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Flow and Effects of Phosphorus From Soil to Plant

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Abstract

Phosphorus (P) is considered a large and important nutrient element, and it is generally concentrated in the surface soil layers, and the absorption of phosphorous by plant roots depends on the moisture content around the roots and the nature and shape of the morphological roots, as the structure of the roots plays a significant role in maximizing the absorption of phosphorus, and its presence is affected In the soil form according to climatic conditions, acidity and alkalinity of the soil, and phosphorus plays many important roles in plants, as it is considered an necessary element in deoxyribonucleic acid RNA and DNA, Which contain the genetic code responsible for the production of proteins, enzymes, phospholipids, membranes, oxidation-reduction reactions, glycolysis, respiration, and other compounds necessary for plant structure, phosphorus is often subjected to sequestration, precipitation, adsorption, and coatings such as phosphorus paint with carbon minerals, which changes rapidly, and it turns into difficult compounds that are not available to plants, matching the types of fertilizers containing phosphorus with the physical and chemical properties of the soil is an effective strategy for the effective and rational use of phosphorous fertilizers, but the dynamics of phosphorus remains dependent on the nature of the morphological and physiological roots as well as the soil structure and the amount of phosphorus.

Keywords: Phosphorus dynamics, Root morphology, Soil, Rhizosphere.

Introduction

The lack of phosphorous available to plants is a main limiting factor for crop productivity (Bhattacharyya *et al*., 2015), and that major limiting factor for crop production in some way has been demonstrated that diversity, including biological diversity, has an important influence on plant-soil interactions, by stimulating root secretions, or by promoting access to microbial aggregates in the soil (Mellado Vázquez *et al*., 2016). In the most cases, plant diversity can drive soil microbial communities to mine organic matter, releasing and providing further nutrients to plant growth and development (Lange *et al*., 2019). P is present in soil in different organic and inorganic chemical forms (Pi/Po) where there is a difference in the behavior and fate of phosphorus isoforms in soils (Hansen *et al*., 2004; Turner *et al*., 2007), organic phosphorus accounts for 35% to 70% of total soil phosphorus (Harrison, 1987). Primary phosphorus minerals including apatite, strengite, and varisite are very stable, and the release of available phosphorus from those minerals by (weathering) is usually slow, although direct application of phosphate rock (i.e., apatite) has been shown to be very effective in crop growth in acidic soils. In contrast, there is a difference between the non-major phosphorous minerals, containing calcium (Ca), iron (Fe), and aluminum (Al), and the disparity and difference between those minerals at the level of dissolution rates, Relative to mineral particle size and soil pH (Pierzynski *et al*., 2005; Oelkers and Valsami-Jones, 2008), apatite and P and K containing rocks are cheaper P and K nutrients sources, however, the nutrients from them are not bioavailable. It is easily soluble and therefore plant available as the nutrients are released slowly over periods. Their use as a fertilizer often does not significantly increase yield in non-acidic soils (Basak *et al*., 2017; Lompo *et al*., 2018). In acidic soils, the sorption of phosphorus is mainly by Al/Fe oxides and hydroxides, like gibbsite, hematite, and goethite (Parfitt, 1989), Phosphorus can initially be adsorbed onto the surface of clay minerals and oxides (iron/aluminum) by forming dissimilar complexes. Diprotic and non-protonated surface complexes may coexist at pH 4–9, while the diprotonated innersphere complex predominates under acidic soil conditions (Luengo *et al*., 2006; Arai and Sparks, 2007). Clay minerals and oxides have larger surface areas, which provide space for adsorption to occur. Soil uptake of phosphorus can be strengthened with increasing ionic strength in the soil.

