Studies on Phosphorous dynamics in soils

Abstract:

More than two-thirds of the world's soils are afflicted with phosphorus shortage (P). Agricultural output suffers because phosphorus is unavailable to all but a tiny percentage of plants. To lessen the severity of the environmental impact, phosphorus-deficient soils have traditionally been fertilized. Improving agricultural management practices for sustainable crop output, including reduction in phosphorus loss in terms of runoff, is the emphasis of this study. Investigating chemical fractionation mechanisms to distinguish between occluded P, acid-extractable calcium-bonded P, and non-occluded P is necessary for increasing inorganic phosphorous (Pi) in mung bean (*Vigna radiata*) types and establishing net grazing systems. Phosphate (P) is known to be transferred between pools due to weathering, with the highest P retention rates found in clay-rich soils. Soil with a finer texture is better able to absorb and fix phosphorus, which means more nutrients and water can be made available to the plant when mungbean varieties are inoculated into it. More photosynthesis means more accumulated dry stuff. The P-treated variety of mungbean had the greatest yield index (13.28). Pods per plant (46.02), pods per crop (8.20), test weight (40.63 gm), pod weight (8.0 g), and seed weight (1.0 g) were all significantly increased when fertilization done with Diammonium phosphate (DAP). An increase in nodule count, leaf area index, plant height, grain yield, total chlorophyll content, and straw output of up to 40% was observed at higher P2O5 concentrations (2988 kilograms per hectare). Each plant developed the maximum number of nodules after receiving injections of Phosphate solubilizing bacteria (PSB) and Aspergillus awamori. The highest levels of chlorophyll were found in its leaves, and its plants were the largest and most productive overall. Liming improved mungbean yields in acid piedmont soil by raising the pH and altering other chemical characteristics. They claim that increasing India's output of pulses is necessary for the country to attain food security in the future. If farmers and extension workers want to see higher quality pulse yields and greater long-term profitability, they need to incorporate P nutrition into their balanced nutrient management programmes.

Keywords: Grain yield, Phosphatic Fertilizer, Plant productivity, Photosynthetic yield

Introduction:

Phosphorus (P) is a macronutrient required by plants for its growth. It accounts for between 0.2 and 0.8 percent of the dry weight of a plant. Phosphorus is necessary for a wide variety of physiological and biochemical processes in plants. Phosphorous can be present in the form of Phospholipids, nucleic acids, coenzymes, enzymes, and nucleotides in soil (Mehrvaz *et al*., 2008). In the early stages of plant growth, enough P availability is also necessary for the laying down of the plant's reproductive parts' primordia (Satyaprakash *et al*., 2017;Kalayu, 2019).The typical amount of phosphorus found in soil is 0.05 percent (w/w). However, only 0.1 percent of this phosphorus is available for plant uptake (Zhu *et al*., 2011). Phosphorus fertilizers have traditionally been used as a method for addressing phosphorus deficiency in the soil. To maintain consistent amounts of phosphorus in soil and plant systems, fertilizers in 52,3 billion **tons** are sprayed yearly (FAO, 2017). This tremendous quantity of phosphorus fertilizer which provides readily available inorganic phosphorus to plants. But, plants can only used 0.2 percent of applied P and rest P was precipitated by metal cations in the soil such as iron, aluminium, magnesium, and calcium (Soumare *et al*., 2020). The phosphate deposit in agricultural soils is sufficient to ensure that optimum crop production may be maintained worldwide for about 100 years (Kalayu, 2019). In addition, the use of fertilizers contributes to a variety of environmental problems, including the contamination of groundwater and the eutrophication of streams (Yu, *et al*., 2011 and Alori *et al*., 2017). Agricultural management strategies are needed to develop and improve the efficiency of phosphorus fertilization for increasing crop productivity, and reducing environmental pollution caused by phosphorus loss from the soil. Also these goals will be achieved by –

1. Nutrient yield response curves can be calculated using multiple regression, quadratic, or linear equations. From this the regression equation of yield response optimum fertilizer rate is estimated depending upon different soil fertility conditions. Thus, strategy has helped to secure good crop yields and optimise fertiliser use on a broad scale providing economic management and fertiliser distribution.
2. Localized applications of phosphorus (P) and ammonium (NH4+) enhanced P absorption and development of maize in a high-intensity agricultural system in Northern China (Jing et al., 2010). In this aspect, rhizosphere interactions are essential for improving crop yield and enhancing P use efficiency.
3. Gene modification for enhancing P use efficiency. White clover (Trifolium repens L.) was genetically modified by the introduction of a phytase gene (MtPHY1) and a purple acid phosphatase gene (MtPAP1) obtained from Medicago truncatula. Higher

accumulation of total P (up to 2.6-fold) was achieved in transgenic plants compared to wild-type plants due to the tripled activity of phytase or acid phosphatase in root apoplasts (Ma et al.,2010).

