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The process of crop photosynthesis assimilative carbon input and turnover

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Abstract

The input of crop assimilated carbon into soil carbon pool and its contribution to soilorganic carbon pool, its distribution and transformation characteristics in soil carbon pool, the microbial mechanism of circulation in soil, and the distribution and distribution of assimilated carbon in soil-microbe system are reviewed. Discuss the distribution and regulation mechanism of assimilated carbon in the aboveground-rhizosphere-soil system, the relationship between the assimilated carbon flow process at the soil interface and the formation of soil microbial diversity; proposed to strengthen the role of crop assimilated carbon in soil-crop at different ecosystem scales Quantitative research on the allocation process in the system is of great significance for clarifying the terrestrial ecological carbon cycle process; it points out the importance of studying the migration of crop assimilated carbon to soil carbon pool, the quantitative process and mechanism of allocation, and the application of microscope imaging technology and isotope tracer technology. The combined nano-secondary ion mass spectrometry technology and the technology of coupling microbial molecules and community ecology are effective means to study the biogeochemical properties of crop assimilation carbon in the future. The biogeochemical process of crop assimilation carbon circulating in the "atmosphere-plant-soil" system significantly affects the carbon cycle process of global terrestrial ecosystems. Crop assimilated carbon is an important source of soil organic carbon and is closely related to the rhizosphere environment and crop growth and development.

Keywords

Assimilated carbon; photosynthetic carbon; soil organic carbon; transformation process; microorganism; isotope tracer.

1. Introduction

The terrestrial ecosystem carbon cycle is at the center of the global carbon cycle. The soil organic carbon pool in the terrestrial ecosystem carbon pool is 1550 Pg, which is about 3 times that of the terrestrial vegetation carbon pool (560 Pg) and the atmospheric carbon pool (780 Pg) twice as much. The annual CO_2 emission from soil respiration reaches 58 Pg, the soil organic carbon storage decreases or increases by 1%, and the atmospheric CO_2 concentration will increase or decrease by 7×10^{-6}[2]. Promoting soil carbon fixation has become one of the main ways to slow down global warming widely recognized by the international community [3]. The research on the key process and control mechanism of soil organic carbon change has become

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a key scientific issue in global change research. The use of plant photosynthesis of atmospheric CO_2 in terrestrial ecosystems to increase carbon fixation is currently the most economical and effective way to deal with climate change [4]. As the main source of soil organic matter, plant assimilated carbon is an important part of the carbon cycle of the "atmosphere-plant-soil" continuum, and is closely related to changes in the atmospheric environment and soil quality. The biogeochemical processes of plant assimilated carbon input and transformation into soil carbon pools include: 1) Plant assimilated carbon is transported and distributed to the underground through the phloem, and transported to the rhizosphere in the form of root sediments (abscesses and exudates). The carbon input into the soil environment, 2) through the action of soil rhizosphere microorganisms, becomes part of the microbial biomass carbon, or is further converted into soil organic matter and stored in the soil carbon pool; The residues enter the soil and are decomposed and transformed under the action of soil microorganisms to release or become part of soil organic carbon; 4) Return to the atmosphere through plant respiration and rhizosphere microbial respiration. At present, the farmland ecosystem is one of the most active carbon pools affected by human disturbance. Prove the distribution, transformation and biogeochemical processes of crop assimilated carbon in farmland soils, comprehensively understand the interaction and mechanism between soil-crop-microbes, and systematically and scientifically regulate the input of crop assimilated carbon to soil organic carbon pools It is of great significance to realize the sustainable utilization of soil and improve the carbon absorption and storage capacity of the ecosystem.