Through many interactions, phosphorus is withdrawn into nanopores, which frequently occur in iron and aluminum oxides, and thus becomes unavailable to plants (Arai and Sparks, 2007). In neutral to calcareous soils, sedimentation reactions dominate the sequestration of phosphorus (Lindsay. *et al*., 1989), but it is nevertheless possible that P is absorbed from the surface of calcium carbonate (Larsen, 1967) and clay minerals (Devau *et al*., 2010; Ganjineh, *et al*., 2019). Phosphate can precipitate with calcium, resulting in the production of dicalcium phosphate (DCP) available to plants , Eventually DCP can be switched to more stable forms such as octalcium phosphate and hydroxyapatite (HAP), which are less available to plants at alkaline pH (Arai and Sparks, 2007). HAP in calcareous soils constitutes more than 50% of Pi (H.Li), and the form of phosphorus, PO, generally represents 30% to 65% of the total phosphorus present in the soil (Harrison, 1987).

The susceptibility to release Po lies in the mineralization processes mediated by microbial communities in the soil and plant roots with each other, as well as phosphatase secretion. These processes are determined by soil moisture, temperature, surface physical and chemical properties, PH and Eh (redox potential). The alteration of Po has a significant impact on the overall bioavailability of phosphorus in soils (Turner *et al*., 2007; Emami *et al*., 2019). Therefore, soil P availability is very complex and needs to be systematically evaluated because it is closely related to the dynamics of P and the shift between different P groups (Figure 1).

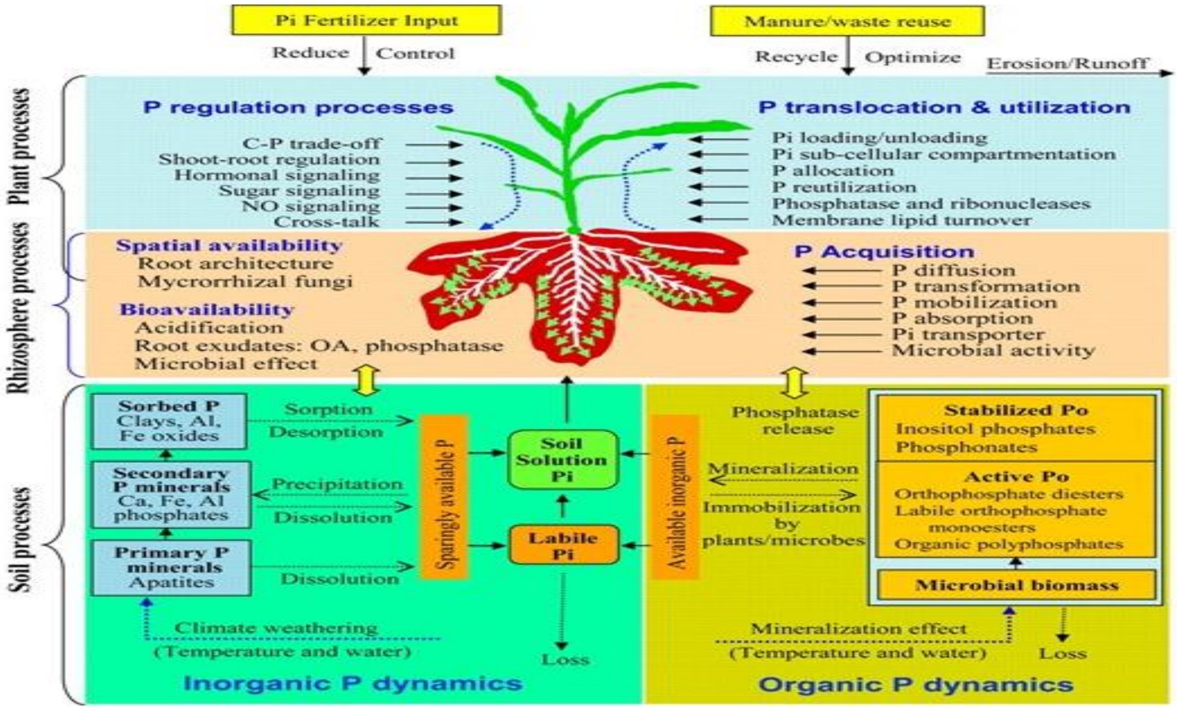

Figure 1. The mechanism of work of roots and their morphological nature (Jianbo Shen *et al.*, 2011).

