Bharathidasan University

Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. M.Tech. Geological Technology and Geoinformatics

*Course Code : **MTIGT0707*** *Optional Elective : **14*** *Credits : **3***

GEOINFORMATICS IN SOIL SCIENCE

Unit–1 Introduction to Soil Science

Prepared by

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Course Objectives:

- ❖ To learn the importance, characters and types of soil and its relation with biotic systems
- ❖ To study the significance of soil nutrients and micronutrients
- ❖ To understand relevant aspects like soil organic matter, water holding property and landscape
- ❖ To learn the application of Geological Technology and Geoinformatics in soil resources mapping and management
- ❖ To learn the application of Geoinformatics in mitigating soil erosion and reservoir siltation.

SEMESTER – VII ELECTIVE PAPER-14 MTIGT0707 GEOINFORMATICS IN SOIL SCIENCE

3 Credits

1. **Introduction to Soil Science :** Nature and Importance of Soil, Soil formation, Soil survey, Physical, chemical and biological characters of soil, Relationship between Soil, plants and animal. **9 Hrs**

2. **Soil Types :** Soil types and classification, Soil genesis, Soil mineralogy and geochemistry of soil types: Laterites, Bauxites, Aridisols, Vertisols, Camborthids. Application of soil micromorphology and landscape evolution. Radiometric age determination of soils. **12 Hrs**

3. **Soil Nutrients and Crop Production :** Elements essential for plants and animals, Soil nutrients - Nitrogen, Phosphorous, Potassium, Calcium, Magnesium and Sulphur in soil and its significance in plant growth, Micronutrients. **9 Hrs**

4. **Soil Quality and Landscape :** Soil and water relations, organic matter in soil, functions of organic matter, organic matter and soil structure, organic matter and essential elements, tillage, cropping systems and fertility and case studies. **12 Hrs**

5. **Soil Management and Conservation :** Introduction, irrigation, drainage and soil management for field crops, gardens, lawns, pastures, rangelands and forests. Problem Soils - Soil surface crusting - Salinity - Erosion - Contamination. Soil conservation factors and implementation methods. **6 Hrs**

6. **Current Contours: (Not for Final Exam; only for Discussion):** Environmentally safe and sustainable methods of mitigating soil erosion and reservoir siltation using Geological Technology and Geoinformatics; Development of suitable and pragmatic methods to protect soil from fertility loss, soil pollution and degradation.

References:

1. Nyle, C. Brady, Ray R. Weil, The Nature and Properties of Soils (13th Edition) Prentice Hall, 2002.
2. Donald, L. Sparks, Environmental Soil Chemistry, 2002.
3. Raymond B. Daniels, Richard D. Hammer., Soil Geomorphology, John Wiley & Sons, 2000.
4. M.E. Sumner, Hand book of soil Science, 1992.
5. Donald Sparks, Donald L. Sparks D, Environmental Geochemistry, Academic Press, 2002.

Course Outcomes:

After the successful completion of this course, the students are able to:

- *Understand the importance and the physical, chemical and biological properties of soils*
- *Know the different types of soils and classification*
- *Differentiate the reflectance properties of soils and mapping them using satellite data*
- *Understand the problems to soils using Remote Sensing, field surveys in GIS platform through modeling.*
- *Suggest pragmatic soil management and conservation practices using Remote Sensing, field surveys in GIS platform through modeling and*
- *Understand the importance of soil nutrients, quality and relation with landscape.*

Unit – 1 Introduction to Soil Science

Nature and Importance of Soil, Soil formation, Soil survey, Physical, chemical and biological characters of soil, Relationship between Soil, plants and animal. **9 Hrs.**

What is soil? – in view of various persons… thoughts /views, descriptions are different. Following are the views of various scientists, Engineers…

Geologist – Weathered rock particles contains minerals

Mining Engineer – Over burden – debris, gangue

Highway Engineer – Platform

Civil Engineer – Foundation media

Agriculturist – Habitat for plants

Hydrogeologist – Aquifer, Filter Bed – Catchment, Reservoir, Media for GW occurrence, etc.

Soil is defined as a dynamic non-renewable natural resource on the surface of the earth, composed of minerals, organic matter and living organisms, naturally unconsolidated, in which plants grow.


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We Study Soil Because It's A(n)

Great integrator

Medium of crop production

Filter of water and wastes

Producer and absorber of gases

Home to organisms (plants, animals and others)

Medium for plant growth

Snapshot of geologic, climatic, biological, and human history

Source material for construction, medicine, art, etc.

Essential natural resource

Waste decomposer

We depend on soil to perform many functions. Healthy soil gives us clean air and water, bountiful crops and forests, productive rangeland, diverse wildlife, and beautiful landscapes. Soil does all this by **performing five essential functions**.

Nutrient Cycling - Soil stores, moderates the release of, and cycles nutrients and other elements. During these biogeochemical processes, analogous to the water cycle, nutrients can be transformed into plant available forms, held in the soil, or even lost to air or water.

Water Relations - Soil can regulate the drainage, flow and storage of water and solutes, which includes nitrogen, phosphorus, pesticides, and other nutrients and compounds dissolved in the water. With proper functioning, soil partitions water for groundwater recharge and for use by plants and soil animals.

Biodiversity and Habitat - Soil supports the growth of a variety of plants, animals, and soil microorganisms, usually by providing a diverse physical, chemical, and biological habitat.

Filtering and Buffering - Soil acts as a filter to protect the quality of water, air, and other resources. Toxic compounds or excess nutrients should be degraded or otherwise becomes dangerous to human and other living plants and animals.

Physical Stability and Support - Soil has the ability to maintain its porous structure to allow passage of air and water, withstand erosive forces, and provide a medium for plant roots. Soils also provide anchoring support for human structures and protect archaeological treasures.

Public, off-site benefits of soil relate to the following resource issues:

Water quality of streams, lakes, oceans, and groundwater

Air quality, especially particulates Greenhouse gases, including carbon dioxide, methane, and nitrous oxide.

Biodiversity

Water flow and flood control

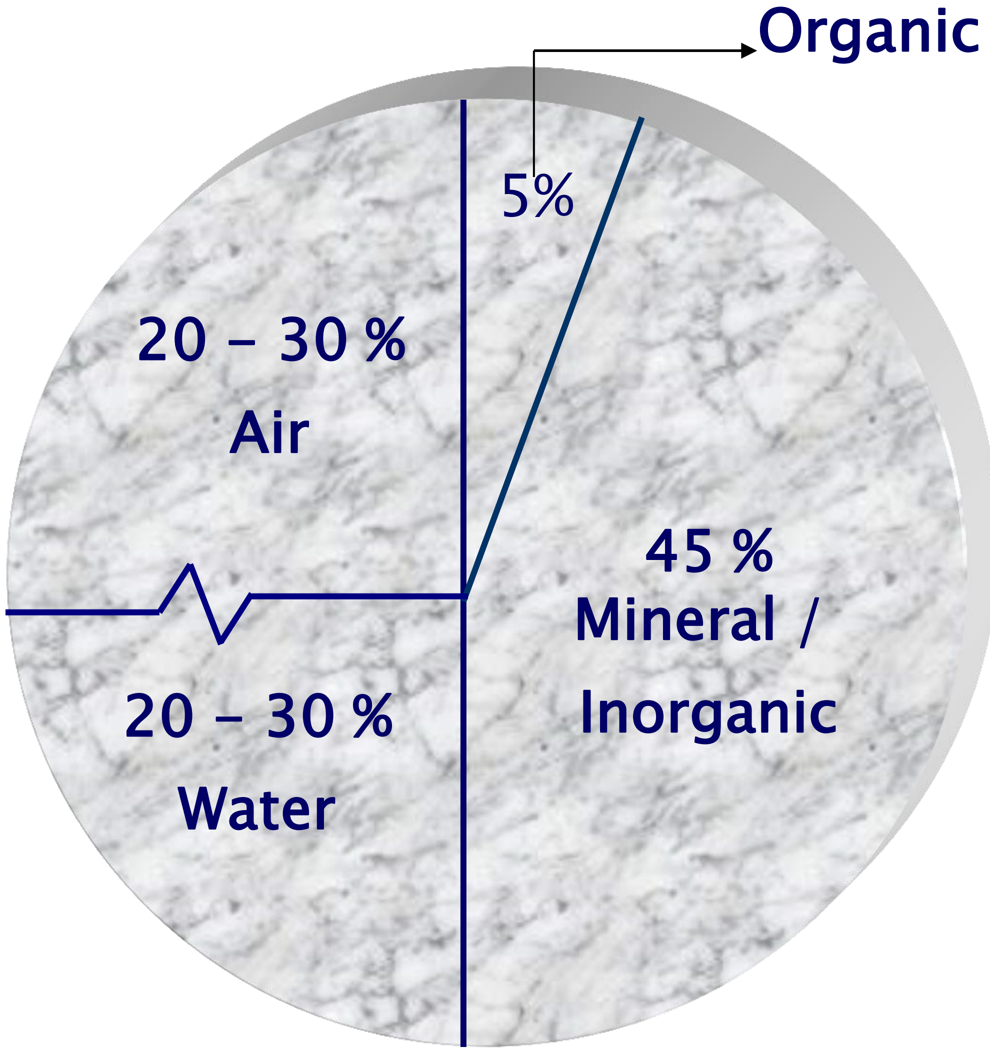
Sustainability of land productivity

Aesthetics

Summary of soil benefits

Soil Function	Benefit of Value to Humans	
	On-site	Off-site
Nutrient cycling	Delivery of nutrients to plants Carbon storage improves a variety of soil functions	Enhances water and air quality Storage of N and C can reduce greenhouse gas emissions
Maintaining biodiversity and habitat	Supports the growth of crops, rangeland plants, and trees May increase resistance and resilience to stress Reduces pesticide resistance	Helps maintain genetic diversity Supports wild species and reduces extinction rates Improves aesthetics of landscape
Water relations	Provides erosion control Allows on-site water recharge of streams and ponds Makes water available for plants and animals	Provides flood and sedimentation control Groundwater recharge
Filtering and buffering	Can maintain salt, metal and micronutrient levels within range tolerable to plants and animals	Improves water and air quality
Physical stability and support	Acts as a medium for plant growth Supports buildings and roads	Stores archeological items Stores garbage
Multiple functions	Sustains productivity	Maintains or improves air and/or water quality

SOIL COMPOSITION



Soil Formation

- **Major Soil forming factors (**Jenny 1941**)are :**

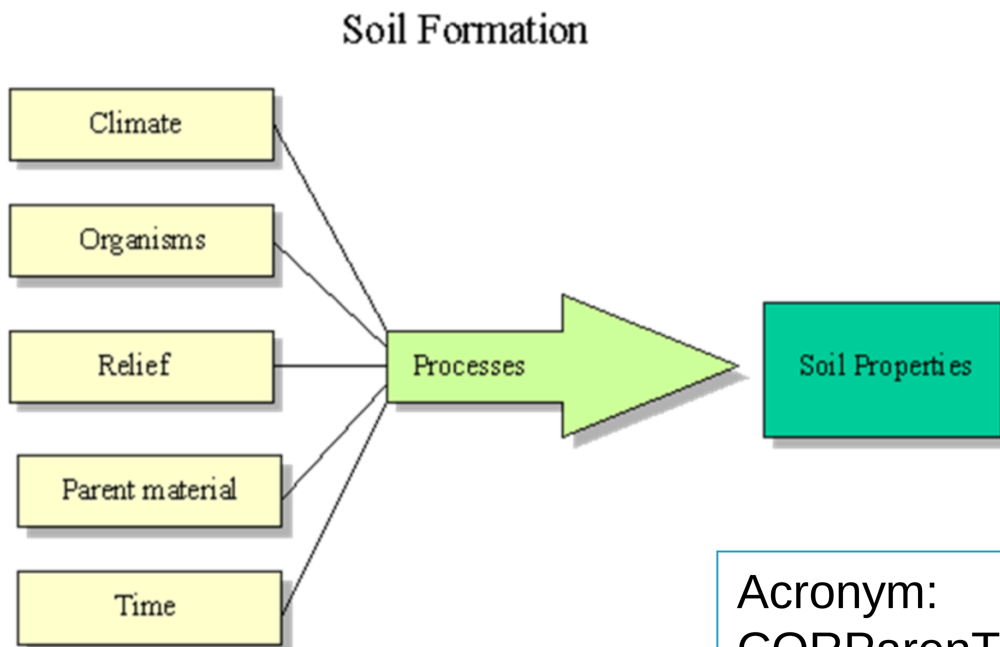
Climatic effects

Biological factors

Shape of the landscape – Topography

Geologic factors

Chronological factors



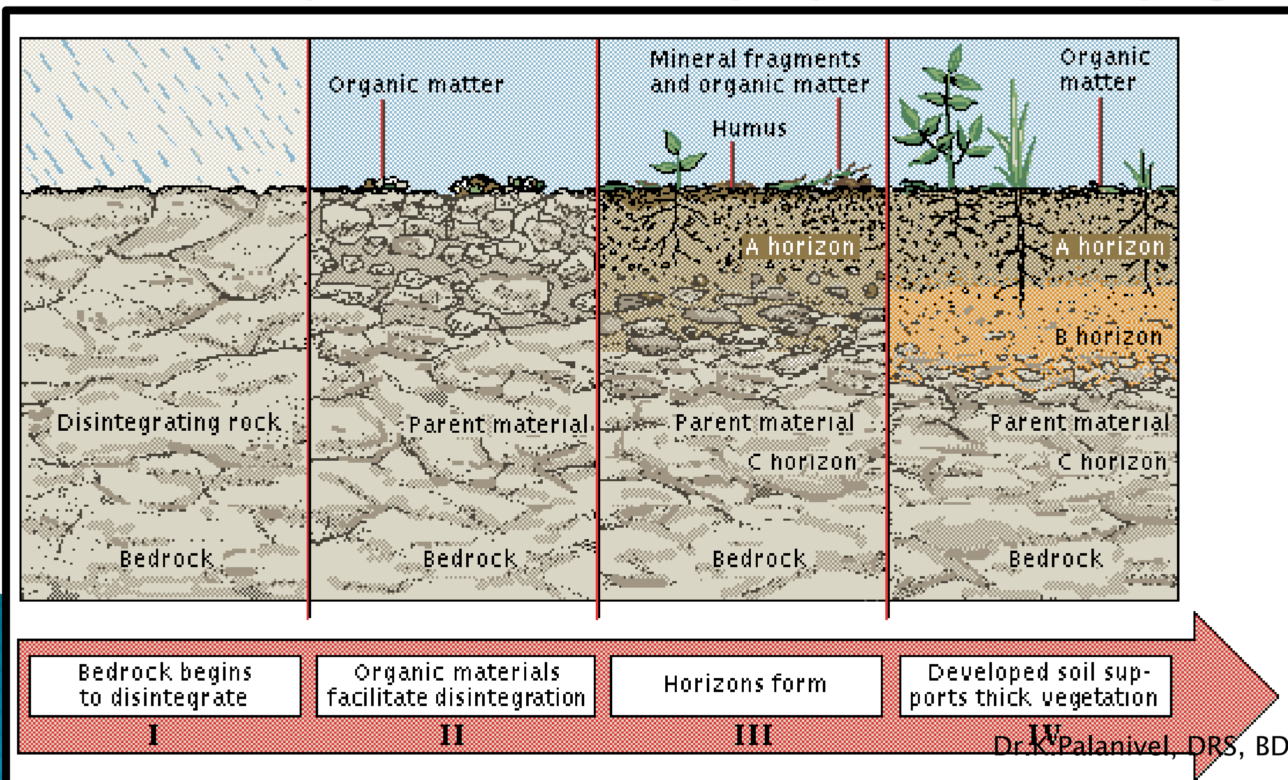
Acronym: CORParenT

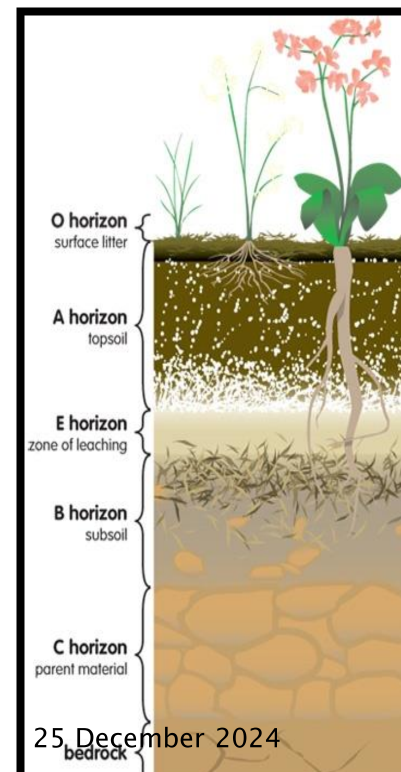
⁂ $$s = f\,(cl, o, r, p, t, \ldots\ldots)$$

The dots indicate that factors of lesser importance such as mineral accession from the atmosphere, or fire, might need to be taken into account.

