SOIL SCIENCE

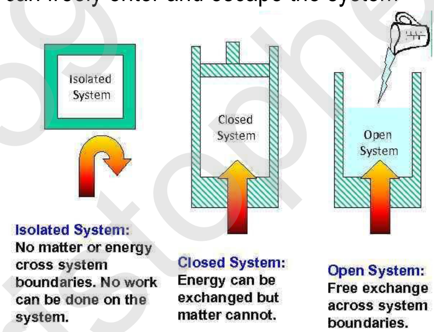
SOIL SCIENCE & THE CONCEPT OF SOIL

SOIL

- Soil – derived from the Latin word "SOLUM" meaning "Floor/Ground".
- Early Definitions
  - Soil is a nutrient bin which supplies the nutrients necessary for plant growth (*Whitney, 1892*)
  - Soil is more or less the loose and friable material in which plants, though the action of their roots, establish anchorage for nourishment as well as other conditions necessary for optimal growth (*Hilgard, 1892*)
  - *VV Dokuchaiev (1900)* – Father of Soil Science. Soil is a natural body composed of mineral and organic matter, having a definite genesis and distinct nature of its own unique from the external environment
  - Soil is a dynamic natural body of mineral and organic matter that is spatially differentiated into different unconsolidated horizons of variable depths and differs from each other and to the underlying parent rock in terms of morphology composition, physico-chemical, and biological properties (*Joffe ,1936*)
- Wholistic Definition given by Buckman, Brady (1969)
  - Dynamic natural body that is a variable mixture of inorganic matter derived from the weathering and disintegration of rocks and minerals and organic matter derived from actively and fully decomposed organic matter, synthesized in profile form, that covers the surface of the earth as a thin layer, and when supplied with adequate amounts of air and water provides mechanical support and sustenance to plants.
- Definition based on Jenny's Equation (1941)
  - Dynamic natural body with properties derived from the combined influence of climate and organisms, modified by topography, acting upon the parent material over significant periods of time.(S=f(Cl, O, R, P, T)

Components of Soil Definition

1. Covers the Earth's Surface (except for bodies of water and bare rock surfaces)
2. Characteristics are based on the interaction and individual magnitude of the soil forming factors ~ climate, organisms, relief, parent material, time – and humans (the ;06th factor)
3. 3 dimensions ~ length, width (L x W = Area), depth (Volume = Area x Depth).
   a. Upper boundary – air and water
   b. Lower boundary – bed rock
4. 3 phases (solid, liquid, gaseous phase)
5. Soil is an open system matter and energy can freely enter and escape the system



6. Dynamic system ~ soil properties and characteristics are always changing
7. Natural body/system ~ not artificial

Tip: PISON Method

P	Purpose	Plant sustenance and mechanical support
I	Importance	Covers the earth's surface (Pedosphere)
S	Structure	Profile form
O	Origin	Rocks and Minerals; OM
N	Nature	Natural and dynamic

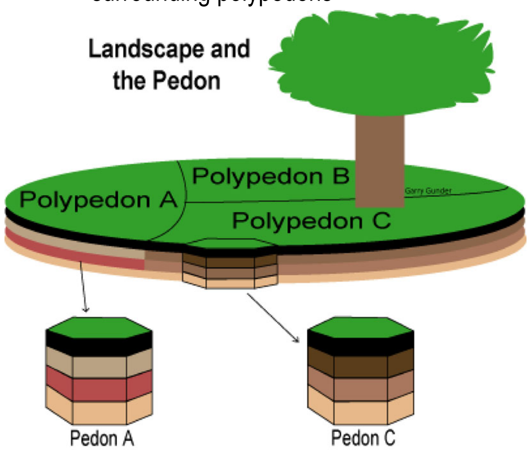
The Basic Units of Soils

PEDON

- a hexagonal column of soil measuring from 1 to 10 sq.m.
- basic sampling unit in soil survey, smallest unit that can be considered as a soil, large enough to represent the nature of arrangement of horizons and variability.
- Descriptions of pedons are based on the examination of profiles.

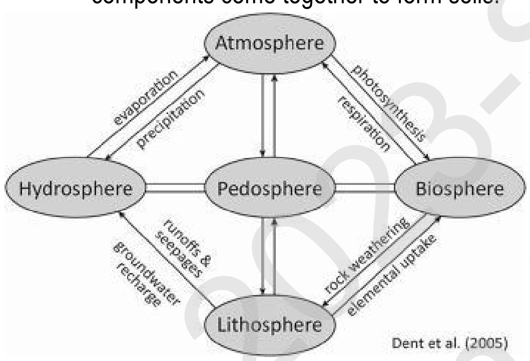
POLYPEDON

- Multiple pedons that has distinct characteristics that differentiate it from surrounding polypedons



PEDOSPHERE

- the conceptual zone within the ecosystem consisting of soil bodies or directly influenced by them
- a zone or sphere of activity in which mineral, water, air and biological components come together to form soils.



<u>**Soil Science**</u>

- the science that deals with soils, as a natural body/resource, its pedology (classification and genesis), physical, chemical, biological and fertility characteristics in ultimate relation to crop management and production.

In the study of soils, a scientist can resort in any of the two approaches;

- **Pedology** – deals with the genesis, survey, classification and study of soils as a natural body. G. "*pedon*" = soil or earth
- **Edaphology** – deals with the study of soils in relation to higher plants. G. "*edaphos*" = soil or ground

<u>**BRANCHES OF SOIL SCIENCE**</u>

SOIL FERTILITY

- Deals with the study of the properties of the soil which enables it to provide essential chemical elements in quantities and proportions for the growth of specific plants.
- Nutrient supplying properties of soils.

SOIL PHYSICS

- Deals with characteristics, properties, or reaction of soil which is caused by physical forces.
- deals with the properties and interaction of the three soil phases.

SOIL CHEMISTRY

- Characterize the chemical properties of the original rocks and minerals which constitute the materials from which soils are derived.
- Study the various chemical reactions in the soil solution, considering that the soil is an open system.

SOIL BIOLOGY AND ECOLOGY

- Characterization of various organisms that dwell in the soil and their roles in biogeochemical and physical changes in the soil.

SOIL CONSERVATION AND MANAGEMENT

- (***Soil Conservation***) Deals with the combination of all management and land-use methods that safeguard the soil against depletion and deterioration caused by nature and/or human
- (***Soil Management***) the sum total of all tillage operations, cropping practices, fertilizer, lime and other treatments conducted on or applied to a soil for the production of plants.

SOIL SURVEY

- the systematic examination, description, classification, and mapping of soils in an area.

SOIL GENESIS, MORPHOLOGY AND CLASSIFICATION

- (***Soil Genesis***) the mode of origin of the soil, with special reference to the processes responsible for the development of the solum, or true soil, from the unconsolidated material

- (***Soil Morphology***) the physical constitution, particularly the structural properties of a soil profile as exhibited by the kinds, thickness and arrangement of the horizon in the profile, and by the texture, structure, consistence, and porosity of each horizon.
- (***Soil Classification / Taxonomy***) systematic arrangement of soils into groups or categories on the basis of their characteristics.

LAND USE PLANNING AND CLASSIFICATION

- **(Land Classification)** the arrangement of land into units of various categories based upon the properties of the land or its suitability for some particular purpose.
- **(Land-use Planning)** the development of plans for the uses of land that, over long periods, will best serve the general welfare, together with the formulation of ways and means for achieving such uses

ECOSYSTEM SERVICES PROVIDED BY THE SOIL

- Soils support plant growth
- Soils regulate water supply
- Soil functions as nature's recycling system
- Soils are alive and home to various and diverse organisms
- Soils influence the composition and physical condition of the atmosphere
- Soils serve as an engineering medium

<u>SOIL COMPOSITION</u>

SOLID (50% by volume; ideal soil)

- provides the skeletal framework of soils
- mixture of inorganic and organic materials

MINERAL MATTER (45%)

- Primary minerals and secondary minerals
- Particle basis (sand, silt, clay)
- Comes from the weathering of rocks and minerals
- Major source of plant nutrient elements (except HCO)

ORGANIC MATTER (5%)

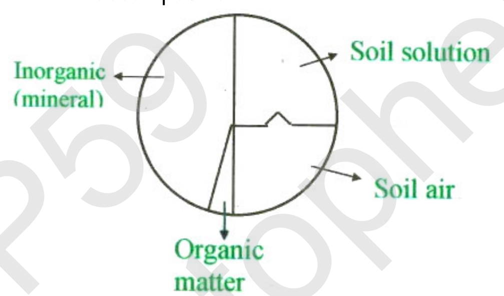
- 2-5% in mineral soils
- Derived from the decayed and decaying remains of plant and animal intimately mixed with the mineral matter
- Organic soils contain more than 20% organic matter
- Most soils contain less than 20% OM (mineral soil)

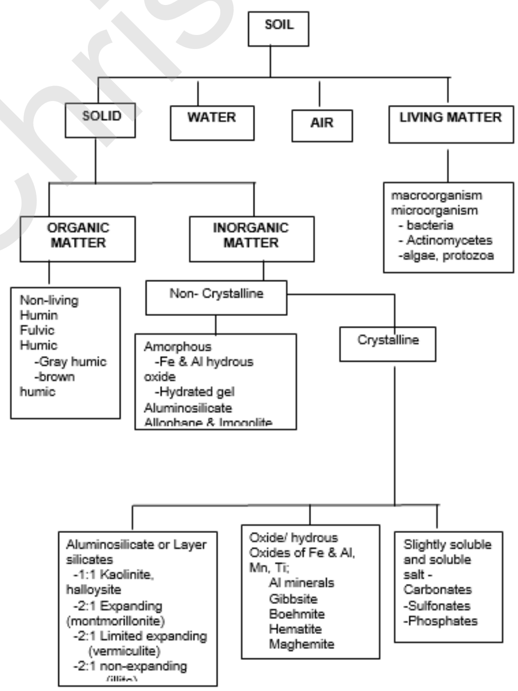
LIQUID (SOIL SOLUTION) (25% by volume)

- soil solution, carries and moves dissolved nutrients
- concentration of salts (100-1000 ppm in dry soils)
- contains Sulfates, Chlorides, Bicarbonates of Ca, Mg, K, and Na

GAS (SOIL ATMOSPHERE) (25% by volume)

- soil air
- 78% N, 20% O, 0.5% CO_2
- CO_2 in soil is significantly higher than that of the Atmosphere due to accumulation from CO_2 evolution from organic matter decomposition





<u>(1) SOIL GENESIS AND DEVELOPMENT</u>

MINERALS

- an inorganic substance that is produced by inorganic processes that has a definite chemical composition and physical configuration.

- Building blocks of rocks

MINERALOGY

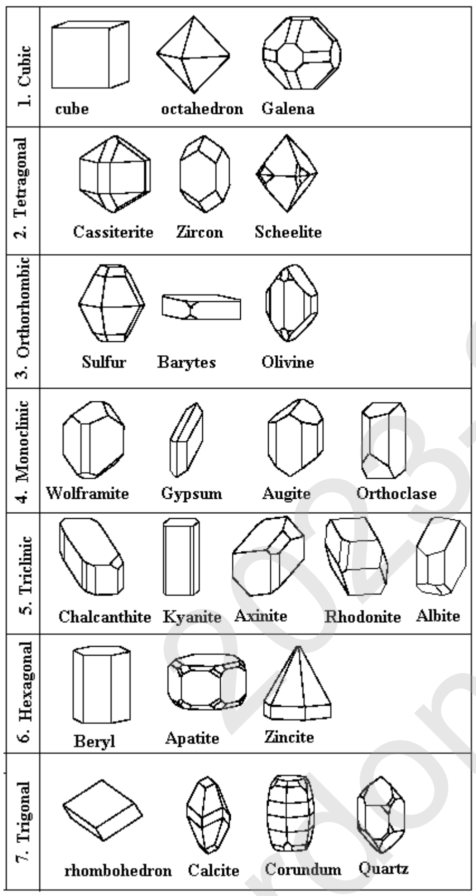
- study of minerals and their properties

PROPERTIES OF MINERALS

- **CRYSTAL FORM**- specific shapes when they have been able to develop without obstruction

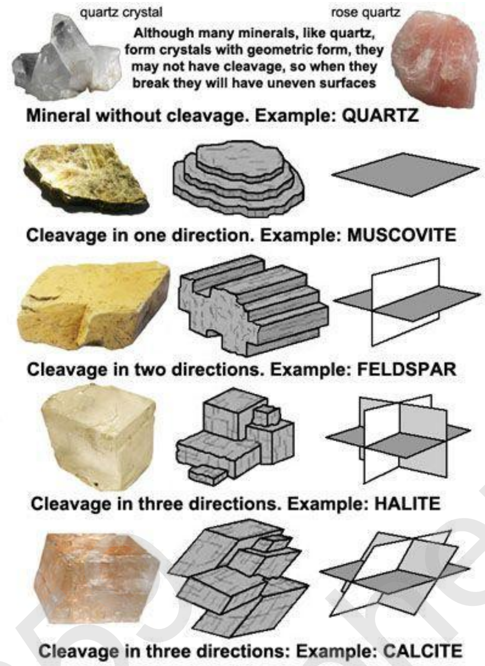
  e.g. prisms, pyramids, needles, cubes, sheets

Crystal form of the seven crystal systems



- **CLEAVAGE**- property that enables a mineral to break along well defined planes of weaknesses related to their atomic structure

  FRACTION- term used when minerals don't have cleavage



- **COLOR**- not preferable to use in identifying minerals for this property is highly variable
- **LUSTER**- characteristic of light reflected from minerals

  e.g. earthy, glassy, metallic, vitreous
- **STREAK**- represents the mineral in powder form and often constant even when mineral color changed.
- **REACTION TO ACID**- calcite reacts with weak acids

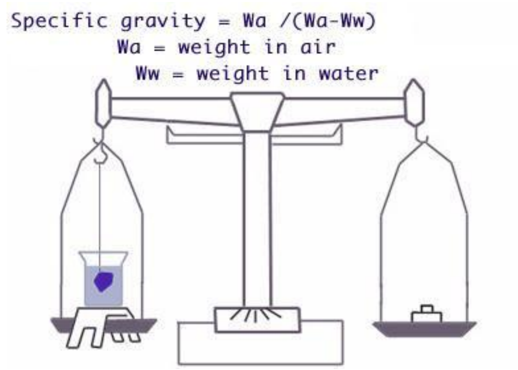
$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2CO_3$$

$$H_2CO_3 \longrightarrow H_2O + CO_2.$$

o

- **HARDNESS**- the relative ease at which a mineral is scratched

  Moh's Scale-the standard scale used in the quantitative determination of mineral hardness. Composed of 10 representative minerals
- **SPECIFIC GRAVITY**- ratio of the weight of a substance of an equal volume of water.



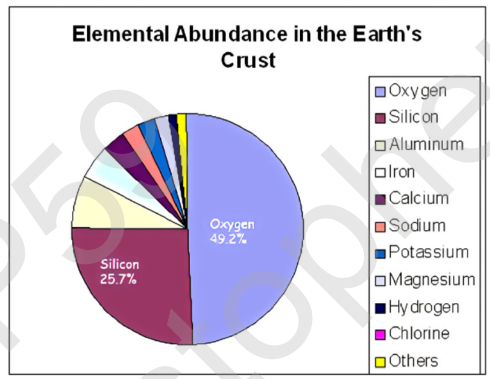
1	Very soft, easily scratched by the fingernail	Talc
2	Soft, just barely scratched by the finger nail	Gypsum
3	Can be scratched by a Cu coin but not with fingernail	Calcite
4	Hard, not scratched by Cu coin but scratched easily with a pen knife, soft iron scratches it	Fluorite
5	Hard, barely scratches glass, can just be scratched by a steel knife blade	Apatite
6	Very hard, scratches glass and steel easily	Feldspar
7	Very hard, no common tool to measure	Quartz
8		Topaz
9		Corundum
10		Diamond

Memorization Mnemonics
(From Talc to Diamond)
Tall **G**iants **C**an **F**ight **A**nd **O**ne **Q**uit **T**o **C**hase **D**inosaurs

CLASSIFICATION OF MINERALS BASED ON ORIGIN

- **PRIMARY MINERAL**- a mineral that has not been altered chemically since deposition and crystallization.
  - The material from which the sand and silt fraction is made
  - *e.g. quartz, feldspar, mica, hornblende, apatite, calcite, dolomite*
- **SECONDARY MINERAL**- a mineral resulting from the decomposition of a primary mineral of from the reprecipitation of the products of decomposition of a primary mineral.
  - *e.g. hematite, limonite, gypsum, kaolinite, montmorillonite, beidellite, nontronite*
- **CLASSIFICATION OF SECONDARY MINERAL**
  - **NON-COLLOIDAL**- not finely divided
  - **COLLOIDAL**- very finely divided forming great amount of effective surface area

Typical soil parent mineral materials;
Quartz: SiO_2
Calcite and Dolomite: $CaCO_3$, $CaMg(CO_3)_2$
K-Feldspar (Orthoclase): $KAlSi_3O_8$
Na/Ca-Fedspar (Plajiyoklaz): (Na, Ca (Si, Al)$_4$O$_8$
Mica: biotite: $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$, muscovite $Kal(Si_3Al)O_{10}(OH, F)_2$
Gypsum: CaSO4.$_2$(H_2O)
Hematite: Fe_2O_3
Hornblande: $Ca_2Na(Mg,Fe)_4,(Al,Si)_8O_{22}(OH,F)_2$
Olivine: $(Mg, Fe)_2SiO_4$

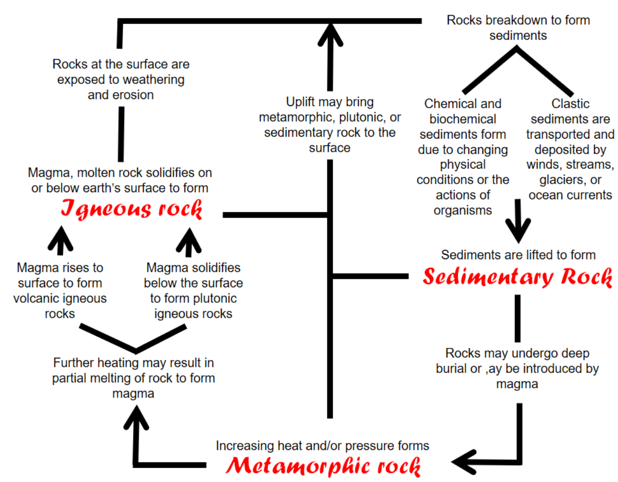


Tip: Mnemonics "OSiAlFeCa(Mag*)NaK(*)"
Order of the most abundant elements in the Earth's

(a) ROCKS- a consolidated mixture/assemblage of minerals

CLASSIFICATION OF ROCKS ACCORDING TO MANNER OF FORMATION

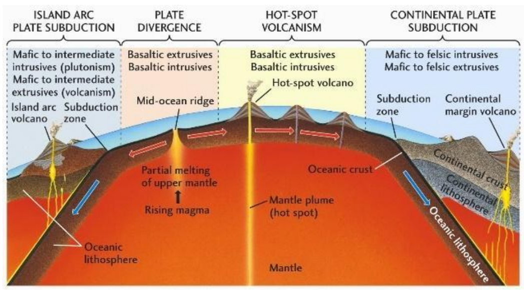
IGNEOUS ROCK- the type of rock formed directly

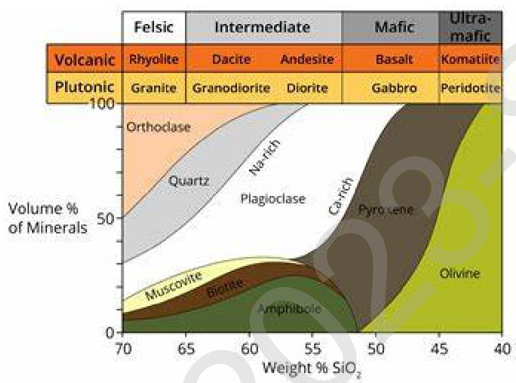


from the solidification/cooling of magma. "*Ignis*"= fire

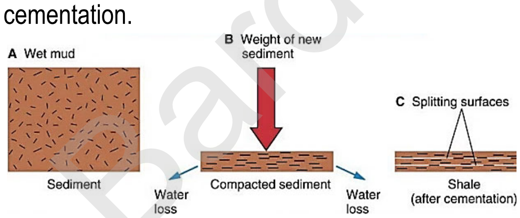
TYPES OF IGNEOUS ROCK

- **EXTRUSIVE IGNEOUS ROCK (VOLCANIC)**- formed when lava solidifies on the earth's surface
  e.g. rhyolite, basalt, obsidian
- **INTRUSIVE IGNEOUS ROCK (PLUTONIC)-** formed when magma solidifies below the surface
  e.g. granite, diorite, andesite
  PLUTONS (INTRUSIONS)- characteristic feature of plutonic rocks that is largely controlled by the volume of magma





- **SEDIMENTARY ROCK**- rocks formed from the compaction and cementation of sediments from pre-existing rocks.
  DIAGENESIS- process of transforming sediments into cohesive, hard and massive rock due to compaction, consolidation and cementation.



  DETRITUS- loosened material accumulated at or near the surface
  STRATIFICATION- the layered arrangement in a sedimentary rock.

TYPES OF SEDIMENTARY ROCK

- **CLASTICS**
  RUDITES (PSEPHITES)- > 2 mm average grain size
  e.g. breccias, conglomerates
  ARNITES (PSAMITES)- sediments of sand grade
  e.g. sandstone
  LUTITES (PELITES)- made of silt and clay
  e.g. shale, mudstone, siltstone
- **CHEMICAL**-a sedimentary rock that forms from the reprecipitation of a dissolved component of a rock/mineral.
  e.g. limestone
- **BIOGENICS**
  e.g. petrified wood

- **METAMORPHIC ROCK**- products of rock metamorphism
  METAMORPHOSIS- occurs when a rock changes because of changing physical conditions ("*meta*"= *change;* "*morphos*"= *structure*)

EFFECTS OF METAMORPHISM

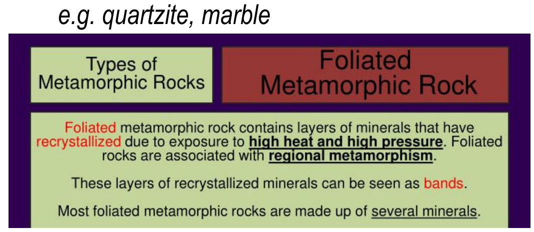
- **MINERALOGICAL**- change in minerals to reflect the new pressure-temperature equilibrium conditions
- **RECRYSTALLIZATION**- change in the crystal size and shape
- **RECOMBINATION** – recombination of elements in pre-existing minerals to form stable new ones.

TYPES OF METAMORPHISM

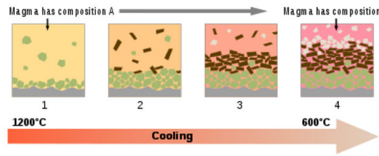
- **CATACLASTIC**- direct pressure
- **CONTACT**- occurs in relatively narrow zones around the heat source (heat is the predominant factor)
- **REGIONAL**- occurs over large areas in association with the formation of mountain belts (pressure is the predominant factor)

TYPES OF METAMORPHIC ROCKS

- **FOLIATED**- mineral crystals are arranged in parallel layers/ bands
  e.g. slate, schist, gneiss
- **NON-FOLIATED**- rocks are not banded and do not break into layers
  e.g. quartzite, marble



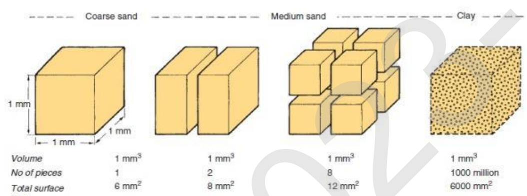
FRACTIONAL CRYSTALLIZATION- refers to the production of rocks with different composition relative to the original magma



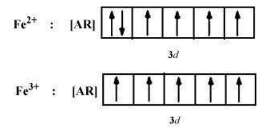
WEATHERING- all physical and chemical changes produced in rocks, at or near the earth's surface, by atmospheric agents.
-A biogeochemical process that involves both destruction and synthesis

TYPES OF WEATHERING

- **PHYSICAL WEATHERING/ DISINTEGRATION**- the breakdown of rocks and mineral particles into smaller by physical forces, without changing their chemical composition
  - **TEMPERATURE**
    - Thermal expansion
    - **EXFOLIATION**- peeling away of outer layers of a rock
  - **ABRASION** by water, ice, and wind
    - Frost wedging
    - Salt wedging



- **CHEMICAL WEATHERING/ DECOMPOSITION** - decomposes, dissolves and weakens rocks and minerals through chemical processes
  - **COMPLEXION**
    $K_2(Si_6Al_2)Al_4O_{20}(OH)_4 + 6C_2O_4H_2 + 8H_2O \leftrightarrow 2K^+ + 8OH^- + 6C_2O_4Al^+ + 6Si(OH)_4$
  - **HYDROLYSIS**
    $KAlSi_3O_8 + H_2O \leftrightarrow HAlSi_3Al8 + K+ + OH-$
    $2HAlSi3O_8 + 11H_2O \leftrightarrow Al_2O_3 + 6H_4SiO_4$
  - **HYDRATION**
    $5Fe_2O_3 + 9H_2O \longrightarrow Fe_{10}O_{15}\bullet 9H_2O$
  - **CARBONATION AND ACID REACTIONS**
    $CO_2 + H_2O \longrightarrow H_2CO_3$
    $H_2CO_3 + CaCO_3 \leftrightarrow Ca^{2+} + 2HCO_3^-$
  - **SOLUTION/DISSOLUTION**
    $CaSO_4\bullet 2H_2O + 2H_2O \leftrightarrow Ca^{2+} + SO_4^{2-} + 4H_2O$
  - **OXIDATION-REDUCTION**
    $3MgFeSiO_4 + 2H_2O \leftrightarrow H_4Mg_3Si_2O_9 + SiO_2 + 3FeO$
    $4FeO + O_2 + 2H_2O \leftrightarrow 4FeOOH$



Tip:
LEO-GER – Loss of Electron, *Oxidation*; Gain of Electron, *Reduction*
OIL-RIG – *Oxidation* is Loss of Electron, *Reduction* is Gain of Electron

TYPES OF CHEMICAL WEATHERING

- **GEOCHEMICAL WEATHERING**- occurs below the solum (purely chemical in nature)
- **PEDOCHEMICAL WEATHERING**- occurs within the solum (influenced by biological activities/processes)

- **BIOLOGICAL WEATHERING**- Disintegrationn of rocks and minerals caused by chemical or physical activity of various organisms (e.g. Root prying)

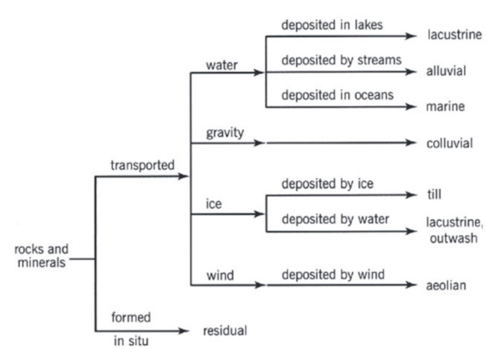
<u>FACTORS OF SOIL FORMATION</u>

Hans Jenny's Equation (1941)

S= f(Cl,O,R,P,T)

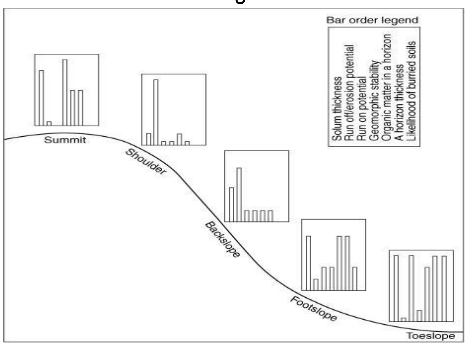
Cl= **climate** (precipitation and temperature)
O=**organism** (biota- native vegetation, microbes, soil animals, human activity)
R=**relief or topography** (slope, aspect, landscape position)
P= **parent material** (geologic or organic precursor)
T=**time** (period since the parent material began to undergo soil formation)

Active Factors = Climate, Organism
Passive Factors = Relief, Parent Material, Time

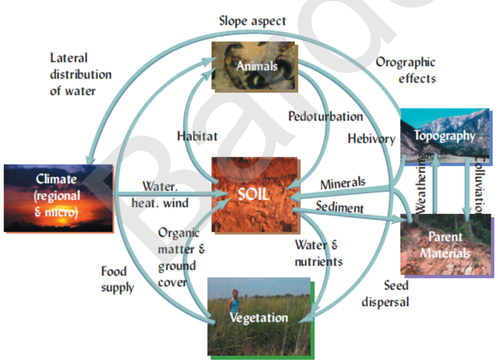


- **CHRONOSEQUENCE**- a set of soils that share a common climate, parent material, slope and community of organism, but differ with regard to the length of time that the materials have been subjected to weathering and soil formation.

- o **CATENA** (latin meaning "*chain*")- soils that commonly occur together in the landscape in sequence. Exhibit properties that reflect the influence of topography on water movement and drainage.



- ▪ **TOPOSEQUENCE**- a type of catena, in which the difference among the soils results almost entirely from the influence of topography because the soil in the sequence all share the common parent material and have similar conditions regarding the other soil forming factors.
- ▪ **LITHOSEQUENCE**- a group of soils that differ, from one another, in certain properties as a result of parent material as soil-forming factor
- ▪ **CLIMOSEQUENCE-** a group of relates soils that differ, one from another, primarily because of differences in climate as a soil-forming factor
- ▪ **BIOSEQUENCE**- a group of related soils that differ, one from other, primarily because of the difference in kinds and numbers of plants and soil organisms as a soil-forming factor.



BASIC PROCESSES OF SOIL FORMATION

1. TRANSFORMATION- occur when soil constituents are chemically or physically modified or destroyed and others are synthesized from the precursor materials

e.g. weathering of primary mineral, disintegrating and altering some to form various kinds of silicate clays.

2. TRANSLOCATION- involve the movement of inorganic and organic materials laterally within a horizon or vertically from one horizon to another

e.g. water, either percolating down with gravity or rising up by capillary action.

3. ADDITION- inputs of materials to the developing soil profile from the outside sources

e.g. organic matter from falling plant leaves

4. LOSSES- materials are lost in the soil profile

e.g. leaching, evaporation, erosion

TERMINOLOGIES

Some processes of soil formation that are complexes of subprocesses and reactions

Term	Fourfold Categorization[a]	Brief Definition
1a. Eluviation	3	Movement of material out of a portion of a soil profile as from an albic horizon
1b. Illuviation	3	Movement of material into a portion of a soil profile as in an argillic or spodic soil
2a. Leaching (depletion)	2	General term for washing out, or eluviating, soluble materials from the solum
2b. Enrichment	1	General term for addition of material to a soil body
3a. Erosion, surficial	2	Removal of material from the surface layer of a soil
3b. Cumulization	1	Eolian, hydrologic, and human-made additions of mineral particles to the surface of a solum
4a. Decalcification	3	Reactions that remove calcium carbonate from one or more soil horizons
4b. Calcification	3	Processes including accumulation of calcium carbonate in Bk and possibly other horizons of a soil
5a. Salinization	3	The accumulation of soluble salts such as chlorides, sulfates, and bicarbonates of sodium, calcium, magnesium, and potassium in salic horizons
5b. Desalinization	3	The removal of soluble salts from salic soil horizons
6a. Alkalization	3	Accumulation of sodium carbonate raises pH above 8.5
6b. Dealkalization	3	Leaching of sodium carbonate lowers pH below 8.5
7a. Lessivage	3	The mechanical migration of small mineral particles from the A to the B horizons of a soil, producing B horizons relatively enriched in clay, as in argillic horizons
7b. Pedoturbation	3	Biological, physical (freeze-thaw and wet-dry cycles) churning and cycling of soil materials, thereby homogenizing the solum in varying degrees
8a. Podzolization	3, 4	The chemical migration of aluminum and iron and/or organic matter, resulting in the concentration of silica (i.e., silication) in the layer eluviated
8b. Desilication (ferrallitization, ferritization, allitization)	3, 4	The chemical migration of silica out of the solum, thus the concentration of sesquioxides in the solum (e.g., goethite, gibbsite), with or without formation of ironstone (laterite; hardened plinthite) and concretions
8c. Resilication	4	Formation of kaolinite from gibbsite in presence of excess $Si(OH)_4$ in solution or formation of smectite from kaolinite in presence of large amounts of $Si(OH)_4$ at higher pH values
9a. Decomposition	4	The breakdown of mineral and organic materials
9b. Synthesis	4	The formation of new particles of mineral and organic species
10a. Melanization	1, 3	The darkening of light-colored, unconsolidated, initial materials by admixture of organic matter (as in a dark-colored A horizon)

10b. Leucinization	3	The paling of soil horizons by disappearance of dark organic materials either through transformation to light-colored ones or through removal from horizons
11a. Littering	1	The accumulation on the mineral soil surface of organic litter and associated humus to a depth of less than 30 cm
11b. Humification	4	The transformation of raw organic material into humus
11c. Paludization	4	Processes regarded by some workers as geogenic rather than pedogenic, including the accumulation of deep (>30 cm) deposits of organic matter as in mucks and peats (Histosols)
11d. Ripening	4	Chemical, biological, and physical changes in organic soil after air penetrates previously waterlogged material
11e. Mineralization	4	The release of oxide solids through decomposition of organic matter
12a. Braunification, rubification, ferrugation	3, 4	Release of iron from primary minerals and the dispersion of particles of iron oxides or oxyhydroxides in increasing amounts. Soils are colored brownish, reddish brown, and red, respectively
12b. Gleization	3, 4	The reduction of iron under anaerobic soil conditions, with the production of bluish to greenish gray matrix colors, with or without yellowish brown, brown, and black mottles, and ferric and manganiferous concretions
13a. Loosening	4	Increase in volume of voids by activity of plants, animals, and humans and by freeze-thaw or other physical processes and by removal of material by leaching
13b. Hardening	4	Decrease in volume of voids by collapse and compaction and by filling of some voids with fine earth, carbonates, silica, and other materials

[a] The four categories (see text) are (1) additions to a soil body, (2) losses from a soil body, (3) translocation within a soil body, and (4) transformation of material within a soil body.

SOIL PROFILE

SOIL PROFILE- a vertical exposure of the characterized sequence in soils

THE MASTER HORIZONS

- **HORIZON** - a layer dominated by organic material forming at the surface of a mineral soil
- **A HORIZON** - a mineral horizon that formed at the surface or below an O horizon and characterized by an accumulation of humified OM and have properties resulting from cultivation, pasturing or similar kinds of disturbance
- **E HORIZON** – mineral horizon in which the main feature is loss of silicate clay, Fe, Al, or some combination of these, leaving a concentration of sand and silt particles of quartz or other resistant minerals
- **B HORIZON** – horizon that formed below an A, E or O and are dominated by CO_3, gypsum or silica alone or in combination; evidence of removal of CO_3s, concentrations of sesquioxides, alterations that forms silicate clays, formation of granular, blocky or prismatic structure, or combination of these
- **C HORIZON** – horizon or layer excluding hard bedrock that are little affected by pedogenic processes and lack properties of O, A, E or B horizons
- **R HORIZON** – hard bedrock (strictly not a horizon) to include granite, basalt, etc and indurated limestone or sandstone that is sufficiently coherent to make hand digging impractical

SOLUM (TRUE SOIL) – A and B horizon
REGOLITH – A, B, C Horizon

ADDITIONAL MASTER HORIZONS

- **L HORIZON**- occur only in certain organic soils and include layers of organic and mineral materials deposited in water or by aquatic organisms
- **W HORIZON**- layers of water found within certain soil profiles
- **V HORIZON**- layer-dominated non-connected, bubble-like pore that occur in or near surface desert soils.
- **M HORIZON**- mainly in urban soils in which manufactured root-limiting materials form a horizontal, near continuous layer.

