University Center abdelhafid boussouf – Mila – Algeria

Agronomy 01 : Soil and Water

By Dr. Sahraoui A.S

2023/2024

Dr . SAHRAOUI Aboubakre seddik

Specialized in Ecology and Environmental Sciences

MAB : university Centre Abdelhafid boussouf – Mila

In charge of tutorials (TD) and practical sessions (TP)

for the module Agronomy 01 : soil and water

Contact:

sah.boubaker@gmail.com

Office hours: Monday and Tuesday.

Généralités sur le module

Fundamental Unit (UEM): Fundamental Unit

Semester: 4th Semester

Target Audience: 2nd Year Agronomic Science Students

Field: Natural and Life Sciences

Program: Biological Sciences

Academic Year: 2024/2025

Weighting (Coefficient): 4

Credits: 4

Total Weekly Hours: 45 hours

Lectures: 1.5 hours

Tutorials (TD): 1.5 hours

Practical Work (TP): 1.5 hours

objectif

The student must understand the concepts and terminology related to water and different soil types, as well as the methods of study and analysis in correlation with various ecosystems.

- ✓ Familiarity with fundamental concepts in biology and chemistry
- ✓ Understanding of the physical and chemical properties of water and soils
- ✓ Prior experience in basic laboratory techniques
- ✓ Introductory knowledge of ecosystems and their functioning
- ✓ Proficiency in mathematical tools for environmental data analysis

Modalité de fonctionnement

Le cours est organisé :

- En séances théoriques qui se passent en Amphi

- En séances de travaux partiques qui se passe en au labo

EVALUATION

60 % : contrôle finale

40 % : évaluation continue

Course Content:

1. Introduction

•Definition of Soil

•Role of Water in Soil Science

A. Soil

2. Constituent Elements of Soil

•Mineral Compositions

•Organic Constituents

•Colloidal Complexes

3. Morphological Organization of Soils

4. Chemical and Biological Properties of Soil

5. Soil Classification (Basic Concepts)

B. Water

•Role of Water in Soil

•Relationships Between the Three Phases of Soil

•Measurement of Volumes Occupied by Different Soil Phases

•Forms of Water in Soil

Introduction to Agronomy 01: ‘’Soil and Water"

1. Introduction

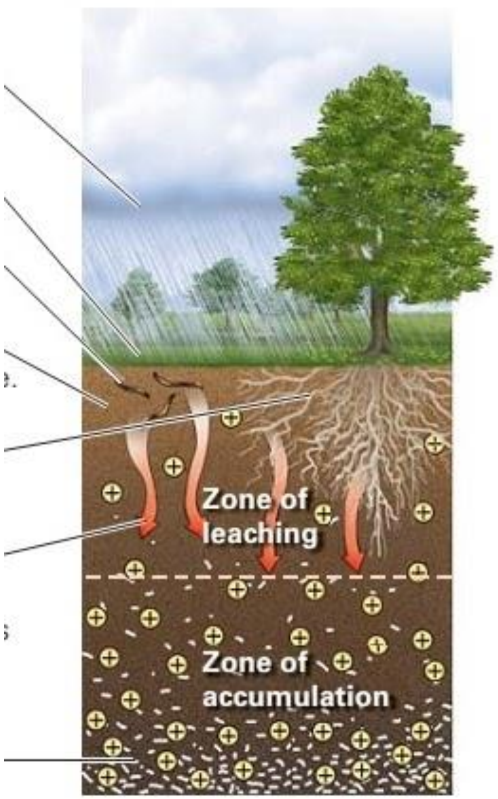
Definition of Soil:

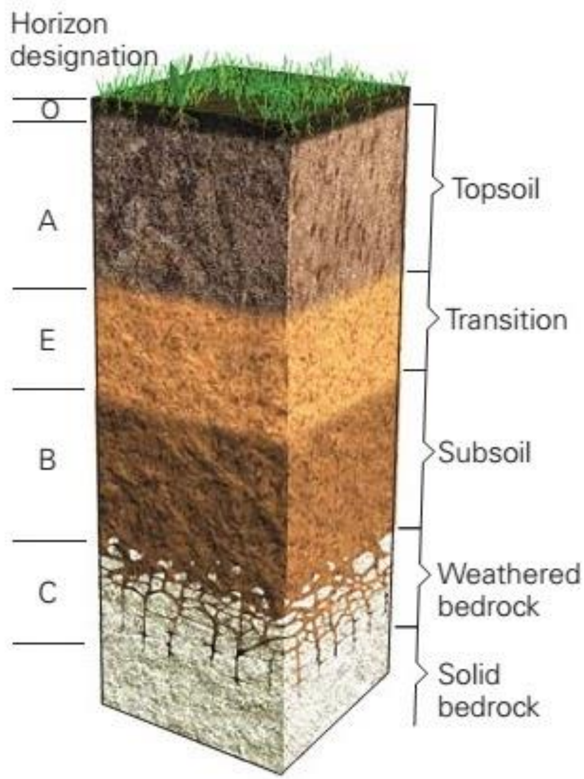
Soil is a dynamic, natural body composed of mineral and organic materials, air, and water, which serves as a medium for plant growth. It is formed through the interaction of physical, chemical, and biological processes over time, influenced by factors such as climate, topography, parent material, and living organisms. Soil performs critical functions in agronomy, including nutrient cycling, water storage and filtration, and providing structural support for plants. Its properties—such as texture, structure, pH, and organic matter content—directly impact agricultural productivity and ecosystem sustainability.

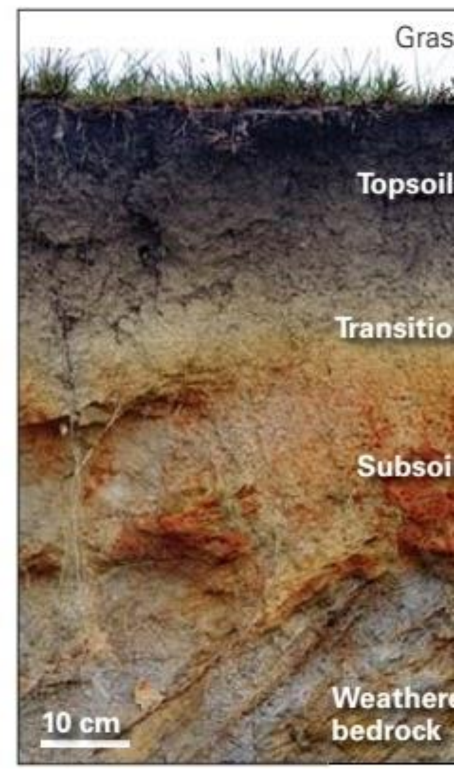
Role of Water in Soil Science:

Water is a fundamental component of soil systems, playing a critical role in sustaining plant life, regulating soil processes, and maintaining ecosystem health. In soil science, water acts as a solvent and transport medium, facilitating the movement of nutrients, minerals, and organic matter essential for plant growth. It also influences soil structure, aeration, and temperature regulation. The availability and movement of water within the soil—governed by properties such as porosity, permeability, and water-holding capacity—directly impact agricultural productivity, water resource management, and environmental sustainability. Understanding the dynamics of soil water is crucial for optimizing irrigation, preventing soil degradation, and ensuring sustainable land use practices.

A. Soil

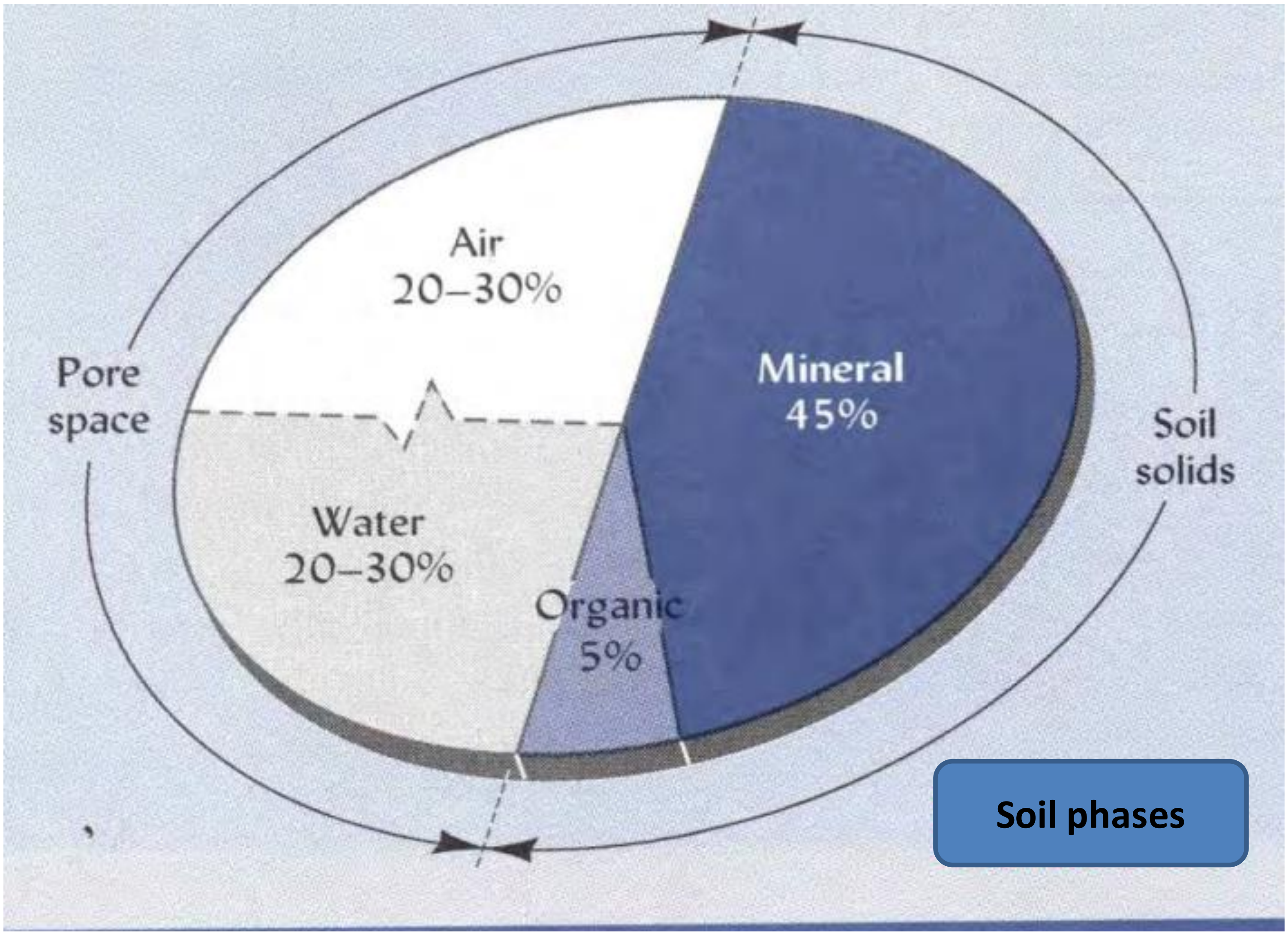

Zone of leaching
Zone of accumulation


Horizon designation
O
A
E
B
C
Topsoil
Transition
Subsoil
Weathered bedrock
Solid bedrock


Topsoil
Subsoi
10 cm

What's In Soil?

