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Editorial: Soil additives for sustaining the soil ecosystem services

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Editorial on the Research Topic
Soil additives for sustaining the soil ecosystem services

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1 Introduction

Soils are fundamental components of ecosystems, forming a complex interface where the lithosphere, biosphere, atmosphere, and hydrosphere converge. They support plant growth, regulate water flow, cycle nutrients, and harbor a vast biodiversity, making them vital for ecological stability and human well-being. Additionally, soils serve as important carbon sinks, contributing to climate regulation and greenhouse gas mitigation (1). Soil is a supporting medium for providing all nutrients for plant growth and development. Soil flora and fauna play an important role in the biogeochemical cycle of nutrients. However, anthropogenic activities such as excessive chemical fertilizer and pesticide use, intensive tillage, and inappropriate irrigation practices are leading to serious threats to sustainable agriculture and environmental stability by degrading soil health and ecosystem services. It also creates major problems for loss of soil fertility and health due to decreasing soil microbial communities. In recent years, increasing awareness of the environmental impacts of soil degradation has highlighted the need for sustainable soil management strategies. Soil additives, both inorganic and organic amendments, offer promising solutions to enhance soil resilience and productivity. These additives improve water retention, soil structure, nutrient availability, and microbial health, fostering a conducive environment for plant growth. Moreover, organic soil amendments play a critical role in carbon sequestration, helping to mitigate climate change by storing atmospheric CO_2 in the soil (2).

With advances in scientific knowledge and technology, the application of soil additives has evolved into a more controlled and environmentally friendly approach, providing alternatives to synthetic chemicals. The aim of this Research Topic is to explore and highlight the potential of soil additives in sustaining and enhancing soil ecosystem services.

2 Soil as supporting function for ecosystem services

This Research Topic highlights the diverse benefits of soil additives across different agroecosystems. Garbowski et al. (2) demonstrated that soil additives notably improve the physical and chemical properties of coarse-textured, sandy soils by enhancing soil structure, increasing water retention, and reducing bulk density.

Pandian et al. presented a comprehensive review on the use of biochar as a sustainable soil conditioner aimed at enhancing soil health, boosting crop productivity, and supporting environmental resilience in the face of climate change. The application of biochar is suitable for both smallholder and large-scale farming systems. When combined with organic amendments, it enhances nutrient availability and supports long-term soil fertility. Biochar contributes to improved nutrient retention, better water holding capacity, and enhanced soil structure, which can lead to higher crop yields and reduced reliance on external inputs, ultimately lowering production costs for farmers. Moreover, its ability to sequester carbon supports environmental sustainability and offers potential participation in carbon credit markets, increasing the economic benefits of adopting biochar in agricultural practices.

In support of this Research Topic, Zhang et al. showed that freeze-thaw cycles weaken the structural stability of composite soil aggregates. Their study highlighted that clay content plays a crucial role in both the formation and structural stability of these aggregates.

This Research Topic primarily focused on ecosystem services related to nutrient cycling and soil health. A key area of interest was the role of seaweed-based bioregulators, derived from red, brown, and green algae, in managing agricultural diseases. Seaweed extracts (SEs) present a natural and eco-friendly alternative to synthetic agrochemicals, helping to reduce environmental harm while promoting plant health. In this context, Singh et al. provided an in-depth review of the effectiveness of seaweed extracts in enhancing crop productivity with minimal environmental impact. Seaweeds have long been used as manure globally, especially in coastal regions, either in composted form or applied directly as organic fertilizer. Their review emphasizes recent developments in the use of seaweed-based soil amendments in agriculture, highlighting their advantages, mechanisms of action, and potential role in sustainable farming systems.