Forms of Phosphorous in soil system:

It is common for soils to have greater concentrations of total P than other key nutrients, such as N or K. More than 80% of P, on the other hand, is inert and so inaccessible to plants (Xu *et al.*, 2020). Figure 1 shows that inorganic and organic forms of P (Pi/Po) are found in soil, and the quantities of each alter over time. Most soil P comes from biological tissues where phosphorus is found in organic substances such as nucleotides, phospholipids, phosphoproteins, and coenzymes (Cross *et al.,* 1995). It is also possible that soil nutrient cycle mechanisms (e.g., nitrogen cycling) are responsible for the dispersion of primary Pi into Po forms. Because of the widespread usage of Po-containing products, including fire retardants, plasticizers, insecticides, and antifoam agents, new Po sources have emerged in the environment, increasing soil Po concentrations and diversity (Adams *et al.*, 1992).

Due to its weak connections with the soil particles, Po is more quickly leached than the more stable forms of primary (variscite, apatite, and stringier) and secondary minerals (calcium, aluminum phosphates, and iron) found in soil (Gebrim *et al.*, 2010). Chemical fractionation processes were created in the early studies to determine the three forms of Pi: occluded P (containing 2nd NaOH extractable P and residual Pi), acid-extractable calcium-bonded P and non-occluded P. Fe and Al oxide coatings and concretions absorb occluded P during diffusive penetration and the development of the soil. Occluded P is more difficult to remove from Fe, and Al oxide surfaces than non-occluded P ions that make up non-occluded P. Phosphorus (P) may be absorbed by plants or soil microbes for use in the secondary Po cycle, or it can flow into streams and accumulate as ocean sediments (Maltais-Landry *et al.*, 2014). A variety of types and amounts of Pi may be found in the soil. Plant structures (such stems, roots, and leaves), plant debris, and microbes gradually return the P they absorbed to the soil when mineralization has occurred. It is important to note that even though P has a wide range of biochemical activities in soil that are crucial to the health of the ecosystem, its cycles are slower than those of C, N, and S. A wide range of geochemical processes (weathering, precipitation/dissolution, and solid-phase transitions) have a long-term impact on soil phosphorus availability and distribution. Soil microorganisms immobilize and mineralize plant-available phosphorus (P) within the soil in a cyclic manner. However, very little is known about the function these biological activities play in limiting soil phosphorus availability due to geochemical processes (Hesterberg *et al.*, 1999 and Hao *et al.*, 2020)

