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Seasonal Changes of Soil Organic Carbon and Microbial Biomass Carbon in Different Forest Ecosystems

Emre Babur and Turgay Dindaroglu

Abstract

Soil organic carbon (SOC) and microbial biomass carbon (MBC) are important components of soil organic matter (SOM). SOC and MBC have generally recognized key parameters of soil quality and health, and also they have been linked to forest ecosystem productivity, using as a sensitive indicator for ecosystem monitoring programs. Both of them play a crucial role in the carbon cycle and influence many environmental, biological, and chemical factors. Soil organic matter decomposition by soil microorganisms contributes to the nutrient availability and release in an ecosystem. This interaction between SOM and MBC is managed in soil aggregation, soil porosity, moisture content, and aeration. Forest soils can store more carbon than other land uses because they contain a wide variety of soil microorganisms. Enhancing these two important components of soil can contribute to climate change mitigation and adaptation strategies. In this chapter, an overview of the understanding of the most important soil quality and health factors managed soil C in forest soils and provided how seasonal changes affect soil organic carbon and microbial biomass carbon.

Keywords: forest soils, seasonal change, soil organic carbon, microbial biomass, soil health

1. Introduction

Soil is one of the most important components of ecosystems. It provides plant growth by regulating the cycling of nutrients, energy, and water. Also, soils play a major role in the carbon cycle among the atmosphere, vegetation, land, and ocean. Soil organic carbon (SOC) stores approximately 1600 PgC in the 100 cm depth, which contains more carbon than in the terrestrial vegetation (approx. 600 PgC) and in the atmosphere (approx. 800 PgC) [1, 2]. The carbon cycle is the exchanges between the various carbon reservoirs: biosphere, lithosphere, atmosphere, ocean, and fossil fuels (**Figure 1**).

In the last decades, atmospheric C concentration is known to increase with anthropogenic carbon emissions (ACEs) (e.g. fossil fuel combustion and cement manufacturing). The ACE was 6 Pg year⁻¹ in the 1980s [3]; it had increased to 10 Pg year⁻¹ in 2014 [4]. This caused a significant increase in global warming (**Figure 2**).

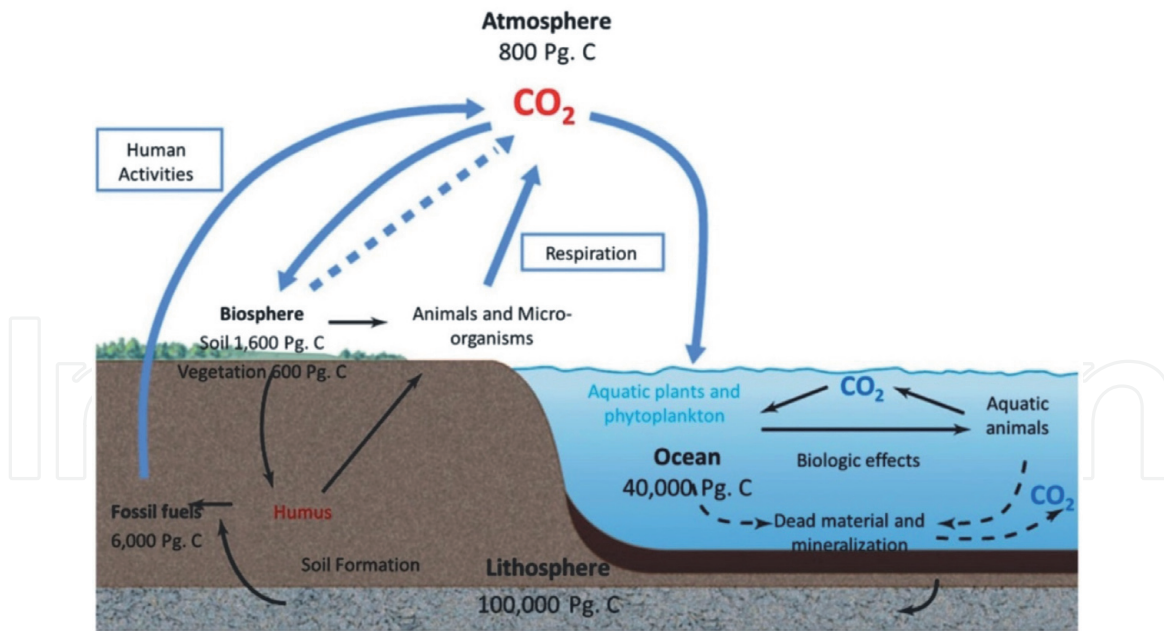


Figure 1.
The global carbon cycle and carbon reservoirs.

Forest ecosystems contain terrestrial C since they store huge quantities of carbon in different pools such as vegetation, litter, and soil and exchange big amounts of C with the atmosphere through respiration and photosynthesis. Among the OC reservoirs in forests, the soil stores *large quantities* of OC, accumulating C as soil organic matter (SOM). Indeed, soils have been accepted as the largest terrestrial carbon pool because of the greater C content than terrestrial vegetation and atmospheric C [5, 6]. Forest soil can friendly contribute to reducing the atmospheric carbon dioxide concentration and the greenhouse effect in global warming, while the soil is considered a big carbon pool [7, 8], linked to the carbon cycle [5] and with the nutrient pool that assigns vegetation productivity [9].

In recent years, the researchers have focused on the SOM properties and soil organic carbon (SOC) which can have significant effects on its dynamics and also the direction of ecosystem reactions related to climate change (e.g., decomposition time, increasing soil temperature and CO_2 levels or changes in composition of vegetation, N deposition, etc.) [11, 12]. Most studies of SOC are related to soil fertility, soil management, SOM decomposition, and effects of greenhouse gas emissions in climate change. SOM is a significantly important factor in soil quality and productivity; however, this alone does not help adequately predict any changes in soil quality and nutrient status [13, 14].

