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Effect of applied phosphorus on soil environment and agricultural productivity: A review

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Abstract
Phosphorus (P) is the most important macronutrients present in soil just after nitrogen (N) that is essential for plant growth, development and productivity. In soil it is available both in organic and inorganic form. But the organic form of P present in soil is unavailable to plant whereas the available form is in inorganic form. In today's modern intensive agricultural system large quantity of P is required to feed the high yielding varieties. To supply this requirement for good productivity one has to rely on the inorganic fertilizers. However, Phosphorus (P) has a significant effect both on environment and agriculture through the process of eutropication and plant root-shoot ratio respectively. Inorganic P fertilization in soil predominantly bound with certain cations present depending on soil pH. In acidic soil the applied P will be bound by Iron (Fe) and aluminum (Al) whereas in alkaline condition by calcium (Ca) and magnesium (Mg) reducing its mobility thereby reducing its availability. So, without proper management practices to enhance the availability, excess amount of inorganic P are applied making more vulnerable to pollution. So, maintaining an optimum value of root-shoot ratio is essential for better production and reducing pollution in agriculture. Because more root distribution in soil will enhance more nutrient use efficiency. The growth of shoot and root of a plant significantly depends on the concentration/availability of P in the soil. In most of the studies shoot growth is more when the concentration of P in the soil is high whereas the root growth will be more during P deficiency. So, it is crucial to find out the optimum doses of inorganic P that maintain the proper ration of root-shoot that will improve both the environment and agricultural productivity.

Keywords: Inorganic phosphorus, pollution, soil sustainability, soil pH, organic phosphate

1. Introduction

Modern high-intensity agriculture strongly relies on inorganic fertilization, among them phosphatic fertilizer is one of the essential nutrients for proper growth and development of plant. In modern technique of sustainable agriculture and environment, management of phosphatic fertilizer is essential (Aimen *et al*., 2022) [1]. Phosphorus (P) has a significant effect both on environment and agriculture through the process of eutropication and plant root-shoot ratio respectively (Zheng *et al*., 2021) [46]. The availability of P to soil depends upon the adsorption and desorption reaction of P in soil through different factors responsible. But most of the time phosphorus is highly immobile in soil due to fixation by certain cations it is relatively unavailable (Mardamootoo *et al*., 2021) [16]. So, in agriculture root growth and development are critical for early phosphorus uptake by plants. Conversely, root growth depends on the phosphorus status of the plant. Understanding phosphorus uptake by plants therefore requires a good knowledge on how this phosphorus plant status affects root growth parameters which are relevant for phosphorus uptake. Phosphorus is readily fixed in most soils and has low availability to plants (Mardamootoo *et al*., 2021) [16]. To enhance phosphorus acquisition, plants and their root growth and other functioning is especially important. Common strategies about root growth are to increased root/shoot ratio, modified root architecture, decreased root diameter, enhanced specific root length (root length per unit root mass), higher root hair length and/or density. With different doses of phosphorus available in the soil, morphological adaptation of plant roots will take place (Xu *et al*., 2021). These morphological adaptations can greatly enhance the volume of soil root and will exploit different essential nutrients in soil increasing the crop production. The effect of P on environmental sustainability relies on the concept of quantity-intensity ratio (Q/I) (Mardamootoo *et al*., 2021) [16]. When the Q/I of P decrease the availability of P in soil solution increases but chances of eutropication also increases due to runoff. It is therefore important to enhance our knowledge about the quantities and forms of P available in soil depending on the different factors that have a significant impact on sustainable agriculture and environment.