Soil is a three-phase system containing solids, liquids, and gasses that strongly interact with each other. Soil contains four components, mineral fragments, organic matter, soil air, and water.



2. The Constituent Elements of Soil (Soil's Components)

2.1 Mineral components (Inorganic materials)

Composition - Not to surprisingly, soils reflect the materials from which they are made. Parent material for the mineral fraction of soils are normally the primary aluminosilicate minerals. As the name implies, these minerals are made from aluminum, silicon and oxygen.

Taken together these elements account for approximately 82 % of the earth's crust by weight. On a mass basis, the importance of O, and Si is easily appreciated. The average composition of the earth's crust is given below.

Average chemical composition of the earth's crust

Element	% by weight	Element	% by weight
O	46.5	Ca	3.6
Si	27.6	Mg	2.1
Al	8.1	Na	2.8
Fe	5.1	K	2.6

2. The Constituent Elements of Soil (Soil’s Components)

These minerals are derived from the weathering of parent rocks and play a critical role in determining soil properties and fertility.

2.1.1. Primary Minerals

Primary minerals are those that have not undergone significant chemical changes since their formation. They originate directly from the parent rock and include:

•**Quartz (SiO_2):** A hard, chemically stable mineral that resists weathering and contributes to soil texture, mainly as sand particles.

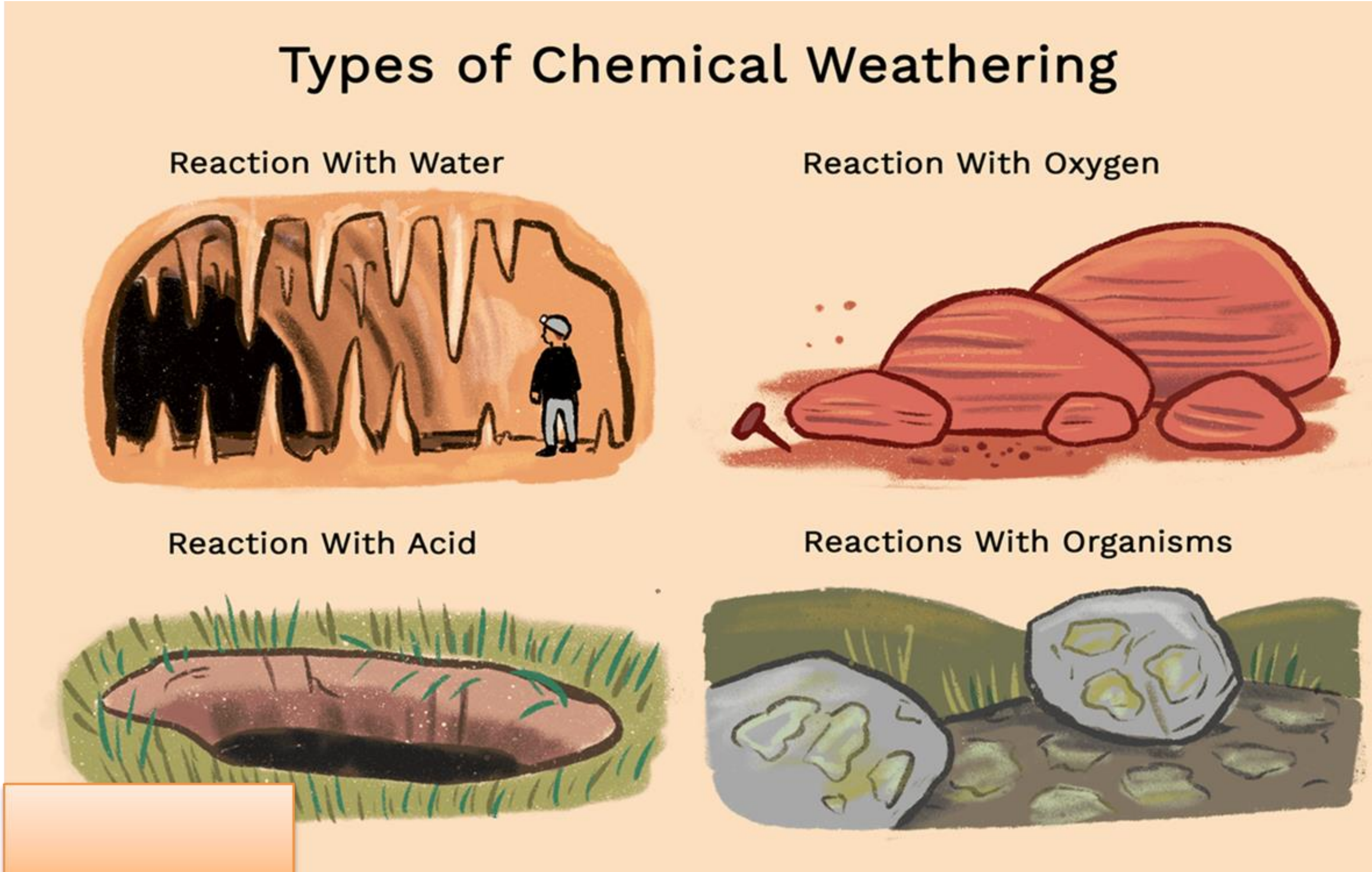
•**Feldspars:** A group of aluminosilicate minerals that weather to form clay minerals, releasing nutrients like potassium, calcium, and sodium into the soil.

•**Muscovite (a type of Mica):** A silicate mineral with a sheet-like structure, contributing to soil's physical properties and slowly releasing potassium during weathering

Soil Chemical Weathering is the process by which rocks and minerals in the soil are broken down and altered through chemical reactions with water, oxygen, acids, and other substances.

Key Processes:

- **Hydrolysis:** Reaction with water, altering mineral structures.
- **Oxidation:** Reaction with oxygen, especially affecting iron-containing minerals.
- **Dissolution:** Minerals dissolve in water, often aided by acids.
- **Carbonation:** Reaction with carbonic acid formed from CO_2 and water.


Types of Chemical Weathering
Reaction With Water
Reaction With Oxygen
Reaction With Acid
Reactions With Organisms

2. The Constituent Elements of Soil (Soil's Components)

Before introducing secondary minerals we should know :

Cation Exchange Capacity (CEC) refers to the soil's ability to hold and exchange positively charged ions (*cations*), such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+}).

Roles of CEC:

Nutrient Retention: Helps retain essential nutrients, making them available for plant uptake.

Soil Fertility Indicator: Higher CEC indicates better nutrient-holding capacity, contributing to soil fertility.

Buffering Capacity: Regulates soil pH and reduces nutrient leaching, promoting stable growing conditions.

2. The Constituent Elements of Soil (Soil’s Components)

2.1.2. Secondary Minerals

Secondary minerals are formed through the chemical alteration of primary minerals. The most important group is **clay minerals**, such as:

•**Kaolinite:** Low cation exchange capacity (CEC) but stable structure.

•**Montmorillonite:** High CEC, excellent water retention, and nutrient-holding capacity.

•**Illite:** Intermediate CEC, common in many agricultural soils.

2.1.3 Role of Mineral Components

•**Soil Structure:** Minerals influence soil texture (sand, silt, clay) and aggregation, affecting water infiltration and root penetration.

•**Nutrient Supply:** Minerals are a source of essential nutrients like potassium, calcium, magnesium, and phosphorus.

