

1.The physical and chemical properties of soil

The physical and chemical properties of soil determine its fertility and ability to support plant life. Physical properties include texture (particle size), structure, and porosity, which affect aeration, drainage, and water retention. Chemical properties include pH, cation exchange capacity (CEC), organic matter content, and nutrient levels (such as nitrogen and phosphorus).

1.1 Physical properties

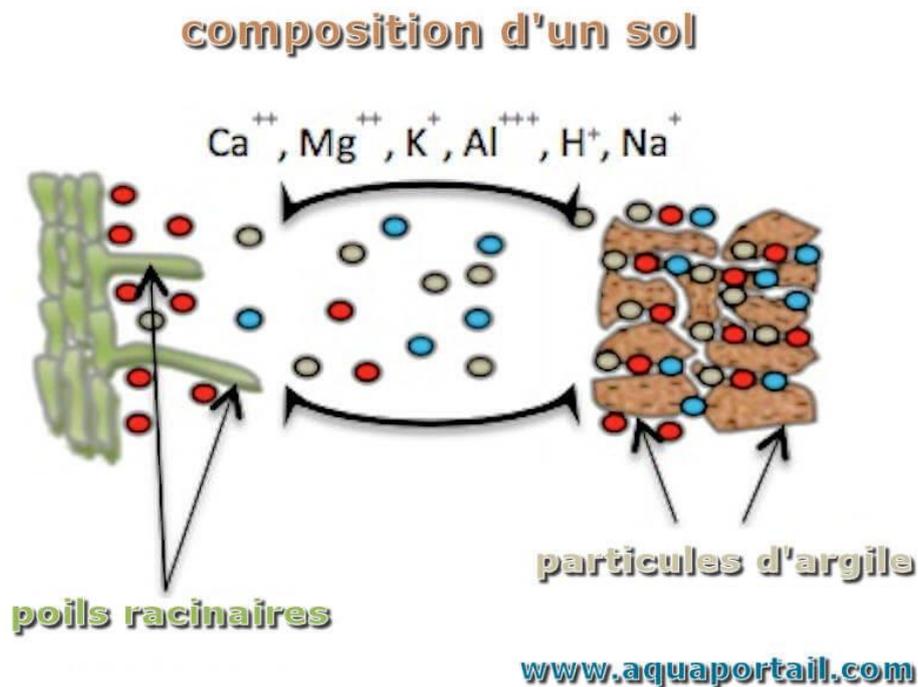
- **Texture:** Defined by the proportion of sand, silt, and clay. It influences water retention capacity and soil workability.
- **Structure:** The organization of soil particles that creates pores. Good structure promotes aeration, drainage, and root growth.
- **Porosity:** The size and arrangement of pores. It determines the amount of water and oxygen available to microorganisms and plants.

1.2 Chemical properties

- **pH:** Measures the acidity or alkalinity of the soil, affecting the availability of nutrients to plants.
- **Cation exchange capacity (CEC):** The soil's ability to retain nutrient cations, which is a key indicator of its fertility.
- **Organic matter:** Improves structure, water retention, and CEC, while providing nutrients.
- **Nutrient content:** The concentration of elements essential for plant growth, such as nitrogen, phosphorus, potassium, and trace elements.
- **Electrical conductivity (EC):** Indicates soil salinity, which can be detrimental to plant growth if too high.

