Chronicle of Bioresource Management 2024, 8(3): 077-081

Chronicle of Bioresource Management
An International E-magazine

September, 2024 Popular Article

Open Access
Corresponding Author
Ramanjit Kaur
e-mail: ramanjitagro@gmail.com

Citation: Ali et al., 2024. Unlocking Soil Phosphorus: The Importance of Phosphate Solubilizers for Crop Growth. Chronicle of Bioresource Management 8(3), 077-081.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

Unlocking Soil Phosphorus: The Importance of Phosphate Solubilizers for Crop Growth

Sk Asraful Ali[1], Ramanjit Kaur[1*], Vipin Chandra Dhyani[2], Megha Kumari[1], Unti Miiri Ezing[1] and Rashmi Jha[3]

Abstract

Phosphorus (P), the second most important macronutrient after nitrogen, plays a crucial role in plant growth and development. However, its availability in soils is often limited due to fixation in insoluble forms, resulting in low phosphorus use efficiency and negatively impacting crop yields. To enhance phosphorus availability, various agents have been identified as effective solutions, including humic substances (such as humic acid, fulvic acid, and humin), phosphate solubilizing microorganisms (PSMs), zeolite, biochar, bentonite, and polymers. These agents increase phosphorus solubility and improve soil health, thereby promoting sustainable agriculture by reducing reliance on chemical fertilizers. Their application not only boosts immediate plant growth but also contributes to long-term soil fertility and enhanced crop yields, addressing critical agricultural challenges and fostering a more resilient agricultural ecosystem. By integrating these solutions into farming practices, farmers can optimize nutrient management, improve crop productivity, and ensure environmental sustainability.

Keywords:

Biochar, humic substances, phosphorus, phosphate solubilizing microorganisms, zeolite

Article History

Article ID: CBM5743
Received on 29th August 2024
Received in revised form on 17th September 2024
Accepted in final form on 26th September 2024

1. Introduction

Phosphorus (P) is an essential macronutrient for plants, playing a pivotal role in their growth and development. It is considered the second most important macronutrient after nitrogen and is required in significant quantities for various physiological and biochemical processes including photosynthesis, energy storage, cell division, signal transduction, and the synthesis of nucleic acids and phospholipids. Despite its importance as an essential macronutrient for plant growth and development, phosphorus is often one of the least available nutrients in many soils. Though most soils contain abundant total phosphorus, a significant portion exists in forms that plants cannot readily uptake, such as insoluble inorganic phosphates and organic forms. Consequently, even when phosphorus is applied as fertilizer, its use efficiency is typically low,

Author's Address

[1]ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi (110 012), India
[2]G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand (263 145), India
[3]Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu (641 003), India

with only 10-15% of applied phosphorus being utilized by crops in the year of application. A significant portion of phosphorus is immobilized through rapid chemical reactions with cations like Ca^{2+} in calcareous soils, forming calcium phosphate, and with Al^{3+} and Fe^{3+} in acidic soils, resulting in aluminum phosphate and ferrous phosphate, respectively. This immobilization leads to low phosphorus availability in soils, adversely affecting crop performance. Besides, the global supply of high-quality rock phosphate, the primary raw material for phosphorus-based fertilizers, faces significant challenges. Based on current usage rates, it is estimated that these reserves may be depleted within this century. After this period, the production of phosphorus-based fertilizers will necessitate the processing of lower-grade rock, which will incur significantly higher costs. Therefore, enhancing phosphorus use efficiency has long been a key challenge in intensive cropping systems. The realization of all these potential challenges related to chemical phosphorus fertilizers, combined with the high costs of their production, has driven the quest for environmentally sustainable and cost-effective alternative methods to improve crop yields (Table 1) in soils that are low in phosphorus or deficient in it.