Another key topic explored in this Research Topic was the long-term impact of silicate- and lime-enriched NPK fertilizers (NPKSi and NPKLi) on the fertility of paddy soils. Amoakwah et al. conducted a comprehensive study to evaluate how these fortified NPK treatments influence soil properties. Their research aimed to clarify the improvements in soil fertility resulting from the combined application of lime and silicate-enriched fertilizers, while also assessing changes in soil carbon stocks and carbon stratification after 67 years of amendment application.

From a broader perspective, the long-term use of silicate- and lime-enriched NPK fertilizers (NPKSi and NPKLi) has shown significant improvements in soil fertility, positively influencing the productivity of paddy soils. Nonetheless, to further enhance soil quality, these treatments should be supplemented with organic amendments like biochar, which can effectively boost soil organic matter and promote carbon sequestration. Converting rice straw into biochar and applying it directly to the soil can help increase stable carbon content and minimize soil carbon losses by limiting microbial decomposition. Additionally, when using NPK fertilization alongside lime and silicate in paddy soils, it is recommended to increase the application rates of phosphorus (P) and potassium (K) to avoid or mitigate potential nutrient deficiencies.

This Research Topic emphasizes the advancement of innovative soil additives designed to improve soil health and quality. Technological progress has enabled more precise engineering of these additives for targeted applications. This includes modifying feedstock materials during production, fine-tuning preparation conditions like temperature, and utilizing a range of physical and chemical techniques to enhance crucial properties such as functionality, pore structure, and specific surface area. As highlighted by Singh et al. (3), these customized approaches allow for the development of more efficient soil amendments tailored to meet specific environmental and agricultural requirements.

To accurately evaluate the advantages of using soil additives in agroecosystems, long-term research is crucial, as short-term studies often show inconsistent results. Liu et al. (4) conducted an extensive global meta-analysis, revealing that the use of soil additives, either independently or alongside chemical fertilizers, significantly increases soil organic carbon (SOC), enhances soil fertility, boosts carbon sequestration potential by 32 – 35%, and helps prevent soil degradation. These findings support the long-term value of soil additives as a sustainable approach to soil management.

3 Future perspective and challenges

The future of soil additives is being shaped by a dual imperative: the urgent need to enhance agricultural productivity to feed a growing global population and the critical demand for sustainable soil health management practices. However, significant challenges remain, including environmental risks, regulatory complexities, and cost-effectiveness.

1. Environmental concerns: A major concern with organic amendments, particularly those derived from animal manure and biosolids, is the potential for contamination with heavy metals, pathogens, antibiotics, and hormones.
2. Effectiveness: Soil additives need to be effective in improving soil health, increasing crop yields, and mitigating climate change impacts.
3. Cost and accessibility: The cost of certain soil amendments, especially innovative biobased options, can be a significant barrier for farmers. While the long-term benefits to soil health and productivity may outweigh the initial investment, the upfront cost can be prohibitive.
4. Regulation and certification: The regulatory landscape for soil additives is complex and varies between regions. In the United States, the USDA's Animal and Plant Health Inspection Service (APHIS) regulates the importation of organic soil

amendments to prevent the introduction of pests and diseases. The European Union also has regulations in place, with a recent overhaul aiming to increase the rigor of import standards for organic products. Navigating these regulations can be challenging for producers and importers. The scaling of mineral-based soil amendments for carbon sequestration also faces regulatory and social license risks, including environmental permitting and community consent for quarrying and spreading minerals.

4 Concluding remarks

This Research Topic has laid a strong foundation for advancing knowledge on soil additives and their role in enhancing ecosystem services. Moving forward, adopting a comprehensive, systems-based approach will be crucial for making informed decisions that maximize benefits, support environmental health, and promote sustainable agricultural development. Embracing this holistic perspective will help ensure that soil additives remain effective and adaptable in the face of evolving challenges, ultimately contributing to a healthier planet and more sustainable food production systems.

Author contributions

AC: Writing – original draft, Writing – review & editing. JV: Writing – review & editing, Writing – original draft. SR: Writing – review & editing, Writing – original draft.

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