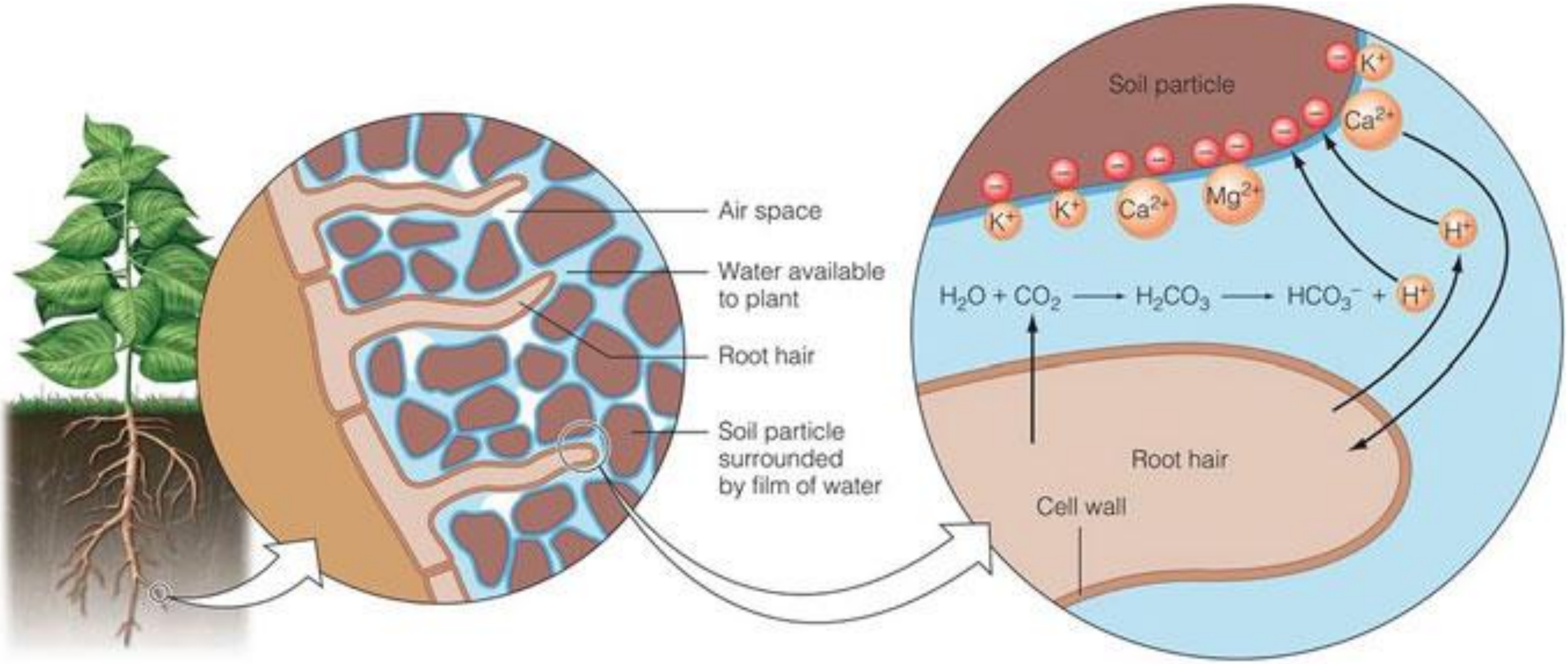
Soil Chemical Properties



(a) Water film around soil particles

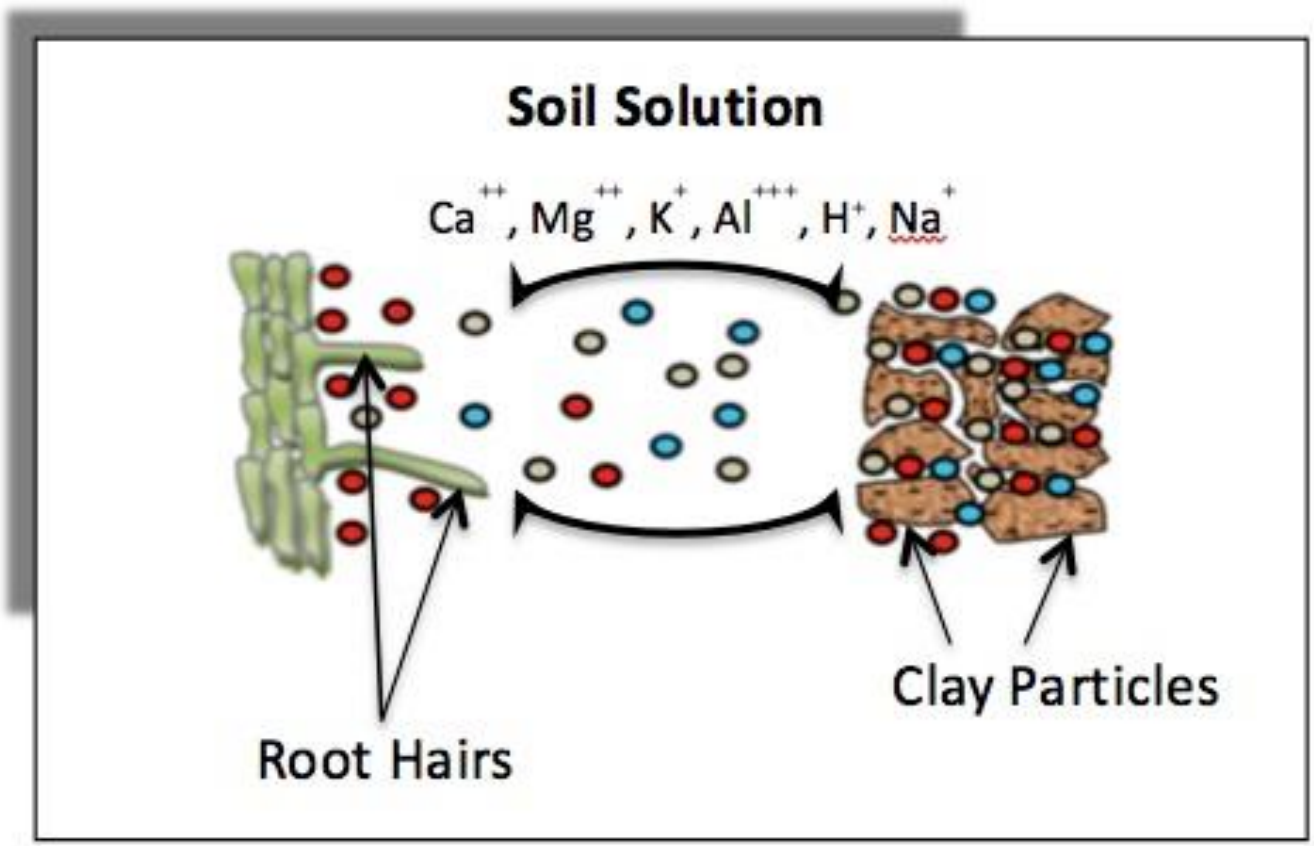
(b) Cation exchange in soil

Ions: Positive Cations and Negative Anions

Nutrients comprise oppositely charged particles known as ions: those with a positive charge are cations (such as calcium **Ca** $^{+2}$, magnesium **Mg** $^{+2}$**,** potassium **K**$^{+}$, sodium **Na**$^{+}$ and ammonium **(NH** $^{+4}$ **);** those with a negative charge are anions (chloride **Cl** $^{-}$**,** nitrate **NO** $^{+3}$, phosphate **PO** $^{+2}$, carbonate **CO** $^{-3}$ and sulphate **SO** $^{-4}$).

These ions bind with negatively and positively charged sites on soil particles, the availability of which is called the ion exchange capacity. Negatively charged mineral or organic soil aggregates are called colloids. Colloids are the most active constituents of soils and determine the physical and chemical properties of the soil. The total number of negatively charged sites on clay and organic matter particles is referred to as the cation exchange capacity (CEC)

These absorption and exchange phenomena primarily involve cations. They govern a wide range of fundamental mechanisms in pedogenesis, particularly those related to transport and accumulation processes. Additionally, numerous morphological, physical, and chemical properties of the soil depend on the state and functioning of the absorbing complex.



Absorbing Complex: This refers to the total surface area within a given volume of soil capable of absorbing ions and molecules. The absorbing complex primarily consists of fine clay and organic particles, forming the clay-humic complex, this expression is equivalent to the **absorbing complex**