Phosphorus (P) is one of the essential nutrients required by the plants that constitute about 0.2% of a plant dry weight, an important constituents of Adenosine triphosphate (ATP), nucleic acid and phospholipids a vital nourishing for plant growth and productivity. Its centralize in plants ranges from 0.05% to 0.5% of total plant dry weight. Though concentration of P in soil is 2000-fold higher than the plant, its availability to the plant is very low. The phosphorus use efficiency (PUE) from soil is in the range of 15–20% in agriculture soil, indicating that most of the soil-applied P remains unavailable to plant instead it is loss from the soil through leaching into ground and surface water runoff leading to eutrophication (Schroder *et al.* 2011). The availability of P for plant assimilation depends on different factors that include the input of P to soil and different soil properties affecting the adsorption and desorption of P in soil. Different sources of P to the soil include the parent materials of P, organic input and inorganic fertilizers. There are 172 naturally occurring phosphate minerals, according to one estimate. Among all apatite contributes 95% of the P in both igneous and sedimentary rocks and ultimate to soil (Tumbure *et al*., 2022) [37]. Apatite solubility is very less which is why it has to be processed to convert it into something that is soluble. So, the parent material apatite is use to produce the inorganic fertilizers after treating apatite minerals with sulphuric acid, phosphoric acid and compounded with ammonia. Another important input of P to soil is through organic matter. About 30 to 60% of P in soil are available in the form of organic P depends on the organic materials return to the soil (Tuszynska *et al*., 2021) [38]. Dead plant/animal remains and soil microorganisms are organic sources of phosphorus. Soil micro-organisms play a key role in processing and transforming these organic forms of phosphorus into plant available forms (inorganic form). Therefore P available in soil can be classified into two types i.e. organic and inorganic P. Inorganic form of P is the one which is important for both environmental and agricultural sustainability. So, maintaining the inorganic form of P by controlling the Q/I ratio of P is essential.

For proper growth of a plant an optimum amount of P in plant is essential. Its restrictions will impact negatively on crop yield and quality. It has been estimated that phosphorus deficiency reduces the crop yields on 30–40% of the world's arable land. This necessitates the use of a large amount of phosphatic fertilizers to correct its deprivation. Phosphorus plays an important role in an array of cellular processes, including energy investment. Its impossibility has a negative impact on crop productivity and quality. It also plays an important role in an array of cellular processes, including maintenance of membrane structures, synthesis of biomolecules and formation of high-energy molecules (Smith *et al.* 2003). It helps in cell division, enzyme activation/inactivation and carbohydrate metabolism at whole plant level, it stimulates seed germination; development of roots, stalk and stem strength; flower and seed formation; crop yield; and quality. In addition, availability of P increases the N-fixing capacity of leguminous plants. Hence, P is essential at all developmental stages, right from germination till maturity (Razaq *et al*. (2017). Phosphorus is an important constituent of energy-rich compounds, including adenosine triphosphate (ATP), cytidine triphosphate (CTP), guanosine triphosphate (GTP), uridine triphosphate (UTP), phosphoenol pyruvate and other phos phorylated intermediate compounds. As a result, it provides energy to many cellular endergonic processes. It is required for reproduction and protein synthesis because it is a component of nucleic acids (DNA, RNA). In order to maintain its role under inorganic phosphate (Pi-deprived conditions), plants undergo various morphological, physiological and biochemical adaptations. These include alterations in root architecture, formation of cluster roots, shoot development, organic acid exudation and alternative glycolytic and respiratory pathways. In this chapter, present an overview of the uptake, translocation and the role played by P in various processes both at cellular and whole plant level (Vance *et al.* (2003) [40]. Phosphorus (P) is the second most abundantly necessary nutrient element after nitrogen among all essential plant nutrients, and it is a significant part of many structural components of plants. In agricultural ecosystems, it determines the soil quality with respect to its production capacity. Being scarce and non-renewable natural resource which is under the threat of rapid depletion as a result of intensive mining across the world more emphasis is being given to increase P use efficiency in soil for successful and sustainable crop production Suzuki *et al*. (2010) [19].

In plant tissues, P exists in either of the two forms: free inorganic orthophosphate form (Pi) or as organic phosphate esters (Wieczorek *et al*., 2022) [43]. P is divided into compartments within plant cells based on its overall concentration. The metabolically active Pi form is found in the cytoplasm, whereas excess P is kept in the vacuole and sent to the cytoplasm when needed. Hence, the vacuole has a buffering function and full is the P demand of the cytoplasm under P deprivation. The esteried P exists in various forms, nucleic acids, phospholipids, phosphorylated metabolites and proteins. The optimum P concentration for most crops is 4 mg g1 DW. RNA is the greatest pool of P, followed by lipids, esters, DNA, and metabolically active Pi.

