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Review Article

Phosphorus in Soils and it's Management Effects on Crop, Soil and Water

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Abstract

For the growth and development of crops, phosphorus is a crucial macronutrient, but it is also a limited resource in agriculture. Phosphorus deficiency happens in acid and alkaline soils due to the fixation of phosphate by iron, aluminum, calcium, and silicate clay to limit crop yield. Acid and alkaline soils cover 45.37, 9.90%, and 40.00, 25.00% of Bangladesh and the world, respectively. Therefore, efficient crop, soil, and water management are required if we wish to guarantee food security for the growing population. P fixation can help to synchronize P availability with crop demand and reduce its loss through runoff, erosion, and leaching pathways. Lime, organic amendments, AMF, partial use of chemical fertilizer with phosphate-solubilizing microorganisms, strip or contour tillage systems, and mulch can increase PUE. For efficient P fertilizer, alternate P sources rather than orthophosphate, blockers, slow releasers, and inducers maintain an optimum supply of P for plant nutrition. P-efficient crop varieties and cropping systems and AI technologies also achieve optimum crop yield, improve internal P-cycling and crop productivity, reduce inefficient P fertilizer use, and improve environment sustainable cropping system by lowering the potential risk of soil-P losses to water bodies.

Keywords: Acid and alkali soils; P fixation; Eutrophication; Management options; Crop yield

Introduction

Phosphorus (P) is a chemical element with the symbol P and atomic number 15. It is one of the essential plant nutrients for its growth and development. Adenosine triphosphate (ATP) is a plant photosynthesis product that contains phosphorus in its structure and processes from seedling growth to grain formation and maturity. In some soils in Bangladesh, P is not readily available for agricultural production, which is the main factor restricting plant development. These problem soils are acidic and alkaline. Acid soil occupies 45.37% of the total area in Bangladesh, whereas it is 9.90% of alkaline soil (Figure 1b). Very strongly, strongly, and slightly acid soils cover 3.74, 55.37, and 40.89% of the total acid soils in Bangladesh, respectively. Bangladesh has soils that are 98.25 percent and 1.75 percent strongly alkaline, respectively [1]. On the other hand, acid and alkaline soils occupy 40.00 and 25.00% respectively in the world. Although inorganic soil contains 0.5% (w/w) of P, plants can only access 0.1% of that amount due to P fixation. The availability of P to pla

nts also varies with the nature of soil, fertilizers, and reaction products, which largely depends upon the ionic form of P present in the added fertilizer [2]. In acidic soils and calcareous in alkaline soils, free aluminum and iron oxides and hydroxides fix P. As a result, plants can suffer from their growth and development, ultimately hampering their crop production.

From 1950 to 2022, Bangladesh's population grew by 337 and the global population by 219 percent, respectively. An increase in crop production is required to feed this ever-increasing population (Figure 1a). Soil P is found in different types of pools, such as organic and mineral P. It is crucial to stress that 20 to 80% of the phosphate (P) in soils is present in the organic form, with phytic acid (inositol-6-phosphate) often making up the majority of this. Inorganic P-form is found in 170 minerals in the soil. Soil microbes release immobilized forms of P into the soil solution and is also responsible for the immobilization of P. As a result, plant uptake is hampered by the limited availability due to the immobilization of P in the bulk soil. Runoff, erosion, and leaching are the primary causes of P loss from arable soil to open water bodies, resulting in environmental pollution. The index of P use efficiency from applied and soil P depends on knowing how P use efficiency can improve soil fertility, increase crop production and reduce environmental pollution. After conducting a comprehensive examination, information and research were gathered and reviewed regarding practical solutions and advice for minimizing P fixation and lowering environmental pollution without affecting crop yield.