2 Cation exchange capacity (CEC)

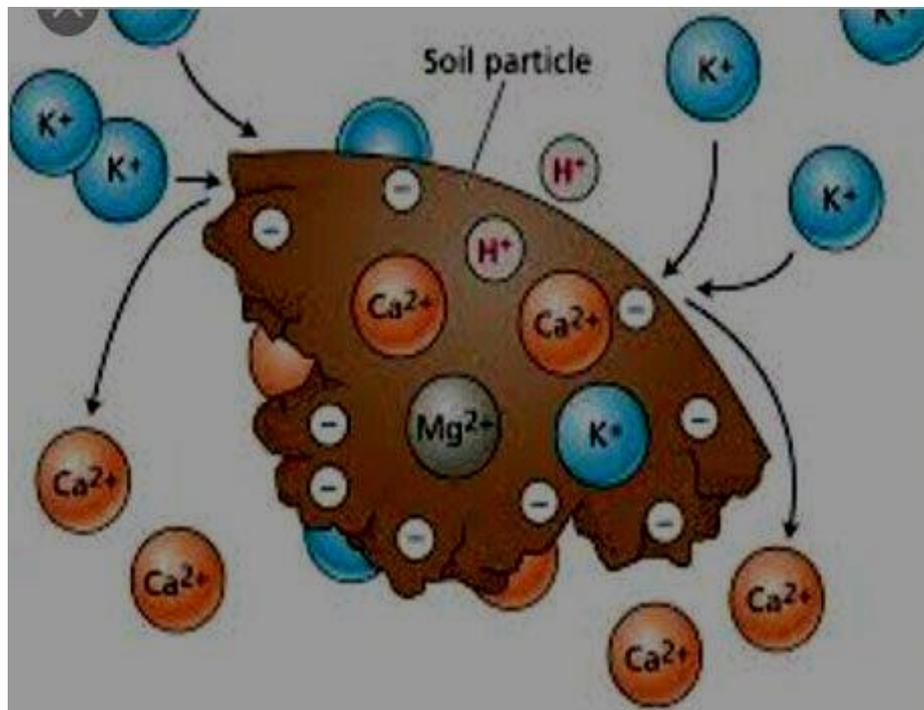
Is the total capacity of a soil to hold exchangeable cations. This influences the soil's ability to retain essential nutrients and provides a buffer against soil acidification. Soils with a higher clay fraction tend to have a higher CEC. Organic matter has a very high CEC.



Cation Exchange Capacity (CEC) is a soil's ability to hold onto positively charged ions (cations) like nutrients (Ca^{2+} , Mg^{2+} , K^+ , NH_4^+) and prevent them from washing away, acting as a nutrient storehouse for plants. High CEC, often found in soils with lots of clay and organic matter (humus), means better nutrient retention, while low CEC (sandy soils) leads to quicker nutrient loss and potential deficiencies. Measured in meq/100g or cmolc/kg, CEC reflects soil fertility, structure, and buffering against acidification, impacting irrigation and fertilizer needs.

1.2.1 How CEC Works

- **Negative Charges:** Clay minerals and organic matter (humus) have net negative charges on their surfaces.
- **Cation Attraction:** These negative sites attract and hold positive ions (cations) like essential nutrients (Ca^{2+} , Mg^{2+} , K^{+}) and some harmful ones (Al^{3+} , H^{+}).
- **Exchange:** When plant roots absorb cations, other cations in the soil water can easily swap places with those held on the soil particles, making nutrients available.



1.2.2. What Influences CEC?

- **Soil Texture:** Clay particles have a large surface area, increasing CEC; sandy soils have little CEC.
- **Organic Matter:** Humus significantly boosts CEC because of its high negative charge.
- **Soil pH:** Affects the net charge of soil particles and the types of cations held.

1.2.3. Why CEC Matters

- **Nutrient Retention:** High CEC soils hold more nutrients, reducing leaching.
- **Fertility:** A key indicator of a soil's potential to supply nutrients.
- **Buffering:** Protects against rapid pH changes (acidification).
- **Management:** Influences irrigation (sandy soils need frequent, light watering) and fertilizer application rates (higher CEC needs less frequent, heavier doses).

