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Importance and Sources of Phosphorus Fertilization in Plant Nutrition

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Introduction

Phosphorus (P), often referred to as the "fuel of life," stands as a cornerstone of plant nutrition, exerting a profound influence on the growth, development, and productivity of plants. This anionic macronutrient is one of 17 nutrients essential for plant growth and its functionality can neither be substituted with any other element. The total P concentration in agricultural crops generally varies from 0.1% to 0.5% and is taken up as mostly as the primary orthophosphate ion ($H_2PO_4^-$), but some is also absorbed as secondary orthophosphate (HPO_4^{2-}). In the quest for sustainable agriculture and global food security, understanding the intricate dynamics of P in plant nutrition is paramount. While P is abundant in soils, its availability to plants is often limited due to complex interactions with soil particles, pH fluctuations, and microbial activity. Consequently, P deficiency poses a significant challenge to crop production, particularly in regions with inherently low P levels or intensive agricultural practices. Furthermore, as the global demand for food continues to escalate amidst burgeoning population growth and environmental constraints, the efficient management of P resources emerges as a critical imperative. Sustainable P management practices, including precision fertilization, soil amendment strategies, and biotechnological interventions, hold the key to mitigating P deficiencies while minimizing environmental impacts such as eutrophication and soil degradation. According to data derived from approximately 9.6 million soil tests, it is revealed that around 49.3% of districts and Union Territories exhibit low levels of available P, while 48.8% fall within the medium range, with only 1.9% classified as high.

Functions of phosphorus in plant nutrition

This essential nutrient plays a multifaceted role in cellular metabolism, serving as a key component of nucleic acids, phospholipids, energy-rich molecules like ATP, and a plethora of vital biochemical compounds. Its significance in plant physiology extends beyond mere structural integrity to encompass pivotal functions in processes such as photosynthesis, respiration, and signal transduction. Consequently, phosphorus is indispensable for ensuring the overall well-being and vitality of plants. Some specific benefits associated with phosphorus include:

- Enhanced root growth stimulation
- Strengthening of stalks and stems
- Improved flower formation and seed production
- Promotion of uniform and early crop maturation
- Increased nitrogen-fixing capacity in legumes
- Enhancements in crop quality
- Boosted resilience against plant diseases
- Support for comprehensive lifecycle development

Sources of phosphorus in agriculture

Fertilizers

The inorganic phosphatic fertilizers which are commonly used in agriculture can be classified into three groups namely, a) water soluble (DAP, SSP, nitrophosphates etc.) b) citrate soluble (basic slag, pelophos etc.) c) insoluble in both water and citrate (rock phosphate). However, mostly used phosphatic fertilizers (DAP, SSP etc.) belong to water soluble category. Currently ammoniated form of phosphatic fertilizers occupy 47 % of global market share followed by NPK composite fertilizers (27%) and single super phosphate (9%). India ranks the second most position just after China by consuming 7 Mt of P annually. But there is demerit of this water-soluble fertilizers of P fixation as well as eutrophication as the P release poorly synchronizes with plant's uptake. Again, most of the P fertilizers are manufactured from high grade rock phosphate (RP) which's availability is very limited in India. This incurs a heavy import cost for phosphatic fertilizers in the country. In the year 2022, 48.82 lakh tonnes of DAP fertilizer were imported in India which costs 4496.3 million USD. Again, the limited reserve of high-grade RP, sedentary nature of P cycle, geopolitical instability of the countries having RP reserves makes it is a way costlier. So, there is a high need to look after different alternative sources of P to sustain its availability for long term. Recently developed nano-sized P fertilizers are also being developed and getting promoted in recent times. a common water-soluble fertilizer containing nitrogen (8% N) and P (16% P_2O_5). However, further studies are needed to fully explore its potential benefits and ensure its safe and sustainable use in agriculture.

Controlled release fertilizers

The controlled release fertilizers (CRFs) offer the advantage of delayed and regulated nutrient delivery, potentially aligning with plant nutrient needs. Opting for super absorbent polymeric fertilizers over conventional water-soluble ones could enhance water and fertilizer utilization efficiency. These polymers possess the capability to absorb and retain substantial amounts of water or aqueous solutions, demonstrating promise for conservation of both water and fertilizers. Utilizing polymer-based carriers for fertilizers, such as nano-clay polymer composites (NCPCs), or coating commercial phosphatic fertilizers with natural or synthetic polymers, enables controlled nutrient release, thereby enhancing the efficiency of applied phosphorus (P). Certain super absorbent clay polymer composites have been reported to absorb and retain aqueous fluids up to a thousand times their own weight, with slow-release kinetics. These polymer composites are increasingly being explored as slow-release carriers for various agrochemicals, as evidenced by studies. However, the high demand for expensive polymeric materials in large quantities presents a limitation to the widespread adoption of polymer-based phosphatic fertilizers. Therefore, there is a need for focused research aimed at developing cost-effective CRFs.

