**Chapter**

# Global Change Drivers Impact on Soil Microbiota: Challenges for Maintaining Soil Ecosystem Services

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**Abstract**

Global change refers to anthropogenic and climate pattern modification. The consequences of these changes are outstanding on aboveground biodiversity. Soil microbiota are key actors in soil processes, contributing significantly to numerous ecosystem services provided by soil. They are involved in the processes of nutrient cycling, organic matter decomposition, or pollutants degradation. Microorganisms are also able to synthesize volatile organic compounds that are secondary metabolites with multiple ecological roles and mechanisms of action—generally contributing to plant development. Changes in soil microbiota community could modify either negatively or positively their contribution in soil-provided ecosystem services through their involvement in soil functions that they mediate.

**Keywords:** microbiome, processes, soil functions, soil microbiota, soil ecosystem

## 1. Introduction

Global change is a hot topic of our days. Briefly, it could be defined as the sum of effects resulting from interactions between climate change and anthropogenic drivers. This phenomenon continues to grow in amplitude in the most part as a consequence of anthropogenic activities. Soil, a key environmental compartment that sustains life on earth and human development, it seems to be a fragile terrestrial ecosystem component in facing the challenges raised by global change. In its interplay with other environmental compartments under the pressure of global change, the soil could be at the same time both a contributor to as well a recipient of the impacts and factors of global change. However, at moment, under the challenge of global change drivers, the soil is considered as the least understood component due to its heterogeneity and complexity of it as properties, functioning, and provided services.

Now, global change is a phenomenon that happens, and its consequences on the ecosystem and delivered ecosystem services are predicted to continue even in future. As phenomenon, global change is the sum of end results between interactions of drivers and effects of changes in climate patterns and anthropogenic activities.

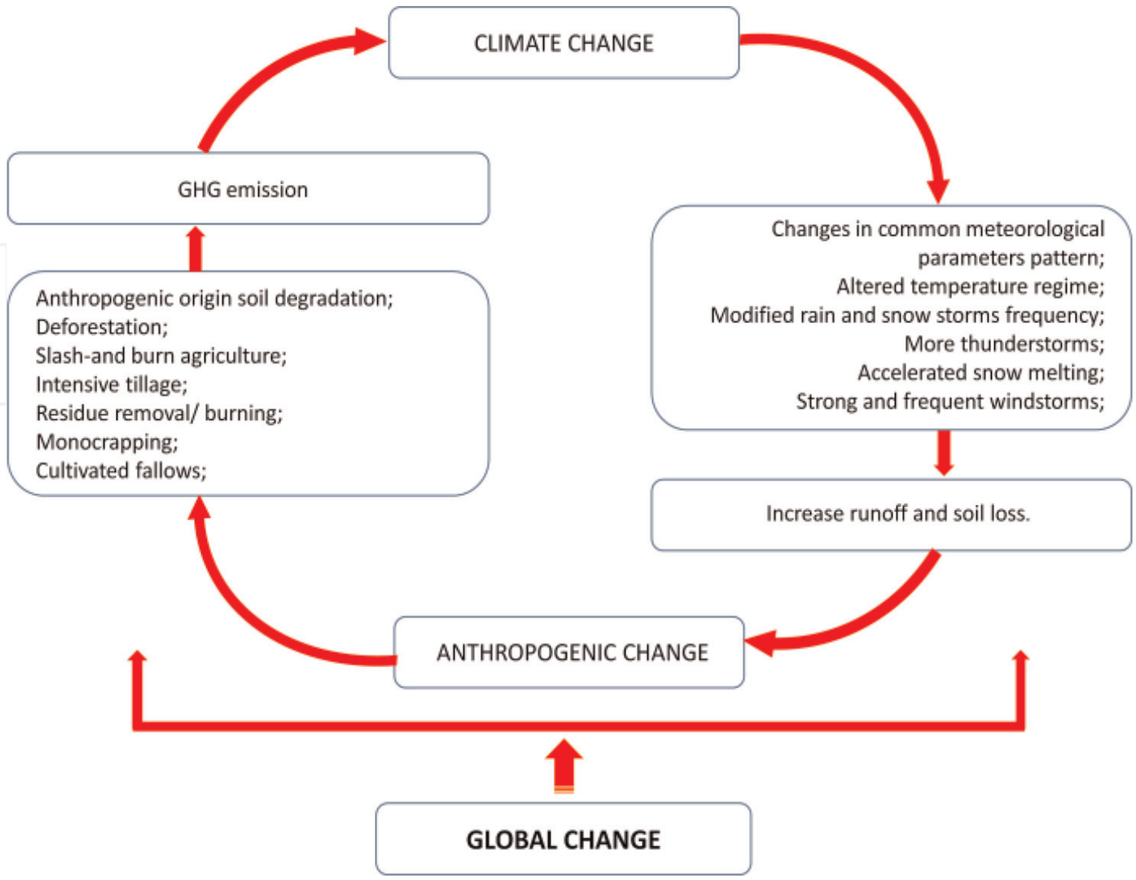


**Figure 1.**
*Soil challenges under interactive effects between anthropogenic and climate change drivers.*

**Figure 1** presents soil faced challenges under the interactive effects between the main anthropogenic and climate change drivers.

Drivers are defined by Millennium Ecosystem Assessment as a natural or anthropogenic factor that induces a change in an ecosystem either directly or indirectly [1]. While *direct drivers* influence ecosystem processes without any doubt, *indirect drivers* usually generate an alteration on one or more direct drivers, thus acting more diffusely.

Ecosystem and delivered ecosystem service changes are usually caused by multiple interacting drivers (direct and/or indirect). They could interact at a multi-level scale, including spatial, temporal, and organizational scales. Therefore, global change drivers can impact ecosystems and consequently ecosystem services both over time, levels of organization, or intermittently [2].

Soil is a key resource for life on earth, acting as a provider of essential raw materials, promoter for human activities, and habitat and gene pool of biodiversity. These global phenomena impact the soil environment, changing its properties, and consequently related biota. The development of soil and its properties takes place most of the time in the presence of living organisms. Soil biodiversity is complex, including diverse micro, meso, and macrofauna and flora with a complex role in soil formation, functioning, and properties. Hereby, soil fauna diversity like invertebrates (earthworms, termites, etc.) modify soil physical and chemical properties [3], while grazers concentrate nutrients through dung middens [4]. Similarly, plants are the main source of organic carbon and also are geochemical pumps that return to soil bio-essential elements through litterfall and degradation [5, 6]. The amount and the distribution depth of organic carbon and essential elements are influenced by plant species [7]. Soil microbiota impact too soil's chemical and physical properties through the quality and quantity of organic compounds that they release, as well as through the biochemical reactions that they mediate [8].