The SOM decomposition process is dependent on substrate type and quality (fragment type and size, decay stage, nutrient availability, and tree species) and amount and activity of the soil microorganisms and environmental factors (climate, soil texture, structure, soil chemical compounds, soil moisture and temperature, aggregation soil nutrient availability and temperature, etc.) [15–20]. For example, though the soils under tropical forests store the highest amount of OC, desert soil stores the lowest amount of OC [21, 22]. Soil silt and clay content maintains organic carbon by aggregation [15, 23]. Hassink [19] revealed an increase in the SOC stored in the $<20 \mu m$ size fraction with an increase of clay + silt content. The soil sample has been shown under a microscope in **Figure 3**. Moreover, Gabarron-Galeote et al. [24] found that the highest soil carbon content is found in the silt and clay size fractions than the sand fractions.

Especially, studies on soil C dynamics and its effect on the global carbon cycle have been increased: (1) the importance of SOC for microbial biomass carbon (MBC) in dimension beyond a depth of 20 cm [17, 20, 25]; (2) the interaction

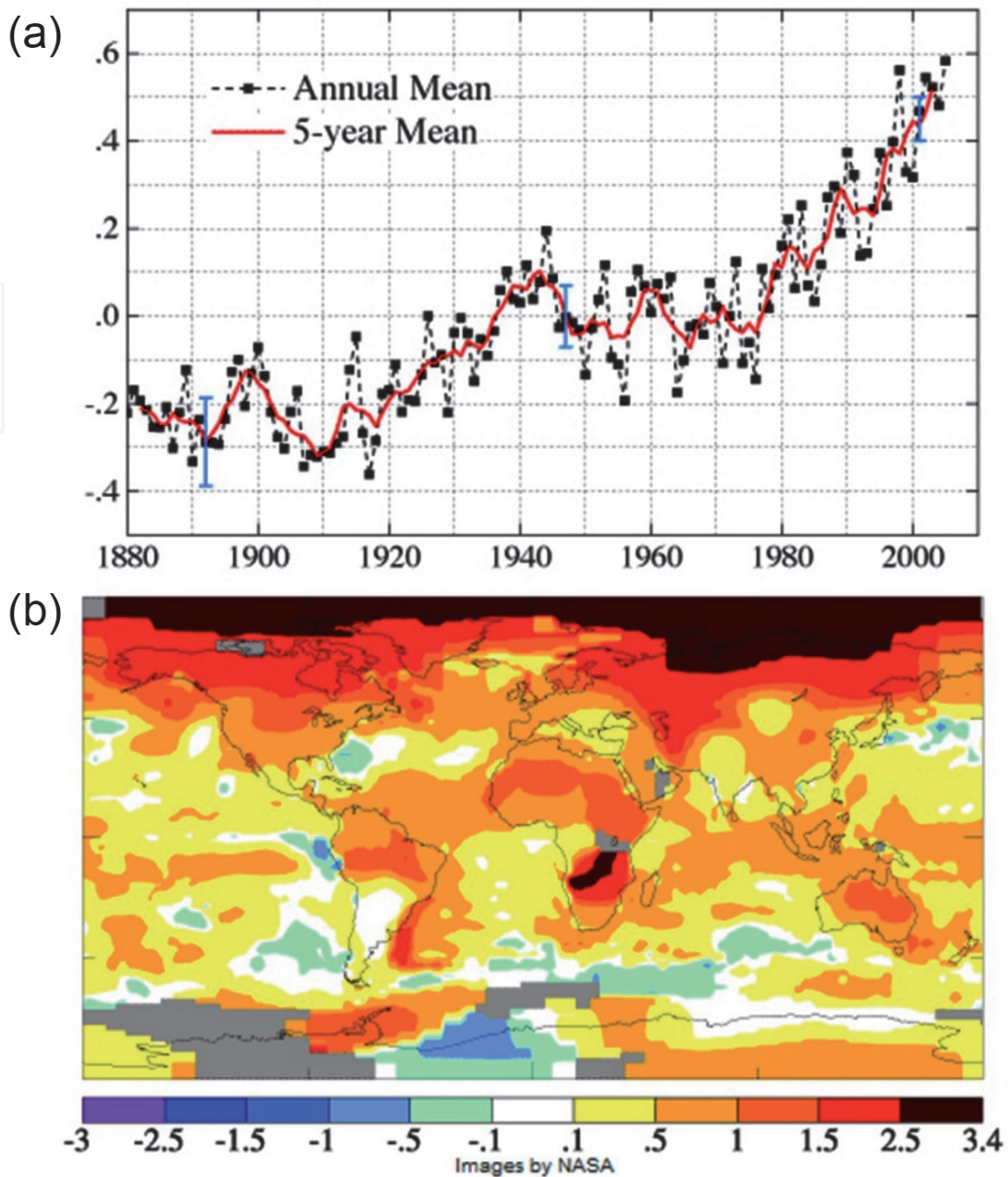


Figure 2. Annual temperature increase (a) and degree of increase (b) in worldwide. Source: images by NASA [10].