SUBORDINATE DISTINCTIONS BETWEEN MASTER HORIZONS

a - (sapric) highly decomposed organic material
b - identifiable buried genetic horizon
c - concretions or hard non-concretionary nodules of Fe ,Al, Mn or Ti cement
e - organic material of intermediate decomposition
g – strong gleying in which Fe has been reduced or removed
h – illuvial accumulation of OM in the form of amorphous and dispersible OM
i – slightly decomposed OM
k– accumulation of pedogenic carbonates particularly CaCO3
m – continuous or nearly continuous cementation or induration of the soil matrix by CO3s (km), silica (qm), iron (sm), gypsum (ym), carbonates and silica (kqm), or salts more soluble than gypsum (zm)
n – accumulation of sodium
o - residual accumulation of sesquioxides
p – plowing or other disturbance of the surface layer
q – accumulation of secondary silica
r – weathered or soft bedrock
s – illuvial accumulation of sesquioxides and OM
t – accumulation of silicate clay
v – plinthite which is composed or iron-rich, humus-poor, reddish material that is firm or very firm when moist
w – development of color or structure in a horizon or alterations
x – fragic or fragipan chracteristics such as firmness, brittleness or high BD
y – accumulation of gypsum
z – accumulation of salts more soluble than gypsum

Suffixes for master soil horizons

Suffix	Used with which master horizons?	Characteristics/comments
O horizon suffixes		
a	O	Highly decomposed organic material. "Sapric" material.
e	O	Organic material of intermediate decomposition. "Hemic" material.
i	O	Slightly decomposed organic material. "Fibric" material.
A horizon suffixes		
p	A	Plowed, tilled or otherwise disturbed surface layer. Disturbed A, E, or B horizons are designated Ap.
v	A	Porous, vesicular horizon, common to desert regions. Informal designation, not recognized by the Natural Resources Conservation Service.
B horizon suffixes associated with illuviation		
c	B, C	Presence of concretions or hard non-concretionary nodules, usually of Fe, Al, Mn or Ti.
h	B	Dark, illuvial accumulations of organic matter and humus. The moist Munsell value and chroma of the horizon must be 3 or less.
j	B	Accumulation of jarosite, either as ped coatings or nodules.
k	B, C	Accumulation of pedogenic carbonates, commonly $CaCO_3$, as ped coatings, filaments or nodules. From German *kalk* (lime).
n	B, C	Accumulation of pedogenic, exchangeable sodium (Na), commonly as sodium salts. From German *natrium* (sodium).
q	B, C	Accumulation of pedogenic, secondary silica (quartz).
s	B	Accumulation of sesquioxides of Fe and Al.
t	B, C	Accumulation of silicate clay, as evidenced by argillans on ped faces or lamellae (clay bands). From German *ton* (potter's clay).
y	B	Accumulation of pedogenic gypsum. From Spanish *yeso* (gypsum).
z	B	Accumulation (pedogenic) of salt more soluble than gypsum.
Other B horizon suffixes		
w	B	Development of color or structure in a horizon but with little or no apparent illuvial accumulation of materials.
x	E, B	Presence of fragipan characteristics (genetically developed firmness, brittleness and/or high bulk density). Generally, fragipans are root-restrictive.
Suffixes associated with cold soils		
f	Any except uppermost	Frozen subsoil horizon which contains permanent, continuous ice (permafrost). Not used for layers that are frozen only seasonally.
ff	Any except uppermost	Frozen subsoil horizon which contains "dry" permanent, continuous ice ("dry permafrost"). Not used for layers that are frozen only seasonally.
Suffixes indicating pedoturbation		
ss	A, B, C	Presence of slickensides.
jj	Any	Horizon showing evidence of cryoturbation.
Other suffixes		
g	E, B, C	Strong gleying in which Fe has been reduced and/or removed or in which Fe has been preserved in a reduced state because of saturation with stagnant water. Most gleyed layers have a moist Munsell chroma of 2 or less.
o	B, C	Residual, pedogenic accumulation of sesquioxides.
v	B	Plinthite (iron-rich, humus-poor, reddish material that is firm or very firm when moist and that hardens irreversibly when exposed to the atmosphere). Not used in A horizons.
r	C	Weathered or soft bedrock, including saprolite or dense till, that roots can easily penetrate along joint planes. Sufficiently incoherent to permit hand-digging with a spade.
d	A, B, C	"Dense" horizon with high bulk density and physical root restriction. Low numbers of connected pores. Examples: dense basal till (Cd) or plow pans (Ad).
m	B	Continuous or nearly continuous cementation or induration of the soil matrix by, for example, carbonates (km), silica (qm), sesquioxides (sm), or carbonates and silica (kqm).
b	A, E, B	Buried horizon of a mineral soil. Implies that the horizon is part of a paleosol.

TRANSITION HORIZONS

- writing the symbol for transitional horizon, what is written first is the horizon where the properties have more similarities.
    - *e.g. OA, AO, AB, BA, EB, BE, BC, (There's no CB transition horizon)*
- If there are distinct parts that are characteristic of one master horizon and are recognizable and enclose are parts characteristic of second recognizable master horizon
    - *e.g. O/A, A/O, A/B, B/A, E/B, E/B, B/C*

SUBDIVISION HORIZON

- Horizons are subdivided if the layer is thick enough (40cm or more) and the numbering is made consecutively within the same horizon
- figure suffix indicates subdivision of a horizon. the numbering is done consecutively (e.g. Bt1, Bt2; C1)
  e.g. Ap1, Ap2; Bt1, Bt2, Btg1, Btg2; B1, B2

LITHOLOGICAL DISCONTINUITY

- figure prefix (*e.g. 2B*) indicates lithological discontinuity or the soil has been derived from two different parent materials.

SOIL PHYSICAL PROPERTIES

1. SOIL TEXTURE

- o refers to the general feel of the soil (qualitative)
- o refers to the relative proportions of sand, silt, and clay particles in soil (quantitative)

Name	Diameter (mm) ISSS	Diameter (mm) USDA	Number of particles/gram	Surface area (mm²/g)
Coarse sand	15	-	-	-
Fine gravel	2-15	2-1	90	11.3
Coarse sand	0.2-2	1-0.5	722	22.4
Medium sand	-	0.5-0.25	5777	45.4
Fine Sand	0.02-0.2	0.25-0.1	46,213	90.7
Very fine sand	-	0.1-0.05	722,074	226.9
Silt	0.002-0.02	0.05-0.002	5,776,674	453.7
clay	≤0.002	≤0.002	50,260,853,860	11,342.5

Mineral matter is classified based on particle size regardless of mineralogy (based on equivalent diameter, because soil mineral matter are not perfect spheres, but we assume that they are).

- ▪ Sand (2 mm – 0.02 mm; 2,000 μm – 20 μm)
  - o coarse sand, 2 mm – 0.2 mm;
  - o Fine sand, 0.2 mm – 0.02 mm)
- ▪ Silt (0.02 mm – 0.002 mm) (20 μm to 2 μm)
- ▪ Clay (< 0.002 mm) (< 2 μm)

NATURE OF SOIL SEPARATES

SAND

- o larger smaller than 2 mm but larger than 0.05 mm (or 0.02 mm)
- o feels gritty between fingers
- o particles are generally visible to the naked eye (angular or rounded).
- o grains contain a single mineral, usually quartz and other primary minerals.
- o the large particles of sand have low specific surface area.
- o possess little capacity to hold water or nutrients.
- o do not stick together into coherent mass

SILT

- o particles smaller than 0.05 (or 0.02) mm but larger than 0.002 mm
- o similar to sand in shape and mineralogy, individual silt particles are so small as to be invisible to the unaided eye.
- o feels smooth or silky like flour
- o even when wet, silt particles don't exhibit much stickiness or plasticity
  PIPING- process wherein silty soil is easily washed away by flowing water.

CLAY

- o smaller than 0.002 mm
- o possess very large specific surface area
- o high water holding capacity and nutrient adsorption
- o hard and massive when dry, sticky when wet
- o clay particles tend to be shaped like tiny flakes of flat platelets.
- o fine clay-sized particles behave as colloids (if suspended in water they do not readily settle out.

Property/ Behavior	Rating Associated with Soil Separates		
	sand	silt	clay
Water holding capacity	Low	Medium to high	High
Aeration	Good	Medium	Poor
Drainage rate	High	Slow to medium	Very slow
Soil OM	Low	Medium to high	High to medium
Decomposition of OM	Rapid	Medium	Slow
Warming up in spring	Rapid	Moderate	Slow
Compactibility	Low	Medium	High
Susceptibility to wind erosion	moderate	high	Low
Susceptibility to water erosion	Low	High	Low if aggregated
Shrink-swell potential	Very low	Low	Moderate to V high
Sealing of ponds/dams	Poor	Poor	Good
Suitability to tillage after rain	Good	Medium	Poor
Pollutant leaching potential	High	Medium	Low
Ability to store nutrients	Poor	Medium to high	High
Resistance to pH change	low	medium	High

- Coarse fragments are described by size and shape

Shape and Size	Class
Spherical or Cube-like	
> 2 – 76 mm diameter	Gravel
> 76 – 250 mm diameter	Cobbles
> 250 – 600 mm diameter	Stones
> 600 mm diameter	Boulders
Flat	
> 2 – 150 mm long	Channers
> 150 – 380 mm long	Flagstones
> 380 – 600 mm long	Stones
> 600 mm long	Boulders

SOIL TEXTURAL CLASSES

Basic soil textural class names

Sands	Loamy sands	Sandy loam	Fine sandy loam[a]	Very fine sandy loam[a]	Loam	Silt loam	Silt	Sandy clay loam	Silty clay loam	Clay loam	Sandy clay	Silty clay	Clay
General texture terms													
----- Coarse -----		-- Moderately -- coarse		------------- Medium -------------				--- Moderately fine ---			--------- Fine ---------		
Sandy soils		------------------------------------ Loamy soils ------------------------------------									----- Clayey soils -----		

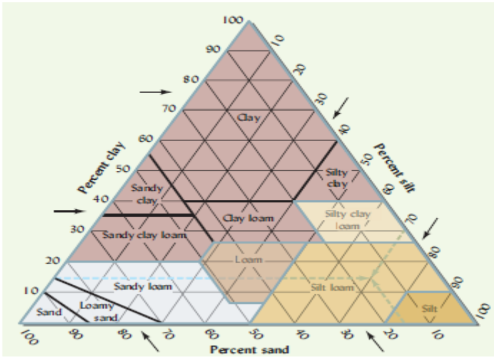
- o **LOAM**- mixture of sand, silt, and clay particles that exhibits the properties of those separates in about equal proportions. (This definition does not mean that the separates are present in equal amounts, but rather, the grittiness of sand, smoothness of silt and stickiness of clay are equally expressed)

Soil Particle Geometry

Since soil particles do not occur as perfect spheres in nature, sphericity and roundness is taken into account when making assumptions/calculations.

- o **SPHERICITY**- relates to the overall shape of the feature irrespective of the sharpness of its edges
  - o measure of the degree to which a particle resembles a sphere

- **ROUNDNESS**- measure of how much a particle's corners and edges are rounded or smoothed.



Soil Texture for Organic Soils
Organic soil materials use terms in place of textural classes based on the degree of organic matter decomposition.

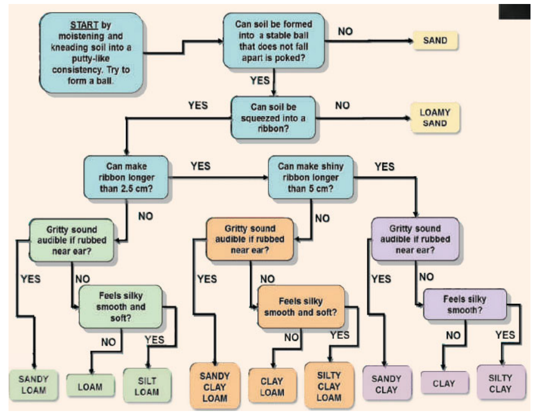
- **Peat** is organic material that is relatively undecomposed plant tissues;
- **muck** is highly decomposed organic material, and few plant tissue fibers are observed;
- **mucky peat** is of intermediate decomposition.

To estimate undecomposed tissue or "rubbed fiber" content wet samples are rubbed with the hands and carefully examined to observe undecomposed tissue.

SOIL TEXTURE DETERMINATION

FEEL AND ROLL METHOD

- qualitative method in the determination of soil texture
- accuracy depends largely on experience
- Field texturing is not as accurate as laboratory testing for particle size
- field textures are influenced by organic matter, different clay minerals, the sodicity and the amount of lime present.



MECHANICAL ANALYSIS
IMPORTANT STEPS IN THE PROCEDURE;

- **DISPERSION**- to make the particles exist as individual grain
  - **MECHANICAL AGITATION** (stirring, shaking, boiling)
  - **CHEMICAL TREATMENT**
    - Organic matter- hydrogen peroxide
    - $CaCO_3$- dilute HCl
    - Fe and Al oxides- Na dithionine
    - Flocculated suspension- Calgon Solution (Na hexametaphosphate)
- **SEPARATION OF THE PRIMARY PARTICLES INTO SIZE GROUPS**
  - **SIEVING**- use of graded sieves down to particle diameter of 0.05 mm
  - **SEDIMENTATION**- analysis for the finer primary particles making use of stokes' law
    - **HYDROMETER METHOD**
      - Effective depth is variable
      - Uses hydrometer, an instrument used in determining the specific gravity of a fluid
    - **PIPETTE METHOD**
      - Effective depth is fixed
      - Uses pipette to draw a part of the liquid suspension from the sedimentation setup

STOKES' LAW (G.G. STOKES, 1851)

- the resistance offered by a liquid to the fall of a rigid spherical particle varies with the radius of the particle

- "*the bigger are they, the faster they settle*"
- the velocity of a falling particle through a fluid is directly proportional to the gravitational force, the difference between the density of the particle and the density of the fluid and the square of the effective particle diameter

$$V = d^2 g(Ds - Df)/18n$$

Where;
d-diameter
g=gravitational acceleration (9.81 N/kg)
Ds= density of the solid particle (2.65 x 103 kg/m^3
Df= density of the fluid (water=1.0 x 103 kg/m^3)
n=coefficient of viscosity (water at 20 ^{o}C= 1/1000 Ns/sq.m

simplified into;

$$v = kd^2$$

"the settling velocity is directly proportional to the square of the diameter of the particle."

ASSUMPTIONS OF STOKES' LAW

- The particles are sufficiently large to be unaffected by the thermal (Brownian) motion of the fluid molecules
- The particles are rigid, spherical, and smooth
- All particles are of same density
- The suspension is sufficiently dilute that particles do not interfere with one another and each settles independently
- The flow of the fluid around the particle is laminar (low Renold's number), no particle exceeds the critical velocity for the on-set of turbulence.

Particles are fully dispersed- depends on the size of Diffuse Double Layer (DDL)

- Potential difference determines the size of the DDL
- The size of the DDL (L) causes dispersion/flocculation of soil particles
  - Increase in L – dispersion
  - Decrease in L – flocculation

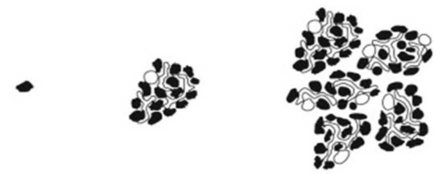
$$L = \frac{1}{3x10^7 \times z \times \sqrt{c}}$$

c – concentration
z – charge of cations

- Zeta potential changes, if zeta potential is zero, flocculation will occur
  - Ba>Ca>Mg – flocculating cations
  - NH_4>K>Na>Li – dispersing cations

2.SOIL STRUCTURE

- refers to the spatial arrangement of particle complex aggregations, pores, and channels
- pattern of arrangement of soil separates into soil aggregates and soil aggregates into soil mass
- The aggregation of primary soil particles into compound particles/cluster of primary particles, which are separated from adjoining aggregates by surface weakness (USDA-Soil Survey Staff, 1951)



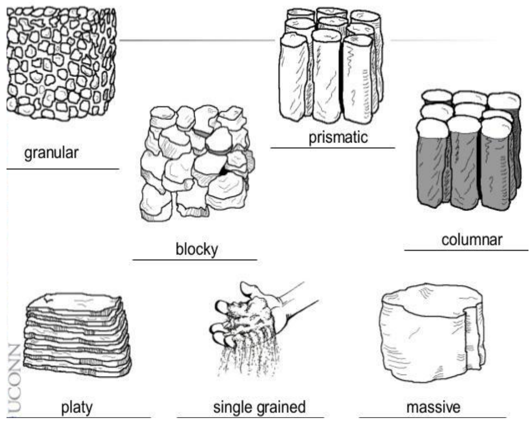
PED- a unit of soil structure such as aggregate, crumb, prism, block or granule formed by natural processes
CLOD- forms as a result of physical disturbance like cultivation or tillage operation

MACROAGGREGATES- 0.25-5 mm in diameter
MICROAGGREGATES- 2-250 um in diameter

TYPES OF SOIL TEXTURE

- **SPHEROIDAL/GRANULAR**
  - Soil separates combine to form small, rounded and loose or porous aggregates.
  - common in most surface soils have
  - soils rich in organic matter and calcium assumes this structure
- **PLATY**
  - the soil separates assume the form of sheets one on top of the other lying horizontally.
- **BLOCKY**
  - the soil separates combine to form cube-like blocks.
  - generally, found in the subsoil.
  - **ANGULAR BLOCKY**- with distinct and sharp edges
  - **SUB-ANGULAR BLOCKY**- with somewhat rounded edges
- **PRISM-LIKE** (**POST-LIKE**)
  - soil separates assume a post like appearance standing upright
  - **COLUMNAR**- with rounded tops
  - **PRISMATIC**- with flat tops
- **STRUCTURELESS**
  - soil separates don't assume any definite form
  - **SINGLE GRAINED**- typical to most sandy soils

- **MASSIVE**- typical to most lowland paddy soil



	Symbol	Description
Granular – less porous Crumb – more porous	gr (granular)	A Spheroids/small polyhedrons
Blocky	abk (angular blocky) sbk (subangular blocky)	B
Platy	pl (platy)	E Horizontal orientation
Prismatic		C (* both prismatic and columnar structures have vertical orientation) Flat tops
Columnar		Rounded tops (common in soils high in Na)
Massive	ma (massive)	Coherent mass
Single grained		Non-coherent

FACTORS AFFECTING AGGREGATION

- **PHYSICO-CHEMICAL PROCESSES**
  - Flocculation
  - Volume changes in clay material
- **BIOLOGICAL PROCESSES**
  - Activities of soil organism
    - Burrowing and molding activities of soil animals
    - Enmeshment of particles by sticky network of roots and fungal hyphae
    - Production of organic glues of microorganisms
      GLOMALIN- a sticky sugar-protein that is produced by a mycorrhiza which is thought to be an effective cementing agent.

SOIL STRUCTURE DETERIORATION

- Reduction of volume of macropores
- Decrease porosity
- Higher bulk density
- Greater root impendence
- Lower amount of available water
- Poor drainage and aeration

INDICATORS OF SOIL STRUCTURE DETERIORATION

- Increasing bulk density
- Declining organic matter content
- Absence of earthworm and other soil organism
- Cloddy soil when tilled
- Higher soil erosion

TILLAGE AND STRUCTURAL MANAGEMENT OF SOIL

- **TILLAGE AND SOIL TILTH**
  - **TILTH**- physical condition of the soil in relation to plant growth
    - highly dynamic property that depends on aggregate formation and stability, bulk density, moisture, degree of aeration, water infiltration and water holding capacity
  - **FRIABILITY**- clods are non-sticky or hard, but rather crumb easily, revealing the constituent aggregates.
    - enhances when the tensile strength of individual aggregates is relatively high compared to the tensile strength of the clods.
  - **CONVENTIONAL TILLAGE**- the USDA defines it as that which leaves 30% of the soil covered by residue
  - **SOIL CRUSTING**
    - **SURFACE SEAL**- a thin, partially cemented, low permeability layer material that covers the soil surface.
  - **CRUST**- as the surface seal dries, it forms as a hard crust
  - **SOIL CONDITIONER**
    - Gypsum (calcium sulfate)
    - Organic polymers
    - Organic matter

PUDDLING

- refers to the destruction of soil aggregates into primary particles at or near moisture saturation
- puddling requires about 200-600 mm H_2O about 10 k joules/m^3 of energy assuming the soil contains 20% clay
- puddling is more effective if soil is clay with 2:1 type

PHYSICAL EFFECTS OF PUDDLING

- Destroy soil aggregates
- Dispersion of silt and clay particles in the soil water suspension overlaying the soil surfaces
- Settling and downward movement of these particles clogged the large pores
- Formation of dense plow soil

CONSEQUENCE OF PUDDLING IN SOIL PROPERTIES

- Initial increase in pore space
- Decline in the number and amount of large pores
- Infiltration and percolation rate decrease
- Initial decrease in the bulk density but this increase as the soil settles down and as the soil shrink upon drying
- Reduced soil strength

DEGREE OF PUDDLING DEPENDS ON;

- Soil moisture content
- soil texture and soil structure
- nature of implements used
- intensity or actual operation

ADVANTAGES OF PUDDLING

- ease in transplanting
- weed control
- moisture conservation
- improvement of the availability of plant nutrients due to soil reduced condition

DISADVANTAGES OF PUDDLING

- involves a great amount of energy and time
- higher water requirements
- problem of soil structure regeneration
- development of plow pan

3. SOIL DENSITY

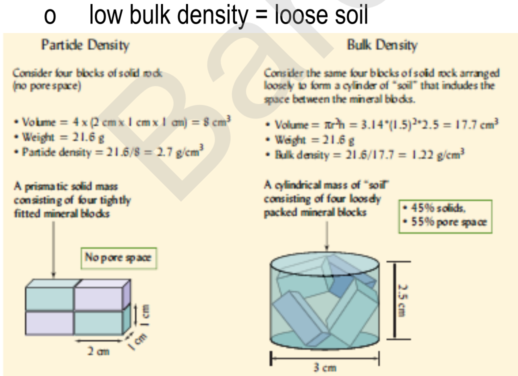
- mass per unit volume of soil

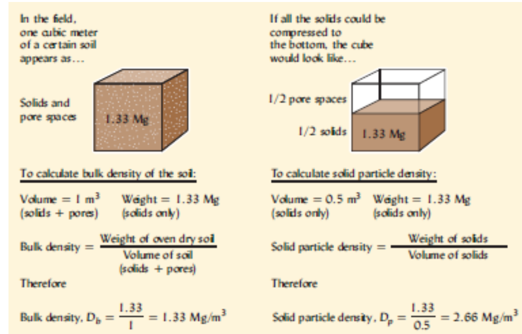
PARTICLE DENSITY (P_s)

- mass per unit volume of soil solid
- also called as the *real density* of the soil
- synonymous to the soil's specific gravity
- an indication of the mineralogical composition of the soil
- high particle density= mineral soil
- low particle density=organic soil

BULK DENSITY (P_b)

- mass of a unit of volume dry soil. The volume includes both solids and pores
- also called as *apparent density*
- an indication of the degree of compaction
- high bulk density = compact soil
- low bulk density = loose soil





FACTORS AFFECTING BULK DENSITY

- **SOIL TEXTURE**- fine textured soils have lower bulk densities than sandy soils
- **DEPTH IN SOIL PROFILE**- deeper in the soil profile, bulk densities are generally higher, as a result of compaction by the weight of the overlying layers, lower organic matter content, less aggregation and few biopores.

4. SOIL POROSITY

- refers to the fraction of the soil volume that is not occupied by soil solids but rather occupied by either soil air or soil solution

*%Pore Spaces= 100%-[(BD/PD)*100]*

TYPES OF POROSITY

- **TEXTURAL POROSITY**
  - pores and their size distribution in relation to the particle size distribution
- **STRUCTURAL POROSITY**
  - pores and their size and distribution to the size, stability, position and orientation of aggregates

TYPES OF PORES

- **MATRIX PORES**
  - changes with soil moisture
- **NON-MATRIX PORES**
  - large voids created by roots, burrowing animals, action of compressed air, and other agents.
- **INTERSTRUCTURAL PORES**
  - delimited by structural units, crevices between structural units, and are generally planar.

TYPES OF PORES BASED ON SIZE

MACROPORES (TRANSMISSION PORES)

- larger than 0.08 mm
- allows the ready movement of air and drainage of water

- large enough to accommodate plant roots and soil animals
- occur as spaces between individual sand grains in coarse textured soils
- in well-structured soils, occurs as spaces between peds (interped pores)
  BIOPORES- a type of macropores created by roots, earthworm and other soil organisms, generally tubular and continuous
- in clayey soils, biopores are the principal macropores

MICROPORES (RETENTION PORES)

- usually filled with water
- too small to permit the air movement
- movement of water is slow, much of the water is retained in this pores and is not available to plants

**note: the size, shape, and interconnection of pores are of greatest importance in determining aeration and drainage rather than the combined volume of the pores*

Simplified class	Class[a]	Effective diameter range, mm	Characteristics and functions
Macropores	Macropores	0.08–5+	Generally found between soil peds (interped); water drains by gravity; effectively transmit air; large enough to accommodate plant roots, habitat for certain soil animals.
Micropores	Mesopores	0.03–0.08	Retain water after drainage; transmit water by capillary action; accommodate fungi and root hairs.
	Micropores	0.005–0.03	Generally found within peds (intraped); retain water that plants can use; accommodate most bacteria.
	Ultramicropores	0.0001–0.005	Found largely within clay groupings; retain water that plants cannot use; exclude most microorganisms.
	Cryptopores	<0.0001	Exclude all microorganisms, too small for large molecules to enter.

[a]The pore size classes and boundary diameters are those cited in Soil Science Society of America (2001).

5. SOIL CONSISTENCY

- designates the manifestation of the physical forces of cohesion and adhesion acting within the soil at various moisture content including behaviour towards gravity and pressure
- term used to describe the ease at which the soil can be reshaped or ruptured.
- describes how a soil resists penetration by an object

ATTERBERG LIMITS

- basic measure of the nature of fine-grained soil, depending on the moisture content, it may appear in four states namely; solid, semi-solid, plastic and liquid
- also known as *soil moisture consistency limits*
- Atterberg limits can be used to distinguish between silt and clay, and it can distinguish between different types of silts and clays.
- created by Albert Atterberg a Swedish chemist
- refined by Arthur Casagrande, who invented the Casagrande

CONSISTENCY LIMITS

FLOCCULATION LIMIT

- the mass wetness at which the soil suspension is transformed from a *liquid to a semi-liquid state*

LIQUID LIMIT

- the mass wetness at which the soil water system changes from a *viscous state to a plastic body*
- minimum soil moisture content when the soil eases to act like a liquid or a maximum moisture content when the soil assumes to be plastic

PLASTIC LIMIT

- the mass wetness at which the sol stiffens from a *plastic to a semi-rigid and friable state*
- the moisture content at which the soil crumbles when rolled into threads of 1/8inch diameter

SHRINKAGE LIMIT

- the mass wetness at which the soil changes from a semi-rigid to a rigid solid with no additional change in specific volume as drying proceed.

STICKY LIMIT

- the minimum mass wetness value at which the soil pas
- te will adhere to a sheet spatula drawn over its surface.

PLASTICITY INDEX

- measure of the plasticity of a soil
- size range of moisture contents where the soil exhibits plastic properties
- the difference between the liquid limit and the plastic limit

$$PI = LL - PL$$

soils with high PI tend to be clayey
soils with lower PI tend to be silty
soils with PI of 0 ted to have little or no silt or clay

0	non plastic
1-5	slightly plastic
5-10	low plasticity
10-20	medium plasticity
20-40	high plasticity
>40	very high plasticity

LIQUIDITY INDEX

- used for scaling the natural water content of a soil sample to the limits
- ratio of the difference between the natural water content, plastic limit and the liquid limit
- describes the moisture condition of a soil with respect to its index limits
- soft clays have an LI of approximately 100%, while stiff clays have LI which approximates 0 and may even be negative

$$LI = (W-PL)/(LL-PL)$$

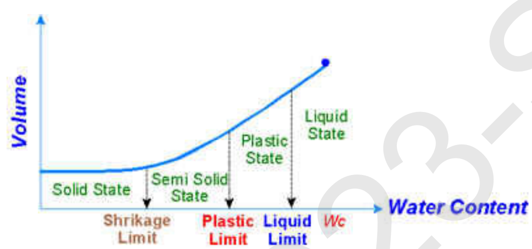
NATURAL WATER CONTENT-corresponds to the water content of a field moist soil and was measured using undisturbed core samples

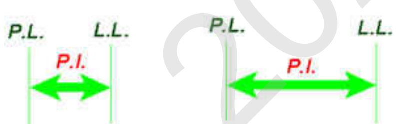
COEFFICIENT OF LINEAR EXTENSIBILITY

- percent reduction in the length of a soil bar upon shrinking
- measure of the expansiveness of soils

$$COLE = [(LM-LO)/LM]*100$$

LM- length at plastic limit
LO- length after air drying





6. SOIL COLOR

- most obvious characteristic of the soil
- little effect on the behaviour and use of soils, provides clues about other soil properties and conditions.

  MUNSELL COLOR CHARTS- developed in 1905 by Albert Munsell to qualitatively and quantitatively describe soils

COMPONENTS
Munsell color notation
e.g. 5YR 5/3
HUE

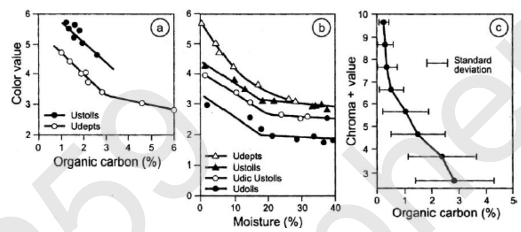
- dominant spectral color (*e.g. 5YR*)
- refers to the chromatic composition of light, or wavelength of light, that emanates from the object
- most dominant factor is the mineralogy of the soil which also reflect the age of the soil

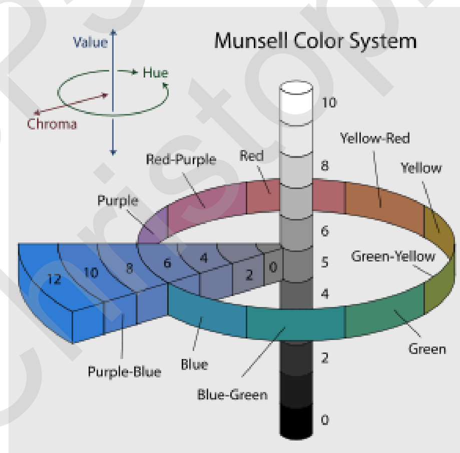
VALUE

- lightness or darkness of the color *(e.g. 5)*
- -low color value imparts dark color, high values are very light
- -low value generally imply high amounts of organic carbon

CHORMA

- intensity or brightness, or the purity, strength or greyness of the color *(e.g. 3)*
- low chroma, all hues converge to a single scale of neutral gray, referred as N0





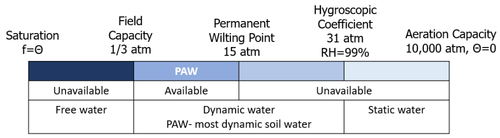
7. SOIL MOISTURE

- defined as the water that may be evaporated from soil by heating at 105 °C to a constant weight.