The above equation assumes a casual relationship between Soil and the 5 factors. Jenny has redefined the factors during 1980, as 'state' variables and included ecosystem properties, vegetation and animal as well as soil properties.

Parent material and relief define the *initial state* for soil development, climate and organisms determine the *rate* at which *chemical* and *biological reactions* occur in the soil (the pedogenic processes), and time measures the *extent* to which a reaction will have proceeded. There is a logical progression: of environment (i.e. the soil forming factors) -> processes -> soil properties underlying the soil formation.





- To simplify the application of the above equation, it has been practiced to solve it for changes in a soil property **s** when **only one of the control variable** (e.g. **climate**) **varies**, the **others being constant** or nearly so.
- The relationship is then called a **climofunction** (climate = control variable):

$$\mathbf{s} = f\,(cl)_{\,o,\, r,\, p,\, t,\, \ldots}$$

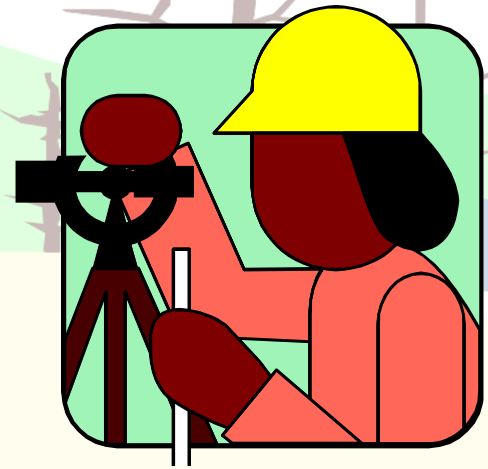
and the range of soils formed is called a **climosequence**.

- Similarly, **Biosequences, toposequences, lithosequences** & **chronosequences** of soils have been recognized in various parts of the world.
- The term toposequence is synonymous with Milne's catena concept (Milne, 1935).
- Indeed, the main virtue of Jenny's attempt to quantify the relationship between soil properties and soil forming factors lies not in the prediction of exact values of **s** at a particular site, but rather in identifying trends in properties and soil groups that are associated with readily observable changes in climate, parent material, etc.

SOIL SURVEY ??!

- DETECT - identify
- DESCRIBE - examine
- DEFINE - classify
- DELINEATE - trace boundaries
- DEDUCE - inferences

SURVEY METHODS(Purpose)



RRSS : 2000 ha / day ➡ i.e., = 2,00,00,000 sq.m/d (or) 2 cr.sq.m/d; (or) 20 sq.km/d; (or) 200 million sq.m/d

RSS : 400 ha / day

SDSS : 200 ha / day

DSS : 80 ha / day

Conversion Factor:
(1 ha = 2.471 acres = 10,000 sq.m
1 acre = 4046.9 sq.m;
i.e., 63.6 x 63.6m

SOIL SURVEY

WHAT IS?….

- DETECT : IDENTIFY

- DESCRIBE : THE CHARACTERS OF SOIL

- DEFINE : ITS TAXANOMICAL UNIT

- DELINEATE : ITS BOUNDARY and

- DEDUCE : INFERENCES TO BEST USE

TYPES OF SOIL SURVEYS :

- **RRSS** **: R**APID **R**ECCONNAISSANCE **S**OIL **S**URVEY - 2000 Ha / day
- **RSS** **: R**ECCONNAISSANCE **S**OIL **S**URVEY - 400 Ha / day
- **SDSS** **: S**EMI **D**ETAILED **S**OIL **S**URVEY - 200 Ha / day
- **DSS** : **D**ETAILED **S**OIL **S**URVEY - 80 Ha / day

- A soil survey describes the characteristics of the soils in a given area,
- classifies the soils according to a standard system of classification,
- plots the boundaries of the soils on a map, and
- makes predictions about the behavior of soils.
- The different uses of the soils and
- how the response of management affects them are considered.
- The information collected in a soil survey helps in the development of land-use plans and
- evaluates and predicts the effects of land use on the environment.

SOIL MAPPING BY CONVENTIONAL SURVEY

BASE MAP PREPARATION

- PLAN TRAVERSING
- FIX SOIL LEGENDS USING ROAD-CUTS, WELL-CUTS, FOUNDATION PITS, AUGER BORINGS
- OPEN PROFILE AND DEFINE
- TRACE BOUNDARY FOLLOWING TOPOGRAPHY, VEGETATION, CULTURAL PRACTICES, ETC.
- FIX MASTER PROFILE AND DESCRIBE
- COLLECT SOIL SAMPLES AND ANALYSE
- MODIFY SOIL NAME BASED ON ANALYSIS
- PREPARE SOIL SURVEY REPORT

SOIL MAPPING THRO RS DATA

- Base map preparation
- Selection of proper season satellite data
- Delineation of soil boundaries using Visual Interpretation keys and collateral data
- Name the polygons by number or alphabet
- Plan field visit – open soil profile, examine and classify
- Improve Visual Interpretation keys and substitute class name to soil polygons
- Check accuracy and area calculation

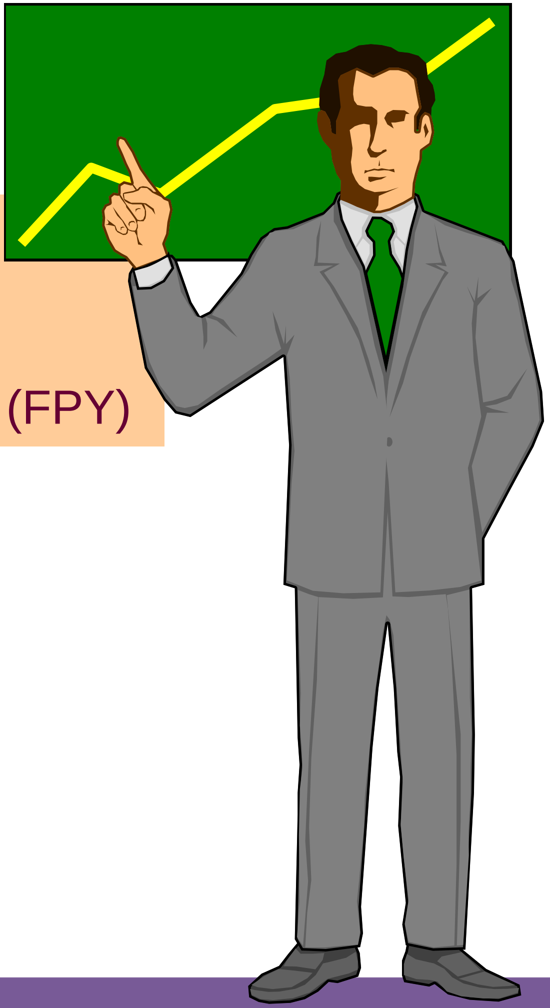
Factors Influencing Soil Reflectance

- SOIL COLOUR
- MINERAL CONTENT
- ORGANIC MATTER
- SOIL MOISTURE
- TEXTURE
- STRUCTURE
- PARTICLE SIZE
- VEGETATION

Efficiency of RS Tech for Soil Mapping

STATE : PUNJAB

GEOGRAPHICAL AREA : 50.3 L.ha



By conventional method :

Per day coverage	2000 ha
Per year (200 WMD)	4 L.ha
To cover 50.3 L.ha	12.6 Field Party Years (FPY)

By RS Technique :

Time spent 310 work man days
which corresponds to 1.5 FPY

Efficiency : 12.6 / 1.5 = approx. 8 times

Remote Sensing Tech thus affords 8 times more efficiency than conventional method **(Sehgal and Karale, 1998)**

Physical properties of soil

Physical properties of soil

- **Texture** – Size distribution of primary mnls
- **Structure** – arrangement of primary particles into secondary particles – granular, blocky, platy, etc.
- **Consistence** – Soil's Physical condition at various moisture content – hard, loose, friable, firm, plastic, sticky
- **Colour** – determined by minor components

PHYSICAL

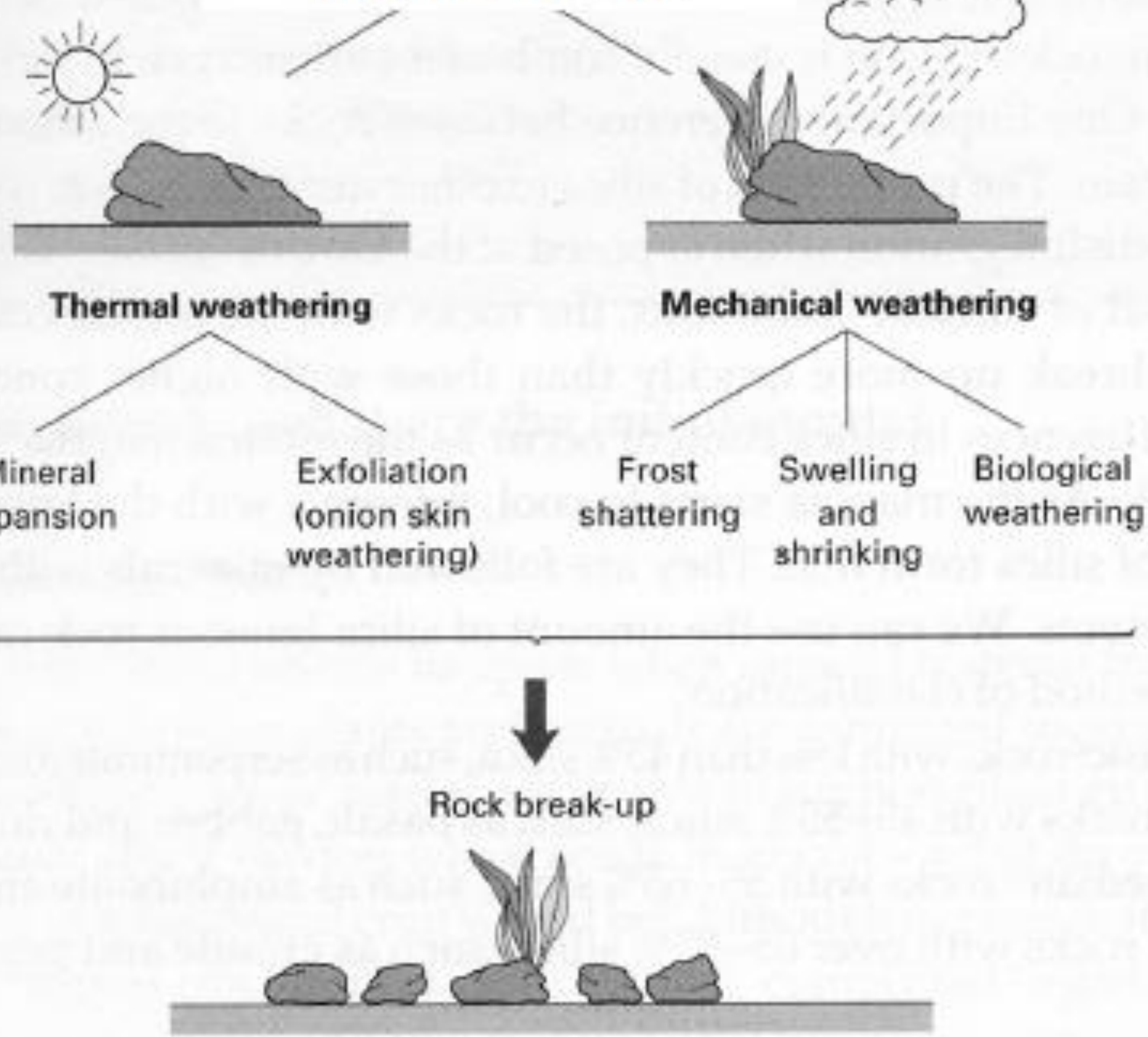


Fig. 1.1 The physical break-up of rocks by thermal and mechanical means.

From Essential Soil Science – Ashman and Puri

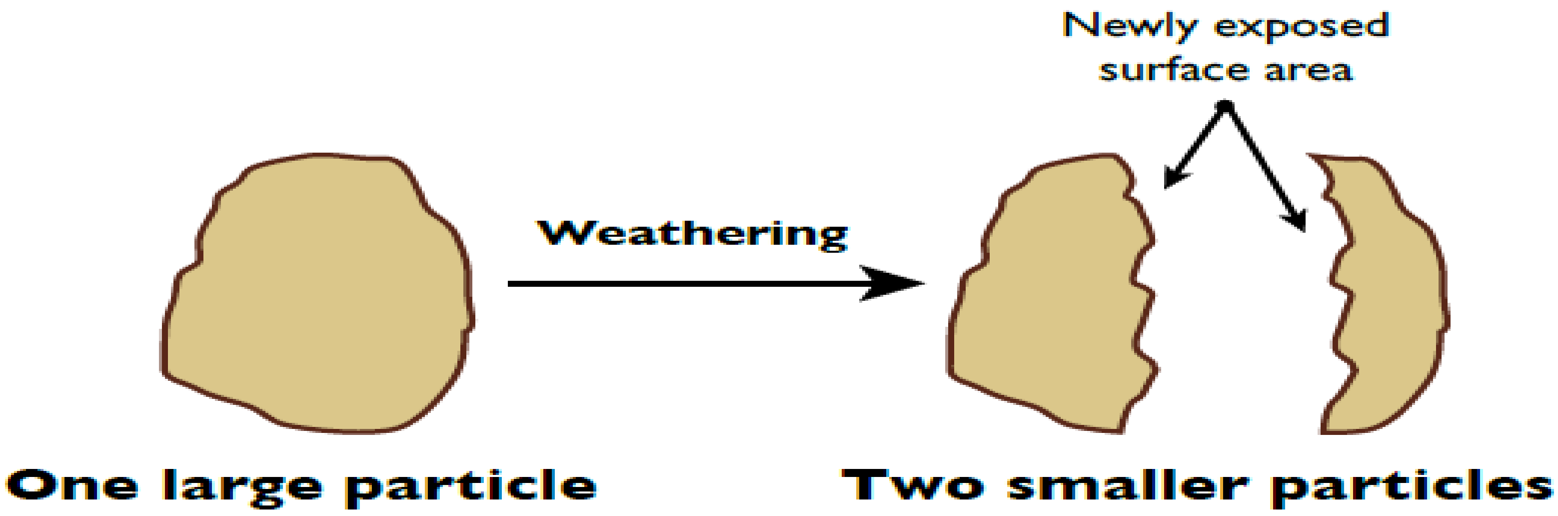


Figure 4. Illustration of surface area. The smaller particles have a greater total surface area than the one larger particle.

Table 1. Diameter and approximate size of four soil particles.

