People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
University of Amar Telidji - Laghouat Faculty of Sciences
Department of Agricultural Sciences

Course copy: Master's 1 Plant Protection

Soil biology

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Foreword

Soil is a precious and fragile resource that is essential for life on Earth. It supports plant growth, provides water and nutrients, and filters pollutants. Soil biology is the study of the living organisms found in soil and their interactions with the soil environment. Understanding soil biology is essential for sustainably managing soils and protecting this precious environment.

This course aims to provide students with a comprehensive introduction to soil biology. Students will cover the following topics: The nature and properties of soil; Soil organisms; Biological processes in soil; Soil health management.

This course is designed for first-year Master's students in Agronomy, specializing in plant protection.

The course will be delivered through lectures, online courses, and field trips. Students will be evaluated based on their assignments, exams, and online participation.

A number of resources will be available to students in this course, including: A textbook, handouts, online videos.

Soil biology is a fascinating and important field that has implications for a wide range of environmental issues. This course will provide students with a solid foundation in understanding soil biology and prepare them for further studies or a career in this field.

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Introduction

Soil biology is the study of the teeming life found beneath our feet! Also known as the edaphon, this encompasses all organisms that make soil their home, either full-time or part-time. This includes tiny creatures such as bacteria, microscopic fungi, and nematodes (roundworms), as well as larger organisms like earthworms, mites, and insects. All these organisms play a vital role in soil health. For instance, they decompose dead organic matter (like leaves and twigs) into nutrients that plants can absorb. They also help aerate the soil and retain water. In short, soil biology is a fascinating science that helps us understand how the living soil beneath our feet is essential for life on Earth.

Soil inhabitants, from microfauna to earthworms, play many essential roles in agriculture. Their actions can be summarized in three key points:

1. Decomposition and plant nutrition: They are the recycling champions! Soil bacteria and fungi break down dead organic matter (leaves, stems, roots) into smaller, plant-assimilable elements. Their feast becomes the nutrient menu for crops.
2. Soil structure improvement: By burrowing tunnels, earthworms and other soil inhabitants aerate the soil, allowing for better air and water circulation. Additionally, their castings form stable aggregates that improve soil structure and its ability to retain water.
3. Maintaining soil health: The diversity of soil inhabitants creates a living and resilient ecosystem. Some organisms regulate the populations of others, preventing the proliferation of pathogens. This biodiversity also contributes to erosion control.

Chapter 01: The Soil

1.1 Definition of Soil

Soil is a loose layer of Earth's surface, formed from the weathering of bedrock. It is covered by vegetation, which draws water and dissolved minerals from it. When vegetation dies, the plant debris forms a litter on the surface.

1.2 Components of Soil

Soils are composed of four main components. The ideal topsoil is often described as containing approximately 25% water, 25% air, 45% minerals, and 5% organic matter by volume (Fig. 1). These elements interact together to form a living and dynamic ecosystem.

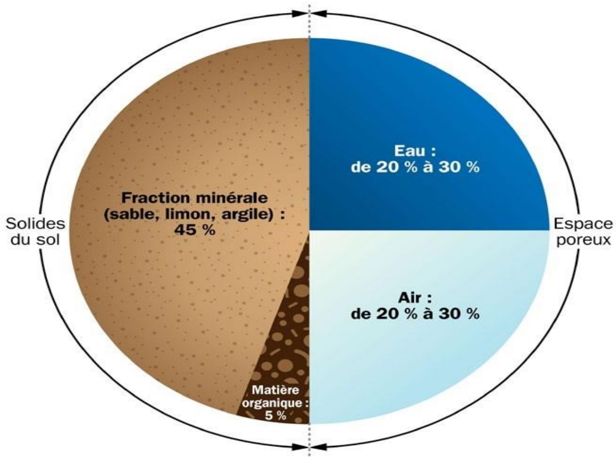

Figure 01: Components of Soil

In summary, soil is a mixture of minerals, organic matter, water, air, and a multitude of living organisms. It is a vital resource for plant growth and a key component of terrestrial ecosystems.

1.3 Soil Fertility

Soil fertility is the capacity of a soil to supply all the nutrients essential to crop growth in adequate amounts and proportions for sustained high yields. The nature and physical properties of a soil, notably texture, porosity, and mineral composition, determine its fertility.

1.4 Soil Horizons

Soil horizons are distinct horizontal layers that form naturally over time. The composition and thickness of these horizons vary depending on factors such as climate, vegetation, drainage, and parent material. A typical soil profile can include several horizons, although not all are always present.

Here are the main soil horizons and their functions (Fig. 2):

- O horizon (Organic): This is the uppermost layer of soil, composed primarily of decomposing organic matter, such as dead leaves, twigs, and animal remains. This layer is rich in biological activity and is essential for soil fertility.
- A horizon (Eluviated): Also called the topsoil, this is the zone of the soil where most plant roots grow. It is generally dark in color and contains a mixture of decomposed organic matter, minerals, and other living organisms.
- E horizon (Elluviated): Also known as the zone of leaching, this layer has lost some of its clays and iron and aluminum oxides, which have been leached downward in the soil profile. It may appear lighter in color than the A horizon.
- B horizon (Illuviated): This layer is enriched with clays, iron and aluminum oxides leached from the overlying E horizon. It may also contain carbonates and other salts accumulated by water moving through the soil.
- C horizon (Parent material): This layer is composed of the weathered rock material from which the soil formed. It shows little soil development and generally does not contain plant roots.
- R horizon (Bedrock): This is the solid layer of unweathered rock that lies beneath the soil.

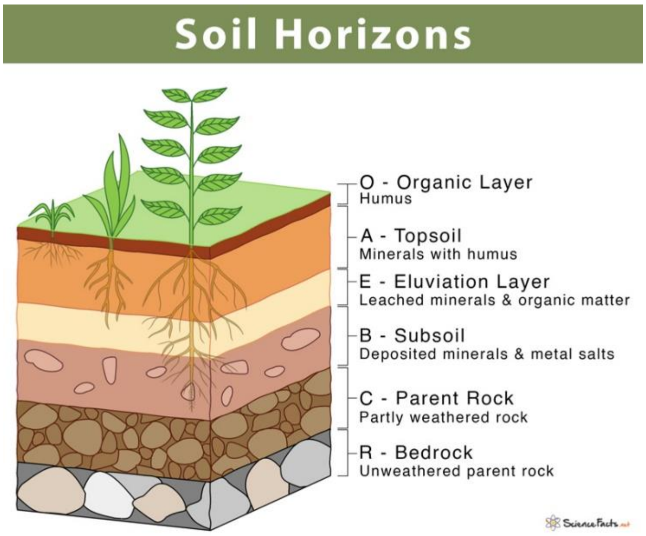

Figure 02: Soil Horizons

It's important to note that these horizons are not always as distinct and can vary considerably in thickness and composition. However, understanding soil horizons is essential for pedologists (soil scientists) who study soil formation, classification, and mapping.

Soil is also structured in horizontal layers called horizons, reflecting its history and development.

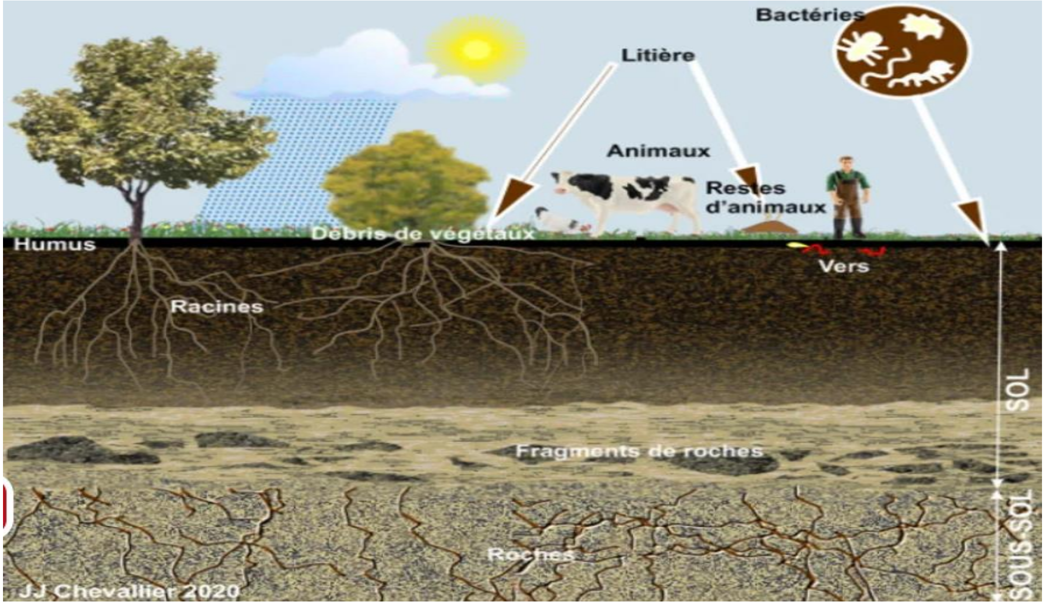

Figure 03: Plant-Soil Relationship

1.5 Soil Chemistry

Soil chemistry is a fascinating field that studies the chemical composition of soil, the chemical reactions that occur within it, and the resulting chemical properties. It is essential for understanding soil health and its ability to support plant growth.