Cation Exchange Capacity (CEC or T): This is the total sum of cations or anions that the soil can absorb onto its absorbing complex. These cations are generally exchangeable, meaning they can be replaced by other cations under specific conditions. The cation exchange capacity is expressed in milliequivalents per gram.

Sum of Exchangeable Cations (S): This represents the total amount of cations absorbed onto the soil complex at a given moment. It primarily includes the sum of the cations **Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and NH_4^{+}**.

•**T - S = H^+:** Represents the amount of **H^+ ions** absorbed onto the soil's exchange complex.

•**Saturation Rate of the Absorbing Complex (V):** This corresponds to the ratio

$$S/T \times 100.$$

A soil is considered **saturated** when the saturation rate is close to **100%**.

When V = **100%**, it means there are no **H^+ ions** on the complex since it is fully saturated with cations (**S = T**). This indicates that **H^+ ions** are low on the complex, and the soil pH is **basic**

Causes of Variations in Cation Absorption:

A- Cation Absorption by Clay Minerals: There are four main causes:

1.Van der Waals Bonding: This is a physical phenomenon of **short-range attraction**. It explains the **retention of certain large organic cations** on clay particles (i.e., organic cations are absorbed onto clays through van der Waals forces). However, this type of bonding does not play a role in the retention of **metallic cations**.