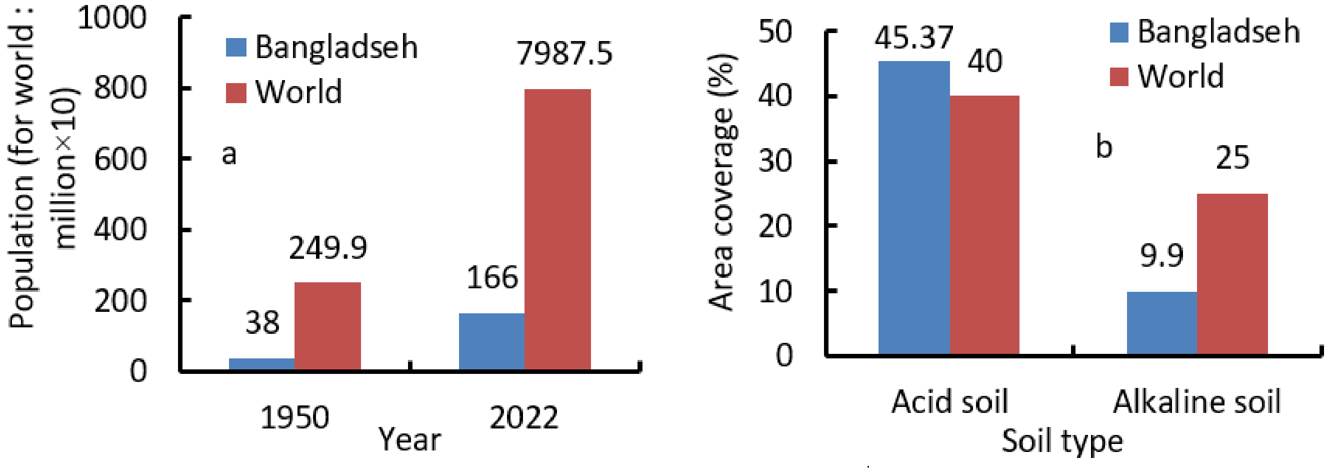


Figure 1: Showing the status of population trend (a) and problem soils (b) in Bangladesh and World.

Methodology

The study is based on a review and utilization of secondary data taken from studies carried out by various academics, institutes, and organizations and published in journals, research magazines, scientific papers, books, and symposia. The library, Web of Science, AGRIS, Research Gate, Science Direct, and other electronic databases were searched for published publications and used to identify them. Articles and published reports were obtained from databases based on the review's aims and content types, with a particular emphasis on empirical results presented on P fixation and its impact on crops, soil, and water through various pathways.

Results and Discussion

P in soil and its functions on crops

Table 1 shows the P distribution, forms in soil, and loss of soil P, as well as its functions in plants. The amount of P varies in different soil profiles and depths due to the form of P. The total phosphorus in the soil is composed of organic and inorganic forms. Although total soil P is generally high, with concentrations ranging from 227–6736 kg per hectare, 80% of this P is immobile and not available for uptake by the plant, and the rest phosphorus is available for plants. The availability of P to the plant is significantly influenced by the pH of the soil. At very low pH levels, primary orthophosphate availability is present, while secondary orthophosphate availability increases with soil pH increase. The amount of PO_4^{---} is greater than $H_2PO_4^-$ at pH 9–10. Iron and aluminum in acid soil and calcium in calcareous soil fix orthophosphate. Clay mineral (1:1) fixes more orthophosphate than 2:1 clay mineral. The CEC of colloids fixes P in soil. Runoff and erosion significantly lose P from the surface of the soil. Optimum P increases crop yield by overcoming the shortfall of P deficiency symptoms. P functions on plants are as follows:

- Due to deficiency of P on the restricts the root and shoot growth with thin and spindly plant, dull greyish green in leaf color with slow growth and low yield of cereal crops, premature leaves with flowering and fruiting may be delayed, stunted growth even under abundant supply of nitrogen and potassium, premature ripening of crops, decrease tiller number of cereal crops with low yield and rusty brown of potato tuber.
- P stimulates root growth and development, encourages the functions of lateral and fibrous root to increase absorbing capacity of nutrients, enhances the early maturity of cereal crops, in high P concentrated absorbs more P by young plant, conducive to rapid development and inhibits fungal root rot disease, induces nodule formation of legume crops and the formation of fat and albumin.

Table 1: P in soil.