Soil Particle	Diameter (mm)	Approximate Size
Gravel	>2.0	●
Sand	0.05-2.0	•
Silt	0.002-0.05	·
Clay	<0.002	Invisible to naked eye

CHEMICAL

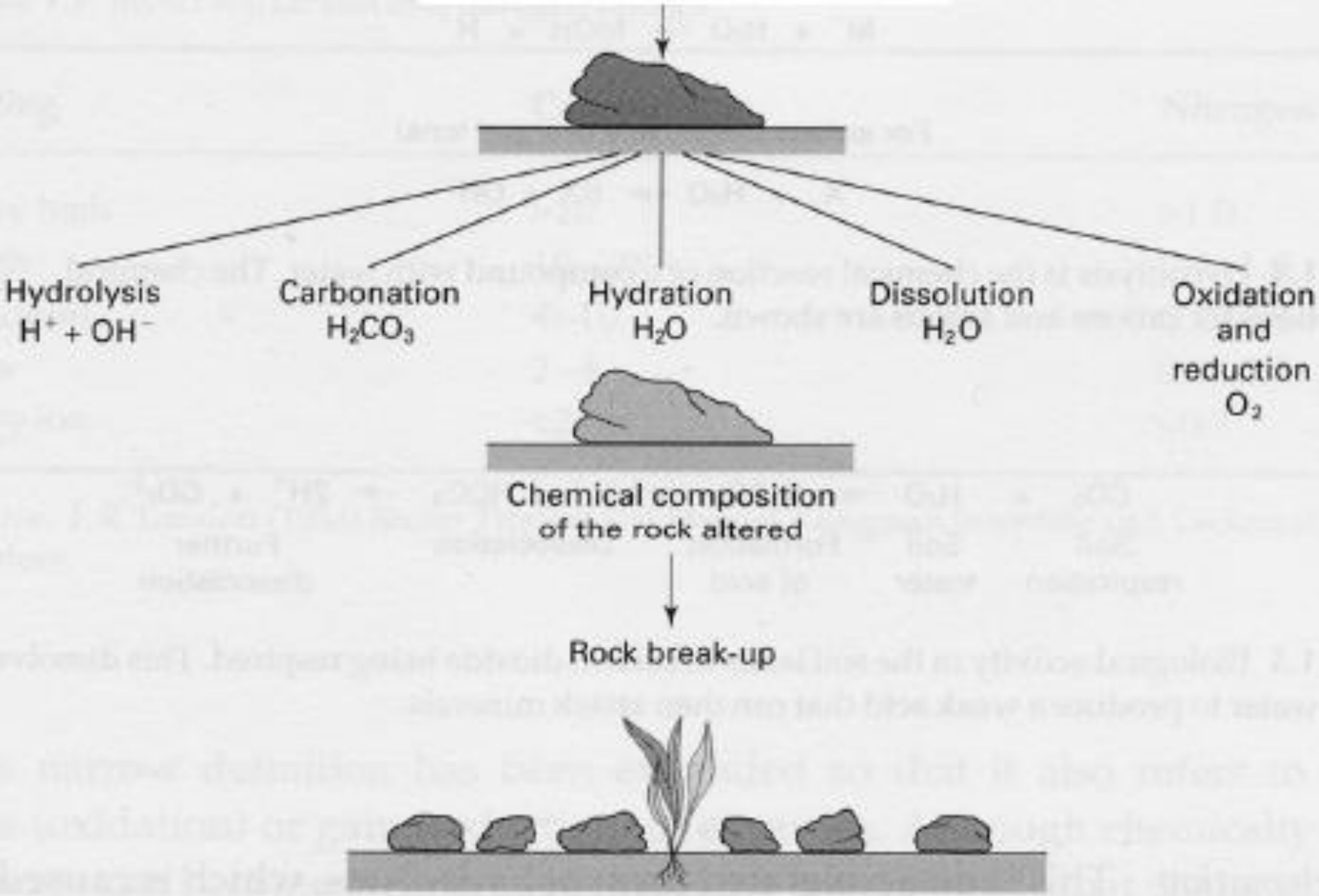


Fig. 1.3 The chemical break-up of rocks by hydrolysis, carbonation, hydration, dissolution, oxidation and reduction. Unlike physical weathering, which simply breaks the rock into smaller and smaller fragments, chemical weathering can also change the physical and chemical properties of the rock. From Essential Soil Science – Ashman and Puri

Soil Texture

- The texture of a soil is its appearance or "feel" and it depends on the relative sizes and shapes of the particles as well as the range or distribution of those sizes.

Coarse-grained soils: Gravel, Sand

Fine-grained soils: Silt, Clay

0.075 mm (USCS)

0.06 mm (BS) (Hong Kong)

← Sieve analysis | Hydrometer analysis →

Unified Soil Classification System (USCS)

- **Soil texture**, has a strong influence on the properties of a soil.
- Particles larger than 2 mm in diameter are considered inert. Little attention is paid to them unless they are boulders that interfere with manipulation of the surface soil.
- Particles smaller than 2 mm in diameter are divided into three broad categories based on size.
- Particles of 2 to 0.05 mm diameter are called **sand**; those of 0.05 to 0.002 mm diameter are **silt**; and the <0.002 mm particles are **clay**.
- The texture of soils is usually expressed in terms of the percentages or proportion of sand, silt, and clay.
- The relative amount of various particle sizes in a soil defines its texture, i.e., whether it is a clay, loam, sandy loam or other textural category
- To avoid quoting exact percentages, 12 textural classes have been defined.
- Each class, named to identify the size separate or separates having the dominant impact on properties, includes a range in size distribution that is consistent with a rather narrow range in soil behavior.

TEXTURAL PROPERTIES

Texture	Feeling & Appearance		
	Dry	Moist-Casts	Moist-Ribbons
Sand	Non-cohesive	Crumbles	No
Sandy Loam	Gritty	Fragile	No
Loam	Velvety/Gritty	Not fragile	Slight
Silt Loam	Flour-like	Not fragile	Slight
Clay Loam	Gritty-aggregates	Durable	Yes
Clay	Gritty-aggregates	Very Durable	Yes

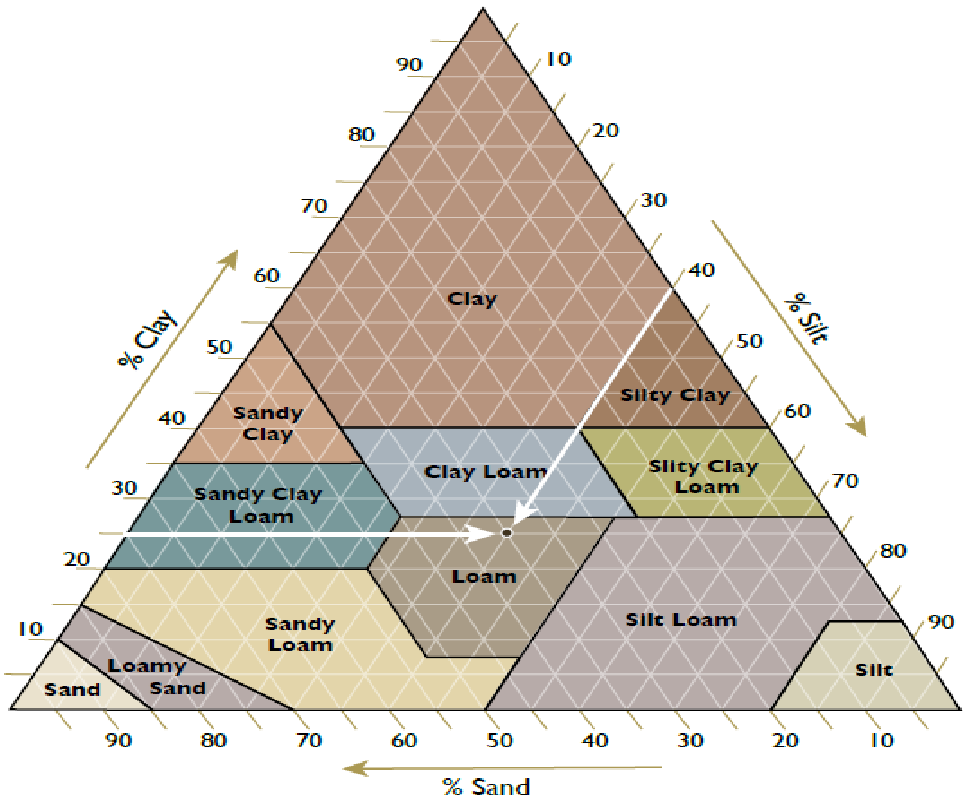


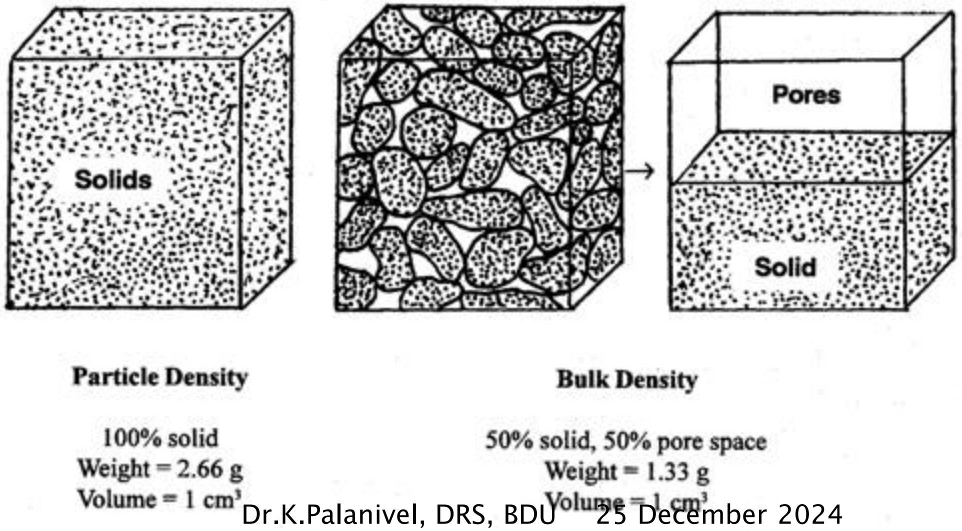
Figure 3. Textural triangle showing a soil's textural class according to the percentage of sand, silt and clay it contains. Note that a solid with 25% clay and 40% silt is loam.

soil texture ... contd...

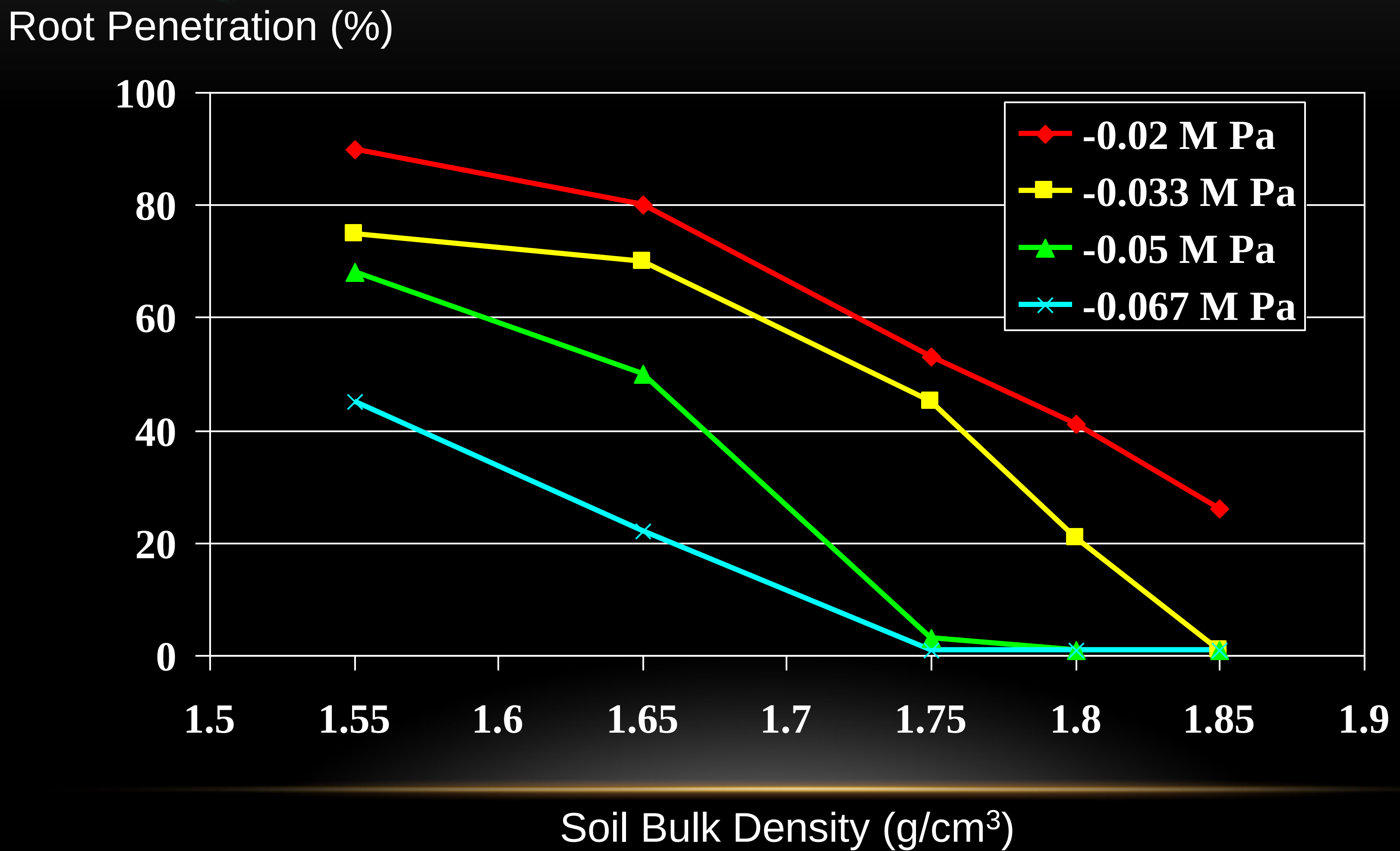
- The **loam** textural class contains soils whose properties are controlled equally by clay, silt and sand separates.
- Such soils tend to exhibit good balance between large and small pores; thus, movement of water, air and roots is easy and water retention is adequate.
- Soil texture, a stable and an easily determined soil characteristic, can be estimated by feeling and manipulating a moist sample, or it can be determined accurately by laboratory analysis.
- Soil horizons are sometimes separated on the basis of differences in texture.