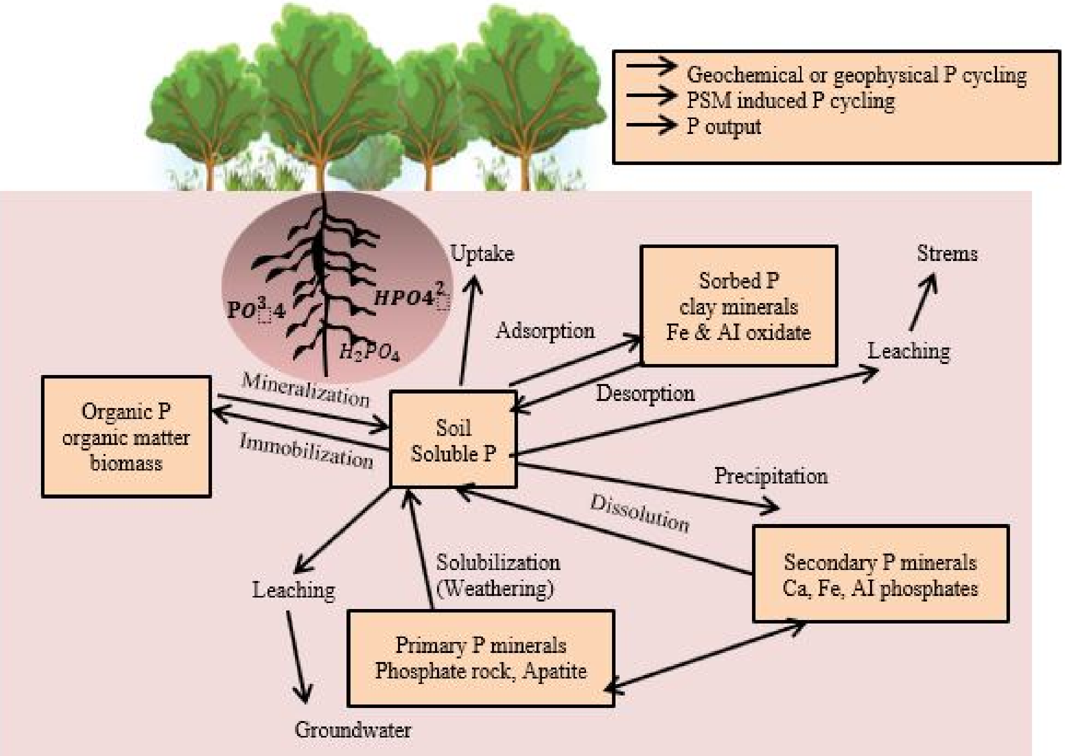
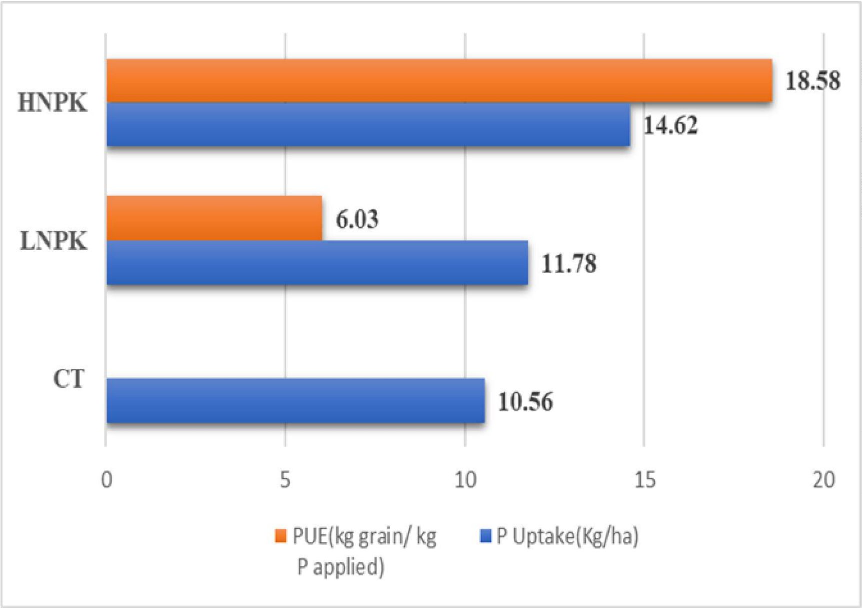


Figure 1: The Phosphorous cycle (Prietzel *et al.*, 2016)

<u>Release of inorganic P in soil from fertilizer application</u>:

Despite the fact that the soil contains a large amount of total P, only a little amount (less than 1%) gets dissolved in it (Bunemann *et al.*, 2015). There are many different forms of phosphorus, including organic P which includes nucleic acids, phospholipids, and orthophosphate), Al/Fe-bound inorganic P (which is found in acidic soils), and Ca-bound inorganic P (found mostly in alkaline soils). Occluding-P and Fe/Al-P percentages rise with rising P concentrations in the soil (Bai *et al.* 2017). Progressively, these compounds release soluble P (0.1 percent of the total soil P), which is slowly released over time. Soluble P, labile soil P, and nonlabile soil P are all various types of P in the soil. For plants to flourish they must have both primary and secondary orthophosphate $(H_2PO_4)^{-1}$ and HPO_4^{-2} forms of P (Zhu *et al.*, 2018). Acidic soils contain primary orthophosphates, whereas alkaline soils have secondary orthophosphates (Rashid *et al.*, 2005). Stunted growth, delayed maturity of crops, and poor seed development are all symptoms of a phosphorus deficit in plants. A shortage of total phosphorus in the soil, along with the fixation of extra phosphorus via the use of chemical fertilizers and organic sources such as manure, results in a deficiency of phosphorus in the soil. Several variables, including pH, organic matter content, particle size distribution, and mineralogy of the parent material, may influence the phosphorus concentration in soil (Havlin *et al*., 2005). The most important controls on P dynamics in soil are the sorption and desorption of P by soil matrix, particle size distribution, metal oxides, and soil pH. (Li *et al*., 2016). It has been shown that weathering is a factor in the movement of P across various pools. The largest phosphate retention capacity is found in clay-rich soils, which subsequently adsorbs/fixes more P than coarse-textured soils (Brady *et al*., 2008).