1.2.4. Measuring CEC

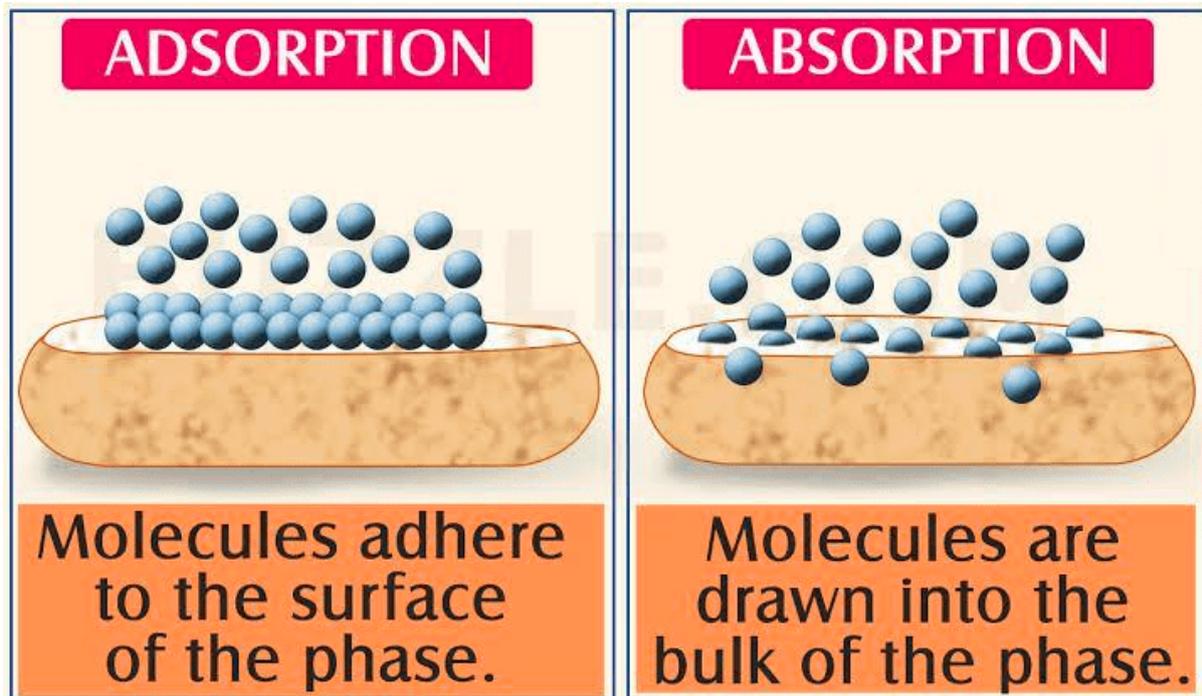
- Expressed as **milliequivalents (meq) per 100 grams of soil** or **centimoles of charge per kilogram (cmolc/kg)**.

How to Improve CEC

- Add organic matter (compost, manure) to increase clay content and humus.
- Get regular soil tests to understand your specific soil's CEC.

3. Absorption and exchange phenomena

Are processes involving the transfer of matter or energy between two phases, where absorption is a volumetric phenomenon (like a sponge absorbing water) and exchange is a more general term that includes processes such as gas exchange in the lungs (oxygen in the blood) or ion exchange in soils. Exchanges can also be chemical (reactive) or physical (non-reactive).

**Absorption and exchange phenomena in soil**

are key chemical and physical processes whereby ions in soil solutions are bound to negatively charged particles (clay and organic matter), creating a dynamic equilibrium. This process allows plants to access nutrients by exchanging ions, and is characterized by cation exchange capacity (CEC), which measures the soil's ability to retain and release these nutrients.

Absorption and ion exchange

- The adsorbing complex: The surfaces of clay and organic matter (the clay-humic complex) are negatively charged and attract cations (positive ions) present in the soil solution, such as

Ca^{2+} cap Ca raised to the 2 plus power Ca^{2+}

Mg^{2+} cap Mg raised to the 2 plus power Mg^{2+}

K^{+} cap K raised to the positive power K^{+}

Na^{+} cap Na raised to the positive power Na^{+}

H^{+} cap H raised to the positive power H^{+} et

Al^{3+} cap Al raised to the 3 plus power Al^{3+}

Dynamic equilibrium: There is a constant equilibrium between the ions on the adsorbent complex and those in the soil solution.

- Desorption and adsorption: When plants absorb nutrients, the cations in the soil solution decrease. To compensate, the adsorbent complex releases cations (desorption), which are replaced by others that are absorbed by the roots. Conversely, the addition of nutrients through fertilizers increases the concentration of ions in the solution, leading to increased fixation of these ions on the adsorbent complex (adsorption).

Anion exchange capacity (AEC) is the amount of anions that a material, such as an ion exchange resin or soil, can retain per unit weight or volume. It is the opposite of cation exchange capacity (CEC), which is the capacity of soil to retain positive cations. AEC is an important measure in water treatment and chemical analysis processes.

4. Nutrients in the soil

Soil nutrients are essential elements like **Nitrogen (N), Phosphorus (P), and Potassium (K)** (NPK), plus secondary nutrients (Calcium, Magnesium, Sulfur) and micronutrients (Iron, Zinc, etc.), that plants absorb from the soil for growth, with NPK being the most critical for development, supporting leafy growth, roots, and blooms, respectively, all derived from decomposing organic matter or weathered minerals.