P Distribution in Soil	P Available in Soil for Plant	Soil pH on Phosphate Ions	P Fixation in Soil	P Loss from Soil
» Minimum P content is in lower A horizon or upper B horizon due to plant uptake and leaching loss from the soil	» Primary orthophosphate (H_2PO_4-) and secondary orthophosphate H_2PO_4= present in soil. Plant prefers H_2PO_4- to H_2PO_4= ion	» Primary orthophosphate ($H_2PO_4^-$) and secondary orthophosphate H_2PO_4= and tertiary orthophosphate HPO_4= ions contain varies with the pH of soil solution	» Iron, aluminium and manganese concentrations increase in soil with the increase of soil acidity. Precipitation of phosphate ($H_2PO_4^-$) is happened with iron, aluminium and manganese. Insoluble hydrous oxide of iron and aluminium oxides sustain as precipitate or adsorbed on inorganic soil colloid. Insoluble of dicalcium phosphate is found in acid soil. Phosphate forms of iron and aluminium are $FePO_4$, $AlPO_4$, $Fe_2(OH)_3PO_4$, $[Al_2(OH)PO_4]$ in acid soil.	» Crop removes 10 kg/ha P from soil
» Sub soil contains more inorganic P than organic P and vice versa	» Plant can uptake metaphosphate and phytophosphate from soil	» Primary orthophosphate is dominated in soil solution at pH 4.0 and it decrease with increase of pH. Secondary orthophosphate is the most common form in alkaline soil solution. (H_2PO_4-) and H_2PO_4= ions are equally sustained in slightly and moderately acid condition. H_2PO_4- is dominant over H_2PO_4= at pH 6.7 of soil. Maximum HPO_4- is fixed by pH 9-10. pH>10, PO_4--- is more than H_2PO_4-. At pH 12, HPO_4=> PO_4--- in soil solution.	» H_2PO_4- is fixed by exposed hydroxyl (OH^-) by a group of silicate mineral crystal and exchange phenomena in soil. Clay mineral (1:1) fixes more phosphate over 2:1 clay mineral. Clay-Ca-H_2PO_4 is fixed by calcium.	» P loss is negligible due to rapid react with soil particles. Significant loss of P in sand and peat soil even heavily use of phosphate fertilizer
» More soluble P from weathering and applied fertilizer contains in finer fraction than coarse fraction of soil	» Plant can uptake directly phytin and indirectly organic and inorganic forms from nucleic acid derived P		» Phosphate is fixed by calcium and magnesium in soil solution or exchange phase. Calcium carbonate fixes phosphate in soil solution. Solubility of calcium orthophosphate salt is in the following order $Ca(H_2PO_4)_2$ >$CaHPO_4$ >$Ca_3(PO_4)_2$. High activity of calcium and magnesium in association with high pH precipitate of phosphorus as dicalcium phosphate and tricalcium phosphate. The presence of Na instead of calcium increses the availability of P due soluble nature of sodium salt of P. Phosphate can retain by silicate clays at a pH slightly below 6.5. Dicalcium and tricalcium phosphates are precipitated above this pH. Aluminium (Al^{+++}) and aluminium hydroxide $[Al(OH)_3]$ present in silicate clay surface can retain phosphorus probably by formation of compound like $Al(OH)_2H_2P_{04}$ in alkaline soil.	» Higher P loss from surface portion of soil by erosion. An average 10.6 kg/ha P loss from crop land by soil erosion
	» Iron and aluminium phytate, precipitate calcium phytate are unavailable for plant		» Reacted iron and aluminium phytate in acid soil and precipitate calcium phytate are unavailable for plant	
	» Clay (montmorillonite) and sorbed from the nucleic acid P are low available for plant		» Nucleic acid retains by soil colloid through CEC to less susceptible to microbial attack. The extent of this reaction more in acid soil than in alkali soil	

Curse of P Fixation in Soil

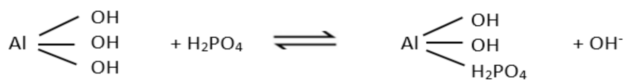
Soil P is finite, non-renewable, and limited in its source. Rock phosphate is a high concentration of phosphate minerals; about 95% of it is used to produce fertilizers, animal foods, and pesticides, but its availability is very limited in the world. The use of phosphate fertilizers is only taken up by 10–20% of plants, which might hinder plant growth due to its unavailability and worsen the eutrophication of open water bodies through erosion and runoff from the applied phosphate fertilizers. Due to the low use efficiency of P, some problems are raised for crop production and environmental security, which are as follows:

P unavailability in soil

P fixation is a widespread issue with soil fertility that has a detrimental effect on agricultural productivity. Organic and inorganic are the two major forms of P in soil. Unavailable P means this P is not instantly available for plants. Its unavailability in soil happens through immobilization, sorption, and precipitation processes. Through an immobilization process, inorganic P is converted to organic P due to the incorporation of organic residue into the soil, which is then absorbed by soil microbes, although only 20% of the P in the soil is inorganic. Phosphorus in soil solution is attached/bound and immobilized by the clay surface, iron, calcium oxides, and hydroxides. Adsorbed P can be released into soil solution via a desorption process [3], and the plant can uptake this released P. Metal ions such as Al^{3+} and Fe^{3+} (acid soil) [4] and Ca^{2+} (in calcareous soil) react with phosphate ions present in the soil solution to form minerals such as Al-, Fe-, or Ca-phosphate, which are unavailable to plants. A persistent charge is incorporated into metal phosphates during the slow process of precipitation. Chemical phosphate fertilizers are utilized in addition to this nutrient for typical crop production. In this regard, plants can uptake 10–20% P from the applied phosphate fertilizers. Sesquioxides, organic matter, and silicate clay restrict the availability of phosphorus during plant nutrition by fixing the remaining applied P (80%). Iron, aluminum, and calcium react with soluble orthophosphate and produce a plant unavailable complex. Reactions are as follows:

$$Al^{+++} + H_2PO_4 \text{ (soluble)} + H_2O \rightleftharpoons 2H^+ + Al(OH)_2H_2PO_4$$