1.5.1 Chemical Properties of Soil

- pH: Indicates the acidity or alkalinity of the soil. A pH of 7 is neutral, a pH below 7 is acidic, and a pH above 7 is alkaline. Most plants prefer a slightly acidic to neutral soil.
- Cation Exchange Capacity (CEC): Determines the soil's ability to hold on to cations (positively charged ions). A soil with a high CEC is more fertile because it can hold more nutrients (Fig. 4).

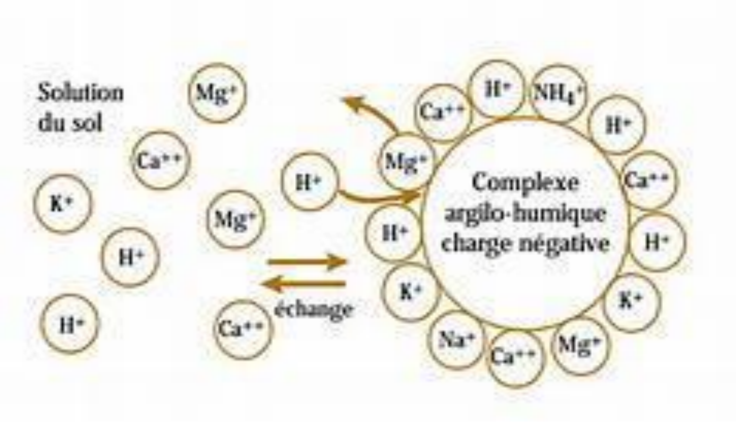

Figure 04: Cation Exchange Capacity (CEC)

- Organic matter: Determined by the amount of decomposing plant and animal matter in the soil. Organic matter is essential for soil fertility as it improves soil structure, retains water, and provides nutrients to plants.
- Salinity: Determines the concentration of soluble salts in the soil. High salinity can be toxic to plants.
- Soil pH: Soil pH affects the availability of nutrients and the activity of microorganisms.

By managing soil chemistry, farmers and gardeners can improve soil health and plant growth.

1.6 Soil Physics

Soil physics is a fascinating field that studies the physical properties of soil, such as its texture, structure, porosity, and permeability. These properties influence the soil's ability to store water and air, support plant growth, and resist erosion.

1.6.1 Main physical properties of soil

- Texture: Determines the proportion of sand, silt, and clay in the soil (Fig. 5). Texture affects the soil's ability to hold water and nutrients, as well as its permeability (Fig. 6).

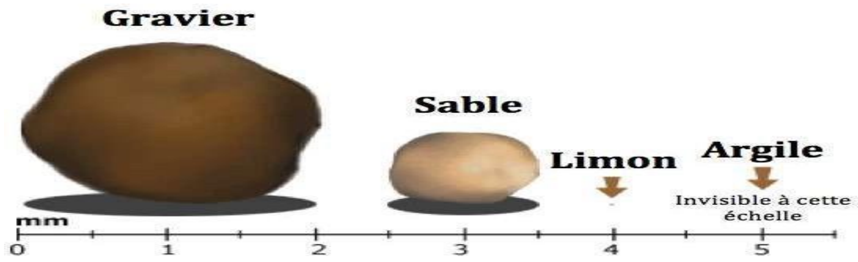

Figure 05: the mineralogical fractions of the soil

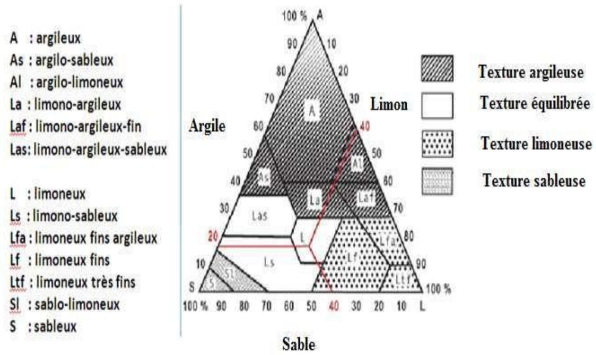

Figure 06: Textural Triangle

- Structure: Refers to the arrangement of soil particles into aggregates. A good structure allows for good water and air infiltration and promotes root growth (Fig. 7).
- Porosity: Determines the proportion of pore space in the soil. Porosity affects the soil's ability to store water and air.
- Permeability: Determines the rate at which water infiltrates into the soil. Permeability affects soil drainage and the risk of erosion.

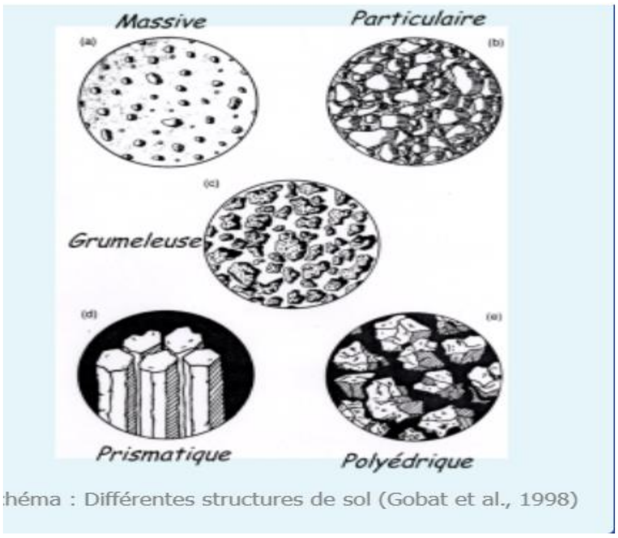

Figure 07: Different Soil Structures

1.7 The Rhizosphere

The rhizosphere is a fascinating and dynamic zone of soil located immediately adjacent to plant roots (Fig. 8). Plant roots constantly release sugars, organic acids, and other chemicals into the soil. These root exudates create a feast for soil microorganisms, including bacteria, fungi, and nematodes. In response to this influx of food, the microbial population in the rhizosphere becomes much denser and more diverse than in the bulk soil. The rhizosphere plays a crucial role in plant health and the productivity of terrestrial ecosystems.

By managing rhizosphere health, farmers and gardeners can improve plant health and soil productivity.

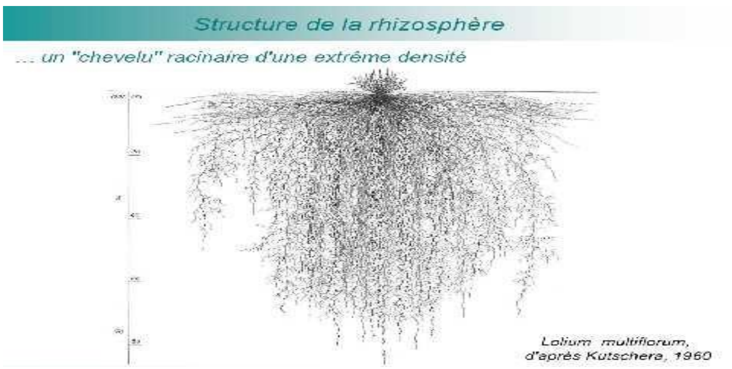

Figure 08: Structure of the rhizosphere

Chapter 02: Biological Constituents of Soil

Soil is a complex and dynamic ecosystem composed of mineral matter, water, and air, but it is also a veritable reservoir of living organisms (Fig. 09). Soil biological life is of paramount importance for soil fertility and plant growth. By managing soil biological life, farmers and gardeners can improve soil health and agricultural production.