2. Different Phosphate Solubilizers

2.1. Humic substances

Humic products, including humic acid, fulvic acid and humin, have been used in agricultural crop lands for many years due to their ability to convert elements from their unavailable forms into forms that plants can absorb. Humic substances can chelate or bind with metal ions,

Table 1: Effects of different phosphate solubilizers on phosphorus concentration, uptake and availability

Study area	Crop	Phosphate solubilizers rate	Findings	Reference
Humic substances				
Kafr El-Sheikh Governorate (Egypt)	Barley	Fulvic acid: 4.75 L ha^{-1} (plus 75% RDP)	↑ 9% straw P uptake (2019-20) ↓ expenditures of fertilizer up to 25% (2019-20)	Alsudays et al. (2024)
Peshawar (Pakistan)	Wheat	Humic acid: 5 kg ha^{-1} (plus 67.5 kg P_2O_5 ha^{-1})	↑ 9.3% plant P conc., 7.8% plant P uptake, 7.4% AB-DTPA extractable P ↓ expenditures of fertilizer up to 25%	Izhar Shafi et al. (2020)
Phosphate solubilizing microorganisms (PSMs)				
Uttarakhand (India)	Rice	*Bacillus licheniformis* + *Pantoea dispersa* + *Staphylococcus* sp. (plus 50% P)	↑ 62.1% PUE, 45.4% apparent recovery efficiency, 41.7% agronomic efficiency (2018) ↓ expenditures of fertilizer up to 50% (2018)	Rawat et al. (2022)
Ben Guerir (Morocco)	Wheat	*P. frederiksbergensis* (plus RP)	↑ 78.6% root APase, 43.9% shoot Pt, 32.7% root Pt (42-day old plant)	Elhaissoufi et al. (2020)
Zeolite				
Lykovrysi (Greece)	Lettuce	Clinoptilolite zeolite: 50 g kg^{-1} dry soil (5% w/w)	↑ 4.8% available P (P-Olsen) and 38.4% leaf P uptake (Ac-LT soils)	Kavvadias et al. (2023)
Sabah (Malaysia)	Maize	Clinoptilolite zeolite: 10.34 g $plant^{-1}$ (plus 75% TSP)	↓ expenditures of fertilizer up to 25%	Hasbullah et al. (2020)
Biochar				
Tamil Nadu (India)	Black gram	Red gram stalk biochar: 5 t ha^{-1}	↑ 18.7% soil available P, 26.1% P uptake	Kannan et al. (2021)
Peshawar (Pakistan)	Maize	Acacia tree biochar: 10 t ha^{-1}	↑ 18% PUE compared to the control	Arif et al. (2021)

reducing their ability to fix phosphorus and by doing so, they maintain phosphorus in a more soluble and plant available form, thereby enhancing its uptake by plants. The application of humic substances has also been shown to positively affect the microbial community in the soil. Enhanced microbial activity can lead to increased phosphatase enzyme production, which further aids in the mineralization of organic phosphorus compounds. This microbial interaction is vital for maintaining soil health and nutrient cycling, ultimately supporting plant growth. Thus, by promoting a more active microbial community, humic substances indirectly contribute to increased phosphorus availability. Furthermore, humic substances enhance the efficiency of phosphate fertilizers by promoting the release of hydrogen ions (H^+) in the rhizosphere. This process helps to lower soil pH, thereby increasing the solubility of phosphorus compounds that are typically bound to soil particles or other elements like iron and aluminum in acidic soils. As a result, more phosphorus becomes available for plant uptake, leading to improved nutrient acquisition. Field studies have demonstrated that the use of humic substances, particularly in conjunction with phosphate fertilizers, results in significant improvements in crop yields. For instance, crops treated with humic acid-enhanced phosphate fertilizers have shown increased height, biomass, and nutrient accumulation compared to those receiving standard fertilizers. The synergistic effect of humic acid and phosphorus not only boosts immediate plant growth but also contributes to long-term soil fertility.