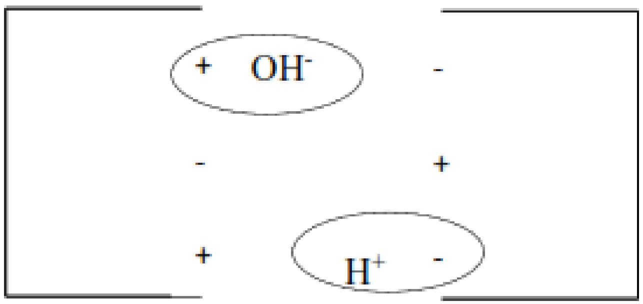
2. Charge Deficit: Many **clay minerals are not electrically neutral**; they have a more or less pronounced **deficit in positive charges**. As a result, clay particles are often attracts cations :

•This charge deficit is **only present in 2/1-type clay minerals**, such as **montmorillonite**, as they have a **high negative sites**.

•**1/1-type clay minerals**, such as **kaolinite**, are almost always neutral. This is why **kaolinite has a very low cation exchange capacity (CEC), around 10 meq/100g**

Causes of Variations in Cation Absorption:

3. Edge Bonding: When a clay sheet is broken, **unsatisfied valences** appear along the edges of the fractured sheet, leading to cation retention.



In aqueous environments, these unsatisfied valences are occupied by **H^+ and OH^- ions** from water hydrolysis. The **H^+ ions**, can be exchanged with other cations.

For **clay minerals with a neutral elementary sheet**, the **cation exchange capacity (CEC)** mainly depends on this mechanism.

This is the case for **kaolinite**, which has a **CEC between 4 and 10 meq/100g**.

The **number of edge bonds increases as particle size decreases**, which explains why **CEC increases when soil particles become finer**.

Causes of Variations in Cation Absorption:

4. Dissociation of Hydroxyl Groups (OH^-) in Clay Minerals

In **clay minerals**, hydroxyl groups attached to the **layers** can dissociate:

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

The released **H^+ ions** can be exchanged with other cations. This mechanism is significant when clay minerals are **poorly crystallized**, allowing **soil solutions to penetrate between layers** and facilitate cation exchange.

- **Well-crystallized kaolinite**: CEC = **5–10 meq/100g**
- **Poorly crystallized kaolinite (Halloysite)**: CEC = **15–40 meq/100g**

Causes of Variations in Cation Absorption:

B. Cation Absorption by Organic Matter (OM)

Organic matter has a **higher cation exchange capacity (CEC)** than clay minerals, ranging between **100 and 500 meq/100g**, depending on its type. Two main mechanisms contribute to this absorbent capacity:

1.Dissociation of Carboxyl Groups ($COOH \rightarrow COO^- + H^+$)

1. **H^+ ions** become exchangeable with other cations.
2. This process occurs when **pH** < **6**.

2.Dissociation of Hydroxyl Groups (OH^-)