RESEARCH METHODS

In this study, by searching in library sources and databases (Irandoc, SID, Scoops, Google Scholar, PubMed and Web of Science) we have tried to find the necessary information related to the flow and effects of phosphorus from soil to plant.

Phosphorus fertilizers

Intensive traditional farming systems, which include a high percentage of chemical fertilizers and pesticides, have led to soil degradation and loss of biodiversity. As an alternative, other (species mixture) systems show many potential advantages in improving soil quality (Malézieux *et al*., 2009). Most studies have focused on positive interactions between species, and have been testing the feasibility of the stress gradient hypothesis (SGH), which is expected it works to increase facilitation and decrease competition between plants under conditions of high environmental stress in natural ecosystems (He *et al*., 2013; Maleki, *et al*., 2014), In particular, intercropping systems can be predicted to restore soil fertility and sustainability from traditional monoculture systems (Tillman, 2020), and intercropping has been defined as the simultaneous cultivation of more than one type of crop in the same land and under the same conditions, it has been proposed as an intensification measure promising sustainable in agriculture (Gurr *et al*., 2016). The interactions between the roots of species are of greater importance in the intercropping system than the interactions that occur with the vegetative parts above the soil surface (Walker and King, 2009; Zhang and Li, 2003).

During the growth period, intertwining of roots can lead to the exchange and transfer of materials and elements between the two types of cultivated crops, which may affect the type and intensity of interactions between one plant and another. In this respect, interactions between underground species play a major important role in sustainable soil management (Zhang *et al*., 2011). The availability of some vital nutrients such as phosphorus (P) may be mediated by root interactions, especially in the legume and cereal cropping system, increasing the application rate of phosphorus can reduce the yield benefits of maize with peanut (Betencourt *et al*., 2012), In addition, low levels of soil phosphorus can significantly increase when cultivars of durum wheat are planted with chickpeas due to enhanced uptake and utilization of phosphorus (Lee *et al*., 2007), and another study showed that maize was consumed 43% more than average and fava beans The Sudanese consumed more than the average by 26% when grown in soils low in phosphorus, where the mobilization of phosphorus by the Egyptian bean can facilitate the growth of maize (Li *et al*., 2007), and a phenomenon has been observed that there are facilitating interactions between the roots of the species in the intercropping system For beans / maize, that the rates of root exudations in maize increased, which led to an increase in the node and fixation of N2 for beans, especially in nitrogen-deficient soils (Li *et al*., 2016).

The main objective of this study and previous studies that dealt with the levels of phosphorus uptake by plant roots in intercropping was the activation processes of phosphorus in the soil that increased phosphorus availability, such as pH changes, acid phosphatase activity, soil water stress gradients on growth, and interspecies facilitation. , and competition in root patterns and behavior among different crops, to mobilize Po plants can secrete phosphatases through enzyme-driven hydrolysis, Phosphatase activities are downregulated under P deficiency (Vance *et al*., 2003; Vance, 2008). However, the effectiveness of these phosphohydrolases can be significantly altered by elemental availability, interactions with soil microorganisms and soil pH, depending on the physicochemical properties of the soil (George *et al*., 2005; Heydari and Maleki, 2014). Therefore, there is often no significant correlation between phosphatase activity and plant growth performance in acidic or calcareous soils (Richardson *et al*., 2009). Moreover, carboxylate leaches may have strong interactions with soil, resulting in low phosphorus mobilization efficiency. Therefore, root-induced bioavailability and phosphorus uptake in combination with root perfusion must be systematically assessed into the soil/roots. The rhizosphere is a critical and sensitive area for plant-soil-microorganism interactions. Plant roots can significantly adapt to their environment through their physiological activities. Different, especially the exudation of organic compounds such as mucilage, organic acids, phosphatases and some specific marking materials, which are major drivers of various root processes, Chemical and biological processes in the rhizosphere not only determine soil nutrient mobilization and stimulation and uptake in addition to microbial dynamics, but also control crop nutrient uptake efficiency, thus directly affecting crop yield (Hinsinger *et al*., 2009; Richardson *et al*., 2009; Wissuwa *et al*., 2009; Zhang *et al*., 2010), given the special features of soil phosphorus such as low solubility, little mobility, and high fixation by soil matrix, the availability of phosphorus to plants is mainly controlled by two major processes: The place of availability of phosphorus and the possibility of its uptake by the roots (the roots that are stimulated in the presence and availability of phosphorus) in terms of the structure of the plant root in addition to the fungal association, the presence, biodiversity and uptake of phosphorus based on the chemical and biological processes in the root zone, it has been proven that P deficiency impairs the activity and growth of the roots primary and stimulates and enhances the length and density of root hairs and lateral roots in many plant species (López-Bucio *et al*., 2003; Desnos, 2008).