Phosphorus fertilizer is very necessary to take full use of the greatest production potentials offered by various crop plants. Since the ratio of phosphorus that is applied determines the amount of phosphorus that is fixed, the amount of phosphorus that is fixed by fertilizer that is broadcast is significantly higher than the amount of phosphorus that is fixed by fertilizer that is applied in bands due to the narrow soil to fertilizer ratio in the latter situation (Rashid *et al*., 1993). One of the primary reasons for the low output in crops is the poor performance of phosphatic fertilizer as sometimes it may include uranium as an impurity). One possible reason will be uranium extraction from rock phosphate. The economic feasibility of uranium extraction from phosphate rock may be improved by using incentives like subsidies for "cleaner fertilizers" or "greener uranium mining." Alternately, regulatory limitations for uranium in fertilizers may be established, as they were for cadmium many years ago. Politicians and government officials that advocated for cadmium in mineral fertilizers to be restricted by law in their individual countries ultimately had to choose "whether to extract uranium from phosphate rock or not" (Haneklaus et al.,2017). Another reason may be fixation of soluble phosphorous by soil matrix whenever they get penetrate into the soil solution formed initial reaction product(sparingly soluble compound). Proper fertilization method resulted in a more significant reaction than broadcast and banding. Mungbean fertigation yielded the maximum mungbean production, as well as P absorption, P recovery, and agronomic efficiency, compared to broadcasting methods. Phosphate fertilizer costs have risen worldwide due to the rising demand for greater yields, which has placed a strain on land resources (Weber *et al.,* 2014; Chowdhury *et al*., 2017). Soil P has been replenished by using phosphate fertilizers. Rock phosphate mining is the primary source for making phosphate fertilizers. Chemical methods must dissolve the phosphate that can only be obtained from mined rock phosphate (Khan *et al*., 2009). Because crops have a high capacity to fix phosphate and a low ability to utilize it, the rock phosphate is applied to the soil each cropping season (Withers *et al.,* 2001). Phosphate fertilizers that have been applied indiscriminately have created a fixed P pool that may be explored and used by various bacteria, enzymes, organic acids, manures, and humic substances. Organic acids and enzymatic activity released by phosphate solubilizing microorganisms aid plant absorption (Dash *et al.*, 2017). However, soil type, parent material, organic matter concentration, soil pH, soil salinity, and metal oxides all influence phosphate dynamics in the soil.



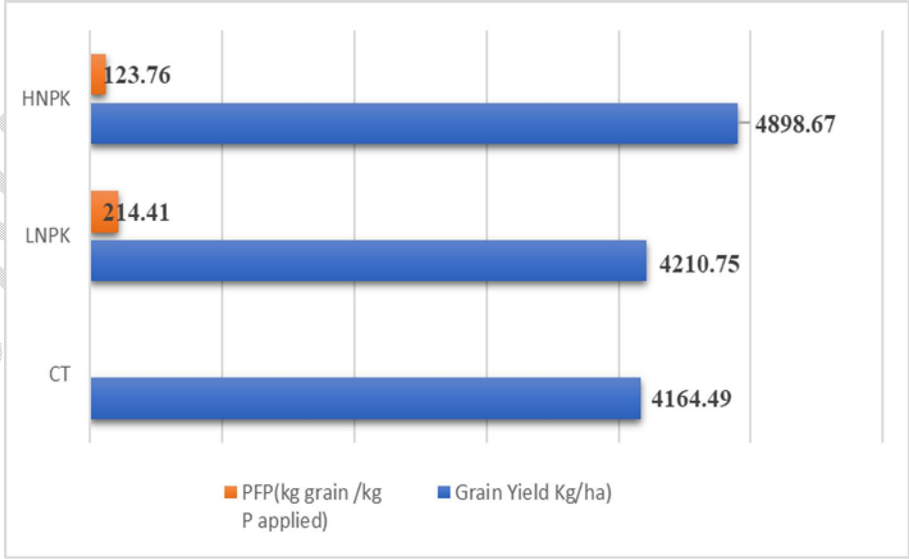


Figure 2. Phosphorus uptake, grain yield, phosphorus use efficiency (PUE), phosphorus recovery efficiency (PRE), and partial factor productivity for P (PFP) under different inorganic fertilizer treatments by rice crop in Jiangxi, Southern China (Ahmed *et al*., 2019)