TYPES OF FORCES ACTING ON SOIL MOISTURE

- **POSITIVE FORCES**- enhances soil affinity for water (forces of cohesion and adhesion)
  - Retains water
- **NEGATIVE FORCES**- take away water from the soil (gravity, plant uptake, evaporation)
  - removes water

SOIL MOISTURE COEFFICIENTS/CONSTANTS



SATURATION

- the pores are completely filled with water
- 0 bar/atm

FIELD MOISTURE CAPACITY/ FIELD CAPACITY

- when a fully saturated soil is allowed to drain freely under force of gravity and there is no loss due to evaporation, after some time the soil's moisture content will approach an equilibrium level.
- upper limit of moisture content that a soil can hold
- moisture content when all macropores have been drained and replaced by air.
- 1/3 or 0.33 bar or atm

PERMANENT WILTING POINT/ WILTING COEFFICIENT

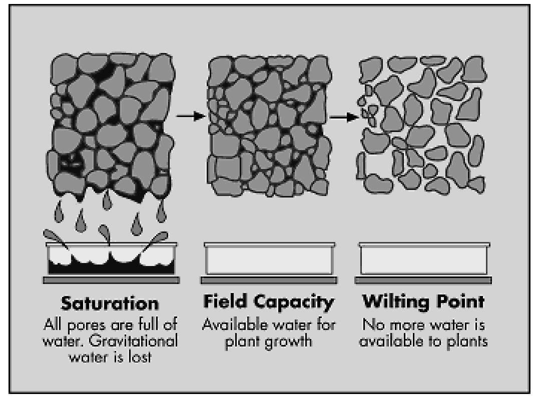
- lower limit of moisture content at which forces of cohesion and adhesion holding moisture in soil far exceed the pull the plant roots can exert to extract moisture from the soil.
- the moisture content at which plant leaves wilt permanently and do not regain their turbidity even when placed in an atmosphere with a relative humidity of 100%
- moisture content at which even the retention pores have been depleted of moisture.
- 15 bar or atm

HYGROSCOPIC COEFFICIENT

- the moisture tension in which the soil water is in equilibrium with an atmosphere of 98% water vapour saturation
- 30 bar or atm

OVEN DRYNESS

- soil has reached equilibrium with the vapour pressure of an oven at 1.5 ºC
- 10,000 bar or atm



PHYSICAL CLASSIFICATION OF SOIL MOISTURE

- **Free (Drainage Water)/Gravitational Water**
  - loosely held
- **Capillary Water**
  - held between FC and HC
- **Hygroscopic Water**
  - held at hygroscopic coefficient

BIOLOGICAL CLASSIFICATION OF SOIL WATER

Superflous Water- free or drainage water, not available for plant uptake because it is simply drained from the soil
Available Water- moisture held between FC and PWP, available for plant uptkae
Unavailable Water- moisture held at PWP, not available for plant uptake

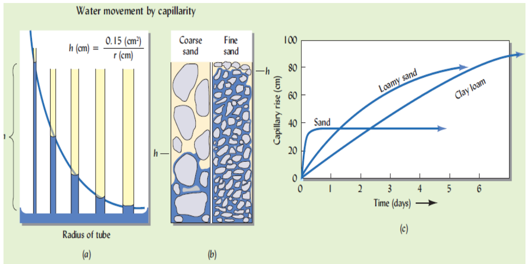
MOVEMENT OF WATER

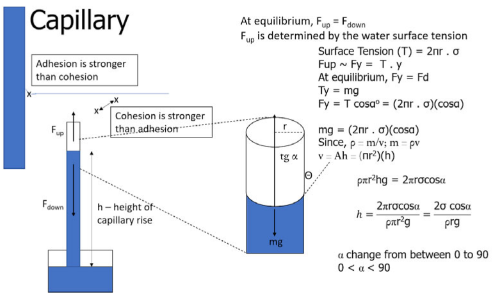
- **CAPILLARY MOVEMENT/RISE**
  - upward movement of water from the water table
  - caused by the attraction of water for the solid (adhesion and adsorption) and the surface tension of water, which is due largely to the attraction of water molecules for each other (cohesion)
  - inversely proportional to the density of the fluid
  - directly proportional to the liquid's surface tension and the degree of adhesive and cohesive attraction to the soil surface

$$h=(2T\cos\alpha)/(r\rho g)$$

where;
h=height
T=surface tension
α= contact angle
r=radius

ρ=density of the liquid
g=gravitational acceleration





- **PERCOLATION**
  - process by which water moves downward into the soil profile
- **INFILTRATION**
  - process by which water enters the soil pores and become soil water
  - measured using an infiltrometer
- **INFILTRABILITY**
  - rate at which water can enter the soil

I=Q/(At)

METHODS OF MEASURING SOIL MOISTURE

Basis of direct methods

- Removal of water by distillation or adsorption by a desiccant
- Displacement of water by another liquid and measuring water-induced changes in properties of liquid
- Measurement of the chemical reaction or reaction products when reactive chemicals are added to the soil

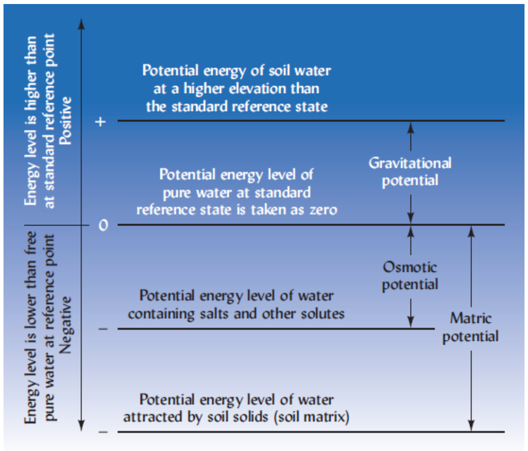
- **DIRECT METHODS**
  - **EVAPORATIVE METHODS**
    - Gravimetric
    - Volumetric
  - **LEACHING METHODS**
- **INDIRECT METHODS**
  - **ELECTRICAL CONDUCTIVITY AND CAPACITANCE**
  - **RADIATION TECHNIQUE**
    - Neutron thermalization
    - Gamma ray attenuation
  - **DIELECTRIC METHODS**
    - Capacitance method
    - Time domain reflectometry
  - **THERMAL CONDUCTIVITY**
  - **REMOTE SENSING**
    - Digital elevation models
    - Gamma-radiation
    - Visible and near infrared spectrum
    - Microwave techniques
  - **ACOUSTIC PROPERTIES**
  - **CHEMICAL PROPERTIES**
  - **VOLUME DISPLACEMENT METHOD**

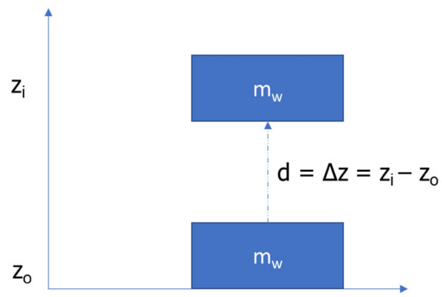
EXPRESSIONS OF SOIL MOISTURE CONTENT

- **MASS WATER FRACTION**
  Mass of water/(mass of water+mass of soil solids)
  Ww/(Ww+Ws)
  also called Moisture Content Fresh/Wet Basis
  MCf=(Fw-ODW)/FW
- **GRAVIMETRIC MOISTURE CONTENT**
  Mass of water/mass of soil solid
  Also called Moisture Content Dry Basis
  MCd=(Fw-ODW)/ODW
- **VOLUMETRIC MOISTURE CONTENT**
  Volume of water/total volume of the soil
  MCv=Vw/Vt
- **DEPTH OF WATER**
  Volumetric moisture content*depth of the soil column/profile/layer
  Dw=MCv*Depth
- **SOIL MOISTURE DENSITY**
  Mass of water/total volume of the soil
  Mw/Vt
- **LIQUID RATIO**
  Volume of water/volume of soil solids
  Vw/Vs
- **SATURATION PERCENT**
  Volume of water/porosity
  Vw/PS

SOIL WATER POTENTIAL

- refers to the relative level of potential energy contained in the soil water
- measure of the relative potential energy of water in the soil in comparison with pure water





Work = Force x distance
$W = F \times \Delta z$; $F = mg$
$W = (mg) \times \Delta z$
$W = (mg) \times (z_i - z_o)$

- Dividing by mass
  - $W/m = mgd/m = g\Delta z$
  - energy per g, ergs/g, Joules/Kg
- Dividing by weight
  - $W/w = mgd/mg = \Delta z$
  - cm, m
- Dividing by volume
  - $W/v = mg\Delta z/\Delta z^3 = mg/\Delta z^2$
  - pressure, force per area, atm, Pa, bar

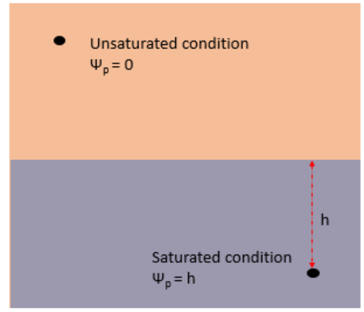
COMPONENTS OF TOTAL SOIL MOISTURE POTENTIAL

$(\Psi T) = \Psi g + \Psi p + \Psi m + \Psi o + \Psi a$

- Total soil water potential is the mechanical work necessary to transfer a quantity of soil water from a standard state to the situation of interest at equilibrium.
- From one position (standard) to another (interest)

PRESSURE POTENTIAL

- water pressure exerted by the overlying saturated column of water on a specific position within the soil
- equal to the water pressure exerted by the height of water above a specific point
- Hydraulic head is determined using piezometer (a pipe used to measure the depth of water in the reference point)
- Depth of water = hydraulic head
- $\Psi p > 0 + h$

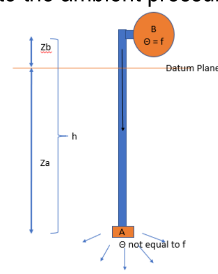


MATRIC POTENTIAL

- exists only in unsaturated soils
- due to the effects of solids, interfacial curvature due to surface tension and forces of cohesion and adhesion of the soil matrix
- matric potential and pressure potential are mutually exclusive

  COMPONENTS OF THE MATRIC POTENTIAL
  - **TENSIOMETRIC POTENTIAL-** the work required to transfer reversibly and isothermally an infinitesimal amount of soil solution from a reservoir in soil to the point of interest in the soil
  - **PNEUMATIC POTENTIAL-** usually negligible, the gauge pressure of the soil air with reference to the ambient pressure

$\Psi_{Tb} = \Psi_{Ta}$ (at this point, water level decrease will stop)
$\Psi_{Tb} = \Psi_{gb} + \Psi_{pb}$; $\Psi_{Ta} = \Psi_{ga} + \Psi_{ma}$
$\Psi_{Tb} = \Psi_{Ta}$
$\Psi_{gb} + \Psi_{pb} = \Psi_{ga} + \Psi_{ma}$
$\Psi_{ma} = (\Psi_{gb} + \Psi_{pb}) - \Psi_{ga}$
$\Psi_{ma} = (\Psi_{gb} - \Psi_{ga}) + \Psi_{pb}$
$\Psi_{ma} = [Z_b - (-Z_a)] + \Psi_{pb}$, $\Psi_{ma} = (Z_b + Z_a) + \Psi_{pb}$
$\Psi_{ma} = h - GR$, GR= Gauge Reading
$\Psi_{ma} < 0, -h$ (0 at $\Theta = f$)

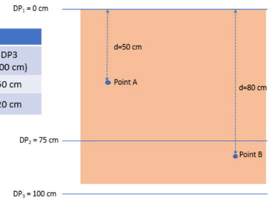


GRAVITATIONAL POTENTIAL

- energy required to move an infinitesimal amount of pure, free water from the reference elevation to the soil water elevation.
- Needs a standard/reference state/plane called "Datum Plane" (arbitrary reference point parallel to the surface)
- Ψg is measured as the distance between point of interest (x) and the datum plane
- $\Psi g = DP - x$

- If X is below DP, then Ψg is (-)
- If X is above DP, then Ψg is (+)

Point (X)	Ψg		
	DP1 (0 cm)	DP2 (75 cm)	DP3 (100 cm)
A	- 50 cm	25 cm	50 cm
B	- 80 cm	-5 cm	20 cm

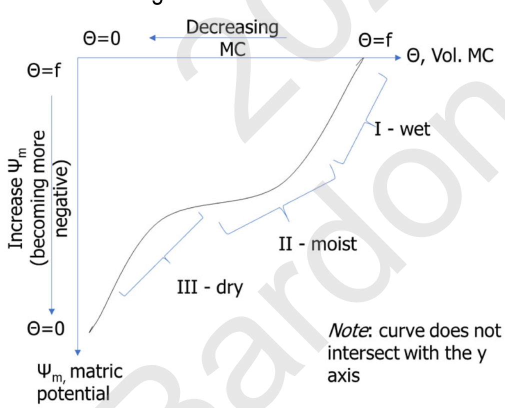


OSMOTIC POTENTIAL

- due to the presence of solutes in soil moisture that affects its thermodynamic properties (entropy, enthalpy, free energy)
- presence of solutes lowers the vapour pressure of soil moisture and thus affects the osmotic potential
- refers to the change in energy per unit volume of water when solutes identical in composition to the soil solution at the point of interest in the soil is added to pure, free water at the elevation of the soil.

SOIL MOISTURE CHARACTERISTIC/RETENTION CURVE

- fundamental relationship between soil's moisture content and soil-matric potential
- Soil moisture characteristic curve=pF curve
- depends on soil structure as determined by total porosity and the pore size distribution.
- change in structure and pore size leads to a change in soil moisture characteristics

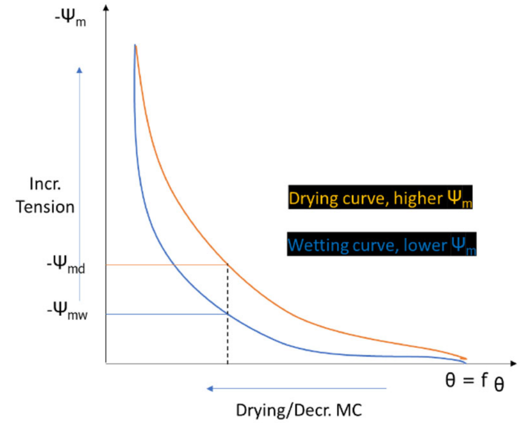


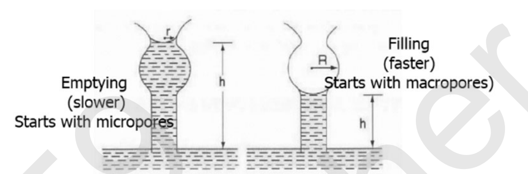
SPECIFIC WATER CAPACITY

- change in soil's moisture content per change in soil matric potential

HYSTERESIS

- the phenomenon of dependence of pF curve on soil moisture history





Filling process is faster because it starts with larger cross sectional area

$$\Psi_m = \frac{force)}{r\ (size)}$$

SOIL WATER MOVEMENT

- movement of water through a porous system occurs whether there is a difference in potential energy of water within the porous matrix
- difference in potential energy of water builds a force in the system, which forces to move from a position of greater potential to smaller potential.

TYPES OF WATER MOVEMENT IN SOIL

SATURATED FLOW

- occurs when the soil pores is completely filled with water

UNSATURATED FLOW

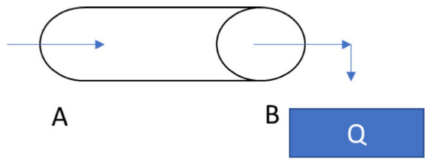
- occurs when the larger pores are completely filled with air, leaving only the smaller pores to hold and transmit water

VAPOR MOVEMENT

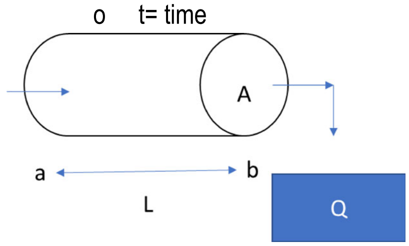
- occurs as vapour pressure differences develop in relatively dry soil

Saturated Flow in Soils

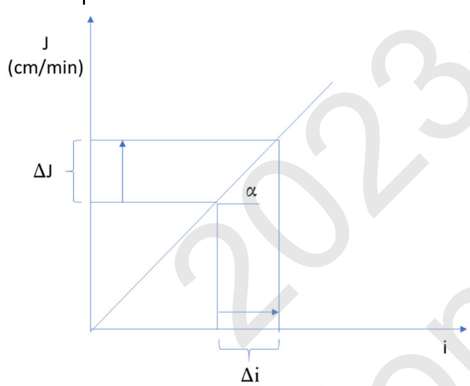
- Under saturated conditions (f = θ) (Ψm = 0)
- Ψm = Ψg + Ψp
- There should be pressure difference between point A and B for water flow to occur,
- if pressure in A and B is the same, no flow will occur (high Ψ to low Ψ)



- Flux (q)=(ΔQ (cm^3))/(Δt (min));
  - o Q = volume of water,
  - o t= time



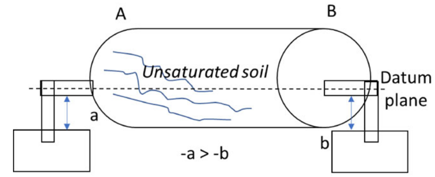
- Flow (J)=q/A;
  - o A is the cross-sectional area
- Flow (J)=(ΔQ)/(A Δt) = $cm3/(cm2\ min)$ = cm/min
- Why not call it velocity? Why flow? \
  - o water moves not in a straight path (turbulent flow)
- If Ψa = Ψb, then J = 0
- Hydraulic gradient (i)=(Ψa − Ψb)/L
- If Ψa = Ψb, then i = 0, some ΔΨ should be present for water to flow



- i is proportional to J (linear)
- Slope =$tg(\alpha)$=(ΔJ)/(Δi)
- The slope of the line is the saturated hydraulic conductivity (Ks)

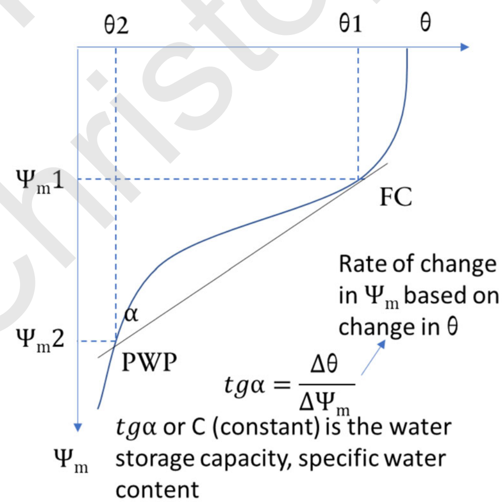
Darcy's Law
- J=Ks ×i

Unsaturated Flow in Soils
- Under unsaturated conditions (f not equal to θ) (0< θ <f)
- Ψm = Ψg + Ψm



Darcy's Law
- J=−K"θ"×i
- i= ΔΨ/Δx = (−b −(−a))/Δx
- Hydraulic conductivity is variable under unsaturated condition
- Kθ or KΨm notation for unsaturated hydraulic conductivity

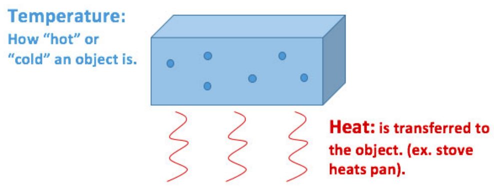
- $J=-K_\theta \times i \rightarrow = K_\theta \times d\Psi_m/dx$
  denotes that if x changes, there will be a corresponding change in Ψ_m
- $d\Psi_m/dx$ = ($d\Psi_m/d\theta$) . ($d\theta/dx$) = (1/C)($d\theta/dx$)
- $J=-K_\theta \times i \sim -K_\theta \times d\Psi_m/dx$
- $J=-K_\theta$ × (1/C)(dθ/dx)⟶J=($-K_\theta$)/(C)(dθ/dx)
- J=($-K_\theta$)/ (C)(dθ/dx)⟶ J= D(θ) × (dθ /dx)
  D(θ) = diffusivity constant



8. SOIL TEMPERATURE
- o affects plant growth as it influences moisture, aeration, structure, microbial and enzyme activity, decomposition of residues and plant nutrient availability

HEAT
- o kinetic energy of the random motion of the ultimate particles on which material bodies are composed.

TEMPERATURE
- o refers to a particular level or degree of molecular activity
- o intensity of heat or the level of heat



THERMAL CAPACITY

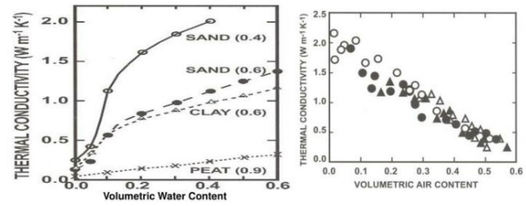
- amount of heat existing in the body (heat capacity)
- amount of heat required to change the temperature of a given mass of a particular substance by a certain amount
- the greater the heat capacity of the substance is, the more heat it can gain (or lose) per unit rise (or fall) in temperature
- soil = 0.2 cal/g ; water 1 cal/g
- $Q = mc\Delta t$
  - Q = energy (J)
  - m = mass
  - c = specific heat capacity (J/Kg C)
    - $c = dQ/dT$
  - t = temperature difference (final – initial)

varies with; MC, bulk density. Mineralogy. OM, initial temperature

Material	Specific Heat, cal/g	Volumetric heat capacity, cal/cc
Humus	0.4	0.56
Water	1.0	1.0
Ice	0.5	0.46
Air	0.25	0.0003
Clay	0.22	0.5
Quartz	0.19	0.5
Mica	0.21	0.59
Granite	0.19	0.5
CaCO3	0.20	0.54
Fe2O3	0.15	0.75
Chalk	0.21	0.46
wood	0.42	0.38

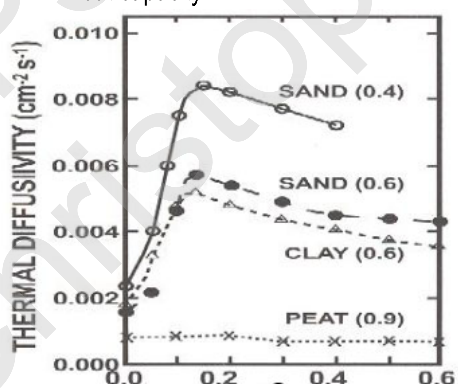
THERMAL CONDUCTIVITY (k)

- ability of the substance to transfer heat from molecule to molecule (molecular conductivity)
- rate of heat transfer through a unit area of soil under a unit temperature gradient (J/m/s/K)
- varies with mineralogy, porosity, degree of saturation, OM content, MC, bulk density
  - conductivity of soil increase with increase in water content.
  - Air thermal conductivity < soil thermal conductivity; clay soils with high bulk density = higher conductivity.



THERMAL DIFFUSIVITY, D_T

- expression of the rate at which a substance heats up as a result of a thermal gradient
- change in temperature produced in a unit volume by the quantity of heat flowing through the volume in unit time under a unit temperature gradient
- ratio of thermal conductivity and heat capacity, directly proportional with thermal conductivity and inversely proportional to heat capacity



FACTORS AFFECTING SOIL TEMPERATURE

SOLAR RADIATION

- the amount of heat from the sun that reaches the earth is 2 g-cal/cm^2-min. The amount received by the soil is much less

RADIATION FROM THE SKY

- much of the sun's energy are absorbed by the atmosphere and is radiated in all directions.
- in the tropics, sun rays pass through the atmosphere more nearly vertical and loose little energy.

CONDUCTION OF HEAT FROM THE ATMOSPHERE

- conduction of heat through air is small, and it can have substantial effect upon soil temperature only by contact

CONDENSATION

- being an exothermic process, whenever water vapour condenses, the soil is heated up by 5 degrees centigrade

EVAPORATION
- being an endothermic process, the greater the evaporation, the more is the soil cooled down.

RAINFALL
- depending on the temperature, rainfall can cool or warm the soil

INSULATION
- during summer, insulated soil is cooler than the soil that is directly exposed to the elements, while during winter the situation is reversed

VEGETATION
- transpiration of water, reflection of incident radiation and energy used for photosynthesis by plants tend to decrease the temperature of the microclimate and indirectly the soil

BIOLOGICAL ACTIVITY
- biological activity evolves heat, and the greater the activity in the soil, the more it is heated up

RADIATION
- Color has a considerable effect on the reflection of the incoming radiation
- darker soils, the smaller fraction of the incoming radiation is reflected
    - **ALBEDO(A)**- ration of the reflected energy with the incident radiation
    - larger the albedo, the cooler the soil
    - rough surface absorbs more solar radiation than smooth surface
    - Dark and moist soils absorb more radiation than dry and light-coloured soils.

STRUCTURE, TEXTURE AND MOISTURE
- compacted soils have greater thermal activity than loose soils
- organic soils have lesser thermal conductivity than mineral soils

SOLUBLE SALTS
- concentration of soluble salts in the soil affects evaporation and indirectly soil temperature
- the higher the salt concentration the higher the temperature needed for evaporation
- salt concentration affects biologic activity and indirectly soil temperature

PROPERTIES AFFECTED BY SOIL TEMPERATURE

SOIL MOISTURE
- change in temperature affects vapour pressure and viscosity of water

MICROBIAL ACTIVITY
- optimal temperature for microbes is 18-30ºC, beyond and below this range microbial activity decreases

SOIL DEVELOPMENT
- higher temperature increases chemical reaction and therefore soil development

PLANT GROWTH
- increasing temperature increases shoot/root ratio

AVAILABILITY OF PLANT NUTRIENTS
- water becomes more available to plants to warms up, and as the water is being absorbed so are the readily available plant nutrients

SOIL CHEMICAL PROPERTIES

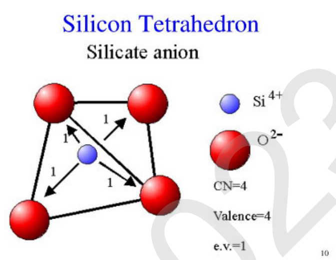
SOIL COLLOIDS
- clay plus humus fraction
- 1 um or 2 um
- Seat of soil chemical reactions – most chemically active fraction of the soil

ORIGIN OF SOIL COLLOIDS
- Slight physical and chemical alteration of certain primary minerals
- Decomposition of primary minerals with the subsequent recrystallization of their products into silicate clays

STRUCTURAL UNITS OF SILICATE CLAYS

TETRAHEDRAL SHEETS
- consist of two planes of oxygen with mainly silicon in the spaces between the oxygen
- interlocking array of tetrahedron, each sharing its basal oxygen with its neighbour

  TETRAHEDRON- basic structural unit of a tetrahedral sheet

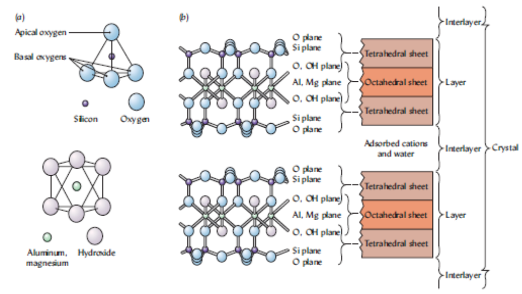


OCTAHEDRAL SHEETS
- numerous octahedral linked together horizontally

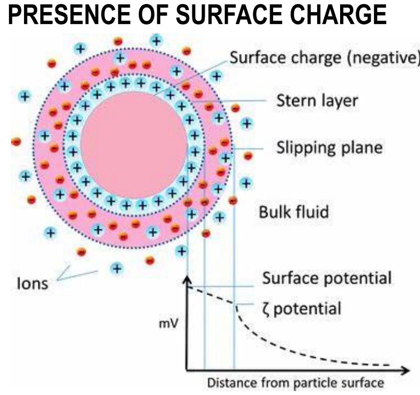
  OCTAHEDRON- six oxygen atoms coordinating a with a central aluminum or magnesium atom form the shape of an eight sided geometric solid

  TRIOCTAHEDRAL SHEET- if three magnesium atoms are coordinated with the six oxygen/hydroxyls

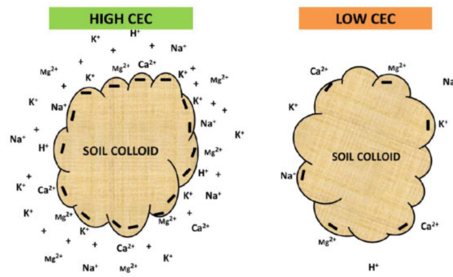
  DIOCTAHEDRAL SHEET- if two aluminum atoms are coordinated with the six oxygen/hydroxyls



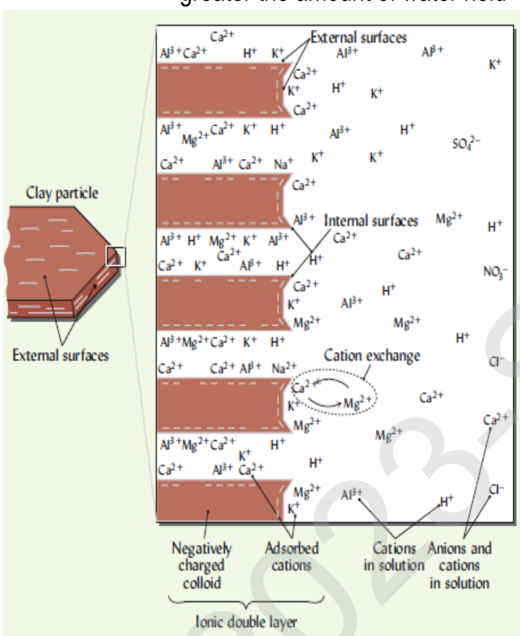
PROPERTIES OF SOIL COLLOIDS
- **SMALL SIZE**
  - particles behave as colloids if they are less than 1 um (0.000001 m) diameter, though some soil scientist consider 2 um to the upper boundary to coincide with the definition of clay particle size fraction.
- **LARGE SURFACE AREA**
  - the smaller the size of the particles in a given mass of the soil, the greater the surface area exposed for adsorption, catalyst, precipitation, microbial colonization
  - total surface area of soil colloids ranges from 10 m^2/g with only external surface, to more than 800 m^2/g for clays with extensive internal surface charge
  - **INTERNAL SURFACE AREA**- exist between the layers of the plate like crystal units
- **PRESENCE OF SURFACE CHARGE**



- **ION ADSORPTION**



- **ADSORPTION OF WATER**
    - o soil colloids attract and hold a large number of water molecules
    - o the greater the surface area, the greater the amount of water held



TYPES OF SOIL COLLOIDS

CRYSTALLINE SILICATE CLAYS

- o dominant in most soils (except in andisols, oxisols, and histosols)
- o characteristic layered structure

1:1 TYPE OF SILICATE CLAYS

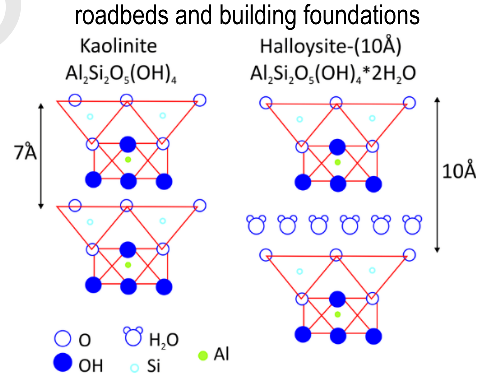
- o consist of one silicon tetrahedral sheet and one aluminum octahedral sheet, tightly held together
- o the apical oxygen atom in each tetrahedron also forms a bottom corner of one or more of the octahedra in the adjoining sheet
- o exposes a plane of oxygen atoms on the bottom surface and a plane of hydroxyls in the upper surface.
- o 1:1 dominated soils are relatively easy to cultivate
- o good for making bricks and ceramics

CONSEQUENCES OF THE ARRANGEMENT

- o The hydroxyl plane is exposed on the clay particle surface, removal or addition of hydrogen ion can produce either positive or negative charge, depending on the pH, the hydroxylated surface can also react with and strongly bind specific anions
- o The hydroxyls of the octahedral sheet in one layer are adjacent to the basal oxygen of the tetrahedral sheet of the next layer. The layers are bound together by hydrogen bonding
    - o due to hydrogen bonding the structure of kaolinite is fixed, and no expansion occur between the layers when the clay is wet
    - o effective surface area is restricted to the external surface area

KAOLINITE

- o most common type of 1:1 silicate clay in soils
- o comes from the Chinese words “kao” and “ling” which means “high ridge” as the material was first mined from a hillside in Klangsi Province
- o hexagonal in shape and larger than other clays
- o exhibit less plasticity, stickiness, cohesion, shrinkage, and swelling
- o low water holding capacity
- o kaolinite containing soils are well suited for roadbeds and building foundations



EXPANDING 2:1-TYPE SILICATE CLAYS

- o characterized by one octahedral sheet between two tetrahedral sheets

SMECTITE GROUP

- o flake-like crystal structure
- o high amounts of negative charge resulting from isomorphous substitution, mostly derived from magnesium ions substituted in the aluminum positions of the octahedral

sheets, but some are derived from the substitution of aluminum ions for silicon in the tetrahedral sheets

- 20-40 times the capacity of kaolinite to adsorb cations
- because of its unique structure, oxygen atoms are exposed at both the top and bottom planes
- adjacent layers are loosely bonded by very weak oxygen bonds and cation-oxygen linkages
- interlayer space is variable
- internal surface area exceeds he external surface area
- high degree of plasticity, stickiness, and cohesion
- smectitic soils are very difficult to cultivate and excavate
- smectitic soils are undesirable for construction activities, but are well suited for applications that require high adsorptive capacity and form seals of very low permeability

MONTMORILLONITE- most prominent of the smectites

VERMICULITE GROUP

- 2:1 type minerals in which the octahedral sheet is aluminum dominated.
- considered limited expanding clay, expanding more than kaolinite, but much less than smectite.
- the tetrahedral sheets of most vermiculite have considerable substitution of aluminum in the silicon positions, giving rise to a CEC that usually exceeds other silicate clays
- interlayer spaces of vermiculites usually contain strongly adsorbed water molecules, Al-hydroxy ions, and cations
- the degree of swelling and shrinkage is restricted by the interlayer constituents which acts primarily as bridges to hold the units together, rather than wedges driving them apart.

NON-EXPANDING 2:1 SILICATE MINERALS

FINE-GRAINED MICA

- more weathered micas, like illite and glauconite are found in the clay fraction
- less weathered micas such as biotite and muscovite are typically found in the sand and silt fractions
- 2:1 structure is similar to those of the unweathered micas
- mains source of charge is the substitution of aluminum ions in about 20% of the silicon sites in the tetrahedral sheets, which results to a net negative charge in the tetrahedral sheet
- the negative charge in the tetrahedral sheet attracts cations, among which potassium ion is just the right size to fit into the certain hexagonal spaces between the tetrahedral oxygen groups and thereby get very close to the negatively charged sites
- due to the mutual attraction of the potassium ions in between, the adjacent layers are strongly bonded together
- similar to kaolinite in terms of water holding capacity and degree of plasticity and stickiness

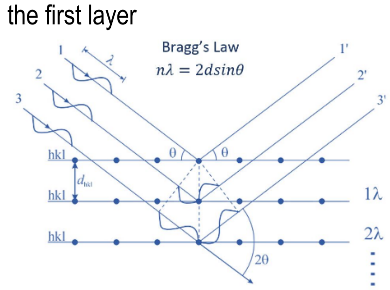
CHLORITE

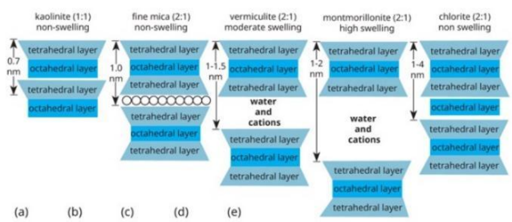
- has a 2:1:1 structure
- non-expansive because of the hydroxylated surfaces of an intervening magnesium octahedron sheet are hydrogen-bonded to the oxygen atoms of the two adjacent tetrahedral sheets
- colloidal properties are quite similar to fine-grained mica

X-RAY DIFFRACTION ANALYSIS

- a procedure used to determine the relative amounts of various types of clay minerals present in a soil
- measures the distance between layers (*d-spacing*) in the mineral structure

  BRAGG'S LAW- states that there is a specific angle that cause the waves to striking the second layer to travel an additional distance exactly equal to their wavelength
- the waves reflected off the second layer will be in the phase with those reflected off the first layer





NON-CRYSTALLINE SILICATE CLAYS

- consist mainly of tightly bonded silicon, aluminum and oxygen atoms, but do not exhibit ordered, crystalline sheets
- **ALLOPHANE** and **IMOGOLITE**- principal types of non-crystalline silicate clays, usually from volcanic ash
- high amounts of both positive and negative charge, and high water-holding capacity
- malleable when wet, exhibit low degree of stickiness
- extremely high capacities to strongly absorb phosphate and other anions, especially under acidic conditions

IRON AND ALUMINUM OXIDES

- "oxides" is used for convenience but these are actually hydroxides or oxyhydroxides due to the presence of hydrogen ions
- commonly found in highly weathered soils (alfisols, ultisols, and oxisols)
- consist mainly of iron and aluminum atoms coordinated with oxygen atoms, the latter are often associated with hydrogen atoms to make hydroxyl groups
- consist of modified octahedral sheets with either iron or aluminum ions in the cation position
- isomorphous substitution rarely occurs, so these clays do not have much negative charges
- charges arise by the removal or addition of hydrogen ions at the surface oxy-hydroxy groups
- low plasticity and stickiness

  GIBBSITE- Al oxide ($Al(OH)_3$)
  GOETHITE- Fe oxide (FeOOH)
  FERRIHYDRITE- Fe oxide ($Fe_2O_3nH_2O$)
  HEMATITE- Fe oxide (Fe_2O_3)

HUMUS

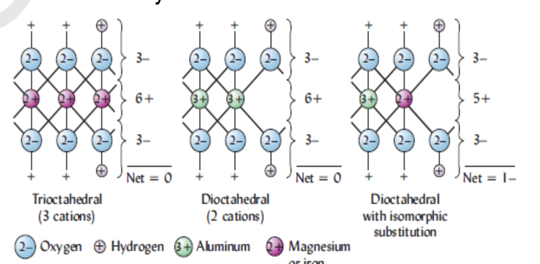
- comprised of non-crystalline organic substance whose chemical composition varies considerably, but generally contains 40-60% C, 30-50% O, 3-7% H, and 1-5% N
- consist largely of polymerized molecules of humic acids with very large molecular weights (1000s of g/mol)
- consist of a wide variety of partially decomposed cell walls and biomolecules derived mainly from microorganisms and parts of tissues derived from plants
- has a complex chain of rings and carbon atoms bonded to hydrogen, oxygen and nitrogen
- very high capacity to adsorb water
- no plasticity or stickiness (non-cohesive)
- high amount of both positive and negative charges per unit mass, but net charge is always negative and varies with soil pH
- negative charge in humus is extremely high in neutral to alkaline soils.
- charges develop as hydrogen ions are either lost or gained by the –OH functional groups present in the humus molecule

SOURCE OF CHARGES

PERMANENT CHARGE

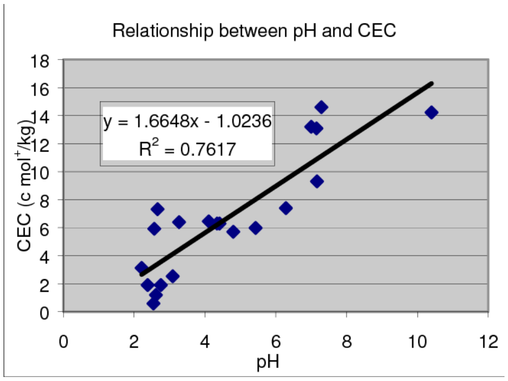
- due to the imbalance brought about in some clay crystal structure by the isomorphous substitution
- a negative charge is found in minerals where there has been an isomorphous substitution of a lower-charged ion for a higher-charged ion.

