

Effects of Global Warming on Soil Ecosystem Carbon Cycle

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Abstract. The effects of warming due to increased greenhouse gases on the soil carbon cycle have attracted considerable attention. This article presents a comprehensive examination of the fundamental mechanisms implicated in the carbon cycling process inside soil. This article examines various aspects of the soil carbon cycle, including soil respiration, soil apoplastic matter, soil microorganisms, and soil carbon stores. The following findings were derived: The soil microbial community exhibited notable structural alterations in response to rising temperatures. An increase in temperature significantly increases fungal activity in soil microbes. The rise in temperature resulted in an enhanced influx of carbon from vegetation into the soil, thereby facilitating an augmentation in carbon reservoirs within the soil. Increased temperatures have been found to have a positive effect on the process of soil mineralization, leading to the decomposition of soil organic carbon and a subsequent reduction in the storage of carbon within the soil. Elevated temperatures have the additional effect of expediting the process of soil mineralization, which in turn results in the breakdown of soil organic carbon and a subsequent decline in the storage of carbon within the soil. Warming results in long-term declines in soil moisture, and ecosystems in very dry regions may experience reduced carbon uptake. Adaptation of soil respiration to higher temperatures is a more general phenomenon.

Keywords: Global warming, carbon cycle, soil.

1. Introduction

The current estimation of human-induced global warming surpasses pre-industrial levels by around one degree Celsius, with a potential range of 0.8 to 1.2 degrees Celsius [1]. As worldwide temperatures rise, arid ecosystems are expected to experience a decrease in carbon sequestration, leading to a positive feedback loop that exacerbates warming. On the other hand, wetland ecosystems can experience negative feedbacks. In addition, warming causes soil moisture to decrease over a longer period of time. Climate warming has profound effects on soil respiration in terrestrial ecosystems, thereby altering the process of the global carbon cycle. Soil temperature is a crucial environmental factor that regulates various intricate biochemical processes in the soil, including soil respiration. Soil temperature plays a crucial role in regulating soil respiration and various intricate biochemical processes within the soil. Soil respiration rate is highly responsive to variations in soil temperature. In the context of global change, even minor shifts in soil temperature can result in substantial alterations in soil respiration rate. Consequently, these changes have notable implications for soil CO₂ flux and the overall carbon balance of terrestrial ecosystems [2]. Global warming directly affects the rate of apoplastic decomposition through short-term effects on environmental factors such as temperature and humidity; it can also indirectly alter the rate of apoplastic decomposition by affecting the quantity and quality of apoplastic material through long-term effects on the structure of the plant community and on the phenology of plants [3].

2. Factors affecting the soil carbon cycle

2.1. Anthropogenic and natural factors

2.1.1. Climatic and Vegetation

Human actions such as land use change and the usage of fossil fuels contribute to the buildup of greenhouse gases in the atmosphere. The average temperature of the Earth's surface rises as a result

of this accumulation [3]. The most important climatic factors are temperature and precipitation. The carbon density at the surface correlates negatively with temperature for the same amount of precipitation. The organic carbon fractions are affected, which in turn leads to varied distributions of organic carbon in the soil. The intensity of photosynthesis and the form of uptake of soil organic matter are both affected by the different types of vegetation, which in turn leads to the different types of vegetation.

2.1.2. Soil physical and chemical factors

The finer the soil texture, the slower the breakdown of organic carbon; On the contrary: the coarser the soil texture, the faster the decomposition of organic carbon occurs. Clay particles can effectively bind organic carbon in the soil and prevent soil decomposition. Soil water content primarily affects soil carbon cycling by regulating the physiological activities of plants and microorganisms, microbial activity, soil oxidation potential, soil permeability, and the diffusion rate of greenhouse gases from soil to the atmosphere.

2.1.3. anthropogenic factors

The soil carbon cycle is influenced by various factors, including agricultural techniques, crop rotation, fertilizer application, soil composition, and land utilization. Anthropogenic alterations in land use and cover, such as the conversion of grasslands into cropland, deforestation, and the transformation of land for agricultural purposes, have resulted in notable declines in soil organic carbon (SOC), which possesses the most immediate influence on carbon sequestration in terrestrial ecosystems. The topic of discussion pertains to the interrelationship between pools and the carbon cycle. Based on statistical data, it can be shown that forest ecosystems possess a significant proportion, approximately 73%, of the worldwide soil carbon content. This significant volume establishes forests as the principal carbon storage within terrestrial ecosystems, making them an important carbon sink in the global carbon cycle. Soil organic carbon cycle refers to the carbon cycling process in which organic carbon is injected into the soil and then decomposed and converted with the participation of soil microorganisms. The organic carbon in soil consists mainly of plants, animals and plant residues. Soil organic carbon consists of soil humus, soil microorganisms and metabolites at different levels [4,5].

