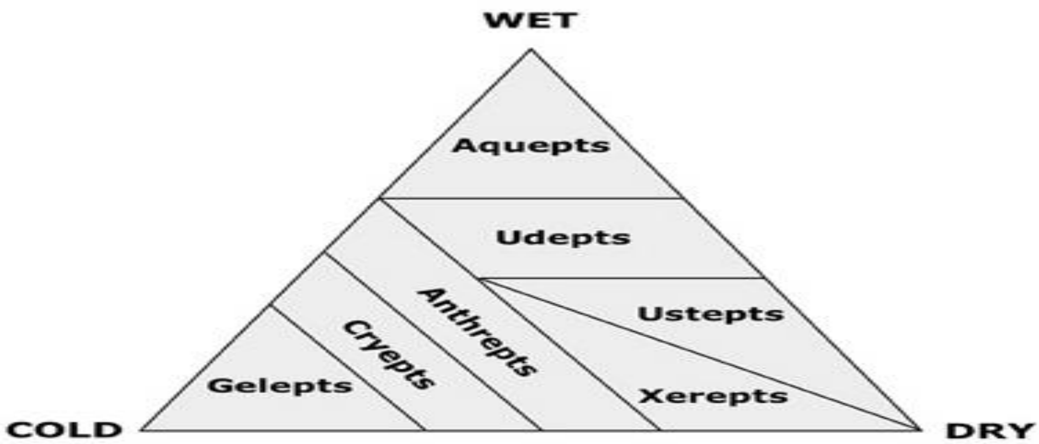


Figure-Relationship among different suborder of Inceptisols

Land Use

Many Inceptisols on level or undulating topographic position are agriculturally productive and provide excellent natural grazing grounds. They can be cultivated for improved pasture and for growing a variety of vegetable and grain crops.

CONSTRAINTS

Major constraints of Inceptisol for crop production:

Limiting soil temperature (cryic) and moisture regimes (xeric, ustic).Such moisture regimes enable farmers to grow one crop in a year, unless irrigated artificial. Other related factors comprise slope inclination, aspect, length of growing period and rainfall reliability and intensity.

The occurrence of sulphuric properties (petro) calcic horizon, duripan, or fragipan results in physical and /or chemical constraints for crop growth.

Soil erosion on sloping landforms, result in continuous loss of surface soils.

Effective rooting depth, especially in soils developed on sloping landforms, limit volume of soil root anchorage, water and nutrient holding capacity.

The fertility of soils may be variable depending on the parent material (that influences texture and clay mineral type, type of vegetation, land use and climate (which affects the organic matter status and nutrients dynamics).

Inceptisols productivity is limited because of imperfect drainage, steep slopes and/or sodicity.

POTENTIAL

Most of the almost level Inceptisols (e.g. Ustepts of Punjab), under assured irrigation, are very productive and produce wheat yield as high as 4.5 tonnes per ha. There exist a range of varying land use, depending upon the agro-ecological setting and socio-economic conditions of the farmers. For instance, live stock grazing on steep lands to complement arable farming in the flatter lands. The steep lands can be stabilized by terracing and conservation effective agricultural practices.

SOIL MORPHOLOGY

Soil morphology deals with the form, structure and organization of soil material. Morphology described and measures a wide range of soil properties and includes as assessment of soil particles and aggregates that provide estimates the soil void characteristics and hydraulic properties. Soil morphology is ordinarily first observed, described and studied in the field, but investigation can be continued in the laboratory with optical and electron microscopes.

Field observation with the unaided eye or with a hand lens are considered macromorphology, whereas observation utilizing a microscope are considered micromorphology.

Soil Macromorphology

The observable attributes ordinarily described in the field include the composition, from soil structure and organization of the soil, colour of the base soil and features such as mottling, distribution of roots and pores, evidence of transloacated materials such as carbonates iron, manganes, carbon and clay, and consistence of the soil.

