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Editorial: Better management of phosphorus fertilizer in intensive cropping systems: An approach based on integrated agronomic, ecological and environmental compromises

Haigang Li[1]*, Gu Feng[2] and Timothy S. George[3]

[1]Inner Mongolia Key Laboratory of Soil Quality and Nutrient Resources, Key Laboratory of Agricultural Ecological Security and Green Development at Universities of Inner Mongolia Autonomous Region, Inner Mongolia Agricultural University, Hohhot, China, [2]College of Resources and Environmental Sciences, China Agricultural University, Beijing, China, [3]Department of Ecological Sciences, The James Hutton Institute, Dundee, United Kingdom

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EDITED AND REVIEWED BY
Ilan Stavi,
Dead Sea and Arava Science Center,
Israel

*CORRESPONDENCE
Haigang Li,
haigangli@imau.edu.cn

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Editorial on the Research Topic
Better management of phosphorus fertilizer in intensive cropping systems: An approach based on integrated agronomic, ecological and environmental compromises

For the last 10,000 years, humans have been growing crops for consumption and trade, but only in the last 200 years have we used industrialized fertilizer production to sustain this. In just two centuries, we have all but used up many of our readily-available mineral resources. We are now reliant on high-yield, yet resource-inefficient, production systems which are wasteful, prone to economic volatility, and environmentally damaging. We need to improve the way in which crop nutrition is managed, by finding ways by which we can use inorganic fertilizer more effectively.

Phosphorus (P), is an essential element for plants, but is easily fixed by mineral surfaces in soils and therefore has a low P use efficiency. Less than 25% of applied P is absorbed by crops in the growing season after application in most soils globally. This lack of efficiency has led to large amounts of P accumulation in soils, known as “legacy P” (Gatiboni et al., 2020). Sattari et al. (2012) suggest that this build-up of legacy P is ca. 550 kg P ha^{-1} between 1965 and 2007 worldwide. This inefficiency enhances the depletion and profligate use of global rock P reserves. This has the potential to deplete the easily extractable and economically viable sources of rock P within the next 100 years if the current consumption rate is not reduced (Cordell et al., 2009). At the same time, some arable lands still need to build up soil P fertility through P fertilizer application, such as in China, where over 50% of arable lands are suffering P deficiency stress (Li et al., 2015) and even more soils in sub-Saharan Africa are in this position. Moreover, recent economic shocks in the fertilizer market due to increasing energy prices and conflict in Ukraine have led to P fertilizer prices reaching peaks not seen since 2008.

Developing better management strategies for the utilization of fertilizer P and soil legacy P are needed and should integrate innovation in agronomy, crop genotype selection, optimization of rhizosphere management for biological mining of sparingly soluble phosphates, improved P uptake efficiency, and implementation of P recycling in soil-cropping systems. In this Research Topic, we have collected together 10 contributions highlighting interactions between soil-plant-microorganisms which determine P use of crops, rhizosphere processes facilitating P uptake of crops, the modification of soil P availability through the addition of organic materials, and the demands of P fertilizer application in different cropping systems.

Soil microorganisms have a critical involvement in the soil P cycle through P mobilization and assimilation, and can also facilitate or reduce the P uptake of plants (Zhang et al., 2018). The paper by Liu et al. demonstrates that combining microbial fertilizer with a reduced conventional fertilizer application increases soil P availability and acid phosphatase activity in soil compared to standard practice, in trials conducted in Jilin province in China. Moreover, the addition of microbial fertilizer increased the relative abundance of beneficial *versus* pathogenic microbes and created a favorable microbial community for maize. In the Inner Mongolia Autonomous Region of China, Qu et al. demonstrate that soil microbial activity was greater with intercropping of legumes and brassica when compared to monocropping. They go on to show that *Proteobacteria*, *Gemmatimonadetes*, *Bacteroidetes*, and *Rokubacteria*, dominant bacterial phyla in soil, are increased in intercropping systems. This modification of soil microorganisms is accompanied by increases in soil organic matter and P availability.

Different plant species show variable adaption strategies to improve P uptake, including morphological and physiological responses. By testing 235 genotypes of Peanut (*Arachis hypogaea* L.) in hydroponic experiments, Zhu et al. find that P deficiency not only improves the P absorption efficiency of the roots but also induces root growth, which means the roots contribute more to the P uptake capacity. Furthermore, Wang et al. show that the over-application of P fertilizer causes O_2-deficient stress of amaranth (*A. mangostanus*). They demonstrate that when rhizosphere O_2 concentration was 250.6 μmol L^{-1}, it stimulated root growth in a pot experiment. Oxygenation also increased Olsen-P in the rhizosphere by promoting organic P mineralization and was related to improved yield and amaranth quality.

Organic material addition can improve soil P bioavailability by desorbing P fixed by soil minerals and P released from organic material. Wang et al. modify the Langmuir equation to describe P adsorption properties in organic material-incubated soils. They find organic material addition decreased the amount of P adsorption by soil. This suggests that organic material addition could be used to improve P availability, but should be controlled in high P soil to avoid increases in the risk of P loss to the environment. Importantly, the addition of organic material to soil was shown to be an efficient approach to building up soil P fertility and promoting the P uptake of maize, as shown by Khan et al. based on a pot experiment.

Sub-optimal P fertilizer application still occurs in some areas of China. The dynamic P pool simulator model was used to predict P pools from 1985 to 2100 in pomelo orchards of Pinghe County in China. Yan et al. find that the labile P pool would increase by more than twofold if the current P application rate was maintained, resulting in serious P resources waste and risk of P loss to the environment. Scenario analyses showed the P application rate can be reduced from 413.63 kg ha^{-1} to 31 kg P ha^{-1} without any yield loss. Shi et al. assess the yield gap of spring maize in the Jilin province of China and found that farmers only achieved 52% of the model yield potential. Suboptimal soil Olsen P levels are one of the major contributors to this yield gap. Therefore, efficient soil P management is still needed in the region. In contrast, in the Yangtze River delta of China, Xiao et al. recommend an optimal P application rate for the rice-wheat rotation system of 72–75 kg P_2O_5 ha^{-1}. Wei et al. assess the P uptake requirements of rice (*Oryza sativa* L.) grown in saline-sodic soils of Northeast China and show that the P requirement ranged from 4.21 kg P Mg^{-1} to 4.61 kg P Mg^{-1} in this region.

Overall, this Research Topic of papers demonstrates that there are a number of ways in which the P use efficiency, and therefore the sustainability, of cropping systems can be improved. Taken together, the papers demonstrate that there are a number of interventions that can be considered including the optimization of fertilizer applications, optimized plant-microbe interactions, consideration of rhizosphere processes, and the judicious use of organic material additions. It is clear that an integrated approach is needed to help secure the sustainability of the use of P resources in the future.

In the end, we would like to thank all the reviewers for their valuable comments and suggestions, which helped to improve the quality of the papers. We hope this Research Topic will stimulate further research into better management of P fertilizer in intensive cropping systems, which needs a multidisciplinary approach to generate novel management strategies.

Author contributions

HL, GF, and TG contributed equally to defining the scope for this Research Topic. They edited the manuscripts submitted to this Research Topic.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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