Major Nutrients (Macronutrients)

These are needed in large amounts.

- **Nitrogen (N):** Key for leafy growth and green color.
- **Phosphorus (P):** Essential for root, flower, and fruit development.
- **Potassium (K):** Important for overall plant health, water regulation, and fruit quality.

Secondary Nutrients

Needed in moderate amounts.

- **Calcium (Ca):** Supports cell walls and development.
- **Magnesium (Mg):** Central to chlorophyll production (photosynthesis).
- **Sulfur (S):** Aids in protein and enzyme formation.

Micronutrients (Trace Elements)

Needed in very small quantities but still vital.

- Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B), Molybdenum (Mo), Chlorine (Cl), and Nickel (Ni).

Where They Come From

- Plants get most nutrients (except Carbon, Hydrogen, Oxygen from air/water) from the soil.
- Nutrients originate from weathered minerals and decomposing organic matter (like compost, dead plants, animals).

Why They Matter

- **Soil Fertility:** Nutrients directly impact how fertile soil is for growing.
- **Plant Health:** Deficiencies lead to poor growth, discoloration (yellowing leaves), and reduced yield.
- **Soil pH:** Soil acidity or alkalinity (pH) affects how well plants can absorb these nutrients, even if they are present.

4.1. Soil nutrients

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CHAPTER 2 : Characterization of the physical, chemical, and biological properties of soil

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4.2. Plant nutrition

Plant nutrition is how plants get essential elements (like Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, Potassium, etc.) from air, water, and soil for growth, using photosynthesis for energy, with nutrients grouped as macronutrients (needed in large amounts) and micronutrients (needed in small amounts) to support metabolism, stress resistance, and reproduction. These nutrients, supplied via soil or fertilizer, are crucial for healthy life cycles, with deficiencies or excesses causing problems.

How Plants Get Nutrients

- **From Air:** Carbon (as CO₂) and Oxygen.
- **From Water:** Hydrogen and Oxygen.
- **From Soil:** Minerals and other elements absorbed through roots.

Key Essential Nutrients

Plants need at least 16 essential elements, categorized by the amounts needed:

- **Macronutrients (Major):** Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S).

- **Micronutrients (Trace Elements):** Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B), Molybdenum (Mo), Chlorine (Cl), and sometimes Nickel (Ni).

Why They're Important

- **Energy & Structure:** C, H, O form carbohydrates (energy), while others build proteins, cell walls, and enzymes.
- **Metabolic Functions:** Nutrients like N, P, K are vital for photosynthesis, respiration, and DNA.
- **Stress Resistance:** Proper nutrition boosts a plant's ability to fight diseases and environmental stress.

Supply & Management

- **Soil:** Provides support, water, and many essential minerals.
- **Fertilizers:** Organic (manure) or synthetic (NPK blends) provide nutrients missing in the soil.
- **Nitrogen Fixation:** Legumes form root partnerships with bacteria to convert atmospheric nitrogen into usable forms.

2.5.Oligo-elements

A trace element is a mineral that is essential for life, present in very small quantities (in trace amounts) in the body, but vital for many biological functions, such as iron, zinc, copper, or selenium. The body cannot produce them itself and must obtain them through a varied and balanced diet. Although essential, excessive or insufficient intake can be harmful, hence the importance of moderation.

Key trace elements and their roles

Iron (Fe): Essential for chlorophyll, respiration, and nitrogen fixation.

Manganese (Mn): Involved in photosynthesis and the synthesis of proteins and chlorophyll.

Zinc (Zn): Helps with protein synthesis, auxin (growth hormone) metabolism, and protects against stress.

Boron (B): Crucial for cell wall formation, root development, and fertile pollen production.

Copper (Cu): Linked to cellular respiration, photosynthesis, and chlorophyll and protein synthesis.

Molybdenum (Mo): Associated with iron and phosphorus metabolism and nitrogen fixation.

Sulfur (S): Important for protein and chlorophyll formation.

Importance and consequences of deficiencies

Essential: Although needed in small doses, their absence blocks major physiological processes.

Symptoms: Yellowing of young leaves (iron), small leaves and rosette (zinc), pollen sterility (copper), slowed growth, flower abortion, deformed fruit.

Prevention: Targeted inputs via appropriate fertilizers are necessary to prevent these deficiencies and ensure good yields.