In this aspect, Ahmed *et al*., 2019 observed that significant increase in P uptake and grain yield of rice under High NPK treatment (HNPK) accounts 10.02% followed by low NPK treatment (LNPK) by 35.20% compared with control (CT) in silty loam textured soils of Southern China and P use efficiency indices were also higher under HNPK than under LNPK. There was a strong positive relationship between grain yield and P use efficiency (R2 = 0.97). He also proposed the combined effect of long term NPK enhances P uptake by plant by increasing the biomass production and the soil carbon inputs (Joshi *et al*.,2015). The long term application of NPK mineral fertilizer promotes P mobility, mechanism of phosphorus transformation and P cycling in paddy soils.

3. <u>Dynamics of Phosphorous in the soil affected by organic sources</u>:

Various phosphorus pools in the soil, such as Al/Fe$_2$ bound P or Ca-bound P, replenish the P that plants take up from the soil solution (Saleque *et al.,* 2004). With mass flow taking over from diffusion, the function of P in the process is diminished (Hinsinger, 2001). The availability of Fe, Al, and Ca, which aid in the fixation of P, is also influenced by soil pH. Sodium phosphate is reduced in alkaline soils by forming several insoluble phosphate derivatives. Phosphorus is depleted from acidic soils by precipitates of hydroxyl phosphates generated by the interaction of iron and aluminum with phosphate ions (Harris *et al*., 2006). Cation and anion concentrations at the exchange sites influence soil adsorption capacity for phosphate, although divalent cations (Ca^{2+}) are significantly more attracted to P adsorption in clays than monovalent cations (Na^{+}) are in soils.

Alkaline calcareous soils have a high concentration of calcium phosphate minerals (CaP) that plants may take up, although most of the P is fixed as CaP. In addition to supplying P, clay minerals in soil play a significant role (Mehdi *et al*., 2007). Both the fixation and transformation of phosphorus are intricate processes, and it may be challenging to pin down

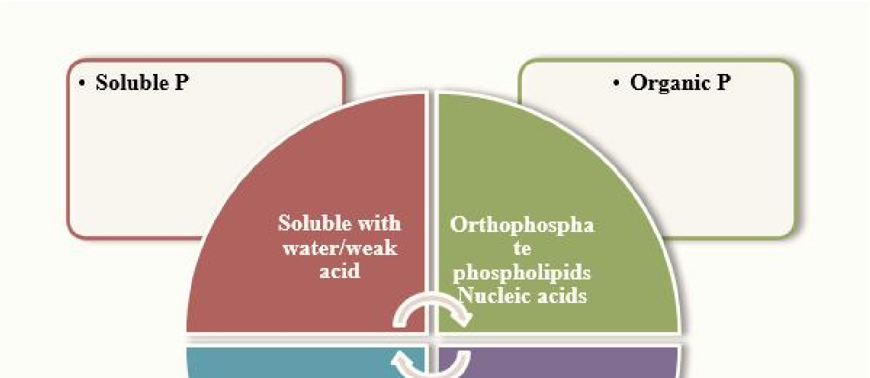


Figure 2: Various types of total Phosphorous in the soil matrix (modified from Syers et al., 2008).

appropriate kinetics for them. Phosphate may be in the soil in several different forms, including solution P, active P, as well as fixed P. Phospholipids, inositol phosphates, and nucleic acids are the three different kinds of organic P compounds. Phospholipids are the most common kind. Inositol phosphates include mono- to hexaphosphate esters as their primary building blocks (Dash *et al*., 2017). One of the most common organic phosphates (Ca–Mg salts of phytic acid) is also phyton. There are three kinds of enzymes that can break down organic P, which include phosphates and phytases as well as phosphatases (Ingle and Padole, 2017).