Changes in soil properties due to global change is expected to impact biodiversity also. Modification or alteration in structure (exclusion or introduction of organisms or species), as well as in abundance of biota, could have also a reversible impact on the connected environment (property, functioning), ecosystem, and delivery of ecosystem services. However, soil ecosystem change is the after-effect of a large number of interactions between drivers. Whereas a considerable number of drivers are global, the current assemblage and interactions that bring about an ecosystem are more or less specific to a particular region or place. Although the influence on soil properties by higher-order plants [9, 10] and animals [11, 12] was well documented, a clear view on the potential influence of microbiota on soil properties is less profound. The reason is due to the difficulty of isolation and identification of species, for example., at moment only 1% of soil bacteria can be cultured. Similarly, there is minor knowledge of how microbiota structure and abundance could be influenced by global change drivers. Know-how on the relationship between global change drivers—soil microbiota—soil properties and functioning nexus are important when soil is accounted as a basic environmental compartment that serves us with various supporting, provisioning, and regulating ecosystem services, and when the way and the intensity of the response of soil system to global change are directly dependent to ecosystem dynamics.

Global change influences soil, and this in turn will impact global change further. Considering the time that is involved in soil formation, made it to be considered as a finite and non-renewable resource. This is the reason why is very important to understand how global change drivers put pressure on it in order to could conserve and protect its properties.

Ecosystem services refer to goods and/or services provided by an ecosystem. Soil functions are directly involved in the support and delivery of ecosystem services. Soil well-functioning depends on soil's physicochemical and biological properties. Changes in any of these properties could contribute either to decline or enhancement of provision with ecosystem services. Anthropogenic and climate change-related drivers are acknowledged to change soil physicochemical properties, which are supposed to influence soil biota. This could change also the soil biological properties. Alteration of soil properties could reduce or change soil functioning thus causing loss or alteration of provided ecosystem services.

## 2. Soil microbiota: key component of soil biodiversity and ecosystem

Soil microorganisms present a great diversity, although more of them are not cultured at moment. They are acknowledged as a key component of soil biodiversity due to their involvement in numerous and significant interactions in terrestrial ecosystems. Such interactions control soil's physical, chemical, and biological processes. Components of soil microbiota directly mediate and influence the stability and cycling of relevant elements and climate change. Microorganisms activities are related to the regulation of soil C sequestration and mineralization, nutrient cycling (N, P, etc.), and not finally with ecosystem productivity once that they facilitate the nutrient resource for higher components of biota (e.g., plants) through fast turnover [13]. Soil microbiota community components are also a relevant source of enzymes. They liaise soil potential for enzyme-mediated substrate catalysis [14, 15]. Microbiota components are indigenous to the environment and most of the time are capable to adapt to variable environmental conditions (temperature, redox potential, pH, moisture regime, and pressure) or to exist under oligotrophic conditions (low nutrients).

### 2.1 Soil microbiota community structure

Microbiota constituents could be grouped into three domain systems consisting *Archaea*, *Eukarya,* and *Bacteria*. *Bacteria* and *Archaea* are generally named as prokaryotes, while *Eukarya* as eukaryotes [16].

#### *2.1.1 Bacteria*

*Bacteria,* the most abundant microorganisms as a number of individuals (around 50 phyla) are free-living fewer complex organisms with great metabolic flexibility. Due to these features, they easily and promptly respond and adapt to changing environmental conditions. Bacteria can be grouped either by considering their cell envelope architecture (structural characteristic) or through their metabolism type (physiologic characteristic). Structurally, bacteria are grouped as Gram-positive (e.g., Bacillus, Clostridium, etc.) and Gram-negative (e.g., *Pseudomonas*, *Shewanella*). This difference mediates their survival in the environment.

*Gram-negative* bacteria cell envelope is a complex structure that allows them to interact with mineral surfaces and solutes from the environment. In that way, they obtain the required amount of nutrients for metabolism [17].

*Gram-positive* bacteria have a less complex cell envelope [18]. Their thick cell wall allows them to withstand challenging physical conditions of the soil environment [19].

*Actinomycetes* is a special group that now is classified as Gram-positive bacteria. These group differentiates by bacteria through their tendency to branch into small dimension filaments or hyphae that structurally resemble the hyphae of fungi [20]. They are widespread in soil environment and are recognized also as valuable antibiotic producers [21, 22]. Actinomycetes abundance increase with decomposed organic matter. However, they are strong pH-sensitive organisms, usually at pH below 5 pH units, their abundance decreases considerably. Contradictory with other bacteria species, their abundance increases once with soil depth. From ecological point of view, as growth strategy soil bacteria could be grouped as copiotrophs (e.g., *Betaproteobacteria*) and oligotrophs (e.g., *Acidobacteria*). Copiotrophs consume easily degradable organic C, while oligotrophs consume recalcitrant organic C. Although oligotrophs grow slowly but constantly, maximizing their yield under poor nutrient availability conditions. Copiotrophs to maximize their yield require high nutrient content. From bacteria metabolism point of view, considering the source of energy and C used for growth, Robert and Chenu [23] classified bacteria in several groups (chemoheterotroph, photoautotroph, photoheterotroph, etc.—see **Table 1**).

Therefore, according to their energy source, bacteria could be divided into four main groups (**Table 1**) as *phototroph* (energy is obtained from light—photosynthesis), *chemotroph* (oxidation of organic and inorganic chemicals), *autotroph* (carbon dioxide), *heterotroph or organotroph* (from organic compounds as glucose) [19]. Chemoheterotrophs (chemoorganotrophs) use organic compounds both as energy and as C source. Chemoautotrophs (chemolithotrophs) obtain energy from the oxidation of inorganic compounds and C from $CO_2$. Photoautotrophs get energy from light and

| Metabolism type – examples | Metabolism | Carbon source | Energy source | Products |
|---|---|---|---|---|
| Chemoheterotroph | Respiration | Organic compounds | Organic compounds | |
| e.g., *Pseudomonas, Bacillus* | (aerobic) | | ($O_2$) | $CO_2$, $H_2O$ |
| e.g., *Micrococcus, Geobacter, Desulfovibrio* | (anaerobic) | e.g.,$NO_3$, $Fe^{3+}$, $SO_4^{2-}$ | | $CO_2$, $NO_2^-$, $H_2O$, $N_2O$, $N_2$, $Fe^{2+}$, S, $S^{2-}$ |
| | Fermentation | Organic compounds | Organic compounds | |
| e.g., *Clostridium* | (anaerobic only) | Organic acids | | $CO_2$, organic acids, alcohols |
| Chemoautotroph or Chemolithotroph | Chemolithotroph | $CO_2$ | $H_2$, $S^{2-}$, $NH_4^+$, $Fe^{2+}$ | $H_2O$, $SO_4^{2-}$, $N^{2-}$, $Fe^{3+}$ |
| e.g., *Hydrogen bacteria* | | | | |
| e.g., *Beggiatoa* | (aerobic) | | ($O_2$) | |
| e.g., *Planctomycetes* | (anaerobic) | | ($NO_3$) | |
| Photoautotroph | Photosynthesis | $CO_2$ | Light + $H_2O$ ($NADP^+$) | $O_2$ |
| e.g., *Cyanobacteria* | (oxygenic) | | | |
| Bacteria including Purple sulfur bacteria (e.g., *Chromatium*); Purple non-sulfur bacteria (e.g., *Rhodospirillum*); Green non-sulfur bacteria (e.g., *Chloroflexus*); Heliobacteria (e.g., *Heliobacterium*) | (anoxygenic) | $CO_2$ | Light + $H_2S$ (bacterio-chlorophyll) | $S^0$ |
| Photoheterotroph | Photoheterotrophy | Organic compounds | Light + $H_2S$ (bacterio-chlorophyll) | $S^0$ |
| e.g., many purple non-sulfur bacteria, purple sulfur bacteria but to a limited extent | | | | |