2.2. Phosphate Solubilizing Microorganisms (PSMs)

Microorganisms play a crucial role in the soil P cycle by facilitating the transport and transformation of phosphorus among various soil phosphorus pools. Phosphate Solubilizing Microorganisms (PSMs) including both bacteria and fungi are integral to this process, as they transform both inorganic and organic soil phosphorus into bioavailable forms through various mechanisms of solubilization and mineralization. Phosphate Solubilizing Bacteria (PSB) i.e. *Pseudomonas*, *Bacillus, Azotobacter*, *Rhodococcus*, *Xanthomonas*, *Pantoea*, *Arthrobacter*, *Serratia*, *Phyllobacterium*, *Delftia*, *Gordonia*, *Enterobacter*, *Klebsiella* etc. and Phosphate Solubilizing Fungi (PSF) i.e. *Aspergillus, Alternaria*, *Fusarium*, *Penicillium*, *Helminthosparium*, *Sclerotium* etc. make up 1-50% and 0.1-0.5%, respectively, of the total PSMs in soil. Additionally, phosphate solubilizing actinomycetes (PSA) contribute to a lesser extent. Generally, PSF produces more acids than PSB, which leads to their greater phosphate solubilizing activity. Nemato-fungus *Arthrobotrys oligospora* and Symbiotic nitrogen-fixing rhizobia have also been identified as having phosphorus solubilizing abilities. Symbiotic nitrogen-fixing rhizobia not only fixes atmospheric nitrogen into ammonia but also enhances phosphorus availability for their host plants. Phosphate Solubilizing Microorganisms (PSMs) produce organic acids including gluconic, formic, fumaric, 2-ketogluconic, acetic, lactic, propionic, and succinic acids which lower the soil pH, leading to the dissolution of bound phosphate forms. PSMs also produce enzymes such as phosphatases that hydrolyze organic phosphorus compounds, further increasing the pool of available phosphorus in the soil. By improving phosphorus availability, PSMs promote better nutrient uptake by plants, leading to increased biomass and crop yields (Figure 1). This is particularly beneficial in phosphorus-deficient soils where traditional fertilizers may not be effective. The use of PSMs reduce the reliance on chemical phosphorus fertilizers, contributing to more sustainable farming practices. This not only lowers input costs for farmers but also minimizes environmental impacts associated with fertilizer runoff and soil degradation.

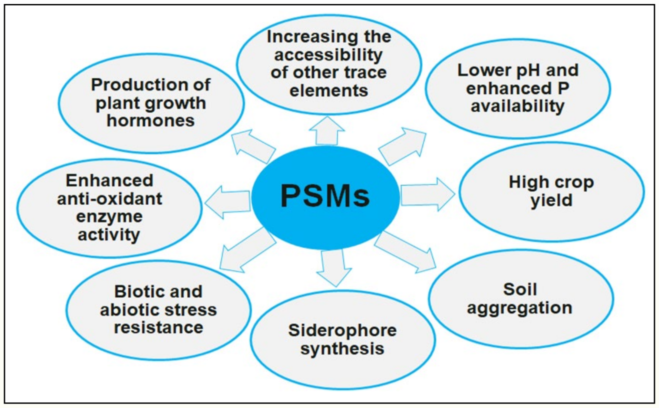

Figure 1: Ecological and sustainable implications of PSMs in soil

2.3. Zeolite

Zeolite, a naturally occurring aluminosilicate mineral with a unique porous structure and high cation-exchange capacity, acts as an ammonium exchanger that helps retain cations in the soil. By exchanging ammonium ions, zeolite can reduce the fixation of phosphorus by aluminum and iron, which are prevalent in acidic soils. This process facilitates the release of phosphorus from insoluble forms, making it more available to plants. The application of zeolite can also help increase soil pH, thereby reducing soil acidity. Additionally, zeolite can retain moisture, allowing for more efficient use of irrigation water, which is crucial in managing phosphorus availability. In experiments where zeolite was used in conjunction with phosphatic fertilizers, there was an observed increase in various phosphorus fractions, including labile and moderately labile phosphorus. This indicates that zeolite improves overall phosphorus availability and enhances the mobility of different phosphorus forms in the soil. While zeolite can improve phosphorus availability, the economic justification for its large-scale use remains a consideration. Studies suggest that higher proportions of zeolite may lead to more significant increases in phosphorus uptake, but the cost-effectiveness of such applications needs further investigation.

2.4. Biochar

Biochar is an effective tool for improving phosphorus availability in soils, contributing to enhanced crop productivity and sustainability in agricultural systems. Its ability to modify soil properties, support microbial activity, and retain nutrients makes it a valuable amendment for addressing phosphorus deficiencies in various cropping systems. Biochar has a high surface area and porous structure, which allows it to adsorb phosphorus and other nutrients, preventing their leaching and making them more available for plant uptake. The alkaline nature of biochar can help to raise the pH of acidic soils, which improves the solubility of phosphorus compounds that are often bound to iron and aluminum in such environments. Biochar can foster beneficial microbial communities in the soil. These microorganisms, including phosphate-solubilizing bacteria, can convert insoluble phosphorus forms into bioavailable forms through various biochemical processes, such as mineralization and solubilization.