5. Pedogenesis

Pedogenesis is the set of processes that interact with each other to result in the formation, transformation, or differentiation of soils.

This soil formation provides an important ecosystem support service.

Traditionally, six major factors are considered to contribute to soil formation, regardless of the climate in which they developed. Figure 1 shows these different factors of pedogenesis as well as their interrelationships. For example, the existence of parent materials depends closely on the combination of rock type and relief position; soils have a significant impact on vegetation, but vegetation in turn influences soils through the formation of humus. A final example: while it is clear that the general climate strongly determines vegetation, vegetation in turn influences the local climate (cooler and more humid mesoclimate in a forest area).

Be careful with the word “humus,” an ambiguous term with various meanings. Comifer (French Committee for the Study and Development of Rational Fertilization) has given it this definition: “all the organic constituents of the soil that no longer have any identifiable biological organization (plant, animal, bacterial, etc.) and that are the result of the slow biochemical evolution of various organic materials in the soil.” For this narrow meaning, scientists now prefer the term “soil organic matter” (SOM).

Be aware of the other meanings of this word:

in everyday language, humus is “blackish soil formed by the decomposition of plants” (Petit Robert dictionary);

in pedology, it incorrectly referred to all surface horizons that are entirely organic and organomineral, containing a lot of organic matter. The term “humic episol” is now preferred.

Soil classification

Soil classification involves grouping soils with similar ranges of properties (chemical, physical, and biological) into units that can be geo-referenced and mapped. Soils are a very complex natural resource, much more so than air and water.

Soils contain all natural chemical elements and combine solid, liquid, and gaseous states simultaneously. Furthermore, the number of physical, chemical, and biological characteristics and their combinations are almost infinite. It is therefore not surprising that many different approaches have been proposed to achieve a sensible grouping of different soils. In addition, soil classification systems have been developed for different purposes:

- Soil Taxonomy for interpreting soil studies;
- FAO legend for representing global soil distribution and geography;
- Global reference base for facilitating correlations between different soil classification systems.

Three distinct stages can be identified to illustrate the development of soil classification systems. The oldest soil classification systems (Russia, USDA 1938) focused on the environment and soil-forming factors to classify soils into zonal soils (determined by climate and vegetation) and azonous and intrazonal soils (determined by parent material and development time). The difference between azonous and intrazonal soils was made on the basis of soil profile development. Further development focused on processes occurring within the soil itself (such as ferallitization, salinization, leaching, and accumulation, etc.). These processes have been broadly characterized by soil properties. A good example of this latter approach is the French classification system (CPCS, 1967). Modern soil classification began with the publication of the 7th edition of the USDA Soil Taxonomy, in which precisely defined and quantified soil properties, either individually or in combination, were used to define “diagnostic horizons.” These were in turn used to define broad soil classes.

Definition of a soil map

A soil map is a **geographical representation showing the distribution of different soil types and their key characteristics (like texture, pH, and organic matter) across a specific area**, created from detailed field surveys to help with land management, planning, and environmental protection by grouping soils into "map units" with similar properties and uses. These maps reveal soil variations, helping users understand land potential for agriculture, construction, or conservation, and can range from traditional paper versions to detailed digital models.

Key components

- **Spatial Distribution:** Shows where different soil types are located.
- **Soil Properties:** Includes data on layers (horizons), texture, color, pH, and organic content.
- **Map Units:** Areas delineated as having similar soil characteristics, often described in an accompanying report.

How they are made

- **Field Surveys:** Soil scientists dig pits and observe soil profiles across the landscape.
- **Classification:** Soils are described and classified based on their properties.
- **Mapping:** Boundaries are drawn between different soil types.

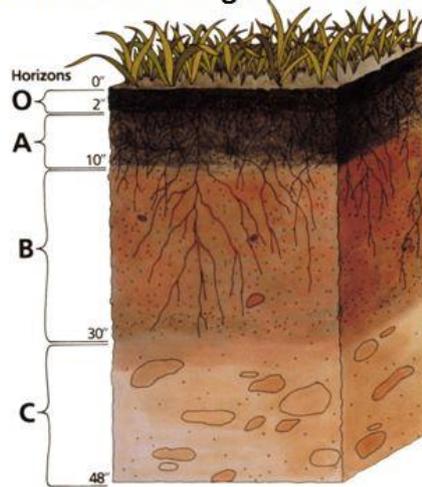
Common uses

- **Land Evaluation:** Assessing suitability for farming, forestry, or development.
- **Environmental Planning:** Monitoring erosion, water quality, and conservation efforts.
- **Agricultural Extension:** Guiding nutrient management and crop selection.