2. Effect of phosphorus on plant root-shoot ratio

Maintaining an optimum value of root-shoot ratio is essential for better production in agriculture. The growth of shoot and root of a plant significantly depends on the concentration/availability of P in the soil (Beroueg *et al*., 2021) [3]. In most of the studies shoot growth is more when the concentration of P in the soil is high whereas the root growth will be more during P deficiency (Zhang *et al*., 2021; Vetterlein *et al*., 2022) [41, 45]. So, the root-shoot ratio increases when the P concentration in soil decreases. Therefore the effect of P on root-shoot ratio is largely concentration dependent. Reducing P concentration in soil mostly affect the leaf characteristics during the vegetative stage and reproductive stage. Cell division and expansion of leaf is drastically affected as a result number of leaves and leaf area reduction is quiet a common causes of P deficiency. In contrast to this when the concentration of P decreases root growth of a plant increases making more root-shoot ratio. Different researcher has reported that the shoot growth of a plant suppress with low availability of P and higher allocation of dry matter to roots in many plant species, such as chrysanthemum (Dendranthema ×grandiflorum) (Hansen and Lynch, 1998) [12], petunia (Petunia ×hybrida), tomato (*Lycopersicon esculentum* Mill.) and common bean (*Phaseolus vulgaris* L.) (Lynch *et al*., 2001) [12]. Different concentration of P in soil results in different root-shoot ratio. But generally when the deficiency increases the root-shoot ration increased. The increase in root growth with low available P in the soil is a mechanism of plant to extract P from the soil. Since P present in soil are mostly in precipitate form complexion with certain cations present in soil depending upon the soil pH. Kumar *et al*. (2021) [11] has reported decrement of root volume, total leaf area, and plant dry weight due to deficiency of P, but greatly increased density of root hairs and root top ratio. Furthermore, phosphorus deprivation resulted in a large increase in phosphorus consumption efficiency as well as the amounts of proline, malondialdehyde, acid phosphatase, peroxidase, and superoxide dismutase (SOD), but a significant decrease in P uptake and soluble protein content. Further, the results based on the correlation analysis showed that the economic yield of wheat landraces had relationships with their morphological and physiological characteristics under P-deficiency. Another study conducted by Lynch *et al*. (2001) [12] in *Triticum aestivum L* observed that root mass ratio decreased with increasing P supply. Furthermore a critical assessment of the role of organic P in soil solution in the nutrition of wheat plants under sterile conditions was also presented. It has been reported that P supply had a positive effect on dry matter and P concentration of the plants. Acid phosphatase secretion by plant roots was 5–11 times higher in organic P treatments than in the inorganic P treatments. It was hypothesized that plants secrete phophatase in response to the presence of organic P in soil solution and organic P might be responsible for the increase in Pi flux to wheat plants. shSo, identification of crop cultivars and inclusion of P to the soil at the right timing of the growth of a plant therefore be useful for increasing P uptake in low input agriculture The amount of P drained from the rhizosphere was connected to the difference in root hair characteristics of the cultivars. And maintaining P in the 4th or 5th week of a plant growth will effectively increase both shoot and root growth making more production. Results also showed that the variation in root hairs of cereal cultivars can be considerable and it can play a significant role in P acquisition, especially in low-P soils.

3. Effect of Phosphorus on Seed Germination

Root systems of individual crop plants may encounter substantial variations in mechanical impedance to root penetration. Root architecture is an extremely plastic and environmentally responsive trait that enables plants to counteract nutrient scarcities with different forging strategies (Mahmood *et al*. 1984) [15]. The supply of accessible nutrients in the rooting Media as well as the root system influence nutrient uptake. The ability of plants to respond appropriately to nutrient availability is of fundamental importance for their adaptation to the environment. Nutrients such As nitrate, phosphate, sulfate and iron act as signals that can be identified (Kellermeier *et al*., 2013) [9]. Phosphorus is one of the most important essential nutrients which are vital during the early growth stage of a plant life cycle and have an impact on good production. Hence higher concentration of P on seed has been regarded as essential for seedling establishment or seed germination. According to Pariasca *et al*. (2015) [23], P content seed is an important factor for seed germination and improved seedling vigour. Seed P is the only P available to plants at the time of germination and helps in supporting the early seedling growth. Although this P pool is of minor importance for mature plant, it has a prime role for the nutrition and faster establishment of young seedlings. Plants get their P from the growth media through their roots after seed germination. Another important findings while comparing wheat seeds with high P and low P reported that seeds containing more P after germination can uptake more P from the soil when compare with low P (Zhu *et al*., 2001) [47]. This was mostly owing to the improved root system development in seeds with greater P reserves (Zhu and Smith 2001) [47]. During early days of seedling development, seed phytate P is hydrolysed, and non-phytate P is then remobilized to support the growth of maize seedling (Nadeem etal. 2011, 2012 [20-21] However, when compared to high seed P plants, lower seed P plants exhibited no difference in seedling vigour, plant biomass, or yield, according to some publications, though some genotypes were found to be sensitive. This implies that an optimum seed P concentration is sufficient for seed germination, and hence, higher P concentration in seeds might be of no use.