  Isomorphous substitution- process by which one element fills a position usually filled by another of similar size

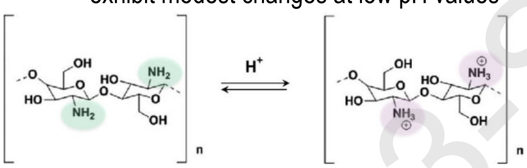


pH DEPENDENT

- due to the hydroxyls and other functional groups on the surface of colloidal particles that have accept or release hydrogen ions resulting to a charge, the opposite results to a positive charge
- under moderate acidic conditions, there is little or no charge, but as pH increases, the hydrogen from the edges of colloids dissociates and negative charge arises.
- under moderate to extreme acidic conditions, positive charges arise by



- **PROTONATION**, the attachment of hydrogen ion to the surface of the OH groups exposed at the surface of the colloids
- the excess H^+ ions (protons) present in the solution are attracted to and bond with the functional groups ($-NH_2$, $-COO^-$, $-O^-$) neutralizing negative charges and creating positively charged sites)
- humus, kaolinite, allophane and oxides have mostly variable negative charges and exhibit modest changes at low pH values



ION ADSORPTION

- ions are held on the charged surfaces of the soil colloid
- both the cations and anions are attracted to the colloid.
- in temperate region soils anions are commonly adsorbed in a much smaller quantity than cations because these soils generally contain 2:1 type silicate clays on which negative charges predominate
- in the tropics, adsorption of anions is more prominent because soils in the tropics are more highly weathered, acid and rich in 1:1 clays and oxides, so that the amount of negative charge in the soil is not so high, and positive charge is more abundant

TYPES OF COLLOID-ION COMPLEXES

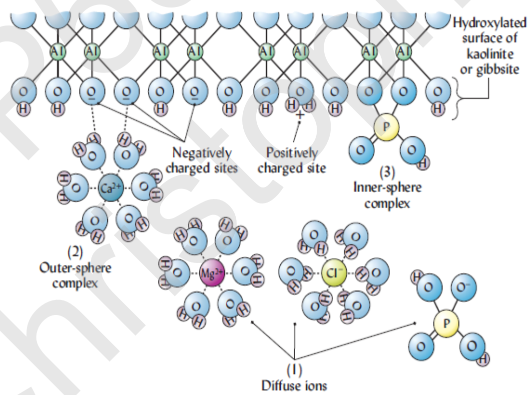
OUTER-SPHERE COMPLEX

- water forms a bridge between the adsorbed ion (hydrate) and the charged colloid
- the ion itself never comes close enough to the colloid surface to form a bond with a specific charged site.
- ion is weakly held by electrostatic attraction, the charge of the oscillating hydrated ion balancing, in a general way, an excess of opposite sign on the colloidal surface.
- ions in an outer-sphere complex are easily replaced by similar charged ions.
- permanent charges from the isomorphous substitution in the interior structure of the colloid can also cause adsorption of outer-sphere complexes

Inner-sphere complex

- do not have intervening water molecules.
- one or more direct bonds are formed between the adsorbed ion and the atoms in the colloid surface.
- other ions cannot replace ions held in an inner-sphere complex because the adsorption involves strong bonds that depends on the compatible nature of the ions and the sites in the colloid.

e.g. K^+, Cu^{+2}, Ni^{+2}, *H2PO*$^{4+}$



FACTORS GOVERNING CATION EXCHANGE REACTIONS

FAST/INSTANTANEOUS

- exchange reaction in soils occur very fast (microseconds)

REVERSIBILITY

- the reversibility of the reaction is represented by the double arrows.

$$\boxed{\text{Colloid}}\,Na^+ + H^+ \rightleftharpoons \boxed{\text{Colloid}}\,H^+ + Na^+$$

CHARGE EQUIVALENCE

- "charge for a charge" principle
- E.g. one Ca^{+2} will replace two H^+ ions

$$\boxed{\text{Colloid}}\,Ca^{2+} + 2\,H^+ \rightleftharpoons \boxed{\text{Colloid}}\,{}^{H^+}_{H^+} + Ca^{2+}$$

RATIO LAW

- at equilibrium, the ratio of the ions adsorbed in the colloid will be the same as the ratio in the solution and will be the same as the ratio of the overall system

$$\boxed{\text{Colloid}}\,20\,Ca^{2+} + 5\,Mg^{2+} \rightleftharpoons \boxed{\text{Colloid}}\begin{matrix}16\,Ca^{2+}\\4\,Mg^{2+}\end{matrix} + 1\,Mg^{2+} + 4\,Ca^{2+} \qquad \text{Ratio: 4 Ca:1 Mg}$$

$$\boxed{\text{Colloid}}\,20\,Ca^{2+} + 80\,Mg^{2+} \rightleftharpoons \boxed{\text{Colloid}}\begin{matrix}4\,Ca^{2+}\\16\,Mg^{2+}\end{matrix} + 64\,Mg^{2+} + 16\,Ca^{2+} \qquad \text{Ratio: 1 Ca:4 Mg}$$

ANION EFFECTS ON MASS ACTION

- an exchange reaction will be more likely to proceed to the right if the released ions is prevented from reacting in the reverse direction
- accomplished if the released cation on the right side of the reaction either precipitates, volatilizes or strongly associates with an anion

CATION SELECTIVITY

- some cations are held much more tightly than others and are less likely to be displaced from the colloid
- the higher the charge and the smaller the hydrated radius of the cation, the more strongly it will be adsorbed to the colloid
- the ion's hydrated radius and not the ionic radius, that affects the strength of adsorption

  LYOTROPIC SERIES- shows the order of strength that a cation is held
  $Al^{3+} > H^{+} > Ca^{2+} > Mg^{2+} > NH_4^{+} > K^{+} > Na^{+}$
  $PO_4^{3-} > SO_4^{2-} > Cl^{-} > NO_3^{-}$

COMPLEMENTARY CATIONS

- the likelihood that a given adsorbed cation will be displaced from a colloid is influenced by how strongly its neighbouring cation (complementary ion) are adsorbed to the colloid surface

CATION EXCHANGE CAPACITY (CEC)

- the number of moles of positive charges adsorbed per unit mass
- CEC increases with soil pH
- centimole of charge per kg (cmol/kg)- updated unit
- milliequivanlent per 100 g (me/100g)- old unit
- 1 me/100g=1cmol/kg

$$equivalent\ weight = \frac{atomic\ weight}{valence}$$

$$m.e.\ weight = \frac{atomic\ weight}{valence \times 1000}$$

$$No.\ of\ me = \frac{weight\ of\ the\ ion}{m.e.\ weight\ of\ the\ ion}$$

$$CEC = \sum me$$

$$\%\ BS = \frac{\sum me\ of\ basic\ cations}{CEC} \times 100\%$$

$$Saturation\ \% = \frac{me\ of\ the\ ion}{CEC} \times 100\%$$

SATURATED PERCENTAGE

- the proportion of CEC satisfied by a particular cation

NON-ACID CATION SATURATION

- the proportion of CEC satisfied by basic cations (Ca, Mg, Na, K)
- base saturation percentage
- indicate the tendency towards neutrality and alkalinity of the soil

ACID CATION SATURATION

- the proportion of CEC satisfied by acid cations

SOIL pH/SOIL REACTION

- master variable that affects a wide range of soil chemical and biological properties
- affects the mobility of nutrients and pollutants in soils, their breakdown, solubility and adsorption
- determined by the balance between the acid and non-acid cations on colloid surfaces and the balance between the H+ and the OH- ions in the soil solution
- soil acidity is associated with the presence of exchangeable H^{+} and Al^{3+} ions

pH

- negative logarithm if the H^{+} ion concentration
- every unit step in the pH scale is tenfold (log scale) change in H concentration
- much more H^{+} ions is involved in the change of 1 pH unit near the low end of the scale compared to a 1 unit change at the high end
- $[H^{+}] \times [OH^{-}] = Kw = 10^{-14}$

$$pH = -\ log(H^{+}) = \frac{1}{log(H^{+})}$$

SOURCES OF H^+

HYDROLYSIS OF WATER

- $H_2O \rightarrow H^+ + OH^-$

CARBONIC AND OTHER ORGANIC ACIDS

- **CARBONIC ACID**- most ubiquitous contributor to soil acidity
- CO_2 comes from root respiration and organic matter decomposition and from natural diffusion
- -microbes produce organic acids
  e.g. citric acid, mallic acid, carboxylic acid, phenolic acid

$$CO_2 + H_2O \longrightarrow H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \qquad pK_a = 6.35$$

$$[RCH_2OH...] + O_2 + H_2O \rightleftharpoons RCOOH \rightleftharpoons RCOO^- + H^+ \qquad pK_a = 3 \text{ to } 5$$

ACCUMULATION OF ORGANIC MATTER

- organic matter forms soluble complexes with non-acid nutrient cations, thus facilitating the loss of these cations by leaching
- organic matter is a source of H^+ because it contains numerous acid functional groups from which ions can be dissociate

OXIDATION OF NITROGEN (NITRIFICATION)

- oxidation reactions generally produce H+ as one of the products
- reduction consumes H+
- ammonium ions from organic matter or from fertilizers are subjected to microbial oxidation that converts N to nitrate ions.

$$NH_4^+ + 2O_2 \rightleftharpoons H_2O + H^+ + \underbrace{H^+ + NO_3^-}_{\text{Dissociated nitric acid}}$$

OXIDATION OF SULFUR

- the decomposition of plant residues involves the oxidation of organic –SH groups to yield sulfuric acid
- the oxidation of reduced sulfur minerals yield strong acids

$$\underset{\text{Pyrite}}{FeS_2} + 3\tfrac{1}{2}O_2 + H_2O \rightleftharpoons \underset{\text{Ferrous sulfate}}{FeSO_4} + \underbrace{2H^+ + SO_4^{2-}}_{\text{Dissociated sulfuric acid}}$$

ACIDS IN PRECIPITATION

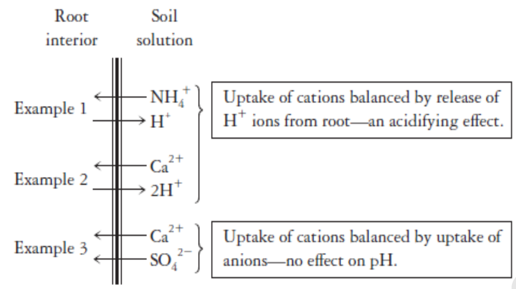
- rain, snow, and fog contain a variety of acids that contribute H+ to the soil receiving the precipitation.

$$H_2SO_4 \rightleftharpoons SO_4^{2-} + 2H^+$$

$$HNO_3 \rightleftharpoons NO_3^- + H^+$$

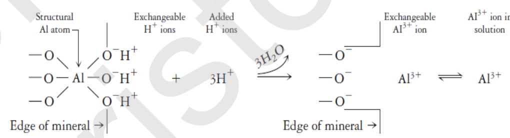
PLANT UPTAKE OF CATIONS

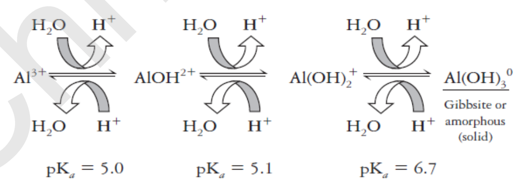
- for every positive charge taken in as a cation, a root can maintain charge balance either by taking up a negative charge as an anion or by exuding a positive charge as a different cation.



ROLE OF ALUMINUM IN SOIL ACIDITY

- Aluminum ions have strong tendency to hydrolyze, splitting water molecules into H^+ and OH^-
- most hydroxyl aluminum ions ($Al(OH)_{xy}^+$) formed as the pH increases are strongly adsorbed to clay surfaces or complexed with organic matter





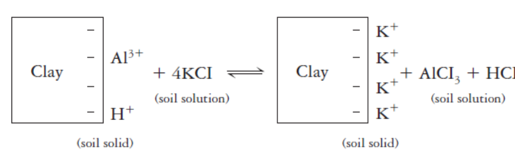
POOLS OF SOIL ACIDITY

ACTIVE ACIDITY- H+ IN THE SOIL SOLUTION

- determine the solubility of many substances and provide the soil solution environment to which plant roots and microbes are exposed.

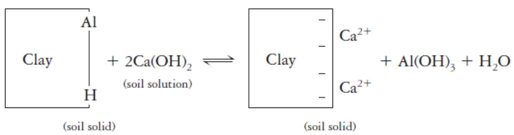
EXCHANGEABLE ACIDITY (SALT-REPLACEABLE)

- Al and H that are easily exchangeable by other cations in a simple unbuffered salt solution



RESIDUAL ACIDITY

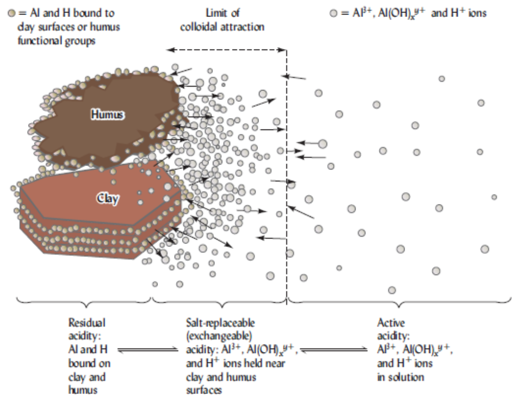
- o H that can be neutralized by limestone or other alkaline materials but cannot be detected by salt replacement
- o associated with hydrogen and aluminum ions that are bounded in nonexchangeable forms by organic matter and clays
- o as pH increase, bounded hydrogen dissociates and the bounded aluminum are released and precipitate as amorphous Al(OH)3



POTENTIAL ACIDITY
- o can arise upon the oxidation of sulfur compounds in certain acid sulfate soils

BUFFERING CAPACITY
- o the ability of the soil to resist sudden change in the pH of the solution when either acid or base is added
- o demonstrated by comparing the titration curves of pure water with that of the soil
- o the equilibrium that exist among the three principal pools of soil acidity (active, salt-replaceable and residual) explains the mechanism of soil buffering.
- o buffering tends to ensure stability of soil pH, preventing drastic fluctuations
- o buffering influences, the amount of amendments required to bring the soil pH to a desirable level (e.g. sulfur and lime)
- o higher CEC, greater buffering capacity

PRINCIPAL SOIL BUFFERING MECHANISMS
- o Hydrolysis, dissolution or precipitation of gibbsite and other aluminum and iron hydroxyoxide clay minerals
- o Protonation or deprotonation of organic matter functional groups
- o Protonation or deprotonation of pH dependent charge sites on clay minerals
- o Cation exchange reactions
- o The dissolution or precipitation of carbonate minerals



TYPES OF HUMAN INFLUENCED SOIL ACIDIFICATION

NITROGEN AMENDMENT
- o wide use of ammonium-based fertilizer materials such as ammonium sulfate and urea are oxidized in the soil by microbes to produce strongly inorganic acids
- o strong acids provide H+ that lower pH
- o H^+ ions are consumed by bicarbonates released when roots take up nitrate anions, net soil acidification results largely from the portion of applied nitrogen that is not consumed by plants
- o acidification results mainly from ammonium oxidation and subsequent nitrate leaching, but stimulated by increased crop yields and their heavy uptake and removal of non-acid cations
- o N-fixing legumes can acidify soils via the production of ammonium nitrogen and an imbalance between anion and cation uptake

APPLICATION OF ORGANIC MATERIALS
- o application of organic matter can decrease soil pH, both by oxidation of ammonium nitrogen released and by organic and inorganic acids formed during decomposition

ACID PRECIPITATION

ACID RAIN- includes all form of acidified precipitation (rain, snow, fog, dry deposition)
- o gases (sulfur dioxide and oxides of nitrogen) reacts with water and other substances in the atmosphere to form HNO3 and H2SO4 (strong acids)

ACID SULFATE SOILS

SULFIDIC- adjective used to describe any material with enough reduced sulfur to markedly lower the pH within a period of being aerated

- during waterlogged conditions, the potential acid sulfate soils retain the sulfur and iron in their reduced form, when soils are drained and aerated, sulfur and iron are oxidized, shifting from potential to active acid sulfate soils.
- acidification is caused by the production of sulfuric acid
- oxidation occurs by purely chemical means, but are generally facilitated by microorganisms (*Thiobacillus ferrooxidans* and *Ferroplasma acidipilum*) that hasten the reaction, especially in warm, moist conditions.
- iron sulfide compounds often give soils a black color

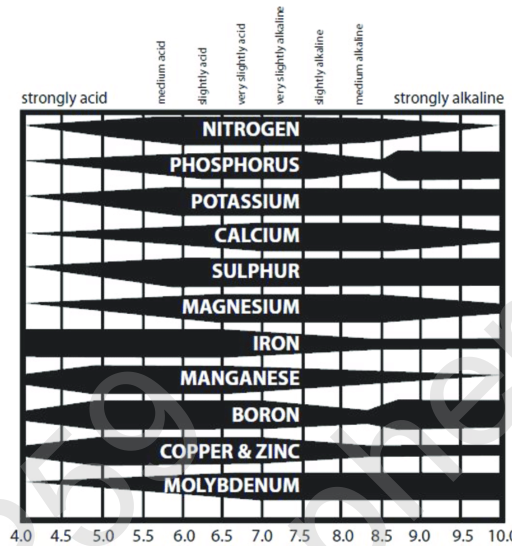
$$\underbrace{Fe^{II}S^{-I}_2}_{\text{Pyrite}} + 3\tfrac{1}{2}O_2 + H_2O \rightleftharpoons \underbrace{Fe^{II}S^{VI}O_4}_{\text{Ferrous sulfate}} + \underbrace{H_2S^{VI}O_4}_{\text{Sulfuric acid}}$$

$$\underbrace{Fe^{II}SO_4}_{\text{Ferrous sulfate}} + \tfrac{1}{4}O_2 + 1\tfrac{1}{2}H_2O \rightleftharpoons \underbrace{Fe^{III}OOH}_{\text{Iron oxyhydroxides}} + \underbrace{H_2SO_4}_{\text{Sulfuric acid}}$$

$$\underbrace{S^0}_{\text{Elemental S}} + 1\tfrac{1}{2}O_2 + H_2O \longrightarrow \underbrace{H_2SO_4}_{\text{Sulfuric acid}}$$

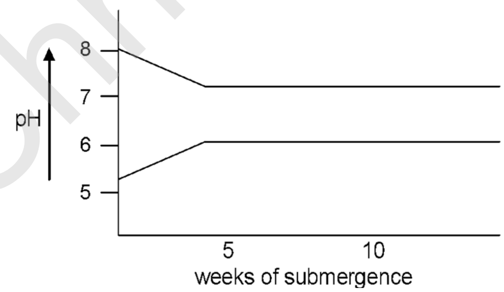
INFLUENCES OF SOIL PH

- **ALUMINUM TOXICITY**- most common and severe problem in acid soils
- Manganese, hydrogen, and iron toxicity
- Fungal activity tends to predominate in low pH because bacteria strong competitors and tend to dominate the microbial activity at intermediate and higher pH.
- **AVAILABILITY OF SOIL NUTRIENT ELEMENT**
  - At low pH, exchangeable bases have low availability
  - Mo availability is increased with increasing pH
  - Fe and N availability decrease with increase in pH
  - P and B tend to be available in calcareous soils due to reactions with Ca, P tends to be unavailable in very acid soils due to fixation by Al and Fe
  - Cu and Zn have reduced availability in both highly acidic and highly alkaline soils
  - Nitrification and N-fixation by bacteria is reduced at low pH, thus low N availability
  - Oxidation of S to SO4 is reduced under very low pH



SUBMERGENCE AND SOIL pH

- -the pH value of acidic soils increases on submergence on calcareous and sodic soils, for most soils, the fairly stable pH attains after several weeks of submergence is between 6.5 to 7.0



LIMING

- application of alkaline material that provide conjugate bases of weak acids to decrease soil acidity (raise soil pH)
- **CONJUGATE BASE**- anions that are capable of consuming H+ to form weak acids
- **LIMING MATERIAL**- used to change the chemical makeup of a substantial part of the root zone
- liming materials react with CO2 and water to form bicarbonate when applied to an acid soil.
- Ca and Mg bicarbonates are much more soluble than carbonates
- bicarbonates formed are reactive with the exchangeable and residual acidity

- adsorption of Ca and Mg lowers the acid saturation of the colloidal complex
- CO_2 will end up in the atmosphere because the partial pressure of CO_2 in the soil is much higher than that of the atmosphere
- liming contributes significantly to CO_2 emission
- silicates can be used as liming material that do not contain carbon that don't yield CO_2
- calcium silicate increases soil pH by consuming H^+ and replacing with Ca^{2+} on the exchange complex
- calcium silicate increases soil pH by consuming H^+ and replacing with Ca^{2+} on the exchange complex

$$CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2$$

$$Ca(HCO_3)_2 + H_2O \longrightarrow Ca(OH)_2 + 2CO_2 + H_2O$$

$$Ca(OH)_2 \longrightarrow Ca^{++} + 2OH^-$$

$$Ca^{++} + \left.\right]\begin{matrix}H\\H\end{matrix} \longrightarrow \left.\right]Ca^{++} + 2H^+$$

$$2H^+ + 2OH^- \longrightarrow H_2O$$

TYPES OF LIMING MATERIALS

- Calcitic limestone ($CaCO_3$)
- Dolomitic limestone ($CaMg(CO_3)_2$)
- Burned lime (CaO, MgO)
- Hydrated lime ($Ca(OH)_2$, $Mg(OH)_2$)
- Basic slag ($CaSiO_3$)- by product of steel making and naturally occurring mineral (e.g. Wollastonite)
- Marl ($CaCO_3$)
- Wood ashes (Cao, MgO, K_2O, K(OH), etc.)

EFFECTS OF LIME

- Decrease Al and Fe toxicity in very acid soils
- Increase Ca, Mg and Si availability
- Increase N supply due to the decomposition of alkali-soluble organic nitrogen
- Increase P availability

FACTORS AFFECTING LIME REQUIREMENT

- The change required in the pH or exchangeable Al saturation
- Buffering capacity of soil
- Amount or depth of the soil to ameliorate
- Chemical composition of the liming material to be used
- Fineness of the liming material

OVERLIMING

- "it is easy to add a little more lime later, but quite difficult to counteract the results of applying too much"
- Fe, Cu, Zn deficiency
- reduced availability of phosphate
- constrains in the absorption of B
- overliming is common in fine textured soil with high buffering capacity
- can also occur in sandy soils with low organic matter content

RELATIVE NEUTRALIZING POWER

- calculated on the basis of pure calcium carbonate as 100%

RNP1 X MW1 = RNP2 X MW2

OTHER METHODS IN AMELIORATING SOIL ACIDITY

GYPSUM ($CASO_42H_2O$) APPLICATION

- gypsum can ameliorate aluminum toxicity despite the fact the it does not increase soil pH
- more effective than lime in reducing exchangeable aluminum in subsoils and thereby improving root growth and crop yields
- Ca from gypsum moves down the soil profile more readily than that of lime
  - as lime dissolves, its reactions raise the soil pH, thus increasing the pH dependent charges on the soil colloid, which in turn retain the released Ca, preventing its downward leaching
  - the anion released by lime is either OH^- or CO_3^{2-}, both which are largely removed by the lime reactions, thus depriving the Ca^{2+} of surplus anions that could accompany them in the leaching process
- gypsum does not increase soil pH and so does not increase CEC
- the SO_4^{2-} released by the dissolution of gypsum is available to accompany Ca^{2+} in leaching
- gypsum increases the level of calcium and reduce the level of aluminum in both the soil solution and on the exchange complex
- released Al^{3+} react directly or indirectly with the sulfate ion

$$\boxed{\text{Fe, Al oxyhydroxides}}\begin{matrix}-OH\\-OH\end{matrix} + Ca^{2+} + SO_4^{2-} \longrightarrow \boxed{\text{Fe, Al oxyhydroxides}}{=}SO_4 + Ca^{2+} + 2OH^-$$

- the $Ca(OH)_2$ can react with Al^{3+} ions in the soil solution and form insoluble $Al(OH)_3$, thereby reducing the concentration of Al^{3+} while increasing that of Ca^{2+}

$$3\,Ca(OH)_2 + 2Al^{3+} \longrightarrow 2Al(OH)_3 + 3Ca^{2+}$$

- another mechanism is the detoxification of aluminum by gypsum thru the formation of $AlSO_4^-$ ions which is nonphytotoxic

ORGANIC MATTER APPLICATION

- more practical than standard liming practice for resource poor farmers and areas far from limestone deposits
- green manure crops and mulches can provide the organic material necessary to stimulate the reactions, thereby reducing Al^{3+} in the soil solution, even if the soil pH is not raised
- aluminum sensitive crops can be grown following the green manure crop

MECHANISM;

- High molecular weight organic matter can bind tightly with aluminum ions and prevent them from reaching toxic concentrations in the soil solution
- Low molecular weight organic produced by microbial decomposition or root exudates can form soluble complexes with aluminum ions that are nontoxic to plants and microbes
- Organic amendments contain substantial amounts of calcium held in organic complexes that leach quite readily down the soil profile

LOWERING SOIL PH

ACID ORGANIC MATTER

- as organic residues decompose, organic acids are formed, these can reduce soil pH if the organic matter is low in non-acid cations
  e.g. leaf mold from coniferous trees, pine needles

INORGANIC CHEMICALS

- supplying ammonium sulfate will promote rapid acidification
- aluminum sulfate or ferrous sulfate may be used if the addition of large amounts of nitrogen or acid organic matter is not feasible
- ferrous sulfate provides available iron Fe^{2+} for the plants and upon hydrolysis enhances acidity
- the process causes the release of fixed Fe in the soil

$$FeSO_4 + \tfrac{1}{4}O_2 + 1\tfrac{1}{2}H_2O \longrightarrow FeOOH + H_2SO_4$$

- elemental sulfur can be used in decreasing soil pH, as sulfur undergoes microbial oxidation, 2 moles of H^+ are produces for every mole of S oxidized
- 4-5 times more effective in developing acidity in comparison with ferrous sulfate

$$2S + 3O_2 + 2H_2O \longrightarrow 2H_2SO_4$$

- quantities to be applied depends on the soil's buffering capacity and the original soil pH

ALKALINE SOIL

- common in areas where precipitation is less than the potential evapotranspiration
- cations released by mineral weathering accumulate because there is not enough rain to thoroughly leach them away
- pH 7 and above
- minimal leaching in dry environments means minimized soil acidification
- **ALKALINITY**- the concentration of OH- ions
- **ALKALI SOIL**- an obsolete term for now is called sodic or saline sodic soil, those with levels of sodium high enough to be detrimental to plant growth and development
- **ALKALI**- the term is derived from the chemical groupings of elements into the monovalent alkali earth metals (Li, Na, K, Rb, Cs)
- **ALKALINE**- the term is derived from the chemical groupings of divalent earth metals (Be, Mg, Ca, St, Ba)*
- **EXCHANGEABLE BASES** (Ca^{2+}, Mg^{2+}, K^+, Na^+)- these cations are nonhydrolyzing and do not produce acid (H^+) upon reacting with water, however they do not produce OH- ions either.
- -their effect is rather neutral, and soil dominated by them tend to have pH of 7, unless certain anions are present in the solution.

FACTORS AFFECTING SOIL ALKALINITY

CARBONATE CO_3^{2-} AND BICARBONATE HCO_3^-

- o anions that generate –OH ions, they originate from the dissolution of minerals such as calcite ($CaCO_3$) or from the dissociation of carbonic acid (H_2CO_3)
- o carbonates and bicarbonates act as bases because they react with water to form OH^- and thus raising pH.

CALCITE PRECIPITATION

- o occurs when the soil solution becomes saturated of Ca^{2+} ions
- o removes Ca from the solution, driving the reaction towards the reactant side thus lowering the soil pH
- o calcite precipitates at pH 7.0-8.0, depending on how the CO_2 concentration is enhanced by microbial activity.

CATIONS

- o the particular cations associated with carbonate and bicarbonate anions influence the pH of the soil
- o Na and Ca are the principal cations involved
- o sodium carbonate and bicarbonate is much more soluble than calcium carbonate, producing more OH-, thus increasing pH

COMMON ION EFFECT

- o the shift in equilibrium that occurs due to the addition of an ion already involved in an equilibrium reaction
- o the presence of high levels of neutral salts in the soil solution tends to lower the pH by moderating the alkalinizing reactions.
- o Ca2+ and Na+ added other than CaCO3 and Na2CO3 will reduce the dissolution of carbonates, with less carbonates in the solution, fewer CO32- and HCO3- are formed, and pH does not rise as high as it would be if the less salts were present.

SALINITY- total concentration of salts

TOTAL DISSOLVED SOLIDS (TDS)

- o the total amount of dissolved salts is equivalent to the dry residues in a water heated in a container until all the water has evaporated (180 degrees centigrade, to ensure the water of hydration is removed), expressed as mg/L

ELECTRICAL CONDUCTIVITY (EC)

- o water in itself is a poor conductor of electricity, but conductivity increase as more salt is dissolved in water
- o EC gives an indirect measurement of salt content
- o expressed as deciSiemens per meter (dS/m), formerly millimhos per centimetre (mmho/cm)
- o 1 S= 1mmho, 1dS/m=1 mmho/cm
- o saturation paste extract- standard method in measuring EC

SODICITY- the tendency of sodium to cause deterioration of soil physical properties

EXCHANGEABLE SODIUM PERCENTRAGE (ESP)

- o the degree at which the exchange complex is saturated with sodium

ESP=(Exch. Na,cmol/kg)/(CEC,cmol/kg)×100

SODIUM ABSORPTION RATIO (SAR)

- o gives information on the comparative concentration of Na, Ca, and Mg in soil solution

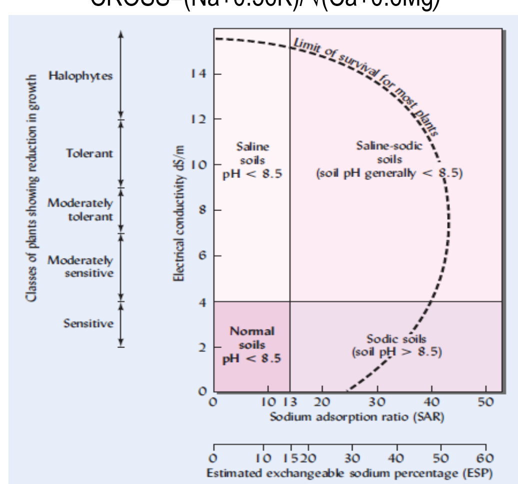
$$SAR = \frac{[Na^+]}{\{0.5[Ca^{2+}]+0.5[Mg^{2+}]\}^{\frac{1}{2}}}$$

- o SAR=13 is equal to ESP=15

CATIONS RATIO OF STRUCTURAL STABILITY (CROSS)

- o reflects theoretically and empirical observations that potassium ions are about 0.56 times as dispersive as sodium ions and magnesium ions are about 0.6 times as flocculating as calcium ions
- o -predict clay dispersion

CROSS=(Na+0.56K)/√(Ca+0.6Mg)



SALINE SOILS

- o soils that contain sufficient salinity to give EC values greater than 4dS/m, but have ESP less than 15 or SAR less than 13

- the exchange complex of saline soil is dominated by calcium and magnesium, not sodium
- pH usually below 8.5
- poor infiltration, aggregate stability and aeration are common plant constraints because soluble salts help prevent the dispersion of soil colloids
- soluble salts lower the osmotic potential of soil water making it difficult for roots to remove water from the soil, this condition requires more energy on osmotic adjustments, accumulating organic and inorganic solutes to lower the osmotic potential inside the cells to counteract the low osmotic potential of the soil solution.
- **WHITE ALKALI**- old term used to describe saline soils due to the presence of white crust on the surface due to the evaporation of water in the surface which leaves precipitates.

SALINE-SODIC SOIL

- soils that have EC levels greater than 4 dS/m and ESP greater than 15 and SAR greater than 13
- exhibit physical conditions intermediate between saline soil and sodic soils
- the high concentration of neutral salts moderates the dispersing influence of sodium
- the salts provide excess cations that move in close to the negatively charged colloidal particles, thereby reducing their tendency to disperse
- subject to rapid change if soluble salts are leached, in such case ESP will increase and salinity will drop, and the saline sodic soils will become sodic.

SODIC SOILS

- most troublesome of salt affected soils
- EC levels less than 4.0 dS/m, but have ESP above 15 and SAR above 13
- pH level exceeds 8.5, rising to 10 or higher
- high pH is due to the fact that sodium carbonate is much more soluble than calcium and magnesium carbonate, so the concentrations of CO32- and HCO3- in the solution is high
- plant growth is restricted by Na+, OH-, and HCO3- toxicity
- the high Na and low salt levels causes dispersion of clay, degradation of aggregate structure, and loss of macropores that restricts the movement of air and water
- low saturated hydraulic conductivity, reduced infiltration rate, as ESP increases, Ksat decreases
- puddling (similar to that of the rice paddy) is a characteristic of sodic soil
- due to poor physical conditions, oxygen becomes deficient and water relations are poor
- high levels of Na+ cause imbalances in the uptake and utilization of other cations
- Na+ competes with K+ in the process of transport across cell membrane during uptake, the presence of Ca2+ helps the plant discriminate against Na+ and K+

CAUSES OF LOW PERMEABILITY

SLAKING

- exchangeable NA increases the tendency of aggregates to break or slake upon becoming wet
- the clay and silt released by slaking clog soil pores as they are washed down

SWELLING

- as expanding type of clay becomes highly saturated with Na, their degree of swelling is increased.

DISPERSION

- the combination of high sodium and low ionic strength leads to soil dispersion
- Clay particles separate from one another, creating an almost gel-like condition
- dispersion is the opposite of flocculation

CAUSES OF SOIL DISPERSION

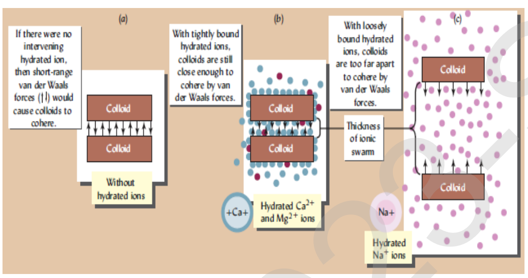
HIGH SODIUM

- the single charge and high hydrated size of Na attract only weak to soil colloids, and so they spread out to form a relatively broad swarm of ions held in very loose outer-sphere complexes around the colloid
- compared to the swarm of divalent cations, twice as many monovalent ions are needed to provide enough positive charges to counter the negative charges on a clay surface, a layer of monovalent Na ions is much thicker than that of a divalent cation such as Ca.
- Na saturated colloids are so far apart that the forces of cohesion cannot come into play to attract one colloids surface to another

- the poorly balanced electronegativity of each colloid surface repels other electronegative colloids

LOW SALT CONCENTRATION

- a low ionic concentration in the bulk of soil solution simultaneously increases the gradient causing exchangeable catios to diffuse away from the clay surface while it decrease the gradient causing anions to diffuse towards the clay which results to a thick ionic layer of adsorbed cations
- **FLOCCULATION VALUE**- concentration of dissolved salts that is just high enough to cause flocculation and prevent dispersion
- flocculation value increases as the proportion of exchangeable Na+ increases



- the effect of sodium can be counteracted by increasing the dissolved salt concentration
- the damaging effects of Na+ are greatest when salt concentrations are lowest
- **BLACK ALKALI**- old term used to describe sodic soils, due to the black color on the surface of the soil due to the evaporation of capillary water flow which carries dissolved and dispersed humus.
- low salt concentration and weakly attracted ions encourage soil dispersion and puddling, while high salt concentrations and strongly attracted ions promote clay flocculation and soil permeability

RECLAMATION

- restoration of soil chemical and physical properties conducive to high productivity

RECLAMATION OF SALINE SOILS

- dependent on the provision of effective drainage and the availability of good-quality irrigation water so the salts can be leached from the soil
- deep rooted vegetation to lower the water table and reduce the upward movement of salts is an applicable practice to areas where irrigation water is not available
- **LEACHING REQUIREMENT (LR)-** the amount of water needed to remove the excess salts from saline soils
- determined by the characteristic of the crop to be grown, the irrigation water and the spoil.

