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Strategies for Efficient Phosphorus Management in Acid and Alkaline Soils

Rewangini Ranjha, Dhanbir Singh, Raj Paul Sharma

Department of Soil Science, CSK HPKV Palampur, H.P., India

Email: rewanginiranjha@gmail.com

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Introduction

In Indian agriculture, phosphorus is considered as the "king-pin" and the "energy currency" of the plants (Dey et al. 2017). In terms of mineral nutrients, phosphorus (P) is the second most crucial element after nitrogen for crop productivity. For the formation and expansion of the roots as well as the establishment of the primordia of the plant reproductive parts, an adequate supply of P throughout the early stages of plant development is crucial. P availability in soil is a key determinant of agricultural productivity. In India, where agriculture is the backbone of the economy and a major source of livelihood for millions of people, understanding the P status of soils is critical for sustainable agricultural production. P is the least accessible to plants despite being plentiful in soils in both organic and inorganic forms. This is because it diffuses slowly and has a high fixation rate under most soil conditions (Shen et al. 2011). P may therefore be a significant nutrient that limits plant development on various soils across the world. Without P, agricultural productivity will be reduced, resulting in less food being produced per unit of land area, particularly in the least developed and emerging nations where access to P fertilizers is limited as a result of P fertilizer's growing price (Lynch 2007). P thus plays a crucial role in the present and future security and production of food worldwide since it is necessary for intensive agricultural production systems (Richardson et al. 2011). Hence, an integrated approach using a combination of these strategies may be required for efficient P management in acid and alkaline soils. However, careful consideration of soil properties, crop requirements, and environmental factors should be taken into account to develop effective P management practices for sustainable agriculture. Therefore, this article aims to provide an overview of current P status of Indian soils, the factors affecting P availability and different strategies for efficient P management in acid and alkaline soils.

Phosphorus Status of Indian Soils

The country's soil-P fertility map was initially published in 1979 and revised in 1993 based on 9.6 million soil test summaries (Hasan 1996); in this research, about 49.3% of the districts and union territories had low, 48.8% had medium, and 1.9% had high levels of accessible P. The low fertility class samples grew by 3% in comparison to previous test summary, whereas the medium and high categories showed decreases of 2.7 and 0.3%, respectively (Dey et al. 2017). According to Rao et al. (2015), the majority of the soils had low or medium soil P fertility levels before 1996. Motsara (2002) also reported that 42, 38 and 20% of the nation's districts fall under the low, medium, and high P status categories, respectively. The soils in Haryana, Gujarat, Uttar Pradesh, Jammu and Kashmir, Maharashtra, Andhra Pradesh, Orissa, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Puducherry, and the Andaman and Nicobar Islands have an average P fertility index that falls into the low category, while the soils in Assam, Nagaland, Tripura, West Bengal, Himachal Pradesh, Goa, Madhya Pradesh, Punjab, Kerala and Tamil Nadu grouped in medium-P category (Dey et al. 2017). Indian Council of Agricultural Research (ICAR), also reported that about 70% of Indian soils are P-deficient or low in available P. The extent of P deficiency varies across different soil types, with the highest deficiency observed in red and lateritic soils, which are prevalent in southern and eastern India. Soils in other parts of India, such as alluvial and black soils, are generally better in P availability, but still have localized areas of deficiency.

Factors Affecting Phosphorus Availability

The availability of P in Indian soils is influenced by a range of factors, including

- ✓ **Soil pH:** In terms of P availability in soils, a pH range of 6.5 to 7.0 is ideal (Penn and Camberato 2019).
- ✓ **Organic matter content:** It can improve P availability by enhancing microbial activity and formation organic complexes (chelation) with soluble Al and Fe (Asmare et al. 2015). Furthermore, the organic acids dissolves calcium phosphate and increase P availability (Martins et al. 2008).
- ✓ **Soil mineralogy:** Particularly the presence of iron and aluminum oxides, can fix P and reduce its availability (Havlin et al. 2013).
- ✓ **Climatic factors:** Temperature and rainfall can also affect P availability by influencing soil moisture and nutrient cycling.