**Table 1.**
*Bacteria classification based on their metabolism (modified after Pepper and Gentry, [19]).*

fix C from $CO_2$. Photoheterotrophs obtain energy from light and C from organic compounds. Bacteria harvest energy either through respiration (aerobic or anaerobic process) or through fermentation (anaerobic process). *Archaebacteria* is a special heterogeneous group of bacteria that have the ability to leave even in extreme environmental conditions (e.g., environments with high sulfur or salt content). Usually, these organisms are classified either as *obligate anoxybiont* (total absence of oxygen in the media where they live) or *facultative anoxybiont* (they could survive in both aerobic and anaerobic environments, e.g., thermoacidophiles) [24, 25]. Obligate anoxynbionts include methanogen (produce $CH_4$ from $CO_2$) and halophile species (live in extremely salt environment). Although there are bacteria in soils that can have a pathogenic effect on plant biodiversity, most bacteria are recognized that have important functions that assure soil health and functioning through decomposing organic matter and contributing to producing nutrients available for other living micro and macroorganisms.

### *2.1.2 Archaea*

*Archaea*, although could appear similar to bacteria they differ from them genetically and biochemically. They appear both in extreme and nonextreme environments. Extremophiles could survive in environment with extreme temperature (hot, cold), salinity, alkalinity, or acidity [19]. Major divisions of archaea are *Crenarchaeota*, usually thermophiles (live in high-temperature environment), and *Euryarchaeota* that include haloarchaeans (live in saline environments) and methanogens (live in anaerobic environment at low temperature) [26]. Their major functions related to soil are those connected to horizontal gene transfer between archaeans and bacteria, and nitrification process control.

### *2.1.3 Fungi*

*Fungi* with great biomass are physically the largest group of eukaryotic microorganisms. They are regnant in soil environment with high adaptability to various conditions. Are valuable components of soil biodiversity due to their essential function as decomposers [27]. Considering their morphological description, fungi are grouped as molds, mushrooms, and yeasts. *Molds*, filamentous fungi, are found in many fungal phyla. *Mushrooms*, filamentous fungi, are part of Basidiomycota. They form the large fruiting bodies known too as mushroom. Both molds and mushrooms are very important decomposers of natural products [19]. They produce also extracellular substances that bind soil particles, forming stable soil aggregates, reducing, therefore, soil erosion. *Yeast*, are unicellular fungi with the ability to ferment under anaerobic conditions. Some components through symbiotic relationships with algae and cyanobacteria form lichens [28]. These secrete organic acids that help rocks and inorganic surfaces in degradation. Fungi have chemoheterotroph metabolism. This supports biosynthesis and energy production based on simple sugars, but they produce also secondary metabolites. These metabolites (e.g., exoenzymes) produced during the stationary phase of growth are acknowledged that help to reduce the competition for nutrients from other microorganisms, and some of them have antimicrobial properties. Exoenzymes break down complex polymers into simple C compounds for cells [29]. Based on that, fungi could be grouped as saprophytic and mycorrhizae.

*Saprophytic fungi* are important organic material degraders (e.g., dead plants and organisms), especially of complex polymers associated with them (e.g., cellulose and lignin from plants; chitin from insects) [30, 31]. They are also able to degrade chemical pollutants [32]. *Mycorrhizae* form a symbiotic relationship with a large number of plants. Through that relation, these fungi increase plant roots' absorptive area and prevent desiccation, as well increase nutrient uptake (especially phosphate) [33, 34]. Similarly, plants furnish sugar (obtained through photosynthesis) to fungi. Mycorrhizal fungi could be divided into ectomycorrhizal and endomycorrhizal fungi group [32].

#### *2.1.4 Protozoa*

*Protozoa*, are eukaryotic microorganisms with fundamental genetic differences between species. Protozoa species are usually heterotrophic organisms and consume bacteria, yeast, fungi, and algae [35]. Usually habit the top part of soil (up to 20 cm depth) and are concentrated near roots (due to availability of the high quantity of prey). They are involved in soil organic matter decomposition processes.

#### *2.1.5 Algae*

*Algae*, phototrophic organisms (metabolize in the presence of light for energy and $CO_2$ for C), are located at the top surface of the soil or very close to it (green algae and diatoms, which are heterotrophs as well photoautotrophs). They are strongly involved in soil formation processes through their metabolism. Once through photosynthesis, they introduce C to the soil, and secondly through metabolizing processes produce and release into soil carbonic acid and polysaccharides [36]. Released carbonic acid help in weathering surrounding mineral particles, while extracellular polysaccharides facilitate soil particle aggregation [37]. Soil algae are seasonally variable, higher abundance having in spring and fall period. In winter and summer, their development and abundance are suppressed considerably due to water-induced stress—soil moisture and/or desiccation [36].

### 2.2 Soil microbiota community structure and abundance: Role in soil processes

Soil, the base of terrestrial ecosystems, is inhabited by a large diversity of organisms. Microbiota inhabitants are key actors in several essential processes in soil. Through their diversity and varied metabolism mediate biochemical reactions and take part in multiple interactions and reactions in and between surrounding microhabitats. Through these, soil microbiota contributes to and liaises essential functions of soil ecosystems. Thus, soil microbiota significantly influences the soil ecosystem in its ability to provide ecosystem services.

#### *2.2.1 Bacteria role in soil processes*

Bacteria are recognized as primer decomposers of both organic matter and organic wastes. They change compounds and elements from inaccessible to usable forms for higher trophic components, thus significantly contributing to the cycling of essential elements and providing the nutritive resources required by below- and aboveground organisms. Geddes et al., [38] with others [39–42] revealed that *Rhizobium sp*. and *Bradyrhizobium sp*., bacteria present inside the host root system (leguminous plants root nodules) fix atmospheric N, the primary nutrient that influences plant growth and development. Arashida et al., [43] showed that *Pseudomonas sp*., *Bacillus sp*., *Azotobacter sp*., and *Azomonas sp*., bacteria from the proximity of plant root system, fix atmospheric N usable form as ammonia. Less frequent bacteria phyla in soils, such as *Verrucomicrobia*, is also involved in N fixation and associative activities [44]. Cyanobacteria are recognized as important improvers of C, N, and exopolymeric substances content in the soil. They release into soil amino acids, proteins, polysaccharides, carbohydrates, vitamins, and phytohormones as elicitor molecules that promote plant growth. Kumar et al., [45] (2013) also reported that cyanobacteria could facilitate plant resistance against both biotic and abiotic stresses. Actinobacteria species have also multiple roles in soil, such as fixation of atmospheric N (*Arthrobacter sp., Rhodococcus sp.*), minerals solubilization (*Ferrobacter sp.*), increase of antagonistic efficiency against different fungal root pathogens (*Streptomyces sp*.) as well as plant growth hormones production (*Frankia sp*.). They are also responsible for soil odor. Studies on dominant culturable bacteria, *Arthrobacter sp.*, *Streptomyces sp*., *Pseudomonas sp*., and *Bacillus sp.* revealed their involvement in nutrient cycling and biodegradation [46], degradation of recalcitrant organic compounds [47], and production of antibiotics [48] and biocontrol agents [49]. Functions in the soil of important autotrophic and heterotrophic bacteria are summarized in **Table 2** [19].