RECLAMATION OF SALINE-SODIC AND SODIC SOILS

- for both soils, attention must be given to reduce the level of Na^+ and the problem of excess soluble salts

GYPSUM APPLICATION- removing Na ions from the exchange complex is most effectively accomplished by replacing then with Ca^{2+} or H^+ ion, provided that the Ca^{2+} in the form of gypsum is the most practical way to carry out such exchange

- when exchangeable Na^+ ions are replaced by Ca and H, soil aggregation and infiltration is improved
- sodium salts formed from the chemical reactions can be easily leached from the soil, reducing both salinity and sodicity.
- soils should be kept moist to hasten the reaction, and the gypsum should be thoroughly mixed into the soil surface by cultivation, not simply plowed under

$$2NaHCO_3 + CaSO_4 \rightarrow CaCO_3 + \underset{\text{(leachable)}}{Na_2SO_4} + CO_2\uparrow + H_2O$$

$$Na_2CO_3 + CaSO_4 \rightleftharpoons \underset{\text{(insoluble)}}{CaCO_3} + \underset{\text{(leachable)}}{Na_2SO_4}$$

$$\begin{matrix} Na^+ \\ Na^+ \end{matrix}\boxed{\text{Colloid}} + CaSO_4 \rightleftharpoons Ca^{2+}\boxed{\text{Colloid}} + Na_2SO_4$$

SULFUR AND SULFURIC ACID ADDITION

- when sodium bicarbonate is high, sulfur and sulfuric acid can be used to reclaim sodic soils
- when S is oxidized, it yields sulfuric acid, which changes sodium bicarbonate to the less harmful and leachable sodium sulfate, and in effect pH decreases

$$2NaHCO_3 + H_2SO_4 \rightarrow 2CO_2\uparrow + 2H_2O + \underset{\text{(leachable)}}{Na_2SO_4}$$

$$Na_2CO_3 + H_2SO_4 \rightarrow CO_2\uparrow + H_2O + \underset{\text{(leachable)}}{Na_2SO_4}$$

$$\begin{matrix} Na^+ \\ Na^+ \end{matrix}\boxed{\text{Colloid}} + H_2SO_4 \rightleftharpoons \begin{matrix} H^+ \\ H^+ \end{matrix}\boxed{\text{Colloid}} + \underset{\text{(leachable)}}{Na_2SO_4}$$

DEEP ROOTED VEGETATION

- roots help provide channels through which gypsum can move into the soil, deep rooted crops help improve the water conductivity of gypsum treated sodic soils

AMMONIA EFFECTS

- the application of nitrogen as anhydrous ammonia to irrigation water has created some problem as ammonia reacts with water to form NH_4OH
- the high pH brought by the reaction causes the precipitation of calcium and magnesium cabonates, removing Ca and Mg though leaching, thus raising SAR and ESP.

$$NH_3 + H_2O \rightarrow NH_4OH$$

$$Ca(HCO_3)_2 + 2NH_4OH \rightarrow CaCO_3\downarrow + (NH_4)_2CO_3 + 2H_2O$$

$$Mg(HCO_3)_2 + 2NH_4OH \rightarrow MgCO_3\downarrow + (NH_4)_2CO_3 + 2H_2O$$

SOIL BIOLOGICAL PROPERTIES

SOIL ORGANISM
- creatures that spend all or part of their lives in the soil environment

Function of Soil Organisms in Relation to Higher Plants
- Organic matter production
- Nutrient cycling
- Breakdown of toxic substances
- Inorganic transformations
- Nitrogen fixation
- Plant protection

Classification of Soil Organisms

BASED ON NUTRITION

Carbon Source
- **AUTOTROPHS**
  CO2 sole or principal biosynthetic carbon source
- **HETEROTROPHS**
  Reduced, preformed, organic molecules from other organisms

Energy Sources
- **PHOTOTROPHS**
  Light
- **CHEMOTROPHS**
  Oxidation of organic and inorganic compounds

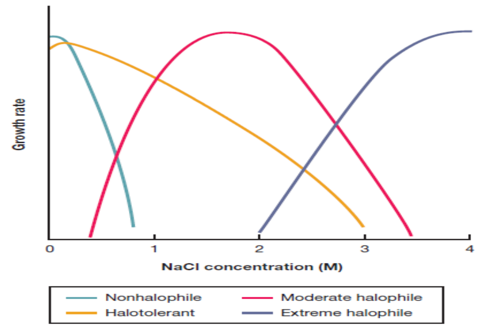
Electron Sources
- **LITHOTROPHS**
  Reduce inorganic molecules
- **ORGANOTROPHS**
  Organic molecules

Nutritional Type	Carbon Source	Energy Source	Electron Source	Representative Microorganisms
Photolithoautotroph	CO_2	Light	Inorganic e^- donor	Purple and green sulfur bacteria, cyanobacteria
Photoorganoheterotroph	Organic carbon	Light	Organic e^- donor	Purple nonsulfur bacteria, green nonsulfur bacteria
Chemolithoautotroph	CO_2	Inorganic chemicals	Inorganic e^- donor	Sulfur-oxidizing bacteria, hydrogen-oxidizing bacteria, methanogens, nitrifying bacteria, iron-oxidizing bacteria
Chemolithoheterotroph	Organic carbon	Inorganic chemicals	Inorganic e^- donor	Some sulfur-oxidizing bacteria (e.g., *Beggiatoa*)
Chemoorganoheterotroph	Organic carbon	Organic chemicals often same as C source	Organic e^- donor, often same as C source	Most nonphotosynthetic microbes, including most pathogens, fungi, and many protists and archaea

BASE ON SOLUTE AND WATER ACTIVITY

OSMOTOLERANT
- Able to grow over wide ranges of osmotic concentration

HALOPHILE
- Requires high levels of sodium chloride (above 0.2 M) to grow



BASED ON pH

ACIDOPHILE
- Growth optimum pH 0-5.5

NEUTROPHILE
- Growth optimum pH 5.5-8.0

ALKALOPHILE
- Growth optimum pH 8.0-11.5

BASED ON TEMPERATURE

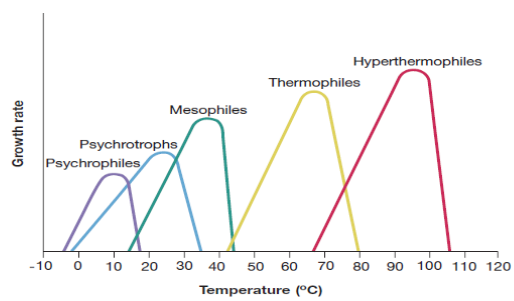
PSYCHROPHILE
- Grows at 0°C and has an optimum growth temperature of 15°C or lower

PSYCHROTROPH
- Can grow 0-7°C; has an optimum often between 20 and 30°C and a maximum around 35°C

MESOPHILE
- Gowth optimum around 20-45°C

THERMOPHILE
- Can grow at 55°C or higher; optimum often between 55 and 65°C

HYPERTHERMOPHILE
- Has an optimum between 80 and 113°C



BASED ON OXYGEN REQUIREMENT

OBLIGATE AEROBE
- Completely dependent on atmospheric O2 for growth

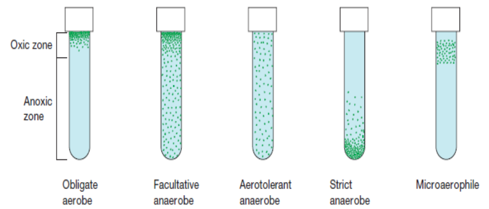
FACULTATIVE ANAEROBE
- Does not require O2 for growth but grows better in its presence

AEROTELERANT ANAEROBE

- Grows equally well in presence or absence of O2

OBLIGATE ANAEROBE
- Does not tolerate O2 and dies in its presence

MICROAEROPHILE
- Requires O2 levels between 2–10% for growth and is damaged by atmospheric O2 levels (20%)



SOIL BIODIVERSITY

BIODIVERSITY
- Set of animal and vegetable species, their genetic material and the ecosystem they belong to
- Function of time (evolution) and space (geographic distribution)

GENETIC DIVERSITY
- Designates gene and genotype variation within species.
- Consist of the whole set of genetic information contained in the genes of all the individuals.

SPECIES DIVERSITY
- Encompasses both the number and abundance of species present in a given area.
- Also takes into account the standard definition of "**SPECIES**"
    - A group of individuals able to breed (effectively or potentially) within a group and issue fecund offspring, where the progeny is morphologically similar.

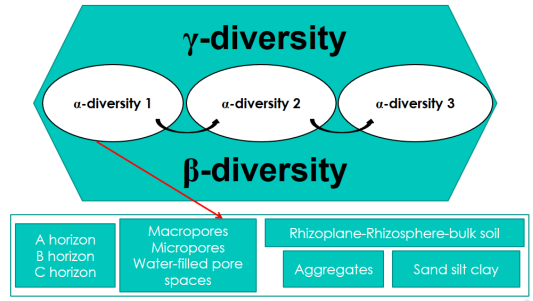
ECOSYSTEM DIVERSITY
- Number and abundance of habitats, of biotic communities, of biotic communities and of ecosystem within which the diverse organisms live.
- Made up of interdependent communities of species related to their physical environment and vary in size.

LEVELS OF DIVERSITY RESOLUTION

α-DIVERSITY
- diversity of species within a community of a habitat

β-DIVERSITY
- rate and extent in change of species along a gradient of habitats

γ-DIVERSITY
- richness of species over a range of habitats



FUNCTIONAL DIVERSITY
- capacity to utilize a wide variety of substrate and carry out a wide array of processes

FUNCTIONAL REDUNDANCY
- presence of several organisms to carry out each task that leads to ecosystem stability and resilience

STABILITY
- describes the ability of soil, even in the face of wide variation in environmental conditions and inputs, to continue to perform functions such as cycling of nutrients, assimilation of organic wastes and maintenance of soil structure

RESILIENCE
- ability of the soil to bounce back to functional health after a severe disturbance has disrupted normal processes

SOIL ORGANISMS

A. SOIL FAUNA

Classification of Soil Fauna Base on Size

MACROFAUNA (greater than 2 mm)
- moles, gophers, earthworm, millipede, centipedes)

MESOFAUNA (0.1 mm – 2 mm)
- springtails, mites and other arthropods

MICROFAUNA (less than 0.1 mm)
- nematodes, single celled protozoans

EARTHWORM (OLIGOCHAETES)
- egg laying hermaphrodites that eat detritus, soil organic matter and microorganisms
- natural tillers

- **CASTS**- expelled globules of ingested soil material
  - usually high in polysaccharides, which stabilizes the cast into granular structure
- prefer cool, moist and well aerated soil well supplied with decomposable organic materials
- optimum pH 5.5-8.5
- sensitive to excessive salinity
- **ENCHYTRAEID**- more tolerant in acidic conditions
  - smaller cousins of earthworms
  - size ranges from less than 1 mm to a few cm
  - population is strongly controlled by soil water potential, enchytraeids are not resistant to soil water stress

TYPES OF EARTHWORM

EPIGEIC
- live in the litter layer of an organic-rich soil very near the surface
- hasten the decomposition of litter but do not mix it in the mineral soil
- *e.g. Eisenia foetida*

ENDOGEIC
- live in the upper 10-30 cm of the mineral soil where they make shallow, large horizontal burrows
- *e.g. Allolobophora caliginosa*

ANECIC
- make vertical, relatively permanent burrows
- emerge in wet weather or at night to forage on the surface litter
- *e.g. Lumbricus terrestris*

ANTS
- most diverse in the humid tropics, but most functionally prominent in temperate semiarid grassland
- act as detritivores, herbivores, and predators (*Selenopsis invicta*, Red fire ant)

TERMITES
- live in complex social colonies
- most prominent in grassland and forest in tropical and subtropical regions
- white ants
- cellulose is the primary food material, and is digested by the enzymes produced by gut microorganisms
- create "islands of fertility" where they build their nests

NEMATODES
- commonly referred to as threadworm or eelworms
- unsegmented round worms
- highly mobile
- some are active and reproduce when soil water potential is so low
- sensitive to soil moisture and porosity
- trophic groups of nematodes is distinguished by the type of mouthparts present
- **CRYPTOBIOTIC STATE**- the resting state of the nematode
  - impervious to environmental conditions and use no detectable oxygen for respiration
  - occurs when the soil becomes too dry, and serve as a survival mechanism

PROTOZOA
- mobile, single celled organisms that capture and engulf their food
- unicellular animals
- most varied and numerous microfauna in soils
- larger than bacteria (4-250 um)
- prey upon bacteria, exerting significant influence on soil bacterial populations and decomposition pathways in soils
- thrive best in moist and well aerated soils
- feed on dissolved organic substances and other organisms (grazing and predation)

AMOEBA (TESTATE, NAKED)
- move by extending and contracting pseudopodia
- feed on bacteria, protozoa, yeast, fungal spores, algae

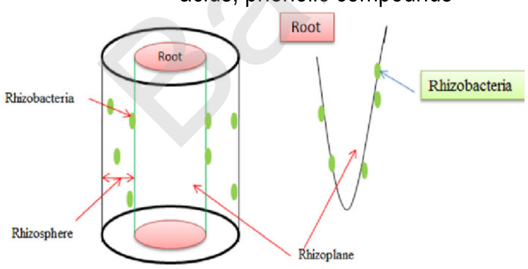
CILIATES
- moves by waving hair-like structure
- food is primarily bacteria, yeast or other protozoa

FLAGELLATES
- move by waving whip-like appendage called flagellum)
- **CYST**- resistant resting stage, forms when the soil dries and becomes food scarce.
- a rise in the number of bacteria if followed by the rise in the population of protozoa

  - protozoan grazing keeps the population physiologically young, thus more efficient in residue decomposition

B. SOIL FLORA
ROOTS

- **MUCIGEL**- a non-water soluble gel-like substance exuded by cells near root tips to lubricate the root's push through the soil
- **RHIZOSPHERE**- zone of soil significantly influenced by living roots
  - 2-3 mm from the root surface
- **ENDORHIZOSPHERE**- consist of the root cortex where the cells are lossely packed and the intercellular spaces that is filled with an extension of the soil solution and easily colonized by bacteria
- **RHIZOPLANE**- consist of the outer surface of the root including the root hairs adhering soil
- **EXTORHIZOSPHERE**- consist of soil close enough to the root to be profoundly under the its influence
- **RHIZODEPOSITION**- chemical additions of the root to the soil
  - Cells from the root cap and epidermis continually slough off as the root grows and enrich the rhizosphere with a wide variety of cell contents
  - Cells near the root tip excrete large quantities of mucigel
  - Epidermal cells are lysed by friction or microbial attack and spill their cell contents to the adjacent soil
  - Epidermal cells actively produce and exude specific compounds
  - Cortical cells passively leak a wide variety of plant metabolites, organic acids, sugars, amino acids, phenolic compounds



- **ALLELOPHATY**- a phenomenon in which some root exudates exert growth regulating influenced on other plants and soil microorganisms
  - Cortical cells export organic compounds directly to symbiotic fungi and bacteria, compounds that serve as substrate for beneficial microbes with which plants have evolved symbiotic relationships
- **RHIZOBACTERIA**- bacteria especially adapted to living in the rhizosphere
- **PLANT-GROWTH PROMOTING RHIZOBACTERIA (PGPR)** - beneficial rhizobacteria that promotes plant growth either thru direct or indirect mechanisms

SOIL ALGAE

- eukaryotic, photosynthetic, chlorophyll bearing
- 2-20 um
- grow best under moist to wet conditions, and very important in hot and cold desert conditions
- **LICHEN**- symbiotic association of fungi with algae and certain cyanobacteria

COMMON SOIL ALGAL DIVISIONS

- **CHLOROPHYCOPHYTA**- green algae
- **CHAROPHYTA**- stoneworts
- **EUGLENOPHYCOPHYTA**- euglenoids
- **PHAEOPHYCOPHYTA**- brown algae
- **CHRYSOPHYCOPHYTA**- golden and yellow-algae
- **PYRRHOPHYCOPHYTA**- Dinoflagellates
- **CRYPTOPHYCOPHYTA**- cryptomonads
- **RHODOPHYCOPHYTA**- red algae

SOIL FUNGI

- eukaryotic, aerobic, heterotrophic, non-chlorophyll bearing
- cell wall primarily made up of chitin
- most abundant in terms of biomass
- extensive, filamentous morphology
- hyphal length per m^2 and biomass is used to measure fungal presence in soils
- play significant roles in organic matter stabilization and aggregation
- can tolerate extreme low and high pH conditions
- most prominent and versatile of any groups of saprophytes in the soil
- more efficient in using organic materials they metabolize and convert it in cellular components (50% in fungi, 20% in bacteria)
- **WHITE ROT FUNGI**- a group of fungi that can break down more resistant materials

such as lignin and cellulose and even complex ring-structured compounds

- **YEAST**- single celled organisms, living in waterlogged anaerobic soils
- **MOLD** (*Penicillium, Mucor, Fusarium, Aspergillus*) and **MUSHROOM FUNGI**- filamentous fungi, characterized by thread-like, branching chains of cells
- **HYPHAE**- individual fungal filament
  - -septate or non-septate, commonly multinucleated
- **MYCELIA**-woven ropes of hyphae
- **MYCOTOXINS**- highly toxic chemicals that are produced by fungi
  e.g. *Aspergillus flavus*- aflatoxin

FUNGI COMMONLY ASSOCIATED WITH SOIL AND PLANTS

- **SLIME MOLDS**
  - Acrasiomycetes
  - Myxomcetes
- **FLAGELLATE FUNGI**
  - Oomycetes
  - Chytrisiomycetes
- **SUGAR FUNGI**
  - Zygomycetes
- **HIGHER FUNGI**
  - Ascomycetes
  - Basidiomycetes
- **FUNGI IMPERFECTI**
  - Deuteromycetes
  - Mycelia sterilia

MYCORRHIZAE

- Root fungus
- association between fungi and roots of higher plants
- greatly enhance the ability of plants to take up of water, phosphorus, and relatively immobile and nutrient that has a low concentration in the soil solution
- protects plants from aluminum toxicity and excessive uptake of potential toxins
- protects plants from certain soil borne diseases and parasitic nematodes by producing antibiotics, altering root epidermis, and competing with fungal pathogens for infection sites.

TYPES OF MYCRORRHIZAE
ECTOMYCORRHIZAE (EM)

- the hyphae penetrate the roots and develop in the free space around the cells of the cortex but do not penetrate the cortex walls
- ecto=outside
- causes infected root system to consist of stuby, white structures with a characteristic Y shape, visible to the naked eye
- **HARTIG NET**- net-like fungal structure in the cortical cells of roots.
- **ROBERT HARTIG**- father of forest biology
- Occurs in plants under Pinaceae, Fagaceae, Betulaceae, Myrtaceae
  e.g. Botelus betulicola, Pisolithus arhizus

ARBUSCULAR MYCORRHIZAE (AM)

- most important member of endomycorrhiza
- penetrate the cortical cell walls and form small, highly branched structures called
- **ENDOMYCORRHYZAE**- general tem for mycorrhizal fungi that grows within the cortical cells
- **ARBUSCULES**- transfers nutrients from the fungus to the host plant, and sugars from the plant to the fungus
- **VESICLES**- serves as storage organs for the mycorrhizae
  - also serves as reproductive propagule for fungi
- **AUXILLARY CELLS**- coiled or knobby
- all fungi that form AM are classified under order Glomales
- **GLOMINEAE**- vesicles in the roots and the formation of chlamydospores borne from subtending hyphae
- **GIGASPORINEAE**- absence of vesicles in the root and formation of auxiliary cells and azygospores

ERICACEOUS MYCORRHIZAE

- mycrorrhyzal associations found on plants in the order Ericales
- can penetrate cortical cells but no arbuscules are formed

TYPES OF ERICACEOUS MYCORRHIZAE
ERICOID

- cells in the inner cortex becomes packed with fungal hyphae. A loose welt of hyphae grows over the root surface, but a true mantle is not formed
  - Ascomycetes of the genus Hymenoscyphus

ARBUTOID

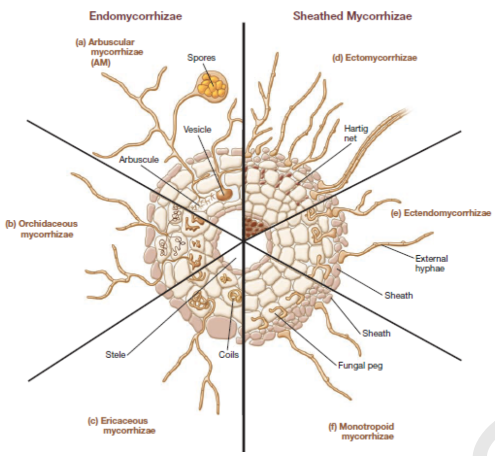
- characteristics of both EM and endomycorrhyzae are found
- -intercellular penetration can occur, a mantle forms, and a hartig net is present
  - Basidiomycetes

MONOTROID

- a fungi colonize achlorophyllous plants in Monotropaceae producing hartig net and mantle

ORCHIDACEOUS MYCORRHYZAE

- fungus grows inside the orchid shortly after germination, invaginating the cell membrane and forming hyphal coils within the cells



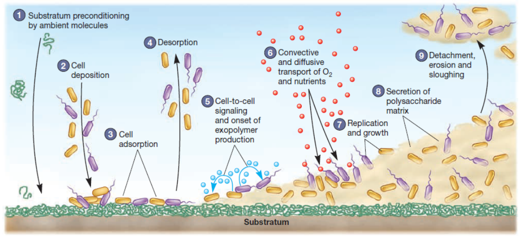
PROKARYOTES: BACTERIA AND ARCHAEA

- lack membrane bound nucleus
- 0.5-5 um
- variety of shapes; coccus (round), bacillus (rod), spirillum (spiral)
- rod-shaped predominate in the soil
- motility by means of cilia (hair-like) or flagella (whip-like)
- social organisms, individual cells act together in a coordinated manner to form a "super organism"
- communication via exocellular chemical signals that diffuse in the soil solution and protein shared via intercellular connections
- autotrophic or heterotrophic
- participate in almost all the organic processes/transactions that characterize a healthy soil
- monopolies the oxidation or reduction of certain chemical elements in the soil

BACTERIA

- most numerous of the microorganisms
- cell wall is principally composed of peptidoglycan
- **CONJUGATION**-involves transfer of large portions of genetic material between donor and recipient cells in mating pairs
- **TRANSDUCTION**-involves direct transfer of DNA by bacteriophages
- **BACTERIOPHAGE**- bacteria attacking virus
- **AUTOCHTHONOUS ORGANISMS**- those growing slowly in the soil containing no easily oxidizeable substrate
  - most competitive at low substrate concentrations
  - indigenous soil organism that 'tick over' under conditions of low substrate availability and persist actively in soils for long periods of time
  - autochthonous populations have a fairly low maximum specific growth rate, but a very low Michaelis constant.
- **ZYMOGENOUS ORGANISMS**- burst activities when fresh residues are added to the soil
  - not a significant component of the soil community under normal conditions, but proliferate when considerable additions of substrate are introduced to the soil
  - capable of rapid multiplication and then tends to revert to resistant spore structures once the substrate has been largely exhausted
  - in physiological terms, zymogenous populations tend to have a high maximum specific growth rate and high Michaelis constant
- **r-STRATEGIST**- populations of species that intrinsically provide for rapid proliferation in response to abundance in resource/substrate
  - analogous to zymogenous populations
- **K-STRATEGIST**- populations or species living near the carrying capacity of the environment
  - Analogous to autochthonous populations
- **G+ GRAM POSITIVE**- cells retain the crystal violet following subsequent exposure to KI solution, alcohol and counterstain
- **G- GRAM NEGATIVE**- cells from which the crystal violet readily distains
- **BINARY FISSION**- reproductive mechanism of bacteria

- **BIOFILMS**- dense colonies of cells embedded in layers of excreted polysaccharides



ARCHAEA
- cell membranes of archaea differ from bacteria, such as the use of isoprene derivatives instead of fatty acids
- most important group in the breakdown of hydrocarbon compounds, e.g. petroleum

CYANOBACTERIA
- previously called blue-green algae
- chlorophyll bearing
- numerous in rice paddies and other wetland environments
- fix appreciable amounts of nitrogen
- forms microbial crusts
- tolerant to saline and arid conditions

ACTINOMYCETES
- term traditionally used for bacteria in the order actinomycetales within the phylum actinobacteria
- develop well in most, warm and well aerated soils
- can tolerate low osmotic potentials
- active in arid-regions, salt affected and drought conditions
- filametous and often profusely branched, that has a fungi-like appearance
- important in decomposition and mineralization
- capable of breaking resistant compounds, cellulose, chitin, and phospholipids
- become dominant in the later stages of decay when the easily metabolized substrates have been used up (curing stage of composting)
- **GEOSMINS**- volatile derivatives of terpene, that gives the soil the earthy aroma of soils
- **STREPTOMYCETES**- a genus of Actinomycetes capable of producing antibiotics (Streptomyces)

MAJOR GENERA OF ACTINOMYCETES IN SOILS
- **MICROMONOSPORA**
- **NOCARDIA**
- **STREPTOMYCES**
- **STREPTOSPORANGIUM**
- **THERMOACTINOMYCES**

VIRUS
- consist of RNA and DNA molecules with a protein coat
- metabolically inert and do not carry out respiratory or biosynthetic functions

SOIL CHARACTERISTICS THAT INFLUENCE THE ACTIVITY OF SOIL MICROORGANISMS

ORGANIC RESOURCES
- the addition of energy-rich organic substances stimulates microbial growth
- bacteria respond most rapidly to the additions of simple organic compounds
- fungi and Actinomycetes overshadow other microbes if the added organic resources are rich in cellulose and other resistant compounds
- fungi dominate the microbial activity in surface litter
- bacteria play vital roles of substrates are mixed with the soil

OXYGEN LEVEL
- **AEROBIC**- uses O2 as the electron acceptor in their metabolism
- **ANAEROBIC**- uses other substances other than O2 as electron acceptor
- **FACULTATIVE**- can either be aerobic or anaerobic

MOISTURE AND TEMPERATURE
- optimum moisture potential is best for aerobic microbes
- too high water content limits oxygen supply
- microbial activity is greatest at 20-40 degrees centigrade
- psychrophilic microbes- most efficient at temperature ranging from 3-5 ^{o}C- **BIOLOGICAL ZERO**
- thermophiles- microbes that prefer temperatures greater than the mesophilic range

EXCHANGEABLE CALCIUM AND pH
- determine the specific organism that will thrive in a particular soil
- high calcium and near-neutral pH-prokaryotes dominate
- bacteria diversity increases with pH
- fungi dominate under low pH conditions

SOIL ORGANIC MATTER (SOM)

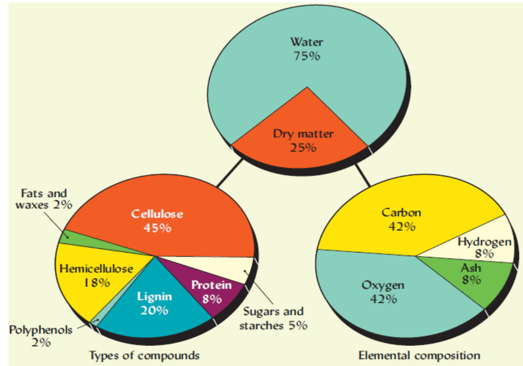
- refers to the entire organic portion of the soil
- complex mixture of substances that exist in association with other soil components
- surface residue is not considered to be part of SOM
- encompasses all the organic components of the soil;
  - living biomass
  - plant litter or residues (particles that do not pass 2 mm sieve opening is not included)
  - dissolved organic biomolecules
  - complex mixture of biomolecule agglomerates on particle surface no longer identifiable tissues occluded inside micro aggregates and charred materials
- **SOIL ORGANIC CARBON (SOC)-** used to refer to the C component of soil organic matter
- SOM is higher in temperate areas than in tropical areas
- **PARTICULATE ORGANIC MATTER (POM)**-bits of plant tissue and microbial cell walls
- **HUMUS**- dark-colored, heterogeneous, mostly colloidal-sized mixture of bits of plants and microbial tissues, modified lignin and other plant compounds
  - relatively stable because it is much less water soluble and its association with the mineral fraction of the soil makes it less susceptible to enzymatic attack

POOLS OF ORGANIC MATTER

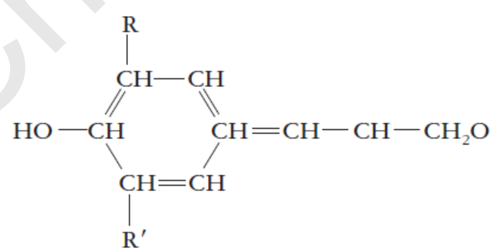
Pool	Constituents	Mean residence time (years)
Labile pool		
(i) Metabolic litter	Plant and animal residues, cellulose	<0.5
(ii) Structural litter	Plant residues, lignin, polyphenol	0.5–2
Active labile pool	Microbial biomass, simple carbohydrates, enzymes	0.2–1.5
Intermediate pool	Particulate organic matter	2–50
Recalcitrant pool	Humic and fulvic acids, organo-mineral complexes	500–2000

ORGANIC MATTER DECOMPOSITION

- Composition of plant material



- **CELLULOSE**- most abundant polysaccharide
- the linking the sugar molecules are difficult to break that those of starch
- **CELLULASE**- enzyme that can break the bonds cellulose, thus catalysing the decomposition of starch
- **LIGNIN**- complex compound with multiple phenol structures
  - Component of cell wall
  - lignin content increases as plant matures, especially in woody tissues
  - complex molecule consisting of hundreds of interlinked phenolic ring subunits, mostly are phenylpropene-like structures with various methoxyl ($-OCH_3$) groups attached



- **PROTEIN**- when undergo decomposition yields, CO_2, water, and amino acids, in turn these amino acids are further broken down into ammonium, nitrate and sulfate ions

  RATE OF DECOMPOSITION
- Simple sugars, starches, and simple proteins > crude protein > cellulose > hemicellulose > fats and waxes > lignin and phenolic compounds

DECOMPOSITION

- breakdown of large organic molecules into smaller, simple components

PROCESSES

- **ENZYMATIC OXIDATION**

$$\underset{\text{Carbon- and hydrogen-containing compounds}}{R\text{—}(C, 4H)} + 2O_2 \xrightarrow[\text{oxidation}]{\text{Enzymatic}} CO_2\uparrow + 2H_2O + \text{energy } (478 \text{ kJ mol}^{-1} \text{ C})$$

- **RELEASE OF ESSENTIAL NUTRIENT ELEMENTS**
- **SYNTHESIS OF NEW COMPOUNDS**
- **PROTECTION FROM FURTHER MICROBIAL DECAY**
  - **PHYSICAL PROTECTION-** organic material lodge inside soil pores too tight to allow access by most organisms
  - **CHEMICAL PROTECTION-** binding tightly with the surface of mineral particles

SOIL RESPIRATION
- shows the rate of microbial activity in soil by monitoring the CO2 emission from the soil

K-STRATEGIST
- developed enzymes with high affinity constants for specific types of resistant substances
- competitive advantage when the soil is poor in easily digestibale organic materials
- maintain a low but constant population

r-STRATEGIST
- rapid rate of growth and reproduction that allows them to take advantage of a sudden influx of food

PRIMING EFFECT
- the stimulated breakdown of some of the more protected soil organic matter brought by intense microbial activity

ANAEROBIC DECOMPOSITION
- occurs in waterlogged conditions
- products are partially decomposed organic compounds, acids, alcohols, and methane gas
- commonly products of anaerobic decomposition have foul odour
- releases low amounts of energy
- typically carries out by methanogenic bacteria and archaea
- anaerobic soils tend to accumulate large amounts of partially decomposed organic material;
  - under low oxygen conditions, decomposition takes place slowly,
  - certain products of anaerobic metabolism are toxic to many microbes

FACTORS AFFECTING ORGANIC MATTER DECOMPOSITION

CN RATIO
- lower CN ratio, faster decomposition

OXYGEN SUPPLY
- more oxygen bought by good aeration, faster decomposition

MOISTURE

TEMPERATURE
- higher temperature, higher rates of decomposition

pH= near neutral pH

AMOUNT OF PHENOLIC COMPOUNDS
- the higher the amount of phenolic substances such as lignin and tannins, the slower the decomposition rate.