Soil Micromorphology

Soil micromorphology begins in the field with the routine and careful use of a 10x hand lens, much more can be described by careful description of thin sections made of the soil with the aid of a petrographic, polarizing light microscope. The soil can be impregnated with an epoxy resins, but more commonly with a polyester resin and sliced and ground to 0.03mm thickness and examined by passing light through the thin soil plasma. Micromorpholgy is the branch of soil science that is concerned with the description, interpretation and, to an increasing extent, the measurement of components, features an fabrics in soils at a microscopic level" (Bullock et al, 1985)

Soil micromorphology is the systematic study of the soil constituent and associated pore in an undisturbed state of the soil at a particular time (Kubiena, 1938). Historically micromorpholohy has focused on the genesis and classification of soil.

Micromorphology is an established sub-discipline of soil science. Its foundation probably lies in the use of hand lenses for magnifying the features of soils in the field, hence expanding the view available to the naked eye. Thin sections have been studied under optical microscopes for the understanding of soil genesis since the beginning of the 20th century (Stoops 2010), but Stoops (2010) considers that the study of micromorphology had its real start with the publication of W.L. Kubiëna's book Micropedology in 1938. Any study of the fine-level structures or morphology visible through microscopy, including those of non-soil materials, can be strictly characterised as micromorphology. SEM continues to be widely used in soil studies, for minerals (e.g., Churchman et al. 2010b), organic materials, and also their associations (e.g., Miltner et al. 2011).

This is especially advantageous for studying biological entities in soils, as well as, potentially, for some soil aggregates (Foster 1994; Churchman et al. 2010a). Effects of irrigation on an Inceptisol, New Zealand (Churchman & Tate 1986). This study employed only SEM for micromorphology. Hence, this study seeks to ascertain the role that micromorphology, using optical, electron-optical, and also newer techniques such as those using X-ray microscopy (e.g., Wan et al. 2007) and computer-assisted tomography (Tracy et al. 2010), may be able to play in better defining soils as a philosophical entity.

Micromorphological features

S- Matrix-the arrangement of primary and secondary particles or structures and void among this is called S-matrix. The primary and secondary particles have geometrical configuration and are frequently distributed in soil system.

Part of S- matrix-

1. Relative stability and stationary: it is an important part of S-matrix formed a skeleton grain which may be inorganic as well as organic in behaviour.
2. Relative active and mobile: under this part, plasma like substances are considerd which are mobile. They may be soluble and insoluble in nature. Under soluble fraction high electrolytes and organic substances are included which have high dielectric constant, while in insoluble fraction simple clay are included.
3. Simple liquid: soil water which held between intraspecific cavity or void, which determines the soil moisture, availability of water and minerals to plants.

MICROPEDOLOGY

Micropedology" (1938) is considered as the official birth of this discipline. It contains the basic philosophy, some techniques (among others on the preparation of thin sections of unconsolidated materials) and a first terminology to describe soil microfabrics in a morphoanalytical way, i.e., by giving an enumeration of the morphologically distinguishable units present. The basic fabric types described by Kubiëna were the basis for the later classifications of related distributions patterns by Brewer (1964) and Stoops and Jongerius (1975).

Micropedology is the microscopic study of soil and sediments in undistrubed resin impregnated thin sections.Micropedology is referred to study of pedons that are small basic soil entities and the part of the continum mantling the land.

In general, micropedology covers the whole scenario of pedon development and processes which are governing the pedon characteritics. We know that soil is developed by unconsolidated inorganic materials (minerals) with alittle contibution of organic matter. The composition of soils is variable and depends upon the soil forming factors. Therefore, soil is also considered as heterogenous system.

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Genesis, development, morphology, taxonomy and micropedology of Mollisols

I. Introduction

1.Concept

Mollisols are a soil order in USDA soil taxonomy. These are the soils of grassland (tall or short) vegetation, form in semi-arid to semi-humid areas and cryic to thermic climatic environment. Mollisols have deep, high organic matter, nutrient-enriched surface soil **(A horizon),** typically between 60–80 cm in depth. This fertile surface horizon, known as a mollic epipedon, is the defining diagnostic feature of Mollisols. Mollic epipedons result from the long-term addition of organic materials derived from plant roots, and typically have soft, granular, soil structure. Subsurface horizons, rich in illuviated clay (argillic or Bt), calcareous (clacic or Bk) or gypsiferous (gypsic or By) materials may be present, but are not definitive of the order.

