ENVS 334: Applied Soil Science and Land Management

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Brief Course Outline

1. Introduction – soil basics
2. The soil profile; soil types & formation
3. Soil physical properties
4. Soil water & hydraulic characteristics
5. Chemical properties of soil
6. Biological features of soils
7. Soil and land management
8. Land degradation and rehabilitation

1. Introduction – soil basics

What is soil?

- **By definition**, soil is the uppermost part of the lithosphere (terrestrial surface of the earth) that is comprised of mineral and organic material, weathered rocks or deposits (parent material), and overlies the bed rock (geologic substratum).

- Soil is indeed a complex and living entity that can be regarded as an ecosystem in itself, but forms the foundation of larger terrestrial ecosystems.

- It also serves as a habitat for a whole range of different fauna and micro-organisms.

- Soils are the foundation of human societies and civilizations.
Humans are dependent upon soils:

- Soils form the basis for terrestrial life.
- Soil is the only viable medium for large-scale crop production and the ultimate source of food.
- They underlay foundations of houses & buildings.
- Form the beds for roads & enable surface transportation.
- Absorb domestic wastes and act as a recipient of a variety of other wastes (municipal, industrial, animal).
- Buffer, filter and transform hazardous wastes into less harmful compounds
Soils and their management are indeed of broad societal concern.

- Great civilizations of the past have had good soils as one of their main natural resources.
  - Ancient civilizations of the Nile valley
  - Mesopotamian civilization in the Tigris & Euphrates valley
  - Civilizations of the Indus (India), Yangtse & Hwang-Ho (China) river valleys.
- Mismanagement and destruction of soils have been associated with the downfall of past civilizations.
- Even today, there are many who do not fully realize the importance and long-term significance of soils.
- Thus, the concept of soil must encompass viewpoints of land owners and users (farmers, engineers, home owners).
Brief historical account of soil use and concepts

- Earliest historical records indicate people had learned to distinguish between soils (good, fertile v. poor/infertile)

- >4000 y ago, Chinese used soil maps for taxation

- 1000 B.C. Homer (Greek) wrote about use of manure on land for farming.

- Greek and Roman civilizations had elaborate agricultural systems and practices for soil management.

- Van Helmont, John Woodward, Jethro Tull (1700s) observed soil and water to be the sources of nutrients for plant growth.

- Boussingault (1834), French, early field experiments to describe plant growth.

- Von Liebig (1840), German, crop growth limited by the most limiting minerals which came from manure applied to the soil.

- Late 1800s & 1900s – American, European soil scientists
Approaches to the study of soils

- Two broad approaches to the study of soils:
  - Pedology – study of soil as a natural body
  - Edaphology – study of soil as a habitat for plants (crop growth)

- Pedology considers the soil as an natural entity
  - As a biochemically weathered and synthesized product of nature
  - Pedon (Greek) = soil or earth
  - Soil formation, morphology, classification

- Edaphology examines soil from standpoint of higher plants
  - Edaphos (Greek) = soil or ground
  - Practical, production and management aspects of soil
  - Soil fertility, crop production, soil conservation are main goals
The occurrence of soils – a generalized soil profile

- Soils occur on terrestrial landscapes and are influenced by the location (position) and climate.
- Most soils, whether shallow or deep, are organized into roughly horizontal layers called horizons.
- These differ in features from the surface to the underlying geologic substratum.

Diagram:

- **O** Leaf litter & debris
- **A**
- **B (one or more)**
- **C**
- **R** Bed rock

- **Solum** (soil)
- **Regolith**
Basic components of mineral soils

- Mineral soils have four basic components:
  - Mineral matter (approx. half of the total volume of soil)
  - Organic matter (ranges from near zero to 8-10% of volume)
  - Air (ranges from <20 to >30% of the volume of soil)
  - Water – fills some or all of the pore spaces in the soil (also ranges from <20 to >30%)
Mineral constituents of Soil

- The mineral fraction of the soil is the inorganic material originating from massive rocks/geologic substratum that has weathered over time.

- They are highly variable in size and composition:
  - Rock fragments (2 to several mm) – not highly altered from the original massive rock.
  - Primary minerals, like quartz, feldspars and hornblende, are persistent and have not changed much in composition; found mainly in sands (0.05 to 2 mm).
  - Secondary minerals are those formed from the weathering of less resistant minerals (e.g., mica, schist & phyllite), and have been altered in chemical composition; iron/aluminum oxides and silicate clays. These are very minute in size.
Four main size classes of inorganic soil particles and their general properties.