INFLUENCE OF OM ON PLANT GROWTH AND SOIL FUNCTION
- **BIOLOGICAL**
  - increases microbial diversity
  - provides food for heterotrophic organisms
  - improves SOM accumulation
- **CHEMICAL**
  - Increases CEC
  - Increases nutrient availability through chelation
  - Alleviates Al toxicity by binding Al in nontoxic complexes
- **PHYSICAL**
  - encourages granulation
  - improves aggregate stability
  - reduce plasticity, cohesion and stickiness in clayey soils
  - increase infiltration and water holding capacity

COMPOSTING
- controlled biological aerobic decomposition of organic materials into stable humus-like substance called compost

- process by which various aerobic microorganisms decompose raw materials to obtain energy and material they needed for growth and development
- essentially the same process as natural decomposition except that it is enhanced and accelerated by mixing organic wastes with other ingredients to optimize microbial activity

STAGES OF COMPOSTING

ACTIVE STAGE
- period of vigorous microbial activity
- readily degradable materials and compounds is decomposed as well as some of the more decay resistant materials (priming effect)
- characterized by the rapid increase in temperature

CURING STAGE
- follows the active stage
- lower level of microbial activity
- further decomposition of the decay resistant materials
- mineral transformations

PRINCIPAL COMPONENTS OF THE COMPOST MIX

PRIMARY SUBSTRATE
- main waste material that requires treatment (e.g. rice straw)

AMENDMENT
- any material that can be mixed with the primary substrate to balance the CN ratio, modify pH, improve stability and achieve proper moisture content (e.g. manure)

BULKING AGENT
- decay resistant material whose main purpose is to provide structure and porosity of the pile (e.g. carbonized rice hull)

COMPOSTING METHODS

PASSIVE PILES
- involves forming the mix of raw materials into a pile that is turned periodically primarily to rebuild porosity
- aeration is achieved by the passive movement of air through the pile

WINDROW SYSTEM
- windrow is elongated and is turned periodically
- aerated by passive aeration

PASSIVELY AERATED WINDROWS
- windrows are not turned

AERATED STATIC PILES
- uses blowers that either suck the air into the pile, or blow air into the pile using positive pressure

SUCTION METHOD
  - better odor control

BLOWER METHOD
  - has better cooling effect to the pile

- **IN-VESSEL SYSTEM**

BIN
  - uses constructed bins

RECTANGULAR BED
  - uses long, narrow beds and automated turner for periodic turning

SILO
  - rapid composting method that requires a prolong curing stage

ROTATING TUBE
- used when small amount of water is required for composting

MICROBIAL TRANSFORMATIONS OF N

MINERALIZATION
- conversion of organic N to inorganic N which renders N available for plant use

IMMOBILIZATION
- conversion of inorganic N to organic N which renders N unavailable for plant use
- occurs when available N is used by soil microorganisms and assimilated into their bodies

$$\xrightarrow{\hspace{3em}} \text{Mineralization} \xrightarrow{\hspace{3em}}$$

$$R{-}NH_2 \underset{-2H_2O}{\overset{+2H_2O}{\rightleftharpoons}} OH^- + R{-}OH + NH_4^+ \underset{-O_2}{\overset{+O_2}{\rightleftharpoons}} 4H^+ + \text{energy} + NO_2^- \underset{-\frac{1}{2}O_2}{\overset{+\frac{1}{2}O_2}{\rightleftharpoons}} \text{energy} + NO_3^-$$

$$\xleftarrow{\hspace{3em}} \text{Immobilization} \xleftarrow{\hspace{3em}}$$

AMMONIFICATION
- process by which ammonia is produced by the microbial breakdown of organic matter

ANAMMOX
- anaerobic oxidation of NH4+ in conjuction with NO2- (electron acceptor) to produce N2O gas
- more recently discovered bacterial process
- anammox bacteria are very unusual group of microorgansms within the phylum

Planctomycetes, also have some features more typical in archaea and fungi

$$NH_4^+ + 1\tfrac{1}{2}O_2 \rightarrow NO_2^- + 2H^+ + H_2O \text{ (aerobic)}$$

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O \text{ (anaerobic)}$$

$$2NH_4^+ + 1\tfrac{1}{2}O_2 \rightarrow N_2 + 2H^+ + 3H_2O \text{ (combined net anammox reaction)}$$

- carbon source is CO2, so no organic carbon is needed for anammox to occur
- the process requires the presence of linked oxidizing and reducing environments
- typically occurs in redox transition zones (e.g. upper layers of saturated soils, capillary fringe above the water table, rhizosphere, interior of microaggregates in moderately wet soils

NITRIFICATION

- microbial oxidation of ammonium to nitrite and subsequently to nitrate
- carried out by autotrophs
- significantly increase soil acidity by producing H+ ions (reaction 1)

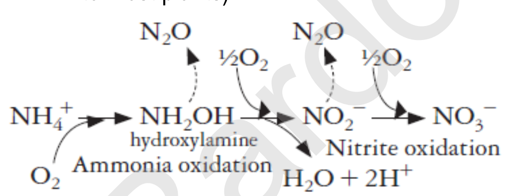
Steps;

- oxidation of ammonium to nitrite (carried by bacteria of the genus Nitrosomonas)
- oxidation of nitrite to nitrate (carried by bacteria in the genus Nitrobacter)

$$\underset{\text{Ammonium}}{NH_4^+} + 1\tfrac{1}{2}O_2 \xrightarrow[\text{bacteria}]{\textit{Nitrosomonas}} \underset{\text{Nitrite}}{NO_2^-} + 2H^+ + H_2O + 275 \text{ kJ energy}$$

$$\underset{\text{Nitrite}}{NO_2^-} + \tfrac{1}{2}O_2 \xrightarrow[\text{bacteria}]{\textit{Nitrobacter}} \underset{\text{Nitrate}}{NO_3^-} + 76 \text{ kJ energy}$$

- the second reaction follows the first very closely enough to prevent the accumulation of nitrite (nitrite is quite toxic to most plants)



- when oxygen supply is limited, nitrifying bacteria may produce some NO and N2O which are potent greenhouse gas

FACTORS AFFECTING NITRIFICATION

OXYGEN SUPPLY

- nitrification if favoured by well drained soils

MOISTURE CONTENT

- 60% of the pore spaces is filled with water

TEMPERATURE

- 20-30 degrees centigrade
- proceeds rapidly when there is an abundance of exchangeable Ca++ and Mg++
- constrained by soils high in smectite or allophane clays

DISSIMILATORY NITRATE REDUCTION TO AMMONIUM

- anaerobic bacterial process that reduces NO3- to NO2- and then to NH4+

DENITRIFICATION

- anaerobic process by which heterotrophic bacteria reduces nitrate to NO, N2O, and N2
- mostly carried out by heterotrophic facultative anaerobic bacteria (Pseudomonas, Bacillus, Micrococcus, Achromobacter)
- some are autotrophic (Thiobacillus denitrificans)

$$\underset{\substack{\text{Nitrate ions}\\(+5)}}{2NO_3^-} \xrightarrow{-2O} \underset{\substack{\text{Nitrite ions}\\(+3)}}{2NO_2^-} \xrightarrow{-2O} \underset{\substack{\text{Nitric oxide gas}\\(+2)}}{2NO\uparrow} \xrightarrow{-O} \underset{\substack{\text{Nitrous oxide gas}\\(+1)}}{N_2O\uparrow} \xrightarrow{-O} \underset{\substack{\text{Dinitrogen gas}\\(0)}}{N_2\uparrow} \longleftarrow \text{Valence state of nitrogen}$$

- oxygen released from the reaction is used to form CO2 or SO4--- (Thiobacillus) by the nitrifying organism)

SOIL CONDITIONS THAT INFLUENCE DENITRIFICATION

- Low oxygen level, 10% or lower (at very low oxygen levels, the end product released form the overall denitrification process is N2, NO and N2O is also released especially in fluctuating aerobic conditions)
- Optimum temperature at 25-35 degrees centigrade, but process will still occur at 2-50 degrees centigrade
- Very string acidity inhibits rapid denitrification and favours the formation of N2O
- **CODENITRIFICATION**= related microbial process by which nitrate in the soil solution is reduced to N_2O and N_2 gases by such nitrogen compounds as NH_4 or NH_2OH
    - carried out by bacteria and fungi (e.g. *Streptomyces* spp, *Fusarium oxysporum*)

- fungal codenitrification is the main source of N_2 emission from grassland soils.

AMMONIFICATION

- release of ammonium ions from organic compounds

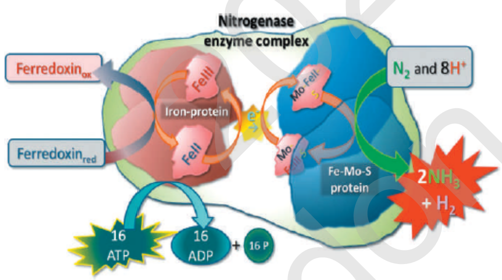
BIOLOGICAL N FIXATION (BNF)

- next to photosynthesis, probably the most important biochemical reaction for life on earth
- coverts inert N_2 to reactive N that becomes available to all life forms.
- carried out by a limited number of bacteria (rhizobium species), actinomycets, and cyanobacteria)
- Mechanism of reaction

$$N_2 + 8H^+ + 6e^- \xrightarrow[\text{(Fe,Mo)}]{\text{(Nitrogenase)}} 2NH_3 + H_2$$

$$NH_3 + \text{organic acids} \longrightarrow \text{amino acids} \longrightarrow \text{proteins}$$

- **NITROGENASE**
  - catalyses the reduction of N_2 to ammonia
  - an enzyme complex, consisting of two proteins, the smaller which contains Fe while the larger which contains Mo, S, and Fe



Salient features
  - Breaking the strong triple bond of N2
  - Rendered ineffective by free oxygen
  - **LEGHEMOGLOBIN**
    - binds the oxygen in such way as to protect the nitrogenase while making oxygen available for respiration in other parts of the nodule tissue
    - gives the actively fixing nodules a red interior color
    - virtually the same with the haemoglobin molecule
  - Reduction reaction is end-product inhibited
  - N-fixing plants have relatively high requirement for Mo, Fe, P, and S

SYMBIOTIC BNF

- occurs primarily in the plant legume family (fabaceae)
- legume association with several genera of bacteria (in the sub class apha-proteobacteria) collectively known as rhizobial bacteria.
- genus Rhizobium, Mesorhizobium, Bradyrhizobium, Ensifer
- **SYMBIOSIS**- mutual beneficial relationship among organisms
- **ROOT NODULE**-site of nitrogen fixation
- **CROSS INOCULATION GROUP**- a legume can only be inoculated by a given rhizobium species
  - specificity of interaction

Bacteria		
Genus	Species/subgroup	Host legume
Ensifer	*E. meliloti*	*Melilotus* (sweet clovers), *Medicago* (alfalfa), *Trigonella* spp. (fenugreek)
Rhizobium	*R. leguminosarum*	
	bv. *viceae*	*Vicia* spp. (vetches), *Pisum* (peas), *Lens* (lentils), *Lathyrus* (sweet pea), *Vicia faba* (faba bean)
	bv. *trifolii*	*Trifolium* spp. (most clovers)
	bv. *phaseoli*	*Phaseolus* spp. (dry bean, string bean, etc.)
	R. Fredii	*Glycine* spp. (e.g., soybean)
	R. spp.	*Securigera varia* (crown vetch)
	R. spp.	Trees in Leucaena group: *Leucaena* spp. *Sesbania grandiflora; Calliandra calothyrsus; Gliricidia sepium; Prosopis* spp.
	R. lupini	*Lupinus* spp. (lupins)
Bradyrhizobium	*B. japonicum*	*Glycine* spp. (e.g., soybean)
	B. spp.	*Vigna* (cowpeas, mung bean), *Arachis* (peanut), *Cajanus* (pigeon pea), *Pueraria* (kudzu), *Crotalaria* (crotalaria), and many other tropical legumes; *Phaseolus lunatus* (lima bean) *Acacia* spp. (acacia trees), *Desmodium* spp., *Stylosanthes* spp., *Centrosema* sp., *Psophocarpus tetragonolobus* (winged bean), *Lablab purpureus* (Lablab bean), *Pueraria phaseoloides*
Mesorhizobium	*M. loti*	*Lotus* (trefoils), *Lupinus* (lupins), *Cicer* (chickpea), *Anthyllis*, *Leucaena*, and many other tropical trees
Azorhizobium	*A.* spp.	Produces stem nodules on *Sesbania rostrata*

N FIXATION IN NON LEGUMES

- occurs in some plant families known to develop nodules and accommodate symbiotic N fixation when the roots are infected with actinomycetes of the genus franskia
- common in actinorhizal plants (e.g. genus Alnus, Ceanothus, Myrica, Casuarina, Eleaegnus, Coriaria)
- genera form symbiotic association with the cyanobacteria of the genus Nostoc, which forms nodules

SYMBIOTIC N FIXATION WITHOUT NODULE

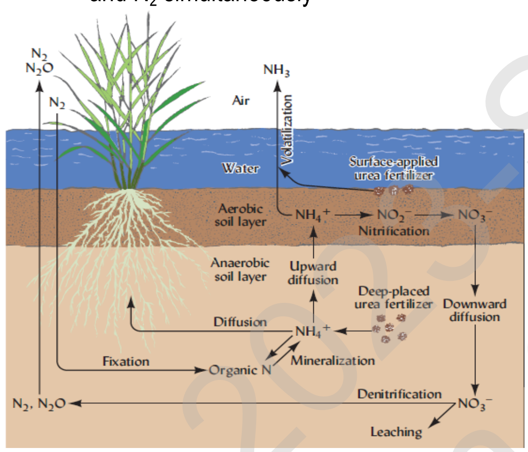
- cyanobacteria is the most significant non nodule nitrogen fixing organism
- **AZOLLA**- anabaena complex
  - anabaena cyanobacteria inhabit the cavities of the leaves of the floating fern azolla
  - the fixed N is comparable with those of rhizobium-legume complexes

NON SYMBIOTIC N FIXATION
FIXATION BY HETEROTROPHS

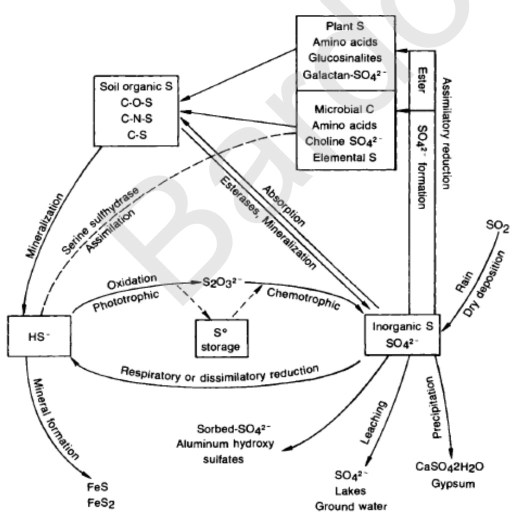
- several groups of bacteria and cyanobacteria are able to fix nitrogen non-symbiotically
  e.*g.* heterotrophic aerobic organisms= *azotobacter, azospirillum, Beijerinckia,*
  e.g. anaerobic bacteria=Clostridium

FIXATION BY AUTOTROPHS

- carried out by certain photosynthetic bacteria and cyanobacteria that fixes CO_2 and N_2 simultaneously



MICROBIAL TRANSFORMATION OF S



SOURCES OF S

- **ORGANIC MATTER**
  - Forms of organic S in SOM
  - Reduced forms of S to C (sulphides, disulfides, thiols, thiophenes) in proteins such as cysteine, cysteine, and methionine.
  - Intermediate redox state (sulfoxides, sulfonates) in which S is bonded to C but also to O (C-S-O)
  - Highly oxidized forms of S in ester sulfates (C-O-S), in which S is bound to oxygen rather than directly to C

SOIL MINERALS

- inorganic S is primarily present in either sulfates or sulfides
- **SULFUR GASES**
  e.g carbonyl sulfide, hydrogen sulfide, sulfur dioxide

MINERALIZATION

- when conditions are favourable for microbial growth, S mineralization occurs

$$\underset{\text{Proteins and other organic combinations}}{\text{Organic sulfur}} \longrightarrow \underset{\text{H}_2\text{S and other sulfides are simple examples}}{\text{decay products}} \xrightarrow{O_2} \underset{\text{Sulfates}}{SO_4^{2-}} + 2H^+$$

IMMOBILIZATION

- occurs when low S, but energy rich organic materials are added to the soil (high CS ratio)

OXIDATION OF S

- during the decomposition of organic C-bonded S compounds, sulphides are formed along with other incompletely oxidized substances (S, $S_2O_3^{2-}$, $S_{2x}O_{3x}^{2-}$)
- reduced products are subjected to oxidation, like that of ammonium compounds when N materials are decomposed

$$H_2S + 2O_2 \longrightarrow H_2SO_4 \longrightarrow 2H^+ + SO_4^{2-}$$

$$2S + 3O_2 + 2H_2O \longrightarrow 2H_2SO_4 \longrightarrow 4H^+ + SO_4^{2-}$$

- oxidation of sulphites and sulphides can occur by strict chemical reactions
- most S oxidation reactions are carried out by bacteria in the genus Thiobacillus

REDUCTION OF S

- sulfate ions are unstable under anaerobic conditions
- sulfate is reduced to sulfide by bacteria of the two genera, Desulfovibrio and Desulfotomaculum

- bacteria use the oxygen in sulfate and oxidize organic materials

$$\underset{\text{Organic alcohol}}{2R{-}CH_2OH} + \underset{\text{Sulfate}}{SO_4^{2-}} \longrightarrow \underset{\text{Organic acid}}{2R{-}COOH} + 2H_2O + \underset{\text{Sulfide}}{S^{2-}}$$

- under waterlogged conditions the sulfide reacts with Fe and Mn, which is typically present in forms
- prevent De toxicity in rice paddy by tying up the soluble reduced Fe
- sulfide ions will undergo hydrolysis to form gaseous hydrogen sulfide, which causes rotten-egg smell

$$\underset{\substack{\text{Dissolved}\\\text{ferrous iron}}}{Fe^{2+}} + \underset{\text{Sulfide}}{S^{2-}} \longrightarrow \underset{\substack{\text{Iron sulfide}\\\text{(solid)}}}{FeS}$$

$$\underset{\substack{\text{Dissolved}\\\text{reduced}\\\text{manganese}}}{Mn^{2+}} + \underset{\text{Sulfide}}{S^{2-}} \longrightarrow \underset{\substack{\text{Manganese}\\\text{sulfide}\\\text{(solid)}}}{MnS}$$

MICROBIAL TRANSFORMATIONS OF P

MINERALIZATION AND IMMOBILIZATION OF P

$$\xleftarrow{\text{Immobilization}}$$

$$\text{Organic P forms} \underset{\text{Microbes}}{\overset{\text{Microbes}}{\rightleftharpoons}} \underset{\substack{\text{Soluble}\\\text{phosphate}}}{H_2PO_4^-} \overset{Fe^{3+},\ Al^{3+},\ Ca^{2+}}{\rightleftharpoons} \underset{\text{Insoluble fixed P}}{\text{Fe, Al, Ca phosphates}}$$

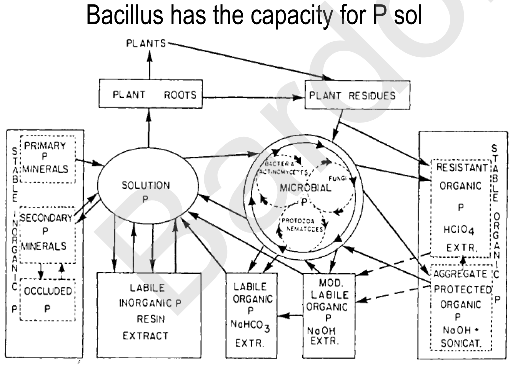
$$\xrightarrow{\text{Mineralization}}$$

CP RATIO OF THE RESIDUE

- Greater than 300:1= net immobilization
- Below 200:1= net mineralization

P SOLUBILIZATION

- organisms solubilize P thru the production of CO2 and organic acids
- bacterial in the genus Pseudomonas and Bacillus has the capacity for P sol



PRINCIPLES AND MANAGEMENT OF SOIL FERTILITY

SOIL FERTILITY
- quality that enables the soil to provide the proper compounds in the proper amounts and in the proper proportion, for the proper growth of specific kind of plants when all factors are favourable for growth

SOIL PRODUCTIVITY
- capability of the soil to produce a specific plant under a specified system of management

FACTORS AFFECTING SOIL FERTILITY
- Favourable Physical Properties
- Good aeration and drainage
- Proper moisture holding capacity
- Favourable Chemical Properties
- Optimal reaction (pH)
- High buffer capacity
- High CEC
- Absence of toxic compounds
- Favourable Microbiological Properties
- Active functioning of beneficial organisms
- Suppressed activity of harmful organisms
- Abundant and Well-Balanced Nutrient Supply
- **MACRONUTRIENT** (NKPCaMgS)
  absorbed by the plants in large amounts
- **MICRONUTRIENT** (Zn, Cu, Mo, Mn, Fe, Cl, B, Ni, Cl)
  needed by the plants in relatively low amounts

NUTRIENTS
- chemical elements or compounds required by plants for normal growth and development

GROWTH
- progressive development of an organism

SIGMOID CURVE
- S shaped curve/graph typical of the growth of an individual, either in the level of an organ, organisms or a population

  INTIAL Lag PHASE
- during which changes occur that are preparatory to growth

  Log PHASE
- phase of ever increasing rate of growth
- grand period of growth
- vegetative to flowering

  STEADY STATE
- growth rate gradually diminishes

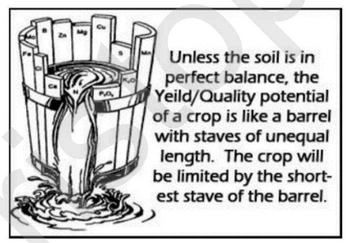
  DEATH/SENESCENCE
- point in which orgasm reaches maturity and growth ceases

  $$G=f\{x1,x2,x3,\ldots,xn\}$$

  G= growth expression
  X=growth factor

Leibig's Law of Minimum
- the growth of plants is limited by the plant nutrient element present in limiting amounts
- growth is a function of several factors, G = f (x1, x2, … xn), isolating the influence of a single factor on growth can be represented by a linear relationship
- G = Ax + B
  where;
  A and B are constants
  X = growth factor
  An increase in the quantity of the limiting growth factor will result to a proportional increase in plant growth

Liebig's Law of the Minimum - 1840



Or – the nutrient in lowest supply will set the limit to plant growth

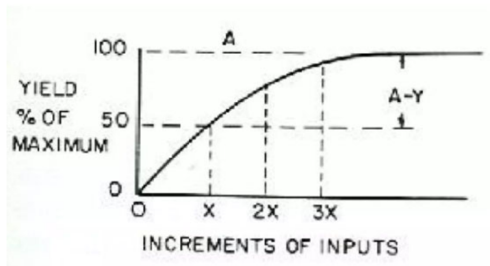
Mitscherlich's Equation
- the increase in growth with each successive additions of element in question progressively becomes smaller (law of diminishing returns/increaments)

  $$dy/dx = (A-y)C$$

  the yield increase (dy) per unit increase in available nutrient (dx) decreases as the actual yield (y) approaches a maximum level (A) with c being a proportionality constant.

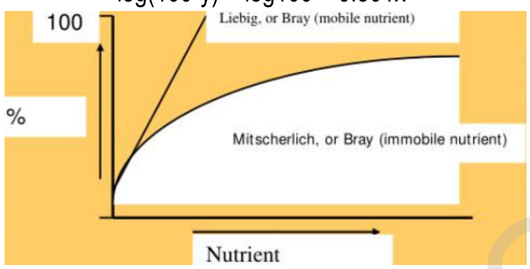
  $$dy/dx = (A-y)C$$
  $$y = A(1-10^{cx})$$
  $$\log(A-Y) = \log A - cx$$

  A= maximum yield possible, obtainable by supplying all nutrients in optimum amounts
  Y= yield produced when x unit of the nutrient in question are present in the soil
  X= units of nutrient limiting
  C=proportionality constant which varies with the kind of nutrient
- c value is not constant for all kinds of crops and soils and environmental conditions



- **MITCHERLICH-BAULE EQUATION**
    - introduced the concept of relative yield and baule unit
    - **BAULE UNIT**- the amount of growth factor required to produce a yield which is 50% of the maximum

$$\log(100-y) = \log 100 - 0.301x$$



ESSENTIAL NUTRIENT ELEMENT

CRITERIA OF ESSENTIALITY (Arnon and Stout, 1939):

- a deficiency of the element makes it impossible for the plant to complete the vegetative of reproductive stage of its life.
- the deficiency symptom of the element in question can be prevented or corrected only by supplying the element, and
- the element is directly involved in the nutrition of the plant (structural or functional).

16 Essential Nutrient Elements Required for the Growth and Reproduction of Plants

Nutrient Elements Derived from the Atmosphere and Water	Nutrient Elements From the Soil		
	Macro-nutrients		Micro nutrients
	Primary	Secondary	
C	N	Ca	Fe, B
H	P	Mg	Mn, Zn
O	K	S	Cu,Cl
			Mo

- elements that are essential to some plants under some conditions; Si, Na, F, Al, Co, Sr, and Ba.

FORMS IN WHICH ELEMENTS OCCUR IN SOIL

UNAVAILABLE

- is the form in which the element is combined as a part of a compound and is not accessible to plant absorption until the compound is "decomposed".

EXCHANGEABLE FORM

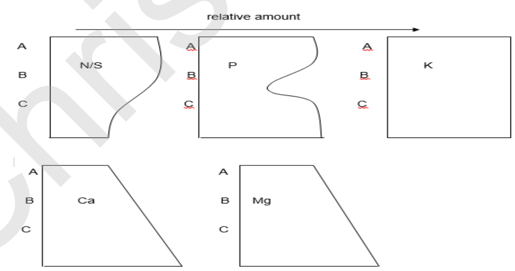
- is the form which the element exists as a cation or anion adsorbed (surface attraction) on the surface of organic compounds or clay minerals. The exchangeable ions are partly available to plants.

SOLUTION FORM

- is assumed to be the most available form. The ionic/available forms of the 16 essential elements

Element	Available Form/s
Carbon (C)	CO_2
Hydrogen (H)	H_2O
Oxygen (O)	HCO^{-3}
Nitrogen (N)	NH_4^+, NO^{-3}
Phosphorus (P)	$HPO_4^=$, $H_2PO_4^-$
Potassium (K)	K^+
Calcium (Ca)	Ca^{+2}
Magnesium (Mg)	Mg^{+2}
Sulfur (S)	$SO_4^=$, $SO_3^=$
Iron (Fe)	Fe^{+2}, Fe^{+3}
Manganese (Mn)	Mn^{+2}, Mn^{+3}
Zinc (Zn)	Zn^{+2}
Molybdenum (Mo)	$Mo0_4^{-2}$
Chlorine (Cl)	Cl^-
Boron (B)	BO_3^{-3}

PROFILE DISTRIBUTION OF NUTRIENTS



ROLES OF ESSENTIAL ELEMENTS IN PLANT NUTRITION

CARBON, HYDROGEN, OXYGEN

- serve largely in the synthesis of carbohydrates, proteins, fats, and related compounds.
- They are the major constituents in most plant compounds.

NITROGEN

- it is a part of many proteins which serve as enzymes
- part of the chlorophyll molecule
- found in greater quantities in young or growing parts of plants than in the older

tissues and especially abundant in the leaves and seeds.

PHOSPHORUS

- it is present in seeds in larger amounts than in any other parts of plant, although it is found extensively in the young growing parts.
- Like nitrogen it is a constituent of every living cell. It is a constituent of phospholipids, nucleoproteins, and phytin, the latter being a storage form of phosphorus in seeds.
- This element plays an important role in energy transformation in the cells of both plants and animals.
- necessary for normal transformations of carbohydrates in plant – the changing of starches to sugar.
- necessary for the assimilation of fats, and apparently it increases the efficiency of the chloroplastic mechanisms.

POTASSIUM

- it is essential in all cell metabolic processes and apparently has a specific role in influencing the uptake of certain mineral elements
- regulate the rate of respiration, in affecting the rate of transpiration, and perhaps also influencing the actions of enzymes, and aiding in the synthesis and translocation of carbohydrates.
- does not become a component of plant compounds and remains in ionic form in the plant. For this reason, it is easily lost from plant foliage through leaching.

CALCIUM

- Calcium in the form of calcium pectate is a part of the cell wall
- necessary for the growth of meristems
- It exists in plants in the oxalate form.

MAGNESIUM

- This element is active in enzyme systems
- part of the chlorophyll molecule
- aids in the translocation of phosphorus in plants.

SULFUR

- It is a constituent of compounds including amino acids (cysteine and methionine), and in the oil of plants of the crucifer and mustard families
- Cabbage and turnips have a high sulfur requirement.

IRON AND MANGANESE

- Both iron and manganese play important role in plant enzyme systems.
- They are required for the chlorophyll synthesis.
- Their utilization in the plant is interrelated - an excess of manganese causes an inactivation of the iron.

BORON

- It functions in carbohydrate metabolism
- facilitates the movement of the sugar by forming a permeable boron- sugar complex or by joining the cell membrane in such a way that is made more permeable to sugars.

COPPER AND ZINC

- They are components of enzymes
- Both are apparently necessary for formation of growth promoting substances.

MOLYBDENUM

- The reduction of nitrate in plant is dependent on Mo.
- deficiency results in the piling up of nitrates and an interference in protein synthesis.
- Nitrogen fixation in legumes is also dependent in the presence of Mo.

CHLORINE

- This element is rarely, if ever deficient for plant growth
- Functions attributed to Cl include those of a regulator of osmotic pressure and cation balance.
- Its role is not well established.

NUTRIENT ABSORPTION

PASSIVE UPTAKE

- This will occur when there is a higher concentration of the ions outside the cell. Ions will flow from greater to lesser concentrations without addition of energy.
- osmosis and transpiration pull

ACTIVE UPTAKE

- If ions are taken up by a cell against a concentration gradient – energy must be supplied to enable the cell to perform this kind of work.

MECHANISM OF NUTRIENT UPTAKE

ROOT INTERCEPTION

- nutrient come in contact with roots as the roots push their way through the soil
- anything that restricts root growth is a factor of restricting root interception

MASS FLOW

- nutrients must be dissolved in solution and as the solution moves through the roots, the nutrients are also carries and hence becomes positionally available

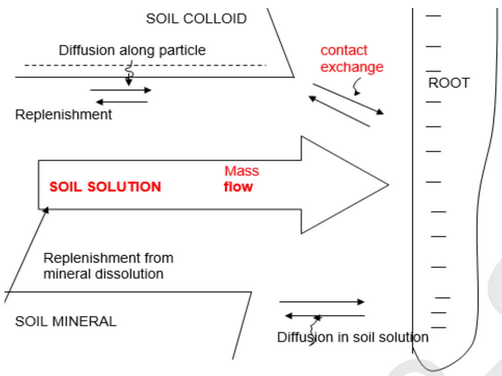
FACTORS AFFECTING MASS FLOW;
- Mositure Content
- Temperature
- Size of The Root System

DIFFUSION
- the movement from an area of high concentration to an area of low concentration

THEORIES FOR ABSORPTION

SOIL SOLUTION THEORY
- ions are absorbed by roots from the soil solution

CONTACT EXCHANGE THEORY
- ions are absorbed from surfaces of soil colloids



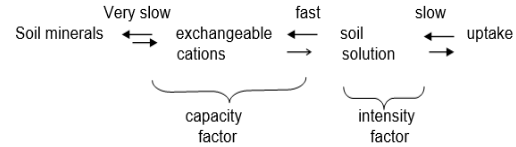
FACTORS AFFECTING WATER AND ION UPTAKE
- Temperature
- Toxic substances
- Maturity of roots

AVAILABILITY
- This is the relative ability of the soil to supply nutrients to the plants. It is determined by the following factors:

INTENSITY FACTOR
- The concentration of ions in the soil solution.

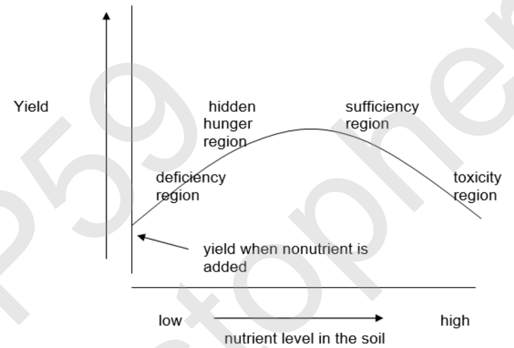
CAPACITY FACTOR
- The ability of the soil to renew the ions in the soil solution as they are taken up by plants.
- Nutrients adsorbed by the soil

RATE OF CHANGE FACTOR
- As ion s are removed from the soil solution, the intensity factor is decreased and the solid phase only partially replaces the ions removed from the solution.
- The intensity factor changes appreciably with time.



EVALUATION OF SOIL FERTILITY
DIAGNOSTIC PROCEDURES

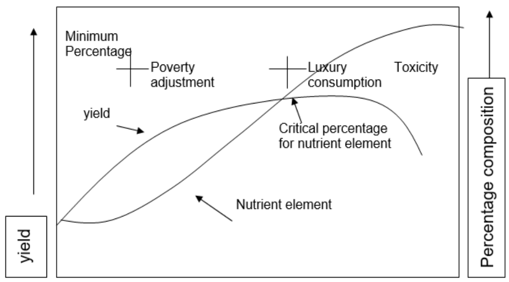
NUTRIENT DEFICIENCY SYMPTOMS IN PLANTS
- Plants express through growth characteristics certain symptoms associated with a lack of an essential element or growth factor.



KEYS TO NUTRIENT DEFICIENCY SYMPTOMS IN CROPS

NUTRIENT	COLOR CHANGE IN LOWER LEAVES
N	Plant light green, older leaves yellow
P	Plants dark green with purple cast, leaves and plants small
K	Yellowing and scorching along the margin of older leaves
Mg	Older leaves have yellow discoloration between veins-finally reddish purple from edge inward
Zn	Pronounced interveinal chlorosis and bronzing of leaves
NUTRIENT	**COLOR CHANGE IN UPPER LEAVES(Terminal bud dies)**
Ca	Delay in emergence of primary leaves, terminal buds deteriorate
B	Leaves near growing point turn yellow, growth buds appear as white or light brown, with dead tissue.
NUTRIENT	**COLOR CHANGE IN UPPER LEAVES (Terminal bud remains alive)**
Fe	Leaves yellow to almost white, interveinal chlorosis at leaf tip
Mn	Leaves yellowish-gray or reddish, gray with green veins
Cu	Young leaves uniformly pale yellow. may wilt or wither without chlorosis
Mo	Wilting of upper leaves, then chlorosis
Cl	Young leaves wilt and die along margin
S	Leaves including veins turn pale green to yellow, first appearance in young leaves.

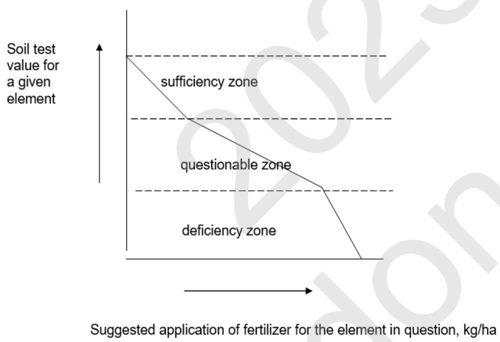
PLANT ANALYSIS
- The principle behind this method is that the nutrient content in plants is related to that available in the soil. If the nutrient level in the tissues falls below the "critical level" then the soil must be deficient in that element for optimum growth



SOIL TESTING

- Soil testing refers to the rapid chemical analysis for assaying the fertility status of a soil.

  PHASES OF SOIL TESTING:
  - collecting the soil samples
  - extracting and determining the available nutrients
  - interpreting the analytical results
  - formulating the fertilize recommendations
- A chemical procedure in the laboratory should extract approximately the same amount of nutrients as a crop would do during a growing season. The extraction attempts to do in a few minutes what occurs slowly in the soil during several months. The amounts of nutrient extracted in such a way are considered available to plants.



<u>FERTILIZERS AND SOIL FERTILITY MANAGEMENT</u>

TERMINOLOGIES

FERTILIZER
- any substance that is added to the soil to supply the plants with one or more elements.

INORGANIC FERTILIZER
- it has definite chemical composition; man made.

ORGANIC FERTILIZER
- fertilizer materials of organic origin.

SINGLE FERTILIZER
- carries only one element (either N, or P2O5 or K2O).

COMPOUND FERTILIZER
- it carries two elements.

COMPLETE FERTILIZER
- it contains all the three basic (primary) elements. N P K

MIXED FERTILIZER
- it contains several elements and the source of elements can not be identified. A chemical or mechanical combination of two or more fertilizers.

FERTILIZER ANALYSIS/ GRADE
- The minimum guarantee of the plant nutrient in terms of percentages of N-P_2O_5-K_2O.