A Mollisol profile

2.Limits Between Mollisols and Soils of Other Orders

1. Unlike Gelisols, Mollisols do not have either of the

Following

a. Permafrost within 100 cm of the soil surface; or

b. Gelic materials within 100 cm of the soil surface and permafrost within 200 cm of the soil surface;

2. Unlike Histosols, Mollisols do not have organic soil materials that meet one or more of the following:

a. Overlie cindery, fragmental, or pumiceous material and/or fill their interstices and directly below these materials have either a densic, lithic, or paralithic contact;

b. When added with the underlying cindery, fragmental, or pumiceous materials, total 40 cm or more between the soil surface and a depth of 50 cm; or

c. Constitute two-thirds or more of the total thickness of the soil to a densic, lithic, or paralithic contact and have no mineral horizons or have mineral horizons with a total thickness of 10 cm or less; or

d. Are saturated with water for 6 months or more in normal years (or are artificially drained), have an upper boundary within 40 cm of the soil surface, and have a total

thickness of either:

(1) 60 cm or more if three-fourths or more of their volume consists of moss fibers or if their bulk density, moist, is less than 0.1 g/cm3

(2) 40 cm or more if they consist either of sapric or hemic materials, or of fibric materials with less than three-fourths (by volume) moss fibers and a bulk density,

moist, of 0.1 g/cm3 or more

3. Unlike Spodosols, Mollisols do not have a spodic horizon or an Ap horizon containing 85 percent or more spodic materials and do not have one or more of the

following:

a. An albic horizon in 50 percent or more of each pedon and a cryic soil temperature regime

b. A spodic horizon with all of the following characteristics:

(1) One or more of the following:

(a) A thickness of 10 cm or more; or

(b) An overlying Ap horizon; or

II.Environmental conditions for the formation of Mollisols

1. Climate: Mollisols occur in a variety of climatic zones, ranging from cryic (e.g. Mongolia, North Dakota), frigid (e.g. Iowa), mesic (e.g. Pakistan), or thermic (e.g. central Oklahoma) temperature regimes. The average annual precipitation amount ranges from 200 mm where short-grass steppe vegetation predominates to 800 mm where tall-grass vegetation grows. For example, climate in the Great Plains favor the development of Mollisols: severe, dry winters with much wind and relatively slight accumulation of snow; relatively moist springs and droughty summers with some thunderstorms and/or tornadoes (e.g. typical climate of the Great Plains). Mollisols occur under several soil moisture regimes: udic, ustic, xerix, and aquic.

2. Vegetation: Most of the Mollisols have formed under prairie or grassland vegetation. There are different types of prairie: In tall-grass prairie grasses stand 1 to 3-m at maturity, whereas in short-grass prairie grasses stand 13 to 30-cm in height. The prairie or grassland vegetation add plentiful raw organic matter to the soil, mostly by in situ root death. Legumes in the prairie or grassland community contribute considerable nitrogen to the soil. Prairies develop under relatively moist condistions, whereas grass steppe develop under drier climate. Prairie extension was largest approximately 5000 to 2000 B.P. Common species of prairie vegetation are bluestem (Andropogon gerardi), buffalo grass (Buchloe dactyloides), or western wheat grass (Agropyron smithii). Nowadays, most of the prairie in the U.S. is replaced by farmland. Mollisols are fertile soils and in the U.S. approximately 25 % of the land area are covered by Mollisols which produce much of the wheat, soybean, and alfalfa yield. A few Mollisols have formed under forest, under special conditions of poor drainage and/or calcareous or high base status parent material.

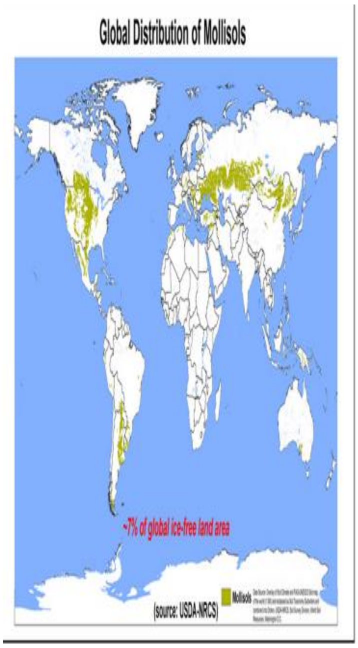
3. Relief: Mollisols cover a wide range of land forms (e.g. flat or gently rolling plains, undulating plains, mountain areas). Extensions of prairies by fire have formed preferentially on topography over which fire moves easily (e.g. ridge tops, windward slopes).