2.2. Soil respiration

Soil respiration is the entire metabolic process of CO₂ emissions from the soil, which can be roughly divided into biological processes, non-biological processes and anthropogenic factors etc. Collectively, these terms encompass several soil biological phenomena, such as microbial respiration occurring within the soil matrix and roots. The topic of discussion pertains to respiration, specifically focusing on the respiration processes in animals and the soil. While it is true that global warming can initially enhance soil respiration and result in significant CO₂ emissions, it is important to note that this effect is not sustainable over the long term [4]. The term "root respiration" encompasses all biological and chemical processes that take place in the rhizosphere [6]. Soil respiration is a prominent source of carbon emissions within terrestrial ecosystems, exerting significant influence on a global scale. It is noteworthy that the annual emissions resulting from soil respiration surpass those arising from the combustion of fossil fuels by a factor of over eleven. As temperatures rise, the link between soil respiration and temperature becomes less sensitive. This observation leads to the proposition that the adaptation of soil respiration to rising conditions could potentially mitigate the positive feedback loop between terrestrial ecosystems and global warming [5]. The effects of climate change on root respiration depend mainly on temperature. When the temperature is low and the respiration rate is limited primarily by biochemical reactions, root respiration also increases exponentially as the temperature increases. An adaptation of soil respiration to rising temperatures is common. The main causes of this phenomenon are the change in the position of the dominant factor and the synergistic effect between the influencing factors, which can be viewed as a negative feedback mechanism between the carbon cycle and global warming and respiratory adaptation. The manifestation of

diverse temporal and spatial reactions of the carbon cycle in response to global warming can be observed in conditions of increased temperatures [7]. In situations when soil temperature is heightened, there is a noticeable augmentation in the ratio of root respiration compared to overall soil respiration, whereas the proportion of microbial root respiration relative to total soil respiration diminishes. The inclusion of vegetation enhances the responsiveness of soil respiration to alterations in temperature, potentially as a result of microbial respiration occurring in the vicinity of plant roots, hence promoting the conversion of soil organic carbon stocks into minerals [8-10]. The root respiration of the bare soil increased significantly with increasing temperature, but during the growing season, the root respiration of the cultivated soil was significantly higher than the respiration of the bare soil [4]. Soil respiration's temperature sensitivity is commonly quantified using the empirical parameter Q10. Q10 represents the ratio of the change in soil respiration rate per 10 degrees of temperature increase, providing a measure of the soil respiration's responsiveness to temperature variations. Soil respiration exhibits variability in response to temperature fluctuations. Soil respiration displays varying temperature sensitivities under different environmental conditions. Elevating temperature or prolonging heating duration can impede or halt the rise in soil respiration rate. The phenomenon of short-term warming has been observed to have a positive effect on soil respiration, leading to an increase in its rate. However, as time progresses, the sensitivity of soil respiration to temperature diminishes. Consequently, the influence of elevated temperatures on the rate of soil respiration is not found to be significant [6].

2.3. Apoplastic matter

The apoplastic pathway serves as the fundamental mechanism for nutrient transport and represents a critical link between plants and the soil environment. The process of decomposing apoplastic matter holds significant importance in the development of soil organic matter and the soil cycle. The topic of interest pertains to carbon content found inside the forest floor. Temperature is a significant determinant of alterations in the decomposition rate of apoplastic matter, and the phenomenon of climate warming exerts both direct and indirect influences on the decomposition rate of apoplastic matter. Global warming has a direct impact on microbial activity. The concept of the indirect effect pertains to the effects of climatic warming on microbial activity, specifically in relation to the composition of apoplastic matter and its subsequent impact on the pace of apoplastic matter decomposition [4]. The effects of climate warming on the hydrothermal conditions of various ecosystems are mainly reflected in two aspects: an improvement in transpiration of air plants and a decrease in the water content of soil affect the decomposition of apomictic material [3]. Changes in temperature and humidity due to global warming affect the rate of decomposition of apoplastic matter. Global warming will alter the hydrothermal conditions of forest ecosystems, resulting in increased soil evapotranspiration and reduced soil water content, which will negatively impact leaching and decomposition of apoplastic material. Regarding the quantity of decomposed organic material, it is observed that global warming has a tendency to stimulate plant growth and enhance primary productivity, thus leading to an increase in the production of withering matter. Simultaneously, climatic warming has the potential to induce modifications in the composition and structure of plant communities, hence influencing the pace at which the accumulation and degradation of plant detritus occur, thereby influencing the dynamics of carbon stocks at the ecosystem level. In the case of litter quality, the effect of warming on the chemical composition of the litter also leads to a specific response on litter decomposition rates. The chemical nature of the litter, also called "substrate mass", is defined as the relative decomposability of the litter, which includes easily degradable components such as the nutrients C, N and P as well as non-degradable organic components such as lignin and cellulose [3]. Warming is not just an increase in temperature but is accompanied by changes in several other environmental factors, such as increases in atmospheric CO₂ concentration, changes in land use and land cover, and changes in atmospheric humidity, soil and nutrient availability, which affect apoplastic impact vegetation [8].