Some plant species can and because of effective genetic characteristics (Lynch and Brown, 2008), It can and for example the white lupine (Lupinus albus) develop racemose roots with dense, pubescent lateral roots, which are covered by large numbers of root hairs (Lambers *et al*., 2006; Vance, 2008). Therefore, root structure plays an important role in maximizing P gain because root systems with a larger surface area are able to explore a given volume of soil more effectively (Lynch, 1995 Heydari, *et al*., 2011). Root propagation is activated when plant roots encounter nutrient-rich patches, especially when they are Stains are rich in phosphorus/nitrogen (Drew, 1975; Hodge, 2004). Root proliferation in P-rich topsoil layers is associated with a decreased root gravid response under phosphorus limitation (Bonser *et al*., 1996), and ethylene may be involved in regulating these responses (Lynch and Brown, 2008), Root proliferation can be significantly induced in soil patches enriched with phosphorus. However, the mechanisms of P-dependent changes in root proliferation in response to local P supply are not fully understood and need further studies.

Phosphorous in plants

Plants absorb phosphorus from the soil during the diffusion process, but the diffusion coefficients for this element are very low and its concentration in the soil solution is limited (Cui, 2019; Cavalcante 2018; Roy, 2017), because of the low mobility of this element in the soil, phosphate fertilization should be applied close to the plant roots (Parent, 2020). Inside the plant, phosphorus is highly mobile, in contrast to its activity in the soil (Manghabat, 2019), phosphorus deficiency causes distinctive coloration ranging from orange to red hues in older leaves (Fig. 2). This is due to the decrease in chlorophyll biosynthesis and the increase in the production of pigments such as anthocyanin (Wang, 2018; Zhang, 2019; Mirzaei-Heydari, 2013). Soluble phosphorus is transported through the xylem to all growth points, depending on the phosphorus concentration, which is within the appropriate range of 0.1 to 0.3 g.kg-1 phosphorus for most crops (grasses and agro-industrial crops, including fruit and legumes (Cuq *et al*., 2020).