On the other hand, iron and aluminium oxides produce hydroxy phosphate.



Phosphate are fixed by silicate minerals as surface reaction between exposed hydroxyl (–OH) group on mineral crystal and the H2PO4– ions. This type of reaction might be expressed as follows:

$$[Al] + H_2PO_4^- + H_2O \rightleftharpoons 2H^+ + Al(OH)_2H_2PO_4$$

(In silicate clays) (Insoluble)

Calcium is also present in alkaline soils as carbonate. Phosphorus can also be fixed by calcium carbonate to some extent. When concentrated super phosphate is applied to calcareous soils, the reactions take place as follows:

$$Ca(H_2PO_4)_2 + 2Ca^{++} \rightleftharpoons Ca_3(PO_4)_2 + 4H^+$$

(soluble) (adsorbed) (Insoluble)

$$Ca(H_2PO_4)_2 + 2CaCO_3 \rightleftharpoons Ca_3(PO_4)_2 + 2CO_2 + 4H^+$$

(soluble) (Insoluble)

Reduction of crop production

P deficiency is responsible for the reduction of crop yield in acid and alkaline soils. An important ingredient for the growth of plants is phosphorus (P). After nitrogen, it is the macronutrient that is most limited (N). Phosphorus plays a crucial role in plants' ability to absorb, store, and transform solar energy into biomolecules like adenosine triphosphate (ATP), which power biochemical reactions (photosynthesis) from seed germination through grain development to maturity. Plant maturity is delayed, and yields are decreased by inadequate P feeding. On the other hand, fungal root rot is more severe when there is a phosphate deficit. The importance of phosphorus supply in relation to the incidence of plant diseases is apparently less than that of nitrogen supply. P deficiency symptoms reduce crop yield, and they are as follows:

- Plants become spindly and thin as a result of the restriction on root and shoot growth.
- Cereal plant leaves eventually turn a dull, greyish green color. Low yields and poor growth are signs of P insufficiency.
- Premature leaf shedding and a significant delay in flowering and fruiting are also possible.
- Even with a plentiful supply of nitrogen and potassium, growth is hindered, which results in harvests that ripen too early.
- A decreased yield of cereal crops was brought on by a shortage of enough tillers.
- A rusty brown lesion is visible on a potato tuber.

Lack of phosphorus frequently prevents or inhibits the growth of shoots. The leaves may turn dark, a dull light brown color, blue-green, or even pale in cases of severe shortages. Increased anthocyanin production results in the development of reddish, reddish-violet, or violet in color. Symptoms appear first in older parts of the plant.

Eutrophication of open water body

Eutrophication, a form of environmental contamination, is caused by the considerable loss of applied P fertilizer and soil P to water bodies from agricultural fields [5]. Algae thrive, spread, and color the water green as a result of feeding on the nutrients. Excess P causes algae blooms, anoxic conditions, changes in plant species composition and biomass, fish kills, food web disruption, toxicity production, and recreational area degradation [6]. A primary source of phosphorus in streams is soil erosion. When banks erode due to flooding, a lot of phosphorous from the agricultural area might be carried into a stream, lake, or other body of water. The amount of phosphorus transported to watersheds ranges from 0.18 to 8.90 kg P ha^{-1} $year^{-1}$ [7]. In contrast, runoff and erosion remove 10 kg of phosphorus per ha^{-1} from the topsoil and dump it in open water bodies. Algal blooms can occur when phosphate concentrations range from 0.08 to 0.10 ppm in bodies of water, but long-term eutrophication is typically avoided at total phosphorus concentrations of less than 0.5 ppm and 0.05 ppm. On the other hand, unbalanced use of phosphorus in arable soils and eutrophication, a permanent condition of surface waterways, has significant environmental reflections.

Blessing of P Fixation in Soil

Soluble P compounds react with various soil components to quickly convert into slowly available forms, which are a blessing for the maintenance and improvement of soil fertility for crop production.