Soil Particle Density and Bulk Density

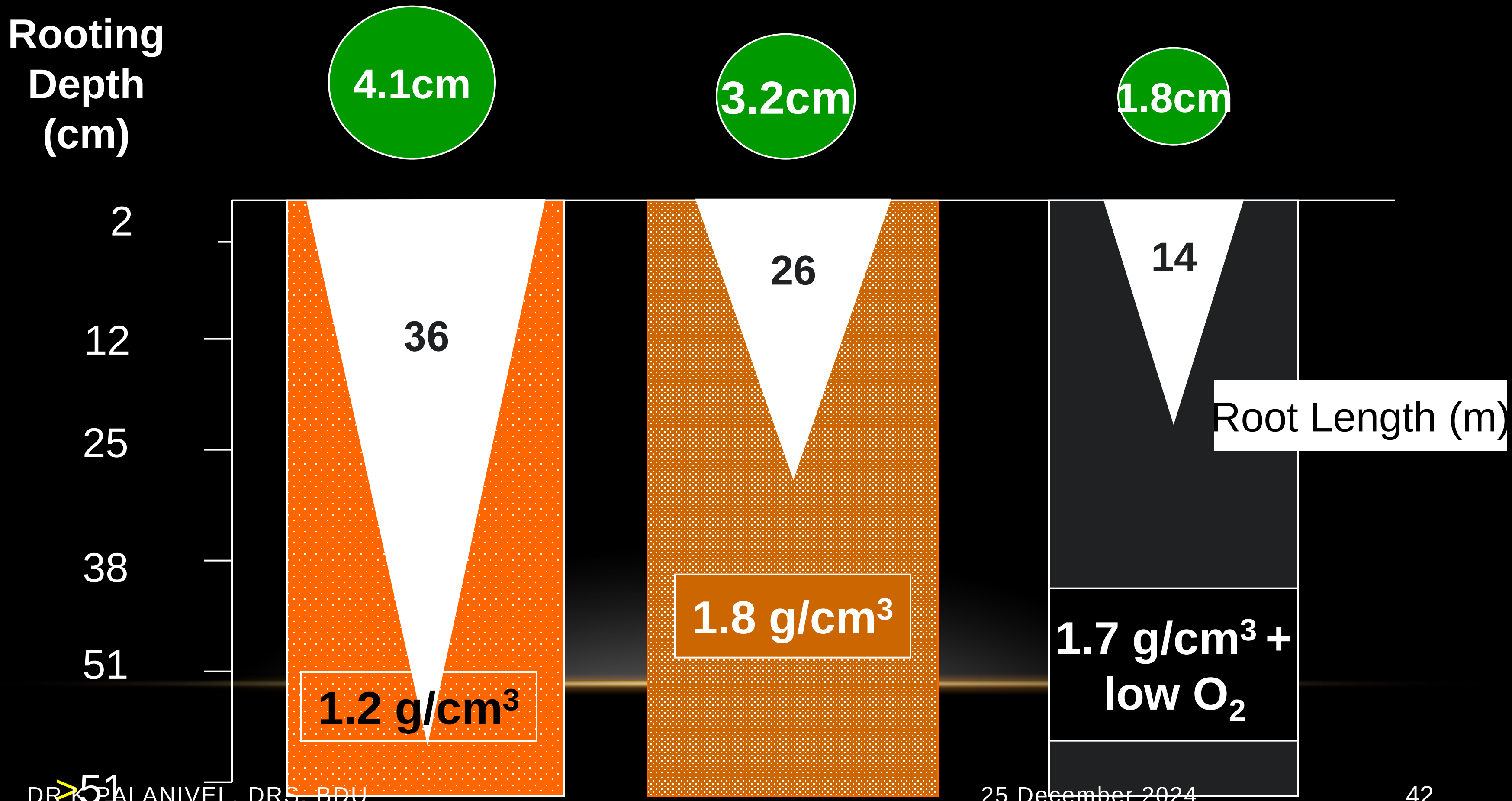
- Soil weight is most often expressed on a soil volume basis rather than on a particle basis.
- *Bulk density* is defined as the dry weight of soil per unit volume of soil.
- Bulk density considers both the solids and the pore space; whereas, particle density considers only the mineral solids.



BULK DENSITY AFFECTS GROWTH



Soil Bulk Density & Hypoxia - Reduce Growth – Gilman et al. 1987



Soil Structure

Anyone who has ever made a mud ball knows that soil particles have a tendency to stick together.

Attempts to make mud balls out of pure sand can be frustrating experiences because sand particles do not cohere (stick together) as do the finer clay particles.

The nature of the arrangement of primary particles into naturally formed secondary particles, called **aggregates**, is **soil structure**.

A sandy soil may be structureless because each sand grain behaves independently of all others.

A compacted clay soil may be structureless because the particles are clumped together in huge **massive** chunks.

In between these extremes, there is the **granular** structure of surface soils and the **blocky** structure of subsoils.

Soil structure is the shape that the soil takes based on its physical and chemical properties. Each individual unit of soil structure is called a **ped**.

Structure ... contd...

In some cases subsoils may have **platy** or columnar types of structure.

Structure may be further described in terms of the size and stability of aggregates.

Structural class is based on aggregate size, while structural grade is based on aggregate strength.

Soil horizons can be differentiated on the basis of structural type, class, or grade.

What causes aggregates to form and what holds them together?

Clay particles cohere to each other and adhere to larger particles under the conditions that prevail in most soils.

- Wetting and drying, freezing and thawing, root and animal activity, and mechanical agitation are involved in the rearranging of particles in soils--including destruction of some aggregates and the bringing together of particles into new aggregate groupings or cracks form around soil masses, creating peds.

- Peds are held together and in place through the adhesion of organic substances, iron oxides, clays or carbonates.
- Cracks and channels between peds are important for water, air, and solute transport and deep water drainage.
- Finer soils usually have a stronger, more defined structure than coarser soils due to shrink/swell processes predominating in clay-rich soils and more cohesive strength between particles.

Structure ... contd...

Organic materials, especially microbial cells and waste products, act to cement aggregates and thus to increase their strength.

On the other hand, aggregates may be destroyed by poor tillage practices, compaction, and depletion of soil organic matter.

The structure of a soil, therefore, is not stable in the sense that the texture of a soil is stable.

Good structure, particularly in fine textured soils, increases total porosity because large pores occur between aggregates, allowing penetration of roots and movement of water and air.

Types of Soil Structure:

1. Single-grained (windblown particles such as silt; sand) - highly erodable
2. Massive (heavy clays)
3. Aggregated (ideal soil structure)

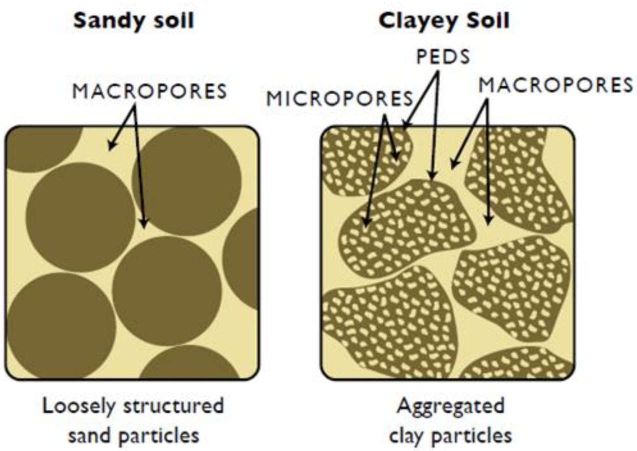


Figure 6. Generalized porosity in sandy and clayey soils.

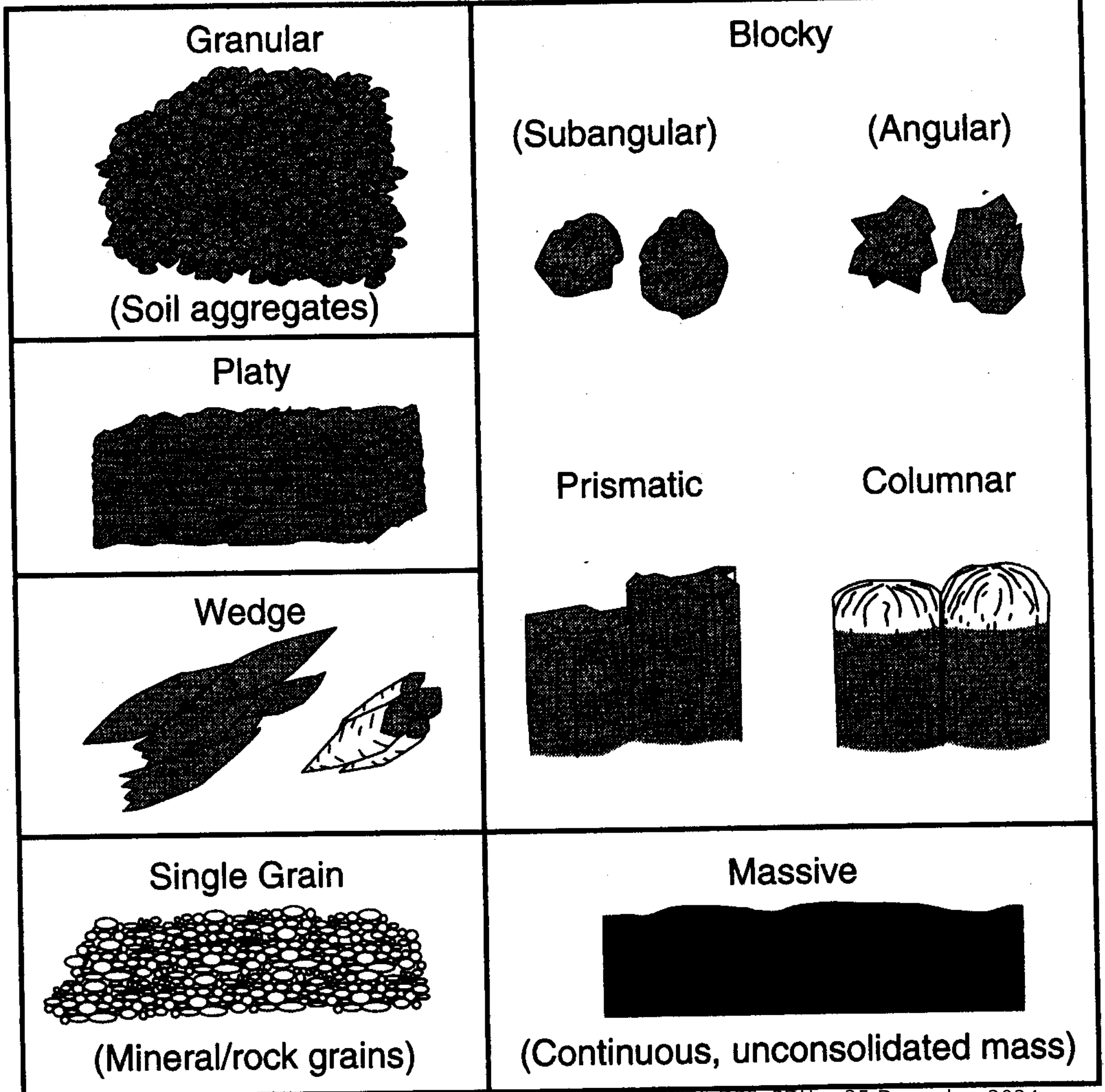
Figure 5. Topsoil exhibiting granular structure

Soil Structure: type, class, & grade

Structure less (single grain) → **Massive**

Grade (stability)	**Class (size)**	**Type (shape)**
weak	very fine	platy
moderate	fine	prismatic
strong	medium	columnar
	coarse	angular blocky
	very coarse	subangular blocky
		granular
		crumb

Type	Drawing	Form	Remarks
Plate-like		Platy-leafy and flaky also found	May occur in any part of profile. At times inherited from the soil material.
Prism-like		Prismatic (Level tops)	Both usually found in the B horizon. Common in soils of arid and semiarid regions.
		Columnar (Rounded tops)	
Block-like		Blocky (Cube-like)	Common in the B horizon, particularly in humid regions.
		Blocky (Subangular)	
Spheroidal		Granular (Porous)	Characteristic of the surface horizons (A). Subject to wide and rapid changes.
		Crumb (Very porous)	



Granular
(Soil aggregates)
Blocky
(Subangular)
(Angular)
Platy
Prismatic
Columnar
Wedge
Single Grain
(Mineral/rock grains)
Massive
(Continuous, unconsolidated mass)

Table 2-3 Size Classes of Soil Structure

	Shape of Structure			
Size Classes	*Platy* (mm)*	*Prismatic and Columnar (mm)*	*Blocky (mm)*	*Granular (mm)*
Very fine	< 1	< 10	< 5	< 1
Fine	1–2	10–20	5–10	1–2
Medium	2–5	20–50	10–20	2–5
Coarse	5–10	50–100	20–50	5–10
Very coarse	> 10	> 100	> 50	> 10

*In describing plates *thin* is used instead of *fine* and *thick* instead of *coarse*.
Source: Soil Survey Division Staff, *Soil Survey Manual,* USDA, 1993.

Soil Compaction

- Compression of an unsaturated soil, resulting in reduction of fractional air volume
- Natural and human-induced compaction:
  - Surface crusts
  - Hardpans
  - Clay pans
  - Carbonates
  - Tillage pans
  - Trampling by animals
  - Machinery
- Compaction measurements
  - Bulk density
- Penetrometer (indirect, and measures soil strength)

Soil Consistency

Consistence is a description of a soil's physical condition at various moisture contents as evidenced by the behavior of the soil to mechanical stress or manipulation.

Descriptive adjectives such as hard, loose, friable, firm, plastic, and sticky are used for consistence.

Soil consistence is of fundamental importance to the engineer who must move the material or compact it efficiently.

The consistence of a soil is determined to a large extent by the texture of the soil, but is related also to other properties such as content of organic matter and type of clay minerals.

Soil Color

The color of objects, including soils, can be determined by minor components.

Generally, moist soils are darker than dry ones and the organic component also makes soils darker.

Thus, surface soils tend to be darker than subsoils.

Red, yellow and gray hues of subsoils reflect the oxidation and hydration states or iron oxides, which are reflective of predominant aeration and drainage characteristics in subsoil.

Red and yellow hues are indicative of good drainage and aeration, critical for activity of aerobic organisms in soils.

Mottled zones, splotches of one or more colors in a matrix of different color, often are indicative of a transition between well drained, aerated zones and poorly drained, poorly aerated ones.

Gray hues indicate poor aeration. Soil color charts have been developed for the quantitative evaluation of colors.

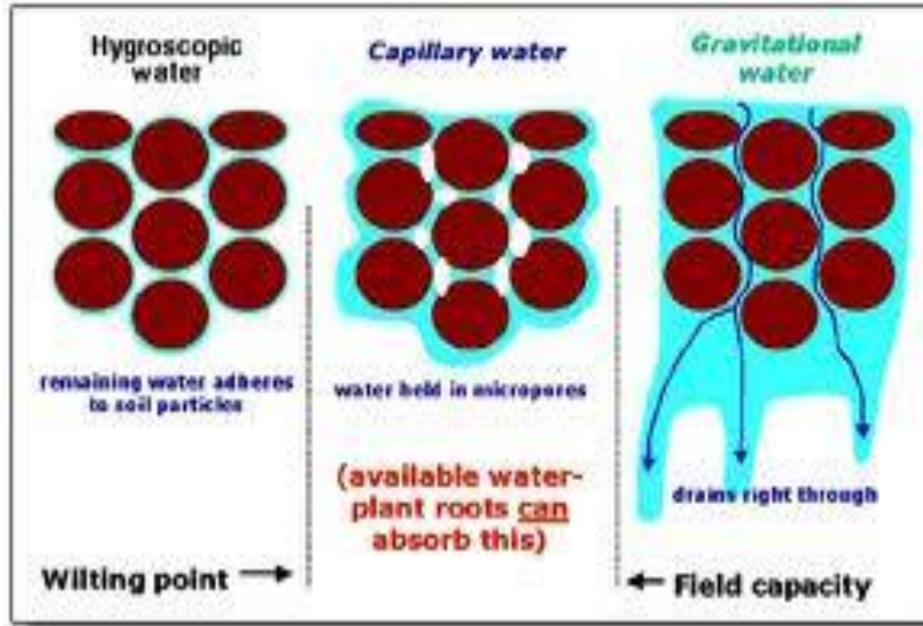
Soil Porosity and Permeability

Soil Temperature

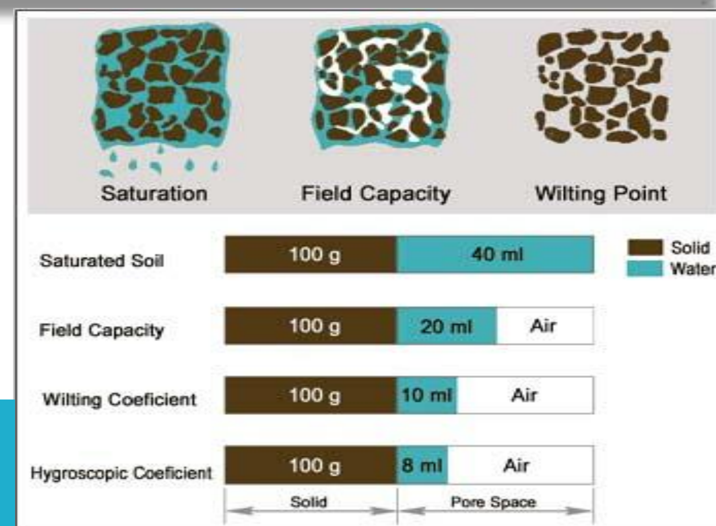
Soil Tillage and Plant Growth

Soil Conservation Tillage

Common soil physical properties analyzed in the laboratory:



- **Soil moisture**
- **Soil particle size - texture**
- **Bulk density**
- **Color**
- **Organic matter content**
- **Soil water retention properties:**
  - Field capacity - 1/3 atm
  - Wilting point - 15 atm
  - Hygroscopic water - 30 atm
  - Available water = field capacity - wilting point



Wilting point - A condition at which there is a loss of rigidity of non-woody parts of plants. This occurs when the turgor pressure in non-lignified plant cells falls towards zero, as a result of diminished water in the cells.