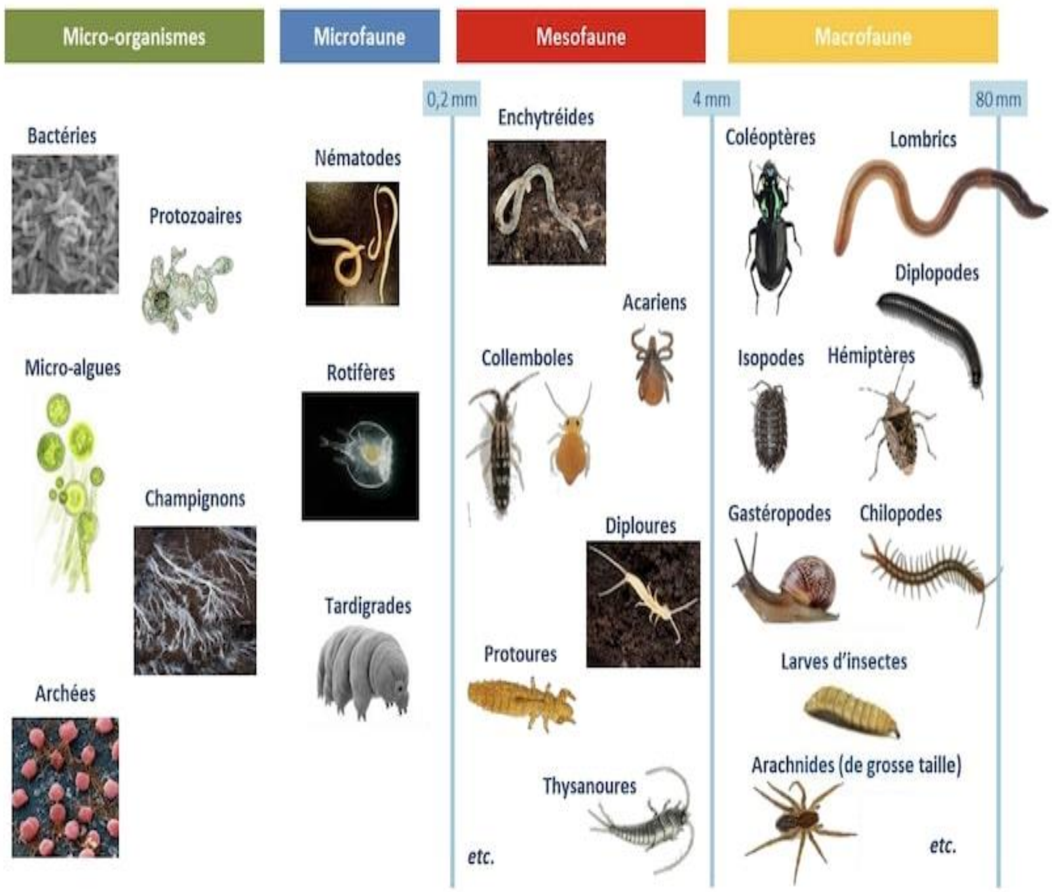

Figure 09: Classification of soil inhabitants

2.1 Different Types of Soil Organisms (Table 01)

- Microorganisms:
  - Bacteria: They decompose organic matter, fix nitrogen, and contribute to nutrient solubilization.
  - Fungi: They form mycorrhizas with plant roots and contribute to the uptake of nutrients and water.
  - Actinomycetes: They decompose complex organic compounds and contribute to humus formation.
- Microfauna:
  - Nematodes: They contribute to the decomposition of organic matter and the regulation of microorganism populations.
  - Protozoa: They graze on bacteria and other microorganisms, thus contributing to the regulation of the microbial population.
- Mesofauna:
  - Springtails: They decompose organic matter and contribute to humus formation.
  - Mites: They contribute to the decomposition of organic matter and the regulation of microorganism populations.
- Macrofauna:
  - Earthworms: They improve soil structure and contribute to the decomposition of organic matter.
  - Ants: They contribute to soil aeration and seed dispersal.
  - Termites: They decompose wood and contribute to humus formation.

Table 01: Different types of soil organisms

Catégorie	Exemples	nombre d'espèces	taille	abondance	biomasse g / m²	"fonction"	régime alimentaire
Microfaune	protozoaires	68	0,2 mm	10^3 à 10^{11} / m²	6 à > 30	microphages consommateurs de colonies bactériennes action de prédation stimulant le renouvellement de la microflore.	champignons, bactéries, débris organiques, algues.
	nématodes	65	0,1 à 5 mm	10^6 à 10^8 / m²	1 à 30		
Mésofaune	arthropodes inférieurs (collemboles, acariens,...)	140	0,2 à 4 mm	$2x10^4$ à $4x10^5$ / m²	0,2 à 400	broyeurs de feuilles.	résidus de végétaux, algues, champignons et bactéries.
	enchytraéidés (annélides)	36					
Macrofaune	taupe, hérisson, lombrics, araignées, myriapodes, fourmis,...	11	3 à 30 cm	10 à 10^3 / m²	20 à 400	fragmentation de la matière organique + brassage avec matière minérale.	résidus de végétaux, cadavres d'invertébrés, champignons et bactéries.
		6	> 1cm	20 à 700 /m²	0,5 à 12,5		
Microflore	bactéries, champignons	10^4	0,01 à 0,05 mm	10^8 à 10^9 / g de sol	2 à 200	indispensables aux cycles du Carbone et de l'Azote.	Matière organique et N atmosphérique.
			< 1micron	10^4 à 10^6 / g de sol	100 à 150	dégradation de la MO.	résidus végétaux, parasite, symbiote mycorhizien.
	algues		0,2 mm	10^2 à 10^4 / g de sol	5 à 20	synthèse de MO à partir de *MM** et CO_2.	

**MM : Matières Minérales*

Figure 10 illustrates a selection of macrofauna, mesofauna, and microfauna, such as springtails, myriapods, and earthworms..

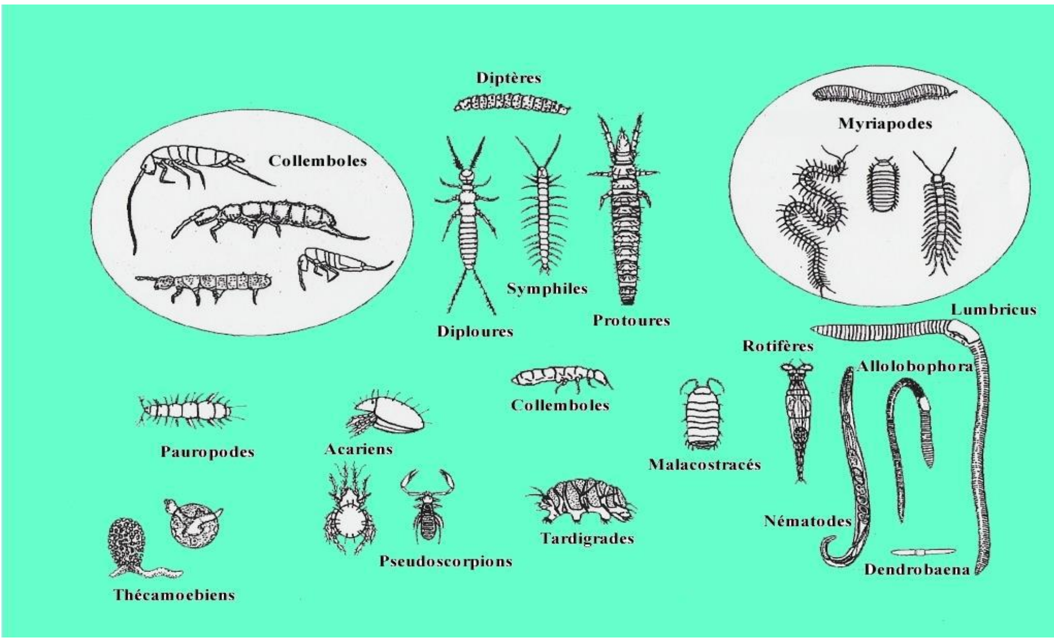

Fig. 10: Schematic presentation of the species of each class of soil constituents

2.2 Roles of Soil Organisms:

- Decomposition of organic matter: Soil organisms break down dead leaves, roots, and other plant and animal debris into nutrients that plants can use.
- Improvement of soil structure: Soil organisms, particularly earthworms, create pores and tunnels in the soil, which improves soil drainage and aeration.
- Nutrient cycling: Soil organisms contribute to nitrogen fixation, phosphorus solubilization, and the release of other nutrients into the soil.
- Plant protection: Some soil organisms can protect plants against diseases and pests.