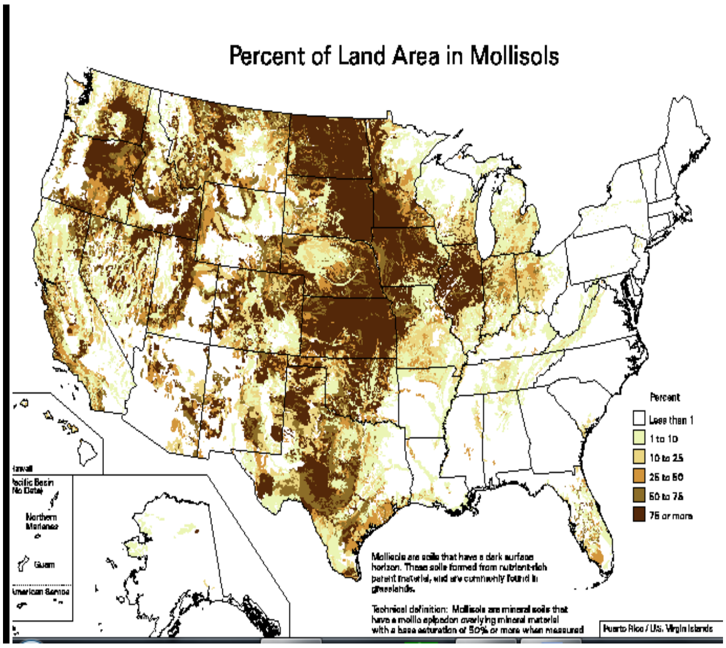
4. Parent Material: Mollisols occur on deposits and landscapes with a wide range of ages. Many Mollisols are formed on deposits associated with glaciations (unconsolidated Quaternary materials), where calcareous rich aolian deposits supported the formation of Mollisols. However, in other areas they develop in residuum weathered from sedimentary rocks.

5. Time: The age for development of Mollisols is indifferent and closely associates to the other environmental factors.

III. Geographic distribution

Mollisols are extensive in subhumid to semiarid areas on the plains of North America, Europe, Asia, and South America. They lie generally between the Aridisols of arid climates and the Spodosols or Alfisols of humid climates. They are most extensive at mid latitudes, but they also occur at high latitudes and high altitudes and in tropical regions. In India, such soils are predominantly observed in the Tarai region of Uttar Pradesh and Uttrakhan (Desphande et al. 1971) and occasionally in Himalayan (Kulu region) of Himachal Pradesh (Sehgal et al 1985), northen Bihar and Maharastra and Madhya Pradesh in association with vertisols In contrast to the generally observed non-acidic and less weathered Mollisols in temperate semiarid and humid climate, acidic and fairly weathered Mollisols on Deccan basalt occur in hills of the Satpura Range of MP and the Western Ghats of Maharashtra under forest cover in the prevailing tropical humid climatic conditions19. The formation of Mollisols in the zeolitized basaltic landscape over millions of years and their persistence in central and western India demonstrate that the quality of parent materials prevents the transformation of smectite to kaolin, helps in the retention of adequate amount of smectite and provides continuous supply of bases (Ca^{2+} ions) required for the formation of Mollisols even under tropical humid climate. Mollisols (brown forest soil) in each of the study areas are a member of Mollisol Alfisol–Vertisol association. The Mollisols of the Western Ghats have argillic horizons unlike those of the Satpura Range. This suggests that the Mollisols and the associated ferruginous Alfisols are formed in a stable basaltic landscape.