  P x 2.29 = P_2O_5
  P_2O_5 x 0.44 = P
  K x 1.20 = K_2O
  K_2O x 0.83 = K

PROPERTIES OF ORGANIC FERTILIZER
- low nutrient content
- bulkiness
- limited supply
- slow nutrient availability
- contains many seeds of weeds
- can be a source of plant disease and spread parasites
- contains matter important in improving soil structure
- supplies some of the minor elements which are not usually present in commercial fertilizer
- Little danger of over supplying to crops

PROPERTIES OF INORGANIC FERTILIZERS
- high nutrient analysis
- high solubility
- good supply
- not bulky

FERTILIZER COMPANIES IN THE PHILIPPINES
- Planter's Products (Damao, Limay, Bataan)
- Ma. Cristina Fertilizer Corp. (Cagayan de Oro)
- Atlas Fertilizer Corp. (Toledo, Cebu)
- Chemical Philippines

NITROGEN FERTILIZERS

Sources of Nitrogen for N-fertilizer

Air (as nitrogen gas, N2)

High pressure

$N_2 + 3H_2 \rightarrow 2NH_3$ (H2 is recovered from the decomposition of CH4 into CO and H2)
High temperature + catalyst (metal)

NITRATE DEPOSITS

$NaNO_3$ in China and Bolivia; KNO_3 deposits in Indonesia, Sri Lanka, and India

AMMONIA RECOVERED FROM DESTRUCTIVE DISTILLATION OF COAL

only Ma. Cristina Fertilizer Corp. uses this as nitrogen source

Solid Ammonium-N sources	%N	% other nutrients	RA	CRH	Solubility
Ammonium chloride (NH_4Cl)	25	-	140	74	132 (25ºC)
Ammonium sulfate ($(NH_4)_2SO_4$)	21	24% S	110	87	103 (100ºC)
Ammonium nitrate	33	none	59	53	843 (100ºC)
Solid Nitrate-N sources					
Ammonium nitrate Sodium nitrate $NaNO_3$	16	16% N	29**** 20****	65	-
Calcium nitrate $CaNO_3$	15	19% Ca		52	-
Liquid N sources					
Anhydrous ammonia NH_3	82	none	148	(stored under pressure	
Amide fertilizers					
Calcium cyanamide $CaCN_2$	20	30% Ca	34**** 84	79	-
Urea (NH_2COH_2)	45	none		80	119

nitrogen, hydrogen → ammonia (NH_3) →

- + HCl → NH_4Cl
- + HNO_3 → NH_4NO_3
- + CO_2 → NH_2CONH_2
- + H_2SO_4 → $NH_4)_2SO_4$
- + H_3PO_4 → Ammophos A
- + H_3PO_4 + H_2SO_4 → Ammophos B
- + H_2O → nitrogen solution

PHOSPHORUS FERTILIZERS
SOURCES

- o rock phosphate mostly Flourapatite $(Ca_{10}PO_4)_6(F_2)$
- o starting point of P fertilizer manufacture
- o with limited supply of this mineral in Palawan although all rock phosphates used in P fertilizer manufactures are all imported.

Property	Ordinary Superphosphate	Concentrated Superphosphate
Color	Grayish brown	Grayish brown
Nature of particles	Granular or powder	Granular
C R H	88%	
Solubility	insoluble ($Ca(H_2PO_4)$ is soluble but $CaSO_4$ is insoluble	80% moderately soluble
% total P	9.5%	19 – 23%
% available P	97 – 100%	99 –100%
% Calcium	18 – 21%	12 – 14%
% Sulfur	11-12%	0 – 1%
Reaction with litmus paper	pH 1- 2 (extremely acidic)	pH 1 –2

N-P CARRIERS

Ammoniated Superphosphate

- o NH_3 + P carriers (Ord. S.P. or Conc. S.P.)
- o Ammonium Phosphate
  - **o Ammophos A**
    - o M.A.P.

$NH_3 + H_3PO_4 \rightarrow NH_4H_2PO_4$

- **o D.A.P.**

$2NH_3 + H_3PO_4 \rightarrow (NH_4)_2HPO_4$

- **o M.A.P.+ D.A.P.**

$3NH_3 + 2H_3PO_4 \rightarrow NH_4H_2PO_4 + (NH_4)_2HPO_4$

- **o Ammophos B**
  - ▪ Ammonium Phosphate-Sulfate

$3NH_3 + H_3PO_4 + H_2SO_4 \rightarrow NH_4H_2PO_4 + (NH_4)_2SO_4$

PROPERTY	M.A.P.	D.A.P	M.A.P. + D.A.P.	AMMOPHOS B
% N	21	21	10-11	16
% P	27	23	21	8.8
% P_2O_5	61	53	48	20
% available P	100	100	100	100
R.A.	67	67	65	75
CRH	73	73	78	not available
Color	grayish	grayish	grayish	grayish
Form	granular	granular	granular	granular
% S	none	none	none	12

POTASSIUM FERTILIZERS
SOURCES OF POTASSIUM

- o The main source of inorganic K fertilizers are potassium bearing minerals: (sylvite, sylvinite, langbainite, kainite).
- o All K fertilizer materials are imported.
- o No K mineral deposits are found in the country.

Property	KCl (Muriate of Potash)	K_2SO_4
% K_2O	60-63%	48-52%
% purity	98-99%	95-98%
% Cl	35-37%	1.8%
Solubility (100ºC)	56.7g/100 g water	241 g/100g water
% SO_4	none	55.7%

REACTION OF FERTILIZERS WITH THE SOIL

Ammonium Sulfate

$(NH_4)_2SO_4 + 2H_2O \rightarrow 2NH_4OH + H_2SO_4$
$2NH_4OH \rightarrow 2NH_4^+ + 2OH^-$
$H_2SO_4 \rightarrow 2H^+ + SO_4^=$
$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$ (causes residual acidity)
$2NO_2^- + O_2 \rightarrow 2NO_3^-$

Urea

$CO(NH_2)_2 + 2H_2O$ ---urease→$(NH_4)_2CO_3$
$(NH_4)_2CO_3 + 2H_2O \rightarrow 2NH_4OH + CO_2 + H_2O$
$2NH_4OH \rightarrow 2NH_4^+ + 2OH^- \quad + 2H_2 + 2H^+$
$2NH_4^+ + 4O_2 \rightarrow 2NO_3^- + 2H_2O + 4H^+$(causes residual acidity)

FERTILIZER PLACEMENT
FOR SOLID FERTILIZER
BROADCAST

- o The fertilizer is applied uniformly over the surface of the land. It may be plowed in. For perennial crops (pastures) fertilizer is spread on the soil surface. For annual crops, only a part of the fertilizer required is applied on this method.

BAND

- Fertilizer is laid in as a narrow band or strip alongside the row, 2.5 cm to the side and 5 cm below the seed or transplant. This method is used for corn and other wide row crops. It is also minimizes fixation of phosphorus and potassium.

TOPDRESSED OR SIDEDRESSED.

- Fertilizer is applied after emergence. Topdressed is broadcast application on crops such as small grains and forage crops. Sidedressed is placement beside the row of the crops such as corn or cotton.

ROW APPLICATION.

- The fertilizer is applied with the seed during seedling. This is applicable for small grains and at low rates of application.

SPOT APPLICATION.

- The fertilizer is applied around the hill as with crops like melon or squash.

FOR LIQUID FERTILIZER

FOLIAR APPLICATION

- Farm crops cannot be supplied with the quantity of macronutrients required for economic crop production by foliar application alone. However, foliar sprays are an effective method in supplying the micronutrients to a plant if and when required. Urea could be supplied in this manner.

SOIL INJECTION

- This is a direct soil application of a liquid fertilizer particularly the anhydrous ammonia.

FERTIGATION

- Applied with the irrigation water. Some solid fertilizer is also applied in this manner.

TIME OF APPLICATION

- *Nitrogen*. As in the case of upland soils and crops, the time of application of nitrogen is dependent upon the texture of the soil, the growing period of the crop and its physiological stage.
- Coarse textured sols demands split applications of nitrogen due to losses caused by high percolation rates.
- *Phosphorus*. Time of application is not as critical for phosphorus because flooding increases the availability of phosphorus. In general, most phosphorus applications should be made as basal treatment. N advantage derived from split applications.
- *Potassium*. Basal application is most suitable. Split application appear to be beneficial only on certain highly leacheable soils.

FACTORS AFFECTING THE RATE AND PLACEMENT OF FERTILIZERS

SOIL FACTORS

- Original fertility of the soil. A poor soil would naturally require more fertilizers.
- Fertilizer reaction with the soil. There are fertilizers that get fixed in the soil thus a
- higher rate is required. Placement should also be considered.
- Physical rate of the soil. This is determined by the moisture, aeration, and structure.

CROP FACTORS

- Nutrient removal of the crop. If the nutrient removal by a given crop is high, fertilizer applications are usually increased to compensate for this loss.
- Absorbing ability of the crops for nutrients. Root systems vary in rapidity and extent of development. Since roots are the principal organs through which material are absorbed, understanding of the characteristics rooting habits and relative activity should be helpful in developing fertilization practices.
- Economic value of the crop.

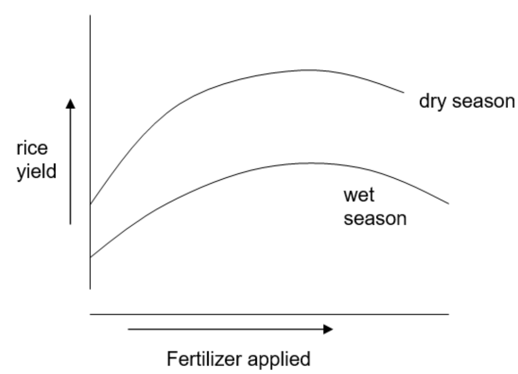
CLIMATIC FACTORS

RAINFALL

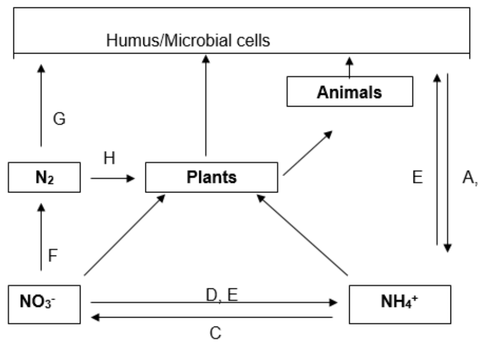
- In areas where there is more rainfall, a higher rate of fertilization is required to compensate for losses.

CROPPING SEASON

- Crops have greater response to fertilizer during the dry season than during the wet season.



<u>N ECONOMY OF SOIL</u>



A – ammonifiction
B – mineralization
C – nitrification
D – nitrate reduction
E – immobilization
F – denitrification
G – N2 fixation, non – symbiotic
H - N2 fixation, symbiotic

FORMS OF SOIL NITROGEN

- **MINERAL/INORGANIC FORM** - NH_4^+, NO_3^-, NO_2^-, N_2, N_2O, NO
- **ORGANIC FORM** - amino acids, amino sugars, purines, and humic acids.
- Plow layer (0-20 cm) – 2,000 kg total N/ha (about 0.03 to 0.44% nitrogen)
- Available form - mere traces to 100 ppm (NH4+ and NO3 –)
- 1 to 2% of total soil N becomes available to plants during any given growing season.

PROCESSES THAT RENDER NITROGEN AVAILABLE TO PLANTS

MINERALIZATION OF ORGANIC MATTER

- conversion of the organic form into inorganic form through microbiological processes.

MINERALIZATION OF NITROGEN IS A 3 STEP PROCESS

AMINIZATION

- heterotrophic microorganism
- Proteins$\rightarrow$R-NH_2 +CO_2 + energy + other products

AMMONIFICATION

- heterotrophic microorganism
- R-NH_2 + H_2O (enzymatic hydrolysis) $\rightarrow$ OH^- + R + NH_3 + e
- $2NH_3 + H_2CO_3 \rightarrow (NH_4)_2CO_3 \rightarrow 2NH_4^+ + CO_3^=$
- Ammonification occurs in both aerated and submerged soils

NITRIFICATRION

- autotrophic microorganism
- NH_4^++ 3/2 0_2 (Nitrosomonas)$\rightarrow$$NO_2^-$+ $2H^+$ + H_2O + e
- NO_2^-+ ½ O_2 (Nitrobacter) NO_3^- + e
- Nitrosomonas works well at high pH and decreases in activity at acidic mediums, thus a high concentration of NO_2 and NH_4 might accumulate.

PROCESSES THAT LEAD TO LOSS OF NITROGEN FROM SOILS

BACTERIAL DENITRIFICATION.

- Anaerobic condition

LEACHING OF NO3$^-$

- Because of its negative charge, it will not be held by the soil, thus is easily leached out.

EROSION LOSSES

- Sheet erosion is highly selective and the eroded fraction contains several times more nitrogen than the original soil.

Volatilization

- Under high pH (pH 8 and above), nitrogen from NH4 fertilizer or compounds is lost as NH_3

$$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$$

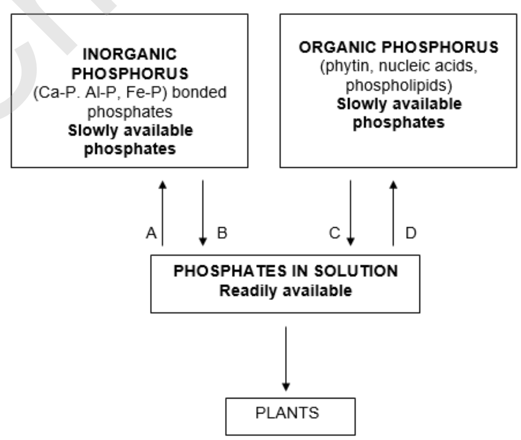
PROCESSES THAT RENDER NITROGEN UNAVAILABLE TO PLANTS

- Ammonium (NH4) fixation by clays.

IMMOBILIZATION OF NITROGEN BY MICROORGANISMS.

- Residues with C/N ratios higher than 20 effect a lowering of mineral nitrogen reserves during decomposition.

P ECONOMY OF SOILS



A – fixation
B – weathering
C – mineralization
D – immobilization

- Philippine soils -100 to 600 ppm (0.01 to 0.06% P)
- Available forms: HPO_4^{-2} and $H_2PO_4^-$ ions
- P concentration in plant tissue: 3,000 ppm (0.3% P).

PHOSPHORUS ADDITION TO SOILS

- Accumulation and recycling of plant and animal residues
- Addition of commercial fertilizers
- Weathering of primary minerals

PHOSPHORUS LOSSES IN THE SOILS
- Crop removal- (5 –6 kg /ha /yr) 0.5% of the total soil P removal in rice: 20 kg P/ha in100 cavans
- Erosion – since P is concentrated in top the soil losses due to erosion losses are significant.
- Leaching losses is negligible due to the low mobility of soil P.

PROCESSES THAT RENDER P AVAILABLE TO PLANTS
- Mineralization of organic P
- Release of fixed P
- Dissolution of soluble P

PROCESSES THAT RENDER P UNAVAILABLE TO PLANTS

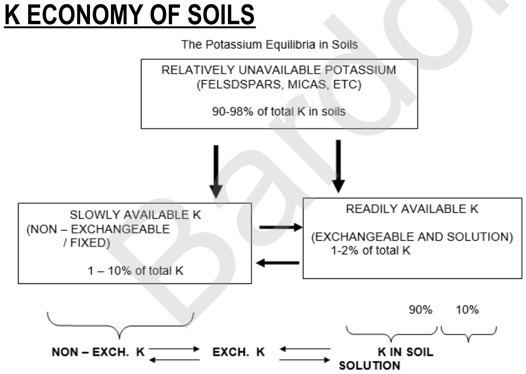
IMMOBILIZATION
- C:P < 200:1 organic P is mineralized while it is immobilized at C/P higher than 200:1.

P FIXATION
- It is the conversion of the available P into unavailable ones

P FIXATION UNDER ACID CONDITION
- $Al^{+3} + H^2PO_4^- + 2H_2O \rightarrow Al_2PO_4(OH) + 2H^+$
- $Fe^{+3} + H_2PO_4^- + 2H_2O \rightarrow FeH_2PO_4(OH) + 2H^+$

P FIXATION UNDER ALKALINE CONDITION
- $3Ca^{++} + H_2PO_4^- \rightarrow Ca_3(PO_4)_2 + 4H^+$

K ECONOMY OF SOILS

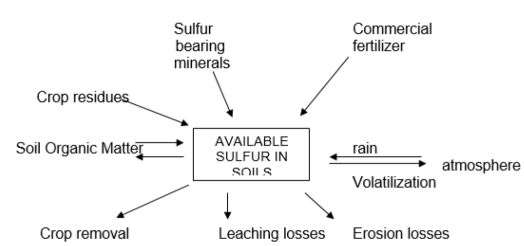


ADDITIONS OF SOIL POTASSIUM
- Crop residues, manures
- Commercial fertilizers
- Weathering of potassium bearing minerals (feldspars and micas) and the potassium trapped in clay minerals.

LOSSES OF SOIL POTASSIUM
- Crop removal
- Leaching losses- degree of leaching depends upon:
  - CEC of the topsoil,
  - amount of water movement
- degree of potassium saturation of the CEC
- moisture content of the soil.
- Erosion losses- losses is not critical for K compared to N & P

POTASSIUM FIXATION
- This is a process by which exchangeable or soluble potassium get trapped in the interlayers of 2:1 clay minerals (vermicullite, illite, etc).
- This is a process affected by:
  - Clay mineral present
  - The potassium as well as the ammonium ions fit in between crystal units of normally expanding clay (in the empty spaces between oxygen atoms in the outside silica layers) and become an integral part of the crystal.
    - alternate wetting and drying
    - degree of potassium saturation
- The fixed potassium cannot be replaced by ordinary exchange methods and consequently is referred to as non-exchangeable potassium.
- this element is not readily available to higher plants.
- This form is in equilibrium, however, with the available forms and consequently acts as an important reservoir of slowly available potassium.

S ECONOMY OF SOILS



SOURCES OF SOIL SULFUR

ORGANIC SOURCES
- plant residues, animal residues

INORGANIC SOURCES
- inorganic fertilizers, primary minerals, rain water

- o About one-half to three-fourths of the soil sulfur is in the organic form, that is, it is still in the combined form in the organic matter.

MINERALIZATION OF SULFUR

- o occurs under conditions that are proper and favorable for microbial activity.
- o sulfur compounds that are mineralized are those in plant, animal, and microbial proteins (specifically the amino acids – cysteine and methionine, B vitamin, thiamine, biotin, folic acid).

MECHANISM:

Cysteine → Cystine→cystine disulfoxide→cystine sulfinic acid)→sulfate

Methionine → volatile compounds (methyl mercaptans dimethyl disulfate)

ORGANISMS INVOLVED:

- *o Microsporeum*
- *o Scopulariopsis*
- *o Aspergillus*

GENERAL REACTION:

Organic sulfur → decay products → sulfates

SULFUR IMMOBILIZATION OR ASSIMILATION

- o Sulfur immobilization is the opposite of I mineralization,
- o inorganic sources of sulfur for microbial growth are sulfates,thiosulfates, tetrathionate, elemental sulfur, sulfite, and sulfide.
- o detrimental effect of sulfur immobilization is probably a result of microbial utilization of available sulfur during the decomposition of the starch. As long as there is less sulfur in the organic matter than required for microbial proliferation, immobilization will be dominant; when the element is in excess, mineral sulfur will be liberated as a waste product.
- o The critical C:S ratio in carbonaceous materials above which immobilization is dominant to mineralization is reported to be approximately 50:1

INORGANIC SULFUR OXIDATION

- o In soil, sulfides, elemental sulfur, and thiosulfate can be oxidized slowly by chemical means
- o microbiological oxidation is far more rapid when conditions are favorable
- o sulfur oxidizers are several kinds of bacteria such as, Thiobacillus spp, Beggiatoa, Thiorix, Thioplaca, and others.

SULFATE REDUCTION

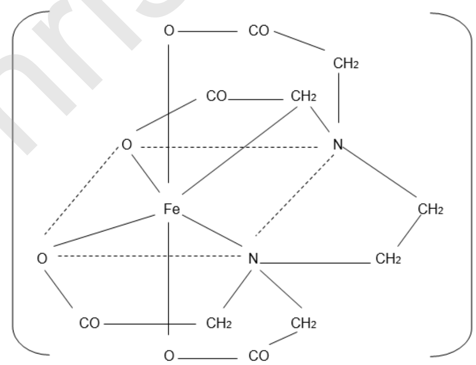
- o In soils they become deficient in oxygen as by flooding, sulfate concentration falls and sulfide level increases. This is due to the increase activity of sulfate reducing bacteria. The predominant microorganisms concerned with the reduction of sulfate are bacteria of the genus Desulfovibrio.

$SO4^{=}$; $SO3^{=}$; $S2O3^{=} + H2 \rightarrow S^{=} + H2O$

MICRONUTRIENTS

Element	Major forms In nature	Suggested analysis of a surface soil
Iron	Oxides, sulfides, Silicates	25,000 ppm
Manganese	Oxides, Carbonates,	2,500 ppm
Zinc	Silicates	100 ppm
Copper	Oxides, oxides, Silicates	50 ppm
Boron	Oxides, Hydroxy,	50 ppm
Molybdenum	carbonates	2 ppm
Chlorine	Borosilicates Borates	50 ppm
	Sulfides, Molybdates	
	Chlorides	

- o Organic matter is an important secondary source of some of the trace elements
- o held by complex combinations by the organic
- o colloids. Each of the micronutrients cations (Zn, Cu, Mn, Fe) form complexes with an organic compound called chelate



EDTA – Ethylene diamine tetra-acetic acid

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- o Chelates are organic compounds that combine with cations, but protecting this cation from harmful inorganic reaction. At the same time, the chelated nutrients can be utilized by growing plants.

SOIL EROSION AND CONSERVATION

FACTORS THAT INFLUENCE THE RATE OF EROSION

ENERGY

- Potential ability of rainfall
- Potential ability of run-off
- Potential ability of wind

RESISTANCE

- Erodibility of the soil.
  - function of physical and chemical properties.
  - Factors that encourage the infiltration of water into the soil decrease erodibility and thereby reduce run-off.
  - any activity that pulverizes the soil increases erodibility.

PROTECTION

- focus on factors related to plant cover
  - by intercepting rainfall and reducing the velocity of run-off and wind
- Various type of plant covers affords different degrees of protection

THE RATE OF SOIL LOSS

- The rate of soil loss is expressed in units of mass or volume per unit area per unit of time.
- Erosion reaches maximum in areas with an effective mean annual precipitation of 300 mm
- At precipitation totals above 300mm, the protection effect of vegetation counteracts the erosive effect of greater rainfall, so that soil loss decreases as precipitation increases

PROCESS OF SOIL EROSION

- Detachment of individual particle from the soil mass
- Rain splash is the most important detaching agent. As a result of raindrop striking a bare soil surface, soil particles maybe thrown through the air over distances of several cm
- Other detaching agents:
  - Intense rainstorm
  - Weathering process
  - tillage and trampling of people
  - alternate wetting and drying
  - running water and wind
  - freezing and thawing and frost action
- Transport by erosive agents like running water and wind
- Deposition of detached and transported materials
- Transport by erosive agents
  - rain splash
  - surface run-off or overland flow
  - running water and wind
  - rill flow, soil flows, slides, and creep

ENERGY AVAILABLE FOR EROSION

POTENTIAL ENERGY (PE)

- This results from the difference in the height of one body with respect to another.
- the product of mass (m), height difference (h) and acceleration due to gravity

$$PE = mhg$$

KINETIC ENERGY (KE)

- Energy in motion
- potential energy converted to kinetic energy for erosion
- related to the mass (m) and the velocity (v) of the eroding agent.

$$KE = ½ mv^2$$

- processes of water erosion are closely related to the routes taken by water in its passage through the vegetation cover and its movement over the ground surface

ACTIONS OF VARIOUS DETACHING AND TRANSPORTING AGENTS

RAINSPLASH EROSION

- The action of raindrops on soil particles is most easily understood by considering the momentum of a single raindrop falling on a sloping surface
- The down slope component of this momentum is transferred in full to the soil surface but only a small proportion of the component normal to the surface is transferred, the remainder being reflected.

OVERLAND FLOW

- occurs on hillside during a rainstorm when surface depression storage and either in the case prolonged rain, soil moisture storage or with intensive rain, the infiltration capacity of the soil is exceeded.

SUBSEQUENT FLOW

- takes place as concentrated flow in tunnels or subsequent pipes
- soil water flow contributes only about 1% of the total material eroded from a hillside and that is mainly in the form of colloids and minerals in ionic solution.

RILL EROSION

- Upslope migration is associated at the development of headcuts on the steep banks at the top end of the channel and its rate is controlled by the cohesiveness of the soil.
- Downslope extension is controlled by the shear stress exerted by the flow.

GULLY EROSION

- Gullies are relatively permanent steep-sided water courses which experience ephemeral flows during rainstorms

TYPES OF GULLY NETWORK

AXIAL GULLYING

- Consists of individual gullies with single headcuts that retreat uplsope by surface erosion and usually occurs in gravelly deposits.

DIGITATE GULLYING

- The retreat occurs in several headcuts extending in the direction of tributary depressions and usually occurs in clay loam soils.

FRONTAL GULLYING

- This is associated with piping and is found particularly in loamy sands with columnar structure. It starts generally in riverbanks where pipes have their outlet and collapse ensures.

MASS MOVEMENTS

- Landslides, creep, mudflows and rockfalls, are the dominant erosion procedures that occur in small numbers every wet season. The quantity of sediments moved from the hillsides into rivers by mass movements is far in excess of that contributed by gullies, hills and overland flow.

FACTORS ENHANCING SOIL EROSION

- **EROSIVITY**

RAINFALL

- Soil loss is closely related partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff.
- applies particularly to erosion by overland flow and rills for which intensity is generally considered the most important rainfall characteristics.
- 25mm/hr rain is enough to start erosion.

ERODIBILITY

- refers to the resistance of the soil to both detachment and transport
- depends in part on topographic position, slope steepness and the amount of disturbance created by man
- varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic chemical content.

SOIL TEXTURE

- large particles are resistant to detachment because of their cohesiveness
- The least resistant particles are silts and fine sands, thus, soils with high silt content are erodible

AGGREGATE STABILITY

- Soils with a high content of base minerals are generally more stable as these contribute to the chemical bonding of the aggregates because it lowers their cohesiveness, softens the cements and cause swelling as the water is absorbed on the clay particles.

SHEAR STRENGTH

- measure of the soils cohesiveness and resistance shearing forces exerted by the gravity, moving fluids and mechanical loads
- An increase in the moisture content of a soil decreases its shear strength and brings about changes in its behavior.

INFILTRATION CAPACITY

- refers to the maximum sustained rate at which soil can absorb water, is influenced by pore size, pore stability and the form of the soil profile
- Soils with stable aggregates maintain their pore spaces between whilst soils with swelling clays or minerals that are unstable in water tend to have low infiltration capacities.

ORGANIC CHEMICAL CONTENT

- The organic and chemical constituents of the soil are important because of their influence on aggregate stability.

EFFECT OF SLOPE

- Erosion would normally be expected to increase with increases in slope steepness and slope length as a result of respective increase in velocity and volume of surface runoff.

EFFECT OF PLANT COVER

- The effectiveness of a plant cover in reducing erosion depends upon
  - height and continuity of the canopy
  - the density of the ground cover
  - the root density
- The height of the canopy is important because water drops falling from 7m may attain over 90 per cent of their terminal velocity
- raindrops intercepted by the canopy may coalesce on the leaves to form larger drops which are more erosive.
- a plant cover dissipates the energy of running water and wind, imparts roughness to the flow and thereby reduces its velocity, since erosion rates vary with either the cube or the fifth power of velocity, the effect on soil loss should be considerable.
- Agricultural crops vary in their effectiveness depending on their stage of growth and the amount of bare ground exposed to erosion at maturity

ASSESSMENT OF EROSION HAZARD

- Erosion hazard is a specialized form of land resource evaluation with the objective of identifying those areas of land where the maximum sustained productivity from a given land use is threatened by excessive soil loss.

METHODS OF GENERAL ASSESSMENT

EROSION INTENSITY

- **DRAINAGE DENSITY (Dd)**
- this refers to the length of streams per unit area.

  $$Dd=L/A$$

  L = total length of streams including intermittent and permanent in km
  A = area of watershed in sq. km.
  Dd = drainage density

EROSION INDICES

- data on erosivity may be used as an indicator of regional variation in erosion potential to pinpoint areas of high risks.
- Using the mean annual erosivity values, high risks areas could be pinpointed, thus, cultivation of the land at this time creates a great risk of erosion.

RAINFALL AGGRESSIVENESS

- This index had shown that sediment yield in rivers is significantly correlated with the rainfall aggressiveness

  $$p2/P$$

- p is the highest mean monthly precipitation (MMP)
- P is the mean annual precipitation (MAP).
- This is strictly an index of the concentration of precipitation into a single month, thus, gives a crude measure of the intensity of the rainfall, thus, as the plant cover decays, it erosion protection becomes low.

FRACTIONAL SCORING

- Stocking and Elwell (1973) devised a simple scoring system for rating erosion risks particularly in Zimbabwe
- consists of rating units of about 184 km2.
- Each unit is rated on a scale from 1-5 in respect of erosivity, erodibility, slope ground cover and human occupation, the latter taking account of the density and the type of settlement.

THE UNIVERSAL SOIL LOSS EQUATION

THE WISCHMEIER AND SMITH MODEL (1962, USA)

- The first attempt to develop a soil loss equation for hill slopes was that of Zingg (1940) who related erosion to slope steepness and slope length
- Further developments led to the addition of climatic factor based on the maximum 30-minute rainfall total with a two-year return period (Musgrave, 1947), a crop factor to take account of the protection-effectiveness of different crops (Smith, 1958), a conservation factor and a soil erodibility factor.
- Finally, changing the climatic factor to the rainfall erosivity index (R) yielded the Universal Soil Loss Equation (USLE)

  $$E = R.K.L.S.C.P.$$

  E is mean annual soil loss (t ac-1 y-1).

FACTORS IN THE EQUATION

R

- This is the rainfall erosivity index
- mean annual soil loss per unit of erosivity for a standard condition of bare soil, no conservation practice, 5° slope of 22 m length.

LS

- The factor of slope length (L) and slope steepness (S) are combined in a single index.
- A value of 1.0 applies to the standard 5° slope, 22 m long
- The appropriate value can be obtained from nomographs (Hudson, 1981a) or from the equation:

  $$LS = \sqrt{[L(0.065+0.045S+0.0065S^2)]/22.13}$$

L is in m, S in per cent.

C

- This is the crop factor
- represents the ratio of soil loss under a given crop to that from bare soil
- Since soil loss varies with erosivity and the morphology of the plant cover, it is necessary to take account of the changes in these during the year in arriving at an annual value
- The year is divided into periods corresponding to different stages of crop growth.

P

- This is the conservation practice factor.
- Values are obtained from tables of the ratio of soil loss where contouring and contour strip-cropping are practiced to that where they are not
- With no conservation measures, the value of P is 1.0
- Where terracing is adopted, the value for strip –cropping is used for the P factor, and the LS index is adjusted for the slope length which represents the horizontal spacing between terraces.

LIMITATIONS OF USLE

- The equation was developed as a design tool for conservation planning, thus, applying the equation to purposes for which it was not intended is not recommended.
- Having been designed for inter rill and rill erosion, it should not be used to estimate sediment yield from drainage basins or to predict gully or stream-bank erosion.
- it was developed to estimate long term mean annual soil loss

SOIL CONSERVATION MANAGEMENT STRATEGIES

SOIL CONSERVATION STRATEGIES

- must be based on covering the soil to protect it from raindrop impact, increasing the infiltration capacity of the soil to reduce run off, improving the aggregate stability for the soil, and increasing surface roughness to reduce the velocity of runoff

AGRONOMIC OR BIOLOGICAL MEASURES

- utilize the role of vegetation in helping to minimize erosion
- less expensive and deal directly with reducing raindrop impact, increasing infiltration, reducing runoff volume and decreasing water velocities
- it is easier to fit them into an existing farming system

MULCHING

- covering of the soil with crop residues such as straw, maize stalks, grasses of standing stubble.
- stimulates the effect of a plant cover, thus it protects the soil from raindrop impact and reduces the velocity of runoff and wind.

COVER CROPPING

- grown as a conservation measure either during the off-season or as a ground protection under trees
- The most common crops used are *Pueraria phaseoloides, Calopogonium muconoides* and *Centrosema pubescens.*

MULTIPLE CROPPING

- aim is to increase the production from the land whilst providing protection of the soil from erosion
- The method involves
  - **SEQUENTIAL CROPPING**, growing two or more crops a year in a sequence, or
  - **INTERCROPPING**, growing two or more crops at the same time on the same piece of land.
  - On sloping, intercropping may be done in strips (**STRIP CROPPING**).

CROP ROTATIONS

- The simplest way to combine different crops is to grow them consecutively in rotation
- The frequency with which row crops are grown will depend upon the severity of erosion
- Ideally, where erosion rates are low, row crops may be grown every other year, but in very erodible areas, they may be permissible only once in five or seven years
- Suitable crops for use in rotations are legumes and grasses as they provide good ground cover, help to maintain or even improve the organic status of the soil, thereby contributing to soil fertility.

STRIP-CROPPING

- best suited to well–drained soils but maybe practiced also to soils which are moderately well drained, crops to be grown must be well-selected.

- row crops and protection effective crops are grown alternating strips aligned in the contour or perpendicular to the wind
- Erosion is largely limited to the row-crop strips and soil removed from these is trapped in the next strip downslope
- Usually, the downslope is planted with a leguminous crop or grass crop

SOIL MANAGEMENT PRACTICES

- High fertile soils result in high crop yields and good plant cover thus, it minimizes the erosive effects of raindrops and runoff.
- Most soils when managed properly to maintain their fertility will also retain their stability and are not adversely affected by standard tillage operations.

ORGANIC CONTENT ENHANCEMENT (OCE)

- One of the ways in achieving and maintaining a fertile soil is to increase organic matter content as this improves the cohesiveness of the soil, increases its water retention capacity and promotes a stable aggregate structure

TILLAGE PRACTICES

- Tillage is an essential management technique for it provides a suitable place for plant growth and helps to control weeds.
- It should be kept in mind that the effect of tillage implement on a soil depends upon its shear strength, the nature of the confining stresses and the direction in which the force is applied.

MECHANICAL METHODS

- To control the movement of water over the soil surface, mechanical field practices are used
- depends on whether the objective is to reduce the velocity of runoff, increase water storage capacity or safely dispose excess water.

CONTOURING

- The effectiveness of this method varies with steepness and slope length for it is in adequate as the soil conservation measure for lengths greater than 180 m at 1º steepness.
- soil loss from contour strip cropped fields is 25-45% of that from fields managed by up-and-down tillage depending upon the steepness of slope.

TERRACING

- Constructed across the slope to intercept surface runoff and convey it to a stable outlet at a non-erosive velocity, and to shorten slope length

WATERWAYS

- These are used to convey runoff at non-erosive velocity by a suitable dispersal point
- Three types of waterway can be incorporated in a complete surface water dispersal system.

DIVERSION DITCHES

- Placed upslope of areas where protection is required to intercept water from top of hillside; built across slope at slight grade so as to convey the intercepted runoff to a suitable outlet.

TERRACE CHANNELS

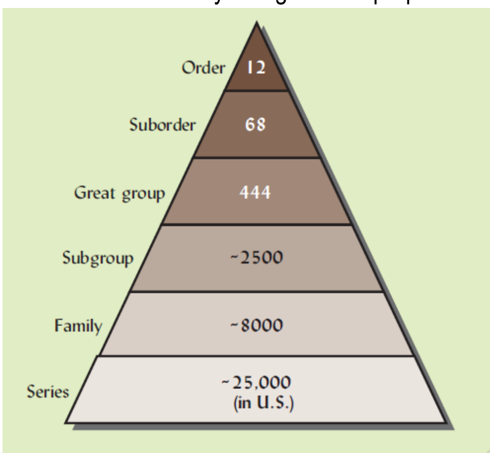
- Placed upslope of terrace bank to collect runoff from inter-terraced area; built across slope at slight grade so as to convey the runoff to a suitable outlet.

GRASS WATERWAYS

- Used as the outlet for diversions and terrace channels; run downslope, at grade of the sloping surface; empty into river system or other outlet; located in natural depressions on hillside.