2.3 Factors influencing soil biological life

- Organic matter: The quantity and quality of organic matter in the soil are the main factors influencing soil biological life.
- Soil pH: Most soil organisms prefer a slightly acidic to neutral pH.
- Temperature and humidity: Soil temperature and humidity affect the growth and activity of soil organisms.

2.4 Management of soil biological life:

- Addition of organic matter: Compost, manure, and cover crops are sources of organic matter that can improve soil biological life.
- Minimal tillage: Excessive tillage can disrupt soil biological life.
- Soil cover: Soil cover protects the soil from erosion and promotes soil biological life.

Chapter 3: Soil-Microorganism Interactions

Introduction

Soil is one of the most important reservoirs of biodiversity on our planet. It is estimated that a gram of soil harbors several billion bacteria and fungi, with over 1000 different species, and that several hundred faunal species (protozoa, nematodes, insects, earthworms) also live in a small volume of soil (a few cm^3). This great diversity varies in terms of taxonomic richness, abundance, and distribution depending on the type of soil, climatic conditions, vegetation, and land use.

3.1. Pedological Factors

3.1.1. Soil Structure

Through the size of the free pore spaces between micro-aggregates, the structure exerts a kind of control over the development of microorganisms. Sporulating Gram-positive bacteria are distributed outside the aggregate, while Gram-negative bacteria are located in the central pores (Fig. 11). This observation can be explained by considering that sporulating bacteria are more resistant to desiccation and can therefore persist towards the exterior where hygroscopic conditions are more variable. Fungi, on the other hand, show an adaptation to the restricted space between soil pores. Structural quality is also strongly influenced by the value of the redox potential of this soil. This value orients the nature and intensity of the microbial population.

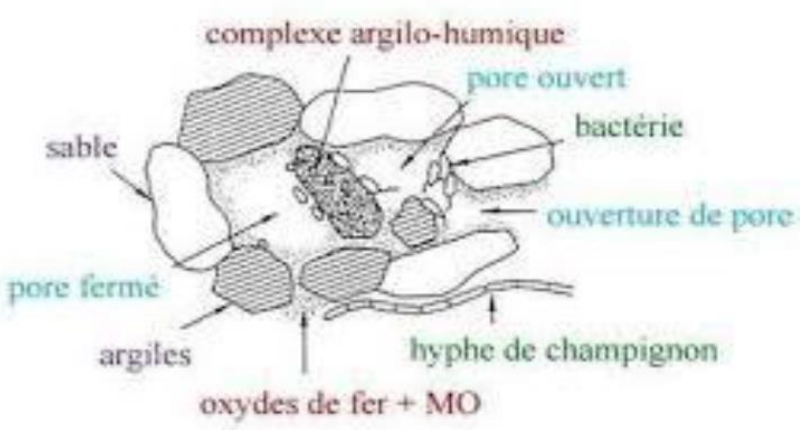

Figure11. Distribution des microorganismes dans les particules du sol (Gobat ,1996)

3.1.2 Soil Texture

The adhesion of microorganisms in the soil is all the more intense as the clay content is high. Soil texture intervenes in two ways: directly, through the action of different mineral fractions, and indirectly, through its major role in the genesis of soil structure. The fine texture (< 50 µm) of the soil has a protective effect on microorganisms and their enzymes, which may be due to the higher proportion of micropores compared to a sandy soil and the limitation of the development of their predators.

3.1.3 Energy Source

Organic matter, as a source of food and energy, is one of the most determining factors for soil microflora.

3.2 Pedoclimatic Factors

3.2.1 Soil Moisture

The activity of microorganisms increases proportionally with the soil moisture content up to a certain maximum percentage of humidity, from which any increase in the water content is accompanied, on the contrary, by a decrease in the activity of aerobic organisms, due to the decrease in oxygen resulting from the excess of water.

3.2.2 Soil Aeration

Any decrease tends to favor anaerobic processes. Soil asphyxia leads to anaerobic conditions that can promote harmful bacterial putrefaction and hinder the multiplication of aerobic microorganisms.

3.3 Climatic Factors

3.3.1 Influence of Climate

Climate intervenes essentially through temperature. Microbial activity increases exponentially with temperature. The number of microorganisms is higher in tropical zones than in temperate zones. Rainfall, which conditions the hygroscopic state of the soil, also plays a major role in limiting the development of microorganisms by excess or lack of water. It is noted that the number of actinomycetes increases from temperate to hot regions, while fungi are more abundant in cold regions. The absolute and relative number of bacilli decreases with latitude and altitude.

3.3.2 Influence of Season

The total number of microorganisms in the soil shows two maxima during the year: the most marked in spring (March and April), in relation to the thermal rise that follows the winter cold, and another less marked in autumn (October), in connection with the increase in food made available to germs by the death of annual plants and the fall of leaves.

3.3.3 Influence of Light

Sunlight has an extremely harmful effect, going as far as instant destruction, on most soil microorganisms, even on phototrophic types such as Algae.

3.4 Effects of Soil Microflora on Soil Properties

3.4.1 Modification of the Composition of the Soil Atmosphere and Soil Solution

The composition of the soil atmosphere is not only dependent on physical factors but also on the activity of living organisms (plants, microfauna, and microorganisms) that produce or consume oxygen or carbon dioxide. Microbial production of oxygen is limited to photosynthetic microorganisms (Algae). Microbial production of CO_2 in the soil can reach very high values when the microflora has an abundant supply of metabolizable organic matter and when the conditions of other factors (temperature, pH) are favorable to its activity. In addition to CO_2, microorganisms can produce other gases such as N_2, N_2O, H_2, CH_4, and H_2S in hydromorphic environments. Note that H_2S is very toxic when it remains free.

3.4.2 Modification of the Redox Potential (Eh)

When the soil is submerged and contains sufficient quantities of metabolizable substrates, the non-photosynthetic microflora rapidly depletes the soil's oxygen reserves. This results in a decrease in Eh, which is all the faster the greater the amount of metabolizable organic matter available to the microorganisms and the less the soil contains substances that delay the decrease in Eh such as NO_3^- and MnO_2.

3.4.3 Microbial Thermogenesis

This is the production of heat by exothermic reactions of microbial origin. In the soil, these reactions induce a generally very slight temperature increase, but becomes more important as soon as the soil microflora has a sufficient supply of energy substrate.

3.4.4 Modification of pH of Microbial Origin

The microflora influences the pH of the soil through its metabolic products which can be acidifying (mineral or organic acids) or alkalinizing (ammonia for example). The lowering of soil pH of microbial origin can also be linked to the nitrification process.

Chapter 4: Soil-Fauna Interactions

4.1 Effect of Fauna on Soil Structure and Texture

4.1.1 Texture

Earthworm casts generally have a finer texture (higher silt and clay contents) than the surrounding soil. This difference in texture, between soil and casts, is due to a preferential ingestion of fine particles (silt and clay) richer in organic matter (Fig. 12). The texture of the casts depends on the size of the worms: the larger they are, the larger the size of the soil particles ingested and then excreted. In addition to these changes in texture, soil structure is also affected during intestinal transit. In the digestive tract of worms, ingested soil particles undergo various treatments: mechanical, chemical, and enzymatic. As they pass through, the mineral particles are reorganized around bacterial colonies or organic particles, affecting both the microstructure and macrostructure of the soil particles.