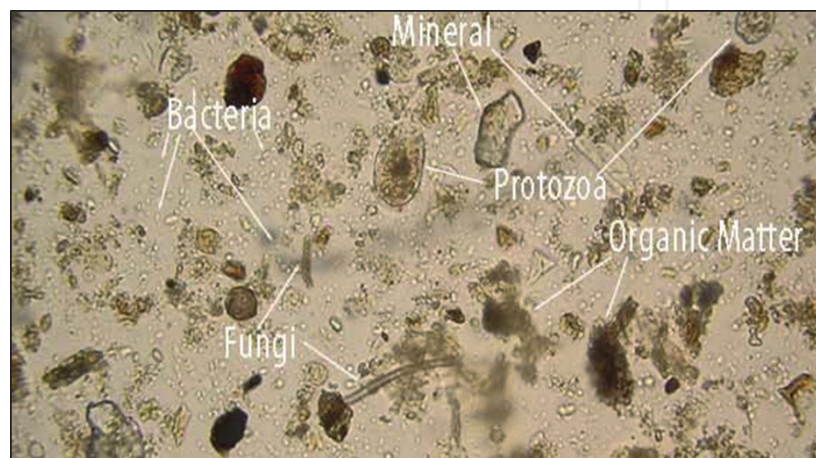


Figure 3. Soil sample under microscope by mauby.com [28].

between microbial communities and its activity with soil properties in relation to the carbon cycle and with other nutrient cycles [26, 27]; and (3) the effects of plant species in increasing soil microbial biomass and soil carbon storage [17].

2. Soil organic carbon in forest ecosystem

Forest ecosystems have been long accepted the most efficient tools for carbon sinks that can reduce atmospheric emissions via carbon sequestration in soil and plant biomass and directly reduce greenhouse effect [29]. Forest soils containing more than 70% of all the soil organic carbon are sequestered by forest ecosystems [30]. Therefore, in the use of forest soils against global climate change, the processes of organic matter cycle in soil and the site factors governing these processes need to be carefully evaluated. In other words we need to know the characteristics and interaction among ecosystems, plants, and soil in forests [31]. In forest ecosystems, SOM can be used as a significant indicator of soil quality and site productivity [32]. Since soil organic matter is composed of the higher amount of dead plant mass (forest floor and dead wood) and animals, OM is higher in forests than other land-use types. Also, the productivity of forest ecosystems depends on soil physical, chemical, and biological characteristics and processes [31]. Soil OC is one of the most essential soil components that contributes to ecosystem productivity through its positive effects on soil structure, aeration, and porosity and maintaining soil water and temperature [33–35]. Moreover, SOM has a strong relation with nutrient availability, because it is an important nutrient source that can be used by plants in long periods. Besides, SOM contributes to forming soil structure and increases water holding capacity in soils.

In recent years, numerous studies have been conducted to state the carbon stocks and relations with soil microbial communities in forest soils [30, 36–42], and other studies conducted on seasonal changes in soil microbial biomass [20, 43–47]. On the other hand, there are limited studies for more sequestering atmospheric C in soils by increasing microorganism populations.

3. Soil microbial biomass carbon in forest ecosystem

The terrestrial carbon cycle is provided by photosynthesis and respiratory balance. Carbon fixation by autotrophs, photosynthetic plants, and photo-chemotrophic microorganisms allows the transfer of carbon from the atmosphere to the soil. The return of carbon to the atmosphere takes place through the fossil fuels and respiration of microbial and other organisms. Soil microorganisms utilize carbon sources around the main objectives for growth and proliferation. Therefore, microbes use different forms of organic and inorganic carbon as carbon and energy sources. Due to the role of microorganism activities in the carbon cycle, it interacts directly and indirectly with climate change. For example, organic C mineralization and CO₂ released by respiration increase with increasing temperature. The amount of CO₂ accumulated in the soil increases photosynthesis and release of root exudates. This leads to microbial decomposition and respiratory instability. Since soil microorganisms in the carbon cycle have an important role, soil microbial biomass is utilized in most carbon cycle models. Soil microbial activity rate indicates the potential and dynamics of the nutrient cycle in a particular ecosystem. Also, microbial properties of soils can be used as an indicator of any fluctuations in the ecosystem due to its sensitivity to weather conditions, plant species or in the characteristics of animal residues [36, 48]. Soil microbial respiration is one of the

most important microbial indices first calculated in the majority of models. Microbial soil respiration explains all activity or energy consumption of the microbial communities [49]; therefore, it is the main parameter to observe decomposition rate [50].

The soil microorganisms are small, containing about 2–3% of SOC. But they are very important component in ecosystem function basically through the regulation carbon sequestering, soil respiration, plant productivity and also related to the nutrient mineralization, which plays a crucial role in the biogeochemical cycling of carbon (C), nitrogen (N), and phosphorus (P) in continental ecosystems [36, 37, 51–53]. SMB is the dynamic fraction of soil organic matter, which includes fungi, bacteria, actinomycetes, algae, protozoa, and other microfauna (**Figure 4**) and demonstrates an important nutrient pool in the soil [37]. Soil nutrient conservation processes and transformation are greatly interrelated to the amount of microbial biomass present in the soil (**Figure 5**).

Soil microorganisms are the active agent of soil organic matter and the most dynamic factor in soil. Hence, soil microbiological or biochemical characteristics are much more susceptible to any changes in soil conditions (degradation, erosion) and supply more accurate and immediate information in soil health and quality [54, 55]. For example, any changes in microbial biomass can be detected rapidly and precisely when compared to changes in soil physicochemical properties [56–58]. Nowadays, international programs for monitoring soil health and quality department noticed that combining the measurement of several microbial indices such as soil microbial diversity, microbial biomass, microbial respiration, and soil enzymes should be determined to measure ecosystem health [40, 50, 59] (**Table 1**). Insam et al. [60] also recommended that the ratio of microbial biomass to total organic carbon might state as an indicator of carbon dynamics in the soil. For example, microorganisms are extremely influenced by anthropogenic effects such as irrigation, fertilization, using insecticide, conventional tillage, etc. [61, 62]. The importance of microorganisms in ecosystem functioning has caused to proliferate the interest in determining soil microbial properties [63]. Soil microbial biomass is a source of microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial biomass phosphorus (MBP), and microbial biomass sulfur (MBS).

