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Effects and regulation Mechanisms of Phosphorus Fertilizer on Soil Carbon Cycle

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Abstract: This paper reviews the effects and regulation mechanisms of phosphorus fertilizer on soil carbon cycle, which is an important process for soil fertility, productivity, and climate change and introduces the background, significance, main pathways, mechanisms, influencing factors, research progress and challenges. The paper shows that phosphorus fertilizer can affect soil carbon cycle through various pathways, such as affecting plant productivity and carbon allocation, soil organic matter decomposition and mineralization, soil microbial community and function, and soil aggregate formation and stability. The paper also shows that the effects of phosphorus fertilizer on soil carbon cycle are influenced by many factors, such as the type, amount, application method and time of phosphorus fertilizer, and the soil type, climate condition, vegetation type and management measures. The paper concludes that the effects of phosphorus fertilizer on soil carbon cycle are both positive and negative, direct and indirect, short-term and long-term, local and global, forming a complex impact network. The paper suggests that more research is needed to clarify the mechanisms, interactions and feedbacks of the effects of phosphorus fertilizer on soil carbon cycle, and to develop effective models and indicators to evaluate and predict the effects of phosphorus fertilizer on soil carbon cycle. The paper also suggests that rational application of phosphorus fertilizer and scientific management of soil carbon cycle are important for improving crop phosphorus use efficiency, reducing excessive application of phosphorus fertilizer, protecting water resources and soil quality, and mitigating climate change.

Keywords: Phosphatic fertilizer, Carbon cycle, Factors, Environment.

1. Introduction

Phosphorus is one of the essential macronutrients for all life on Earth, and it is crucial for plant growth and development. However, phosphorus is unevenly distributed in nature, and most of it exists in insoluble forms in soil, resulting in widespread phosphorus limitation in various terrestrial ecosystems[1-3]. To meet the demand of agricultural production, humans have exploited a large amount of phosphate rock and used a large amount of phosphorus fertilizer in production, which not only causes the waste of non-renewable resources, but also easily leads to environmental problems such as eutrophication of water bodies. Therefore, studying the effects of phosphorus fertilizer on soil carbon cycle has important theoretical and practical significance for improving crop phosphorus use efficiency, reducing excessive application of phosphorus fertilizer, protecting water resources and soil quality, and mitigating climate change.

Soil carbon cycle refers to the process of input, transformation, storage and output of organic carbon and inorganic carbon in soil (Figure 1), which is an important part of the global carbon cycle. Soil carbon cycle not only affects soil fertility and productivity, but also affects the concentration of greenhouse gases in the atmosphere and the change of global climate. The main driving factors of soil carbon cycle include climatic factors, soil physicochemical factors, biological factors, etc., among which biological factors are especially important, because the transformation and flow of organic carbon and inorganic carbon in soil are realized by biological activities. Biological factors mainly include plants and microorganisms, which affect the input, allocation, decomposition, stabilization and output of soil carbon through their own physiological and biochemical processes and interactions.

Phosphorus fertilizer, as an important biological factor, can affect soil carbon cycle through various pathways[4]. First, phosphorus fertilizer can directly or indirectly affect plant productivity[5], thus affecting the quality and quantity of plant-derived carbon input into soil. Phosphorus fertilizer can improve plant photosynthesis and biomass, increase plant contribution to soil carbon[6]; phosphorus fertilizer can also affect plant carbon allocation, change the investment ratio of plant to aboveground and belowground parts, and thus affect the vertical distribution of soil carbon. Second, phosphorus fertilizer can affect the decomposition of soil organic matter, thus affecting the turnover and stabilization of soil carbon. Phosphorus fertilizer can affect the decomposition rate and direction of soil organic matter by changing the content, composition and stability of soil organic matter[7]; phosphorus fertilizer can also affect the decomposition and release of soil native organic matter by priming effect and mineralization effect[8]. Third, phosphorus fertilizer can affect the quantity, diversity, structure and function of soil microorganisms, thus affecting the transformation and flow of soil carbon. Phosphorus fertilizer can stimulate or inhibit the growth and activity of soil microorganisms by providing phosphorus source or organic carbon source, affecting the utilization and metabolism of organic carbon and inorganic carbon by soil microorganisms; phosphorus fertilizer can also affect the production and regulation of carbon cycle related enzymes by soil microorganisms by changing the community composition and functional diversity of soil microorganisms. Fourth, phosphorus fertilizer can affect the formation and stability of soil aggregates, thus affecting the protection and storage of soil carbon[9]. Phosphorus fertilizer can affect the size, number and distribution of soil aggregates by changing the physical and chemical properties of soil; phosphorus fertilizer can also affect the content and composition of organic carbon in soil aggregates by changing the characteristics of soil organic matter and microorganisms.