4. Effect of Phosphorus on Plant Growth

Phosphorus is a chief element affecting the growth of plants right from the cellular to whole plant level. These growth parameters include plant height, leaf area, leaf number and shoot dry biomass (Ali, F. Mishra, H. (2015) [19]. It plays an important role in cell division and cell enlargement. For timely appearance and development of tillers in crop plants, P is essential. The P-deprived leaf cells are found to be smaller than P-sufficient cells. The shoot biomass is reduced as a result of limited cell divisions and expansion. However, the reduction in leaf expansion is not accompanied by a reduction in leaf dry weight (Rodriguez *et al*. 1998) [49]. Plant growth parameters are found to be more sensitive to P availability than the photosynthesis (Blackburn 2018) [17]. Increase in root biomass is considered as an important adaptive strategy by plants under P-deficiency conditions with an aim to explore for more Phosphorous. However, it is only apparent at the start of a P-limited environment. Under long-term Pi-deficient conditions, the relative growth rate decreases as a result of reduced ATP concentration in roots. However, genotypes with greater phosphorus use efficiency (PUE) tend to have higher root biomass and lower rates of respiration than genotypes with lower PUE under P deprivation. This is suggested as a way to maintain greater root biomass without any increase in overall root C costs (Gniazdowska *et al*. 1998) [7]. Phosphorus is necessary for plant reproductive growth, including flower and seed formation. P contributes to the production of anthocyanin's in flower stalks, which was found to decrease under P-deficient conditions. This was attributed to decreased activities of phenylalanine ammonia-ligase (PAL) and chalcone isomerase (CHI). Large quantities of P are found in seeds and fruit where it is believed to be essential for seed formation and developments. The majority of P taken up by plants in cereal crops like rice and wheat is stored in seeds. Thus, an inadequate supply of P can reduce seed size, seed number and viability (Fahad *et al*. 2002) [5]. Optimum P concentration in soil increases the seed number, seed dry matter, seed yield and harvest index. Coating of seeds with 7g per kg of monosodium phosphate enhanced the growth and yield of soybean plants compared the response of white lupin (Lupinus albus) to various P concentrations in soil. It has been reported that low soil Phosphorus (5,10 or 15mg per kg) had a negative impact on lowering time and lower number of soybean plants but no differences were recorded with P supply higher than 20mg per kg. Higher P concentration (25–40mg kg^{-1}) succeeded in increasing the number of pods and hence yields in soybean (Preiss *et al*.

1994). P is a component of phytic, a major storage form of P in seeds. Various crops differ in their concentration of phytate in seed. About 75% of the total P in rice, wheat and maize is stored as phytic or closely related compounds, while inorganic phosphate and cellular-P range from 4–9% to 15–25%, respectively (Ma *et al*. 2002). Phosphorus plays an essential role in crop production and is involved in energy transfer in plants. Without phosphorus, plants are unable to repair carbon dioxide. Phosphorus is required for many physiological functions in plants, including sugar and starch utilisation, photosynthesis, energy storage, and transmission. It is also a constituent of cell nucleus and is essential for cell division and development of meristematic tissues. Phosphorus has been reported to increase the strength of cereal straw, resist abiotic stresses, stimulate root development, encourage flowering, fruit production, and formation of seed and hurry up maturity of the crops. Phosphorus utilization efficiency can be improved by mixing it with farm yard ordure to multiplication the yield of wheat. Farm yard fertilizer mixed with single superphosphate in 1:2 ratio increases phosphorus efficiency significantly. It would be advantageous if we select, screen or improve plants for higher capacity to adapt to mineral stresses. This approach is beneficial in developing countries where capital input resources are limited. Farmers in These countries require nutrient efficient crop cultivars which perform better or do respond better than other cultivars when given a considerable amount of mineral nutrient (Malhotra *et al*. 2005).