### *2.2.2 Archaea role in soil processes*

Ren et al., [50] through studies performed on agricultural soils in that different management strategies and practices were applied demonstrate that archaea are serious contributors to soil processes such as nutrient cycling, ammonia oxidation, and minerals weathering. Archaea are involved also in carrying out $N_2$ fixation as well reduction of atmospheric $N_2$ to $NH_4^+$.

| Bacteria | Characterization | Role and function in soil |
|---|---|---|
| *Autotrophic bacteria* | | |
| *Nitrosomonas* | G-, aerobe | Convert $NH_4^+ \rightarrow NO_2^-$ (first step of nitrification) |
| *Nitrobacter* | G-, aerobe | Convert $NO_2^- \rightarrow NO_3^-$ (second step of nitrification) |
| *Acidothiobacillus* | G-, aerobe | Oxidize $S \rightarrow SO_4^{2-}$ (sulfur oxidation) |
| *Acidothiobacillus denitrificans* | G-, facultative anaerobe | Oxidize $S \rightarrow SO_4^{2-}$ (functions as a denitrifier) |
| *Acidothiobacillus ferroxidants* | G-, aerobe | Oxidize $Fe^{2+} \rightarrow Fe^{3+}$ |
| *Heterotrophic bacteria* | | |
| *Actinomyceyes* | G+, aerobe, filamentous | Produce geosmins and antibiotics |
| *Bacillus* | G+, aerobic, spore former | C cycling, production of insecticides and antibiotics |
| *Clostridium* | G+, anaerobe, spore former | C cycling, fermentation, toxin production |
| *Methanotrophs* | G-, aerobe | Methane oxidizers that can cometabolize trichloroethene using monooxygenase |
| *Rhizobium* | G-, aerobe | Fixes N symbiotically with legumes |
| *Frankia* | G+, aerobe | Fixes N symbiotically with nonlegumes |
| *Agrobacterium* | G-, aerobe | Pathogen for plants |

**Table 2.**
*Main autotroph and heterotroph bacteria roles in soil (adapted after Pepper and Gentry, [19]).*

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#### *2.2.3 Fungi role in soil processes*

Fungi perform several key functions in soil. They are considered important decomposers and mutualists. Saprophytic fungi, the main decomposers, degrade dead organic materials. These are transformed into fungal biomass, $CO_2$, and several small but essential molecules (e.g., amino acids). Hussain et al., [51] and Chaudhary et al., [52] reported that *Phoma sp*. and *Penicillium sp*., respectively, induce synthetic resistance against plant pathogens. Fungi such as *Trichoderma sp.* and *Phoma sp*. enhance biomass production, improve plant growth [53], and promote lateral root growth [54]. Mutualists are mycorrhizal fungi. Most time, these colonize plant roots. They favor phosphorous solubility and bring micro and macronutrients to plants. Arbuscular mycorrhiza fungi were reported that increase soil nutrient availability and improve nutrient acquisition by plants. Heidari and Karami [55] reported that mycorrhizas could enhance crop yield by fostering host resource uptake through sharing. They could minimize nutrient loss under extreme meteorological events also. Celik et al., [56] through their study assessed that arbuscular mycorrhiza fungi are important in both of forming stable soil aggregates as well in the improvement of water retention. Also, there are many studies that report their efficiency in the phytoremediation of polluted soils [50]. Yeast was summarized by Pepper and Gentry, [19] as consumers of bacteria and plant root exudates for the synthesis of plant protectants and many other useful and important compounds that enhance plant growth. Beeck et al., [27] highlighted that yeast produces significant extracellular polymeric substances. For that, yeast is often associated with soil structure formation and maintenance.

#### *2.2.4 Algae role in soils*

Recently, many studies have evidenced that algae are important in maintaining soil fertility. In their life cycle, they contribute to soil particle binding and facilitate soil erosion prevention [36]. It was reported also that algae are involved in rock weathering, thus they could be considered as wrapped up in soil structure building [57]. Algae increase soil water retention capacity, enhance submerged aeration through photosynthesis processes, and contribute in the reduction of soil nitrates through leaching or drainage processes [19]. After their life cycle, they contribute to soil nutrient resources with large amount of organic carbon.

#### *2.2.5 Protozoa role in soil*

Protozoa maintain microbial diversity and functional stability (microbial/bacterial equilibrium) through their nutrition (feeding and ingestion) and multitrophic interactions at that take place. Chen et al., [58] highlight in their paper protozoa positive influences on nutrient availability for plants, release of hormones for plant development, and biological control agents against organisms that could induce potential harmful diseases in plants. Ronn et al., [59] acknowledged that protozoa are also involved in the accumulation and stabilization of organic carbon in the soil.

## 3. Soil ecosystem services: Connection with soil microbiota

According to the implications that components of soil microbiota have in various soil functions, becomes obvious that soil belowground microbiota diversity is an important resource for maintaining the functioning of soil ecosystem and consequently of ecosystem services on which society depends. Soil microbiota through their metabolic pathways is directly involved in greenhouse gas removal, nutrient cycling, pathogens inactivation, and pollutants degradation. **Table 3** gives a summary of the

| Service | Ecosystem services | Soil function | Role of microbiota |
|---|---|---|---|
| Support | Primary production | Support for terrestrial vegetation | Net and gross primary productivity is assured by soil microbiota through reactions in that transform organic and inorganic compounds into usable form for other organisms. Also, microbiota mobilizes nutrients from insoluble minerals to support plant growth. |
| | Soil formation and renewal | Soil formation processes | Microbiota speed up and modify soil physicochemical processes. |
| | Nutrient cycling | Storage, cycling, processing of nutrients and delivery to plants | Nutrient cycling among organic and inorganic pool is driven by soil bacteria, archaea, and fungi turnover. Fungi are effective in C and N storing in organic matter. AMF controls plant P nutrition. Saprophytic fungi generate more degradative enzymes, thus are important decomposers of recalcitrant plant litter. Bacteria higher turnover rate speed up gross mineralization and plant nutrient uptake. Nitrogen, phosphorus, and sulfur mineralization, nitrification, bioweathering of P minerals, and sulfur oxidation is assured by soil bacteria and fungi communities. |
| | Platform | Supporting structure for human activities | Microbes contribute to soil formation through elements cycling, and compounds and organic matter production. They are involved in minerals weathering. Microbial products are critical to soil aggregation. Improved soil structure makes it more habitable for living organisms. |
| Provision | Refuge | Habitat for resident and transient populations (terrestrial habitat) | Soil bacteria, archaea, and fungi contribute to soil formation and are the foundation of soil food webs, thereby underpinning the diversity of higher trophic levels. |
| | Water storage | Water retention and supply in the landscape | Soil microbiota are food and nutrient resources for higher trophic level organisms, such as plant roots, earthworms, and others. These contribute to macropores formation, which is related to hydrological processes (infiltration, drainage). |

