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Phosphorus Management: The Hidden Key to Better Nodulation and Higher Yield in Pulse Crops

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Pulses have been referred to as "the poor man's meat" and the "rich man's vegetable," and rightly so. Pulses like chickpea, pigeonpea, mungbean, urdbean, lentils, and field peas provide a significant amount of protein intake of millions of people around the world, particularly those on vegetarian diets in South Asia. Apart from providing nutritional value, pulses play an important role that not even the best fertilizer can accomplish: through the symbiotic relationship between rhizobia bacteria found in the roots nodules, pulses convert atmospheric nitrogen into a rich soil base for the following crops. Despite this, the yield of pulses in the fields is far lower than what it could be. The missing element here is one nutrient – phosphorus.

Nitrogen differs from phosphorus (P), because pulses can self-fix nitrogen through nodulation, whereas phosphorus comes only from the soil and the fertilizers used by the farmer. Unlike other nutrients, phosphorus is crucial for pulses since it acts as an engine driving the biological nitrogen fixation (BNF) process that requires much energy. Moreover, the presence of phosphorus in the soil is in an unavailable form as a result of soil fixation, which makes the management of phosphorus more essential for the farmers. Because of this natural unavailability and subsequent deficiency, the impact on pulse productivity unfolds progressively: nodulation will be reduced, the vital process of nitrogen fixation will slow down, and ultimately the overall yield of grains will be significantly affected.

To overcome this nutrient barrier and ensure that the pulse crops make maximum ATP energy, optimal use of fertilizer together with the use of biological inputs such as Phosphate Solubilizing Bacteria (PSB) will prove to be very effective in terms of making phosphorus available and also increases the absorption of P by the roots.

Why Legumes Are So Phosphorus-Hungry

Comparing cereals, legumes tend to require higher phosphorus requirements per unit growth. The establishment and function of nodules is energetically costly: the source of energy required by the enzyme complex nitrogenase that fixes the nitrogen from the atmospheric N_2 to form ammonia is ATP, whose production requires phosphorus. Apart from stimulating the growth of rhizobia bacteria, phosphorus plays an important role in the process of nodulation, hence making nitrogen fixation biologically more efficient

Fig. Root system of a pulse crop displaying active bacterial nodulation. Source: Montana Pulse CropCommittee

(Mirriam et al., 2023). This translates to pulses grown under phosphorus deficiencies showing late emergence, poor plant growth, fewer nodules, and less efficient nitrogen-fixation capabilities.

How Phosphorus Drives Nodulation, N-Fixation & Yield

Recent studies in the field as well as pot experiments conducted in chickpea, mung bean, black gram, field pea, and soybeans have revealed the same trend: there's an increase in number of nodules and nodule mass with the increase in phosphorus application rate from deficiency to optimum level for the crops. Application of rock phosphate up to 500 kg ha^{-1} increased nodule numbers and nodule weights per plant, as well as yield and harvest index in chickpea (Ullah et al., 2023) and phosphorus is one of the essential elements that enhances rhizobial association, encouraging root nodulation and consequently the biological nitrogen fixation process (Mirriam et al., 2023). Phosphorus in proper amount ensures rapid growth of roots and their hairs; consequently, Rhizobium bacteria have greater chances to infect the roots; besides, the roots can search larger area of the soil for phosphorus and water resources. The result of this effect increases number of nodules and more active nodules as well as healthy root system, which results in increased capture of nitrogen by the plant and increased grain yield (Bhandari et al., 2025).

Most Indian soils are calcareous, acidic, or high in iron and aluminium oxides, and in each of these situations applied phosphorus is quickly fixed into immobile forms unavailable for plants, usually within a few days after application. The real opportunity, therefore, lies not just in how much phosphorus is applied, but in how it is managed: the source, the placement, the timing, and the biological partners that help unlock it.

Efficient Phosphorus Management in Pulse Crops

A few field-tested practices help pulse crop to maximize their use of each kg of phosphorus applied:

1. **Right Placement** - Banding is generally the best placement method for maximizing plant access and fertilizer use efficiency. Banding puts fertilizer phosphorus into the soil where moisture for dissolving fertilizer granules is higher in comparison to the soil surface, and where plant roots can access it early in the season.
2. **Right Time** - Application of phosphorus at planting, during early nodulation and rooting that causes high demand; foliar spray later are poor substitute.
3. **Right Rate** - Use of soil tests value to decide on the proper rate, because crop responsiveness to this nutrient varies tremendously, from very responsive faba beans to intermediate responsiveness for chickpeas and soybeans.
4. **Right Source** - Monoammonium Phosphate(MAP)& Ammonium Polyphosphate(APP) offers rapid availability; rock phosphate is a better source for building soil reserves, because pulses can acidify their rhizosphere and make it available.
5. **Biofertilizer Synergy -** Co-inoculating seed with Rhizobium and phosphate-solubilizing bacteria (PSB) consistently boosts nodule number and yield beyond either inoculant alone.
6. **Micronutrient Pairing:** Molybdenum and boron work alongside phosphorus in nodule function – pairing them with Rhizobium has lifted nodulation and yield in blackgram.
7. **Mycorrhizal Support:** Mycorrhizal fungi (AMF) can extend root reach for phosphorus uptake, though benefits vary with soil pH and prior crop.
8. **Organic Build-Up:** Manure, vermicompost and crop residues build soil phosphorus reserves over time, easing long-term reliance on mineral fertilizer.

Emerging Frontiers in Phosphorus Optimization

Although there have been established agronomic practices that set the base for efficient nutrient management, there are modern-day developments that provide additional options for optimizing the phosphorus utilization in pulses, including:

- Nano-Phosphorus Fertilizers: Emerging nano-formulated phosphatic fertilizers offer targeted, slow-release nutrient delivery. Nano-P ensures a sustained supply to roots during critical growth stages.
- Precision Placement & Smart Fertigation: Advanced variable-rate application and root-zone fertigation technologies allow exact alignment of phosphorus placement with initial root elongation, minimizing bulk soil exposure and fixation losses.
- Rhizosphere Engineering and Root Exudates: The study of plant genetics is now exploring the potential of pulses that have increased root exudation of organic acids such as citrates and malates to solubilize indigenous phosphorus from the soil.

Conclusion

Phosphorus management sits at the heart of pulse productivity, not as a routine input decision but as the biochemical lever that governs nodulation, nitrogen fixation, and ultimately yield. Matching phosphorus rate to soil test value, placing it close to the root zone, and pairing it with rhizobium and phosphate-solubilizing biofertilizers can unlock nodulation potential that fertilizer alone cannot achieve. Furthermore, integrating modern innovations like nano-formulated phosphatic inputs and rhizosphere-targeted placement with balanced secondary nutrient management bridges the gap between laboratory potential and field productivity. As India works toward closing the national pulse yield gap and reducing its dependence on imported pulses, adopting efficient, biology-informed, and site-specific phosphorus management strategies offers one of the most cost-effective and ecologically sustainable paths forward-simultaneously benefiting the farmer's economic return, optimizing the crop's nitrogen economy, and safeguarding the long-term health of the soil for seasons to come.

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