SOIL SURVEY, CLASSIFICATION AND TAXONOMY

- In classifying soils;
  - the recognition of individuals on the basis of sets of identifying properties, and;
  - the organization of classes containing individuals alike in many though not all properties



US SOIL TAXONOMY

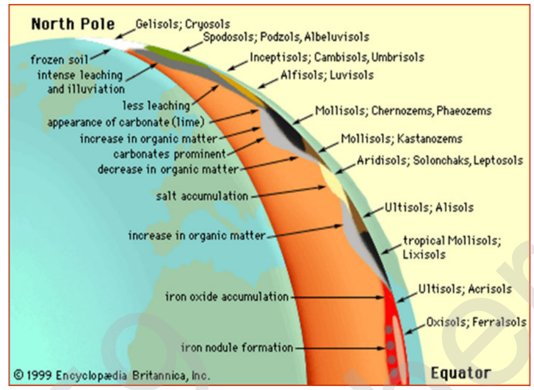
- The level of generalization in Soil Taxonomy relates to the range in properties allowed within the different classes making up a category.
- Down through the system, classes are defined by an increasing number of properties, thus, the lower the level of classification the greater the amount of information required to classify a soil.

CATEGORY	CHARACTERISTICS
ORDER	Soil forming processes indicated by presence or absence of major diagnostic horizon
SUBORDER	Genetic homogeneity. Subdivision according to presence or absence of properties associated with wetness, soil moisture regimes, major parent material and vegetation effects indicated by key properties.
GRTGROUP	Subdivision of suborders according to kind, arrangement and degree of expression of horizons with emphasis on upper sequum, base status, soil temperature and moisture regimes, presence or absence of diagnostic level.
SUBGROUP	General concept taxa for great group and properties indicating inter-gradations to other great groups, suborders and orders.
FAMILY	Properties important for plant root growth, broad soil textural classes averaged over control section or solum, mineralogical classes for dominant mineralogy of solum, soil temperature classes.
SERIES	Kind and arrangement of horizons, color, texture, structure, consistence, and reaction of horizons, chemical and mineralogical properties of the horizons

Diagnostic Horizon
-can be described using quantity or analytical values
Genetic Horizon
-can be defined as qualification in terms of soil formation process

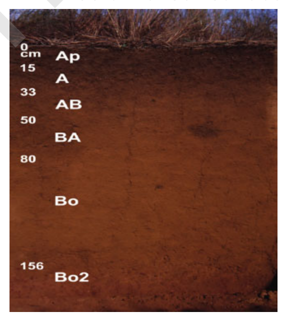
Soil Forming Processes That Produce Specific Soils

1. Laterization and Latosolization
2. Podzolization
3. Calcification
4. Salinization and desalinization
5. Alkalization and dealkalization
6. Paludization
7. Rubification
8. Pedoturbation

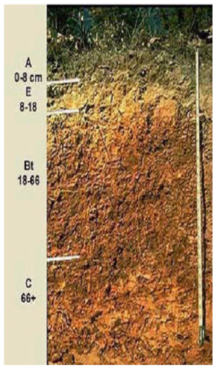


SOIL ORDERS

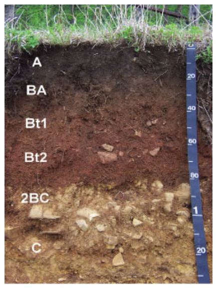
- **OXISOLS** – soils with oxic horizon (< 16 me/100g clay), consisting of mixtures of kaolinite, iron oxides and quartz, low in weatherable minerals. Usually deep, well-drained, red or yellow soils, excellent granular structure, very low fertility, uniform properties with depth.
  - Soils with an oxic horizon within 150 cm of soil surface.



- **ULTISOLS** - soils with an argillic horizon (20% increase in clay content of the control section) with less than 35% base saturation in the control section. Usually deep, well-drained, red or yellow soils, higher in weatherable minerals than Oxisols, with less desirable properties and relatively low fertility.
  - Soils with an argillic or kandic horizon and a base saturation <35% at 2 m depth or 75 cm below a fragipan

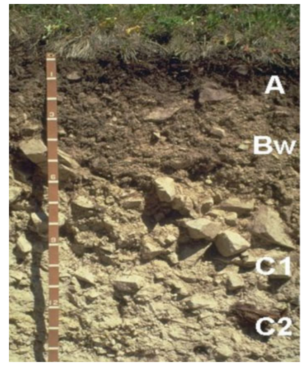


- **ALFISOLS** – soils with an argillic horizon with more than 35% base saturation.

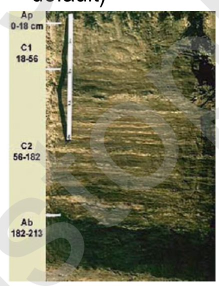


- **ARIDISOLS** – soils of aridic moisture regime, with horizon differentiation.
  - Soils with an aridic moisture regime and some B horizon development or salic horizon

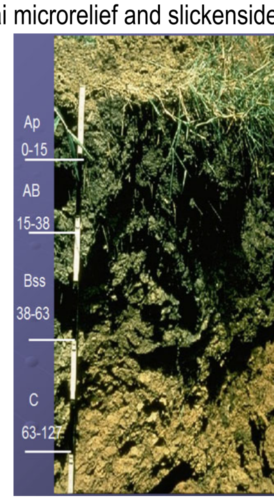
- **INCEPTISOLS** – Young soils with cambic horizon but no other diagnostic horizons.
  - Soils with a cambic, sulphuric, calcic, gypsic, petrocalcic, or petrogypsic horizon, or with a mollic, umbric, or histic epipedon, or with an ESP of >15%, or a fragipan
  - Based on existing criterion, it is impossible for inceptisols to develop in places with arid (dry) moisture regime.



- **ENTISOLS** – soils of such slight and recent development that only an ochric (yellowish) epipedon or simple man-made horizons have formed.
  - if the soil does not meet any criteria for other soil orders, then it is classified as entisol (by default)

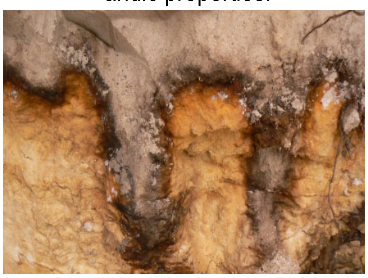


- **VERTISOLS** - heavy, cracking clayey soils with more than 30% or more clay and >50% of 2:1 mineral in clay fractions at a depth of 50 cm. Usually shrink and swell with changes in moisture contents, have gilgai microrelief and slickensides on peds.

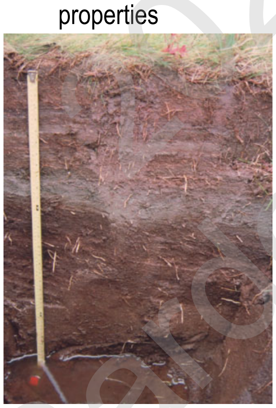


- **MOLLISOLS** – soils with a mollic epipedon i.e. high in organic matter, soft when dry, and >50% base saturation.
  - Soils with a mollic epipedon and a base saturation of > 50% to an impermeable layer or at 1.8 m from the surface

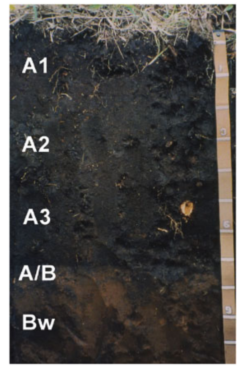
- **SPODOSOLS** – soils with spodic horizon (of iron and OM accumulation) developed on sandy materials
  - Soils with spodic horizon within 2 m of the surface soil and without andic properties.



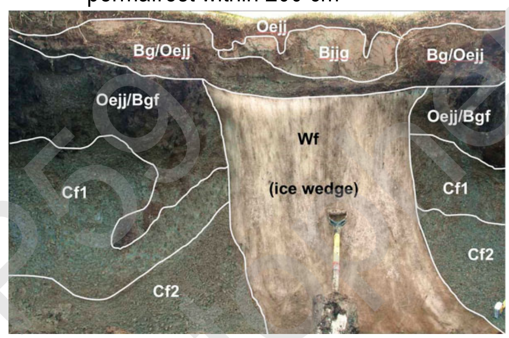
- **HISTOSOLS** – organic soils with a histic epipedon (>20% OM)
  - Soils with organic soil materials expending down to an impermeable layer or with an organic layer that is more than 40 cm thick and without andic properties



- **ANDISOLS** – soils of volcanic origin, soils with andic properties (low density, glass, pumice, short-range order minerals)



- **GELLISOLS** – soils with permarost within 100 cm or cryoturbation within 100 cm plus permafrost within 200 cm



DIAGNOSTIC PROPERTIES AND DIAGNOSTIC HORIZONS

- **DIAGNOSTIC PROPERTY** - refers to the properties (single or combination) used for classifying soils into the taxonomic system.
- Diagnostic horizons (DH) may occur either in the surface (**EPIPEDON**) or in the subsurface position (**ENDOPEDON**).
- EPIPEDONS are defined by properties that are not altered by normal cultivation.

EPIPEDON	**CHARACTERISTICS**
Mollic	At least 25 cm thick that contains more than 1 percent organic matter, but not sufficient to make it an organic layer.
Histic	A layer containing at least 20 percent organic matter if sandy or up to 30 percent organic matter if high in clay.
Anthropic	Having properties of a **mollic** epipedon, but in addition, **contain**, ***a high amount of extractable phosphorus (>250ppm)***
Plaggen	A surface horizon greater than 50 cm thick produced by heavy maturing.
Umbric	A surface horizon of mineral soil darkened by accumulated organic matter but too low in bases or extractable phosphorous
Ochric	Have a light color due to a lack of accumulated organic matter.

ENDOPEDON	**CHARACTERISTICS**
Argillic	Formed by illuviation of crystalline layer clays
Natric	The context of exchangeable Na exceeds 15 percent of the cation-exchange capacity.
Spodic	Horizon containing illuvial humus and amorphous oxides of Fe and Al in excess of certain specified minima
Cambic	Containing illuviated clay, humus or sesquioxides, but insufficient to classed either as argillic or spodic.
Oxic	A highly weathered horizon, high in 1:1 or sesquioxides clays, sometimes in combination with other highly resistant minerals such as **quartz**
Agric	Formed immediately beneath the plow layer, presumably through elluviation and illuviation of clay and humus.

HORIZON	CHARACTERISTICS
Albic	A light – colored A2 horizon
Calcic	Lime enriched layer
Duripan	Layer cemented by precipitated silica
Fragipan	Layer of brittle soil, commonly of a loam texture
Gypsic	Gypsum – enriched layer
Petrocalcic	Lime cemented layer

STR (Soil Temp Regime)	MAT (Mean Annual Temp)
Pergelic	Less than zero ºC
Cryic	0-8 ºC
Frigid	Less than 8 ºC
Mesic	8-15 ºC
Thermic	15-22 ºC
Hyperthermic	>22 ºC
ISO	Attached if difference of summer and winter temperature exists <5 ºC

SMR	CONDITION
Aquic	Reducing condition
Udic	Moist, but not wet, moist of the time
Aridic/Torric	Dry most of the time
Ustic	Intermediate between udic and aridic
Xeric	*Mediterranean*: wet winters; dry summers

NOMENCLATURE OF THE US SOIL TAXONOMY

- The formative element (a key syllable) from each of the higher categories is successively carried down to the great group level.
- The formative element at the lower level is tagged to the formative element at the next higher level to form the first part of the binomial nomenclature

SOIL ORDER	FORMATIVE ELEMENT/DERIVATION
ENTISOL	**(ent)** Meaningless syllable
INCEPTISOL	**(ept)** L. inceptum, beginning
ARIDISOL	**(id)** L. aridus, dry
MOLLISOL	**(oll)** L. mollis, soft
SPODOSOL	**(od)** L. spodos, wood ash
ALFISOL	**(alf)** Meaningless syllable
ULTISOL	**(ult)** L. ultimus, last
OXISOL	**(ox)** F. oxide, oxides
VERTISOL	**(ert)** L. verto, to turn
HISTOSOL	**(ist)** Gr. Histos, tissue
ANDISOL	**(and)** Jap. Ando, ash (volcanic)
GELLISOL	**(ell)**

- Suborder names can be formed by combining the formative element of the order and the suborder.

FORMATIVE ELEMENT - SUB ORDER

FORMATIVE ELEMENT	DERIVATION	CONNOTATION
Alb	L. *albus*, white	Presence of albic horizon
And	Modified from ando	Andolike
Aqu	L. aqua, water	Aquic moisture regime
Arg	L. *argilla*, white clay	Presence of argillic horizon
Bor	Gr. boreas	Cool
Ferr	L. ferrum, iron	Presence of iron
Fibr	L. fibra, fibrous	Least decomposed stage
Fluv	L. fluvius, river	Flood plain
Fol	L. folla, leaf	Mass of leaves
Hem	Gr. Hemi, half	Partial decomposition
Hum	L. humus, earth	Presence of organic matter
Ochr	Gr. ochros, pale	Presence of ochric epipedon
Orth	Gr. orthos, true	The common ones
Plagg	Ger. Plaggen, sod	Presence of plaggen epipedon
Psamm	Gr. psammos, sand	Sand texture
Rend	Pol. rendzina	High carbonate content
Sapr	Gr. sapros, rotten	Most decomposed stage
Torr	L. torridus, hot and dry	Torric moisture regime
Trop	Gr. tropikos, solstice	Continually warm
Ud	L. udus, humid	Udic moisture regime
Umbr	L. umbra, shade	Presence of umbric epipedon
Ust	L. ustus, burnt	Ustic moisture regime
Xer	Gr. xeros, dry	Xeric moisture regime

FORMATIVE ELEMENT - GREAT GROUP

FORMATIVE ELEMENT	DERIVATION	CONNOTATION
Acr	Gr. akros, at the end	Extreme weathering
Agr	L. ager, field	An agric horizon
Calc	L. calcis, lime	A calcic horizon
Camb	L. cambiare, to exchange	A cambic horizon
Chrom	Gr. chroma, color	High chroma
Cry	Gr. kryos, icy cold	Cold
Dur	L. durus, hard	A duripan
Dystr	Gr. dys, ill	Low base saturation
Eutr	Gr. eu, well	High base saturation
Frag	L. fragilis, brittle	Presence of fragipan
Gloss	Gr. glossa, tongue	Tounged
Gyps	L. gypsum, gypsum	Presence of a gypsic horizon
Hal	Gr. halos, salt	Salty
Hapl	Gr. haplos, simple	Minimum horizon
Hydr	Gr. hydor, water	Presence of water
Luv	Gr. lovo, to wash	Illuvial
Natr	L. natrium, sodium	Presence of nitric horizon
Pale	Gr. paleos, old	Excessive development
Pell	Gr. pellus, dusky	Low chroma
Plac	Gr. plax, flat stone	Presence of a thin pan
Plinth	Gr. plinthos, brick	Presence of plinthite
Quartz	Ger. Quartz, quartz	High quartz content
Rhod	Gr. rhodon, rose	Dark-red color
Sal	I. sal, salt	Presence of salt horizon
Sider	Gr. sideros, iron	Presence of free iron oxides
Sombr	Fr. Somber, dark	A dark horizon
Sphagn	Gr. sphagnos, bog	Presence of sphagnum
Sulf	L. sulfur, sulfur	Presence of sulfides
Verm	L. vermes, worm	Wormy or mixed by animals
Vitr	L. vitrum, glass	Presence of glass

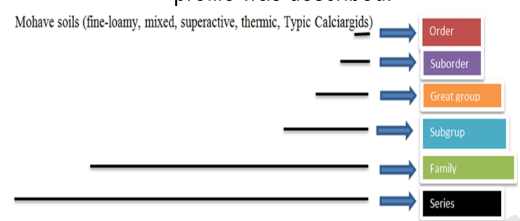
- For the great group name, just combine the formative element at this category to the previous suborder name.
- In naming subgroup, three subcategories are considered as follows:
  - **TYPIC** – a typic subgroup name indicates that the soil is the representative typical to that group of soils.
  - **INTRAGRADE** – a soil with characteristics of, or properties intermediate between, two or more soil units.
  - **EXTRAGRADE** - a soil which exhibits properties that are unique or those properties exceeding that of a normal formation process.

FORMATION OF A FAMILY NAME

- Family name consists of subgroup names followed by up to three or four adjectives that identify a number of additional soil properties or conditions such as:
  - (1) particle size class or texture expressed in rather broad terms;
  - (2) the mineralogy;
  - (3) the temperature or moisture regime if not indicated at higher level; and,
  - (4) other properties as the situation demands.

  - **PARTICLE SIZE CLASS OR BROAD TEXTURAL GROUP**
    - Sandy
    - Loamy
    - Clayey
    - Sandy over clayey
    - Loamy over clayey
    - Sandy over loamy
  - **MINERALOGY**
    - The dominant mineral present in the soil is usually the mineralogical name.
    - Montmorillonite – Montmorillonitic
  - **TEMPERATURE OR MOISTURE REGIME**
    - adopt the different temperature and moisture regimes previously discussed.
    - Mesic, thermic, hyperthermic, iso-hyperthermic
    - Udic, ustic, xeric, torric, aridic
  - Suppose a soil has the following:
    - Particle size class or Broad textural class
    - Mineralogy
    - Temperature regime
    - FAMILY NAME: Clayey, mixed, hyperthermic ENTIC KANDIUDULT

- **SOIL SERIES**
  - The basic unit of Soil Taxonomy and consisting of the soils which are essentially alike in all major profile characteristics, although the texture of the A horizon may vary somewhat.
  - Series names in the Philippines are taken from the locality, district or community where the first profile was described.



SOIL SURVEY- a systematic examination, description, classification and mapping of soils in a given area

BASIC STEPS IN SOIL SURVEY;

1. Mapping of the soil
2. Characterization of mapping units
3. Classification of mapping units
4. Correlation with other soil survey
5. Interpretation of soil suitability for various land uses
6. Organization

World Reference Base for Soil Resource (WRB)

Simplified guide to the WRB Reference Soil Groups (RSGs) with suggested codes

Note – this table is not to be used as a key. For full definitions, please refer to Chapter 3 and the Key (Chapter 4).

	RSG	Code
1. Soils with thick organic layers:	Histosols	HS
2. Soils with strong human influence –		
With long and intensive agricultural use:	Anthrosols	AT
Containing significant amounts of artefacts:	Technosols	TC
3. Soils with limitations to root growth –		
Permafrost-affected:	Cryosols	CR
Thin or with many coarse fragments:	Leptosols	LP
With a high content of exchangeable Na:	Solonetz	SN
Alternating wet-dry conditions, shrink-swell clays:	Vertisols	VR
High concentration of soluble salts:	Solonchaks	SC
4. Soils distinguished by Fe/Al chemistry –		
Groundwater-affected, underwater and in tidal areas:	Gleysols	GL
Allophanes or Al-humus complexes:	Andosols	AN
Subsoil accumulation of humus and/or oxides:	Podzols	PZ
Accumulation and redistribution of Fe:	Plinthosols	PT
Low-activity clay, P fixation, many Fe oxides, strongly structured:	Nitisols	NT
Dominance of kaolinite and oxides:	Ferralsols	FR
Stagnating water, abrupt textural difference:	Planosols	PL
Stagnating water, structural difference and/or moderate textural difference:	Stagnosols	ST
5. Pronounced accumulation of organic matter in the mineral topsoil –		
Very dark topsoil, secondary carbonates:	Chernozems	CH
Dark topsoil, secondary carbonates:	Kastanozems	KS
Dark topsoil, no secondary carbonates (unless very deep), high base status:	Phaeozems	PH
Dark topsoil, low base status:	Umbrisols	UM
6. Accumulation of moderately soluble salts or non-saline substances –		
Accumulation of, and cementation by, secondary silica:	Durisols	DU
Accumulation of secondary gypsum:	Gypsisols	GY
Accumulation of secondary carbonates:	Calcisols	CL
7. Soils with clay-enriched subsoil –		
Interfingering of coarser-textured, lighter coloured material into a finer-textured, stronger coloured layer:	Retisols	RT
Low-activity clays, low base status:	Acrisols	AC
Low-activity clays, high base status:	Lixisols	LX
High-activity clays, low base status:	Alisols	AL
High-activity clays, high base status:	Luvisols	LV
8. Soils with little or no profile differentiation –		
Moderately developed:	Cambisols	CM
Sandy:	Arenosols	AR
Stratified fluviatile, marine and lacustrine sediments:	Fluvisols	FL
No significant profile development:	Regosols	RG

	Order of Soil Survey				
	5th order	**4th order**	**3rd order**	**2nd order**	**1st order**
Type of survey	Reconnaissance	Reconnaissance	Semidetailed	Detailed	Intensive
Survey scale	1:250,000–1:10,000,000	1:50,000–1:300,000	1:20,000–1:65,000	1:12,000–1:32,000	1:1000–1:15,000
Size of mapping unit	2.5–500 km^2	15–250 ha	1.5–15 ha	0.5–4 ha	Smaller than 0.5 ha
Typical components of map units	Orders, suborders, and great groups	Great groups, subgroups, and families	Families, series, and phases of series	Soil series phases of series	Phases of soil series
Kind of map unit	Associations, some consociations, and undifferentiated groups	Associations, and some complexes, consociations	Associations or complexes; some consociations	Consociations and complexes; few associations	Mostly consociations; some complexes
Remote sensing sources	←	Landsat Thematic Mapper digitized data	→	→	
	←				
		SPOT image digital data	→	→	→
		←	High-altitude aerial photography	→	→
			←	Low-altitude aerial photography	→
Use of soil survey in land planning	← Resource inventory	→			
		← Project location	→		
			← Feasibility surveys	→	
				← Management surveys	→

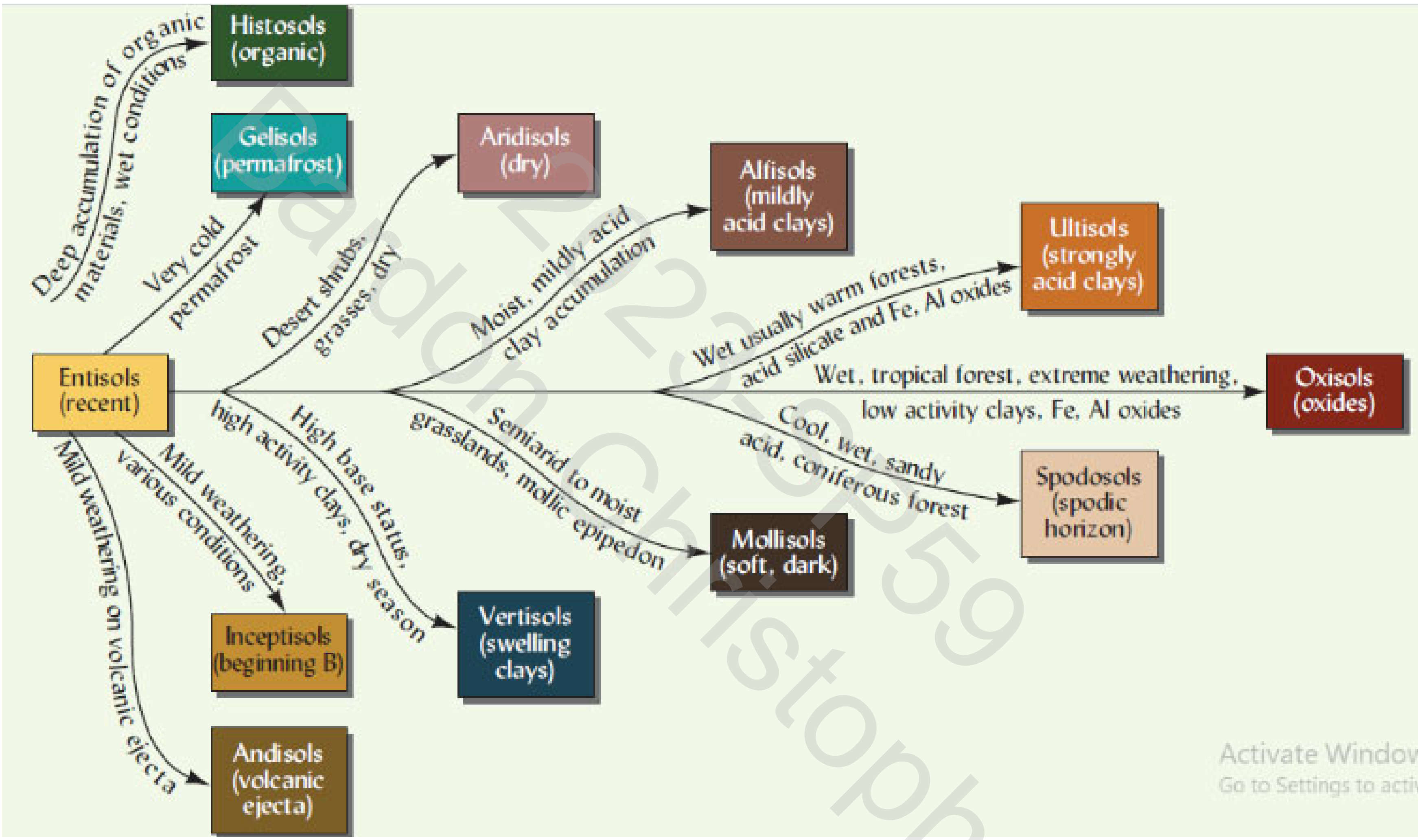
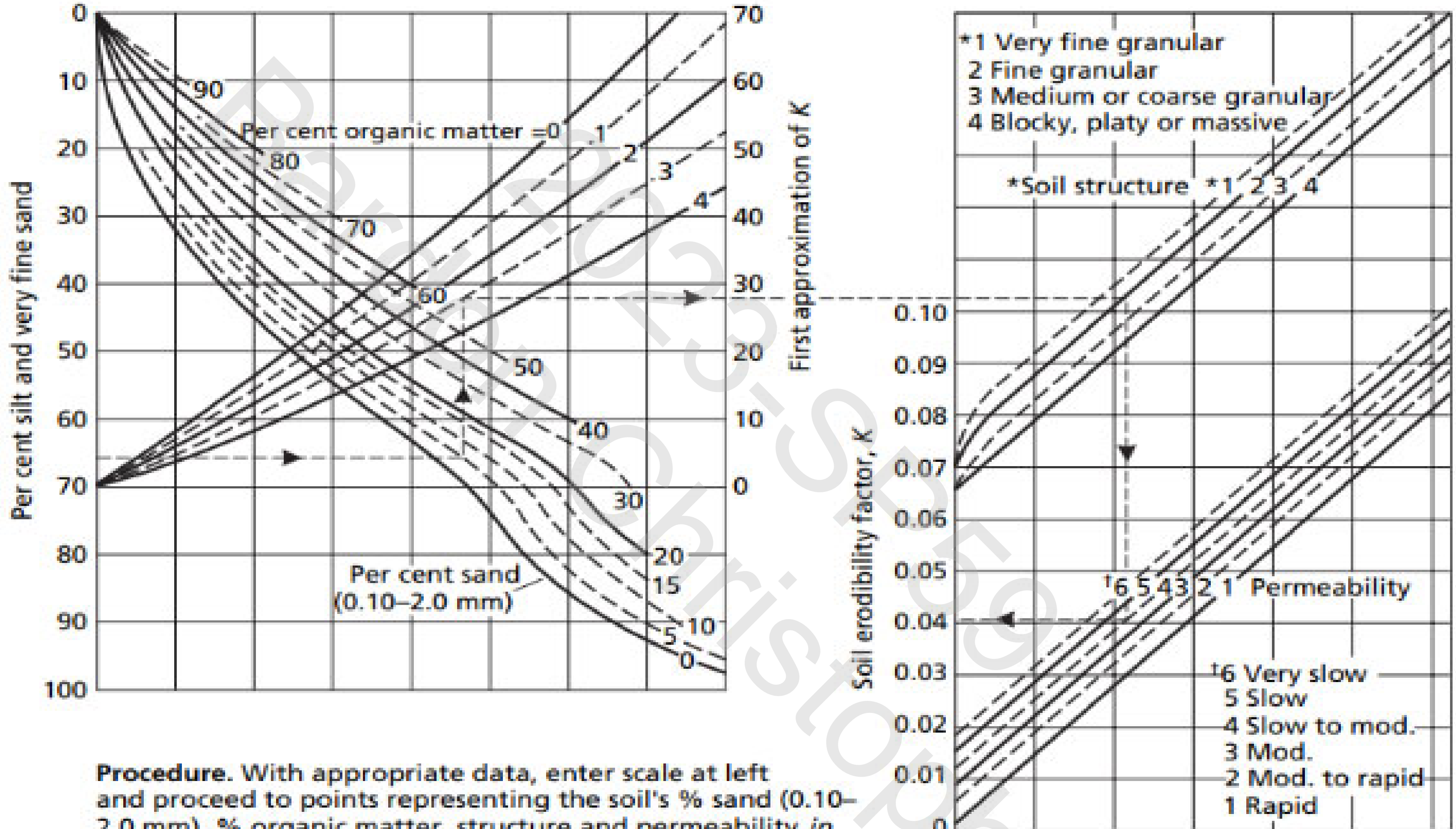

Histosols (organic)
Deep accumulation of organic materials, wet conditions
Gelisols (permafrost)
Very cold permafrost
Aridisols (dry)
Desert shrubs, grasses, dry
Alfisols (mildly acid clays)
Moist, mildly acid clay accumulation
Ultisols (strongly acid clays)
Wet usually warm forests, acid silicate and Fe, Al oxides
Oxisols (oxides)
Wet, tropical forest, extreme weathering, low activity clays, Fe, Al oxides
Spodosols (spodic horizon)
Cool, wet, sandy acid, coniferous forest
Mollisols (soft, dark)
Semiarid to moist grasslands, mollic epipedon
Vertisols (swelling clays)
High base status, high activity clays, dry season
Inceptisols (beginning B)
Mild weathering, various conditions
Andisols (volcanic ejecta)
Mild weathering on volcanic ejecta
Entisols (recent)

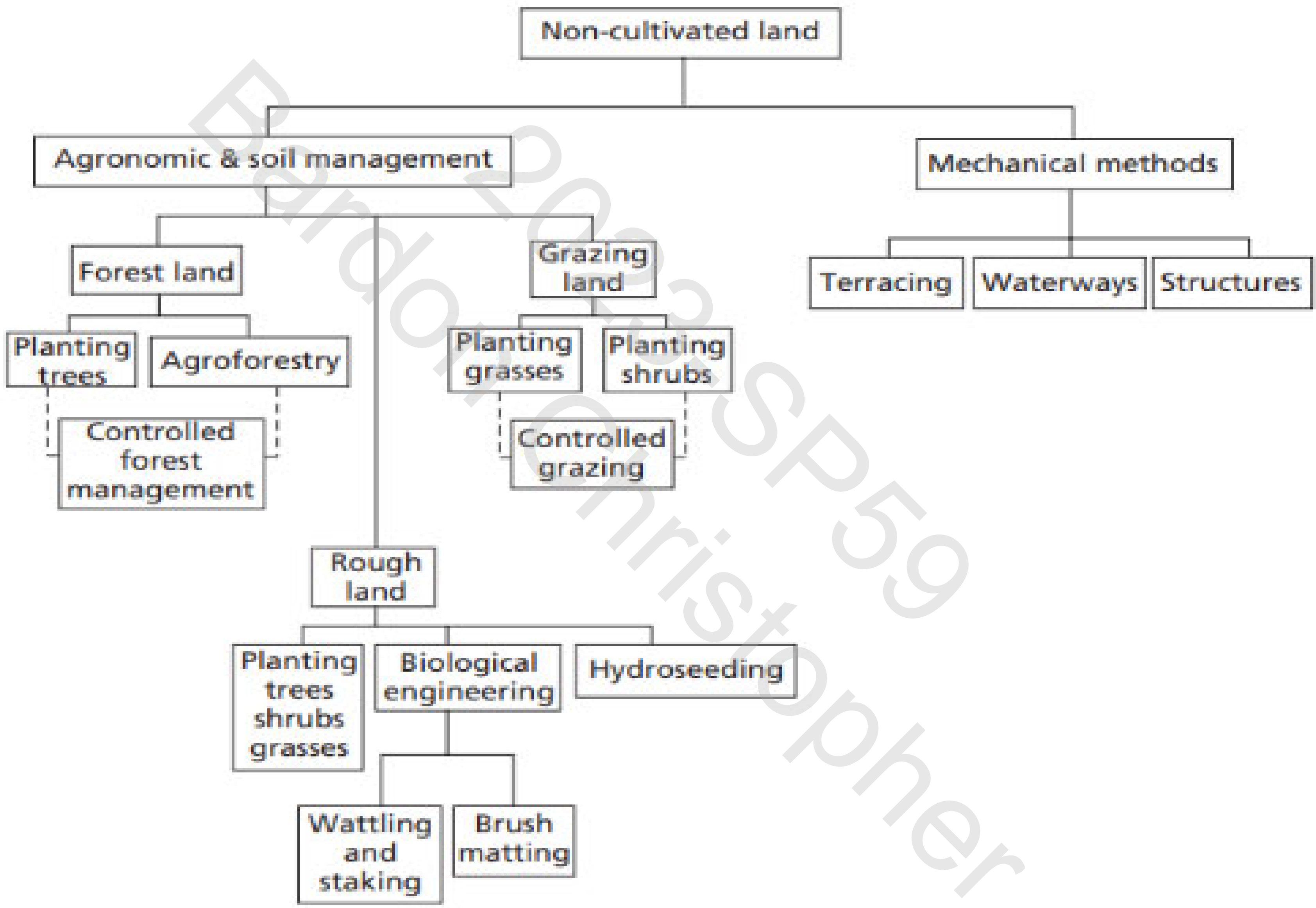
Table 4.1 Land capability classes (United States system)

Class	Characteristics and recommended land use
I	Deep, productive soils easily worked, on nearly level land; not subject to overland flow; no or slight risk of damage when cultivated; use of fertilizers and lime, cover crops, crop rotations required to maintain soil fertility and soil structure.
II	Productive soils on gentle slopes; moderate depth; subject to occasional overland flow; may require drainage; moderate risk of damage when cultivated; use of crop rotations, water-control systems or special tillage practices to control erosion.
III	Soils of moderate fertility on moderately steep slopes, subject to more severe erosion; subject to severe risk of damage but can be used for crops provided plant cover is maintained; hay or other sod crops should be grown instead of row crops.
IV	Good soils on steep slopes, subject to severe erosion; very severe risk of damage but may be cultivated if handled with great care; keep in hay or pasture but a grain crop may be grown once in five or six years.
V	Land is too wet or stony for cultivation but of nearly level slope; subject to only slight erosion if properly managed; should be used for pasture or forestry but grazing should be regulated to prevent plant cover being destroyed.
VI	Shallow soils on steep slopes; use for grazing and forestry; grazing should be regulated to preserve plant cover; if plant cover is destroyed, use should be restricted until land cover is re-established.
VII	Steep, rough, eroded land with shallow soils; also includes droughty or swampy land; severe risk of damage even when used for pasture or forestry; strict grazing or forest management must be applied.
VIII	Very rough land; not suitable even for woodland or grazing; reserve for wildlife, recreation or watershed conservation.

Classes I–IV denote soils suitable for cultivation.
Classes V–VIII denote soils unsuitable for cultivation.



Procedure. With appropriate data, enter scale at left and proceed to points representing the soil's % sand (0.10–2.0 mm). % organic matter, structure and permeability, *in that sequence*. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: sf + vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: $K = 0.041$.


Non-cultivated land
Agronomic & soil management
Mechanical methods
Forest land
Grazing land
Terracing
Waterways
Structures
Planting trees
Agroforestry
Planting grasses
Planting shrubs
Controlled forest management
Controlled grazing
Rough land
Planting trees shrubs grasses
Biological engineering
Hydroseeding
Wattling and staking
Brush matting