Typically mollisosl are formed under grassland vegetation in semi-arid (moist) to humid climatic condition. Most of these are observed in low, rolling or flat landforms, but there are mollisols above the snowline in alpine and northern Himalayn regions provided the rainfall is within limits, not to leach bases from the profile. They develop under a wide range of temperature (cryid or frigid to hyperthermic) from the poles to equator and on diverse topographic positions (lowlands to mountains meadows). Thery are found on a variety of parent materials, especially base-rich sediments and rocks, such as limestone, marl, basalt or alluvium in which there has been decomposition and accumulation of large amounts of organic matter at the soil surface, their characteristic features results from the decomposition of organic material, especially fine roots of grassy vegetation, producing some stable dark compounds and reworking of soil burrowing activity of diverse populations of soil invertibrates, especially earthworm, producing dark, organic matter-rich, well-structured soils qualifying for mollic epipedon-a basic requirement of mollisols

IV. Classification (formative element oll)

While mollic epipedon is a must in all the mollisols, but its presence does not qualify a soil for mollisols, as mollic epipedon can also be observed in some vertisols and inceptisols. Based largely on soil moisture and temperature regimes, diagnostic horizon and $CaCO_3$ content, the mollisols have been sub divided into 7 suborders

1 Suborders:

1 Albolls

Albolls are the Mollisols that have an albic horizon and fluctuating ground water. Most of these soils are saturated with water to or near the soil surface at some time during winter or spring in normal years. In summer ground water commonly is not within a depth of 200 cm. Below the albic horizon, there is either an argillic or, less commonly, a natric horizon. These soils developed mostly on broad, nearly level to sloping ridges, on back slopes, or in closed depressions. Most have episaturation. In the United States, most Albolls are in areas of late-Pleistocene deposits. Most Albolls developed under grass or grass and shrub vegetation. In early stages of development, some are thought to have had forest vegetation that was replaced by grass. Because slopes are gentle, most of the Albolls in the United States are now cultivated.

Definition

Albolls are the Mollisols that have all of the following:

1. An argillic or natric horizon; and

2. An albic horizon that has chroma of 2 or less and that is 2.5 cm or more thick, has its lower boundary 18 cm or more below the mineral soil surface, and either lies directly below the mollic epipedon or separates horizons that together meet all

of the requirements for a mollic epipedon; and

3. In one or more subhorizons of the albic horizon and/or of the argillic or natric horizon and within 100 cm of the mineral soil surface, redox concentrations in the form of masses or concretions, or both, and also aquic conditions for some time in

normal years (or artificial drainage).

2 Aquolls

Aquolls are the Mollisols that are wet and that have dominant low chroma, commonly in olive hues, and have highcontrast redox depletions in or below the epipedon. These soils commonly develop in low areas where water collects and

stands, but some are on broad flats or on seepy hillsides. Most of the soils have had a vegetation of grasses, sedges, and forbs, but a few also have had forest vegetation. In the United States, Aquolls are most extensive in glaciated areas of the Midwestern States where the drift or loess was calcareous. In a layer above a densic, lithic, or paralithic contact or in a layer at a depth between 40 and 50 cm from the mineral soil surface, whichever is shallower, Aquolls have aquic conditions or are artificially drained. They can have any temperature regime

from cryic to isohyperthermic.

Definition

Aquolls are the Mollisols that have, in a layer above a densic, lithic, or paralithic contact or in a layer at a depth between 40 and 50 cm from the mineral soil surface, whichever is shallower, aquic conditions for some time in normal years

(or artificial drainage) and meet one or more of the following:

1. Have a histic epipedon overlying the mollic epipedon

2. Have an exchangeable sodium percentage (ESP) of 15 or more (or a sodium adsorption ratio [SAR] of 13 or more) in the upper part of the mollic epipedon and a decrease in ESP (or SAR) values with increasing depth below 50 cm from the

mineral soil surface

3. Have a calcic or petrocalcic horizon that has its upper boundary within 40 cm of the mineral soil surface

4. Have a mollic epipedon, with chroma of 1 or less, that extends to a lithic contact within 30 cm of the mineral soil surface

5. Have one of the following colors:

a. Chroma of 1 or less in the lower part of the mollic epipedon and either

(1) Distinct or prominent redox concentrations in the lower part of the mollic epipedon

(2) Either directly below the mollic epipedon or within 75 cm of the mineral soil surface if a calcic horizon intervenes, a color value, moist, of 4 or more

3 Cryolls

Cryolls are the cool or cold, more or less freely drained Mollisols. They are moderately extensive in the high mountains of the Western United States. They also are extensive on the plains and mountains of Eastern Europe and in Asia. On the plains they are mainly in areas of late- Pleistocene or Holocene deposits. In the mountains of the Western States, some of the soils may be on older surfaces, but the geomorphology of these areas has had little study. Cryolls have a cryic temperature regime and a udic, ustic, or xeric moisture regime. The vegetation on the Cryolls on the plains was mostly grasses. The Cryolls in the mountains have either forest or grass vegetation. On the Cryolls in Alaska, spruce, birch, and aspen trees are common.