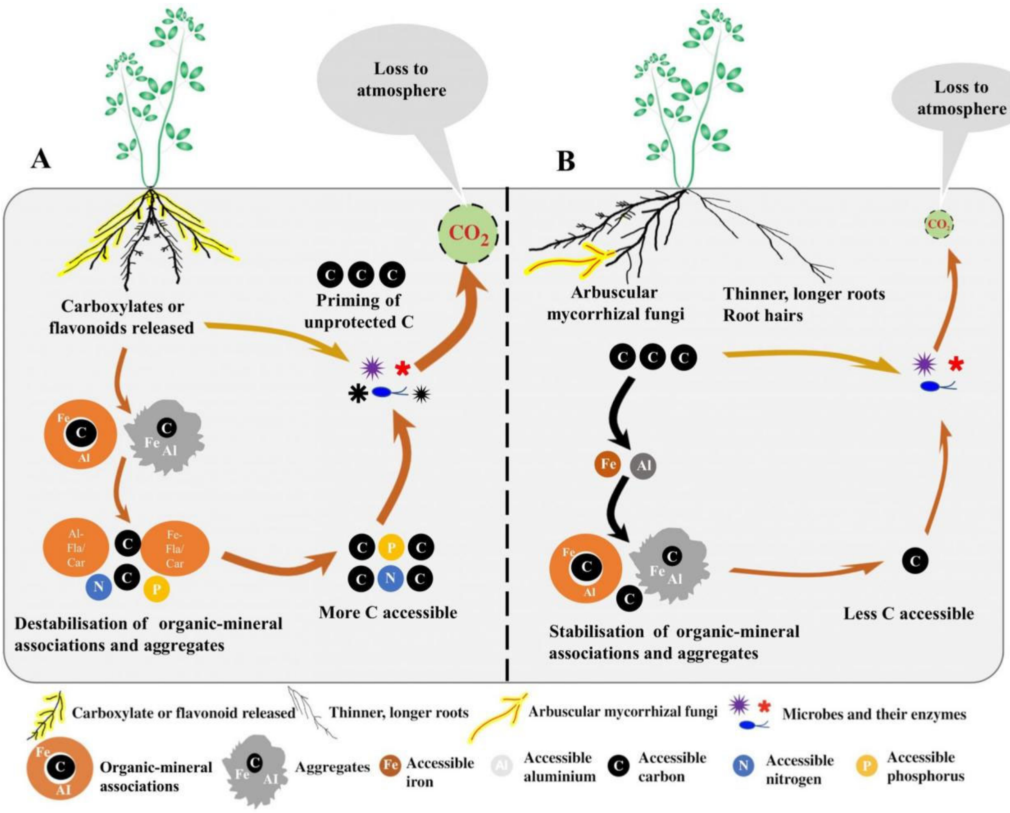

Figure 1. Phosphorus (P)-acquisition strategies (carboxylates or flavonoids, A; arbuscular mycorrhizal fungal or other root morphological traits, B) that drive soil organic matter (SOM) decomposition and nitrogen (N) mineralization under low-P conditions[1]

Although the effects of phosphorus fertilizer on soil carbon cycle have been studied to some extent, there are still many deficiencies and challenges. On the one hand, the mechanisms of the effects of phosphorus fertilizer on soil carbon cycle are not fully clear, especially the interactions and feedback mechanisms between phosphorus fertilizer and plants, soil organic matter, soil microorganisms and soil aggregates. On the other hand, the influencing factors of the effects of phosphorus fertilizer on soil carbon cycle are not fully clear, especially the management factors such as the type, amount, application method and time of phosphorus fertilizer, and the environmental factors such as soil type, climate condition, vegetation type and management measures. In addition, the research methods of the effects of phosphorus fertilizer on soil carbon cycle are not perfect, especially the lack of large-scale, long-term and comprehensive research, and the lack of effective models and indicators to evaluate and predict the effects of phosphorus fertilizer on soil carbon cycle.

Therefore, this paper aims to review the main mechanisms and influencing factors of the effects of phosphorus fertilizer on soil carbon cycle, summarize the research progress and existing problems of the effects of phosphorus fertilizer on soil carbon cycle, propose the future research direction and prospect of the effects of phosphorus fertilizer on soil carbon cycle, and provide reference and reference for the rational application of phosphorus fertilizer and the scientific management of soil carbon cycle.