4.1.2 Effect on Soil Structural Stability

The structural stability and cohesion of soil aggregates in general, and casts in particular, greatly influence the hydraulic properties of the soil and therefore its resistance to erosion. Earthworm casts therefore play a role in stabilizing soil structure. The stabilization of casts results from physicochemical, biological, and organic processes. It depends essentially on the richness in organic matter of the soils but also on the microbial activity in the casts.

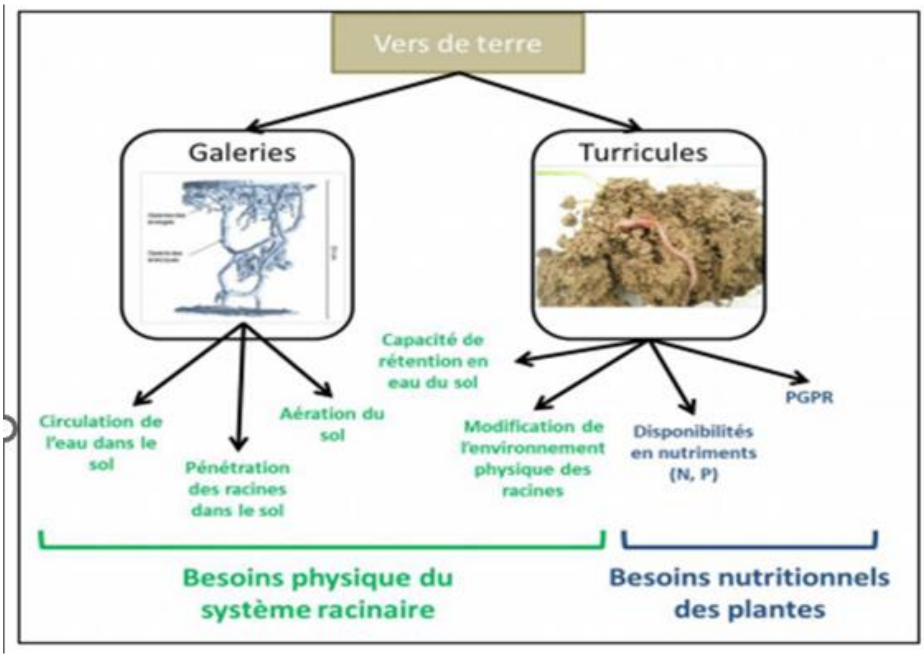

Figure 12: Effect of earthworms on soil structure and texture

However, by promoting the synthesis of bacterial mucus, polysaccharides, and pre-humic compounds, and by intimately mixing these compounds with the mineral fraction of the soil and sometimes adding calcareous secretions that contribute to the flocculation of clay-humic compounds, earthworms increase the structural stability of the soil. Thus, the presence of polysaccharides of microbial origin is strongly correlated with the stability of aggregates. In addition, the residues of ingested plant fibers and fungal hyphae play a mechanical role in the stabilization of aggregates (Fig. 13).

4.1.3 Effect on soil porosity

The biological activity of earthworms significantly increases soil porosity: from 30-40%, it can reach 60-70% under their action. Worms, through their burrows, can limit the compact nature of clay soils. The biogenic structures of worms (burrows and casts) increase macroporosity, but also influence microporosity, both directly via the assembly of casts. The improvement in porosity allows an increase in water infiltration. If the burrows are connected to the surface, they allow rainwater to infiltrate and then flow into the burrows and other granular structures. In the presence of earthworms, it has been shown that rates increase by 122% and 247%, for pores smaller than 2.1 mm and larger than 2.1 mm respectively (pores are differentiated by infiltrometry). Soils with increased porosity also have better aeration as gas diffusion occurs more easily.

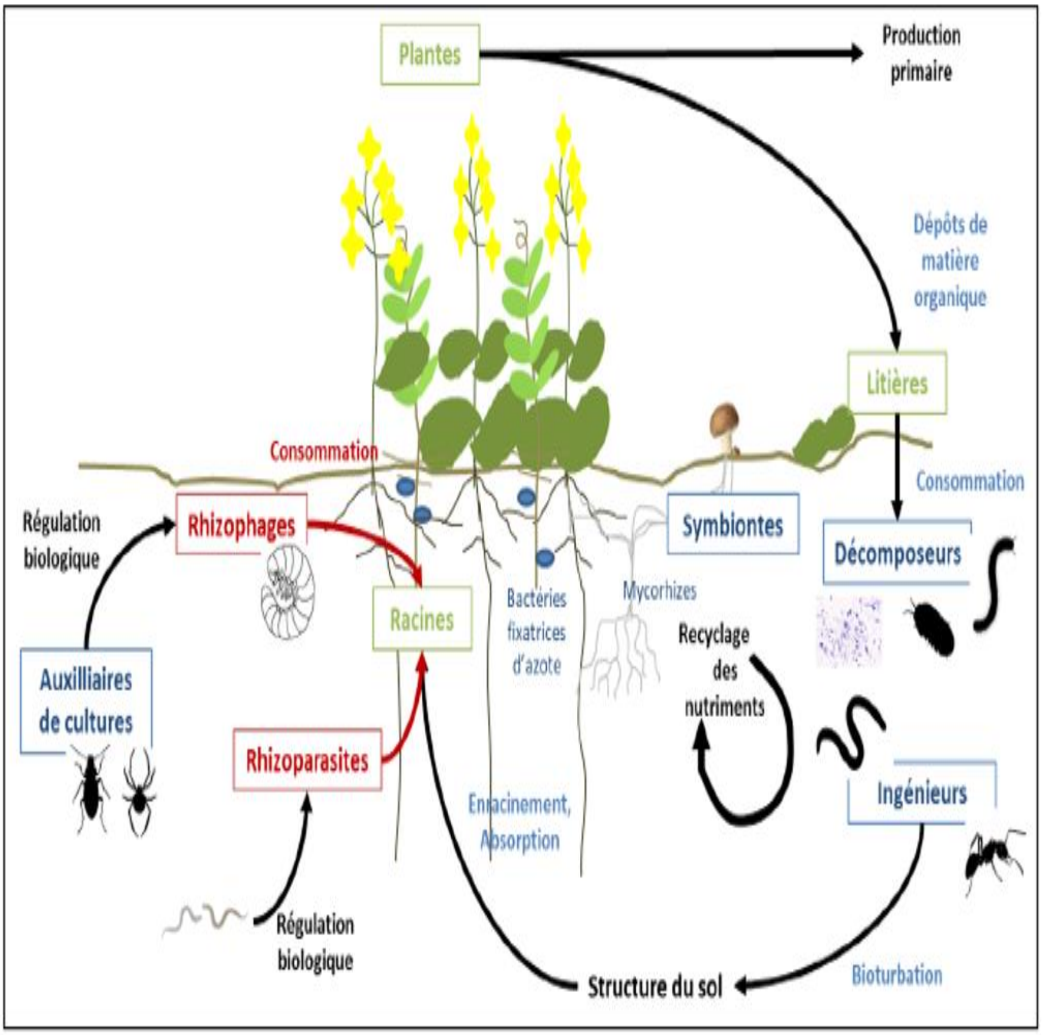

Figure 13: Various actions of fauna in the soil

Chapter 5: Biological Interactions

A biological interaction, also called biotic interaction or ecological interaction, refers to a process involving reciprocal exchanges or relationships between several individuals or species in an ecosystem (interspecific relationships), or between two or more individuals of the same population (intraspecific relationships) (Table 2).

Table 2: Types of biological interactions

	Partenaire A	Partenaire B	Type d'interaction
Effet	+	+	**Mutualisme** (symbiose si coexistence)
	+	-	**Parasitisme** (ou prédation, si mort s'ensuit)
	+	0	**Commensalisme**
	0	-	**Amensalisme**
	0	0	**Neutralisme**
	-	-	**Antagonisme** (dont compétition)

Here are some common types of biological interactions you might consider adding to Table 2:

- Competition: When organisms compete for the same resources (e.g., food, water, space).
- Predation: When one organism (predator) consumes another (prey).
- Mutualism: A symbiotic relationship where both organisms benefit.
- Commensalism: A symbiotic relationship where one organism benefits and the other is neither harmed nor benefited.
- Parasitism: A symbiotic relationship where one organism (parasite) benefits at the expense of another (host).

5.1. Influences of microorganisms on each other

Soil microorganisms exert actions on each other that can be: either positive (synergies), negative (antagonisms), or null (neutralities).