Definition

Cryolls are the Mollisols that:

1. Have a cryic soil temperature regime;

2. Do not have all of the following:

a. An argillic or natric horizon

b. An albic horizon that has chroma of 2 or less, that has its lower boundary 18 cm or more below the mineral soil surface, and either lies directly below the mollic epipedon or separates horizons that together meet all of the requirements for a mollic epipedon

c. In one or more subhorizons of the albic horizon and/or of the argillic or natric horizon and within 100 cm of the mineral soil surface, redox concentrations in the form of masses or concretions, or both, and also aquic conditions for some time in normal years (or artificial drainage)

3. Do not have the characteristics defined for Aquolls; and

4. Have one or more of the following:

a. Either within or directly below the mollic epipedon, mineral soil materials less than 7.5 cm in diameter that have a $CaCO_3$ equivalent of less than 40 percent.

4 Rendolls

These are the Mollisols that are of humid regions and that formed in highly calcareous parent materials, such as limestone, chalk, drift composed mainly of limestone, or shell bars. These soils have a mollic epipedon that rests on the calcareous parent materials or on a cambic horizon that is rich in carbonates. A few of the soils are so rich in finely divided lime that the mollic epipedon has a color lighter than normal but is nevertheless rich in dark colored humus and is within the limits of a mollic epipedon. Rendolls have a cryic soil temperature regime or a udic moisture regime, or both. These soils are not extensive in the United States, but they are extensive in some parts of the world. They formed under forest vegetation or under grass and shrubs.

Definition

Rendolls are the Mollisols that:

1. Have a mollic epipedon that is less than 50 cm thick;

2. Have a $CaCO_3$ equivalent of 40 percent or more on the basis of the whole soil, including coarse fragments as much as 7.5 cm in size in or directly below the mollic epipedon;

3. Do not have an argillic or calcic horizon

5. Udolls

Udolls are the more or less freely drained Mollisols of humid climates. In addition to the mollic epipedon, these soils may have a cambic, calcic, natric, or argillic horizon. They formed mainly in late-Pleistocene or Holocene deposits or on surfaces of comparable ages. In the United States, their vegetation at the time of settlement was dominantly a tall grass prairie, but some of the soils on Pleistocene surfaces appear to have supported at some time a boreal forest that was supplanted by grasses several thousand years ago. Udolls formed in sediments and on surfaces of varying ages from Holocene to mid Pleistocene or earlier. The Udolls that

have a thermic or warmer temperature regime, in particular, may have formed during two or more glacial and interglacial stages. Most of the Udolls are in the eastern part of the Great Plains or are east of the Great Plains. The soils are most extensive in Illinois, Iowa, and adjacent states. Their temperature regime is frigid or warmer, and their moisture regime is udic. Where slopes are not too steep, nearly all of these soils are cultivated. Maize (corn) and soybeans are the major crops.

Definition

Udolls are the Mollisols that:

1. Have a udic moisture regime

2. Do not have both an albic horizon and, within 100 cm of the mineral soil surface, any subhorizon of the albic horizon and/or of the argillic or natric horizon that has redox concentrations in the form of masses or concretions, or both, and also aquic conditions

3. Do not have both aquic conditions and the colors defined for Aquolls

4. Do not have a calcareous horizon that lies directly under the mollic epipedon at a depth of less than 50 cm and that has a $CaCO_3$ equivalent of more than 40 percent, including coarse fragments smaller than 7.5 cm, unless the soil also has an

argillic or calcic horizon or a mollic epipedon 50 cm or more thick

5. Do not have a cryic soil temperature regime

6 Ustolls

Ustolls are the more or less freely drained Mollisols of subhumid to semiarid climates. Rainfall occurs mainly during a growing season, often in heavy showers, but is erratic. Drought is frequent and may be severe. During a drought, soil blowing becomes a problem. Without irrigation, the low supply of moisture usually limits crop yields. Ustolls are extensive soils on the western Great Plains in the United States. In addition to the mollic epipedon, most Ustolls have a