2. Input of crop assimilated carbon to soil carbon pool

The main forms of crop assimilation carbon input to soil carbon pool are root deposition and crop residues, among which root deposition is an important source of farmland soil organic carbon and plays an important role in maintaining farmland soil carbon balance. Plant roots release organic and inorganic compounds input to the roots in various forms, including root exudates, root hairs entering the soil, and root cell defoliants, etc., to the surrounding soil to form rhizosphere deposits, which are exchanged at the interface between the plant and the soil. Rhizosphere deposits such as root exudates, including high molecular polysaccharides (viscous substances), various proteases, low molecular organic acids and sugars, phenols, vitamins, etc. Among them, macromolecular polysaccharide is not only one of the cementing substances that form stable aggregates, but also this polysaccharide is easily utilized by microorganisms and metabolized into more stable soil humus substances (complexes). It not only promotes the formation of soil aggregates, but also is the main carbon sequestration material, which is very important for the stability and balance of soil organic carbon pool. The deposition of carbon in the rhizosphere not only causes changes in soil chemical, physical and biological properties, but is also directly related to soil respiration, CH_4, N_2O emissions and other processes. The organic matter released from the rhizosphere affects the rhizosphere environment of plants, and through the utilization and transformation of rhizosphere microorganisms, affects the carbon cycle process between plant-(rhizosphere/non-rhizosphere) soil, forming a link between plant-soil-microbes. Rhizosphere sedimentary carbon is an important source of soil organic matter. However, due to the rapid turnover of rhizosphere sedimentary carbon metabolism and the lack of structural carbon to form organic matter in time, the complexity and variability of its fixation, turnover and migration processes have exacerbated research in this area. Uncertainty and the contribution of crop assimilated carbon to soil organic carbon pools are also unclear.

Since the 1980s, with the development of isotopic technology, natural abundance method (using the obvious difference in δ13C values of C3 and C4 plants) and isotope pulse labeling and continuous labeling technology (using $^{13}CO_2$ or $^{14}CO_2$ as tracers for plants) have been applied Photosynthetic absorption). It can effectively elucidate the flow of carbon between plants and

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soil, and quantitatively evaluate the relative contribution of rhizosphere deposition to soil carbon storage. Studies have found that 50% of the photosynthetic products of the net photosynthetic fixation of plants are transferred to the underground part for maintenance of root growth and construction, rhizosphere respiration or preservation in the soil. Lu et al. applied the 13C pulse labeling method to study the distribution of photosynthetic carbon in humus after the end of the rice growth period. The results showed that the distribution of photosynthetic carbon in the three components of humus, fulvic acid, humic acid and humin, was not marked. The newly imported crop assimilated carbon (^{13}C) mainly exists in the humus (67.4%), of which the fulvic acid contains 16.7%; the photosynthetic carbon in the rice growth stage is humic acid in the rice mature stage. There are humin-like substances, and the distribution ratios are different in different components of humin-like substances [5]. By summarizing and analyzing ^{14}C labeling experiments, it was found that about 5%-10% of the net photosynthetically fixed C would enter the soil and accumulate as SOC [6]. During a growth period, the amount of assimilated carbon transported by cereal crops to the ground can reach 1500 kg/hm^2[7], and the study also found that about 30% of the photo-assimilated carbon of cereal crops is transferred to the ground, and these carbons Half of it is stored in the root system, 1/3 is lost in the form of rhizosphere respiration, and the rest is converted into SOC[8], and the assimilated carbon will be transported to the root within 1 h and excreted to the rhizosphere environment. The input of rhizosphere carbon varies with plant species, growth period and external environment. Swinnen et al. [9] reported that the distribution of photosynthetic carbon to the ground in barley and wheat differed by up to 40% in different growth stages, and the amount of carbon distributed to the ground in the tillering and jointing stages was more than that in the mature stage, and 30% of the carbon was distributed to the underground in the jointing stage of wheat. 30%-40% of the net photosynthetic carbon, while only 5%-20% in the mature stage. Cheng et al. [10] sampled three plants of winter wheat, ghee and water hyacinth in the laboratory at 8 h after ^{13}C pulse labeling, and found that the carbon transferred into the soil by root exudation of these three plants accounted for 30% of the total photosynthetically fixed carbon, respectively. 2.7%, 2.5% and 3.7%. Different growth and development stages of plants not only affect the distribution of photosynthetic products in plants, but also significantly affect the distribution of carbon assimilation between plants and soils. The plant is older, the less rhizosphere deposition. Ge et al. [11] found through the carbon isotope continuous labeling technology that during the jointing and filling period of rice, 4%-6% of the photosynthetic carbon entered the soil organic carbon pool through rhizosphere deposition, and this part of the new carbon contributed to the soil soluble organic carbon. The contribution to soil microbial biomass carbon is 2%-4%, and the contribution to soil microbial biomass carbon is 9%-18%. As far as rice is concerned, the input of assimilated carbon and its rhizosphere deposition into the soil carbon pool plays an important role in maintaining the balance of the soil carbon pool and mitigating greenhouse gas emissions. In future research, it is necessary to strengthen the process of ecosystem carbon flux-photosynthetic efficiency-assimilation products transfer to soil, as well as the response mechanism of organic matter accumulation to external factors such as crop productivity, cultivation and fertilization methods, and changes in carbon and nitrogen fluxes.