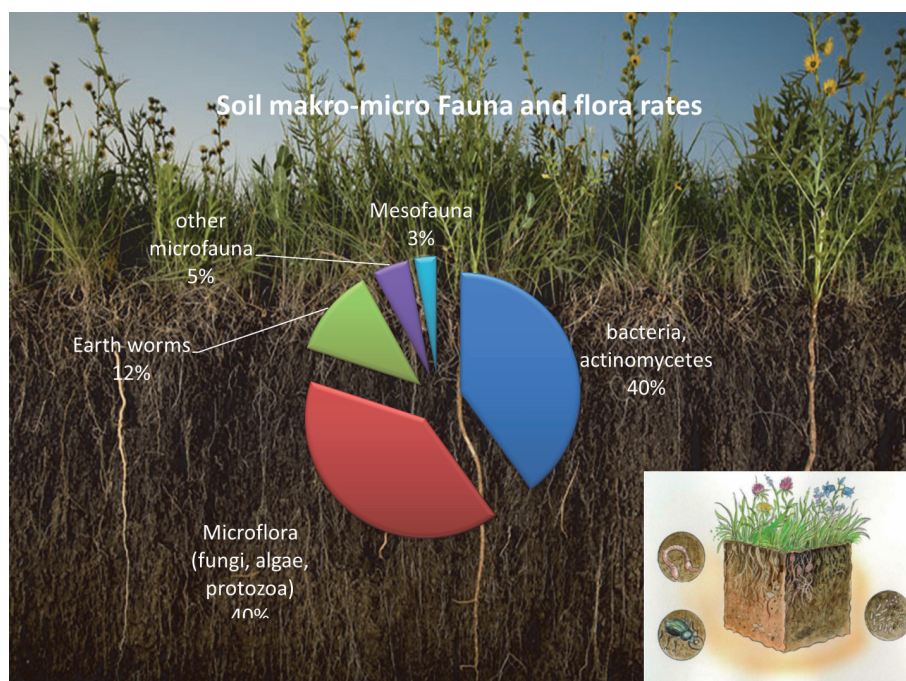


Figure 4.
Soil macro-micro fauna and flora rates.

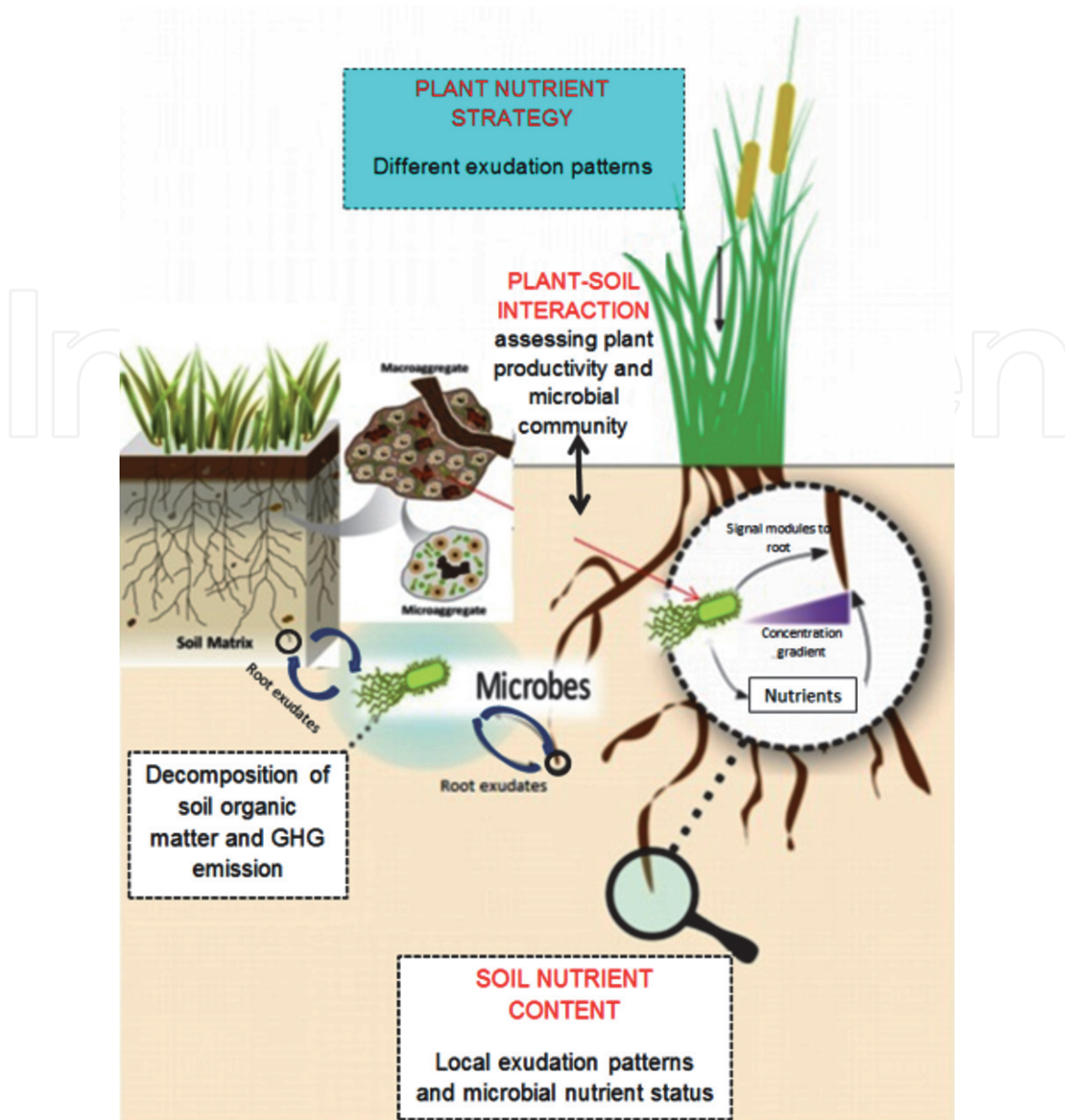


Figure 5. The figure illustrates a summary of the concepts proposed for the role of root exudates in plant-microbe interactions and consequences for ecosystems. Source: By changing from Canarini et al. [65].