5.1.1. Synergistic associations between microorganisms

Synergistic associations between soil microorganisms take two forms: commensalism and nutritional symbiosis.

- 5.1.1.1. Commensalism:
- Only one of the species involved benefits from the association. For example, Corynebacteria make the cellulose substrate assimilable for nitrogen-fixing microorganisms by degrading it to the stage of organic acids.
- 5.1.1.2. Nutritional symbiosis:

In the case of nutritional symbiosis, each of the two types of microorganisms involved benefits. For example:

- a. Synergistic association between: Lactobacillus arabinosus and Streptococcus feacalis.
- b. Nitrogen-fixing synergistic associations: Numerous associations have been demonstrated between nitrogen-fixing microorganisms (Azotobacter, Clostridium, Beijerinckia and Algae) and various non-fixing microorganisms (Fungi, Yeasts, Algae, Protozoa).

5.1.2. Antagonisms between the various elements of the microflora

- 5.1.2.1. Competition:

Competition manifests itself in two ways:

- Nutritional competition: competition between two or more micropopulations for the use of nutrients available in limited quantities in the environment.
- Competition for space: the microhabitat contains sufficient nutrients, but the volume of proliferation of the species is very limited.

The competition process can take place in several ways:

- Modification of the physicochemical composition of the medium: The activity of certain microorganisms leads to more or less important modifications of the medium, such as changes in pH, Eh, the composition of the soil atmosphere in oxygen and carbon dioxide... as an example, the accumulation of CO_2 is unfavorable for aerobic soil microbes. This is the case of amensalism which corresponds to a biological interaction between several partners (of the same species or of different species) in which the interaction is negative for one of the partners while it is neutral for the other partner. This is the case of SH-- ions formed by sulfate-reducing bacteria which inhibit the growth of many microorganisms.

- Production of inhibitory or toxic substances: A very frequent form of antagonism results from the production by a microbial species of toxic substances (mineral acids, antibiotics, lytic enzymes) for the species that are nearby. The effect of these substances is very variable. In general, we distinguish: A bacteriostatic or mycostatic (fungistatic) effect.

5.1.2.2. Predation and parasitism:

Predation and parasitism are two modes of antagonism that consist in the direct attack of one microorganism by another for nutritional purposes. The ingestion of a small organism by a larger one is called predation, the destruction of a large organism by a small one is parasitism. All viruses are obligate parasites (Fig. 14). Most soil protozoa are predators of bacteria. Parasitism: Parasitism is characterized by the fact that the attacked element (host) remains alive for a certain time; it occurs in various forms: Parasitism between fungi or mycoparasitism; Parasitism between bacteria

5.1.2.3. Saprophytism:

This term refers to the way of life of microorganisms living in the natural environment and which are not associated with other living organisms. They draw their nutrients from the inert matter that they decompose and mineralize.

5.1.3. Neutralism

In this type of association, the two populations multiply without any interaction. There are few examples of neutralism in soil microbiology; indeed, it is difficult for two microorganisms to develop independently in the same place.

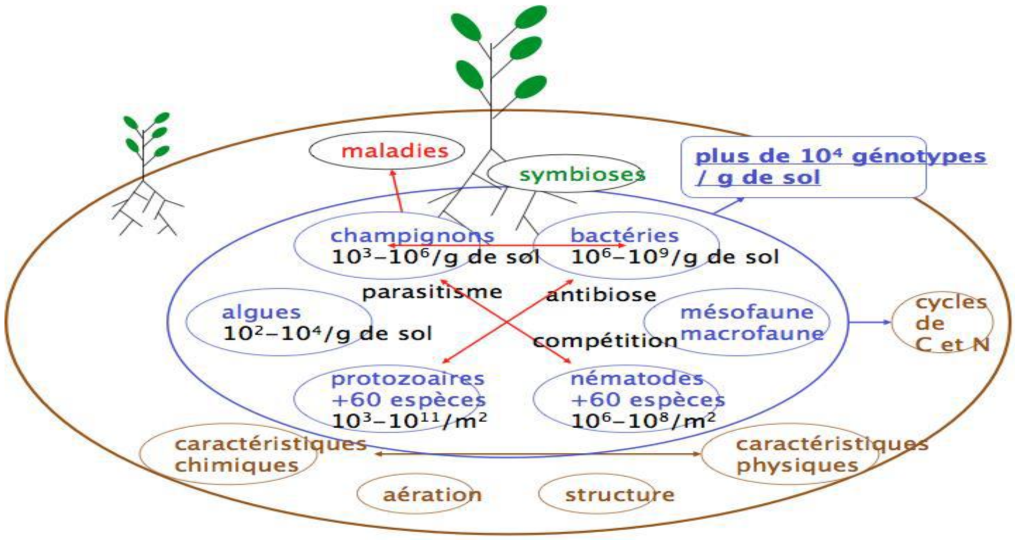

Figure 14: Different types of biological interactions in the soil

5.2. Interaction between microflora and soil fauna

Soil fauna can affect soil microflora in a direct way: through predation, by hosting specific microorganisms, and by promoting the multiplication of certain groups of microbes. And also indirectly: by the translocation of organic and mineral compounds in the soil profile, by the modifications they bring to the physical structure of the soil, which has the effect of modifying the intensity of the movements of nutrients, water and gas.

5.2.1. Interaction between nematodes and microflora

a. Actions of nematodes (Fig. 15) on the microflora: According to their nutrition, nematodes can be grouped into:

- Predators: which feed on soil fauna (protozoa, other nematodes).
- Phytophages: which feed on underground organs affected by rot.
- Saprophages: which feed on debris, more particularly microorganisms, which govern these (Bacteria, Fungi, Algae, Actinomycetes).
- Mycophages: which feed on fungal hyphae.
- Nematodes play a regulatory role similar to that of protozoa towards microorganisms.

b. Actions of the microflora on nematodes: The microflora exerts an attractive or repulsive effect on nematodes. For example, Mycophages are attracted to Fungi or Actinomycetes. Certain Fungi can also become predators of nematodes (Ex: Monibiales, Basidiomycetes, Zygomycetes).

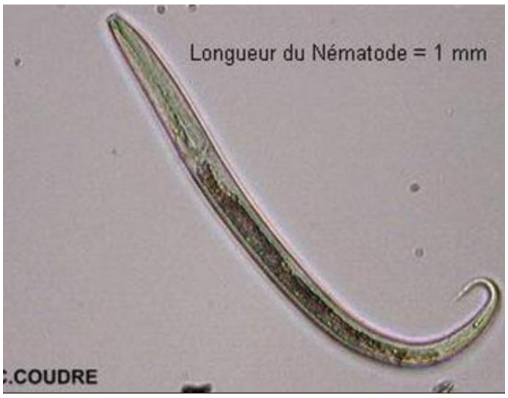

Figure 15: Schematic representation of a Nematode

5.2.2. Interaction between mesofauna and microflora

Mesofauna includes all animals whose dimensions vary from a few hundred μm to about 1 cm. Their main representatives are:

- Mites (Fig. 16): small arachnids that feed on numerous species such as nematodes, yeasts, bacterial mucilages, fungal spores and hyphae, etc

Figure 16: Different types of mites

- Springtails (Fig. 17): These are small wingless insects with a varied diet: bacteria, molds, algae, and fungi.

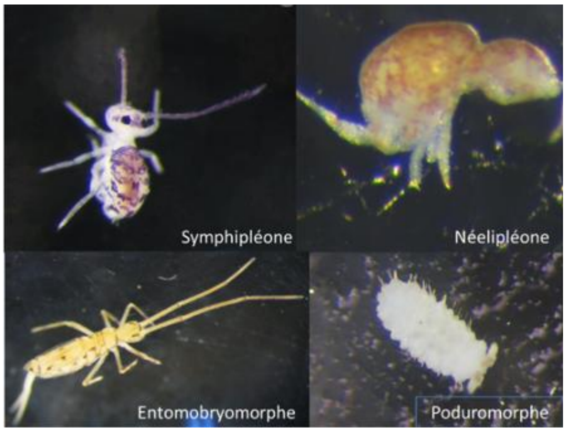

Figure 17: Types of springtails

5.2.3. Interaction between macrofauna and microflora

The most typical example of this interaction is the association between earthworms and soil microflora. Earthworms are oligochaete annelids (e.g., the common earthworm, Fig. 18) that live on decaying roots and leaves in the soil.

