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EDITORIAL

Biological cycling of nitrogen and phosphorus in soils

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Introduction

The bioavailability of nitrogen (N) and phosphorus (P), as two important macronutrients in biological systems, is a vital factor in determining and sustaining global agricultural production and food security (Chang et al. 2021; Masso et al. 2022). Biogeochemical cycling of N and P in soil determines the immediate plant availability and utilization of native and added N and P in managed ecosystems. Most agricultural soils are not able to supply adequate N and P to plants, mainly due to the fact that the plant availability of ionic forms is limited by a combination of reversible and irreversible sorption on mineral surfaces (NH_4^+ (clays), $H_2PO_4^-/HPO_4^{2-}$ (oxides)), drainage transfer (NO_3^-, $H_2PO_4^-$ /HPO_4^{2-}), gaseous N loss (NH_3, NO, N_2O and N_2), and biological immobilization into organic N and P (Haygarth et al. 2013). Furthermore, inefficient plant recovery from N and P inputs (~20%-40%) in the form of mineral fertilizers and manures contribute to increasing global warming and eutrophication (Conant et al. 2013; Masso et al. 2022). These concerns highlight the need to better understand the biological cycling of N and P within the plant-soil continuum, with the aim of enhancing overall nutrient-use efficiency, which in turn will contribute to reducing N and P inputs and alleviating adverse environment impacts (Fig. 1).

The aim of this special issue was to bring together a range of studies that contribute to the mechanistic understanding of how plants, microorganisms, and fauna influence the biological turnover of N and P in soils, with a focus on managing N and P availability and minimizing losses. We gathered 10 papers in this special issue, comprising one review and nine original research articles. The research articles covered diverse ecosystems, including vegetable, paddy, upland, pasture, and agroforestry systems, and assessed the impact of different management practices on N and P cycling.

Over 90% of total N and 30–65% of total P in soil is present in organic forms which means that biological and biochemical processes play important roles in determining N and P dynamics and bioavailability (Haygarth et al. 2013). In this special issue, four papers specifically examine the impact of land use and management on the biological transformations of organic N and P in soils. Based on a series of ^{15}N-tracing pot experiments, Dan et al. (2024)

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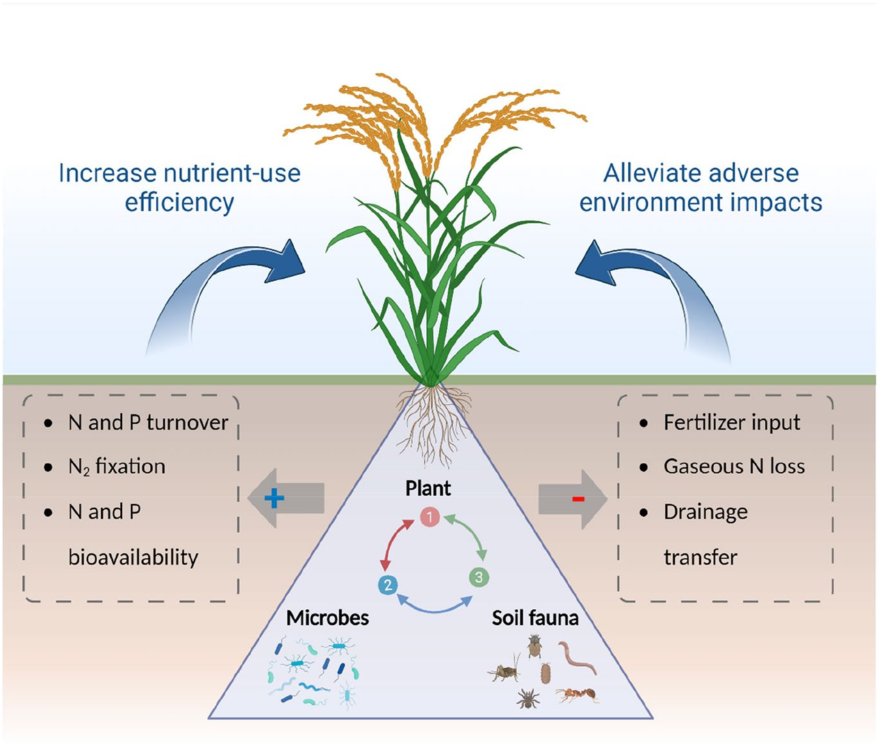