Properties	• Soil mineralogy	• pH	• Microbial biomass
	• Texture	• Electrical conductivity	• Basal respiration
	• Soil depth	• Cation-exchange capacity	• N mineralization
	• Bulk density	• Organic matter	• Enzyme activities
	• Water holding capacity	• Macro-nutrition elements	• Micro-flora community
	• Porosity	• Heavy metals	• Plant biodiversity
			• Root diseases
			• Plant growth

Table 1. Physical, chemical and biological soil properties used as indicators in determining soil quality (changed from Pankhurst et al. [58]).

The MBC and MBN comprise 1–5% and 2–6% of the total soil C and N contents and tend to be relatively more stable. Approximately 1.4% of the world’s soil organic C content comprises soil MBC, but it contributes significantly to the global C cycle [64].

Soil microbial biomass plays a significant role in linking the plants and soil. A variety of plant species can influence soil characteristics, soil microbial composition and activity via their root activity, the release of root exudates, exogenous enzymes, sloughed-off cells, lysates, and litter decomposition into the rhizosphere [17, 66–68]. Exudates of plant halophytic roots supply sources of energy and carbon to microbes, considering that vegetation type, vegetation growth stage, metabolism type, and seasonal change are the main factors that influence the root exudates quantity and quality [69–71]. Thanks to different growth patterns, root structure and development, and resource distribution of different plants can lead to different microbial communities and their activity [69]. Richards et al. [72] and Malchair et al. [73] found that changes in tree species and composition potentially affect SOM quantity and dynamics. Additionally, some environmental factors such as moisture, temperature, and seasons influence soil microbial activities and result in changes in key biogeochemical cycles [71, 74]. The decomposition of SOM begins with enzyme-mediated hydrolysis of complex substrates, and these enzyme activities are used as indicators of soil quality [67, 75]. Bolat et al. [76] found that black locust trees significantly affect the total nitrogen (TN) content of the soil, because of the enzymatic activity and N-fixing ability by roots. It is also noticed that the SOC and TN content occurs due to the decomposition and accumulation of organic material in soils [77–79]. If organic material is added to a soil, it is decomposed by soil microorganisms and converted into some nutrients such as C, N, P, and K which are released in the soil.

Among the soil microbial indices, the soil microbial respiration is influenced by seasonal patterns, but seasonal change directly influences soil metabolism or indirectly affects the changes in microbial community composition and substrate availability. Determining any changes in microbial biomass C and N contents is important in a terrestrial ecosystem. However, many previous studies reveal that it is difficult to determine how changes in soil microbial biomass are regulated [80, 81].

Numerous studies have been conducted on the soil microbial biomass in different forest ecosystems [38–40, 82, 83], and also other studies that focused on seasonal changes in soil microbial biomass [43–45, 47, 84–88]. In general, some soil properties differ in the year. Zhou et al. [89] found that the changes in soil biomass in tropical and subtropical regions are higher in the summer than in the winter. This study noticed that whether moisture and temperature directly influence the soil community and biochemical processes.

Seasonal changes affect the soil temperature, soil moisture, organic matter content, root activity and amount of microbial community, and composition causing fluctuations in the soil. Also, these changes vary according to soil texture, structure, vegetation diversity and type, land-use type, and management application [87, 90]. Investigating the seasonal changes of microbial activities and biomass is essential for a better understanding of the nutrient dynamics in tree plantation.

4. Relationship between soil microbial biomass and organic carbon

Soil quality and health indicate the condition of the soil, depending on the chemical, physical, and biological factors that manage the biogeochemical processes of the soil. Some soil properties are rapidly affected by changes in environmental factors; other soil properties, which are not suitable for assessing soil health and quality, change very slowly in a long time [78, 91–92]. For instance, some studies have noticed that soil microbial indexes and activity may use more rapid indicators of soil health and quality than the physical and chemical soil properties (e.g., OC and TN). Therefore, soil's biochemical characteristics (e.g., MBC, MBN, C_{mic}/C_{org}

percentage, C_{mic}/N_{mic} ratio, basal respiration, and qCO_2 ratio) respond immediately to environmental stress [50, 57, 93].

Soils that have a high OC content usually have higher microbial biomass quantities [20, 39, 76, 94]. SOM decomposition by soil microorganisms plays a crucial role in global carbon and nitrogen cycling [95]. Substrate quality (e.g., lignin, cellulose, hemicellulose content) and the labile C and nutrient availability significantly affect soil microbial decomposition [96, 97]. The availability of nutrient sources affects the decomposition processes by influencing microbial physiology such as the production of extracellular enzyme activities. When there is an insufficient available nutrient or substrate, the microbial production of extracellular enzymes is stimulated [98–100]. Winding et al. [101] noticed that soil biogeochemical process can be determined by organic matter degradation or basal respiration, and it provides an estimation of microbial activity rate. A variety of microbial activities may show differences in the organic carbon cycle and nutrients within the terrestrial ecosystem. Also, Insam et al. [102] reported that the metabolic quotient (qCO_2) can be an indicator of soil development and decreases with ecological succession. For the abovementioned reasons, it is necessary to know the microbial properties of the soil for nutrient cycle balance and soil quality indicating plant growth.