- They exert a positive effect on the activity of microorganisms:
    - They accumulate dead leaves in their digestive tract.
    - They ingest more or less altered organic matter along with a large quantity of soil, allowing them to reduce it to fine particles. This state of division increases the surface area of the debris and makes them more sensitive to the enzymatic actions of the microflora.

Figure 18: An Earthworm

5.3. Interaction between soil microflora and vegetation

The interaction between plants and microorganisms in the soil is based on trophic exchanges involving costs and benefits for each partner. Benefits represent the goods and services that an organism cannot obtain or that are difficult for it to obtain in the absence of another organism. This includes, in particular, the acquisition of nutrients, and protection against biotic and abiotic environmental factors.

5.3.1. Effect of vegetation on the microflora

- 5.3.1.1. Influence of litter on the microflora: Litter is formed by the aerial organs of plants (leaves, flowers, stems,...) that die and fall to the ground. Litter can have both positive and negative influences on microorganisms:
    - Supply of energy substrates and nutrients: diverse for autotrophic soil microflora. In addition, the microflora also benefits from the vitamins contained in plant debris.
    - Supply of toxic products: Some forest litter is very inhibitory to microorganisms sensitive to toxic substances. These microorganisms are mainly: autotrophic nitrifying bacteria and nitrogen-fixing bacteria (Azotobacter and Beijerinckia).
- 5.3.1.2. Influence of the rhizosphere on the microflora (rhizosphere effect):

The rhizosphere most often exerts a favorable influence on the growth and development of the microflora by modifying the physical microenvironment (structure, water regime, composition of the soil atmosphere) or chemical (immobilization of nutrients, pH) by the release of organic or mineral substances by plant roots. These are mainly sugars, organic acids, and amino acids

5.3.2. Effect of Microflora on Plants

Conversely, microflora in turn affects plant nutrition and its environment. The inhibition of microflora activity is often detrimental to vegetation. It is the cause of orchard decline or the toxicity of forest soils. In the rhizosphere, microorganisms can be free-living or closely associated with roots.

a. Free-living Microorganisms: Among the free-living microorganisms in the rhizosphere, there are both beneficial organisms for growth such as so-called "PGPR" (Plant Growth Promoting Bacteria), certain fungi, as well as harmful or pathogenic organisms. The group of fluorescent Pseudomonas offers multiple examples of both beneficial and harmful bacteria. The genus Trichoderma includes a large number of species with beneficial activity for plant growth, while the genera Fusarium or Phytophthora have many species pathogenic to plants.

b. Symbioses: Some symbioses are manifested by the formation of specialized organs such as nodules and mycorrhizae. For example, legumes and rhizobia, nitrogen-fixing bacteria, and on the other hand, the relationships between Glomales, fungi that form mycorrhizae with a large number of plant species.

Chapter 6: Biological Control and Biostimulants

6.1 Definition of Biological Control

- 1) It is a control method that uses natural enemies of pests to maintain the pest population below damaging levels.
- 2) Biological control is a process acting at the population level whereby the population density of a species is reduced by the effect of another species acting through predation, parasitism, pathogenicity, or competition.
- 3) Biological control is the use of living organisms to limit the population growth and/or harmfulness of various crop pests such as rodents, insects, nematodes, plant diseases, and weeds.

6.2 Organisms Used in Biological Control

Beneficial organism: This has the same meaning as antagonist or natural enemy. Practically all living organisms can be considered beneficial organisms. When focusing on arthropod pests, they can be subdivided into four groups.

- 6.2.1 Microorganisms: These are biopesticides developed from pathogens such as viruses, bacteria, and fungi. They have certain advantages over conventional pesticides. They are more selective, generally non-toxic to predators and parasitoids, and have less harmful effects on the environment.
- 6.2.2 Entomopathogenic nematodes: Entomopathogenic nematodes exploit insects as a resource for growth and reproduction. Entomopathogenic nematodes can be found in 30 families, representing about 4000 species.

6.3 Role of Bacteria in Plant Health

Phytopathogenic bacteria promote growth by reducing the level of certain diseases. For example, bacteria of the genus Bacillus or Pseudomonas, known as "PGPR" (Plant Growth Promoting Bacteria), are able to stimulate plant growth and oppose the activity of pathogens.

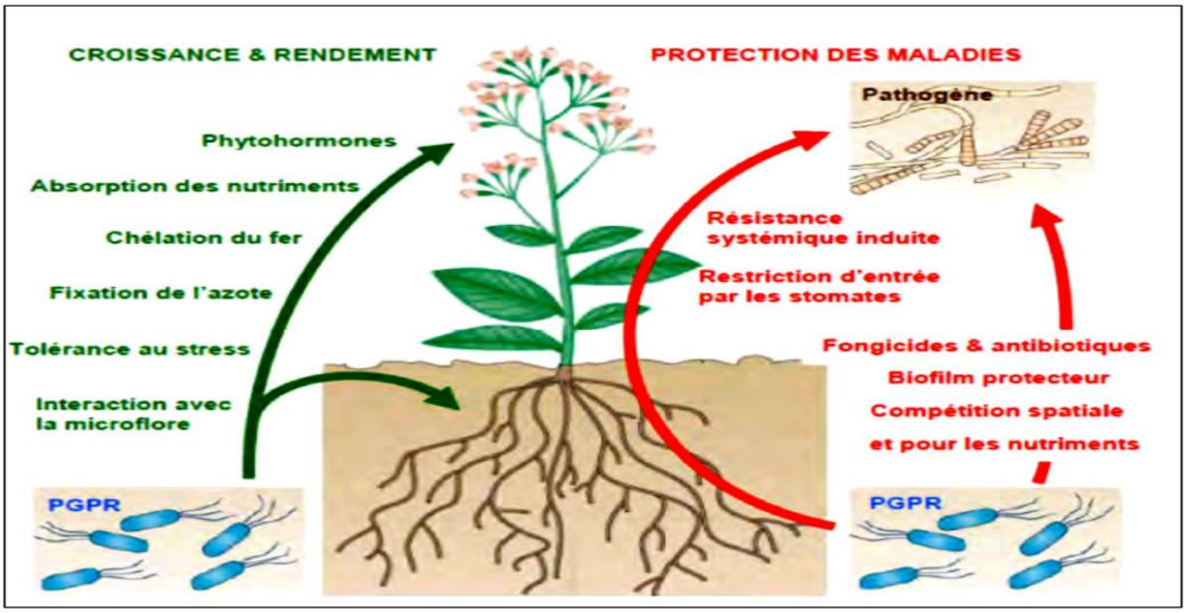

Figure 19: Roles of PGPR bacteria in the soil

They can act in several ways:

- Through antagonism by producing antibiotics harmful to pathogens.
- By interfering with signals, destroying the signal molecules of pathogens.
- By activating induced systemic resistance in plants, which increases plant resistance to pathogen attacks.
- Or by controlling the growth of pathogens by competing for nutrients, such as carbon and iron, whose availability in the soil is very low. However, microbial diversity can also lead to harmful effects and the presence of certain microorganisms that are pathogenic to plants (such as *Plasmopara viticola* and *Fusarium*) and humans (*Pseudomonas aeruginosa*, *Listeria monocytogenes*).

6.4 Role of fungi in plant health

In addition to their beneficial effects in improving plant nutrition, mycorrhizal fungi strengthen the plant's natural defenses against biotic or abiotic stresses (Fig. 20).

Explanation of Terms:

- PGPR: Plant Growth Promoting Rhizobacteria - beneficial bacteria that promote plant growth.

- Antagonism: The inhibition of one organism's growth by another.
- Induced systemic resistance: A defense response in plants that is triggered by exposure to a pathogen.
- Mycorrhizae: A symbiotic association between a fungus and a plant root.