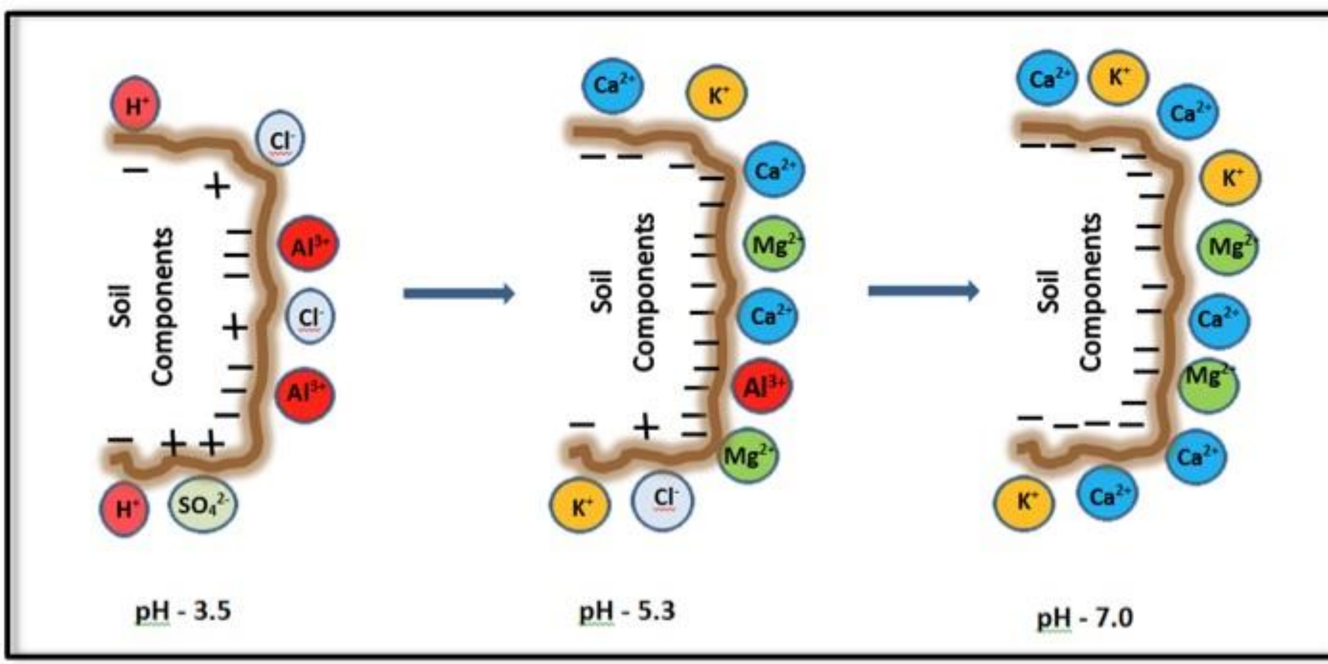
1. This occurs when **pH** > **6**

Causes of Variations in Cation Absorption:

Variation of Cation Exchange Capacity (CEC) with pH

CEC remains **constant** for **pH < 6** (e.g., 15 meq/100g for pH 2–6). However, for **pH > 6**, **CEC increases with pH** (e.g., 20 meq/100g at pH 7, 25 meq/100g at pH 7.5).

For example, **kaolinite** has a **CEC of 4 meq/100g at pH 6** but increases to **10 meq/100g at pH 7** due to the **dissociation of hydroxyl groups (OH^-) linked to silicon (Si).**



Causes of Variations in Cation Absorption:

Variation of Cation Exchange Capacity (CEC) Based on Absorbed Cations

CEC varies depending on the type of absorbed cations. A given surface of clay or organic matter does not retain the same amount (in meq) of **H^+, Na^+, Ca^{2+}, Mg^{2+}, etc.** The main reason for this variation is the **valence of the cations**

Adsorption and Desorption

Adsorption is the process by which ions are electrochemically bound to the surface of soil colloids carrying opposite charges. Adsorbed ions are held on the charged edge of the colloidal particles. Desorption is the process by which the electrochemically bound ions are detached from the surfaces of the colloids. The two processes take place simultaneously giving rise to the phenomenon of ion exchange in the soil.

Soil acidity

Acidity refers to the condition of the soil when the exchange complex is dominated by hydrogen and aluminum ions. Forms of soil acidity include active acidity, exchange acidity, residual acidity, and total acidity

Active acidity: Refers to the hydrogen ions present in soil solution due to the ionization of organic acids or desorption of H+ from the surface of soil colloids. This is measured by using pH meters or pH indicator papers

Exchangeable acidity (salt-replaceable): The aluminum and hydrogen that can be replaced from an acid soil by an unbuffered salt solution such as KCl or NaCl.

Soil acidity

Total acidity: The total acidity including residual and exchangeable acidity. Often it is calculated by subtraction of exchangeable bases from the cation exchange capacity determined by ammonium exchange at pH 7.0. It can be determined directly using pH buffer-salt mixtures (e.g., BaCl2 plus triethanolamine, pH 8.0 or 8.2) and titrating the basicity neutralized after reaction with a soil.

Soil Buffering Capacity

Soils generally act as a **buffered medium**, meaning their **pH does not change drastically** when acids or bases are added. This buffering ability is due to the **absorbing complex.**

•In **basic soils** rich in **Ca^{2+}**, adding acid causes **Ca^{2+} desorption**, preventing a sharp drop in pH.

•The **exchange of ions** between the soil complex and solution helps maintain pH stability.

•**Clay and humus-rich soils** have a **strong buffering capacity**, resisting pH fluctuations, while **sandy soils** have a **weak buffering capacity**, making their pH highly sensitive to external factors like rainfall and fertilizers.

The higher the clay and humus content in a soil, the greater its buffering capacity.

Example: A clay-rich soil with a high Meitnerium (Mt) content exhibits strong buffering capacity, meaning its **pH changes very slowly** in response to external factors. In contrast, a **sandy soil has low buffering capacity**, causing its **pH to fluctuate rapidly** under external influences such as rainfall or fertilizer application.

Liming

- Liming is the application of liming to soil with intention of reducing its acidity. Liming materials are substances that when added to soil are able to increase the pH.
- Liming requirement is the amount of liming material required to raise the pH of the soil to a specified level. It is experimentally determined.
- Examples of liming materials are oxides, hydroxides, carbonates and silicate of Ca and Mg. The anion present in the substance reduces the activity of **Al**
- The effectiveness of liming material is measured by the neutralizing value

OXIDATION –REDUCTION REACTIONS IN SOIL

Oxidation and reduction reactions are two reactions occurring simultaneously.

These reactions are common in the soil;

Oxidation is a reaction which involves gain of oxygen, or loss of hydrogen or electron.