•**Cation Exchange Capacity (CEC):** Clay minerals contribute to the soil’s ability to retain and exchange nutrients, which is vital for plant growth

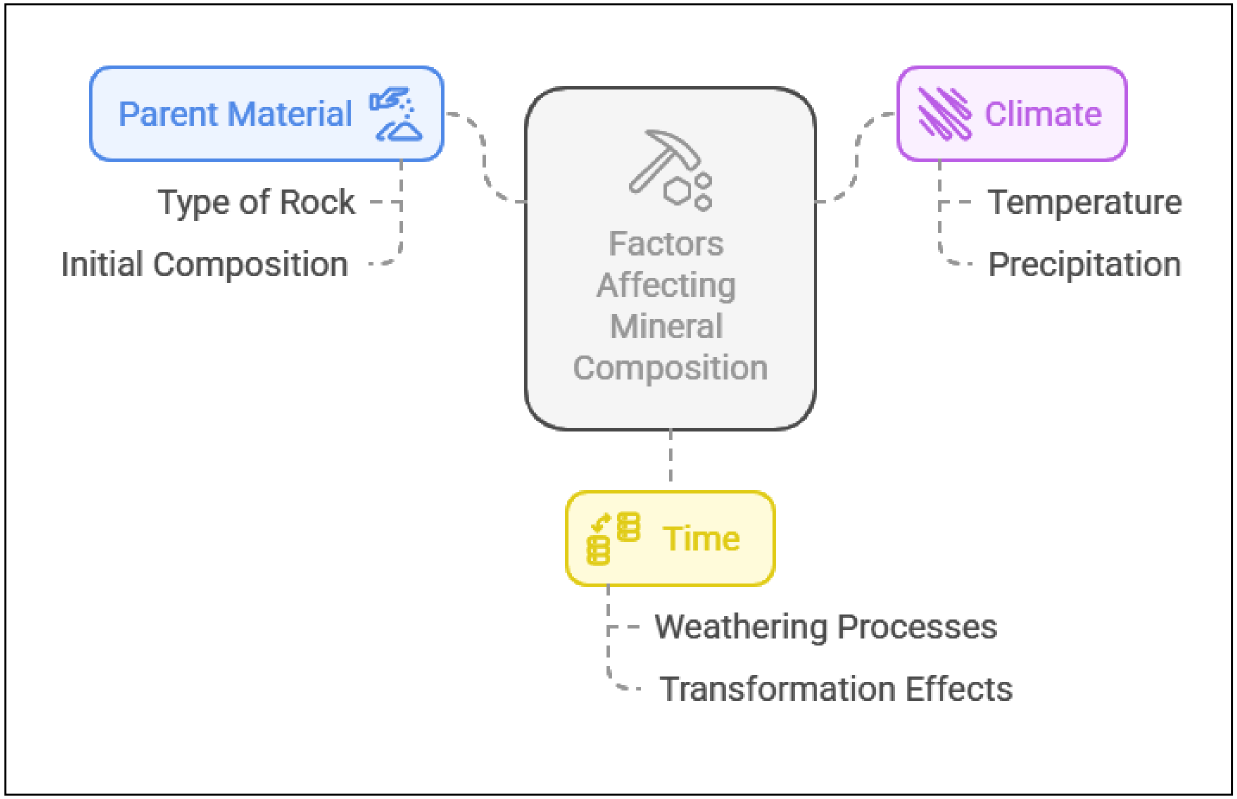
2. The Constituent Elements of Soil (Soil's Components)

2.1.3. Factors Affecting Mineral Composition

•**Parent Material:** The type of rock from which the soil forms determines its initial mineral composition.

•**Climate:** Temperature and precipitation influence the rate of mineral weathering.

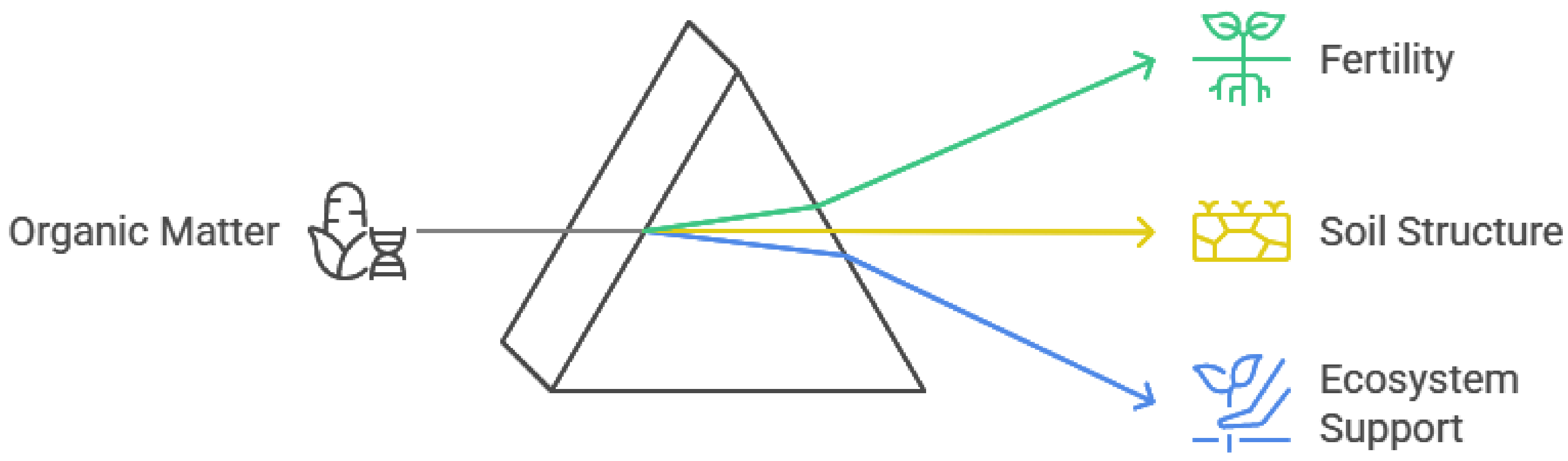
•**Time:** Over time, minerals break down and transform, altering soil properties.



2. The Constituent Elements of Soil (Soil's Components)

2.2. Organic components (Organic materials)

Organic matter is a vital component of soil, contributing to its fertility, structure, and overall health. It is derived from the decomposition of plant and animal residues and plays a key role in supporting plant growth and sustaining ecosystems.



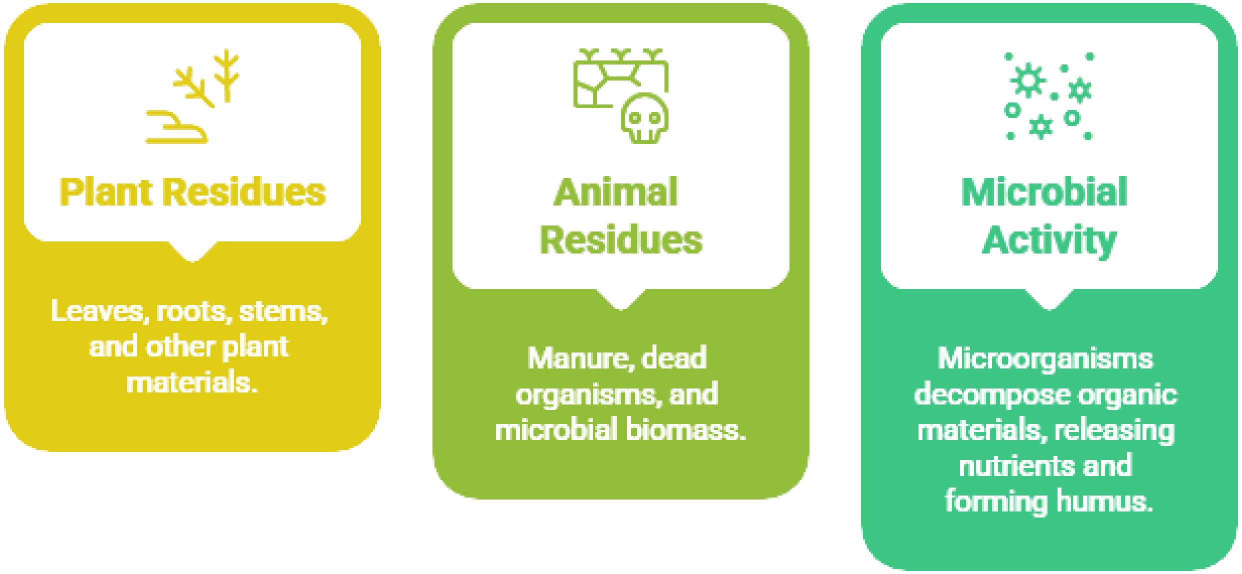
2. The Constituent Elements of Soil (Soil's Components)

2.2. Sources of Soil Organic Matter

•**Plant Residues:** Leaves, roots, stems, and other plant materials.

•**Animal Residues:** Manure, dead organisms, and microbial biomass.

•**Microbial Activity:** Microorganisms decompose organic materials, releasing nutrients and forming humus.

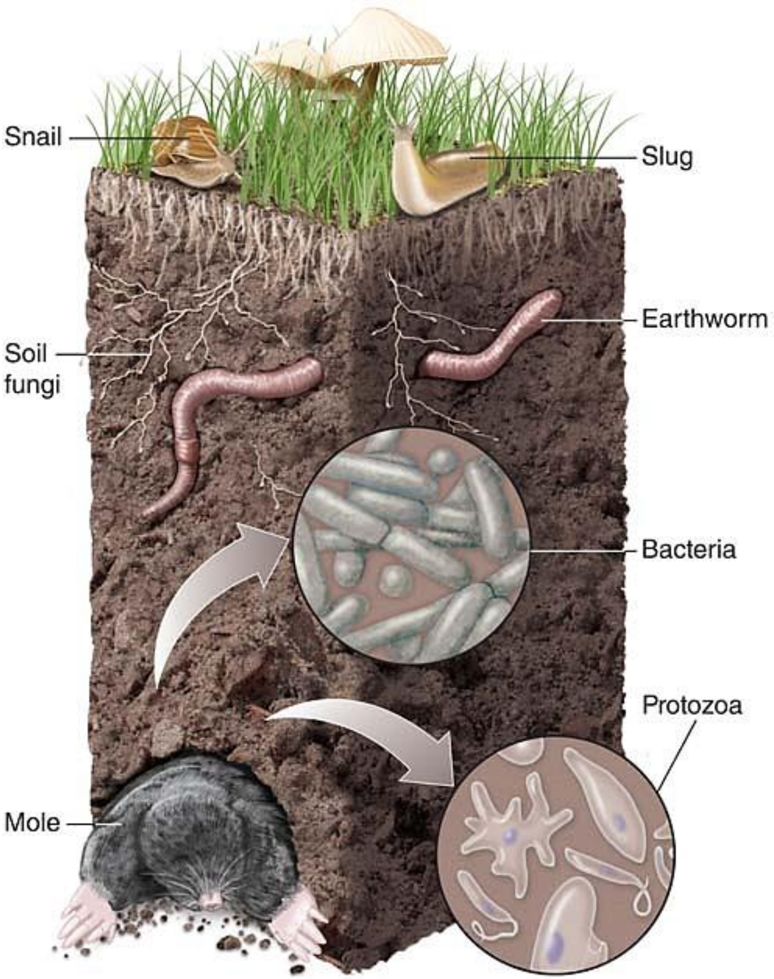


2. The Constituent Elements of Soil (Soil's Components)

2.2.1. Composition of Soil Organic Matter

•**Living Organisms:** Bacteria, fungi, earthworms, and other soil organisms.