2. Main Mechanisms of The Effects of Phosphorus Fertilizer on Soil Carbon Cycle

Phosphorus fertilizer, as an important biological factor, can affect soil carbon cycle through various pathways, including directly or indirectly affecting plant productivity[10], thus affecting the quality and quantity of plant-derived carbon input into soil; affecting the decomposition of soil organic matter, thus affecting the turnover and stabilization of soil carbon; affecting the quantity, diversity, structure and function of soil microorganisms, thus affecting the transformation and flow of soil carbon; affecting the formation and stability of soil aggregates, thus affecting the protection and storage of soil carbon.

2.1. Plant productivity

Phosphorus fertilizer can also affect plant carbon allocation, changing the investment ratio of plant to aboveground and belowground parts, and thus affecting the vertical distribution of soil carbon[11]. Carbon allocation is the process of distribution and utilization of photosynthetic products by plants, and it is an important mechanism for plants to adapt to environmental changes. Phosphorus fertilizer can affect plant carbon allocation pattern by changing plant physiological state and signal transduction. Studies have shown that phosphorus fertilizer application can promote plant carbon allocation to aboveground parts, increase plant harvest index, and thus increase the input of surface residues. Phosphorus fertilizer can also inhibit plant carbon allocation to belowground parts, reduce plant root-shoot ratio, and thus reduce the input of root residues and root exudates. Generally speaking, the effect of phosphorus fertilizer on plant carbon allocation depends on soil phosphorus availability, plant phosphorus demand and phosphorus use efficiency, plant growth stage and environmental conditions, etc.

2.2. Soil organic matter decomposition

Studies have shown that phosphorus fertilizer application can significantly affect the decomposition rate and direction of soil organic matter, thus affecting the balance and dynamics of soil carbon. Generally speaking, the effect of phosphorus fertilizer on soil organic matter decomposition depends on soil phosphorus availability, soil organic matter source and nature, soil microbial activity and diversity, soil moisture and temperature, etc.

Phosphorus fertilizer can also affect the decomposition and release of soil native organic matter by priming effect and mineralization effect. Priming effect is the phenomenon that the input of exogenous organic matter into soil stimulates the decomposition of soil native organic matter, which is an important feature of soil carbon cycle. Mineralization effect is the phenomenon that the input of exogenous organic matter into soil inhibits the decomposition of soil native organic matter, which is an important regulatory factor of soil carbon cycle. Phosphorus fertilizer can stimulate or inhibit the growth and activity of soil microorganisms by providing phosphorus source or organic carbon source, affecting the decomposition and release of soil native organic matter. Studies have shown that phosphorus fertilizer application can significantly affect the size and direction of soil priming effect and mineralization effect, thus affecting the loss and storage of soil carbon. Generally speaking, the effect of phosphorus fertilizer on soil priming effect and mineralization effect depends on soil phosphorus availability, exogenous organic matter quality and quantity, soil native organic matter content and nature, soil microbial quantity and diversity, soil moisture and temperature, etc.

2.3. Soil aggregates

Phosphorus fertilizer can affect the formation and stability of soil aggregates, thus affecting the protection and storage of soil carbon[12]. Soil aggregates are clump-like structures formed by granular materials through physical, chemical and biological actions in soil, which are important carriers of soil carbon cycle. Soil aggregates can protect soil organic matter from microbial decomposition, thus increasing soil carbon storage. The formation and stability of soil aggregates are affected by many factors, among which phosphorus fertilizer is an important factor. Phosphorus fertilizer can affect the size, number and distribution of soil aggregates by changing the physical and chemical properties of soil. Phosphorus fertilizer can also affect the content and composition of organic carbon in soil aggregates by changing the characteristics of soil organic matter and microorganisms. Studies have shown that phosphorus fertilizer application can significantly affect the formation and stability of soil aggregates, thus affecting the protection and storage of soil carbon. Generally speaking, the effect of phosphorus fertilizer on soil aggregates depends on soil phosphorus availability, soil organic matter source and nature, soil microbial quantity and diversity, soil moisture and temperature, etc.

3. Effects and Regulation Factors of Phosphorus Fertilizer on Soil Carbon Cycle

The factors affecting the effects of phosphorus fertilizer on soil carbon cycle mainly include management factors such as the type, amount, application method and time of phosphorus fertilizer, and environmental factors such as soil type, climate condition, vegetation type and management measures. These factors can regulate the size and direction of the effects of phosphorus fertilizer on soil carbon cycle by affecting the availability of phosphorus fertilizer, the source and nature of soil organic matter, the quantity and diversity of soil microorganisms, the formation and stability of soil aggregates, etc.