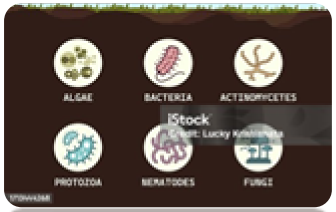
Reduction on the other side is the reaction which involves loss of oxygen, or gain hydrogen or electron.

Oxidation – reduction reactions generally involve transfer of electrons from one substance to another (no bonding formed or broken).

Oxidizing agents **(oxidizers)** accept electrons from other substances.

Reducing agents **(reducers)** donate electrons to other substances.

SOIL ORGANISMS



- The soil is a very complex medium where many chemical, biological, biochemical, geochemical, biogeochemical and physical processes take place.
- The soil is also the medium where plants obtain most of their nutrients.
- The soil has a vast population of living organisms including micro and macro flora, micro and micro fauna, insects etc.
- The activities of some of these organisms are detrimental to plants, particularly the disease causing organisms.
- The activities of most are however beneficial to crops particularly with regards to soil aggregation, nutrient cycling, biological nitrogen fixation, nutrient uptake, disease control/prevention and production of growth hormones.

SOIL ORGANISMS

These organisms interact with one another in the soil giving rise to diverse relationships/interactions such as symbiosis, parasitism, commensalism, protocooperation, neutralism, competition.

The soil microorganisms constitute the highest populations of soil organisms and because of their enzymatic capabilities, they are more important in soil processes than other soil organisms.

SOIL ORGANISMS

1. Soil Microflora

a) Bacteria:

Bacteria are unicellular organisms that adapt to environmental changes.

They generally prefer nitrogen-rich and slightly acidic soils. Bacteria are particularly abundant in the rhizosphere (around plant roots).

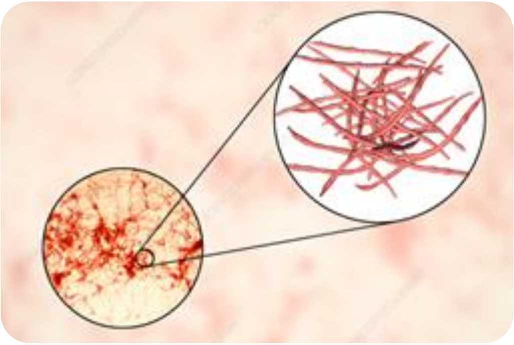
Most of them are heterotrophic and saprophytic, decomposing cellulose to obtain energy. Their biomass is highest in soils rich in organic matter and can reach up to 13 million units per gram.

SOIL ORGANISMS

Among soil bacteria, we can identify:

- **Azotobacter:** Free-living nitrogen-fixing bacteria that capture atmospheric nitrogen (N_2).
- **Sulfobacter:** Bacteria that reduce sulfates.
- **Nitrifying bacteria:** Convert ammonium ions (NH_4^+) into nitrites, which are subsequently oxidized into nitrates.
- **Denitrifying bacteria:** Convert nitrates into gaseous nitrogen (N_2), returning it to the atmosphere.

b) Actinomycetes:

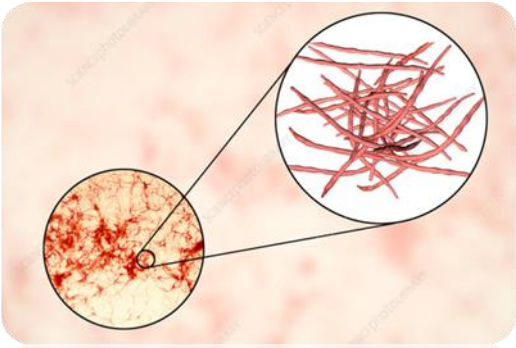


Actinomycetes are organisms that are intermediate between bacteria and fungi.

They are heterotrophic and primarily utilize carbohydrates in the soil (such as cellulose and hemicellulose) as their energy source.

They are also capable of degrading other substances like lignin and proteins and of assimilating nitrogen from organic matter.

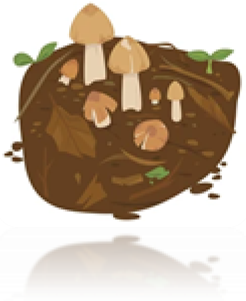
b) Actinomycetes:



Actinomycetes are strictly aerobic and are commonly found in sandy soils. They prefer slightly alkaline conditions (pH ≈ 7.8) and are sensitive to acidic soils.

Actinomycetes represent about **10 to 17% of the total soil biomass**, with populations ranging from **10 to 30 million units per gram** of soil.

c) Fungi:



Fungi are heterotrophic organisms, and their abundance is particularly significant in soils rich in organic matter. They generally prefer well-aerated environments with adequate moisture and warmth.

Fungi can degrade carbohydrates such as cellulose, hemicellulose, and lignin into simpler compounds. The most notable genera include *Penicillium*, typically found in temperate regions, and *Aspergillus*, which is characteristic of warmer climates.

c) Fungi:

Fungi also play a role in **ectomycorrhizal** association ; symbiotic relationships between fungi and higher plants. In this interaction, the fungus absorbs carbohydrates synthesized by the plant, while the plant benefits from nutrients such as **nitrogen (N)** and **phosphorus (P)** released through the decomposition of organic matter by the fungus.