Soil fertility

P fixation with Al and Fe is an important factor in reducing Al and Fe toxicity to plants and soil microbes. So, P fixation is useful in some aspects, which are as follows: Firstly, P fixation reduces the toxic metals to plants. Secondly, P fixation is sparingly soluble from, Al-P and Fe-P fixed compounds in soil. Results for Al, Fe, and Ca fixation by phosphate are presented (Figure 2). One hundred grams of P can fix 5.53, 180.00, and 63.71 grams of Al, Fe, and Ca from the soil solution, respectively [8]. The P in this pool is released slowly for plant uptake. Adsorption is another process to control the runoff and erosion of P from the soil. This process also inhibits the leaching loss of soluble P from the soil. Goethite and gibbsite desorbed 70.4–81.0% and 50.7–42.6% phosphorus, respectively, from the soil [9].

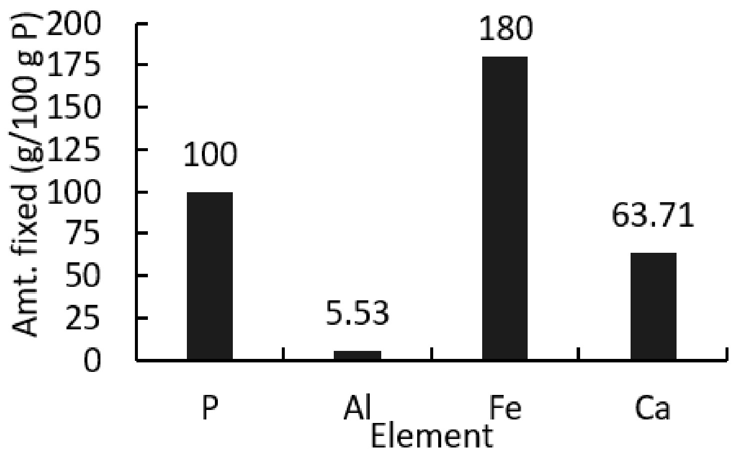


Figure 2: Comparative performance of Al, Fe, and Ca fixed by phosphate in the soil [8].

Crop production

P encourages blooming and grain development, as well as root and shoots growth [10]. The ideal supply of nutrients for plants can be maintained through P fixation. As a result, the limitation of root and shoot growth with thin and spindly plants, dull grayish green leaves symptom with slow growth and low yield of cereal crops, delays in flowering and fruiting, stunted growth despite an abundance of nitrogen and potassium, premature ripening of crops, decreased tiller number of cereal crops with low yield, and rusty brown of potato tubers are all overcome by optimal P. P also promotes the growth and development of roots, supports the lateral and fibrous roots' capacities to increase nutrient absorption, promotes cereal crops' early maturity in high-P-concentrated soil, encourages young plants to absorb more P, which is conducive to rapid growth, and inhibits the fungal root rot disease. It also causes nodule formation in legume crops and promotes the production of fat and albumin. Grain and straw yield, P concentration in grain, and total P uptake by wheat are all positively and significantly linked with available P, saloid-P, and Al-P [11-13].

Safe environment

The agricultural field loses a significant amount of the applied P fertilizer and soil P to water bodies by runoff and erosion, which causes eutrophication-related environmental pollution issues. In this way, P fixation improves the following aspects of the environment:

- Phosphorus supply can synchronize with crop demand to reduce P loss through fixation.
- It lessens Al and Fe's toxicity to plants.
- It reduces the amount of P lost from the soil surface due to erosion and runoff processes.
- It enhances the soil's available P for use by following crops.
- Last but not least, it regulates fish kills, food web disturbance, toxin production, algal blooms, anoxic conditions, changes in plant species composition and biomass, and deterioration of recreational areas.

Management Options for Soil, Water and Crop to Increase PUE

Soil and crop management can effectively control P loss from arable land and reduce pollution in the environment. Phosphorus eutrophication mitigation strategies include controlling nutrient loads and ecosystem restoration.

Use of lime, organic amendments, microbes, P-efficient crop varieties, tillage and mulch

Lime used as a soil supplement can increase agricultural yields. The following processes are enhanced by liming, which also enhances the characteristics of the soil (Figure 3).