Bk horizon that has identifiable secondary carbonates or have a calcic horizon, but a few of the soils that formed in noncalcareous materials do not have secondary lime. Ustolls may also have a cambic, argillic, kandic, petrocalcic, or nitric horizon. If there is a natric horizon, there may be an albic horizon overlying it, or if there is a cambic or argillic horizon, there may be a duripan below it. The presence or absence of these horizons is used, in part, as the basis for defining the great groups of Ustolls. Most of the Ustolls on the Great Plains in the United States had a grass vegetation when the country was settled. Some of the Ustolls in the mountains of the Western States supported forest vegetation. The Aridic subgroups supported mostly short grasses, and the others supported mixtures of short and tall.

Definition

Ustolls are the Mollisols that:

1. Have an ustic moisture regime or an aridic moisture regime that borders on ustic

2. Have a temperature regime warmer than cryic

3. Do not have both an albic horizon and, within 100 cm of the mineral soil surface, any subhorizon of the albic horizon and/or of the argillic or natric horizon that has redox concentrations in the form of masses or concretions, or both, and also aquic conditions

4. Do not have both aquic conditions and the colors defined for Aquolls.

7 Xerolls

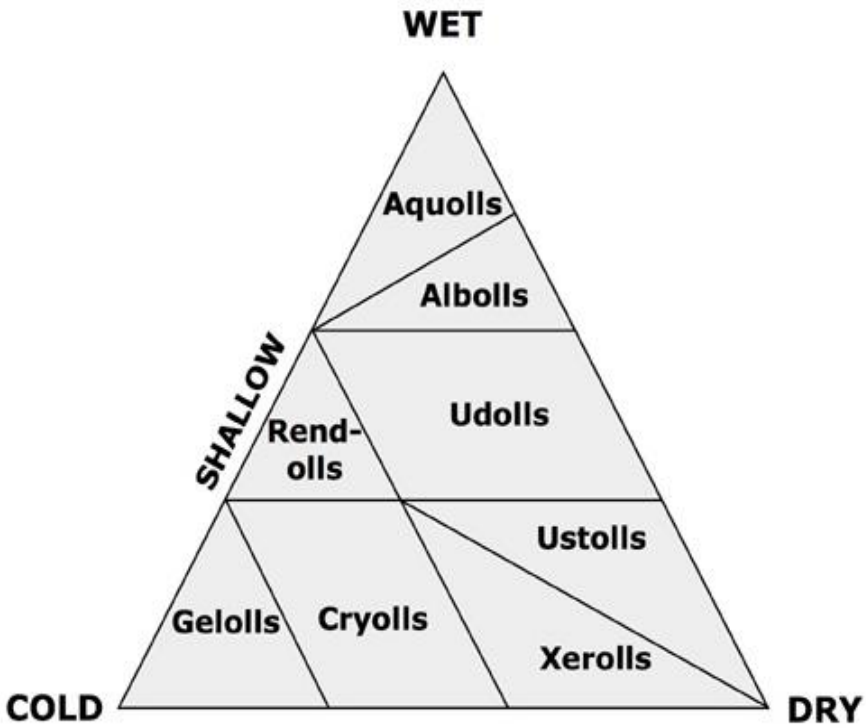
1. Have a mean annual soil temperature lower than 22oC and mean summer and mean winter soil temperatures at a depth of 50 cm that differ by 5oC or more;

2. Do not have both an albic horizon and, within 100 cm of the mineral soil surface, any subhorizon of the albic horizon and/or of the argillic or natric horizon that has redox concentrations in the form of masses or concretions, or both, and also aquic conditions;

