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EDITORIAL
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Editorial: Sustainable Phosphorus Use in Agriculture

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Editorial on the Research Topic

Sustainable Phosphorus Use in Agriculture

The rational use of nutrients in agriculture is critical to improving the sustainability of crop production while ensuring optimum crop development and yield. This can be achieved by promoting the equilibrium between the inputs and recycling of nutrients with crop demand, thus reducing external inputs of fertilizers and/or enhancing nutrient use efficiency. In most agricultural land around the world, phosphate fertilizers will still be required to meet plant demand and to overcome the competing action of phosphorus (P) sorption and immobilization on soil mineral surfaces. However, the amount of P applied via fertilizers (organic or mineral) over several decades has often led to P saturation of the soil, resulting in environmental issues and even negative interactions with other nutrients (e.g., nitrogen). In those high-P soils, if water-soluble P or sediments are transferred to water bodies by runoff/erosion, water eutrophication is the main environmental concern.

The phosphate rock (PR) mines, which are deemed economically viable, are finite and represent a non-renewable resource that will become progressively exhausted. For this reason, it is critical that agricultural systems are pushed to improve P-use efficiency (PUE), essentially producing more with less. By necessity, this requires a better balance between inputs and outputs of P to slow the depletion of PR mines and future P scarcity. Some management systems around the world can reach 80–90% PUE, however, most current management regimes barely reach 40–50% PUE. Therefore, new strategies for improving PUE need to be developed and adopted, including readjusting fertilizer recommendations, use of crop rotations to explore distinct soil volumes as well as the use of P-mobilizing plant and microbial species, intensifying the use of wastes and by-products, adopting the best management practices that consider soil P legacy, and continuously revise the environmental regulations to avoid excessive accumulation of P in the soil, impairing water quality. All these strategies can improve the P use of soil/fertilizers by plants and the sustainability of agriculture. In this Research Topic, some of these strategies have been addressed, and a brief overview of each of these studies is presented below.

FERTILIZER SOURCES AND MANAGEMENT

Nunes et al. investigated labile P content and root distribution in the soil profile and their effect on soybean and maize yield in a long-term (17 y) experiment fertilized with triple superphosphate (TSP) and reactive PR, both band-applied or broadcast under a conventional tillage (CT) or

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no-tillage (NT) regime. They observed that the soil disturbance in CT promoted a more homogeneous soil P distribution, while in NT there was a strong depth gradient, with soil-available P accumulation in the application zone. Root distribution of soybean in NT and maize in both tillage systems showed a strong relationship with soil P distribution. Unlike maize, the grain yield of soybean in CT was influenced by P fertilization management and generally presented lower performance than in NT. Greater stratification on soil available P and the superficial distribution of roots in NT did not represent a major limitation on nutrient uptake and yields, not even in the extreme case where the fertilizer was continuously broadcast on the soil surface.

ORGANOMINERAL FERTILIZERS

Benites et al. evaluated P application rates using two organomineral-based fertilizers derived from poultry litter, compared to mono ammonium phosphate (MAP) for soybean production over 5 consecutive cropping years. They observed that the remaining legacy P from previous fertilization events was enough to maintain soybean crop yield in the first season but that an annual dose $>40\,kg\,ha^{-1}$ P_2O_5 was needed to maintain soil P availability and soybean yield over the years in a Ferralsol from central Brazil. They also concluded that organomineral fertilizers based on poultry litter, raw or composted with sugarcane bagasse, possessed a similar capacity to supply P to soybean relative to MAP. These organomineral fertilizers were proposed as a valuable P source for agriculture in tropical soils, being even more efficient than mineral fertilizer at high P doses.

PHOSPHATE ROCKS

Soares et al. evaluated three phosphate sources (igneous PR, sedimentary PR, and TSP) applied in isolation or in combination with organic compost derived from a sugarcane mill (filter cake). They evaluated sugarcane yield and soil residual P over 24 months in Southern Brazil. Filter cake, as a source of nutrients and organic matter, made an important contribution to making more P available for sugarcane uptake, especially when combined with TSP and sedimentary PR application. These associations were effective in improving crop yield and PUE in sugarcane. Sedimentary PR and TSP were very effective at supplying P for sugarcane, which was not the case for igneous PR from Brazil.

Iwasaki et al. investigated the development of locally-sourced fertilizers to establish optimal P fertilization approaches in Burkina Faso for wider application in Sub-Saharan Africa. Their two-year study considered calcined phosphates and partial acidulated PRs compared to TSP and single superphosphate (SSP) for sorghum and cowpea production. The fertilization effects were evaluated through the PUE index. Water restrictions limited crop response in 1 year for sorghum, but cowpea was able to overcome that limitation because of its shorter growing period, with a significant increase in grain yields under any P fertilization and with better response under soluble P sources. They concluded that partial acidulated PRs were effective for sorghum production, but would only be effective for cowpea when the acidulation level is sufficiently high to ensure plant uptake. Moreover, the long growing period of sorghum is favorable for absorbing slow-release P, but this effect can be restricted by the periodicity and amount of rainfall in this region.

MOBILIZATION OF P BY MICROORGANISMS

Jatana et al. evaluated animal byproducts such as meat and bone meal (MBM) as a source of P. As more than 75% of P in MBM is Ca-bound P (as hydroxyapatite) with low bioavailability for plants, they investigated the potential of two microbial inocula -arbuscular mycorrhizal fungi (AMF) and *Penicillium bilaiae* in improving the mobilization of P from MBM and the subsequent P uptake by maize. Their interesting findings demonstrate that P solubilizing microbes possessed the capacity to mobilize the P from recalcitrant P fractions, while AMF could help plants mobilize soil P that is not available to plant roots. This combined effect of *P. bilaiae* and AMF can therefore ensure greater uptake of P for maize and improved PUE.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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