2.5. Other phosphate solubilizers

Additional phosphate solubilizers include bentonite, mugineic acid, water-dissolved organic polymeric compounds, ABT rooting powder, polyvinyl alcohol (PVA), polyacrylamide (PAM), and polyethylene glycol (PEG). Each of these substances plays a vital role in enhancing plant growth and improving nutrient uptake. Bentonite increases Pi in the soil, primarily in forms like Ca_2-P and Ca_8-P. Mugineic acid, with a high affinity for Fe, activates Fe-P. ABT rooting powder, containing IAA (indole-3-acetic acid) and IBA (indole-3-butyric acid), promotes root P absorption and plant growth, enhancing survival rates under abiotic stress while PVA has low permeability and high-water adsorption due to its hydroxyl groups. PAM is non-toxic and soluble in polar solvents, while PEG is known for its unique solubility properties. These polymers release phosphate through the protonation of their functional groups, interacting with Al^{3+} and Fe^{3+} phosphate.

3. Conclusion

Enhancing phosphorus availability is essential for improving plant growth and agricultural productivity. Biochar, zeolite, humic substances, and phosphate solubilizing microorganisms (PSMs) effectively increase phosphorus uptake by reducing fixation and improving nutrient cycling. Integrating these solutions optimizes fertilizer use efficiency, reduces costs, and promotes sustainable agriculture. As phosphorus scarcity and soil degradation intensify, adopting these innovative approaches is crucial for ensuring food security and environmental sustainability.

4. References

Izhar Shafi, M., Adnan, M., Fahad, S., Wahid, F., Khan, A., Yue, Z., Datta, R., 2020. Application of single superphosphate with humic acid improves the growth, yield and phosphorus uptake of wheat (*Triticum aestivum* L.) in calcareous soil. Agronomy 10(9), 1224.

Alsudays, I.M., Alshammary, F.H., Alabdallah, N.M., Alatawi, A., Alotaibi, M.M., Alwutayd, K.M., Awad-Allah, M.M., 2024. Applications of humic and fulvic acid under saline soil conditions to improve growth and yield in barley. BMC Plant Biology 24(1), 191.

Rawat, P., Sharma, A., Shankhdhar, D., Shankhdhar, S.C., 2022. Improvement of phosphorus uptake, phosphorus use efficiency, and grain yield of upland rice (*Oryza sativa* L.) in response to phosphate-solubilizing bacteria blended with phosphorus fertilizer. Pedosphere 32(5), 752–763.

Elhaissoufi, W., Khourchi, S., Ibnyasser, A., Ghoulam, C., Rchiad, Z., Zeroual, Y., Bargaz, A., 2020. Phosphate solubilizing rhizobacteria could have a stronger influence on wheat root traits and aboveground physiology than rhizosphere P solubilization. Frontiers in plant science 11, 979.

Kavvadias, V., Ioannou, Z., Vavoulidou, E., Paschalidis, C., 2023. Short term effects of chemical fertilizer, compost and zeolite on yield of lettuce, nutrient composition and soil properties. Agriculture 13(5), 1022.

Hasbullah, N.A., Ahmed, O.H., Ab Majid, N.M., 2020. Effects of amending phosphatic fertilizers with clinoptilolite zeolite on phosphorus availability and its fractionation in an acid soil. Applied Sciences 10(9), 3162.

Kannan, P., Paramasivan, M., Marimuthu, S., Swaminathan, C., Bose, J., 2021. Applying both biochar and phosphobacteria enhances *Vigna mungo* L. growth and yield in acid soils by increasing soil pH, moisture content, microbial growth and P availability. Agriculture, Ecosystems & Environment 308, 107258.

Arif, M., Ali, S., Ilyas, M., Riaz, M., Akhtar, K., Ali, K., Wang, H., 2021. Enhancing phosphorus availability, soil organic carbon, maize productivity and farm profitability through biochar and organic–inorganic fertilizers in an irrigated maize agroecosystem under semi-arid climate. Soil Use and Management 37(1), 104–119.