3. Do not have both aquic conditions and the colors defined for Aquolls;

4. Have a xeric moisture regime or have a moisture regime that is aridic bordering on xeric; and

5. Do not have a cryic temperature regime are an aridic (torric) moisture



1. Great Groups

In all, there are 7 subroder and 36 Great Groups within mollisols order

Classification of Mollisols from order to series

Order	Suborder	Great Group	Subgroup	Family	Series
Mollisols	Aquolls	Endoaquolls	Cumulic	fine, smectitic, isohyperthermic	Kaloko
				very-fine, smectitic, isohyperthermic	Nohili
			Cumulic Vertic	very-fine, smectitic, isohyperthermic	Keaau
			Fluvaquentic	fine, halloysitic, isohyperthermic	Kalihi
			Thapto-Histic	fine, halloysitic, isohyperthermic	Pearl Harbor
	Udolls	Hapludolls	Cumulic	fine, mixed, isohyperthermic	Kolokolo
	Ustolls	Argiustolls	Pachic	fine, parasesquic, isothermic	Kanepuu
		Haplustolls	Andic	clayey-skeletal, parasesquic, isohyperthermic	Kainaliu
				fine, mixed, isohyperthermic	Koloa
			Aridic	fine, kaolinitic, isohyperthermic	Ewa
				clayey over fragmental, mixed, isothermic	Kamaole
				clayey over fragmental, kaolinitic, isohyperthermic	Keawekapu
			Cumulic	fine, mixed. isohyperthermic	Haleiwa
				fine, mixed, isohyperthermic	Iao
				fine-loamy, mixed, isohyperthermic	Kawaihapai
				fine-loamy, mixed, isohyperthermic	Pulehu
				fine, mixed, isothermic	Koele
			Entic	clayey over sandy or sandy-skeletal, mixed, isohyperthermic	Mokuleia

Natri.albolls,Natri.aquolls, Natri.cryolls, Natri.xerolls, Natri.ustolls and Natri.udolls: Aquolls,Cryolls,Xerolls, Ustolls and Udolls that have a nitric horizon.

Agri. Albolls, Agri.aquolls, Agri.cryolls, Agri.xerolls, Agri.i.ustolls and Agri.udolls: Aquolls,Cryolls,Xerolls, Ustolls and Udolls that have a argillic horizon.

Cry.aquolls and Cry.rendolls: other Aquolls and Rendolls that have a cryic soil temperature regimes.

Epi.aquolls: Other Aquolls that have episaluration.

Duri.aquolls, Duri.cryolls, Duri.xerolls and Duri.ustolls: Aquolls, Cryolls, Xerolls and Ustolls that have a duripan that has its upper boundaries within 100 cm of the soil surface.

Endo.aquolls:Other Aquolls, not meeting requirements of orther Great Groups

Pale.xerolls and Pale.ustolls: Xerolls and Ustolls that have a petrocalcic horizon with its upper boundaries within 150 cm of the soil; surface or have an argillic horizon that shows no clay decrease of 20% or more from its maximum within 150 cm soil surface.

Pale.cryolls: Other Cryolls that have an argillic horizon that has its upper boundaries 60cm or more belo0w soil surface and a texture of finer than loamy fine sand in all layers above argillic horizon

Paleudolls: Udolss that have a petrocalcic haorizon with its upper boundaries within 150 cm of the soil; surface or no densic or lithic or paralithic contact within 150cm of the soil surface or na argillic horizon with Hues of 7.5YR or redder and chromas of more than 5 or frigid soil temperature regime and texture finer than loamy fine sand above argillic horizon.

Verm.ustolls and Verm.udolls: All such soils, Ustolls and Udolls, that have a mollic epipedon that below Ap horizon or 18 cm of the soil surface contains more than 50% wormholes, wormcasts or filled animals burrows and either rersts on lithic contact or has a transition layer which consist of 25% or more wormholes, wormcasts or filled animals burrows with material from mollic epipedon

Haplo.rendoll, Haplo.cryoll, Haplo.xerolls, Haplo.ustolls and Haplo.udoll: Rendoll, Cryolls, Xerolls, Ustolls and Udolls that do not qualify for any of the above Great groups.

Land use:

These are inherently the best agricultural soils of the world and pose real constraints. These soils produce optimum yields both under irrigated and unirrigated conditions with minimum inputs. In rainfed Mediterranean regions, mainly northen Iraq because of the winter rain such soils represents the wheat belt of the regions. These soils in drier regions are mostly used for grazing. In subhumid regions, they are widely cultivated for wheat, maize and a variety of vegetable crops. In Tarai regions of India because of summer monsoon rain these are cultivated in kharif season for maize sorghum and other crops. Under irrigated conditions these are intensively cultivared for growing a variety of other creops including vegetables and plantation crop.

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