3. Transformation characteristics of crop assimilated carbon

After crops assimilate carbon into the soil, within the range of several microns to several millimeters in the rhizosphere, plants, soils, microorganisms and their environmental factors form a highly organized structure through the interaction and mutual restriction of energy flow, material flow and information flow. It is generally believed that the input of crop assimilation carbon will first change the soil active carbon pool, thereby causing dynamic changes in the distribution of physical and chemical components of the soil carbon pool.

Liang et al. [12] found that the input of maize rhizosphere carbon significantly changed the content of soil soluble organic carbon; Nie San'an et al. [13] used 14C continuous labeling technology to label rice for 80 days in four typical subtropical rice soils and found that soil soluble organic carbon The carbon renewal rates ranged from 6.72% to 14.64%, and the relative contribution of photosynthetic carbon to soil MBC turnover was small. Lu et al. [14] also found that the DOC content in the soil with rice was about 3 times higher than that in the soil without rice, and with the growth of rice, the content of soil DOC gradually increased, and it was closely related to root biomass and root exudates. Therefore, the ratio of fixation, turnover and redistribution of crop assimilated carbon into soil varies with crop growth and development and root environment. After crop assimilation carbon is input into the soil, its mineralization and decomposition are affected by soil properties. The different response mechanisms of crop assimilation carbon decomposition and mineralization may be highly correlated with their different binding and protection states. In recent years, studies on the physics, chemistry and biology of aggregate scales have gradually realized the differences in the protection and stabilization mechanisms of carbon pools in soils. Garten et al. [15] studied the organic matter density grouping and aggregate particle grouping of mineral soils under forests, and showed that more than 70% of the organic carbon in mineral soils was in the aggregate particle group of silt and clay grades, showing that aggregates was important role of physical protection on organic carbon fixation. Soil respiration is the main way of soil carbon output. It is estimated that about 50-75 PgC was emitted each year due to soil respiration. Soil respiration is an important part of the global carbon budget. Therefore, understanding soil respiration intensity and its main influencing factors is an important scientific issue in carbon cycling. A study found that after winter wheat and spring wheat assimilated carbon into soil, 66% of the carbon was consumed as the respiration product (CO_2) of roots and microorganisms during the whole growth period, and the rest was present in soil and soil microorganisms, which was very important for maintaining soil carbon. The sink function plays a very important role. By labeling ryegrass, it was found that root respiration accounts for 10%-15% of plant photosynthetic fixed carbon. Kuzyakov et al. [16] reported that ryegrass root respiration accounted for 41% of rhizosphere respiration. Different amounts and compositions of rhizosphere sediments or external environmental conditions will affect the intensity of rhizosphere respiration, which in turn can affect the total soil respiration intensity.

Although the above studies fully recognize the importance of crop assimilation of carbon in the carbon cycle, due to the limitations of research methods and technologies, the current research on the fixation, distribution and turnover of rhizosphere sedimentary carbon mainly focuses on the surface soil, and does not involve root The migration process of rhizosphere sedimentary carbon in the horizontal and vertical directions and its ecological significance, while the migration process of rhizosphere sedimentary carbon, especially the research on bottom soil carbon fixation and nutrient transformation, has been paid more and more attention. According to the analysis results of the soil profile of the paddy field, the accumulation of soil organic carbon has a tendency to expand to the deep soil layer, which means that the soil organic carbon of the paddy field tends to move down to the bottom of the plow. The rate of mineralization, making the carbon stored in the deep soil more stable. The rhizosphere sedimentary carbon is an important source of soil organic carbon in paddy fields, and its migration and microbial action processes may play a very important role in improving the carbon sequestration capacity and potential of paddy soils. Past studies have far underestimated the importance of rhizospheric sediment carbon transport and its key functional microbes for carbon sequestration in bottom soils. The research on the distribution and turnover dynamics of the soil-microbe system in the paddy field (bottom layer) is still very limited in the migration process of rhizosphere sedimentary carbon. Carry out in-depth and systematic research on the migration, transformation and distribution mechanisms of carbon in rice rhizosphere sediments at different spatial scales (vertical and horizontal), the role of carbon in rhizosphere sediments and key functional microorganisms, and their coupling mechanisms with environmental factors.