•**Detritus:** Partially decomposed plant and animal residues



2. The Constituent Elements of Soil (Soil's Components)

* **Soil Humus** is the dark, organic component of soil formed from the decomposition of plant and animal matter by microorganisms. It is stable, resistant to further decomposition, and rich in nutrients.

Roles of Humus:

•**Nutrient Reservoir:** Stores and slowly releases essential nutrients like nitrogen and phosphorus.

•**Improves Soil Structure:** Enhances soil aggregation, promoting better aeration and water retention.

•**Increases Cation Exchange Capacity (CEC):** Helps retain and supply nutrients to plants.

•**Boosts Microbial Activity:** Provides energy and habitat for beneficial soil microorganisms.

•**Carbon Storage:** Acts as a long-term carbon sink, influencing soil carbon dynamics.

2. The Constituent Elements of Soil (Soil’s Components)

2.2.2. Role of Organic Matter in Soil

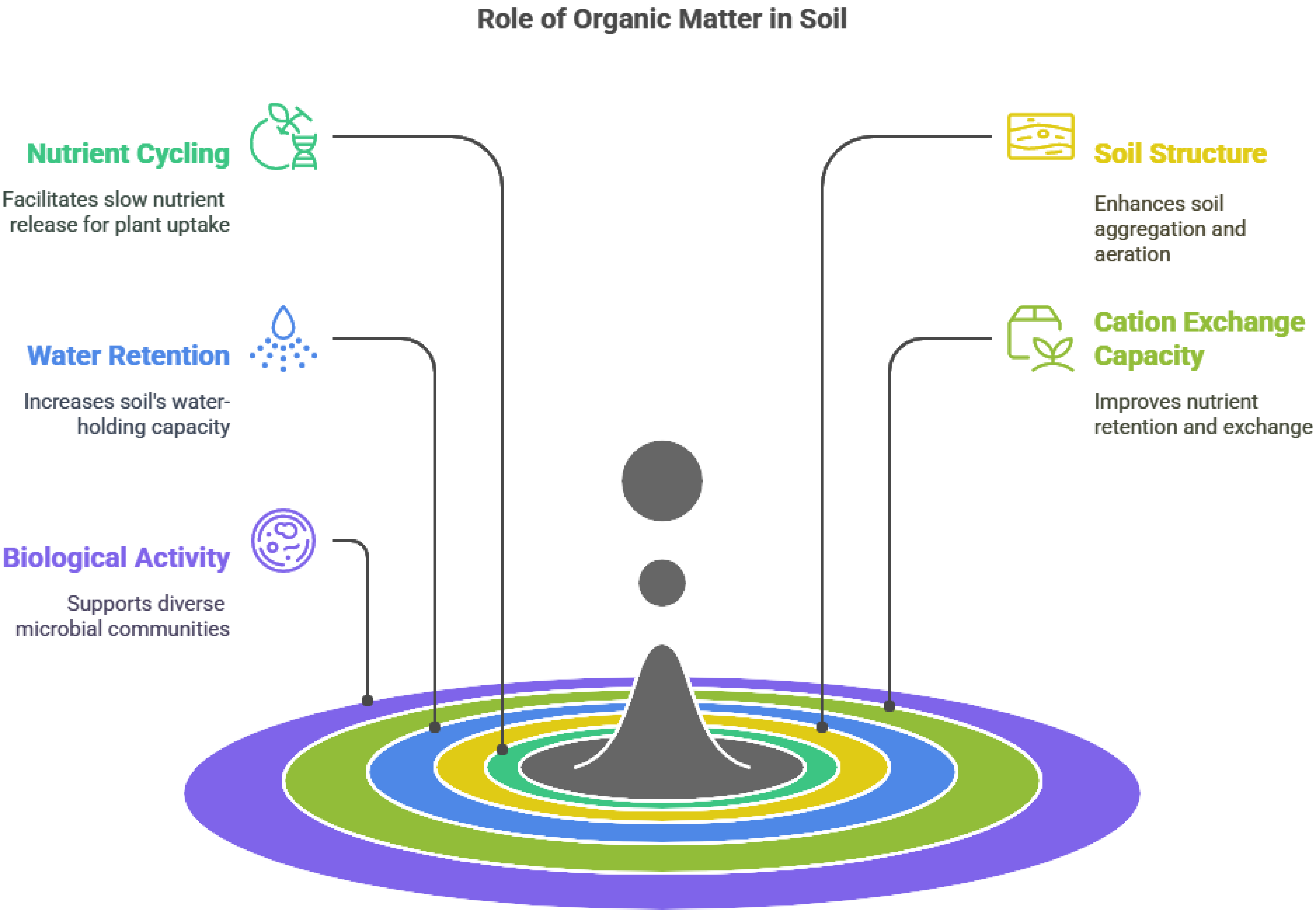
•**Nutrient Cycling:** Organic matter is a reservoir of essential nutrients like nitrogen (N), phosphorus (P), and sulfur (S), which are released slowly for plant uptake.

•**Soil Structure:** It promotes the formation of soil aggregates, improving aeration, water infiltration, and root penetration.

•**Water Retention:** Organic matter increases the soil’s ability to hold water, reducing drought stress for plants.

•**Cation Exchange Capacity (CEC):** Humus has a high CEC, enhancing the soil’s ability to retain and exchange nutrients.

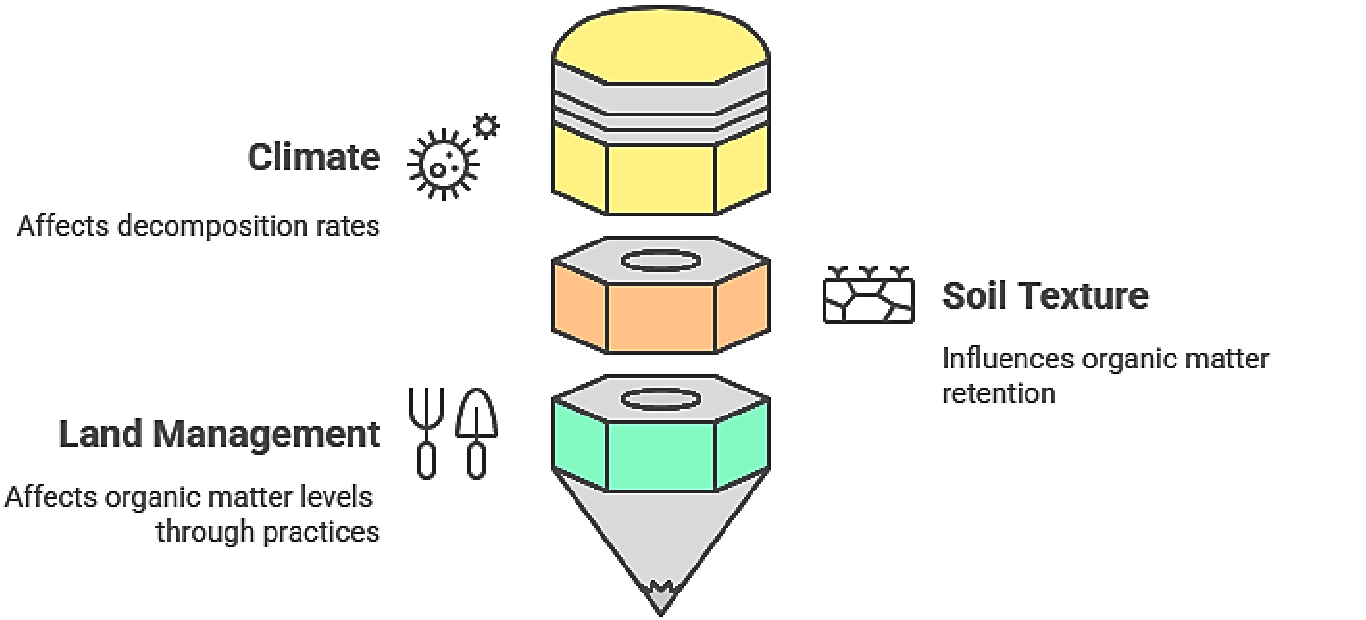
•**Biological Activity:** It supports a diverse and active microbial community, which drives decomposition and nutrient cycling


Role of Organic Matter in Soil
Nutrient Cycling
Facilitates slow nutrient release for plant uptake
Water Retention
Increases soil's water-holding capacity
Biological Activity
Supports diverse microbial communities
Soil Structure
Enhances soil aggregation and aeration
Cation Exchange Capacity
Improves nutrient retention and exchange

2. The Constituent Elements of Soil (Soil’s Components)

2.2.3. Factors Affecting Organic Matter Content

- **Climate:** Warm, moist climates accelerate decomposition, while cold or dry climates slow it down.
- **Soil Texture:** Clay soils tend to retain more organic matter than sandy soils.
- **Land Management:** Practices like crop rotation, cover cropping, and reduced tillage can increase organic matter levels



2. The Constituent Elements of Soil (Soil's Components)

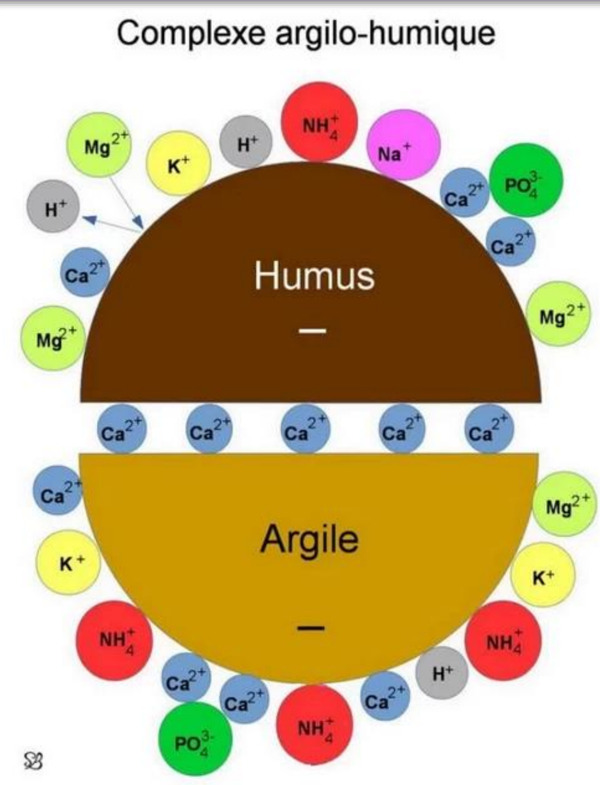
2.3. Colloidal Complexes in Soil

Colloidal complexes are finely divided particles in soil that play a crucial role in determining its physical, chemical, and biological properties. These particles are so small that they remain suspended in soil solution and have a high surface area relative to their size. They include both inorganic (clay minerals) and organic (humus) colloids.