5. Seasonal changes of SOC and SMBC

Seasonal changes have a significant effect on the soil OC, microbial biomass C and N, and other related microbial properties in soil. Some studies about seasonal changes in MBC and SOC have been shown in **Table 2**. SOC changes in an ecosystem usually occur gradually and take a long time. However, soil microorganisms are very sensitive to any changes due to seasonal inputs of plant residues, structure, and growth of roots, chemical component released by root exudates, or decomposition of organic material inputs. Because the soil microbial activity has a direct impact on the stability and productivity of the ecosystem, microbial biomass provides very accurate and fast information about the quality of soil [55]. Few data is describing the seasonal variation of C and microbial carbon in the soil. If seasonal variation influences soil OC, environmental parameters that play an active role in this event should be determined, and their interaction with each other should be demonstrated in the same experimental unit over time.

Soil organic matter is considered to be composed of a large pool very slowly changing and protected [103, 104]. Also, it is believed that soil C and microbial activity is responsive and sensitive to any changes in terrestrial ecosystems. The amount of soil OC and MBC largely depends on the quality and quantity of litter input and microbial activity rate that could be affected by soil moisture, temperature, porosity, presence, and amount of nutrients. Climatic factors especially temperature and moisture are the most significant environmental factors affecting soil microbial biomass population and activity. Seasonal changes in soil temperature and humidity directly cause fluctuations of soil microbial biomass population and activity rates [43–45, 84–88]. In different types of microbial populations have the highest or lowest limits in which growth and activity decline [105]. Allen et al. [106] recommended that the determining effects of seasonal changes in the microbial activity of studies of spatial variability rarely consider sampling at the same time in a year. Seasonal effects in soil OC reveal numerous studies measuring basal respiration and microbial indexes, but total OC analysis is insufficient. Bolat et al. [76] found that seasonal fluctuations showed significant effects on microbial indexes such as MBC, MBN, and MBP in the forest floor and soil because of seasonal fluctuations that alter the climate and biogeochemical process of the soil. In the

Studies	Tree species	Organic carbon %				Cmic $\mu\text{g C g}^{-1}$				Ntop %			
		Aut.	Win.	Spr.	Sum.	Aut.	Win.	Spr.	Sum.	Aut.	Win.	Spr.	Sum.
Barbhuiya et al. [88]	<i>Dipterocarpus macrocarpus</i> , <i>Shorea assamica</i> , <i>M. ferrea</i> , <i>T. nudiflora</i> , <i>Castanopsis indica</i> and <i>Vatica lanceaefolia</i>	1.33	1.65	1.51	—	1135	800	600	—	0.77	0.63	0.8	—
Devi and Yadava [80]	<i>Quercus serrata</i> and <i>Schima wallichii</i>	—	—	2.75–4.4		—	465.14	1182.6	738.32	—	—	0.39–0.54	
	<i>Q.serrata</i> and <i>Lithocarpus dealbatus</i>	—	—	2.6–4.34		—	382.58	740.73	392.92	—	—	0.33–0.50	
Muscolo and Sidari [116]	<i>Pinus laricio</i>	—	—	—	—	93	63	179	269	—	—	—	—
Bolat [45]	<i>Abies nordmanniana</i> subsp. <i>Bornmülleriana</i> Mattf.	6.08	5.35	6.06	5.21	1345	1016	714	845	0.36	0.32	0.34	0.32
	<i>Fagus orientalis</i> L.	3.75	3.75	3.26	4.15	650	567	517	629	0.23	0.24	0.2	0.26
	Mixed <i>abies-fagus</i> forest	3.33	3.33	3.01	2.28	844	476	505	757	0.22	0.19	0.17	0.16
Bolat et al. [76]	Black locust	—	—	0.64	0.72	—	—	—	311.97	483.34	0.17	0.21	—
Siles et al. [117]	<i>Q. pubescens</i> , <i>Q. robur</i> , <i>F. sylvatica</i> , <i>Pinus sylvestris</i> , <i>Picea abies</i> , <i>Larix decidua</i> , <i>Fraxinus ornus</i> , <i>Ostrya carpinifolia</i>	29.25	—	18.19	—	—	—	—	—	1.06	—	0.78	—
Bargalia et al. [118]	Oak forest	2.99				554.3	540.7	545.7		0.21			
	Pine forest	1.96				467.3	446	451.3		0.09			
	Mixed oak-pine forest	5.3				728	710	716		0.32			
Babur [47]	<i>Cedrus libani</i>	4.93	4.39	4.78	4.48	807	401	635	486	0.405	0.303	0.393	0.361
	<i>Fagus orientalis</i>	5.36	5.2	4.62	5.58	691.8	547	539.99	658.08	0.34	0.223	0.315	0.353
	Black pine	4.56	4.62	4.33	4.45	659	252	309	590.2	0.27	0.179	0.239	0.23

Table 2.
Some studies about seasonal changes in MBC and SOC, TN.

same study, it was stated that microbial biomass reached the highest populations in the summer season.

In some of the studies mentioned below, the changes in soil organic carbon have been observed at different times of the year. Boerner et al. [107] studied on three mixed oak forest ecosystems in Ohio and found statistical differences in a variety of season and plant species. In another study in the Canadian prairie, four different samples were taken in spring, summer, autumn, and winter season [108]. In a study in Michigan, significant differences were found in the sampling in April and June which were 23% in a wheat field and 18% under poplar trees [109]. These studies indicate that seasonal changes are an important factor, but other factors may also be similarly involved, such as soil sampling technique and design and changes in soil water and temperature.