4. Microbial mechanism of crop assimilation carbon circulation

Soil organic carbon transformation (input, distribution, stabilization, etc.) is driven by biochemical processes dominated by microorganisms, and is the core of soil carbon cycle research, which controls the input-output balance, interception and renewal of soil carbon. Limits determine and affect soil fertility. Since the rhizosphere sedimentary carbon released by plants into the soil contains many small molecular substances, such as carbohydrates and amino acids, these substances are effective carbon sources and energy sources for microorganisms, so the rhizosphere sedimentary carbon is the link between plants, soil and microorganisms, in the rhizosphere micro-ecosystem composed of plant-soil-microbes, plays a very important role in soil carbon fixation and the growth and metabolism of rhizosphere microorganisms. Rhizosphere deposition of carbon can cause soil carbon fixation or depletion by affecting microorganisms. A large number of studies have also confirmed that rhizosphere carbon is an important factor affecting the structure and activity of rhizosphere microbial communities. At the same time, soil microorganisms are the driving force for soil organic matter and soil nutrient transformation and cycling, and are the executors of soil organic matter transformation. Crop rhizosphere deposits in soil. The distribution and transformation of organic carbon pools are also biogeochemical processes mediated by microorganisms. Although most microorganisms in soil can participate in the main process of soil organic carbon conversion, how microorganisms participate and which microorganisms participate preferentially is still unclear; in a complex microbial environment, is the competition mechanism or the conditional control mechanism among the various microorganisms? Scientific questions to be revealed. The research on the mechanism of the effect of crop assimilated carbon in soil on the formation of soil microbial diversity has received increasing attention.

^{13}C can be used to track the flow of carbon in the plant-microbe-soil system and to determine the functional population of key microorganisms in this process, Butler et al. Nine days after the period; $^{13}CO_2$ pulse labeling was used to measure the PLFA and ^{13}C-PLFA of microorganisms in the rhizosphere and non-rhizosphere soils. The study found that the temporal difference of microbial community structure was greater than the spatial difference. Lu et al. pulse-labeled rice with $^{13}CO_2$, and found that different rhizosphere microorganisms have different absorption characteristics for plant photosynthesis products through "^{13}C-PLFA map analysis", proving that the rhizosphere microbial population of rice is closely related to plant photosynthesis [18]. They further sequenced soil ^{13}C-DNA and found that the ribosomal RNA of the rice Cluster I Archaea group contains ^{13}C, indicating that such archaea may play an important role in the process of methane production from plant carbon sources and have an important impact on global climate change. SIP, as a technology that can link function and population classification, has great application potential in microbial ecology research, and with the increase of available substrate species (N, H), SIP technology will make it possible to identify more microorganisms that play an important role in the cycling of carbon, nitrogen and other elements. However, at present, it is necessary to conduct in-depth research on the microbial action mechanism of crop assimilation of carbon at the level of soil microbial population structure and function, so as to provide scientific basis and key technologies for improving carbon cycle and accumulation in farmland soil. The application of new molecular biology techniques (such as DNA chip technology, DNA/RNA-SIP, high-throughput sequencing, etc.) provides an important means for this research.

5. Assimilated carbon stabilization in soil-microbe system

After the assimilation of carbon into the soil, the organic carbon components contained have unique molecular characteristics due to differences in chemical composition, degree of decomposition and transformation, and the relative contributions of plant and microbial sources, resulting in high heterogeneity of soil organic carbon. Source and detection of its dynamic distribution process and stabilization mechanism in the soil-microbial system has become the biggest difficulty in soil carbon cycle research. At the same time, the input of organic carbon affects the formation of soil microstructure, which in turn changes the soil microenvironment and induces the succession of soil microbial community structure. The accessibility of microorganisms to organic matter determines its decomposition rate and stability. The turnover rate of soil organic carbon is affected by Controlled by microbial species and accessibility to substrates. However, the traditional homogenization and homogenization studies ignore the high microscopic heterogeneity of organic carbon and microorganisms. Institute ignored. On the other hand, the individual scale of soil microorganisms is at the μm level, and the scope of microbial community action is also at the sub-millimeter and micron scales. Due to strong dependence, selection and transformation, the turnover process of soil organic carbon needs to be focused on at the micro-scale. For a long time, due to the opacity of soil, soil biology is based on the black (grey) box theory, and often only focuses on the macro-results. Microdynamic processes are ignored. Therefore, linking the heterogeneity of soil organic carbon with its impact on microbial processes is one of the research frontiers in soil microbial ecology today.