2.3.1. Types of Soil Colloids

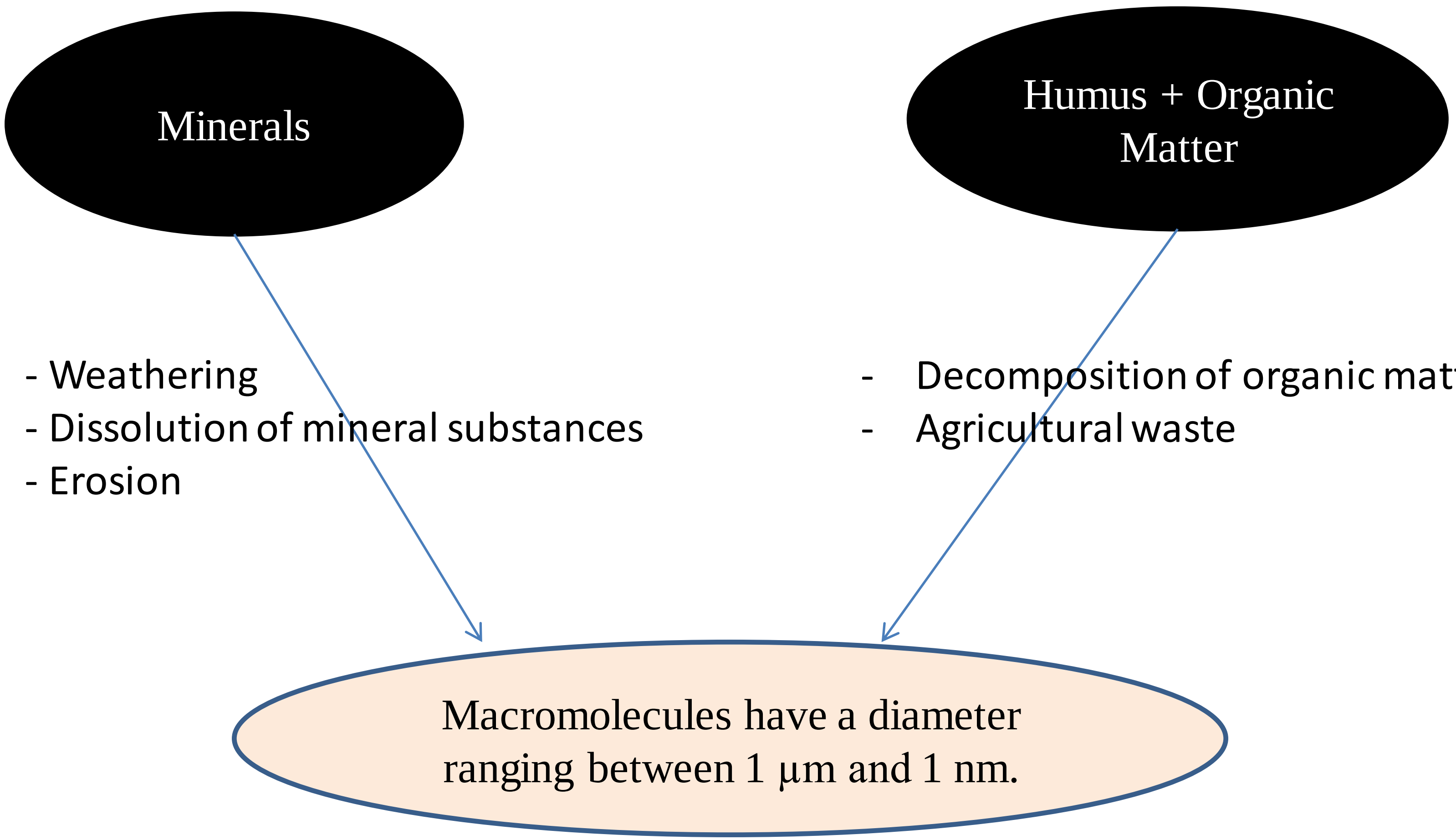
•**Inorganic Colloids:** Primarily clay minerals such as kaolinite, montmorillonite, and illite. These are derived from the weathering of rocks and minerals.

•**Organic Colloids:** Mainly humus, which is formed from the decomposition of organic matter.



2. The Constituent Elements of Soil (Soil’s Components)

As shown in the following diagram, colloids originate either from mineral or organic sources.



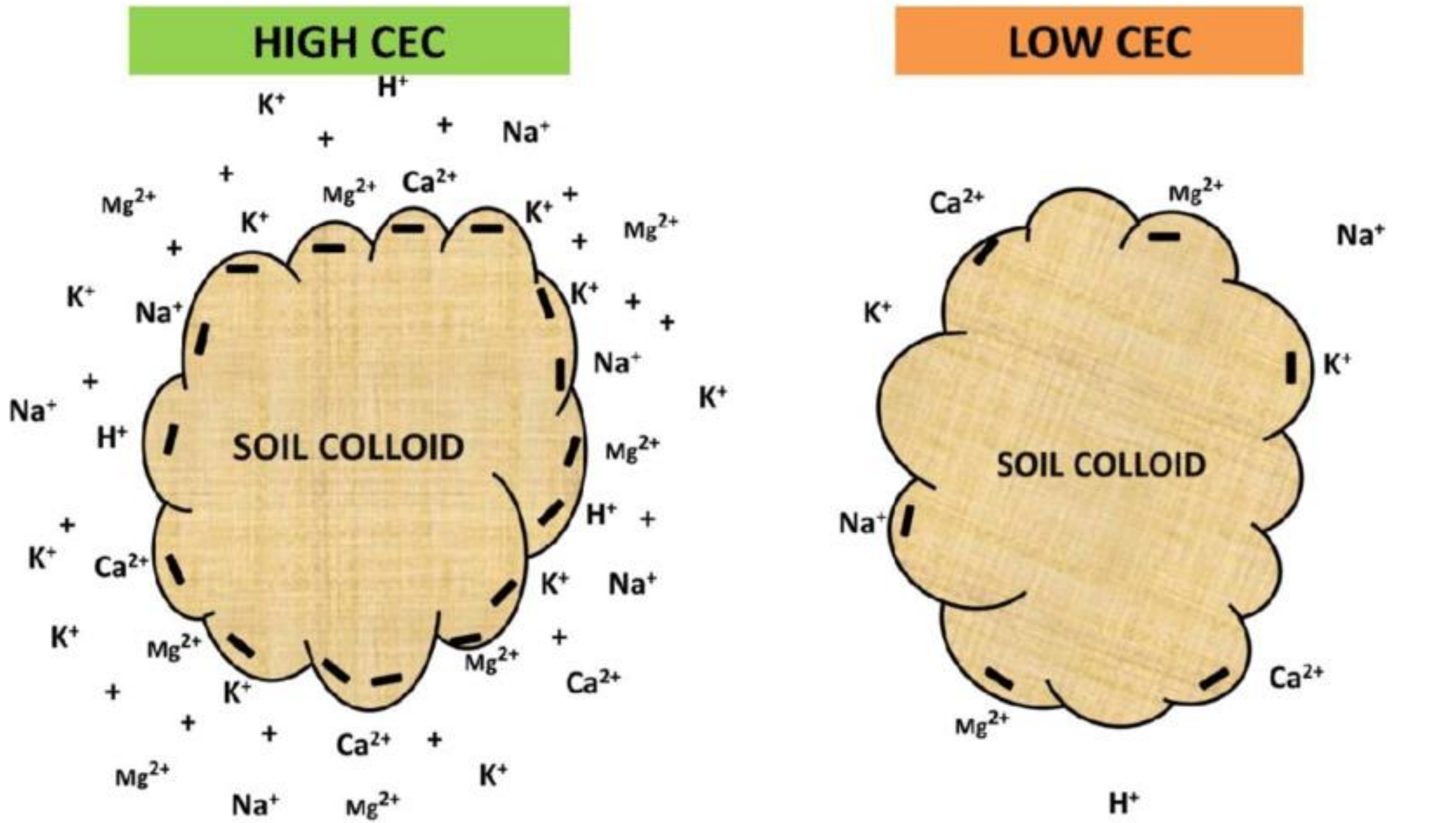
2. The Constituent Elements of Soil (Soil's Components)

2.3.2. Properties of Soil Colloids

High Surface Area: Colloids have a large surface area relative to their size, allowing them to adsorb water, nutrients, and other ions.

Charge Characteristics: Colloids carry negative charges on their surfaces, which attract and hold positively charged ions (cations) like calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and ammonium (NH_4^{+}).

Swelling and Shrinking: Some clay colloids, like montmorillonite, can swell when wet and shrink when dry, affecting soil structure and porosity.