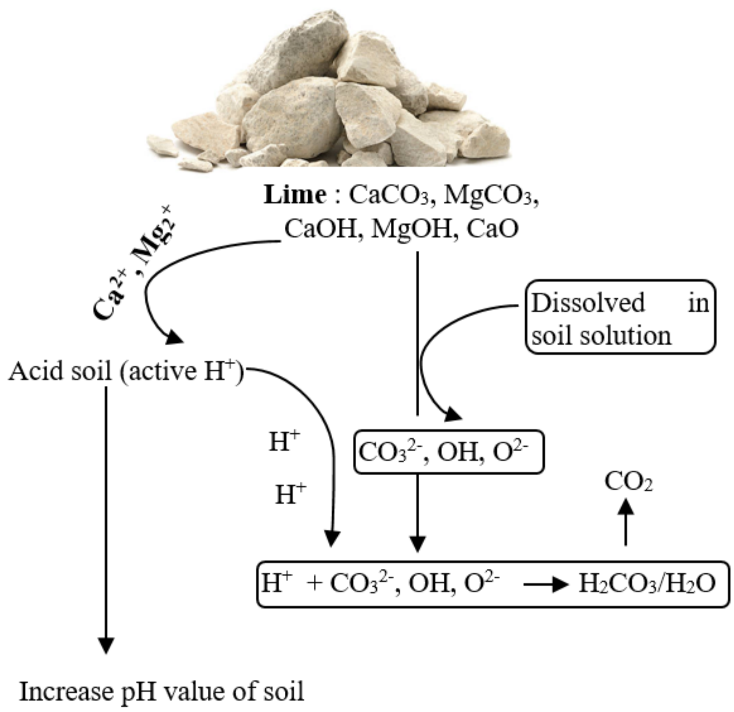


Figure 3: Liming on soil pH.

- lowering the toxicity of substances like H, Al, and Mn.
- improving the capacity for cation exchange (CEC).
- enhance the biological activities of soil microbes.
- increasing P, Ca, and Mg availability
- improving the structure of the soil.
- stimulating the process of nitrification.
- enhancing biological N fixation, and
- decreasing the availability of K and micronutrients.

When the pH of the soil reaches 6-7, plants can access phosphorus the greatest. The pH of the soil can be kept between 6 and 7 by liming. Soil amendment with biochar or compost or a mixture of biochar and compost increase the total phosphorus, available phosphorus, inorganic phosphorus fractions (soluble inorganic phosphorus, aluminium-bound inorganic phosphorus, iron-bound inorganic phosphorus, redundant soluble inorganic phosphorus, and calcium-bound phosphorus), and organic phosphorus. This is achievable because the organic additions raised the pH of the soil and decreased the soil's exchangeable iron, aluminum, and acidity. P is mostly transported through the soil by diffusion, whereas soluble minerals like K are transported through flow.

Since the rate of diffusion of P is slow (10^{-12} to 10^{-15} m^2 s^{-1}), high plant uptake rates create a zone around the root that is depleted of P. To enhance the root surface for the acquisition of P from the non-rhizosphere soil, arbuscular mycorrhizal fungi (AMF) are soil organisms that colonize with roots [14]. The symbiosis is typically considered mutualistic because the fungus provides soil resources, particularly phosphorus, to the plant and receives photosynthate in turn [14]. Contrarily, single and dual inoculation combined with P fertilizer increases wheat grain production by 30–40% more than P fertilizer alone, whereas dual inoculation without P fertilizer increases grain yield by up to 20% more than P application [15,16]. Different kinds of organic acids are secreted by phosphate-solubilizing bacteria, which lowers the pH in the rhizosphere and subsequently dissociates the bound forms of phosphate like $Ca_3(PO_4)_2$ in calcareous soils. The use of these microorganisms as environmentally friendly biofertilizers reduces the cost of far more expensive phosphorus fertilizers. Phosphatic biofertilizer could help to increase the availability of accumulated phosphorus in soil. The probable loss of P from the field can be detected using the phosphorus index. To lessen runoff and erosion from agricultural areas, use crop selection and soil conservation techniques. Keep a perimeter of buffer zones around water sources. Moldboard plowing is an example of conventional tillage that exposes the soil's surface and loosens soil particles, leaving them open to erosion from wind and water. In this way, mulch-assisted conservation tillage techniques prevent erosion by shielding the soil's surface and promoting infiltration over runoff.

Different mechanisms for more efficient P fertilizers

Different mechanisms can help to increase the performance of phosphate fertilizers during crop production (Figure 4). Slow-release P products can inhibit strong P bond formation, which is helpful to better synchronize P availability with crop demand. Most of the promising products are available as coatings, scaffolds, organic matrices, and minerals of limited solubility. Highly water-soluble

P-fertilizer like mono-ammonium phosphate (MAP) is coated with a material that can restrict water movement into the product and retard the diffusion of P out to the soil solution. Coating use as polymers, advanced modifications, and pH modifiers synchronizes P availability with crop demand. Attention to coating thickness, its solute permeability, granule properties, such as density and solubility, and the variance of these properties across the entire applied population can allow for better control of timing and rate of P release when applying these products [17].