As a result of using goat dung in combination with low-rates of P fertilizers, the amount of the less-labile NaOH-Pi fraction in the soil may be reduced, ensuring that the soil's labile P levels are maintained at an adequate level. P needs for Smallholder farmers may be met with this cost-effective technique for enhancing fertilizer P usage efficiency (Gichangi *et al*., 2009).

After two and 16 weeks of composting in labile pools, it was shown that the Pi percentage soil was more likely to be dominated by compost P. However, the amount of labile P (51-58 percent), as well as total Pi (61-98 percent) in soil, was the same or nearly identical to that obtained from inorganic KH_2PO_4 alone. Compost from potato trash had a higher proportion of organic P (Po) than those from the other composts investigated when Po was extracted using $NaHCO_3$. While this study indicated that Pi was the most necessary form of compost P, it is still hard to assess the availability of compost Pafter it is applied to soil (Gagnon *et al*., 2012).

Additionally, it was shown that the soil formed from Basalt might lose some of its ability to bind P when organic molecules were introduced through the treatments. The intensity of P adsorption decreased when chicken dung as compost was added to soils originating from granite and river alluvial deposits but rose following the application of organic fertilizer. The three adsorption isotherm equations for basalt-derived soils all fit well. Langmuir >Freundlich >Temkin adsorption models were used for soils generated from granite and alluvial deposits as parent materials. It was shown that organic fertilizer and chicken manure had no effect on soils generated from basalt's MPBC or SPR, however organic fertilizer and incubation time had a significant impact on these parameters in soils formed from granite and alluvial deposits (Yu *et. al.*, 2013).

As in both soils, a sandy loam acidic soil (Aquepts) and a silt loam alkaline soil, extraction efficiency was in the sequence of Bray and Kurtz-II>Mehlich–3> Kelowna>Olsen amended with diverse organic sources, such as cow manure (CM), poultry manure (PM),city waste (CW), and triple superphosphate (TSP). As evaluated by $NaHCO_3$, organic additions improve the effectiveness of the additional P, but the efficiency of Triple superphosphate with days of incubation decreases (Ara *et al.*, 2018).

Nitrogen (N), as well as Leaf litter, had an effect on the bacterial action and this enhances to increase the orthophosphate form of phosphorus (Po), which resulted in a rise in the NaOHPi fractions, as a result, the quantity of Po detected in the NaOHPi portion increased overall (Kunito *et al.*, 2018).To increase P availability, organic matter may reduce P-selectivity and the maximum phosphate buffering capacity. At a soil organic matter (SOM) concentration of 75.3 grams per kilogram (g/kg), there is a growing tendency toward greater availability.

The relationship between different sources and sinks of phosphorus by using an intense cropping system that included rice, maize, and green gram (residual) was determined. Inorganic P fractions were for 71.9–86.0 percent of total P in surface soil, whereas organic P fractions accounted for 14.0–28.1 percent. The percentages in the subsoil ranged from 75.9–81 percent and 18.1–24.1 percent. The following is the order of the pools: Up to the first 15 centimetres of the soil, the order is FeP> RS-P > Al >Ca > Occluded >Saloid P; however, the lowest 15–30 centimetres of soil have the following order: "Occluded P" = "Al-P" > "saloid P" in the RS-P Both fractions provide a large quantity of phosphorus to the surface layer of the soil. In terms of inorganic phosphorus forms, there is a positive association between surface soil P absorption and Fe-P as well as a significant relation between the subsurface soil P uptake and Al-P (Chauhan *et al*., 2012).

Strategies for enhancing P use efficiency by plants in rhizosphere zone

Improvements in phosphorus management, for the purpose of increasing phosphorus use efficiency in crop production, need an understanding of the dynamics of phosphorus in the soil-rhizosphere-plant continuum. Successful techniques for P fertility management may include a variety of multi-level approaches that work in conjunction with soil, rhizosphere, and plant processes. P input into agricultural land may be optimized depending on the balance between P inputs and outputs. Due to the relative stability of P in soils, soil-based P management needs a long-term management approach to maintain an adequate soil-available P supply via monitoring soil P fertility. While comparing with conventional farming practices, this strategy might result in a 20% reduction in the amount of phosphorus fertilizer used to high-yielding cereal crops in the North China Plain (Zhang et al., 2010). This may be of great relevance for conserving P resources without sacrificing crop yields. Rhizosphere-based P management provides a cost-effective strategy to improve P-use efficiency and crop production, through the use of biological potential for effective mobilization and acquisition of P by crops, and decreasing the excessive dependence on application of chemical fertilizer P. According to Jones and Oburger (2011), field experiments with phosphorous solubilizing microorganism (PSM) demonstrate improvements in crop production of 0% to 20%. Coapplication of arbuscular mycorrhizal fungi (AMF) and PSM also demonstrates synergistic benefits in P acquisition (Babana and Antoun, 2006) due to interaction of microorganism with the root of higher plants contribute to more P mobilization as well as acquisition.