Seasonal changes in environmental conditions such as humidity and temperature facilitate the microbial biomass cycle, and therefore microbial biomass plays a crucial role in regulating nutrient uptake. Microbial biomass is considered dead if the soil substrate dries in summer or freezes in winter. Increases in microbial activity and population due to wetting and dissolution phenomena are attributed to the increase in available nutrients from dead microorganisms. Changes in soil temperature and humidity affect the C mineralization rate, the species structure of the microbial community, and the availability of nutrients from the soil solution [110, 111, 125, 126]. Carbon and microbial biomass carbon contents of soils formed under pure forest stands were investigated in research conducted in karstic areas of the Eastern Mediterranean region [47]. As a result of these investigations, it was stated that there was an increase in microbial biomass during the seasons where the soil temperature and humidity were optimum and that the seasons and plant species significantly affected the organic carbon and microbial biomass carbon contents of the soils (**Figure 6**) [47]. However, in another study conducted in the tropical Amazon rainforest, microbial biomass C indicates no significant seasonal changes [112]. Many researchers state that seasonal changes in microbial biomass are related to the water content and temperature conditions of the substrate [113–115]. In Spruce (*Picea rubens* Sarg.) forest, in a study carried out after heavy rains that occurred when the soil temperature reached +5° C, microbial biomass C was found to have a negative relationship with soil temperature, whereas microbial C, N, and P showed a positive relationship with soil moisture [116]. In another study, it was stated that the seasonal changes in microbial biomass were not only related to climatic conditions. Seasonal changes in microbial biomass may also be related to

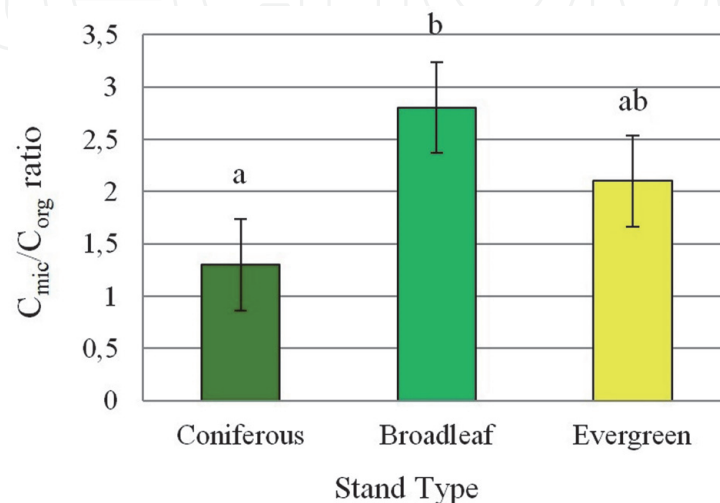


Figure 6.

The C_{mic}/C_{org} ratio determined in different stand types (changed from Bauhaus and Khanna, 1999).

changes in the amount of C that can be obtained from the amount of fine root, root secretions, and dead cover [111]. In various studies, it is emphasized that it is difficult to generalize the effect of tree species on microbial parameters.

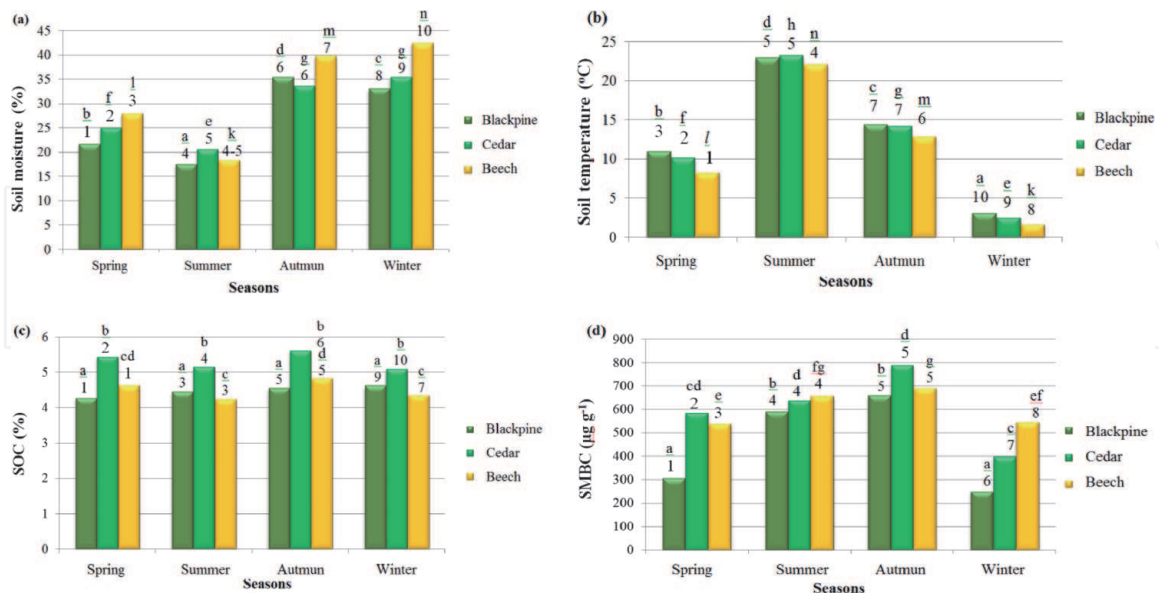


Figure 7. (a) Moisture (%), (b) temperature (°C), (c) SOC and (d) SMBC mean values at soil samples. According to seasons $n = 90$ and tree species $n = 120$ total soil samples were analyzed. Different letters between seasons; the different numbers indicate differences between the tree species at the significance level of $P < 0.05$.