- **Field capacity** : The water content of a soil after gravitational drainage over approximately a day. The suction that defines this value varies from soil to soil, but is generally in the range of **10–33 kPa**. Drainable porosity of a soil is defined as the water content between field capacity and saturation.
- **Wilting point /permanent wilting point** : The amount of water per unit weight or per unit soil bulk volume in the soil, expressed in percent, that is held so tightly by the soil matrix that roots cannot absorb this water and a plant will wilt.
- **Gravitational water :** This is a free form of water which is held loosely in soil. This water could be easily lost by gravitational force. Hence, plants are not able to use this water as much as they move rapidly out of the soil.
- **Capillary water :** It is the water that is contained in the micropores of the soil, in the soil pore spaces precisely. This water, which composes the soil solution, is loosely held around the particles of soil. This form of water is the most available water form made available to plants for utilization.
- **Hygroscopic Water :** This form of water makes for a fine film wrapping particles of water and is typically not readily available to plants. It is found not only in pores but also on the surface of soil particles. These are tightly held in soil and cannot be eliminated except for over drying at 105 ℃.

Chemical properties of soil

Chemical properties of soil

- **Major elements**
  - **8 Chemical elements**
  - Amongst 8, **Oxygen (**1. **O)**– a negatively-charged ion (**Anion**) in crystal structures – most prevalent on both weight and volume basis
  - The next common elements, all positively-charged ions (**Cation**) in decreasing order are: **silicon (**2. **Si), aluminium (**3. **Al), iron (**4. **Fe), magnesium (**5. **Mg), calcium (**6. **Ca), sodium (**7. **Na)** and **potassium (**8. **K)**.
  - Ions of these elements (O, SiAl, FeMa, CaNaK) combine in various ratios to form different minerals.
  - More than 80 other elements also occur in soils and the earth's crust, but in much smaller quantities.

- Soils contain less of the water soluble weathering products, Ca, Mg, Na, K, Fe, Al.

- Old and highly weathered soils normally have high concentrations of Al and FeO.

- Organic fraction of a soil is much less than 10% of the soil mass by weight

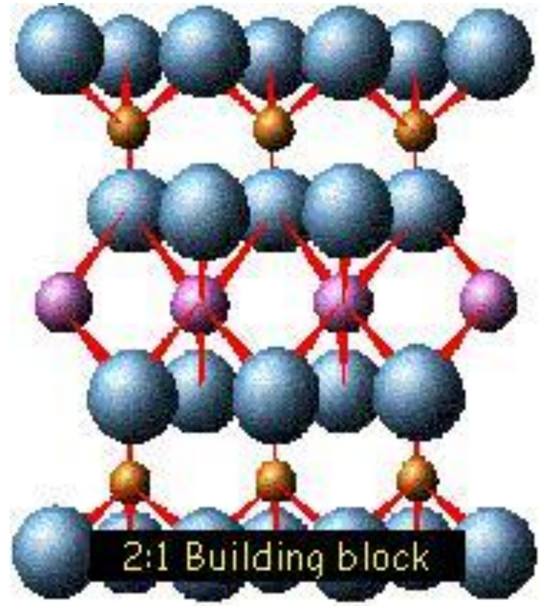
- But it has great influence on soil chemical properties.

- Soil organic matter is composed chiefly of carbon, hydrogen, oxygen, nitrogen and smaller quantities of sulphur and other elements.

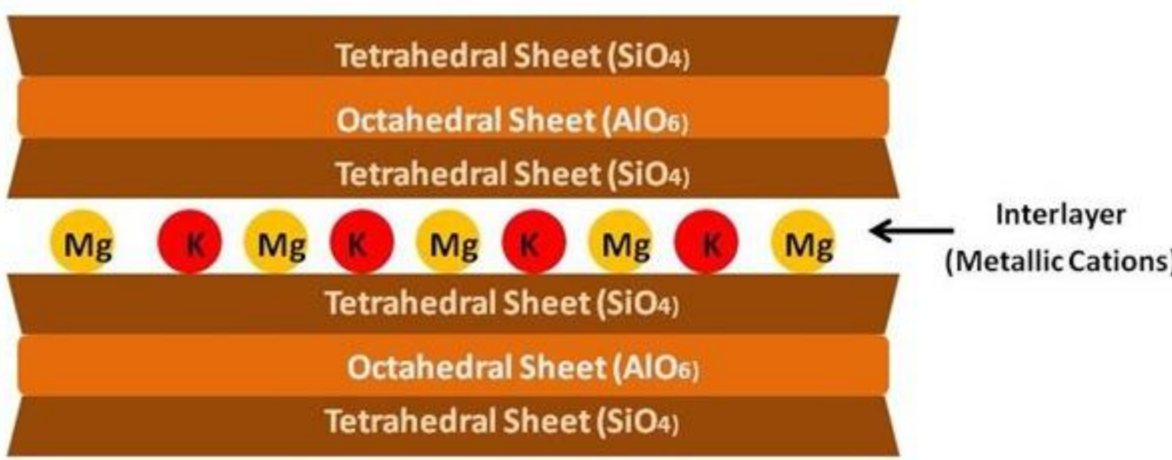
- Organic fraction
    - serves as a reservoir for the plant's essential nutrients
    - Increases soil water holding capacities
    - Increases cation exchange capacities
    - Enhances soil aggregation and
    - Enhances soil Structure.
- Most chemically active fraction of soils consists of colloidal clays and organic matter

Soil is made up of ?

- The most chemically active fraction of soils consists of **colloidal clays and organic matter.**
- **Colloidal particles** are so small (< 0.0002 mm) that they remain suspended in water and exhibit a very large surface area per unit weight with high adsorptive capacity.
- **Montmorillonite, Vermiculite, and Micaceous clays** are examples of **2:1 clays**, while **Kaolinite** is a **1:1 clay** mineral.
- 2:1 CLAYS: Clays having a layer of Al_2O_3(octahedral sheet) sandwiched between two layers of silicon oxide (tetrahedral sheets)
- 1:1 CLAYS: Clays having one tetrahedral sheet bonded to one octahedral sheet.



2:1 Clay Structure



Cation Exchange Capacity

It is the ability of soil clays and organic matter to adsorb and exchange cations with those in soil solution (water in soil pore space).

A dynamic equilibrium exists between adsorbed cations and those in soil solution.

Cation adsorption is reversible if other cations in soil solution are sufficiently concentrated to displace those attracted to the –ve charge on clay and organic matter surfaces.

The quantity of cation exchange is measured **per unit of soil weight** and is termed **Cation Exchange Capacity.**

Organic colloids exhibit **much greater** CEC than silicate clays.

Cation Exchange Capacity is an important phenomenon for two reasons:

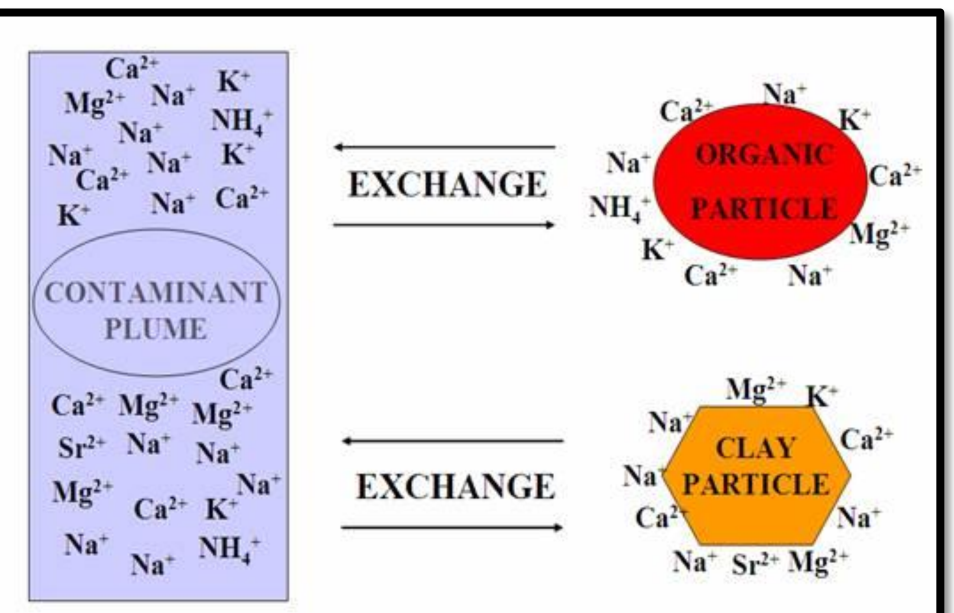
1. Exchangeable cations such as Calcium, Magnesium, and Potassium are readily available for plant uptake and
2. Cations adsorbed to exchange sites are more resistant to **leaching**, or downward movement in soils with water.

- Various clays also exhibit different exchange capacities.
- Thus, cation exchange capacity of soils is dependent upon both organic matter content and type of silicate clays.

Movement of cations below the rooting depth of plants is associated with weathering of soils.

Greater cation exchange capacities help decrease these losses.

Pesticides or organics with positively charged functional groups are also attracted to cation exchange sites and may be removed from the soil solution, making them less subject to loss and potential pollution.



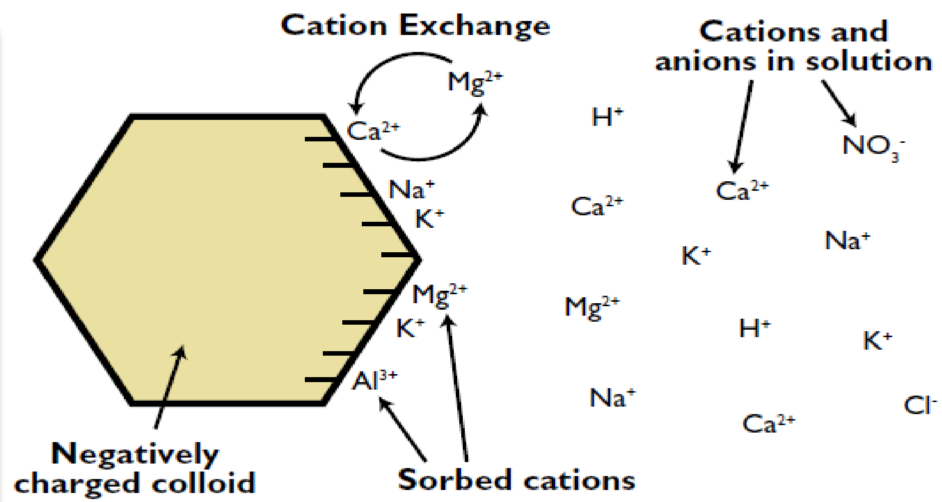


Figure 9. Simplified representation of exchange capacity. Because the colloid is primarily negatively charged, cations dominate the exchange sites. (Adapted from Brady and Weil, 2002)

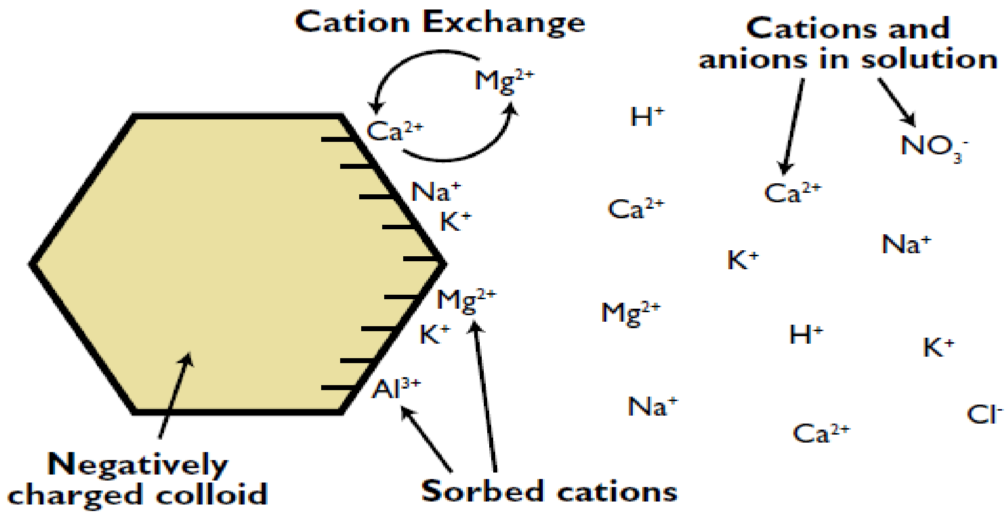


Figure 9. Simplified representation of exchange capacity. Because the colloid is primarily negatively charged, cations dominate the exchange sites. (Adapted from Brady and Weil, 2002)

Calcium (Ca^{++}) is normally the predominant exchangeable cation in soils, even in acid, weathered soils.

In highly weathered soils, such as oxisols, aluminum (Al^{+3}) may become the dominant exchangeable cation.

The energy of retention of cations on negatively charged exchange sites varies with the particular cation.

The order of retention is: aluminum > calcium > magnesium > potassium > sodium > hydrogen.

- Movement of cations below the rooting depth of plants is associated with weathering of soils.
- Greater cation exchange capacities help decrease these losses.
- Pesticides or organics with positively charged functional groups are also attracted to cation exchange sites and may be removed from the soil solution, **making them less subject to loss and potential pollution.**
- **Calcium (Ca^{++})** is normally the predominant exchangeable cation in soils, even in acid, weathered soils.
- In highly weathered soils, such as oxisols, **Al^{+3}** may become the dominant exchangeable cation.

Cations with increasing positive charge and decreasing hydrated size are most tightly held.

Calcium ions, for example, can rather easily replace sodium ions from exchange sites.

This difference in replaceability is the basis for the application of gypsum ($CaSO_4$) to reclaim sodic soils (those with $\geq$ 15% of the cation exchange capacity occupied by sodium ions).

Sodic soils exhibit poor structural characteristics and low infiltration of water.

The cations of calcium, magnesium, potassium, and sodium produce an alkaline reaction in water and are termed bases or **basic cations**.

Aluminum and hydrogen ions produce acidity in water and are called **acidic cations**.

The percentage of the cation exchange capacity occupied by basic cations is called **percent base saturation**.

The greater the percent base saturation, the higher the soil pH.

Cation exchange, in the soil. 1) Clay and organic matter have negative charges that can hold and release positively charged nutrients. (The cations are *adsorbed* onto the *surface* of the clay or humus.) That static charge keeps the nutrients from being washed away, and holds them so they are available to plant roots and soil microorganisms.

2) The roots and microorganisms get these nutrients by exchanging free hydrogen ions. The free hydrogen H+ fills the (-) site and allows the cation nutrient to be absorbed by the root or microorganism.

3) The unit of measure for this exchange capacity is the milligram equivalent, ME or meq, which stands for 1 milligram (1/1000 of a gram) of exchangeable H+. In a soil with an exchange capacity (CEC) of 1, each 100 grams of soil contain an amount of negative (-) sites equal to the amount of positive (+) ions in 1/1000th of a gram of H+.

Soil pH

Soil pH is probably the most commonly measured soil chemical property and is also one of the more informative.

Like the temperature of the human body, soil pH implies certain characteristics that might be associated with a soil.

Since pH (the negative log of the hydrogen ion activity in solution) is an inverse, or negative function.

Soil pH decreases as hydrogen ion (or acidity) increases in soil solution.
Soil pH increases as acidity decreases.

Soil pH refers to a soil's acidity or alkalinity and is the measure of hydrogen ions (H+) in the soil
A high amount of H+ corresponds to a low pH value and vice versa.
The pH scale ranges from approximately
0 to 14 A soil pH of 7 is considered neutral.

Soil pH values **greater than 7** signify **alkaline (basic) conditions**, whereas those with values **less than 7** indicate **acidic conditions**.

Soil pH typically ranges from **4 to 8.5**, but can be as low as 2 in materials associated with **pyrite oxidation** and **acid mine drainage**.