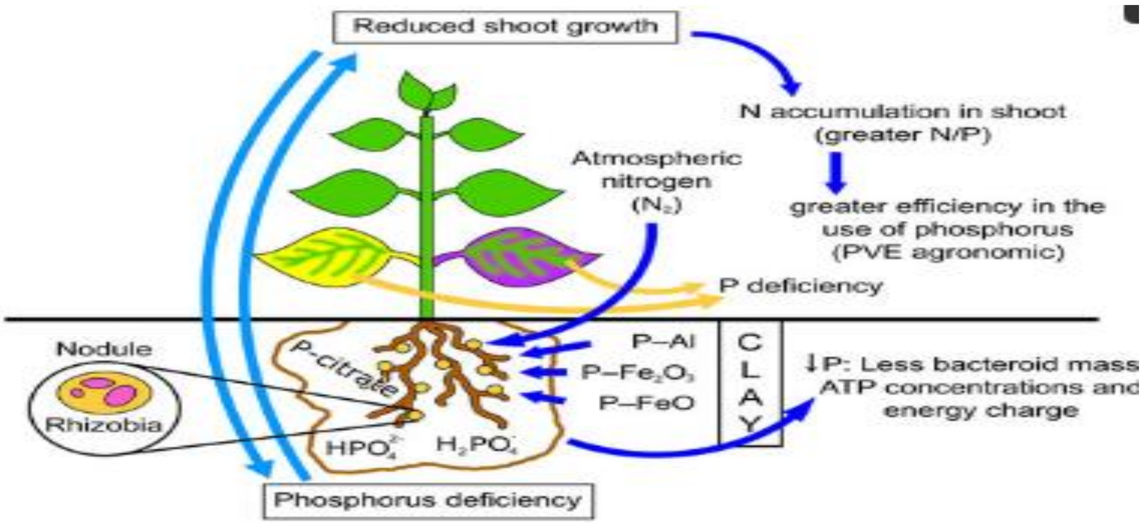

Figure 2. Phosphorus cycle and N fixation process in the plant, soil and environment system (Lizcano -Toledo *et al*, 2021).

Inside plant cells, phosphorus is a major component of nucleic acids, living membrane lipids, phosphorous intermediates, redox processes, respiration, and all vital activities related to energy metabolism within plant cells. Phosphorus deficiency, plants can develop adaptive responses to not only facilitate the acquisition and efficient transfer of Pi, but also to efficiently utilize stored phosphorus by internally resetting and cycling Pi, limiting its consumption, and reallocating P from old tissues to young tissues and/or active outgrowths, In order to recycle phosphorus within the plant in case of deficiency, the process needs phosphatase to release and stimulate Pi , These phosphatase and Ribonuclease genes are induced by leaf senescence, supporting their important role in the process of recycling phosphate within the plant (Gepstein *et al*., 2003). Plants have evolved a series of adaptive responses to efficient intake and use of phosphorus, including morphological, physiological, and chemical responses. Vitality (Fig. 1). This complex network is required to control Pi feeding in plants either locally or systemically. The molecular mechanisms that determine the phosphate signaling pathway have been presented in several recently published reviews (Doerner, 2008; Lin *et al*., 2009; Rouached *et al*., 2010).

Phosphorus as fertilizer and phosphorus in the soil

The losses and limitations of phosphorus in the soil are very high. On the one hand, low-soluble (Thomas slag and phosphorus rock) and high-soluble fertilizers, among which DAP, TSP, MAP and H3PO4 can be used in fertilization programmes. On the other hand, processes such as adsorption, precipitation, and microbial fixation can occur due to the physical, chemical, and microbial conditions of the soil (Meyer 2018) , Phosphorus is absorbed by plant roots from either H2PO4- or HPO42−. Since the concentrations of these ions in soil are in the micromolar range, active, high-affinity transport systems are required for Pi uptake against a steep chemical potential gradient across the plasma membrane of root and cortical epidermal cells. This process is mediated by the high-affinity Pi/H+ symbionts belonging to the PHT1 gene family. Disruption of PHT1 gene expression leads to a significant decrease in the acquisition of P by roots (Shin *et al*., 2004; Ai *et al*., 2009).

Phosphate adsorption is mainly determined by iron and aluminum oxyhydroxides and occurs mainly in reduced crystalline forms and with positive charges. This adsorption takes place at Lewis acid sites, where -OH and OH2+ groups, mono- or triple-symmetric to the metal (Fe and Al), are exchanged by phosphates (Barrow, 1983). Thus, the balance between adsorption and desorption is mainly related to soil pH (Gustafsson, 2012).