The fungal biomass in soil typically ranges between **1000 and 1500 kg per hectare**.

d) Algae:

In soil, the most common algae are **Cyanophyceae (blue-green algae)** and **Chlorophyceae (green algae)**. These algae require high moisture and nitrogen content to thrive. They play a role in **soil formation (pedogenesis)** by contributing to the **weathering of parent rocks** on which they grow, and by **enriching the soil with organic matter**.

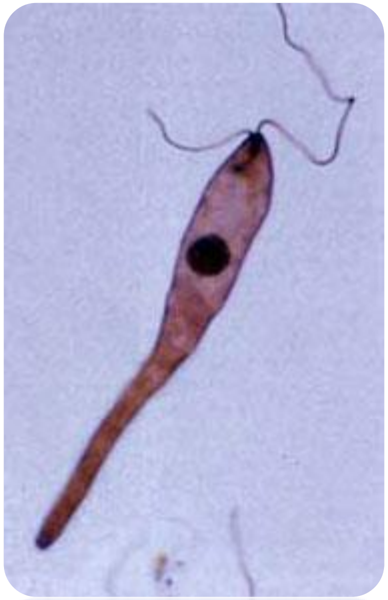
In soils, their biomass can reach up to **140 kg per hectare**.

2. Soil Fauna:

Soil fauna can be divided into three groups based on the size of the organisms:

a) Microfauna:

Mainly composed of **protozoa** (the most common being *Heteromita globosa*, *Colpoda cucullus*, and *Hartmanella hyalina*) and **nematodes**, microfauna are predominantly found in **very moist soils**. These organisms feed on soil microflora such as **bacteria, actinomycetes, and fungi**.



b) Mesofauna:

Includes organisms **ranging in size from 100 µm to 1 cm**, primarily **lower arthropods** such as **mites (Acari)** and **springtails (Collembola)**. These organisms are typically abundant in **acidic environments**.

c) Macrofauna:

Consists of organisms **larger than 1 cm**, including **earthworms**, **insect larvae**, and soil-dwelling insects such as **ants**, **some beetles (Carabidae)**, as well as **woodlice**, **millipedes**, **slugs and snails**, **spiders**, and **harvestmen (Opiliones)**. They play a significant role in **pedogenesis**, particularly in **structuring soil horizons through weathering** and contributing to the **decomposition of organic matter**.

3. Transformation of Organic Matter:

Organic matter is **99% of plant origin**, and since the **composition of plant material varies from one species to another**, the content of various components in the dry organic matter can differ. Typically, we observe the following proportions:

- **Cellulose**: accounts for **20% to 50%** of the dry organic matter
- **Hemicelluloses**: represent **10% to 20%** of the dry organic matter
- **Lignin**: ranges from **10% to 30%** of the dry organic matter
- **Proteins**: make up **1% to 15%** of the dry organic matter
- **Ashes**: constitute **1% to 8%** of the dry organic matter
- **Tannins**: vary between **1% to 8%** of the dry organic matter

These components undergo transformation to form litter, and this transformation occurs in several stages:

3.1 Debris Stage:

Organic matter of plant and animal origin undergoes leaching by rainwater, which results in the removal of all soluble products such as sugars and salts.

3.2 Physical Degradation Phase:

This is a stage where the **soil fauna intervenes**, leading to the **fragmentation of debris** and their **interaction with mineral matter**.

a) Decomposition of carbohydrates (Cellulolysis):

During its breakdown, **cellulose is converted into simple sugars** (such as hexoses and pentoses).

This process is closely linked to **environmental conditions** like **aeration** and **acidity level**.

•In **aerated environments**, *Myxobacteria* are involved, leading to the **mineralization of cellulose into glucose**, which is then converted into $\mathbf{CO_2}$.

•In **highly acidic environments**, **certain fungi** contribute to the decomposition of cellulose.

•In **anaerobic environments**, **Clostridium bacteria** are responsible for cellulose mineralization, resulting in the production of **butyric acid,** $\mathbf{CH_4}$ **(methane), and** $\mathbf{CH_2}$. However, **humic substances are not formed** in this condition.

b) Decomposition of aromatic compounds (Ligninolysis):

Lignin is decomposed primarily by fungi; bacteria do not participate in this process.

- In **aerobic conditions**, **lignin is broken down into acids and phenols**.
- In **anaerobic conditions**, **lignin does not decompose effectively**, leading to the **formation of peat** (partially decomposed organic matter)

c) Decomposition of Nitrogen Compounds (Proteolysis):

Proteins are rich in carbon (approximately 50%) and **nitrogen** (ranging from 7% to 10%), and their content is significant in plant material.