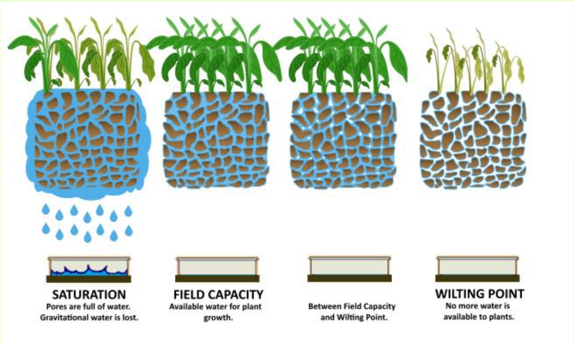
HIGH CEC
SOIL COLLOID
H^+
K^+
Na^+
Mg^{2+}
Ca^{2+}
LOW CEC
SOIL COLLOID
Ca^{2+}
Mg^{2+}
Na^+
K^+
K^+
Na^+
Ca^{2+}
Mg^{2+}
H^+

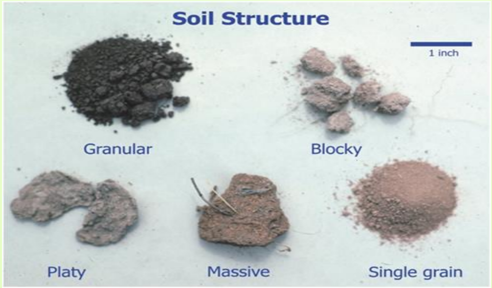
2. The Constituent Elements of Soil (Soil's Components)

2.3.3. Role of Colloidal Complexes in Soil

•**Nutrient Retention and Exchange:** Colloids are the primary sites for cation exchange capacity (CEC), which is essential for nutrient availability to plants.

•**Soil Structure:** Colloids help form soil aggregates, improving soil porosity, aeration, and water infiltration.

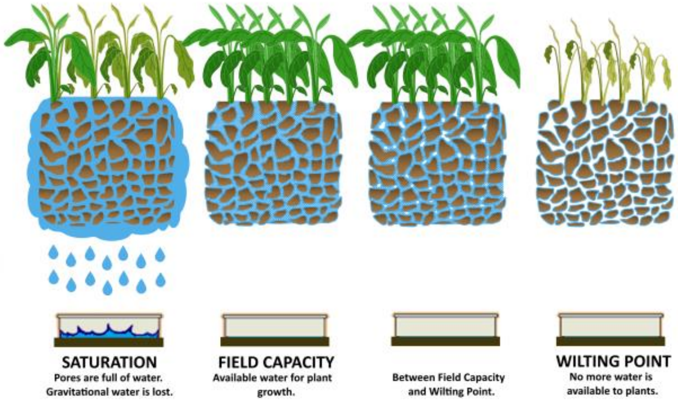




•**Water Retention:** Colloids can hold water molecules, contributing to the soil's ability to retain moisture.

•**Buffering Capacity:** Colloids help stabilize soil pH by adsorbing and releasing hydrogen ions (H^+) and other cations

2.3.3. Role of Colloidal Complexes in Soil



- Soil structure resists the degrading effects of rain due to clay colloids that do not mix with water.

- Humus is a protective colloid, shielding clay from excessive moisture. By :
  - Prevents Clay Dispersion ,
    Enhances Aggregate Stability ,
    Regulates Water Retention

- Clay protects humus from microbial decomposition with the help of colloidal matter.

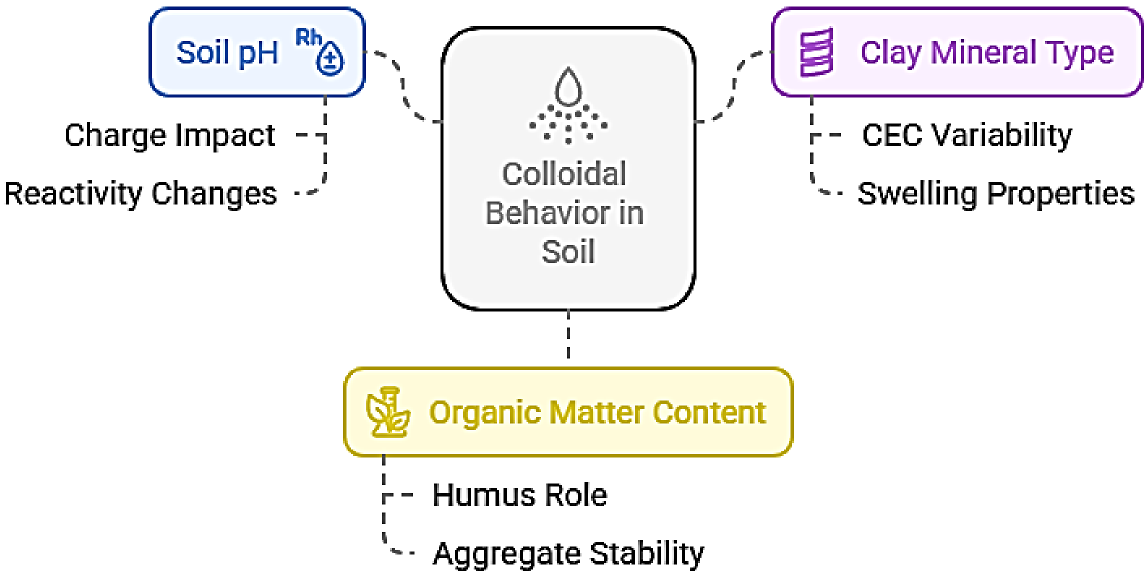
2. The Constituent Elements of Soil (Soil's Components)

2.3.4. Factors Influencing Colloidal Behavior

•**Soil pH:** Affects the charge and reactivity of colloids.

•**Clay Mineral Type:** Different clays have varying CEC and swelling properties.

•**Organic Matter Content:** Humus increases the CEC and improves the stability of soil aggregates



2. The Constituent Elements of Soil (Soil's Components)

The aggregation of colloids.

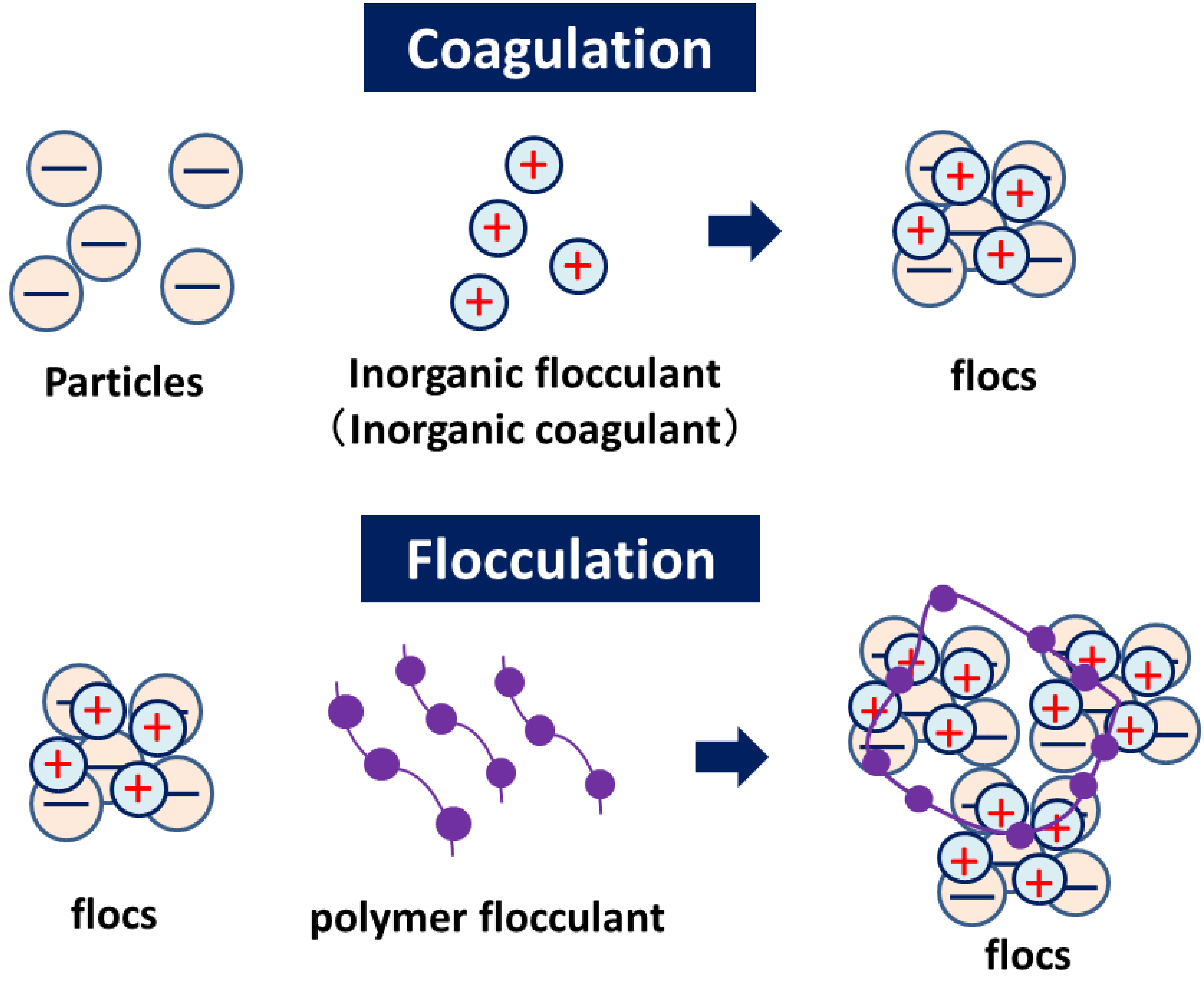
Aggregation is the phenomenon that leads to the assembly of colloidal particles.

According to the terminology used by Stumm and Morgan (1981), we distinguish:

1) **Aggregation due to electrolytes, called *Coagulation*** : This happens when electrolytes (charged ions like calcium or magnesium) help tiny soil particles (especially clay) come together and form larger clumps. These ions neutralize the negative charges on clay, reducing repulsion and allowing particles to stick together.

2) **Aggregation due to polymers, called *flocculation*.**: This occurs when **polymers** (large organic molecules, like humus) **act like glue**, linking soil particles into bigger aggregates. These polymers wrap around particles and hold them together, improving soil structure.

Both processes help create stable soil aggregates, which improve **aeration, drainage, and root growth**.