In comparison, the pH of a typical cola soft drink is about 3.

SOIL pH & PLANT GROWTH

- Soil pH has a profound influence on plant growth.
- Soil pH affects the:
  1. quantity
  2. Activity &
  3. types

  of **microorganisms** in soils, which in turn influence the decomposition of :
  1. crop residues,
  2. Manures,
  3. Sludges &
  4. Other organics.

It also affects other nutrient transformations and the solubility, or plant availability, of many plant essential nutrients.

Phosphorus, for example, is most available in slightly acid to slightly alkaline soils, while all essential micronutrients, except Molybdenum, become more available with decreasing pH.

Aluminum, Manganese, and even Iron can become sufficiently soluble at $pH < 5.5$ to become toxic to plants.

Bacteria which are important mediators of numerous nutrient transformation mechanisms in soils generally tend to be most active in slightly acid to alkaline conditions.

- **Macronutrients** tend to be less available in soils with **low pH**.
- **Micronutrients** tend to be less available in soils with **high pH**.

➢A higher concentration of H+ (lower pH) will neutralize the negative charge on colloids, thereby decreasing CEC and increasing AEC (Anion Exchange Capacity), the opposite occurs when pH increases.

Range of pH in soils

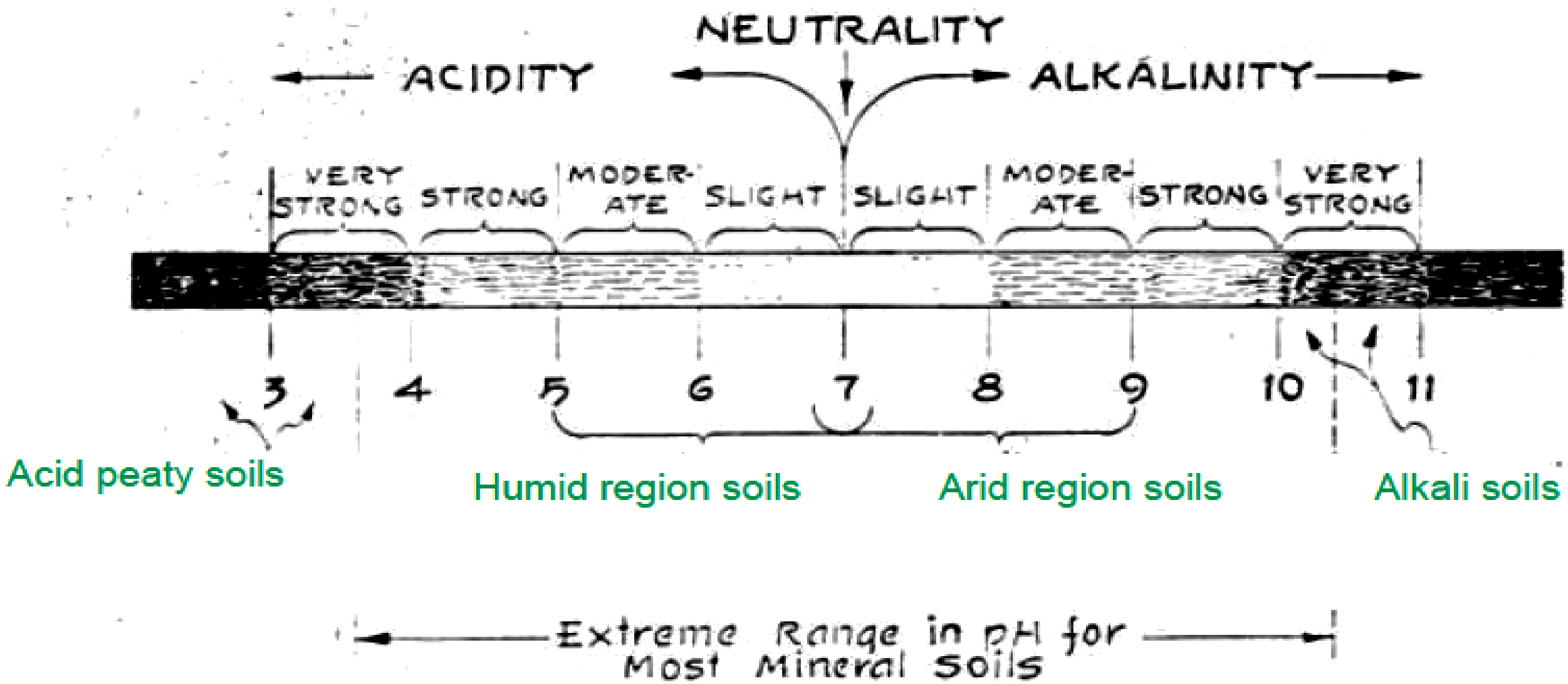
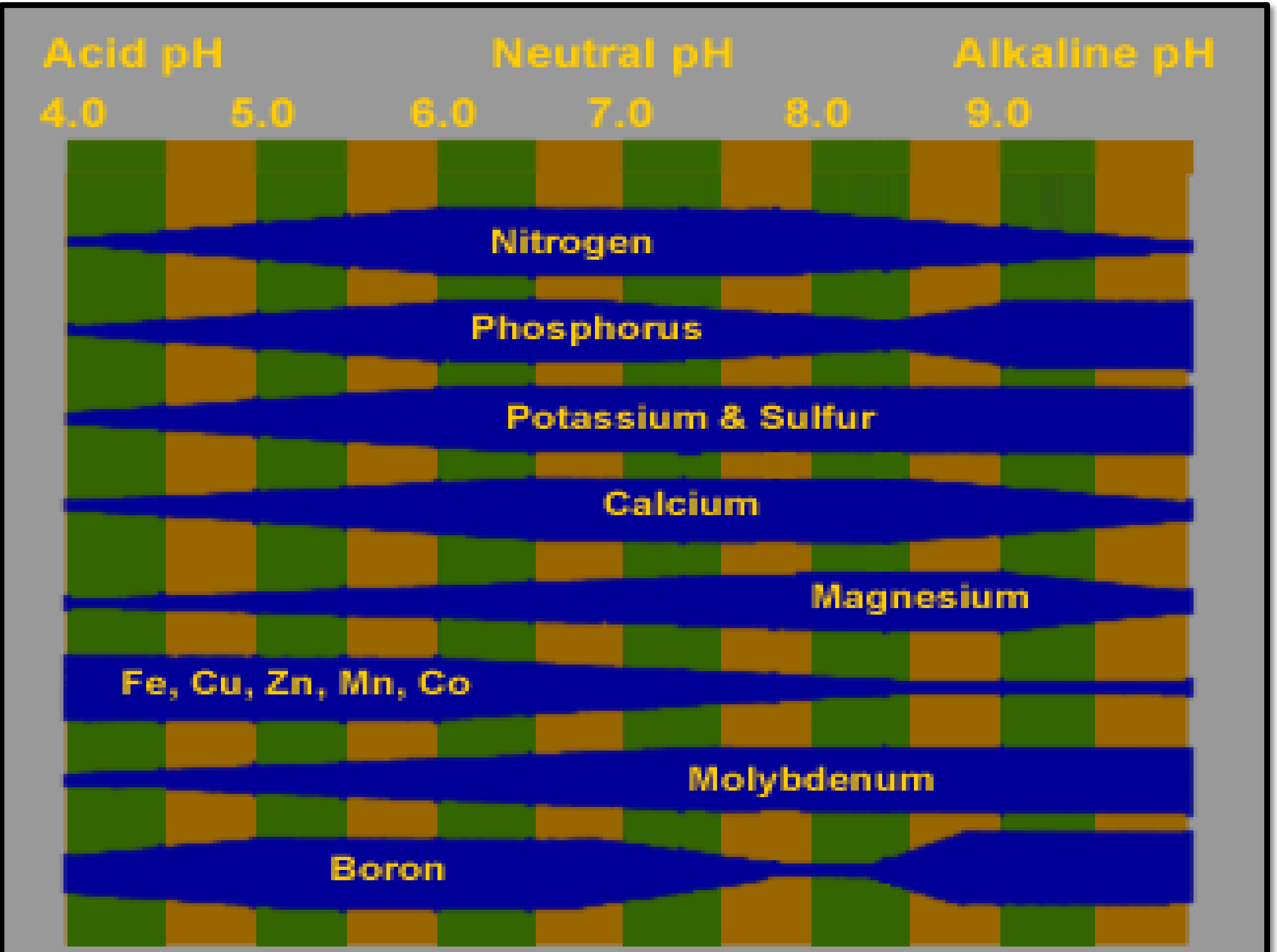


Figure 2:6. Diagram showing the extreme range in pH for most mineral soils and the range commonly found in humid-region and arid-region soils respectively. The maximum alkalinity for alkali soils is also indicated, as well as the minimum pH likely to be encountered in very acid peat soils.


Acid pH
Neutral pH
Alkaline pH
4.0
5.0
6.0
7.0
8.0
9.0
Nitrogen
Phosphorus
Potassium & Sulfur
Calcium
Magnesium
Fe, Cu, Zn, Mn, Co
Molybdenum
Boron

Cont.....

- It also affects
  - Other nutrient transformations
  - The solubility &
  - Availability of many plant essential nutrients.
- Phosphorus, is most available in slightly acid to slightly alkaline soils, while all essential micronutrients, except Mo, become more available with decreasing pH.
- Al, Mn and even Fe can become sufficiently soluble at pH < 5.5 to become toxic to plants.
- *Bacteria* which are important mediators of numerous nutrient transformation mechanisms in soils generally tend to be most active in slightly acid to alkaline conditions.

COMMON SOIL CHEMICAL PROPERTIES ANALYZED IN THE LABORATORY

- **Soil pH** – negative logarithm of hydrogen ion concentration in soil
- **Cation Exchange Capacity** - total amount of cations(including H+) that can be displaced
- **Base saturation** - the percent of the cation exchange complex occupied by exchangeable bases (mostly plant nutrients such as Ca, Mg, Na, K, etc.)
- **Nutrients** - amounts of macronutrients and micronutrients

SALT-AFFECTED SOILS

- The presence and concentration of salts in soil can have adverse effects on soil function and management.
- Salt-affected soils are most common in arid and semiarid regions where evaporation exceeds precipitation and dissolved salts are left behind to accumulate, or in areas where vegetation or irrigation changes have caused salts to leach and accumulate in low-lying places (saline seeps).
- The three main types of salt-affected soils are: **saline, sodic** and **saline-sodic**.

- Saline soils contain a high amount of soluble salts, primarily Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Potassium (K^+), whereas sodic soils are dominated by Sodium (Na^+).
- Saline-sodic soils have both **high salt** and **Na+** content.
- High Salts in soil can affect **structure**, **porosity** and **plant/water relations** that can ultimately lead to decreased productivity.
- Salt-affected soils needs proper management.

CALCAREOUS SOILS

- Calcareous soils often form from the weathering of carbonate-rich parent material, such as limestone or lime-enriched glacial till, and generally occur in areas where precipitation is too low to leach the minerals from the soil.
- **Carbonates** can be found **throughout a soil profile** or **concentrated** in the **lower horizons** due to **downward leaching**.
- The subhorizon letter **'k'** denotes a **calcareous horizon layer** (e.g., Bk).
- Calcareous soils can be distinguished in the field by an **effervescence** (fizz) reaction that occurs when a drop of dilute acid (10% hydrochloric acid or strong vinegar) is applied (Brady and Weil, 2002).
- The presence of carbonates in soil can affect soil productivity by influencing soil pH, structure, WHC (Water Holding Capacity) and water flow. Calcareous soils have a high 'buffering capacity,' or resistance to changes in pH.
- This is due to free carbonates being able to effectively neutralize acids in the soil. Thus, the pH of calcareous soils changes very little and is maintained near 8. Because calcareous soils are so well-buffered, reducing the pH with acidifying amendments (NM 10) is often difficult and costly.

N.B.: Leaching (Soil/agriculture): the loss of water-soluble plant nutrients from the soil; or applying a small amount of excess irrigation to avoid soil salinity

- Carbonates can **alter soil structure** by **affecting texture** and **promoting aggregation.**
- Carbonate deposits can be of varying size, ranging from very fine clay-like powder to coarser, silt-like deposits, which can impact texture.
- If carbonates are not removed prior to analysis, soils may be incorrectly classified.
- For instance, a soil analyzed for texture without the removal of $CaCO_3$ may classify as a clay loam, however after removing carbonates it may classify as a sandy loam.
- Thus, it is important to consider the presence of carbonates when analyzing the texture of calcareous soils, both in the field and laboratory. Additionally, Ca^{2+} and Mg^{2+} in soil causes soil particles to '**flocculate**,' or **clump together**, thus increasing the formation of stable aggregates (SW 2) – **Cancar** / **Kankar**.
- The influence of carbonates on soil structure can cause calcareous soils to have different water relation properties than non-calcareous soils.
- WHC can be affected by the size and concentration of carbonates.
- Very fine carbonate particles can **coat clay** and **silt** particles and **reduce** their **surface tension** with water, and when a large percentage of $CaCO_3$ is present in the clay fraction (30% or higher), the soil's WHC (Water Holding Capacity) may get reduced (Massoud, 1972).
- **Diffusivity**, a measure of how well water moves through soil, may also be affected by carbona

BIOLOGICAL PROPERTIES

Soil Biological Properties

- Soil Biota
- Soil Micro organisms
- Nutrient cycling by soil microbes

BIOLOGICAL PROPERTIES

- "*Soil is not a dead mass but an abode of millions of organisms, which includes crabs, snails, earthworms, mites, millipedes, centipedes*"
- These feed on plant residues, burrow the soil and help in aeration & percolation of water.
- The soil organisms are of two types:
  1. **Microflora &**
  2. **Macrofauna**
- *Bactro Actinomycetes, Fungi and Algae* relate to former and *Protozoa, Nematodes* relate to some of these have symbiosis with other organisms.
- They act on plant and animal residue and release the food material which in turn used by plants.

Soil Biota

- The soil contains a vast array of life forms ranging from submicroscopic (the viruses), to earthworms, to large burrowing animals such as gophers and ground squirrels.