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| Service | Ecosystem services | Soil function | Role of microbiota |
|---|---|---|---|
| | Supply of food, fibers, biofuels, and wood (biomaterials) | Provision of plant growth and production | Soil microbes produce antimicrobial agents and enzymes useful for several biotechnological purposes. Microbiota species produce plant growth hormones, symbioses (mycorrhizal fungi and $N_2$ fixing bacteria), pathogen control, and degradation of stress ethylene (ACC deaminase-positive bacteria). |
| | Supply of raw materials of mineral origin | Provision of source materials | Soil microbes are involved in minerals weathering processes. |
| | Biodiversity and genetic resources | Source of unique biological materials and products (soil biota) | Soil bacteria, archaea, and fungi comprise a vast majority of the biological diversity on earth. Further, they are the foundation of soil food webs, thereby underpinning the diversity of higher trophic levels. Interactions among soil microbes and plants often determine plant diversity. |
| Regulation | Control of potential pests and pathogens | Population regulation (soil biota) to control pests, pathogens, and diseases | Soil bacteria, archaea, and fungi support plant growth by increasing nutrient availability, and by outcompeting invading pathogens through inter and intraspecific interactions (symbiosis, competition, host-prey association). |
| | Recycling and remediation action | Disposal and decomposition of residues and pollutants | Soils absorb and retain solutes and pollutants, avoiding their release into the water. Microbiota contributes to both the hydrophobicity and wettability of soils, impacting the ability of soils to filter contaminants. |
| | Water quality regulation | Filtration and buffering of water | Soil macropores are formed by plant roots, earthworms, and other soil biota, which may depend on soil microbes as food or for nutrients. Also, microbiota is involved in pollutant degradation. Nitrate respiring bacteria, fungal and bacterial contaminant degraders, metal oxidizing and reducing bacteria (e.g., sulfate oxidizers, *Geobacter metallireducans*) assure a dissimilatory nitrate reduction, co-metabolism and mineralization of organic contaminants, sulfate reduction and subsequent metal precipitation, metal respiration, and precipitation. |

| Service | Ecosystem services | Soil function | Role of microbiota |
|---|---|---|---|
| | Water regulation, and flood and drought control | Regulation of hydrological flows, buffering, and moderation of hydrological cycle | Soil pores through their capacity to retain and store quantities of water can mitigate and lessen the impacts of extreme climatic events. Soil microbiota are involved in soil pores characteristics defined as macropore formation and soil aggregate formation. |
| | Regulation of atmospheric GHG and climate regulation | Carbon sequestration and accumulation, regulation of the atmospheric chemical composition, and climate processes | Soil microbiota is involved in litter fragmentation and decomposition, and physical and chemical stabilization of residue carbon. By mineralizing soil carbon and nutrients, microbes are major determinants of the carbon storage capacity of soils. Denitrifying bacteria, fungi, and methane-producing and consuming bacteria regulate $N_2O$ and $CH_4$ emissions from soil. Methane production is done by methanogens, while methane oxidation by methanotrophs. Chemoautotrophic nitrification, heterotrophic nitrification, denitrification, and co-denitrification are assured by nitrifying and denitrifying bacteria and fungi. |
| | Erosion control | Sediment retention | Soil microbiota promote plant growth through nutrient cycling and transformation in an available form for the plant, as well as through soil-root exchange enhancement, thus alleviating soil surface enhancement. Microbiota produces biological glues, and facilitates physical entanglement by roots and fungal hyphae. |

**Table 3.**
*Soil microbiota involvement in soil functions and processes assures diverse support, provision, and regulation services provision by the soil ecosystem (adapted after Aislabie and Deslippe, [60]).*

main soil services description linked to soil microbiota. Therefore, to benefit from soil ecosystem services depends on soil biodiversity, which contributes to the capacity of soil to function. Soil functions assure and sustain plant and higher trophic levels of healthy development, as well as air and water quality. At moment, based soil functions in that soil microbiota are involved, acknowledged their potential implication in regulating, supporting, and provisioning services.

### 3.1 Regulating services

*Regulating services*, generated or intermediated by soil microbiota include in high proportion soil ecosystem processes related to climate regulation; water purification and cycle regulation; pest, pathogens, and diseases control; and bioremediation (e.g., degradation of organic pollutants). *Climate regulation* is mainly mediated by soil bacteria and fungi as they are involved in processes of C exchange between land and atmosphere. Soil as a global carbon sink relies on plants to fix atmospheric carbon and soil microbiota to convert that carbon into the soil. Consequently, soil microbiota excites carbon sequestration and storage through essential interactions with plants. Plant growth and plant biomass could be positively stimulated through nutrient solubilization and phytohormone production and regulation, processes mediated by soil bacteria and fungi. Moreover, soil microbiota are involved in soil structure formation and maintenance through aggregate formation, physically defend the decomposition of soil organic carbon. Conversely, soil microbiota are acknowledged in direct implication in soil organic matter decomposition, which leads to greenhouse gases emission into the atmosphere. Overall, soil microbiota plays an essential role in regulating the global carbon cycle. Soil carbon store and emission depend on land use and applied management practices. Therefore, soil climate regulation depends on that. Studies are divided into two, based on the potential effects of climate change on soil microbiota and their functions related to climate regulating services. The acceleration of heterotrophic microbiota activities rate is correlated positively with an increase in temperature. This was, first, considered to be a positive effect [61]. However, heterotrophic microbiota respiration under aerobic condition increases with temperature rise. Capek et al., [62] described that this will also increase soil organic carbon stock depletion. Loss of soil organic carbon was associated with significant climate feedback effects, such as rising $CO_2$ and $CH_4$ level in the atmosphere. In turn, Drigo et al., [63] showed that a higher $CO_2$ level damaged soil bacterial community structure. The level at which bacterial community is damaged depends on the cover plant type and nutrient availability in the soil. These depend most of the time on soil management practices. Moreover, several agricultural practices are associated with a higher $CH_4$ and $N_2O$ emissions, both contributing further to climate change amplitude increase.

*Water regulation and purification*, implying soil microbiota, is assured through their degradation ability of various contaminants. Almansoory et al., [64] showed that *Serratia marcescens* can degrade total petroleum hydrocarbons from soil. *Pseudomonas sp*. degrade in soil herbicides as diuron. Song et al., [65] presented in their paper that *Rhizobium* bacteria degrade di-(2-ethylhexyl) phthalate. Soil bacteria could modify soil organic matter quality and quantity. This could change the water infiltration rate. Therefore, that could be also considered as an indirect effect of soil bacterial communities' influence on water regulation and purification services. *Diseases and pest regulation* by soil microorganisms could be assured through different mechanisms such as antagonism, competition, interference with pathogen signaling, or stimulation of host plant defenses [66]. Plants are often exposed to potential pathogens (e.g., *Erwinia*, *Pectobacterium*, *Pantoea*, *Acidovorax*, *Xanthomona*, etc.) that could cause leaf spots and blights, wilts, overgrowths, scabs, loss of fruits or even of species. Contrarily, the most efficient and dynamic bacteria that could suppress the development of diseases are those that belong to *Firmicutes, γ-* and *β- Proteobacteria*. Among fungi, *Ascomycota phylum* is the most representative.