Soil profile

Soil Profile is a vertical sequence of recognizable horizons (pedologists use to distinguish from layer, which is used in geology and sedimentology) resulting from the development of a soil (pedogenic processes) over time. A hypothetical profile would comprise: organic horizons (H and O) and mineral (with some organic matter) horizons (A, E, B), and C (considered by some pedologists as a layer), and R (rock) layer. (**Guidelines for soil description fourth edition**)

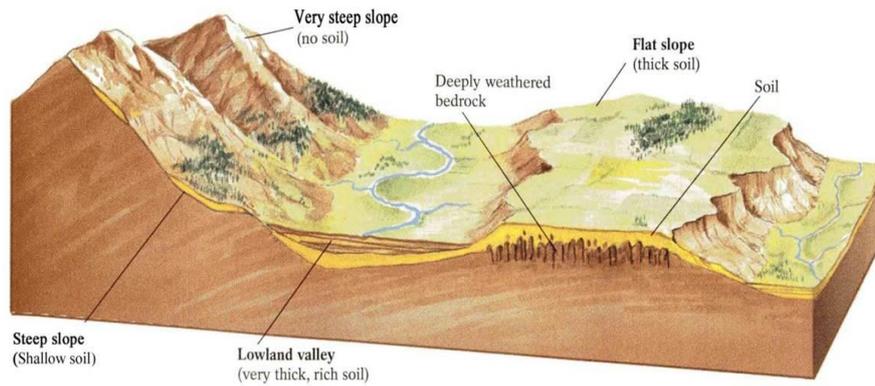
Click on the image to start a video.



Source: USDA Natural Resources Conservation Service.

The landscape relationship

Soil varies in space since there are different climatic zones in the world, it will have influence on soil forming processes. In dry areas, chemical weathering will be very slow resulting in slower soil formation. In wet tropics, chemical weathering will be much faster, this results in deeper soils. Also there will be plenty of organic matter, which will influence soil development. Another reason is that soil parent materials are different from one another because of differences in their mineral composition it is logical that soils derived from one parent material differ from other soils that are developed from other parent materials.



Soil is the outermost layer of earth. It is derived from its parent materials (rocks). It is a natural body created by soil forming factors, which are climate (precipitation, temperature), relief (elevation, slope), organisms (flora and fauna) and time (thousands of years).

Since parent materials can be different from one another in its mineral composition, it is logical that soils developed from one parent material can differ from other soils developed from another parent material.

In addition, topography plays a very important role in soil formation. Soil in the mountainous areas can be different from soils in the flat areas. In figure 1 a schematic three dimensional view of landscape and soil occurrences is shown. Soils on the steep slopes are generally thin or nonexistent because water required for chemical weathering runs off such slopes and because any soil that does accumulate would wash away down the slopes. In the lowland valleys soils tend to be thicker, where water and loose material transported from upland area accumulate. Generally speaking soil tends to be thicker in lowland flat areas. In addition, the availability of water in lowland areas helps in chemical weathering of bedrock. In very drier areas soil formation is generally very slow.

Soil variability

Soils have properties (physical and chemical) that result from the combined action of the factors that constitute them. Physical properties, such as depth, particle size, structure, and porosity, determine variations in moisture and water

circulation in the soil. Chemical properties, such as pH, organic matter content, and nutrients (N, P, K), determine the soil's nutrient content necessary for plant growth.

Soils exhibit continuous variability within a single plot and between farms. This heterogeneity, studied by Burrough (1993), can be explained by the action and interaction of different factors at various spatial and temporal scales.

Characterizing this spatio-temporal variability is essential for a better understanding of the complex relationships between soil properties, environmental factors, and land use systems (Yemefack, 2004). Soils differ significantly at the regional scale (Brejda et al., 2000), and high variability is to be expected due to the diversity of pedogenic factors.

At the plot scale, soil properties are influenced by human activities such as land use and management practices (Kotto-Same et al., 1997; Nye and Greenland, 1960). Soil performance and crop yields can be affected.