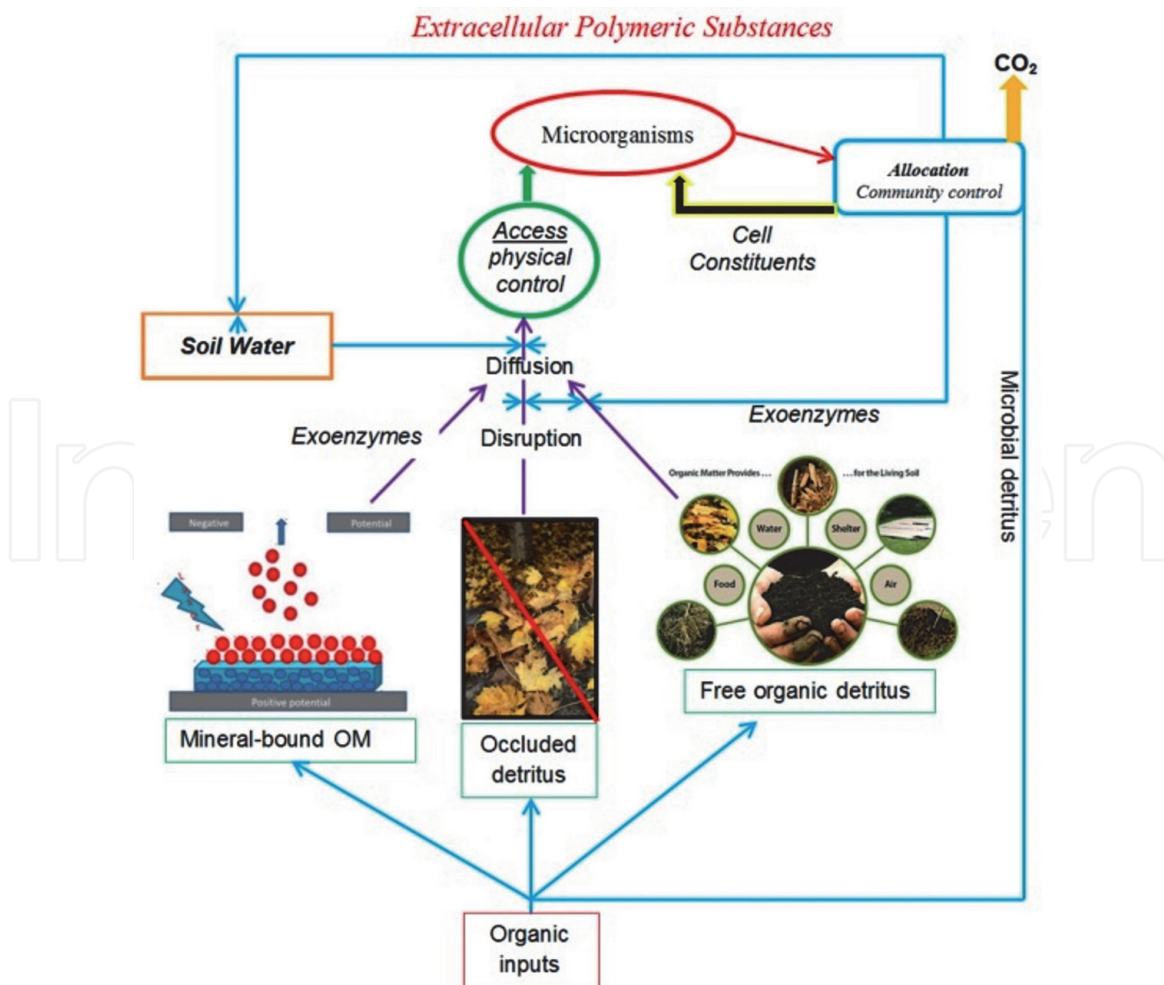


Figure 8. Microbial C cycling the relative roles of physical access to soil C pools and of microbial allocation patterns in regulating overall soil C dynamics.

It is stated that C_{mic}/C_{org} percentage in leaf litter is higher in broadleaf forests (2.58%) than coniferous forests (1.27%), whereas it is stated that this value does not have a significant difference in evergreen forests (2.06%) (**Figure 7**). As a result of this study, it can be said that the litter quality of broadleaf species is better than the coniferous species or that the site factors of the broadleaf species are more suitable than the coniferous species for the microbial activity [111]. Similarly, Scheu and Parkinson [117] found that the amount of C_{mic} in the litter layer and the C_{mic}/C_{org} percentage were higher in the poplar stand than in the pine stands. The effective role of microorganisms in soil dynamics and the C cycle is shown in **Figure 8**.

Although soil microorganisms are a small part of soil organic material, it is an important factor that significantly and positively affects carbon storage in soil [36]. In addition to altering the physiology of microbial communities, changes in the availability of resources may indirectly affect microbial processes. The differences in substrates differ in the diversity of soil microorganism's community. These can lead to the supply of C, and nutrients from substrates are required for the productivity and biomass growth of forest ecosystems [110, 120–126], and also changes in sources have been shown to cause differences in microbial community composition [118, 119]. Changes in the composition of the microbial communities can significantly affect microbial processes, as certain enzymes are produced by specific groups of microorganisms [120, 121].

6. Conclusion

Consequently, any changes in quantity and quality of C and N in the soil directly influence on soil's biological characteristics. Furthermore, some various characteristics of soil such as temperature, moisture content, pH, silt, and clay content influence soil microbial activities [45–47]. Microbial microorganisms are very important in controlling nutrient dynamics and availability of soil ecosystem; on an annual basis, most of the nutrients for plants are maintained through mineralization of soil organic matters [105, 115]. Therefore, it is essential to investigate the seasonal changes of microbial activities and microbial biomass and the effects of seasonal changes (mostly temperature and water content) on them, to better understand the nutrient dynamics in tree species. The amounts of microbial population and activity significantly changed with the seasons and followed a sequence order (summer > autumn > spring > winter). In other words, microbial indexes such as MBC, MBN, and basal respiration rate in summer and autumn seasons are found to be higher than in spring and winter seasons.

This study illustrates that soil microbial community structure would vary with seasonal changes and tree species affect soil microbial community composition by changing the soil physicochemical properties.

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