*Soil organic waste and xenobiotics biodegradation* are assured by soil microbiota through processes such as transformation, mineralization, and stabilization. In order that these processes to take place favorable conditions are required. Generally, soil microbiota could use chemicals as substrate resources (energy, C, N, other nutrients, etc.) or could transform them by consecutive microbial enzymes or cofactors (co-metabolism) [66]. Microorganisms could adapt to contaminants; thus, the contaminant could promote their development. Microbiota in turn could tolerate or degrade contaminants (due to homeostatic capacity). The degradation capacity of microorganisms could be enhanced by supplemental nutrients/amendments addition, augmentation of degrading, or by promoting rhizosphere microbial degradation activity.

### 3.2 Supporting services

*Supporting services* are not directly used by humans, although they underpin soil ecosystem functions and processes on which humans depend. Soil microbiota are mainly involved in soil formation, nutrient cycling, water cycling, primary production, and habitat for biodiversity. All of these are related with supporting. Both bacteria and fungi are involved in supporting soil aboveground biodiversity through involvement in catabolic reactions throughout C and nutrients cycles are either break down, mineralized, or transformed. Bacteria that belong to *Actinobacteria*, *Proteobacteria*, and *Firmicutes* were reported to produce organic compounds that have influence on plant root system proliferation. Atmospheric N fixation is provided by free-living bacteria (*Azotobacter, Bacillus*, etc.). Higher available iron-chelating compounds are produced by bacterial species such as *Pseudomonas and Frankia*,. Dimkpa et al., [67] reported that species belonging to *Streptomyces* have the potentials for biofertilization, while *Agrobacterium sp*., *Bacillus sp*., and *Penicillium sp.,* possess phosphate-solubilizing capabilities. Recent studies show that plant rhizobacteria can smooth abiotic stresses related with global change drivers (drought, soil salt intrusion, extreme temperature, poor nutrient availability, contaminants, etc.).

### 3.3 Provisioning services

*Provisioning services* of soil ecosystems refers to goods that humans can use and benefit immediately. These are food, water, fiber, fuel, genetic resources, chemicals, medicines, and pharmaceuticals. Soil microorganisms are an important bioresource for several bioactive substances (antibiotics, biosurfactants, enzymes) [66]. They also mediate and facilitate several reactions and soil functions that the promote provision of mentioned soil goods. The complexity of linkages between soil functions (most mediated by communities of soil microbiota) and provided ecosystem services as well as their interrelations is given in **Figure 2**.

## 4. Challenges on soil ecosystem services: implications of global change drivers

Majority of ecosystem services required for humans' survival and development are resulted from soil processes and functions mainly mediated by biodiversity. This is due to involvement in soil biogeochemical and physicochemical processes, as well as in shaping the aboveground biodiversity and terrestrial ecosystem functioning through liaising nutrient cycles and turnover [48]. Once their structure can be influenced by environmental (soil physicochemical properties) and climatic conditions [68], they are considered as a relevant indicator of soil health and ecosystem sustainability. Thereby, soil biota is the main pillar that sustains and maintains the soil ecosystem. They are pivotal in supporting services such as soil organic matter decomposition, nutrient cycling, and organic and inorganic compounds degradation.

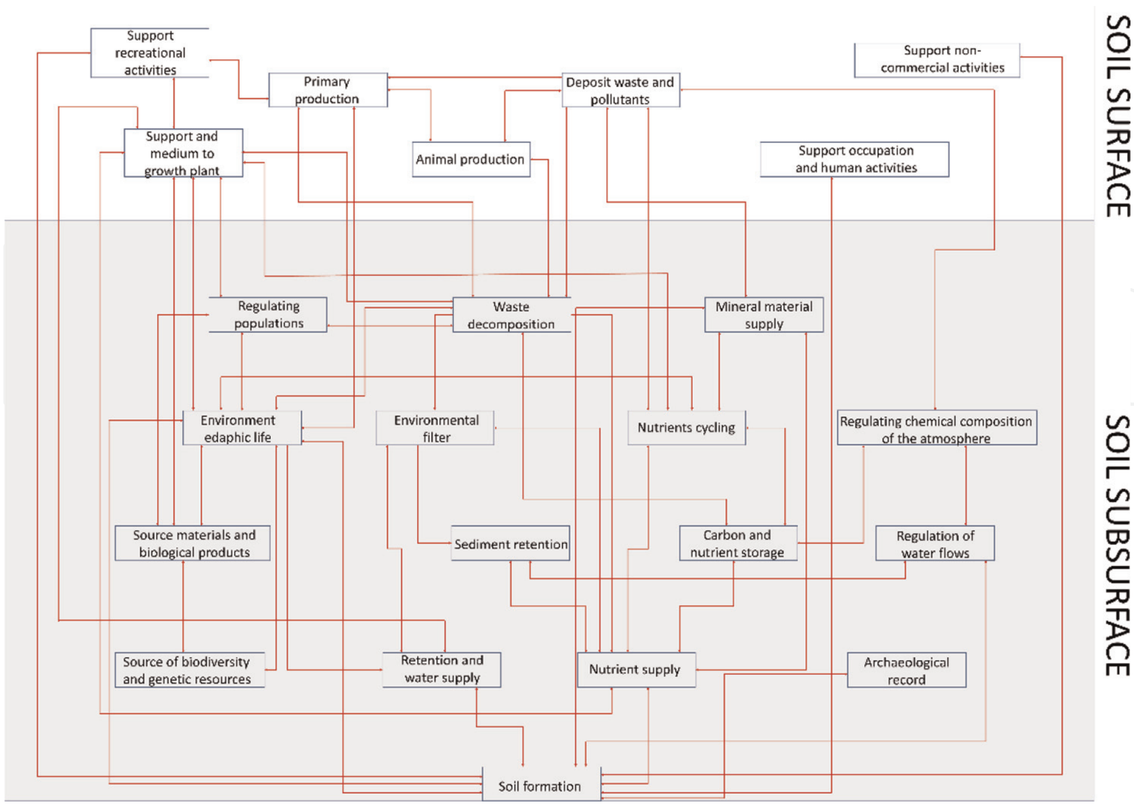


**Figure 2.**
*Interrelationship between microbiota mediated and other soil functions and ecosystem services.*

Through these, they contribute to soil fertility and quality. Microbiota sustains soil provisioning services by producing a wide range of organic compounds (e.g., polysaccharides, mucilage) that cohere soil particles. This influences soil supporting services as soil structure formation and development in time, through soil particle cementation. Further, soil structure stabilization is sustained by fungal filaments. Microbiota components are at the same time producers and consumers of soil organic carbon; thus, it is linked with supporting and regulating services of soil. Many studies underlay that soil microbiota could be a serious element in regulating services such as reducing atmospheric greenhouse gases. In this manner, they could limit climate change amplitude in future. Under favorable microhabitat conditions (optimal nutrient and carbon sources, available inorganic nutrients, proper acidity/alkalinity, temperature, aeration, moisture, etc.) microbial activity could considerably favoring and facilitating soil functions, and consequently the provision of soil ecosystem services at a higher amplitude. Niego et al., [69] reported that changes in soil microbiota diversity and abundance impact soil ecosystem processes. One of them is involvement in nutrient retention and cycling. These processes are related to the ability of soil microbiota components to break down organic matter and to release resources back into aboveground biota. Both plant litter decomposition as well N release back into aboveground plant diversity decrease with soil biodiversity shift in structure and abundance. Moreover, phosphorous, after increased rain events, could be lost through leaching. This is positively correlated with soil microbiota transformation and/or decline. Loss of soil biota become a great concern due to global change-related drivers induced pressures on it. Shift or loss of soil biota communities and abundance are thought to threaten soil ecosystem performance, further reducing the provision of ecosystem services [70]. Although it starts to become more clearer the importance of soil microbiota community structure and abundance in provision of soil ecosystem services, at the moment it is unclear how global change drivers will impact that. According to literature, until now most studies have focused on global change drivers' ecological consequences on aboveground biodiversity loss and less on belowground biodiversity. This is mostly attributed to the soils hidden diversity and heterogeneity. There are studies performed on land use and land management potential impact on soil microbiota. Usually, these connected soil microbiotas threaten with lower cycling of nutrients and other resources. Moreover, most studies focused on the effects and implications of a specific group or species. While soil microbiota components interact within complex food webs, which also contribute to changes in structure, abundance, and distribution within on trophic group or functional guild it is assumed that these may cause changes in the abundance, diversity, and functioning of another [70]. Therefore, become emergent to understand and get knowledge on how loss of soil microbiota will impact soil functions performance in providing ecosystem services.