5. Effect of Phosphorus on Physiological Properties

The availability of P is critical to the photosynthetic process. The primary substrates for photosynthesis include inorganic phosphate (Pi), CO_2 and H_2O that utilizes light energy in the presence of chlorophyll forming sugars and ATP. This ATP serves as a driving force to carry out various metabolic reactions within the plant and sugars help in the generation of other structural and storage components (Flugge *et al*. 1984) [6]. The first stage in photosynthesis is photophosphorylation, in which Pi interacts with ADP to generate ATP, followed by the discharge of a proton gradient into the chloroplast stroma via an ATPase. The atmospheric CO_2 is fixed in the chloroplast via photosynthetic carbon reduction (PCR) cycle, consuming ATP. For every three molecules of CO_2, nine Pi are consumed forming three molecules of O_2. Out of these nine Pi, eight are released into the chloroplast via PCR cycle, while one is exported from chloroplast to the cytosol in the form of triose phosphate (triose-P), where it is transformed to sucrose and Pi is released and recycled. This P is now available to move back into the chloroplast to further form triose-P in chloroplast. In chloroplast, the inner envelope is impermeable to hydrophilic solutes including Pi and other phosphorylated compounds. Hence, the counter-exchange of various metabolites such as triose-P, 3-phosphoglyceric acid (3-PGA) and Pi across the envelope is carried out via Pi translocator (Mikulska *et al*. 1990) [32]. Through this Pi translocator, the photosynthetically fixed C is trans-ported from chloroplast to cytosol in the form of triose-P and in exchange of Pi released in the cytosol during sucrose synthesis is shuttled back into the chloroplast via Pi translocator for the synthesis of ATP. The function of the Pi translocator is altered by external P levels, which regulate photosynthesis. Low P levels in the cytosol restrict triose-P flow into the chloroplast, lowering Pi release from sucrose synthesis in the chloroplast and lowering ATP production of PCR cycle. Also,Pi translocator participates in the transport of ATP and NADPH produced during photosynthesis to the extra-chloroplastic compartments envelope is carried out via Pi translocation (Ascencio, J. 1994). Low P levels in cytosol reduce the Flow of triose-P into the chloroplast, thereby decreasing the Pi release from sucrose Synthesis in chloroplast and reducing (Rychter *et al*. 1992) [31]**.** The function of the Pi translocator is altered by external P levels, which regulate photosynthesis. Low cytosol P levels restrict triose-P flow into the chloroplast, lowering Pi release from sucrose synthesis in the chloroplast and lowering ATP production necessary for the PCR cycle. Also, Pi translocator participates in the transport of ATP and NADPH produced during photosynthesis to the extra-chloroplastic compartments (Kholi *et al*. 2001). Changes in Pi availability in cytoplasm alters the activation of enzyme (RuBisCO, sedoheptulose-1, 7-bisphosphatase and fructose-1,6-bisphosphatase) and amounts of intermediates of the PCR cycle. The concentration of phosphorylated metabolites, including RuBP, PGA, triose-P, FBP, F6P, G6P, adenylates, nicotinamide, nucleotides and Pi, is reduced under P deficiency. This is due to a reduction in C supply, as the majority of C is diverted to starch manufacture. However, the cytosol concentration of P remains stable due to the availability of P in vacuole, and hence the vacuolar pool is found to lower under P-deficient conditions (Bhagwat *et al*. 1981) [4].

6. Effect of Soil Physiochemical Properties on Phosphorus

The availability of P in soil for plants has a significant relationship with some of the important physicochemical properties of soil. One of the most important factors responsible for P availability is soil pH (Wan *et al*., 2021) [42]. Technically pH is the negative logarithm of H^+ ion activities. Its value ranges from 0-14 and the value of soil pH 7 is considered neutral whereas value >7 alkaline and <7 acidic. The relationship of P with soil pH lies with the availability of cations under various ranges of pH value in soil. As an example in alkaline condition the dominant cations present in the soil is mostly Ca^{2+} and Mg^{2+} whereas under acidic condition Fe^{3+} and Al^{3+} dominates. So, P in soil always forms a complex with the cations under entire ranges of soil pH making unavailable for plant absorption (Amarasinghe *et al*., 2022) [2]. This is also the reason of P does not readily leached out from the soil. Like other essential nutrients the availability of P in soil for plant absorption is more in the pH range of 6.5-7.5. So, depending on soil pH it is always recommended to use either gypsum (for alkaline soil) or lime (for acidic soil) for improving the P availability for plant absorption. Another important chemical property of soil is electrical conductivity (EC) which is a measure of a material's ability to carry an electrical current and is one of the most important indicators of salt affected soil. Since there lays a negative relationship with P availability and cations present in soil. Likewise when EC of soil increases the P availability of soil for plant decreases (Mengmeng *et al*., 2021) [18]. In soil P are bound to soil organic matter (SOM) affecting the adsorption and desorption of P in soil. The adsorption and desorption reaction of P in soil is very important for plant P availability, P erosion loss, eutropication, etc. When adsorption reaction is more, less availability of P to the plant whereas when desorption is more than plant availability will be more however chances of pollution also increases through eutropication. But the effect of SOM on P adsorption and desorption reaction is unclear because of contradictory findings. However it has been found in many studies that the availability of P in the soil increases with increase in SOM decomposition either native P or fertilized P. Regarding adsorption and desorption reaction of P, with decrease in SOM decreased the adsorption capacity for P, indicating that removing SOM decreased the amount of bound P present. On contrary to this the amount of adsorbed P increased when SOM content decreased indicating SOM could inhibit P adsorption through competitive adsorption.