In recent years, the spectrum and spectroscopic analysis of soil organic matter (NMR, Near-edge X-ray absorption fine structure spectroscopy) and the combination of ultra-high-resolution microscopy imaging technology and isotope tracer technology have been developed. Ion mass spectrometry (NanoSIMS) has broken through this difficulty, and has made significant progress in elucidating the distribution and stabilization mechanism of soil organic carbon in soil-microbe systems at the microscopic scale (single cell, millimeter, nanometer), showing good results. Through NanoSIMS imaging analysis, it can not only provide information on the physiological and ecological characteristics of microorganisms at the single-cell level, but also accurately identify metabolically active microbial cells in complex environmental samples and their taxonomic information. This method is useful for understanding microorganisms at the microscopic scale. Mechanisms mediated by elemental biogeochemical cycling provide a new perspective. Scanning electron microscopy (SEM), halogen in situ hybridization (HISH), microbial marker technology (^{13}C-PLFA-SIP, DNA/RNA-SIP) and other technologies developed in recent years combined with NanoSIMS have been widely used in carbon cycle mechanism and research. Coupling of these technologies is a powerful tool to study the interaction of soil organic carbon and microorganisms at the microscopic scale. In addition, NanoSIMS can also play its unique advantages in the study of microbial groups that promote the stabilization of crop assimilated carbon in soil, the spatial distribution of active groups of target microorganisms in soil, and the micro-scale factors that affect microbial horizontal gene transfer. In conclusion, the rise of analytical techniques represented by NanoSIMS provides a new opportunity to study the coupling study of crop assimilation carbon cycle and microbial ecology. It shows great advantages and important application prospects.

6. Summary and Research Prospects

In summary, crop assimilated carbon is an important part of the carbon cycle in the "atmosphere-plant-soil" system. Quantifying the distribution and transformation of crop assimilated carbon in the soil-crop system is essential for understanding the global carbon cycle. The vast majority of soil organic carbon comes from the input and transformation of photosynthetic carbon and photosynthetic carbon enters the soil carbon pool through root turnover and root exudates. Soil microorganisms dominate the soil carbon cycle and regulate the input-output balance of soil carbon. Using microbial markers (phospholipid fatty acids (PLFA), nucleic acid substances (DNA/RNA) combined with isotope labeling technology, the function and contribution of microorganisms in the process of soil organic carbon cycling can be clarified, thereby revealing the number and community structure of key functional microorganisms At the same time, soil microstructure, aggregates and their related physicochemical properties also play an extremely critical role in the distribution process of soil organic carbon in the soil-microbial system, so , to study the process mechanism of the migration, transformation and distribution of crop assimilated carbon to the deep soil, especially the distribution, interception and stabilization mechanism of photosynthetic carbon and microbial assimilated carbon in the soil-microbial system at the microscopic (aggregate) scale. Therefore, the following aspects are recommended for future research:

(1) Carry out quantitative research on the distribution of assimilated carbon from different sources in the soil-crop system and its input, transformation, protection, and stabilization of several carbon transformation links, and clarify the components of assimilated carbon input into soil by crop rhizosphere deposition, structure and its relationship with oxidative and mineralized stability to reveal its contribution to different soil organic carbon components and the mechanism of crop assimilated carbon transport to deep soils, which has important implications for maintaining soil organic carbon stability and balance .

(2) Global change has become an indisputable fact, and land use, N deposition, and climate change caused by human activities will have a profound impact on the biogeochemical process of carbon assimilation. The impact of crop assimilation carbon cycle is still lack of systematic understanding. Therefore, studying the characteristics of crop assimilation carbon cycle in the context of global change is an important content of future work.

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