Concurrent use with intensified management of the soil for agriculture, forestry, grazing, urbanization, mining, etc. purposes has serious outcomes on the provision of soil ecosystem services. Climate change-related events such as extreme meteorological events, higher temperature, and altered precipitation frequency amplify the effects. Although not fully elucidated which species in which manner has an impact on soil ecosystem services provision, it started to become clearer that soil microbiota components have a relevant role in soil functions and processes. Consequently, this could influence the provision of ecosystem services. It was reported that generally, microorganisms could manifest resistance, resilience, or extinction against some abiotic and biotic disturbance or stress. However, even in that cases the mechanisms are not completely understood. The impact amplitude seems to depend directly on the type of stress or disturbance, combinations of these, and their end influence on micro and macrohabitat properties.

### 4.1 Climate change impact on soil ecosystem services

It is acknowledged that soil biodiversity from all geoclimatic regions is affected by climate change. There are several reports that attest to the impact of various climate change drivers on several aboveground biodiversity components' health, functioning, and distribution. Considering literature, often reported that selected species have become extinct while others are endangered [71, 72]. However, both extinctions as well changes in health and functional status of species can alter seriously important ecological processes because they control, and mediate functions related to it. However, plants and animals respond in different ways at the pressures of climate change drivers. Usually, species have a tendency to cope with them. This is because of their evolutionary and ecological properties. Low-altitude inhabiting species extend their distribution at higher elevations while species from higher altitudes reorganize their relationships between community structure. Therefore, species range expansion poleward in latitude and upward in elevation is a common feature under changing climate properties. Generally, species are vulnerable due to their native habitat fragmentation and the negative effects of climate change drivers. They present individualistic responses to these challenges, but these will present a more pronounced and extended impact on the composition and functioning of future ecosystems [73]. Projected data reported in the literature consider macro-biodiversity. Information on how climate change impacts soil belowground microbiota, their involvement in ecosystem services provision as well how soil ecosystem will change, are scarce at present.

#### *4.1.1 Atmosphere composition*

Soils play a fundamental role in climate maintenance under favorable conditions, one of the major regulating services. Soil processes, mainly mediated by soil biodiversity, regulate climate through a balance of thermal and moisture exchange ratio, and greenhouse gases ($H_2O$, $CO_2$, $CH_4$, and $N_2O$) emission and retention [74]. Threatening of soil biodiversity can alter atmosphere quality and composition, which consequently will amplify climate change drivers further.

#### *4.1.2 Temperature and precipitation regime*

Degradation of soil ecosystem become frequent in many regions of the world. Changes in temperature, seasonality, and precipitation patterns have the potential to exacerbate soil ecosystem degradation. Many times, this results in lowering of ecosystem services' amount and efficiency. The high quality and quantity of ecosystem services are correlated with the health, complexity, and abundance of ecosystem species. However, species are limited in their adaptation to pressures such as temperature rise. Dow et al., [75] reported that an increase in average night temperature by 1° C decreased rice yield by 10%. Thus, changes in both temperature and precipitation regimes are often linked with food and other provisioning services decline. Alteration of evapotranspiration contribute also in the decline of primary productivity and food production [73]. These are supporting and provisioning services.

#### *4.1.3 Extreme climate events*

As changes in meteorological parameters could induce an alteration of the soil system's ability to translate the various ecosystem functions that support crop growth into provisioning services such as food, feed, and fiber, it becomes obvious that extreme climate events such as flood, drought, heat waves, and others, will have a more pronounced and dramatic effect.

### 4.2 Anthropogenic impact on soil ecosystem services

The prevalence of anthropogenic disturbance in the surrounding environment is obvious. These are highlighted through the soil physical and chemical properties decline. Soil properties decline manifest mainly through loss of its key constituents (clay, silt, soil organic carbon), diminution of water availability and holding capacity, abatement of key nutrients content, truncation of soil profile, and shallowing of topsoil depth as well through chemicals contamination and runoff. These deplete ecosystem C pool, enhance GHG reemission, and could induce anaerobiosis in soil layers. In part or in combination they could threaten soil microbiota through damage to their functioning, reduction in richness and abundance, or even in the extinction of species. The microbiology within soils supports a wide range of ecosystems underpinning the productive capacity and environmental sustainability of land use. Ample occupation of forests, grasslands, and wetlands for various purposes as the extension of living space and agricultural land resulted predominantly in the loss of biodiversity. This loss registered negative consequences on the soil chemical, biochemical, and physical properties. Ecosystem services are in high percent the end-result of interactions between plants, animals, and microorganisms from an ecosystem; biotic and abiotic properties of system; and human-engineered components of social-ecological systems. Ecosystem services provision, both in terms of quality and quantity, directly depends on land use type and use intensity, production system, and applied management [76]. These have an extensive impact on soil ecosystem services. Anthropogenic drivers and induced environmental stressors impact natural ecosystems through propagation of ecosystem functions that hamper ecosystem services provision [13, 30].

*Land use change* links human activities with ecological processes change that is closely connected with ecosystem services provision. Modification of land with aim of other use changes seriously soil ecosystem and its native biota abundance and spatial distribution. For example, in agriculture farms diversity (crops and/or livestock) is characterized mainly as "planned biodiversity." This always modifies soil ecological system structure and function, which end in failure of soil ecosystem ability to provide services. Therefore, the way of the use of soils has a decisive role on soil ecosystem services provision. Changes in natural land systems into agricultural or urban environment hampered soil ecosystem development, thereby reducing or stopping the provision of most support, provision, regulating and cultural services. Such alteration of services often amplifies soil issues such as erosion, poor fertility, desertification, and salinization [77]. Removal of forests for feedstock production for biofuels changed and damaged most services provided originally by the forest soil ecosystem. These are regulating services such as climate and water regulation through functions connected with carbon sequestration and accumulation, regulation of the atmospheric chemical composition and climate processes, as well functions linked to regulation of hydrological flows, buffering, and moderation of hydrological cycles. Provisioning services such as fiber, timber, genetic resources, and biochemicals are also reduced or totally shifted due to habitat modification and properties alteration. Such alterations extend their impact also on supporting and cultural services as well. Urban expansion is pronounced all around the world. This is also a driver associated with habitat loss and soil system degradation. Moreover, He et al., [78] and Wu et al., [79] reported that the continued expansion of urban areas will decrease significantly regional carbon storage, fostering thus climate change continuum and amplitude.