The type, amount, application method and time of phosphorus fertilizer are common management factors in agricultural production, which can affect the availability and utilization of phosphorus fertilizer in soil, thus affecting the effects of phosphorus fertilizer on soil carbon cycle[13]. The type of phosphorus fertilizer can affect the solubility[14], adsorption, mobility and bioavailability of phosphorus fertilizer, thus affecting the effectiveness and persistence of phosphorus fertilizer. Generally speaking, water-soluble phosphorus fertilizer has higher effectiveness than insoluble phosphorus fertilizer, but it is also more easily fixed or lost by soil, so it is necessary to increase the application amount or adopt split application. The amount of phosphorus fertilizer can affect the supply and balance of phosphorus fertilizer, thus affecting the utilization efficiency and residual effect of phosphorus fertilizer. The amount of phosphorus fertilizer should be determined according to the availability of soil phosphorus, the phosphorus demand and phosphorus use efficiency of plants, etc., to avoid excess or deficiency, and to ensure the best effect of phosphorus fertilizer. The application method of phosphorus fertilizer can affect the distribution and contact of phosphorus fertilizer, thus affecting the effectiveness and utilization efficiency of phosphorus fertilizer. The application method of phosphorus fertilizer should be selected according to the physical and chemical properties of soil, the root characteristics and growth stage of crops, etc., such as deep application, shallow application, topdressing, base application, foliar application, etc., to increase the contact opportunity and absorption ability of phosphorus fertilizer and roots. The application time of phosphorus fertilizer can affect the effective period and utilization timing of phosphorus fertilizer, thus affecting the utilization efficiency and residual effect of phosphorus fertilizer. The application time of phosphorus fertilizer should be determined according to the temperature, humidity, pH and other factors of soil, as well as the phosphorus demand and phosphorus use efficiency of crops, etc., such as early application, late application, staged application, etc., to ensure that phosphorus fertilizer provides sufficient phosphorus source in the critical period of crop growth.

4. External Conditions and Management Measures

Soil type, climate condition, vegetation type and management measures are common environmental factors in agricultural ecosystems, which can affect the source and nature of soil organic matter, the quantity and diversity of soil microorganisms, the formation and stability of soil aggregates, etc., thus affecting the effects of phosphorus fertilizer on soil carbon cycle. Soil type can affect the physical and chemical properties of soil, the content and composition of organic matter, the availability and fixation of phosphorus, etc., thus affecting the rate and direction of soil carbon cycle.

4.1. Soil type

The effect of soil type on soil carbon cycle mainly reflects in soil texture, pH, cation exchange capacity, etc. For example, clayey soil is more likely to form stable organic-inorganic aggregates, thus protecting soil organic matter from decomposition; acidic soil is more likely to fix phosphorus fertilizer, thus reducing the effectiveness and utilization efficiency of phosphorus fertilizer.

4.2. Climate condition

Climate condition can affect the temperature, humidity, oxygen content, etc. of soil, thus affecting the decomposition and mineralization of soil organic matter, the growth and activity of soil microorganisms, the formation and collapse of soil aggregates, etc., thus affecting the rate and direction of soil carbon cycle. Climate condition affects soil carbon cycle mainly in terms of temperature and moisture. For example, the increase of temperature can accelerate the decomposition and mineralization of soil organic matter, thus increasing the loss of soil carbon; the increase of moisture can increase the dissolution and migration of soil organic matter, thus affecting the distribution and storage of soil carbon. Vegetation type can affect the input and quality of plant-derived carbon, the phosphorus demand and phosphorus use efficiency of plants, the interaction between plants and soil microorganisms, etc., thus affecting the rate and direction of soil carbon cycle.

4.3. Vegetation type

The effect of vegetation type on soil carbon cycle mainly reflects in plant biomass, carbon allocation, root characteristics, rhizosphere effect, etc. For example, herbaceous plants are more likely to allocate carbon to belowground, thus increasing the input of soil carbon; deep-rooted plants are more likely to secrete organic acids, thus increasing the decomposition of soil organic matter; leguminous plants are more likely to symbiosis with arbuscular mycorrhiza, thus affecting the formation of soil aggregates.

4.4. Management measures

Management measures can affect the disturbance, addition of organic matter, planting and harvesting of crops, etc., thus affecting the input and decomposition of soil organic matter, the quantity and diversity of soil microorganisms, the formation and collapse of soil aggregates, etc., thus affecting the rate and direction of soil carbon cycle.

5. Conclusion

This paper reviewed the main mechanisms and influencing factors of the effects of phosphorus fertilizer on soil carbon cycle, summarized the research progress and existing problems of the effects of phosphorus fertilizer on soil carbon cycle, and proposed the future research direction and prospect of the effects of phosphorus fertilizer on soil carbon cycle. The main conclusions of this paper are as follows:

The effects of phosphorus fertilizer on soil carbon cycle are both positive and negative, direct and indirect, short-term and long-term, local and global, forming a complex impact network.