2.4. Soil microbiological

Soil microorganisms, as the primary constituents of soil, are subject to the effects of variations in soil temperature, soil moisture, and the soil microbiological milieu, including soil microbial biomass, microbial activity, and soil structure. The microbiological community. The impact of temperature fluctuations on soil microbial community structure and activity exhibits a higher degree of sensitivity. The total number of soil microorganisms did not change significantly with increasing temperature, but the structure of the microbial community changed significantly, and increasing temperatures significantly increased the activity of soil microorganisms and fungi and increased their richness, which in turn increased the efficiency of soil microorganisms in using organic Carbon in soil [4]. The sensitivity of soil microorganisms' community structure and activity is heightened in response to temperature variations. Climate warming has been observed to have a positive impact on the growing environment of fungus, mostly due to its influence on the yield and quality of apoplastic material and the availability of nutrients. Furthermore, fungi play a necessary role in the recycling of scarce nutrients within the cytoplasm, resulting in a notable increase in fungal population, alteration of microbial community composition, and expansion of soil volume. The study investigates the relationship between microbial activity and respiratory rate. Higher temperatures have been observed to enhance the prevalence of fungi and improve the soil's capacity to utilize specific fungal enzymes, therefore, this exerts a substantial impact on the composition of the soil microbial community. The subterranean debris resulting from their recent transition to an offline existence. The underground allocation of organic carbon input to the soil ranges from 14% to 87%, surpassing the carbon input derived from the decomposition of aboveground litter. This implies that unless precautions are implemented, the conversion of soil organic carbon can be diminished by 20% to 80%. Root secretions are also an important source of carbon for soil microorganisms, and the supply of carbon flows through the above-ground parts of the plant to the root system, which is decomposed by root secretions and living and dead roots, has significant effects. Influence on the size of organic carbon stores in the soil [4].

In addition to directly altering the processes and rates of soil microbial metabolism, warmer temperatures may also indirectly affect nitrogen cycling processes in planted ecosystems by increasing the ecosystem's net production [9].

2.5. Soil carbon pool

The retention of soil organic carbon is dependent on the balance between the influx of plant biomass and the outflow caused by the decomposition of residues and previously stored carbon [10]. As an important link in terrestrial ecosystems, soil provides the basis and nutrients for the survival of soil plants and animals. and microorganisms [6]. The storage of carbon in soil encompasses both organic carbon and inorganic carbon components. Due to its presence in the form of carbonate, inorganic carbon exhibits a significantly low level of activity and demonstrates insensitivity towards various environmental conditions. Increased temperatures alter the growth rate of plants, and grassland vegetation increases net productivity and carbon sequestration ability to improve vegetation input into the soil, resulting in increased soil carbon stocks; In contrast, elevated temperatures have an impact on the microbial and enzymatic processes occurring within the soil, leading to alterations in its inherent physical and chemical characteristics. This, in turn, results in an accelerated rate of soil mineralization, the breakdown of soil organic carbon, and an enhancement of soil respiration. Consequently, these changes ultimately diminish the soil's capacity to store carbon [4].

3. Conclusion

The response of different types of microorganisms to global warming varies. Warming can affect the physiological activity of soil microorganisms and even change their community structure so that soil respiration adapts to warming. The reaction of the carbon cycle to global warming might vary in space and time due to the adaptation of soil respiration to increased temperatures. Rising temperatures

can have significant impacts on the hydrothermal dynamics and microenvironment of ecosystems, altering the structure and composition of biological communities in soils and litter. Heating can have direct or indirect effects on microbial activity that can regulate apoplastic degradation. Heat effects on the chemical composition of apoplasts also trigger specific responses on the rate of apoplast degradation. The intricate and enduring ecological process of the carbon cycle in the forest floor is greatly influenced by global warming. However, the research in this domain faces notable challenges stemming from the intricate nature of both above-ground and below-ground ecological processes, as well as the constraints imposed by technical resources and experimental approaches for investigating subterranean ecological processes. Currently, the response of carbon cycling processes such as soil respiration to climate warming remains the main source of uncertainty in climate change prediction models. When examining the role of each individual factor, the interactions between factors are often ignored and the apoplastic decomposition process cannot be integrated and fully analyzed. Climate warming may improve soil respiration in the short term, but will adapt over time, which may largely be due to soil microbial adaptation. Human activities have a significant impact on changes in soil organic carbon content and carbon cycling in terrestrial soils through the changing of land use and land cover. Additionally, it significantly affects the function and condition of use and cover alterations of land within the carbon cycle of soil. Previous research focused more on aboveground apoplastic decomposition processes, and the lack of knowledge about belowground apoplastic decomposition processes has limited the effective integration of aboveground and belowground apoplastic decomposition processes.

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