One of the most important soil physical properties affecting P availability is soil texture (Padalia *et al*., 2021) [22]. Soil texture (such as loam, sandy loam or clay) can be defined as the relative proportion of sand, silt and clay sized particles that make up the mineral fraction of the soil. Depending upon different soil forming factors soil texture varies from one place to another making different soil property. Basically soil texture can be classified as fine texture and coarse texture soil. Fine soil texture with higher proportion of clay particles has high P retention capacity. In this type of soil the P availability increases but the availability to the plants depends on the diffusion coefficient of P relating the variation in the rate of uptake by a plant. The diffusion coefficient of P of a fine texture soil is more than that of coarse texture soil. So, clay because of its colloidal properties has very large surface area per unit volume which can retain more P in the soil whereas coarse texture can retain less. Other soil physical factors like soil moisture, temperature and aeration also affect the P availability indirectly with its effect on soil organic matter decomposition. Since about 30 to 65% of the P available in soil is in organic form, so any soil properties that enhance the SOM decomposition will enhance the P availability to soil for plant absorption.

Soil organic matter is an important source of P to soil. It has been reported that approximately 30 to 65% of P present in soil are in organic form. Inositol phosphates, phospholipids, and nucleic acid are important forms of organic phosphate derived from organic matter (Upadhayay and Sharma, 2022) [39]. The organic P present in soil is not available to the plant. To make it available for plant absorption it has to be converted into inorganic form through mineralization process. And for mineralization of organic P to inorganic P microbial involvement is a must. So, soil biological properties are very important to consider as far as soil P availability is concern. One of the important extracellular enzymes secreted by almost all microorganisms present in soil is phosphatase enzyme. This enzyme will cleave phosphoric acid monoester into a phosphate ion and an alcohol or in other words it will remove phosphate group from the organic P present in soil. The removed P will be made available to the soil for plant absorption.

7. Conclusion

Phosphorus is one of the most important essential nutrients that limit proper plant growth. Because of its important constituents on ATP, it serves as a driving force to carry out various metabolic reactions within the plant and help in the generation of other structural and storage components. P plays a numerous roles in maintaining physiological properties of a plant so its availability in soil is vital for plant growth, development and productivity. P is available is soil both in organic and inorganic form. The inorganic form contributes larger proportion and availability to plants suggesting its important role. Nevertheless its availability in the soil for plant absorption relies on the physical, chemical and biological properties of the soil. Most important factors include soil pH, organic matter content and soil texture. Most of the applied inorganic P to soil remained unavailable to plant because of its complex formation with different cations in soil. This leads to decrease the P use efficiency of the applied inorganic P. But, higher concentration of P in soil could lead to soil and water pollution which ultimately affect the environmental sustainability. Therefore to improve both environmental and soil sustainability an optimum dose of P must be applied in such a way to improve the nutrient use efficiency. On the other hand for increasing PUE of the applied inorganic fertilizers, root growth plays an important role. With larger distribution of root in soil more absorption of P by the plant take place decreasing loss of P from the soil. Therefore for an efficient use of applied nutrient, role of root is very essential whereas as far as yield is concern proper shoot growth is vital. However the root-shoot ratio of any plant depends on the concentration of P available to the soil. So, with an optimum dose of P in soil proper growth of both root and shoot will achieve and improve the soil and environmental sustainability.

8. Reference

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