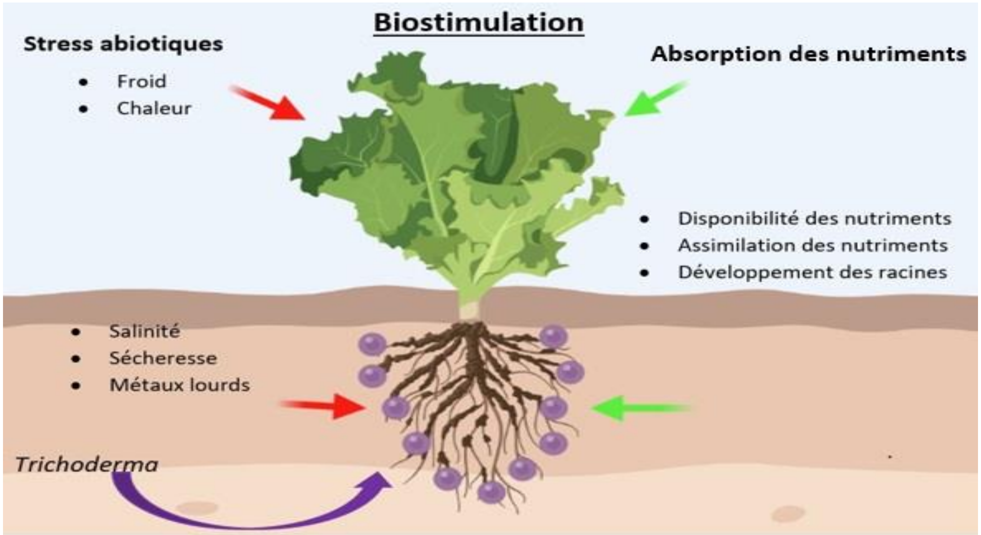

Figure 20: Role of Trichoderma in plant nutrition and resistance

Some fungi are antagonistic to pathogens and protect plants against their attacks (such as *Trichoderma* or *Gliocladium*). The balance between these various organisms determines the health of plants growing in this environment. The following processes are harmful to plants: The synthesis of phytotoxic substances such as organic acids, antibiotics, and hydrogen sulfide; Antagonism towards beneficial bacteria such as *Rhizobium*.

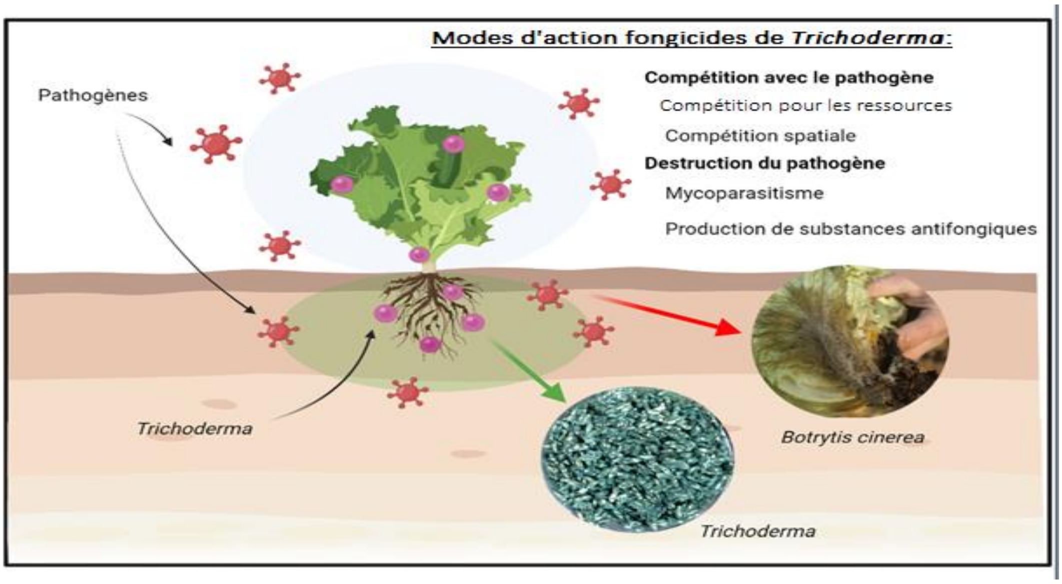

Figure 21: Mode of action of Trichoderma fungicides

6.5 Introduction of biostimulants

The massive introduction of microorganisms previously selected for their beneficial activities involves the use of "biostimulants". These compounds contain one or more substances or microorganisms whose role is to improve the absorption of nutrients by plants and increase their tolerance to abiotic stress.

- Biostimulants contain strains of living or dormant cells, some of which have a direct action on plant growth and others that have an indirect action through phytohormones.
- The first biostimulant products on the market were based on Pseudomonas, Bacillus, and Trichoderma.

6.6 Conditions for the application of biofertilizers

PGPR used as biofertilizers and/or antagonists against phytopathogens constitute a promising alternative to chemical fertilizers and pesticides. However, the ability of these bacteria to colonize roots and survive in the soil is often limited. The selection and use of PGPR should consider the adaptation of the inoculant to: A specific plant, A particular ecosystem.

6.7 The different types of biofertilizers

Different types of biofertilizers are used in agriculture, including:

- Biofertilizers based on free-living and symbiotic nitrogen-fixing bacteria
- Biofertilizers based on bacteria that solubilize mineral elements
- Biofertilizers based on plant growth-promoting rhizobacteria (PGPR)
- Biofertilizers based on arbuscular mycorrhizal fungi

Chapter 7: Factors Influencing Soil Microbial Diversity

Many biotic and abiotic parameters influence the structure of soil microbial communities in terms of both diversity and abundance. Factors that have a significant impact on the structure of bacterial communities can be classified as follows:

7.1 Abiotic Factors

The structure and composition of bacterial communities can vary considerably with changes in climate (drought, erosion, floods, etc.), pedoclimatic characteristics (salinity, humidity, temperature, etc.), and edaphic characteristics (pH, carbon content, nitrogen, etc.).

7.2 Biotic Factors

7.2.1 Plant Presence

The presence of plants affects the growth of soil bacterial communities and also influences the abiotic properties of the soil. Plants induce profound changes within the soil bacterial community. It has been observed that many plants select specific groups of microorganisms through the exudation of compounds in the rhizosphere, as well as providing protection against attacks by pathogens and parasites.

7.2.2 Presence of Microfauna

Microfauna plays a role in the biological balance of the soil, either by increasing or decreasing the density and biodiversity of soil microbes.

7.2.3 Anthropogenic Activities

Agricultural techniques used in recent decades (use of large quantities of chemical inputs, soil compaction, etc.) have led to a depletion, or even elimination, of certain beneficial microorganisms in most cultivated soils, leading to changes in the characteristics of the microflora and a decrease in the diversity of soil microorganisms.

7.3 Factors Improving Soil Microbial Fertility

7.3.1 Cultural Practices

The use of methods that stimulate the activity of beneficial microorganisms in situ involves:

7.3.2 Crop Rotation

Crop rotation is necessary to meet the nutrient needs of soil microorganisms. Crop rotation thus acts as a biological pump. Moreover, the rotation of various plant species allows for diversification of the soil flora, as roots secrete organic substances that attract a whole range of bacteria and fungi.

7.3.3 Choice of Soil Tillage Techniques

Adequate soil tillage allows for better aeration, especially in deep layers; increases the exchange of carbon dioxide and oxygen, and leads to an intense proliferation of aerobic germs, thus accelerating the oxidation phenomena of organic matter. Mechanical soil tillage also allows for the exposure of a portion of organic matter that becomes more accessible.

7.3.4 Effect of Plant Cover

This is the set of complex effects that vegetation exerts on the soil microflora, especially through processes inducing modifications of the pedoclimate. Without plant cover, the soil is abruptly exposed to sunlight and its mineralizable nitrogen content (in the form of ammonia or nitrate) is reduced. Following certain experiments in arid zones, windbreaks have contributed to the protection of fungi, actinomycetes, ammonifying germs, bacteria, and have allowed the accumulation of humus and nitrogen.

7.3.5 Exogenous Input of Organic Matter

The exogenous input of organic matter plays a very important role in improving the biological fertility of soils. For example, the addition of manure leads to a series of extremely complex phenomena. It enriches the soil, on the one hand, in organic and mineral matter, and on the other hand, in special germs of the manure flora which constitute a high percentage of microbial proteins. The input of exogenous organic matter also acts indirectly on soil microorganisms by improving the physical and physicochemical properties of the soil.

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