- Microscopic life forms in the soil are generally called the **"soil microflora"** (though strictly speaking, not all are plants in the true sense of the word) and the larger animals are called **macrofauna.**

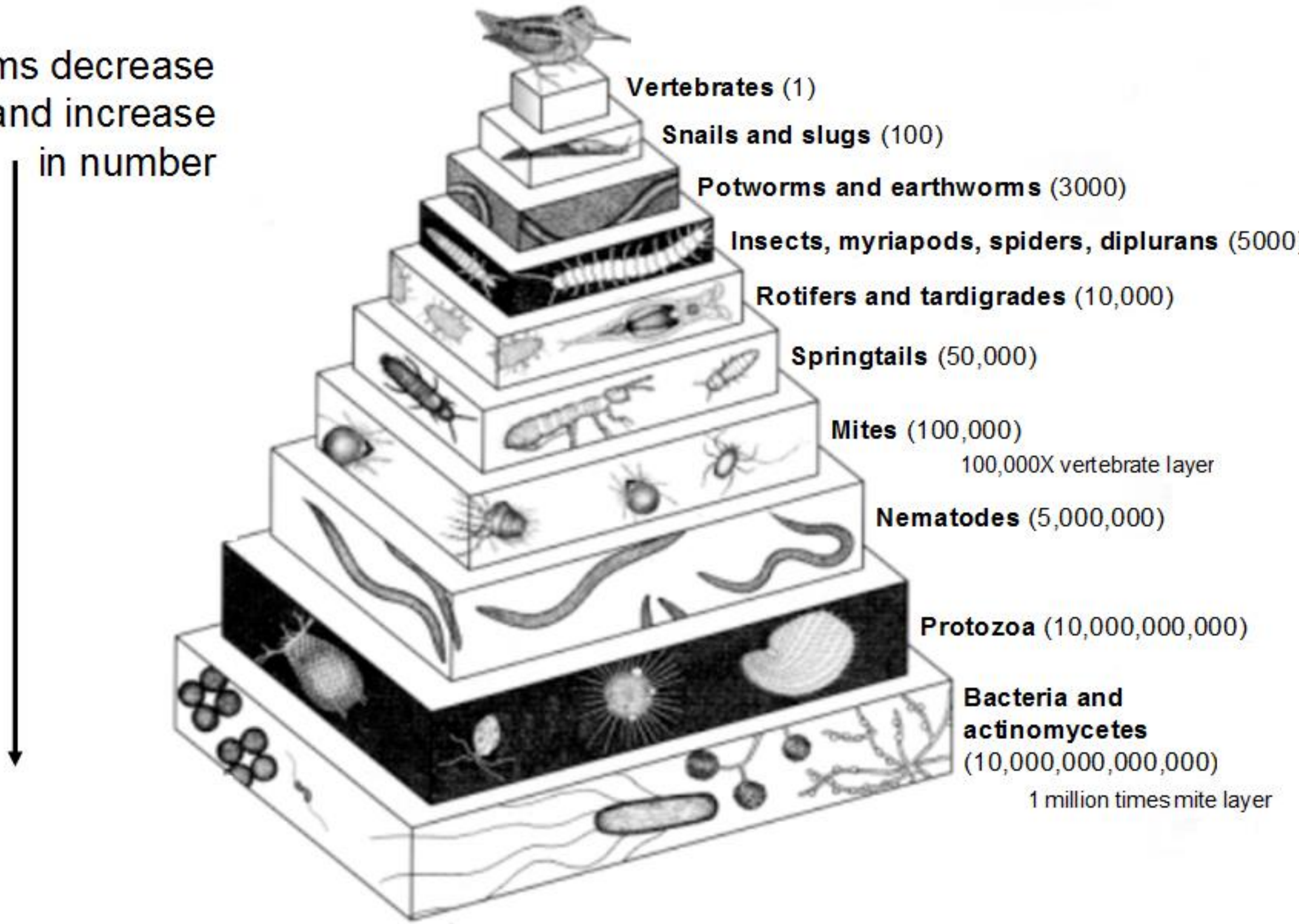
- Soil animals, especially, the earthworms and some insects tend to affect the soil favorably through their burrowing and feeding activities which tend to improve aeration and drainage through structural modifications of the soil solum.

- In general, they affect soil chemical properties to a lesser extent though their actions indirectly enhance microbial activities due to creation of a more favorable soil environment.

In one square meter of soil....

(within a depth range of a few meters)

Organisms decrease in size and increase in number



Soil Micro organisms

- Soil micro organisms occur in huge numbers and display an enormous diversity of forms and functions.
- Major microbial groups in soil are bacteria (including actinomycetes), fungi, algae (including cyanobacteria) and protozoa.
- Because of their extremely small cell size (one to several micrometers), enormous numbers of soil microbes can occupy a relatively small volume, hence space is rarely a constraint on soil microbes.

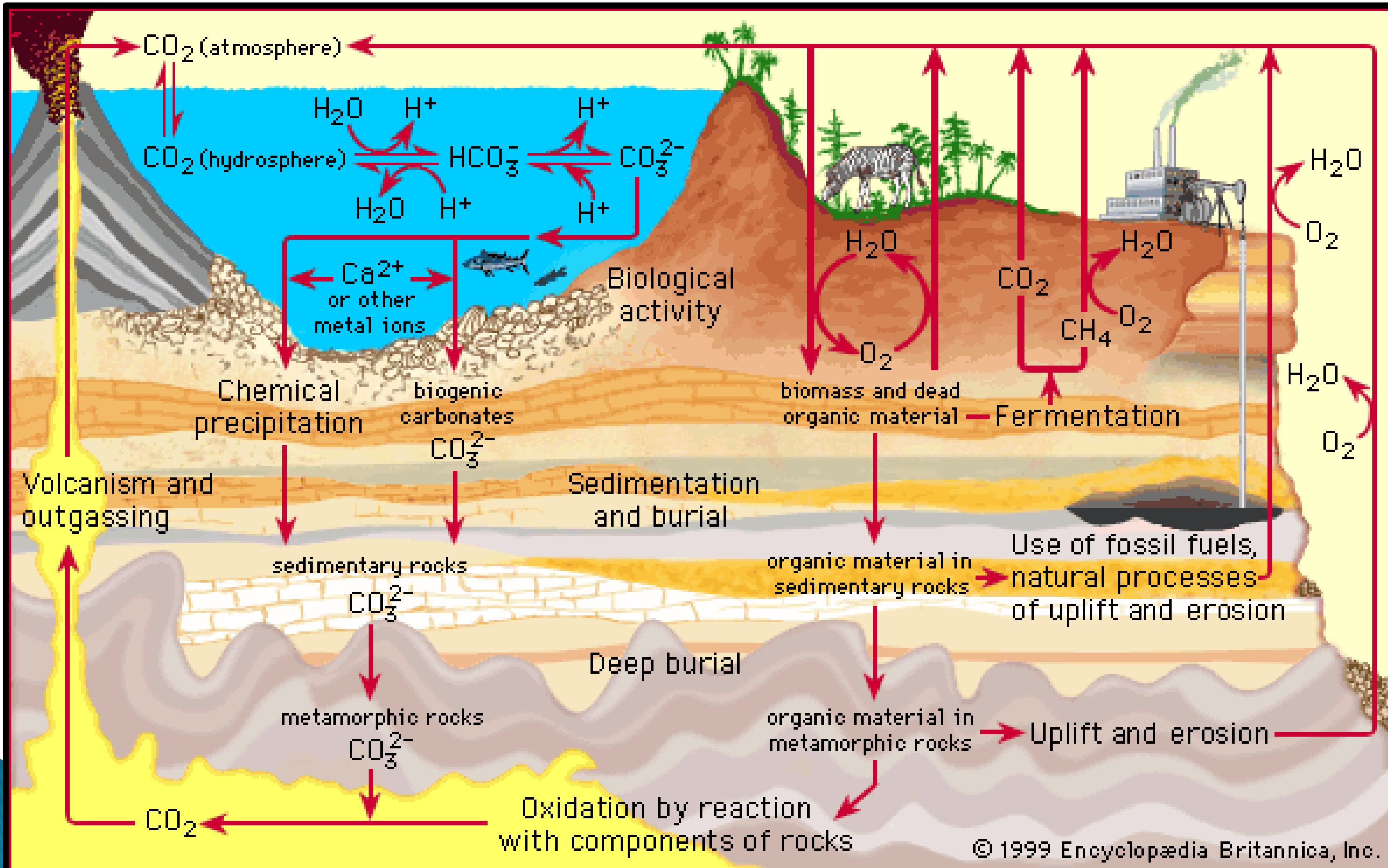
- Soil microbes can occur in numbers ranging up to **several million or more in a gram** of **fertile soil** (a volume approximately that of a red kidney **bean**).
- Note that the bacteria are clearly the most numerous of the soil microbes.
- Perhaps more important than the numbers of the various soils microbes is the **microbial biomass** contributed by the respective groups.
- It is the **soil fungi** which tend to contribute the most biomass among the microbial groups.
- In fact, it is because of their large contribution to the biomass that they are generally regarded as being the **dominant decomposer** microbes in the soil.
- It surprises us that there are literally "tons" of microbes beneath your feet as we walk across a grassland in Africa or Australia or through a cornfield in the American Midwest. Interestingly, a fungus discovered in the state of Michigan may be one of the largest living organisms on the planet.

- A fungus, *Armillaria bulbosa*, discovered in the U.S. in the state of Michigan, could turn out to be earth's largest creature or at least among the largest.
- Scientists discovered the fungus growing among the roots of hardwood trees in a forest.
- The microscopic, branched filaments (called hyphae) of the fungus occupy a 14.8 ha (37-acre) area of land.
- Careful genetic analysis has shown the filaments constitute a single organism.
- Fungi generally radiate outward in a circular pattern as they grow through the soil.
- In fact, the **fairy rings** (a ring of darker grass caused by fungi) of mushrooms (named because ancient peoples thought they represented the paths of fairies dancing in the night) often seen in lawns or on golf courses actually represent the outer boundary of a developing fungus.
- Scientists estimate that the portion of the Michigan fungus they have been able to identify, may weigh as much as 100 tons, slightly less than a blue whale.
- Imagine the biochemical capacity of a soil micro organism this large!

Nutrient cycling by soil microbes

- Soil microbes influence much in controlling the quantities of chemical elements.
- The **mineralization** of organic materials by soil microbes liberates carbon dioxide, ammonium (which is rapidly converted to nitrate by soil microbes), sulphate, phosphate and inorganic forms of other elements.
- This is the basis of nutrient cycling in all major ecosystems of the world.
- John Burroughs once said, *"Without death and decay, how could life go on?"*
- This pool of microbial biomass constitutes a portion of the soil organic matter which turns over (cycles) fairly quickly and therefore represents a "*fertility buffer*" in the soil.
- The liberation of carbon dioxide through microbial respiration makes possible the continued *photosynthesis* (i.e. carbon dioxide fixation) by algae and green plants which in turn produce more organic materials which may ultimately reach the soil, thereby completing the cycle.

CARBON CYCLE



- In the world's agricultural soils, the source of our food supply, *mineralization of nitrogen by soil microbes* is a most important process.
- In those soils not receiving external inputs of fertilizer nitrogen the liberation of ammonium from organic debris makes possible the continued growth of new plant matter.
- Therefore, it is the soil microbial population which controls the productivity of these soils if other environmental factors (moisture, temperature) are suitable.
- Nitrogen tied-up (**assimilated into cell constituents**) in microbial cells is not available for plants or other microbes until that tissue has been decomposed by other microbes.
- In other words, nitrogen contained in tissues is said to be **immobilized**.
- *Microbes are the keys for the remobilization* of these nutrients.

Bacteria as a controlling factor of forms of ions…

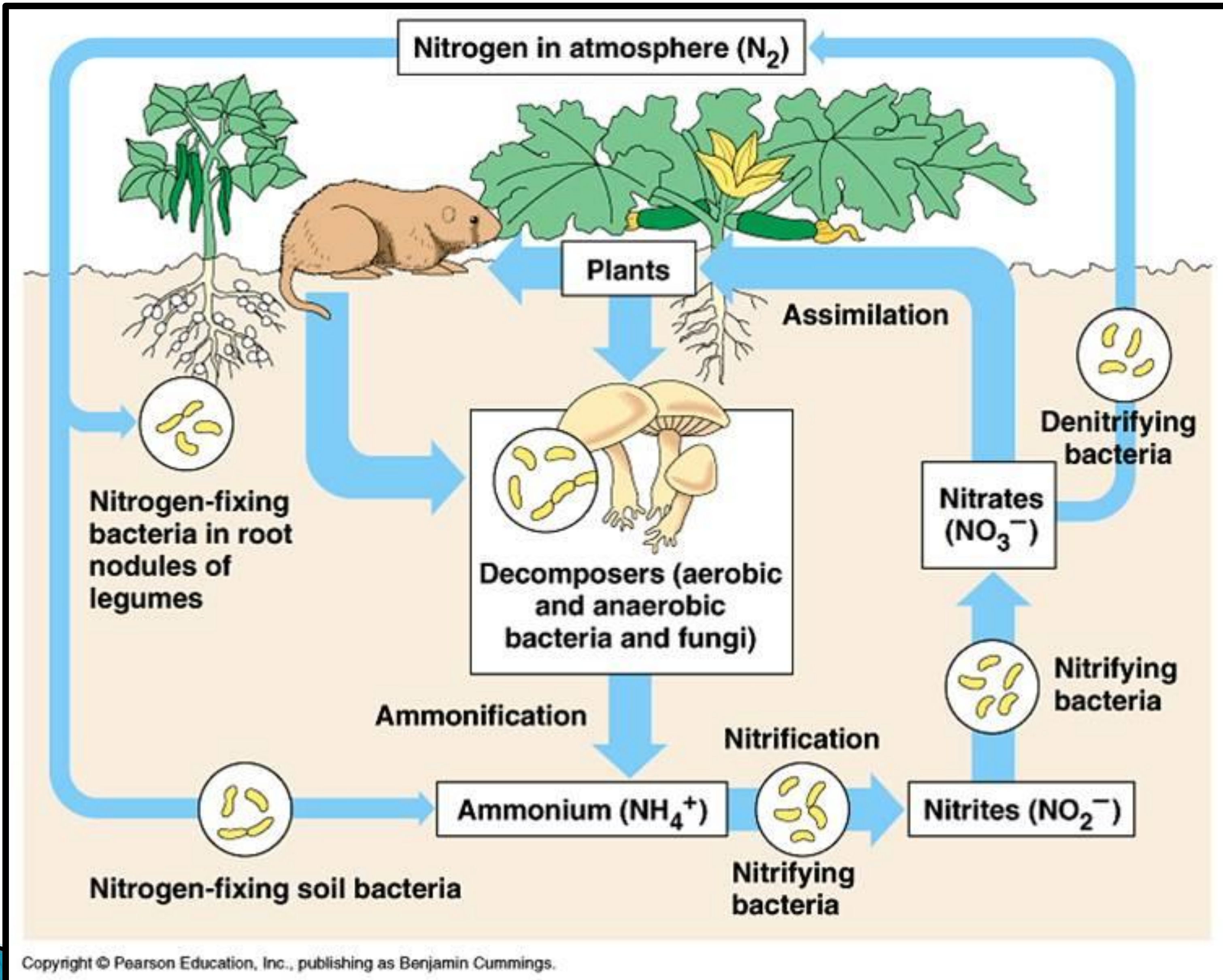
- Soil bacteria, can control the forms of the ions in which these nutrients occur.
- For example, ammonium (NH_4^+) in the soil is usually rapidly oxidized by bacteria first to nitrite and then to nitrate (NO_3^-) which may readily leach through soil.
- Ammonium is oxidized to nitrite and then to nitrate by the bacteria *Nitrosomonas* and *Nitrobacter*, respectively.
- Similarly, reduced sulfur compounds such as thiosulphate, elemental sulphur and even iron pyrite (FeS_2, "Fool's Gold") can be oxidized to sulphuric acid by soil bacteria.
- Unlike the decomposer microbes which use organic carbon compounds from organic matter for energy and to make cell matter (e.g. they are called **heterotrophs**), these specialized bacteria called **chemoautotrophs** obtain their carbon for cell synthesis from carbon dioxide or from dissolved carbonate.

DE-NITRIFICATION

- Nitrogen and sulphur may be converted to gaseous forms (volatilized) and lost to the atmosphere.
- Nitrogen in the form of nitrate can be converted to gases such as nitrous oxide (N2O) and dinitrogen (N2) through the process of **denitrification** (the bacterial reduction of NO_3^- to N_2O or N_2) by soil bacteria under anaerobic conditions.
- A consequence of denitrification is that nitrogen, a precious nutrient for plants, is lost from the soil.
- On the other hand, this process is a useful way to remove excess nitrate from wastewater.

NITROGEN FIXATION

- *Rhizobium* - legume root-nodule symbiosis.
- Soil bacteria belonging to the genera *Rhizobium* and *Bradyrhizobium* are capable of inducing the formation of nodules on roots of specific legumes (plants like peas, beans, peanuts, soybeans, alfalfa, etc.) and fixing large quantities of nitrogen in these structures.
- In the nodule, the bacteria are supplied with carbon sources that they need in order to fix nitrogen.
- In return for this carbon, the bacteria fix atmospheric nitrogen which is converted to amino acids used by the plant for growth.
- Nearly two-thirds of the world's nitrogen supply is from biological nitrogen fixation.
- Legumes have been used since the beginning of recorded history as "*soil improving*" crops known as "*green manures*".
- **Green manuring** is the practice of growing a legume species for the sole purpose of returning it to the soil to serve as a source of nitrogen for an ensuing crop.