The **decomposition of proteins** is carried out by **bacteria**, and it occurs in **both aerobic and anaerobic environments**.

- In **slightly acidic conditions**, proteins are first broken down into **polypeptides**, then into **amino acids**, and in some cases, **amides** such as **urea** $[CO(NH_2)_2]$ may also be formed

4. Factors Involved in the Evolution of Organic Matter

4.1. Extrinsic Factors

a) Climate:

In equatorial climates, where conditions remain constant throughout the year, the decomposition of organic matter is rapid due to **high temperatures and humidity**. However, as we move away from these zones, **decomposition slows down** due to **reduced humidity** and **lower temperatures**.

b) Soil Aeration:

The transformation of organic matter requires a certain degree of **aeration** to support the development of **humification agents**. In the **absence of oxygen**, organic matter **accumulates** and does **not decompose effectively**.

c) Soil pH:

When the soil is highly **acidic**, **mold activity increases**, which can be **detrimental to bacteria and soil fauna**. High acidity also leads to the formation of **acidic humus**. This form of humus can still be **favorable for agriculture**, particularly in soils rich in **calcium (Ca^{2+})** and **magnesium (Mg^{2+})**.

4.2. Intrinsic Factors

Plant debris is generally rich in **nutrients**, especially in **calcium (Ca^{2+})**. However, this richness becomes less significant when the soil itself already contains a high level of this element.

Humification agents make use of calcium released from the decomposition of organic matter when there is a **deficiency** of this element in the soil.

The **evolution of organic matter** is therefore closely linked to the **nutrient richness of the soil**, particularly elements needed for the development of humification agents.

To evaluate the degree of organic matter decomposition in the soil, the **Carbon/Nitrogen (C/N) ratio** is often used:

- A **high C/N ratio** indicates **slow decomposition** of organic matter.
- A **low C/N ratio** indicates **rapid decomposition** of organic matter.

1. Russian Soil Classification

•Developed by **V.V. Dokuchaev**, the father of modern pedology, in the late 19th century.

•Based on a **genetic approach**, classifying soils according to their **formation processes**, influenced by natural factors like climate, vegetation, and topography.

•Examples of soil types:

- **Chernozems** (very fertile black soils),
- **Podzols** (leached soils in cold, humid climates),
- **Steppe soils, brown forest soils**, etc.

•Widely used in **Eastern Europe and Russia**.

3. French Soil Classification

- Developed in the 1960s–70s by **INRA** (National Institute for Agronomic Research).
- Based on a **morpho-genetic approach**, considering both the **morphology** of soil horizons and **pedogenic processes**.
- Soils are named using the **"Référentiel Pédologique"** (latest version: 2008).
- Examples:
  - **Brown soils**, **Rendzinas**, **Podzols**, **Hydromorphic soils**, etc.
- Mainly used for **soil mapping in France**.

American Classification – Soil Taxonomy

•Developed by the **USDA (United States Department of Agriculture)** from the 1960s.

•A **morphological and taxonomic approach**: classifies soils based on measurable **horizon properties** (pH, texture, base saturation, etc.), regardless of formation history.

•Composed of **six hierarchical levels**: **Order, Suborder, Great Group, Subgroup, Family, Series**.

•Examples of soil orders:

- **Mollisols** (organic-rich, fertile soils),
- **Ultisols, Alfisols, Aridisols, Oxisols**, etc.