Coagulation
Particles
Inorganic flocculant
（Inorganic coagulant）
flocs
Flocculation
flocs
polymer flocculant
flocs

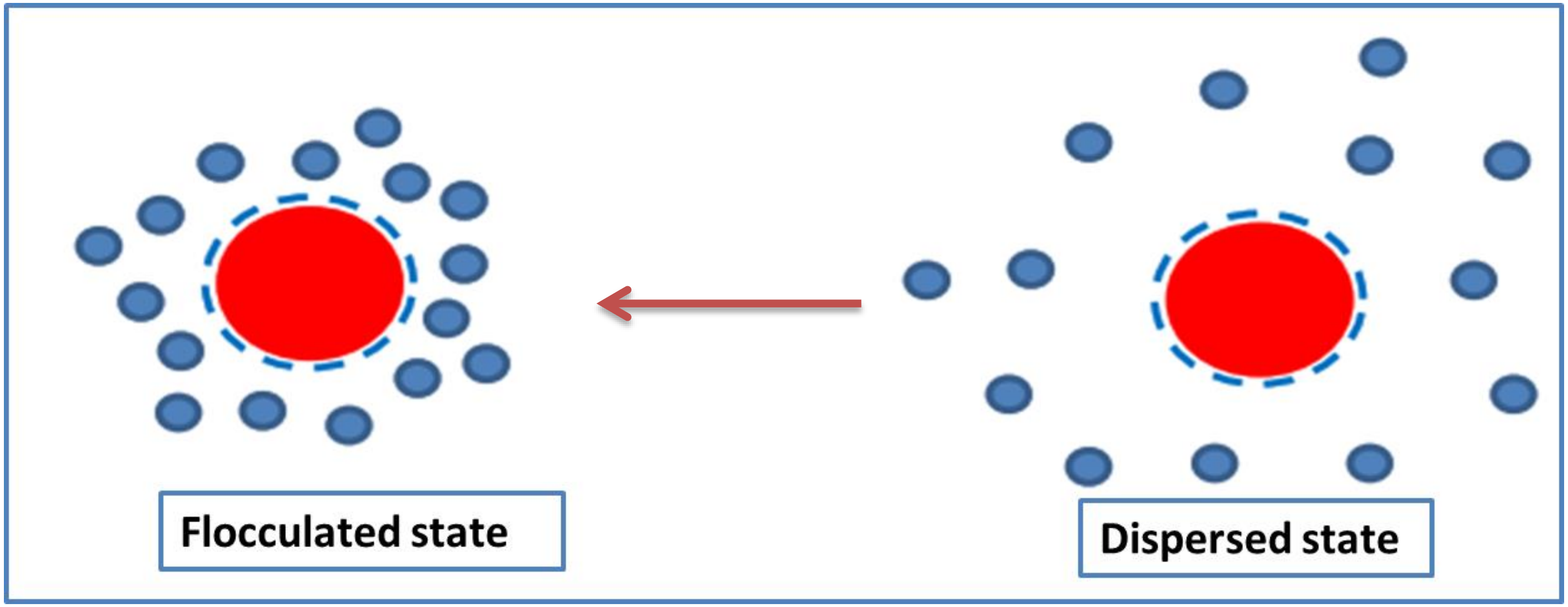
Inter-particle forces:

The evolution of colloids towards a dispersed state or, conversely, towards a flocculated state has a significant impact on stability, structure, and the particulate transport of matter. This evolution is driven by different forces acting between the particles.

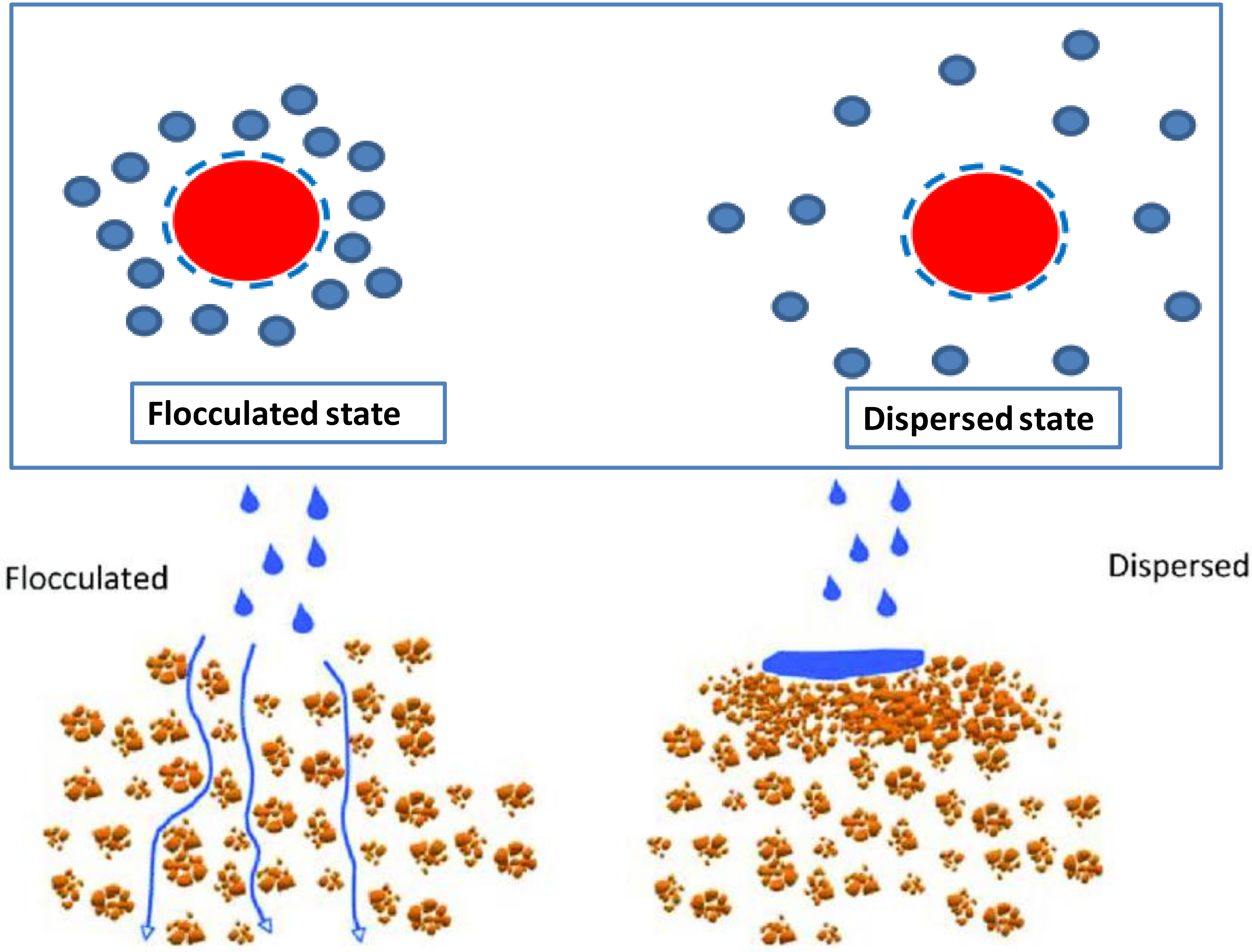
1) The force due to the **gravitational** field, which causes the sedimentation of particles.

2) Inter-particle forces:

- Van der Waals forces, which generate attraction.
- Electrostatic forces which can lead to either attraction or repulsion.



2. The Constituent Elements of Soil (Soil's Components)



2. The Constituent Elements of Soil (Soil's Components)

Another Types of Colloids:

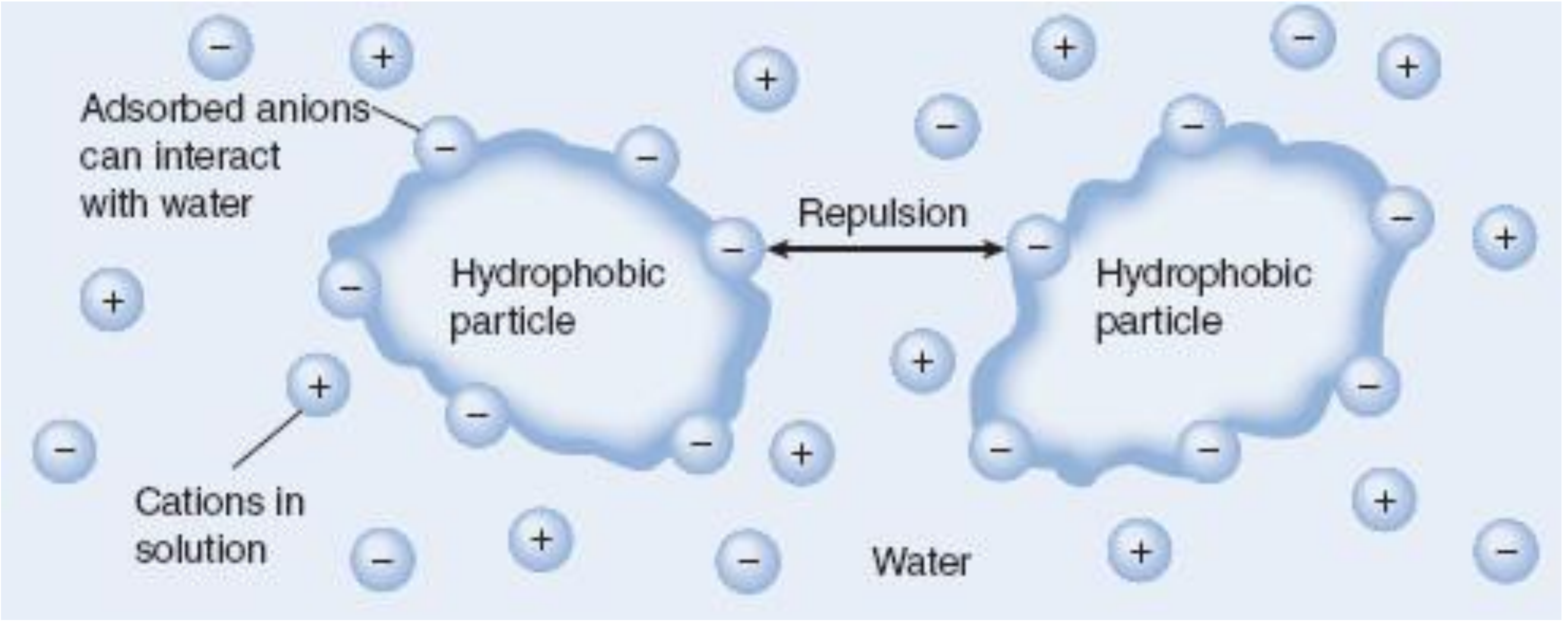
There are two types of colloids:

Hydrophilic Colloids ("Water-Loving")

•These colloids easily mix with water because they have special chemical groups (like **R-NH$_2$** and **R-OH**) that attract water molecules.