Fig. 1 A conceptual diagram illustrating the potential effects of biological nitrogen and phosphorus cycling on agriculture production and environment

demonstrated that reductive soil disinfestation promoted vegetable N uptake by stimulating soil gross N transformation and improving the quality of degraded soil. They also emphasized the importance of N-fertilizer management to mitigate NO_3^- leaching and gaseous N losses, given the elevated autotrophic nitrification rate and NO_3^- accumulation under reductive soil disinfestation. The two papers by Peng et al. (2024) and Lv et al. (2024) focused on soil organic P dynamics in response to agricultural abandonment and zinc application, respectively. Peng et al. (2024) found that agricultural abandonment caused redistributions of soil inorganic P to organic P, with alkaline phosphatase-mediated phosphomonoester turnover playing a crucial role in P availability during post-agricultural succession in a karst ecosystem. Lv et al. (2024) found that zinc application enhanced the turnover of organic P and P availability in the rice rhizosphere by increasing the abundance of P-solubilizing bacteria, acid phosphatase activity, and expression of functional genes (*phoC*, *phoD*, *ppk*, and *pqqc*). These findings endorse the potential utilization of soil organic P for sustainable crop production (Menezes-Blackburn et al. 2018), emphasizing the need for a thorough understanding of organic P dynamics in the rhizosphere. To fill this gap, Zhang et al. (2024) performed a systematic review to assess the knowledge on the root and microbial processes and root-microbe interactions that affect organic P dynamics in the rhizosphere, with a focus on recent progress in understanding organic-P-acquisition strategies that integrate carbon cycling. They highlight the importance of enhancing root-microbial community interactions and using diversified crop patterns, along with optimizing nutrient inputs, to maximize the rhizosphere biological potential for sustainable organic P utilization.

In two additional papers, the authors examined the impact of root-microbe interactions and fauna activity on soil P fractions in subtropical/tropical plantations. Zeng et al. (2024) demonstrated that N deposition increased plant and microbial P demand and reduced soil labile P and organic P in the wet season due to enhanced plant P absorption and acid phosphatase activity, while showing minor effects on soil P fractions in the dry season due to decreased P adsorption on Fe-Al oxides. These findings highlight the seasonal variation in major factors determining biological transformation of soil P in response to N deposition. Separately, Lin et al. (2024) investigated the impact of termite activity on soil aggregate stability and aggregate-associated P cycling, the results suggest that termite activity enhanced P availability and cycling in aboveground mounds, despite the low aggregate stability, whereas stable P fractions increased after mound abandonment. These findings by Lin et al. (2024) draw attention to the interlinked relationship between soil aggregates and P dynamics as determined by soil fauna activity. Collectively, these studies demonstrate the importance of interactions among biota and abiotic factors in soil P dynamics and the underlying mechanisms.

The major pathways for N loss from terrestrial ecosystems to the atmosphere or hydrosphere include gaseous emissions of NO_x and N_2, as well as leaching of NO_3^- and organic N (McNeill and Unkovich 2007). In this special issue, Reimer et al. (2024) studied how urine urea N concentration affects soil nitrifier and denitrifier abundances, activities, and N_2O production, and found that doubling urea concentration doubled N_2O fluxes from urea sources but not total N_2O fluxes. They further demonstrated that the sustained and proportional response of *nirS* denitrifier activity and stronger response of *nosZ-II* denitrifier activity constrained short-term N_2O emissions and mitigated the potential emission in response to excess urine N excretion. Based on a two-year lysimeter field experiment, Wang et al. (2024) compared the characteristics of N leaching under different greenhouse vegetable production systems, and found that organic farming decreased dissolved inorganic N and total N leaching, but increased dissolved organic N leaching compared with conventional farming. These findings suggest that there is a need to optimize irrigation and fertilization management in organic farming systems to minimize dissolved organic N leaching.

Plants and microbes may exhibit various strategies to improve the P efficiency when soil P availability is low (Richardson et al. 2011). In this special issue, Liang et al. (2024) examined whether plant leaves, roots, and soil microbial communities can reduce P requirements by substituting phospholipids with non-P containing lipids across natural gradients of soil P availability. They found that plants and soil microbes decreased investment of P into all phospholipid classes in response to P deficiency without a concomitant increase in non-P lipid concentration, highlighting the crucial role of phospholipids in their P economy for persistence in low-P ecosystems. Additionally, Yang et al. (2024) conducted a field experiment to assess the effects of various intercropping systems on soil microbial resource limitation and identify controlling factors through exploring functional gene abundance and soil C-N-P stoichiometry. The results revealed that soil microbial P limitation was notably related to plant N and P uptake and maize yield, with intercropping effectively alleviating P limitation through increased abundance of functional genes related with P activation.

In summary, this special issue contributes to advancing mechanistic understanding of biological N and P cycling in soil–plant systems by providing insights into the development of management practices designed to optimize N and P cycling. However, transformations of N and P in heterogeneous soils are influenced by a complex interplay of physical, chemical, and biological factors, with these interactions further influenced by soil type, vegetation, climate conditions, land use, and management. Continued development and application of multidisciplinary approaches that integrate plant biology, soil science, and microbiology are needed to further unravel the complex interactions that determine nutrient efficiency and crop productivity.

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Data Availability Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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