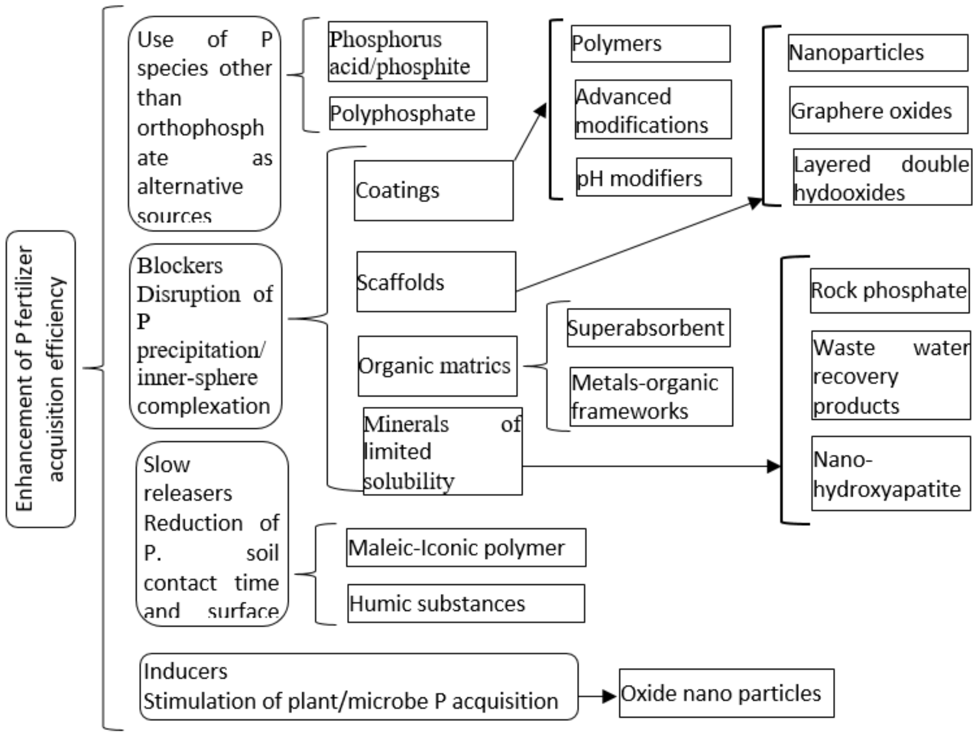


Figure 4: Use of different mechanisms for efficient phosphate fertilizers [18].

The first is to load the nutrient onto a material that then allows the anion to release into soil solution by a combination of chemical mechanisms, such as ligand displacement and dissolution, dictated by the interactions between P, scaffold material, plant, and environmental conditions. P-loaded nano-Al_2O_3 possessed a greater capacity to supply P to *Brassica napus* L. compared with an unbuffered aqueous supply of orthophosphate in a hydroponic medium [19]. Because P uptake is likely a diffusion-limited process, nanoparticles suspended in a solution that moves into the diffusive layer around roots are capable of buffering P solution concentration. As a result, P concentrations at transport sites of the root remain closer to bulk solution concentrations than would otherwise be achievable without the additional benefit of colloidal transport. Although the effectiveness of this method in the soil is unknown, it does highlight a crucial process through which nanoparticles may one day be better equipped to deliver P. The co-addition of large, carbon-based compounds possessing a high negative charge with phosphate can block fixation reactions caused by antagonistic polyvalent cations (Ca^{2+}, Fe^{3+}, Al^{3+}) and ultimately lead to improve P lability. Additionally, acid phosphatase, alkaline phosphatase, phytase, and dehydrogenase enzymatic activity in the rhizosphere soil of ZnO nanoparticulate treatments greatly increase along with the populations of fungi, bacteria, and actinomycetes. As a combined result of all these parameters, total P uptake is increased by 11% as compared to control, while the bulk ZnO only increases P uptake by 2%. The authors attributed the results to nanoparticles' increase transport through the leaves, enhance intracellular movement, greater ease of dissolution, and the negative surface zeta potential. The presence of polyphosphate as an alternate source of phosphorus in liquid formulations, even at concentrations as low as 10% of total P, may dramatically reduce P precipitation as Ca-P relative to technical grade MAP in a calcareous soil [20]. One hypothesis is that polyphosphate disrupts the crystal structure of Ca-P minerals, rendering them more soluble.