Manures and composts

Different manures and composts which are primarily used to enrich organic matter content of soils, also contributes towards P fertilization. Use of different manures and composts like farm yard manure (0.3% P_2O_5), green manure (0.2% P_2O_5), poultry litter (2.5% P_2O_5), urban and rural compost (0.5% P_2O_5), night soil (3.0% P_2O_5) not only adds P into soil but also helps in release of fixed P through various mechanisms. Apart from manures and composts, various oil cakes which are used in agriculture also contains P like mustard cake (1.5% P_2O_5), safflower cake (2.0% P_2O_5), neem cake (1.0% P_2O_5), groundnut cake (1.5% P_2O_5). Bone meal (20% P_2O_5), meat meal (2.5% P_2O_5), blood meal (1.5% P_2O_5) and fish meal (6.0% P_2O_5) are some major animal origin sources of P. But the main problem associated with these sources are low P content, high cost, low availability and lack of proper production infrastructure in the country. Thus, these P sources are being utilized by only a small fraction of the farmers in India.

Rocks and minerals

The name RP signifies a series of minerals containing P and broadly they are classified into Apatites (Ca-P) and Aluminous phosphates (Al-P). Rock phosphate is primarily used as a raw material for P fertilizer industry and its direct application in field is limited to acid soils. However, as RPs are allowed in organic farming it plays a major source P in such systems. It remains in its raw form, gradually releasing P over extended periods, often spanning several years. Struvite ($MgNH_4PO_4 \cdot 6H_2O$) is another P mineral that can be precipitated from aqueous waste streams which has low water solubility and high citrate solubility. Due to its low solubility, struvite has a greater P recovery efficiency compared with rapidly solubilized conventional P fertilizers, such as DAP, MAP and SSP while producing similar or increased crop response to fertilization.

Polyphosphate

Polyphosphate, a liquid P source, provides convenience and simplified handling compared to dry alternatives. These fertilizers comprise two P forms: orthophosphate, readily accessible to crops, and polyphosphate, requiring initial breakdown before conversion into orthophosphate. Approximately half of the polyphosphates typically undergo conversion within 1-2 weeks. Soil microbes, thriving in warm and moist conditions, facilitate the breakdown of polyphosphate. However, use of polyphosphate is very rare in Indian agriculture.

Sewage Sludge

Sewage sludge, a byproduct of wastewater treatment, presents a promising source of P for agricultural applications. Rich in nutrients, including P, sludge can be recycled to enhance soil fertility and crop productivity. Sewage sludge has a high P content, approximately 8% (w/w), which makes it a potential source of the P. Effective management practices, such as sludge application and composting, can maximize P utilization with minimizing environmental risks. Harnessing sewage sludge as a P resource promotes circular economy principles, fostering agricultural sustainability and reducing dependency on finite phosphate reserves.

Crop residues

Crop residue (CR) incorporation is an integral component of conservation agriculture. In India, CR are generated in the farm sector each year in the amount of 696.3 million tons and which may contribute to 1.74 million tons of P (considering average 0.25% P). The release of P from CR depends on the rate of decomposition of those residues. Through decomposition, CRs release P, enriching soil fertility and supporting subsequent crop growth. Harnessing crop residues as a P source highlights their significance in sustainable agriculture and ecosystem stewardship.

Microbial interventions

Phosphate-solubilizing microorganisms (PSMs) represent a sustainable approach for converting insoluble phosphate into soluble forms, enhancing plant accessibility. Various bacterial strains (e.g., *Pseudomonas*, *Bacillus*, *Rhizobium*, and *Enterobacter*) and fungal strains (e.g., *Aspergillus* and *Penicillium*) exhibit potent phosphate solubilization capabilities. Through acidification, chelation, exchange reactions, and organic acid production, PSMs transform insoluble phosphates into available forms. Despite P often limiting soil fertility, practical utilization of PSMs as biofertilizers or bio-converters remains limited. Hence, the isolation, identification, and characterization of soil PSMs are vital for expanding the pool of phosphate solubilizers applicable in agricultural contexts.

Silicate applications

Application of silicon has been found to have positive impact on P availability to crops. Different Si containing organic (rice straw, sugarcane leaf etc.) and inorganic sources (sodium silicate, basic slag etc.) were examined and positive results were been examined by various scientists. Silicon application might have increased soil P availability through several mechanisms. One key mechanism is the promotion of P desorption from soil particles, making it more accessible for plant uptake. Silicate compounds can alter soil pH, creating conditions that enhance P solubility. Additionally, silicate application can stimulate microbial activity in the soil, leading to the release of organic acids that aid in P mobilization found an increment in water soluble P and decrement in Fe and Al bound P due to Si application. Overall, silicate application represents a promising strategy for enhancing soil P availability and promoting plant growth in P-limited environments.

Time and method of application

The timing and method of phosphatic fertilizer application play crucial roles in optimizing nutrient uptake and maximizing crop yield. Generally, P fertilizers should be applied before planting or during early crop growth stages to ensure sufficient P availability throughout the growing season. The specific timing and method depend on factors such as soil properties, crop type, and local climate conditions. Broadcasting P fertilizers evenly across the soil surface before planting is a common method followed by farmers. However, banding or placement of P fertilizers near the seed or plant roots is advantageous, as it reduces nutrient fixation and enhances nutrient uptake efficiency by reducing the chances of its fixation. For perennial crops or established orchards, surface application followed by irrigation or rainfall can facilitate P penetration into the root zone. Foliar application of nano P fertilizers is also done which has an advantage of higher P use efficiency as compared to conventional methods.