<table>
<thead>
<tr>
<th>Size Fraction</th>
<th>Common Name</th>
<th>Means of Observation</th>
<th>Dominant composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very coarse</td>
<td>Stone, gravel</td>
<td>Naked eye</td>
<td>Rock fragments</td>
</tr>
<tr>
<td>Coarse</td>
<td>Sands</td>
<td>Naked eye</td>
<td>Primary minerals</td>
</tr>
<tr>
<td>Fine</td>
<td>Silt</td>
<td>Microscope</td>
<td>Primary &amp; secondary minerals</td>
</tr>
<tr>
<td>Very fine</td>
<td>Clay</td>
<td>Electron microscope</td>
<td>Mostly secondary minerals</td>
</tr>
</tbody>
</table>

Source: Brady (1974)
Organic constituents of soil

- Soil organic matter is composed of partially decayed and partially synthesized plant and animal residues.
- It is continually being broken down due to the activity of soil microorganisms and hence must be constantly renewed (by addition of plant/animal residues).
- Usually SOM only comprises 3-5% of most mineral soils.
- Yet, it has an important role:
  - It can be regarded as the glue that holds soil particles together
  - Main source of P & S; almost sole source of N
- SOM consists of two general groups of materials:
  - Original and partially decomposed plant/animal tissue/residues
  - Humus – gelatinous, resistant products of decomposition
Soil water

- Water in soil is a dynamic solution that is essential for plant growth and activity.
- Water in the soil pores is held with varying degrees of tenacity depending on amount present.
- Along with dissolved salts, soil water makes up the soil solution, which is the medium for supplying growing plants with needed nutrients.
- Water behavior in soil is governed by the unique nature of the water molecule and the porous, heterogeneous nature of soil.
- The water holding capacity and its availability to plants is determined by soil texture, OM, porosity and bulk density.
Soil air

- Soil air is also a high variable component of soils.
- Aeration is important both for plant root and soil organism activity.
- It differs from the atmosphere in a number of ways:
  - Soil air is discontinuous, located in the pore spaces
  - It generally has a higher moisture content than the atmosphere; it is frequently near 100% relative humidity
  - The carbon dioxide content of soils is usually tens to hundreds of times that of the atmosphere (~0.035% or 350 ppm in the atm).
  - Oxygen content is often only 10-12% (compared to ~20% in the atmosphere).
  - The content and composition of soil air is determined by soil-water relationships and microbial/root activity.
2. The soil profile; soil types, and formation

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The soil profile

A soil profile is a vertical section of the upper, weathered part of the land surface down to the bed rock. It is the basis for distinguishing different soil types. Notable features of the soil can be seen after exposing the profile, such as:

- Horizons – roughly horizontal layers differing from adjacent layers in colour, texture, OM, structure or some other aspect.
- Roots of higher plants – abundance, size
- Drainage characteristics – water logging or dryness
- Accumulations of clay, OM, calcium, sodium, or other minerals (sesquioxides – iron/aluminium oxides)
- Impervious, gravelly, clayey or other layers
General soil types

- **Mineral soils generally have less than 10% OM;** made up predominantly of inorganic (mineral) matter; occupy majority of the land area.

- **Organic soils are very high in OM, often 80-95%;** formed in swamps, bogs or marshes; very productive when drained; occupy only small localised areas/regions of the land.

- **Surface soil (topsoil) –** main rooting zone; plowed & manipulated; main source of nutrients and water for plants.

- **Subsoil –** is the underlying layers down to the parent material; important in determining overall depth of soil and for drainage, as well as, chemical nature of the soil.
Soil formation factors and processes

The formation of soil begins with the physical and chemical weathering of exposed massive rocks:
- Action of rain, wind, sun and freezing/thawing
- Action of flowing water and dissolved substances in the water

Subsequently, biochemical weathering takes a lead role
- Lichens and mosses inhabit and grow on bare rocks
- Exudates and the activity of these lower plants and microorganisms speed up the process of break down
- Eventually, higher plants become established in the young soil and the action of their roots, along with other soil organisms and microbes enhances biochemical weathering & transformation of rock fragments into soil.

Soil formation process can take from a few hundred to thousand years to form 1 inch (2.5 cm) of soil.
Soil formation continued. . .

Soil forming factors:
- Climate
- Topography (relief)
- Parent material
- Organisms
- Time

Interaction of these factors through various physical, chemical and biochemical processes leads to the formation of a variety of soil types and characteristic surface or subsurface layers.