Artificial intelligence on soil, water, crop and weather for increasing PUE

Artificial intelligence (AI) integrates all the above-mentioned factors in effective ways to improve soil fertility, reduce the cost of production, and increase crop production without environmental pollution (Figure 5). Artificial intelligence (AI) is also an effective tool to precisely handle crop production. AI can be minimized by using proper sources of P as fertilizer, proper timing and methods of P fertilizer application, soil P management, transport management, use of plant growth promoting microorganisms which help in efficient use of P by crops, and use of green manure crops which improve soil fertility as well as help in efficient use of P by crops. Improved abovementioned parameters and agro-climatic conditions can help to effectively use of AI technologies for precision farming [22]. Skilled manpower and community and crop zoning-based farming systems are the prerequisites for the successful application of AI. AI also helps with effective soil management practices. A thorough understanding of the different soil types and conditions helps increase agricultural output and protect soil resources. It is the use of operations, practices, and treatments to improve soil performance. Management-oriented modeling (MOM) minimizes runoff and erosion loss of P to improve crop production. An artificial neural network (ANN) model accurately predicts and classifies soil structure, monthly mean soil temperature, soil moisture, and nutrients. It also predicts soil texture and microbial enzyme activity. A remote sensing device integrated into a higher-order neural network is used to describe and estimate the dynamics of soil moisture [23]. By sensing soil factors (soil type, pH, nitrogen, phosphate, potassium, organic carbon, calcium, magnesium, sulfur, manganese, copper, iron, depth, temperature, rainfall, and humidity), as well as meteorological parameters, crop prediction methodology is used to determine the right crop [24].

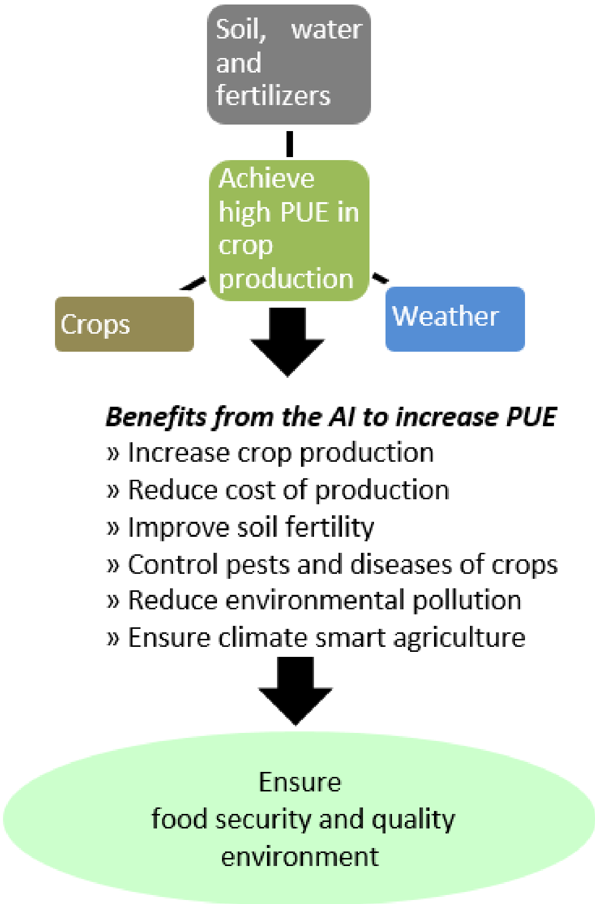


Figure 5: Use of AI to ensure food security and quality environment through reducing P loss in soils [21].

Conclusion

A better understanding of P nutrition of crops, P response to plants, P availability in soils, and P adsorption in soils is necessary before going for P fertilization in crop cultivation. Both soil and fertilizer contain phosphorus that is lost over time, contributing to environmental contamination. Better management techniques that reduce P losses and maximize the utilization of P by crops can help to reduce these pollution issues. These are the use of a proper source of P as fertilizer based on soil, crop, and environmental conditions, proper timing and methods of P fertilizer application based on soil, crop and environmental conditions, soil P management, transport management, use of plant growth promoting microorganisms which help in efficient use of P by crops, and use of green manure crops which improve soil fertility as well as help in efficient use of P by crops. AI can ensure an optimum supply of phosphorus and reduce environmental pollution by addressing all the parameters.

Acknowledgement

None

Conflict of Interest

No conflict of interest.

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