#### *4.2.1 Land management*

Intensive farming, mining, and industrial activities; as well as extended urbanization endangers local ecosystem services across landscapes. Soil erosion is a common feature of these activities. These reduce soil nutrient content which made microorganisms sensitive to this disturbance. Hereby, microbiota functions related to supporting services provision as nutrients element cycling and organic matter decomposition will decline [27, 32]. Until that moment farm diversity (crops and/or livestock) was characterized as "planned biodiversity." Although it comprised also "unplanned diversity," as weeds and pests, most of the time measures have been taken against them. Applied management practices were directed either to eliminate (e.g., pests) or promote (e.g., cultivated crops) populations or to enhance specific ecosystem processes (e.g., N fixation). Today, these practices and their effects at the macro-level made us to suppose that actions were felt also by associated species and functional diversity (e.g., soil belowground diversity), and consequently by their function performances in soil. The amplitude at which these were felt by soil belowground microbiota is not clearly acknowledged although there are evidence of their importance in several soil functions and processes performance. Crop diversification through crop rotations, cover crops, or intercropping enhanced regulation and sustainability of provided services. This was achieved through the facilitation of pest, weeds, and disease control by minimizing considerably or avoiding the use of agro-chemicals. Furthermore, crop diversification stimulates soil microbial abundance and, in turn, soil biodiversity. Also, it supports carbon sequestration, which provides additional ecosystem services. Brussard et al., [80] stated in their paper that after abiotic disturbances or stresses, soil ecosystem and its inhabiting diversity could either restart succession from the stage to which it was set back or transcend into a new stability level. They assumed that after release from disturbance or stress, the reversion could take a long time. The required time usually could depend on spatial heterogeneity where recolonization must take place, and on microorganism restoration and dispersal abilities. However, studies in this sense are at early stage at this moment and the mechanisms and multilevel effects are not fully understood. Soil microbiota community resistance against stress and resilience from disturbance are important to be acknowledged for the proper management of biodiversity and provisions of linked ecosystem services. Crop production is associated with soil carbon content decline. This impacts soil functions as water and nutrient retention. The application of high amount of chemical N for intensive crops and vegetable cultivation caused an array of soil and connected ecosystem services alterations associated mainly with ecosystem pollution. These could be summarized in reactive N losses and greenhouse gas emissions. According to literature tilled agroecosystems without crop rotation decrease microbiota abundance and certain species richness. Opposite, agricultural practices such as crop-rotation, no-tillage and use of organic amendments enhance diversity abundance and community structure richness [81]. However, based on applied organic matter quality, the effects on microbiota could be either positive or negative. Drainage and irrigation, in proper manner, could enhance soil microbiota diversity and abundance. Tillage, a usual field operation practice modifies soil s-tructure favoring agronomic processes (seed contact, root proliferation, water infiltration, etc.). Under conventional tillage, soil microbiota is altered structurally, morphologically, and functionally. This reduces microbial biomass, nutrient cycling, and enzymatic activities. Tillage reduces especially bacteria abundance and AMF diversity.

#### *4.2.2 Chemicals and other extraneous elements addition to soil ecosystem*

Pesticides and fertilizers can adversely impact selected soil biota species. This could result in the diminishment of their functionality, lower health status, or extinction. Such threat to soil biodiversity species will damage soil food webs, thereby underpinning the diversity of higher trophic levels. Moreover, modified interactions among soil species as well as a lower abundance or altered functioning of biota will significantly reduce supporting (nutrient cycling, soil formation, primary production) and regulating services (disease regulation pollination, climate, and water regulation). These consequently will negatively impact soil provisioning and cultural services. Municipal compost and animal slurries application to agricultural soils were considered as means to replace fertilizers used in conventional agricultural practices, and to reduce waste deposition in landfill sites. Acceptance of this practice was sustained also by other potential benefits such as the reduction of carbon emissions linked with mineral fertilizers production and use and with reduction of greenhouse gases emission through organic material decomposition and degradation in storing landfills. However, once with application of these management procedure on agricultural lands, new studies were performed assessing their impact. These evidenced several new safety issues linked to them. Most of these issues are related to the higher loads to the soil of potentially toxic chemicals, crops phytotoxicity, higher $CH_4$ and $N_2O$ emission, as well as high potential in the introduction of alien and potential toxic microbiota components (e.g., pathogens). However, understanding and knowledge related to the impacts of applying organic waste materials to agricultural lands is developing at moment. There is information that introduction of alien species and/or pathogens in soil have the potential to change physical environment properties but is not clear how will this modify microbiota community structure and abundance that are involved in several key soil functions. EA published a report in 2008 [82] highlighted that organic waste material with higher Zn content shifted rhizobium bacteria abundance, which is responsible for nitrogen fixation into the soil. Considering agricultural and organic wastes, Garcia et al., [83] published that they could degrade the local ecosystem in multiple ways, reducing and altering therefore the provision of ecosystem services. They mentioned that swine manure ends up in nearby waters (rivers, streams, creeks, etc.) impacting fish diversity health and abundance, and water quality as well. However, more experimental and confirmatory data are still required in order to comprehend relations and connections between organic waste materials application to agricultural lands and changes in soil microbiota and ecosystem services, respectively.

## 5. Conclusions

Collectively, soil microbiota has key roles in soil ecosystem functioning processes, such as organic matter decomposition, nutrient cycling, and soil fertilizing. Through these, they assure soil with essential nutrients and elements with that soil could sustain the continuation and development of living organisms. As producer and consumer of soil organic carbon, they could sequester C into soil for a large period. They contribute to atmospheric greenhouse gas reduction and have the potential to limit the effects caused by greenhouse gases generated by climate change. Microbiota through their biochemical reactions assures in large part soil structure development and soil water retention capacity. With released polysaccharides and mucilage help to cement soil aggregates and consequently, reduce aggregates crumble when exposed to water. Summarizing all involvement and effects of soil microbiota components in soil processes and reactions, it could be concluded that most microbiota community components break down organic matter, recycle nutrients in soil, create humus, influence soil structure, fix nitrogen, promote plant development and growth as well protect them against pests and diseases. It is obvious that soil biodiversity is a critical element that assures soil ecosystem functioning and sustainability. Soil belowground microbiodiversity is as valuable as aboveground biodiversity, as they are being involved in many soils' biochemical and physicochemical processes. The effects of global change drivers on aboveground species are acknowledged through literature but knowledge on these how will impact soil microbiota and how a change in their structure and functioning will modify the sustainability of soil ecosystem functioning and ecosystem services delivery require additional research. In this context, exploring the influences of global change drivers on soil microbiota involved in key functions that contribute to and deliver ecosystem services is significant for understanding potential changes in regional soil ecosystem, ecology, and environment; enhancing soil ecosystem and ecology security; to promote a sustainable development maintaining in safe limits soil environment resources.

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## Conflict of interest

The authors declare no conflict of interest.

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