Nitrogen in atmosphere (N_2)
Plants
Assimilation
Denitrifying bacteria
Nitrogen-fixing bacteria in root nodules of legumes
Decomposers (aerobic and anaerobic bacteria and fungi)
Nitrates (NO_3^-)
Nitrifying bacteria
Ammonification
Nitrification
Ammonium (NH_4^+)
Nitrites (NO_2^-)
Nitrogen-fixing soil bacteria
Nitrifying bacteria
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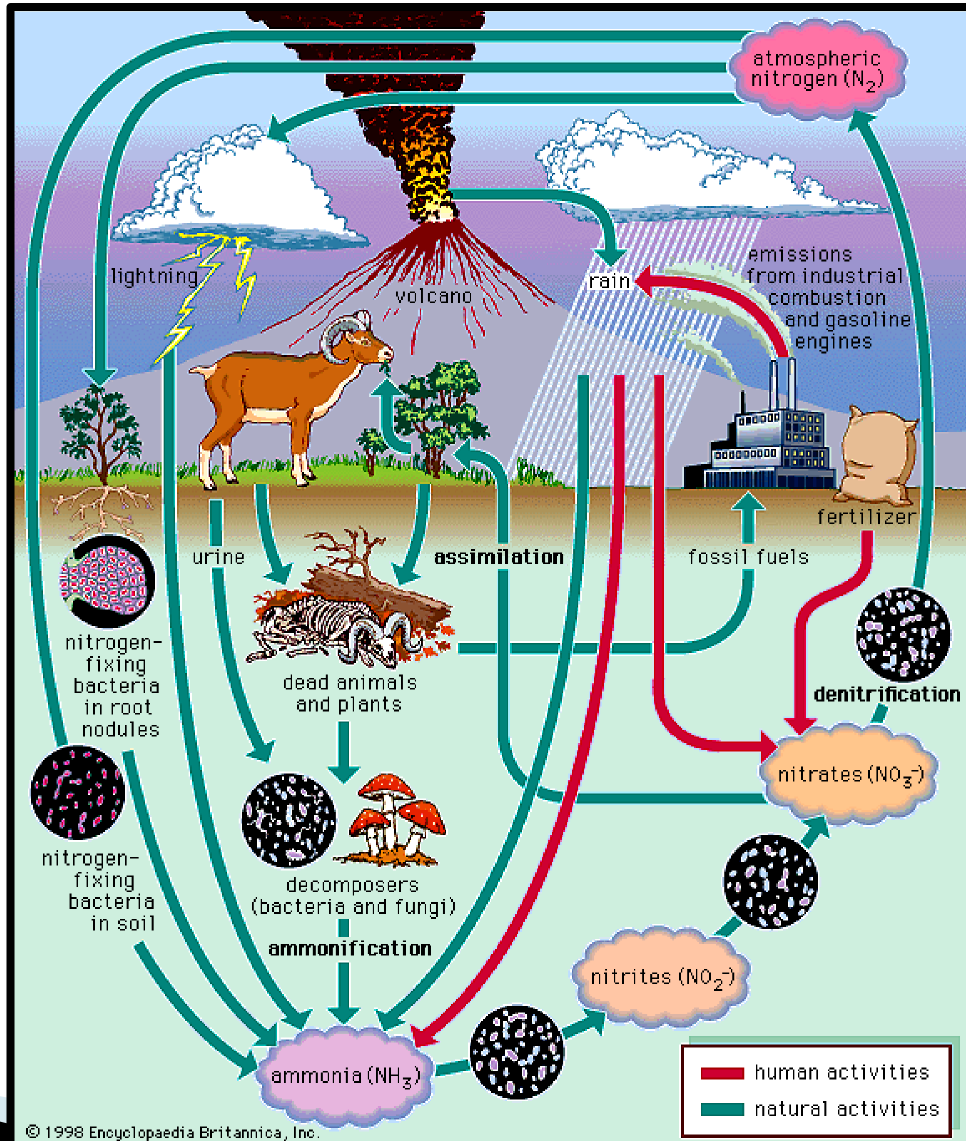
NITROGEN CYCLE



SOIL MICROBES AND BIO REMEDIATION

- **Bioremediation** may be defined as the controlled use of microorganisms for the destruction of chemical pollutants.
- A large number of processes have been developed to handle various wastes and for the cleanup of spilled organic materials.
- At the heart of all of these processes lies the premise that the metabolic activities of bacteria or fungi can be used to degrade many of the organic chemicals of commerce (solvents, pesticides, hydrocarbon fuels, etc.).

BIOSTIMULATION & BIOAUGMENTATION

- In **biostimulation** the environment into which the material has been spilled or otherwise introduced is made favorable for the rapid development of microbes.
- Adding sufficient nitrogen and phosphorus fertilizer to overcome nutrient limitations to microbial growth and providing some mechanism for increased aeration of the system.
- Development of the indigenous microbial population which usually contains microbes able to degrade the compounds of interest.
- In the practice of **bioaugmentation**, an external microbial population is added in order to speed up the degradation process.

Conclusions arrived on the use of microbes in soil:

- It is probable that in due time useful microbial products or processes will be developed for use in the clean-up of oil or other chemical spills.
- What is certain is that successful bioremediation will require detailed knowledge of the factors which make some microbes more competitive than others in a given environment.
- Only when these details are established will we know "***how to use sound ecological principles to add microbes to these complex environments to insure their establishment and function in the clean-up process***".

Relationship between Soil, plants and animal

Relationship between Soil and plants

- All the plants are uptaking its maximum essential macro and micro nutrients from soil solutions only.
- Different plant species requires different nutrients in different quantities.
- It is really a difficult task of estimating the amount of nutrients for the better growth of plants
- Though a lots of research have brought out different information on plant's nutrition.

- Plant nutrition is a difficult subject to understand completely, partially because of the variation between different plants and even between different species or individuals of a given clone
- The macronutrients are consumed in larger quantities and are present in plant tissue in quantities from 0.2% to 4.0. Micronutrients are present in plant tissue in quantities measured in parts per million, ranging from 5 to 200 ppm, or less than 0.02% dry weight.
- Each of these nutrients is used in a different place for a different essential function.

ESSENTIAL NUTRIENTS FOR ANIMAL GROWTH

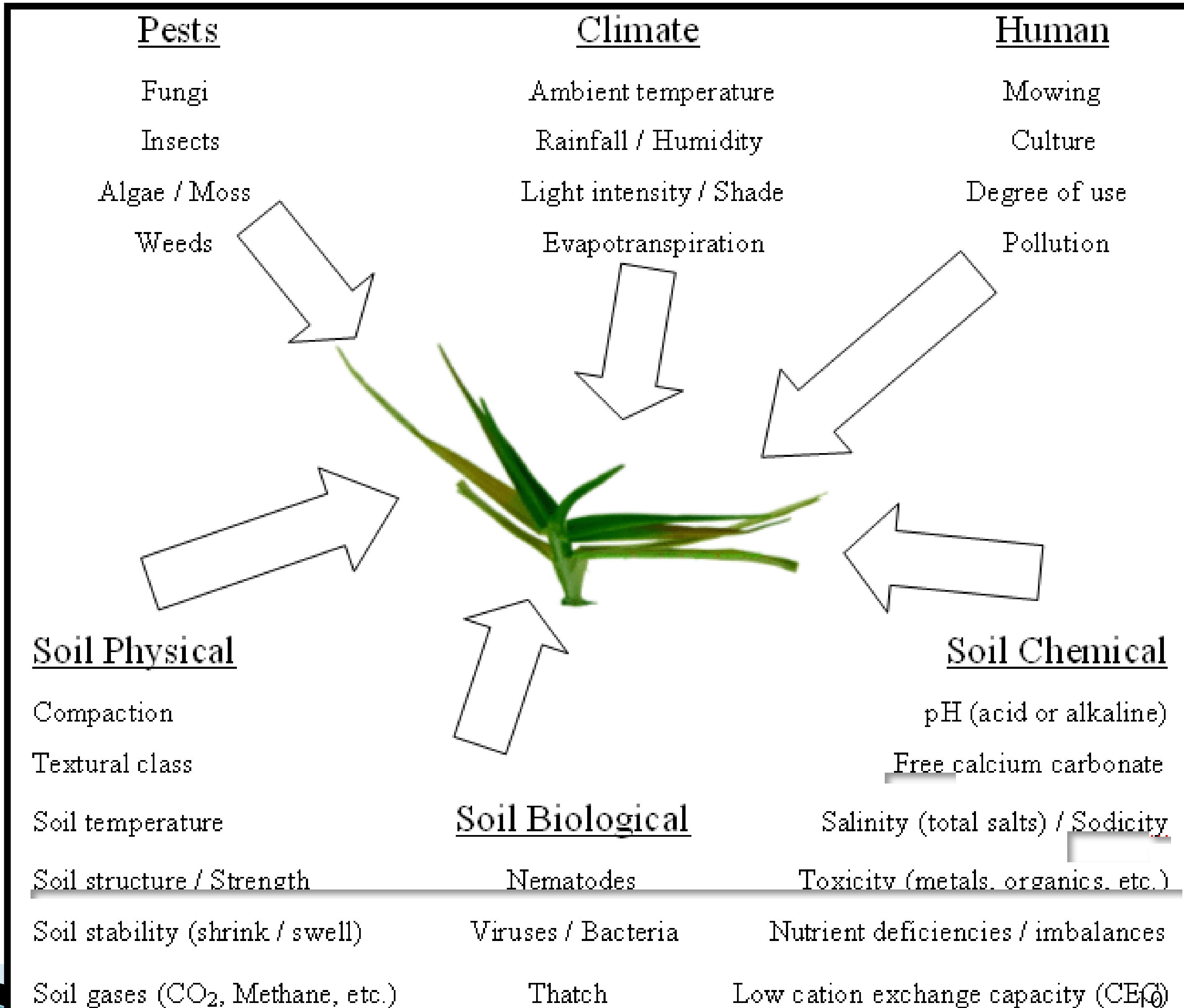
- Carbon, nitrogen, oxygen, phosphorus, potassium, calcium, magnesium, sulphur and the micronutrients are boron, chlorine, cobalt, copper, iron, manganese, molybdenum, nickel and zinc are the mineral needed for animal growth. In addition to this, some elements such as selenium and iodine, though not required by plants, are essential nutrients for animals.

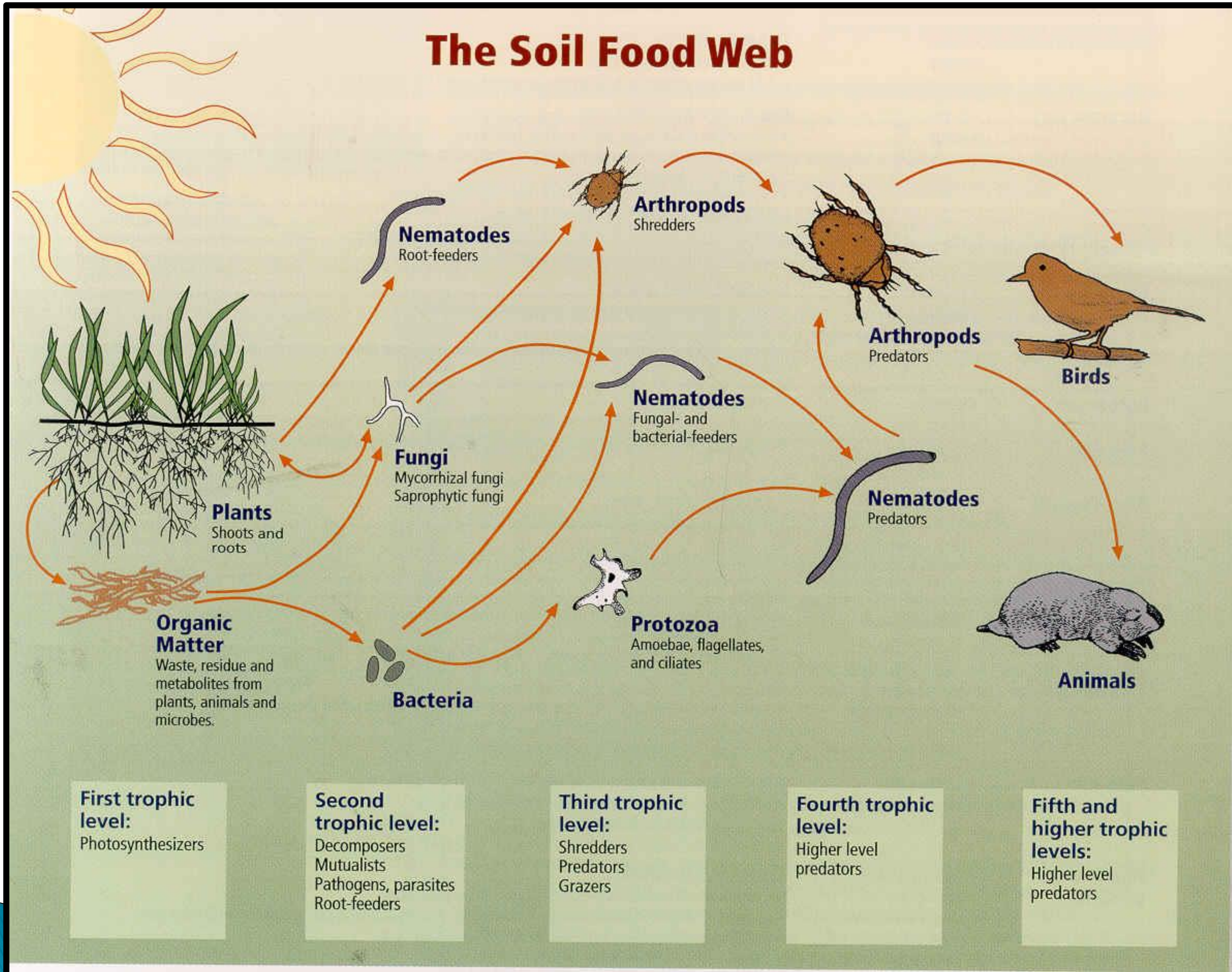
Soil – Animal relations ... contd.......

- Over the millions of years animals have been on the planet, there has been ongoing adjustment in a particular period to changing soil and climatic conditions.
- In each climatic period, generally there has been a balance created between the nutrient needs of the animals and the ability of the soil to supply it.
- Nutrient cycling is essential ultimate sustenance for plants and animals.

Relationship between Soil, plants and animal

- Web of Life




The Soil Food Web
Nematodes
Root-feeders
Arthropods
Shredders
Arthropods
Predators
Birds
Plants
Shoots and roots
Fungi
Mycorrhizal fungi
Saprophytic fungi
Nematodes
Fungal- and bacterial-feeders
Nematodes
Predators
Organic Matter
Waste, residue and metabolites from plants, animals and microbes.
Bacteria
Protozoa
Amoebae, flagellates, and ciliates
Animals
First trophic level:
Photosynthesizers
Second trophic level:
Decomposers
Mutualists
Pathogens, parasites
Root-feeders
Third trophic level:
Shredders
Predators
Grazers
Fourth trophic level:
Higher level predators
Fifth and higher trophic levels:
Higher level predators

Selenium

- Selenium is among the rarer elements on the surface.

- Selenium occurs naturally in the environment.

- Well fertilized agricultural soil generally has about 400 mg/ton since the element is naturally present in phosphate fertilizers and is often added as a trace nutrient.

- Selenium is more readily absorbed by animals through the digestive tract. It has been estimated that lactating dairy goats absorb about 65% of ingested selenomethionine

- Selenium substances in soil are usually broken down to selenium and water fairly quickly, so that they are not dangerous to the health of organisms.

Iodine

- **Iodine compounds are found in** seawater, soil, and rocks.
- Once in the air, iodine can combine with water or with particles in the air and can enter the soil and surface water, or land on vegetation when these particles fall to the ground or when it rains
- Iodine can remain in soil for a long time because it combines with organic material in the soil. It can also be taken up by plants that grow in the soil
- Cows or other animals that eat these plants will take up the iodine in the plants.
- The reason that iodine ultimately concentrates in the soil is the result of its chemistry. Iodine is one of the halogens. The halogens are prominent anions in the environment.
- "The horse has a high sensitivity for iodine"
- Even just an extra of 35 mg iodine per day (adult horses, dry matter intake: 10 kg) can cause severe health risks,

THANK YOU