•They often come from organic matter and contribute to the color of water.

•They form **hydrogen bonds** with water, keeping them dispersed and stable in solution.



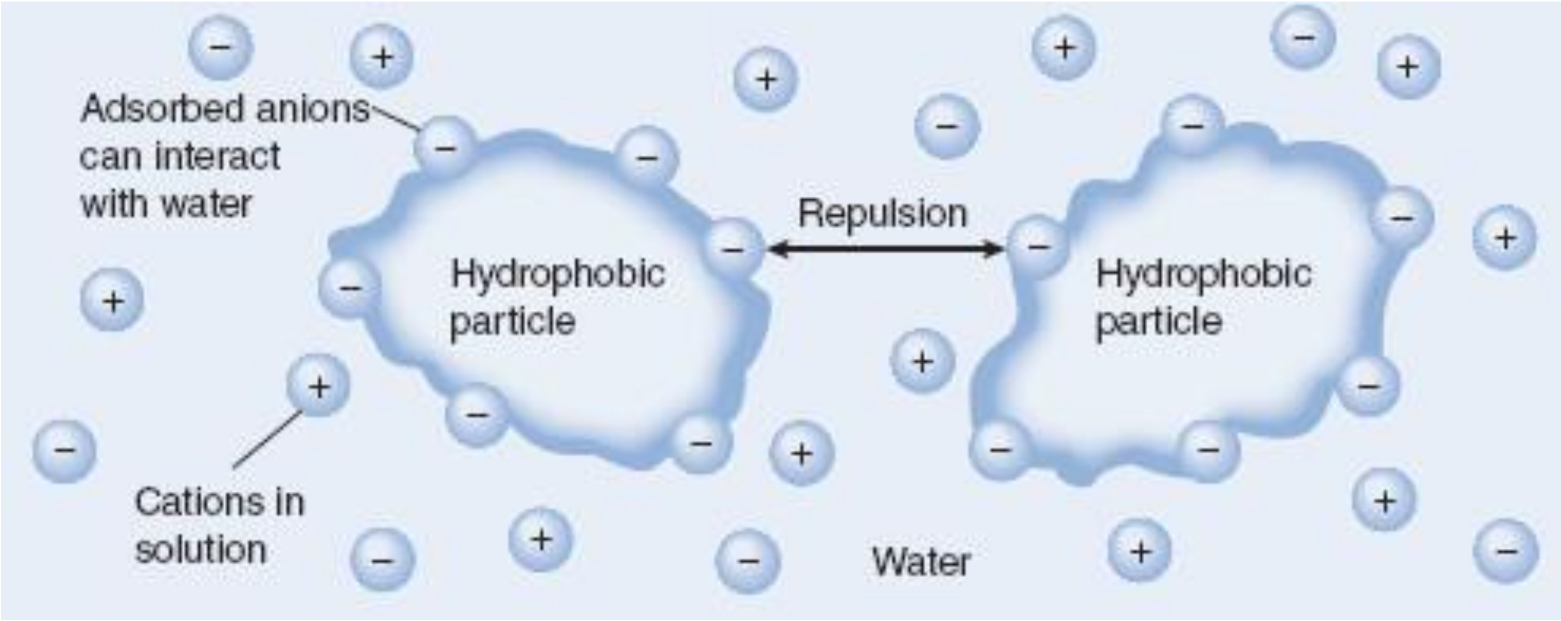
2. The Constituent Elements of Soil (Soil's Components)

Hydrophobic Colloids ("Water-Fearing")

These colloids **do not** mix well with water because their surfaces carry **electrical charges** that cause them to repel each other.

They are mostly of **mineral origin** (like clay particles).

Since they repel water, they don't dissolve easily and tend to stay separate unless something (like salts or organic compounds) helps them clump together



2. The Constituent Elements of Soil (Soil's Components)

2.4. Limestone

Limestone in the soil has a dual origin; it can originate from the parent rock or groundwater.

It plays two main roles in the soil:

- **A physicochemical role**: It acts as a binding agent in the soil.
- **A physiological role**: It contributes to plant nutrition.

Detection of Limestone in Soil: Limestone in the soil can be identified using two methods:

Field method: By reacting a strong acid (HCl) with a soil sample.

The stronger the effervescence, the richer the soil is in limestone.

Laboratory method: This method allows us to measure the amount of CO_2 released following the reaction of carbonates with 0.1N hydrochloric acid (HCl), according to the following reaction:

$$CaCO_3 + 2HCl \longrightarrow CO_2 + CaCl_2 + H_2o$$

2. The Constituent Elements of Soil (Soil’s Components)

The CO_2 content is estimated using Bernard's calcimeter. The higher the CO_2 content, the richer the soil is in limestone.

Forms of Limestone in Soil:

There are four distinct forms of limestone in the soil:

1. The Diffused Form: This refers to the heterogeneous distribution of limestone particles within a horizon or throughout the entire soil profile.

2. The Pseudomycelium Form: This consists of a deposit and a thin film of limestone particles around soil aggregates or along pore spaces.

3. The Nodular Form: Limestone stones can reach a diameter of up to 20 centimeters. There are two types of nodular forms:Coherent nodule (hard).Friable nodule, which can easily be reduced to powder. This form is the most dangerous for vegetation, as limestone particles in the soil can lead to toxicity.

4. Crusty Form: This is a compact slab that can exceed one meter in thickness, occupying a single horizon or the entire soil profile.

2. The Constituent Elements of Soil (Soil's Components)

The CO_2 content is estimated using Bernard's calcimeter. The higher the CO_2 content, the richer the soil is in limestone.

Distribution of Limestone in Different Regions

In **Mediterranean, arid, and semi-arid zones**,

limestone accumulation generally occurs in **nodular and crusty forms**.

This is due to low moisture infiltration and high evaporation,

which promotes the upward movement and accumulation of limestone particles within the soil profile.

In **temperate zones**, characterized by **high rainfall**,

limestone accumulation occurs **below a depth of one meter**,

primarily in **diffused and pseudomycelium forms**.

Table 01 : Classification of Calcareous Soils Based on Limestone Content

Class	Calcium carbonate ($CaCO_3$) content:
Very weakly calcareous soils	$CaCO_3$ content < 2%
Weakly calcareous soils	$CaCO_3$ content **between 2% and 10%**
Moderately calcareous soils	$CaCO_3$ content **between 10% and 25%**
Strongly calcareous soils	$CaCO_3$ content **between 25% and 50%**
Very strongly calcareous soils	$CaCO_3$ content **> 50%**

Active limestone refers to the fine particles present in the soil solution. It can be determined using **Drouinéau's method.**

Importance of Active Limestone

Active limestone plays a crucial role in soil properties and plant growth. Its significance can be summarized as follows

1. Soil Structure and Stability

Active limestone acts as a **cementing agent**, improving **soil aggregation** and **stability**.

It enhances **soil porosity**, which facilitates **water infiltration and aeration**.

2. Soil pH Regulation

It helps **neutralize soil acidity**, maintaining a suitable **pH** for microbial activity and plant growth.

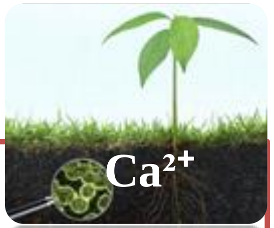
In alkaline soils, excessive active limestone can lead to **iron and phosphorus deficiencies** due to reduced nutrient availability

3. Nutrient Availability and Plant Nutrition

Provides an essential source of **calcium (Ca^{2+})**, which is vital for **cell wall development** and **enzyme activation** in plants.

Affects the **availability of phosphorus (P), magnesium (Mg), and trace elements** in the soil.

High active limestone levels can **induce chlorosis** in sensitive plants due to **iron immobilization**.



4. Impact on Microbial Activity

Active limestone influences **soil microbial communities**, particularly those involved in **organic matter decomposition** and **nutrient cycling**.

It can enhance the activity of **beneficial microorganisms**, such as nitrogen-fixing bacteria in **leguminous crops**.

5. Agricultural Implications

Soils with moderate active limestone content are beneficial for crops requiring **calcareous conditions** (e.g., wheat, barley, alfalfa).

Excessive active limestone can be **detrimental** to plants that prefer acidic soils, such as **blueberries, potatoes, and some conifers**.

Understanding and managing **active limestone levels** is essential for **soil fertility, crop productivity, and sustainable land management**.

Table 02 : Limestone Vs Active limestone

Feature	Limestone	Active Limestone
Definition	Total amount of calcium carbonate ($CaCO_3$) present in the soil.	The fine, reactive fraction of calcium carbonate available in the soil solution.
Role in Soil	Contributes to soil structure and overall carbonate content.	Influences soil pH, nutrient availability, and plant nutrition.
Reactivity	Less reactive, primarily exists in solid form.	Highly reactive, affecting chemical reactions in the soil.
Determination	Measured as total $CaCO_3$ content.	Determined using **Drouinéau's method** with ammonium oxalate.
Agricultural Impact	Provides a stable calcium source but may not affect immediate soil chemistry.	Directly affects nutrient solubility, microbial activity, and can induce **iron chlorosis** in sensitive plants.