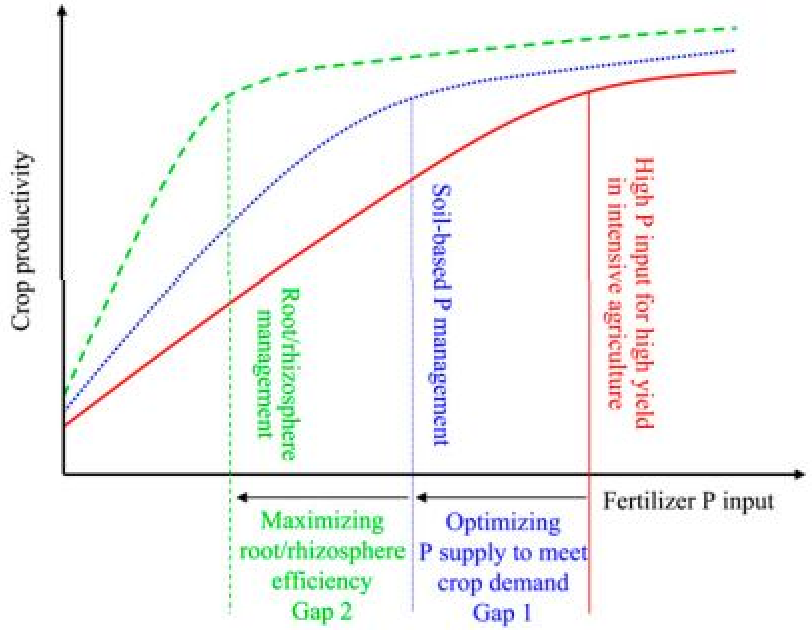


Figure 3 – Conceptual model of root/rhizosphere and soil-based nutrient managements for enhancing P usage efficiency and crop yield in intensive agriculture. By optimizing P supply to fulfill crop demand, soil-based nutrient management may close the first P input saving gap. Gap 2 can be overcome by root/rhizosphere management by exploiting root/rhizosphere efficiency and further reducing P resource input. This would improve P-use efficiency and crop yield. The solid red line depicts the response of crop production to increased P inputs in intensive agriculture. The blue line (dotted curve) depicts the response of crop production to P input in soil-based P management. Under root/rhizosphere management, the green line (dashed curve) shows the crop production response to P input (Adoptaed from Shen *et al.*, 2011)

Conclusion

Phosphorus plays an important role in pulses nutrition mainly for mungbean production. Most of the Indian soils are deficient in phosphorus leading to affect the nutrition of pulse crop as pulses occupy an important position in food and nutritional security in India. India produces over 280 million tonnes of foodgrains every year with an increase of four folds since independence. Increased efforts to produce more food have resulted in tremendous shift in cropping systems towards cereal-cereal based systems. Accordingly, vision of Indian Institute of Pulse Research, 2030, the projected pulse requirement by the year 2030 would be 32 million tons with an anticipated required growth rate of 4.2%. The growing Indian population enhanced the pulses demand. The burgeoning human population in India needs higher pulses production for fulfilling the dietary protein requirement. It requires to mitigating the demand of protein. In this regard, balanced fertilization with NPK alongwith biofertilizers has been proved beneficial in pulses both under rainfed and irrigated conditions. Hence, phosphorous needs to be taken care of while balanced fertilization in pulses. A concerted effort by farmers, researchers, development agencies, and government are needed to ensure that India becomes self-sufficient in pulses in the future. Therefore, farmers and extension functionaries must recognize that it is highly needed to include P nutrition in their nutrient management practices in balanced manner in present day intensive farming to harvest higher pulse yields of superior quality earning maximum sustainable profitability.

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