The main mechanisms of the effects of phosphorus fertilizer on soil carbon cycle include the effects of phosphorus fertilizer on plant productivity, soil organic matter decomposition, soil microbial community and soil aggregates, which have complex interactions and feedbacks, and jointly determine the positive and negative effects of phosphorus fertilizer on soil carbon cycle.

The influencing factors of the effects of phosphorus fertilizer on soil carbon cycle mainly include management factors such as the type, amount, application method and time of phosphorus fertilizer, and environmental factors such as soil type, climate condition, vegetation type and management measures, which can regulate the size and direction of the effects of phosphorus fertilizer on soil carbon cycle by affecting the availability of phosphorus fertilizer, the source and nature of soil organic matter, the quantity and diversity of soil microorganisms, the formation and stability of soil aggregates, etc.

The research methods and results of the effects of phosphorus fertilizer on soil carbon cycle have some deficiencies and challenges, such as the limitation of research scale, the singularity of research indicators, the lack of research mechanisms, the imperfection of research models, etc., which need to be further improved and perfected.

References

[1] Ding W, Cong W-F, Lambers H. Plant phosphorus-acquisition and -use strategies affect soil carbon cycling. Trends in Ecology & Evolution. 2021;36(10):899-906.

[2] Lambers H, Shane M, Cramer M, Pearse S, Veneklaas E. Root Structure and Functioning for Efficient Acquisition of Phosphorus: Matching Morphological and Physiological Traits. Annals of botany. 2006;98:693-713.

[3] Lu J-l, Jia P, Feng S-w, Wang Y-t, Zheng J, Ou S-n, et al. Remarkable effects of microbial factors on soil phosphorus bioavailability: A country-scale study. Global Change Biology. 2022;28(14):4459-71.

[4] Li Y, Yang R, Gao R, Wei H-A, Chen A, Li Y. Effects of long-term phosphorus fertilization and straw incorporation on phosphorus fractions in subtropical paddy soil. Journal of Integrative Agriculture. 2015;14.

[5] Tofa A, Kamara A, Babaji B, Aliyu K, Ademulegun T, Jenneh Fatima B. Maize yield as affected by the interaction of fertilizer nitrogen and phosphorus in the Guinea savanna of Nigeria. Heliyon. 2022;8.

[6] Guo L, Yu H, Kharbach M, Wang J-W. The Response of Nutrient Uptake, Photosynthesis and Yield of Tomato to Biochar Addition under Reduced Nitrogen Application. Agronomy. 2021;11:1598.

[7] Ji L, Si H, He J, Fan L, Li L. The shifts of maize soil microbial community and networks are related to soil properties under different organic fertilizers. Rhizosphere. 2021;19:100388.

[8] Sharpley A, Bergström L, Aronsson H, Bechmann M, Bolster C, Börling K, et al. Future agriculture with minimized phosphorus losses to waters: Research needs and direction. Ambio. 2015;44:163-79.

[9] Mi W, Chen C, Ma Y, Guo S, Liu M, Gao Q, et al. The Combined Application of Mineral Fertilizer and Organic Amendments Improved the Stability of Soil Water-Stable Aggregates and C and N Accumulation. Agronomy. 2022;12:469.

[10] Cordell D, Drangert J-O, White S. The Story of Phosphorus: Global Food Security and Food for Thought. Global Environmental Change. 2009;19:292-305.

[11] Xiao M, Zang H, Chen A, Zhu Z, Zhou P, Atere C, et al. Effect of nitrogen fertilizer on rice photosynthate allocation and Carbon input in paddy soil. European Journal of Soil Science. 2019;70.

[12] Six J, Elliott ET, Paustian K. Soil Macroaggregate Turnover and Microaggregate Formation: A Mechanism for C Sequestration under No-Tillage Agriculture. Soil Biology and Biochemistry. 2000;32:2099-103.

[13] Liangliang Z, Niu J, Lu X, Zhao Z, Li K, Wang F, et al. Dosage effects of organic manure on bacterial community assemblage and phosphorus transformation profiles in greenhouse soil. Frontiers in microbiology. 2023;14:1188167.

[14] Fitriatin B, Simarmata T, Joy B. Effect of application of phosphate solubilizing bacteria and organic fertilizers on soil phosphorus solubility and growth of maize (Zea mays var. saccharata Sturt L.) on andisols. International Journal of Frontiers in Life Science Research. 2023;5:014-21.