P availability in acid soils

In acid soils, P is often fixed by aluminum (Al) and iron (Fe) oxides and hydroxides, making it unavailable to plants. The solubility of P decreases as soil pH decreases, and at pH values below 5.5, P is almost completely immobilized. In acidic soils, P is made unavailable by two mechanisms: precipitation and sorption by Al or Fe oxides and hydroxides (haematite, gibbsite and goethite) (Wang 2012). It can be explained by following equations:

$$Al^{+++} + H_2PO_4^- + 2H_2O \longrightarrow \underset{\text{Aluminium hydroxy phosphate}}{2H^+ + Al(OH)_2H_2PO_4} \longrightarrow \underset{\text{Variscite (insoluble)}}{AlPO_4.H_2O}$$

$$Fe^{+++} + H_2PO_4^- + 2H_2O \longrightarrow 2H^+ + Fe(OH)_2H_2PO_4 \longrightarrow \underset{\text{Strengite (insoluble)}}{FePO_4.H_2O}$$

Some strategies to enhance phosphorus use efficiency in acid soils

- ✓ **Liming:** Liming increases soil pH, reducing Al and Fe toxicity and increasing P solubility. However, excessive liming can also lead to the formation of calcium (Ca) and magnesium (Mg) compounds, reducing P availability. Therefore, liming to a pH of 6.0-6.5 can increase P availability in acid soils.
- ✓ **Organic matter addition:** Organic matter addition enhances soil biological activity and nutrient cycling, increasing P availability. Moreover, organic matter can form complexes with Al and Fe, reducing their negative effects on P availability.
- ✓ **Use of low-solubility P fertilizers:** P fertilizers with low water solubility, such as rock phosphate, can be applied

in larger amounts without risk of leaching or runoff, and slow-release formulations can improve P use efficiency.

- ✓ **Split applications of P:** Split applications of P can reduce P fixation and improve P uptake by plants, especially in soils with high P sorption capacity.
- ✓ **Use of P-efficient crop varieties:** Selecting P-efficient crop varieties can improve P use efficiency and reduce fertilizer requirements. These varieties are better adapted to low-P soils and have better root systems for P uptake.
- ✓ **Low soluble P-fertilizers:** Fertilizers with low water solubility, such as rock phosphate, can be applied in larger amounts without risk of leaching or runoff, and slow-release formulations can improve P use efficiency.

P availability in alkaline soils

In alkaline soils, P is often fixed by Ca and Mg compounds, reducing its availability by forming calcium phosphates (Siebielec et al. 2014). However, the solubility of P increases as soil pH increases, but at pH values above 8.5, P can also become immobilized. The following equations are used to explain this:

$CaH_4(PO_4)_2$ + $CaCO_3$ → $Ca_2H_2(PO_4)_2 + CO_2 + H_2O$

Monocalcium-P   Ca-carbonate   Dicalcium Phosphate (less soluble)

$Ca_2H_2(PO_4)_2$ + $CaCO_3$ → $Ca_3(PO_4)_2 + CO_2 + H_2O$

Dicalcium Phosphate   Tricalcium phosphate (least soluble)

$Ca_3(PO_4)_2$ → Carbonate apatite and Hydroxy apatite

Tricalcium phosphate   (Extremely insoluble)

Some strategies to improve P availability in alkaline soils

- ✓ **Soil acidification:** Soil acidification using elemental sulfur can lower soil pH and increase P availability. However, it is important to apply these amendments in the correct amounts and monitor soil pH to avoid over-acidification.
- ✓ **Use of acidifying P fertilizers:** P fertilizers with acidifying properties, such as monoammonium phosphate (MAP), can improve P availability in alkaline soils by releasing acid during their breakdown. These fertilizers can also supply both P and nitrogen (N) to crops.
- ✓ **Application of gypsum:** Gypsum helps in reducing phosphorus and other nutrients losses as it prevents runoff and erosion and improves soil physical properties (Khardia et al. 2022).
- ✓ **Use of P-solubilizing microorganisms and biofertilizers:** Some microorganisms, such as phosphate-solubilizing bacteria and fungi, can release P from soil minerals, making it available to plants. These microorganisms can be applied as biofertilizers or inoculants to enhance P availability (Ranjha et al. 2022).
- ✓ **Balanced fertilization:** Applying P fertilizers in conjunction with other nutrients such as nitrogen and potassium can improve P use efficiency and enhance crop yields.

- ✓ **Precision agriculture:** The use of precision agriculture techniques, such as site-specific nutrient management, can help optimize P fertilizer application and reduce its losses.

Conclusion

The efficient management of P in Indian soils is critical for sustainable agricultural production and the livelihoods of millions of people. While the P deficiency problem is widespread in Indian soils, a range of strategies, including balanced fertilization, use of P-efficient crop varieties, biofertilizers, soil amendments, and precision agriculture, can help improve P availability and use efficiency. To achieve sustainable and productive agriculture in India, it is essential to develop and implement effective P management practices based on local soil and crop conditions.

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