The rate of soil formation is influenced by climate to a large extent.
- Warm climates with high rainfall leads to rapid biochemical action and weathering.
- Cool, dry climates have slower soil formation rates.
- Cold climates with part of year frozen soil conditions inhibit OM decomposition, hence, have organic soils.
- Arid (desert) climates have little to no soil formation.
Pathways of rock weathering (disintegration) to form soils

Rocks (igneous, sedimentary & metamorphic)

Physical breakdown (disintegration into minerals)

- Very slowly weathered (e.g., quartz, muscovite)
  - Continued disintegration
  - Resistant primary minerals
- Slowly weathered (e.g., feldspars, biotite)
  - Physical & chemical alteration
  - Silicate clays
- Easily weathered (e.g., calcite, augite)
  - Decomposition & recombination
  - Other silicate clays
  - Decomposition, Oxidation and hydration
  - Fe, Al oxides
  - Soluble ions: Ca$^{2+}$, Mg$^{2+}$, K$^+$, Fe$^{2+}$, SO$_4^{2-}$
Geological categorization of parent materials

Rocks & minerals

- Deposited in lakes: Lacustrine
- Deposited by streams: Alluvial (fluvial)
- Deposited in oceans: Marine
- Deposited by ice: Till, moraine
- Deposited by water: Outwash
  - Lacustrine
  - Alluvial
  - Marine
- Deposited by wind: Eolian

Formed in place

Residual parent material

- Water transported
- Ice transported
- Wind transported
Vegetation and organism effects on soil formation & characteristics

- **Vegetation effects on soil characteristics:**
  - Soil formed under grassland (prairie) tend to be deep, with thick surface layer and uniform OM content to significant depths; dark coloured
  - Forest soils typically have organic surface layers, a dark but shallow surface horizon and an *eluviated* (leached out), white-coloured layer near the surface; often somewhat acidic

- **The nature of rocks or geologic deposits upon which soils are formed influences its properties**

- **Soil fauna have important role in soil formation/modification:**
  - Macrofauna – physically mix/manipulate soil; aid incorporation of organic matter within soil profile
  - Microfauna/flora – decomposition of organic litter/debris and transformation of organic substances into stable forms (humus)
Influence of landscape position on nature and type of soil

- Landscape position influences moisture, aeration and vegetation, hence soil:
  - Level upland areas – dry, well drained, moderately deep profiles
  - Sloping areas – eroded, shallow, moderately well-drained.
  - Lowland areas – deposited material (sandy/silty), deep profiles, poorly drained, frequently wet & reduced conditions.
Soil Taxonomy – a classification system for soils (USDA)

- As with other branches of science, like botany or zoology, soil science also has a classification system.
- Different countries developed their own classification systems in the 1800-1900s (Russia, USA, Europe).
- Two main classification systems used world-wide today:
  - FAO system (Europe, Africa & Asia)
  - USDA system
- US Department of Agriculture system is more versatile and comprehensive, hence, adaptable to any part of the world.
Soil Classification

- Seven levels of increasing specificity:
  - Order – based on morphology & formation process of soil
  - Suborder – subdivisions based on wetness, climate, vegetation (e.g., genetic homogeneity)
  - Great groups – differentiated by diagnostic horizons
  - Subgroup – typical vs. intermediate features distinguishing great groups
  - Family – further differentiation based on texture, mineralogy, soil pH, temperature and depth.
  - Series – collection of essentially uniform soils (individuals)
  - Phase – degree of erosion (slightly, moderately, severely, eroded)
12 Soil Orders Worldwide

1. Alfisol – brown to grayish, moderately weathered soils
2. Andisol – soils formed from volcanic deposits
3. Aridisol – soils of arids (desert-like) areas with high salt content
4. Entisol – very young soils with little or no profile development
5. Gelisol – soils of cold regions (tundra, subarctic) with permafrost
6. Histosol – organic soils; developed in water-logged conditions
7. Inceptisol – young soils with only slight profile development
8. Mollisol – deep, dark, fertile soils with high base-saturation
9. Oxisol – most highly weathered soils with high Fe/Al oxides
10. Spodosol – soils with subsurface accumulation of OM and Al; coarse textured acidic parent material (temperate forest soils)
11. Ultisol – highly weathered, reddish brown-yellow acidic soils
12. Vertisol – soils with high content of swelling-type clays
Weathering of rocks and minerals in soils

“Exfoliation” – a type of weathering of rock

Breakdown of potassium feldspar and formation of clay

Weathering of mica and formation of smectite
Root—soil interactions