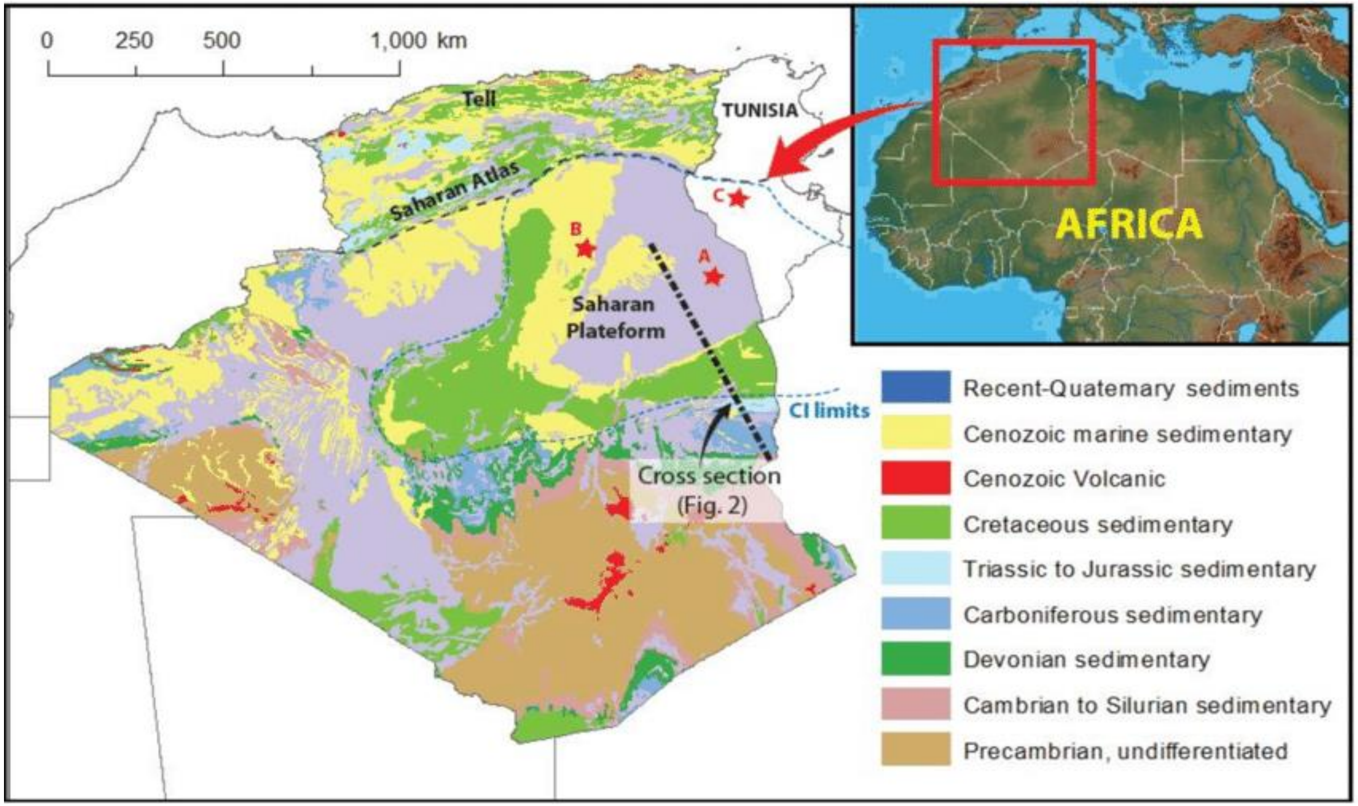
•One of the **most widely used** classifications globally.

Comparative Table of Major Soil Classification Systems

Feature	Russian Classification	American Soil Taxonomy	French Classification
Origin	Late 19th century (Dokuchaev)	1960s (USDA)	1960s–1970s (INRA)
Main Approach	Genetic	Morphological & Taxonomic	Morpho-genetic
Focus	Soil formation processes	Physical and chemical properties	Horizon morphology + pedogenesis
Hierarchy Levels	Few major soil types	6 levels (Order to Series)	Mainly descriptive, no hierarchy
Examples	Chernozems, Podzols, Steppe	Mollisols, Ultisols, Aridisols	Brown soils, Podzols, Rendzinas
Region of Use	Eastern Europe, Russia	USA, widely adopted worldwide	France

Overview of Algerian Soils and Their Relationship with Climate and Geomorphology

Algeria, the largest country in Africa, displays a wide diversity of soil types due to its varied climatic zones and complex geomorphological structure. The distribution, formation, and evolution of soils across the country are strongly influenced by factors such as climate (precipitation, temperature), topography, parent material, and vegetation cover.



1. Climatic Influence on Soils

Algeria can be broadly divided into three major climatic regions:

- **The Northern Region (Tellian Atlas)**: Characterized by a Mediterranean climate with relatively high rainfall (400–1,200 mm/year). This favors the development of fertile soils such as *Mediterranean soils*, *brown forest soils*, and *terra rossa*, especially under forest and agricultural land.
- **The Highlands (High Plateaus and Saharan Atlas)**: This semi-arid zone receives moderate rainfall (200–400 mm/year). The soils here are often shallow, calcareous, and less developed, such as *rendzinas* and *calcimagnesic soils*.
- **The Southern Region (Sahara Desert)**: An arid to hyper-arid climate prevails, with annual rainfall below 100 mm. Soils in this area are dominated by *aridisols*, *gypsiferous soils*, and large expanses of *raw mineral soils* or *reg soils* with low fertility and organic matter.

2. Geomorphological Influence

The geomorphology of Algeria—composed of coastal plains, mountain chains, high plateaus, and vast desert basins—also plays a significant role in soil distribution:

- In **mountainous regions** (Tellian and Saharan Atlas), the steep slopes lead to higher erosion rates and the presence of shallow, poorly developed soils.
- The **high plateaus** and **intermontane depressions** promote the accumulation of finer materials and the development of moderately fertile soils.
- In the **Saharan region**, ancient alluvial plains, sand dunes (*ergs*), and rocky plateaus (*hamadas*) present a variety of soil types, though generally low in organic content.

3. Soil Diversity and Agricultural Potential

Due to this interplay of climate and landforms, Algeria hosts a variety of soil types, but only a limited portion mainly in the north is suitable for intensive agriculture.

Soil degradation processes such as erosion, salinization, and desertification, especially in semi-arid and arid zones, remain a major challenge for sustainable land management.