Depending on the pH, the absorption of P reaches its highest value in the pH range between 5.0 and 7.0, this was presumably related to the presence of soluble forms of phosphorus, such as H2PO4− or HPO42−. With a positive pH-dependent surface charge, at higher pH values, phosphorus can precipitate with calcium, forming amorphous calcium phosphate, octalcium phosphate, and apatite (hydroxyapatite or fluorapatite). This is again pH dependent, increasing with increasing pH (Hesterberg, 2010). The release of phosphorous into agricultural soils is an important threat to water quality (Kleinman, 2017). Phosphorus losses can be due to runoff, leaching, and erosion in soluble (<0.45 mM) and particle (>0.45 mM) forms. Phosphorus particles are usually the major nutrient transferred from crop soils to water, and account for 80% of all carriers (Edwards, 1998; Heathwaite, 2005).

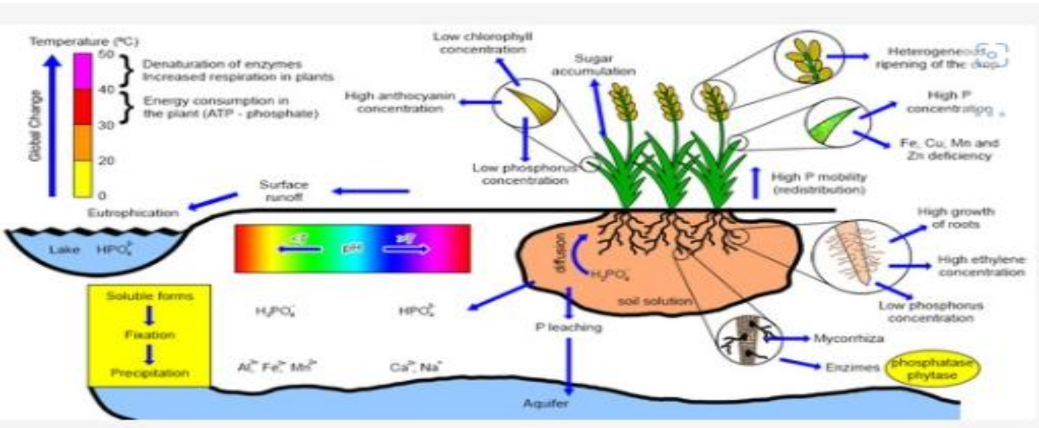

Figure 3. Phosphorus dynamics in the Soil–Plant–Environment relationship in cropping systems (Lizcano -Toledo *et al*., 2021).

Various studies confirmed, as in (Fig. 3), that the risks of surface water pollution are very large, resulting from processes such as runoff during periods of high rainfall, linked to the high solubility of these materials (Kumaragamage 2011; shigaki, 2006; Hart, 2004). The authors investigates (Liu cui; 2013) showed that the loss of phosphorus due to runoff was similar for different soluble mineral fertilizers such as MAP, DAP and KH2PO4.

CONCLUSION

Phosphorus interactions, readiness, absorption and movement within the plant are controlled by a trio (soil / roots / plant). The distribution and dynamics of phosphorus in the soil vary according to the spatial and temporal factor, physical and chemical properties of the soil, availability of seasonal moisture, biological factors, distribution of root crops and their activity. The application requires correct knowledge of P in crop systems appropriate and good knowledge of the complex interactions between soil microorganisms and plants and their interrelationships with water bodies and the atmosphere, so the roots and their morphological nature play an important role in attracting the absorption and exploitation of the availability of phosphorus. And there may be possibilities to match the adaptations of root morphology and physiology to the environments that determine the effective exploitation of phosphorus by the plant with the heterogeneous presence and distribution of phosphorus in the soil, which leads to an increase in the spatial availability and bioavailability of the soil, in the past twenty years good progress has been made in understanding Soil, roots and plant processes associated with conversion of phosphorus in the soil, phosphorus availability and uptake, and plant reactions to phosphorus deficiency and scarcity. However, many aspects of overall P dynamics in the (soil-root-plant) series , So far, it is not fully and completely understood, and more research should be done on these topics, to provide a scientific and strategic knowledge structure for integrated management, which includes the possibility of changing the availability of phosphorus and its movement in the soil and in the plant.

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