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# Metabolism and Transport of P Nutrient in the Rhizosphere Zone in Acidic Soils

*Metabolisme dan Transfortasi Hara P pada Zona Rizosfir di Lahan Masam*

Niluh Putu Sri Ratmini[1*)]

[1]South Sumatra Assessment Institute for Agricultural Technology, Palembang 30153, South Sumatra, Indonesia
[*)]Corresponding author: nps_ratmini@yahoo.com

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## ABSTRAK

Lahan-lahan masam dicirikan dengan pH tanah rendah, serta kelarutan besi dan aluminium tinggi, sehingga mempengaruhi ketersediaan P menjadi rendah. Konsentrasi P pada larutan tanah disekitar rizosfir akan dipengaruhi kehadiran dan metabolisme akar tanaman. Tanaman mendapatkan P dalam bentuk anion fosfat inorganik (Pi) dari larutan tanah. Eksudat akan mempengaruhi aktivitas mikroorganisme di rizosfir dan rizoplan. Tulisan ini bertujuan untuk mengulas faktor-faktor yang mempengaruhi metabolism P di daerah rizosfir. Beberapa faktor yang mempengaruhi metabolisme P di daerah rizofir adalah pH, eksudat akar, mikroorganisme, temperatur, dan kelembaban. Transformasi hara di wilayah rizosfir sangat sempit. Beberapa hal yang mempengaruhi transformasi P antara lain temperatur, rezim kelembaban, Oksigen, pH dan ketersediaan ion, sinar matahari, dan $CO_2$. Pada tanah yang kekurangan P, akar tanaman mengalami adaptasi melalui perubahan morfologi akar. Ketersedian P pada tanah masam dapat ditingkatkan dengan integrasi tanaman dengan bakteri atau jamur pelarut fosfat. Pemahaman akan metabolisme P di daerah rizosfir diharapakan dapat untuk menentukan upaya pengelolaan P yang lebih efisien.

Kata kunci: fosfor, lahan masam, metabolisme, rizosfir

## ABSTRACT

Acidic soils are characterized by low soil pH and high solubility of iron and aluminum affecting the availability of P to be low. The P concentration in the soil solution around the rhizosphere will be influenced by the presence and metabolism of plant roots. Plants get P in the form of inorganic phosphate anion (Pi) from soil solution. Exudate will affect the activity of microorganisms in rhizosphere and rhizoplan. This paper aimed to review the factors that affect P metabolism in the rhizosphere region. Some of the factors that influence the P metabolism in the rhizophir region are pH, root exudates, microorganisms, temperature, and humidity. Nutrient transformation in the rhizosphere was very narrow. Several things affecting the P transformation include temperature, humidity regime, oxygen, pH and ion availability, sunlight, and $CO_2$. In the soil deficient in P, the plant roots undergo adaptation through changes in root morphology. The P availability in acid soils can be increased by the integration of plants with phosphate solubilizing bacteria or fungi.

It is hoped that an understanding of P metabolism in the rhizosphere can determine a more efficient P management effort.

Keywords: acid soil, metabolism, phosphor, rhizosphere

## INTRODUCTION

Acidic soils are characterized by low pH and high solubility of iron and aluminum. The high solubility of iron and aluminum results in low P availability, this is because the P is bound by iron and aluminum so it is not available to plants. Generally, the form of iron found in acidic soils is iron oxide, which can bind to anions, cation and molecules without a charge (Latta et al., 2012). The iron adsorption against the cations through proton exchange while anion adsorption is through the ligand exchange mechanism (Dave & Chopda, 2014). The reactivity of iron oxide adsorption to ions in the soil is determined by the size of the positive and negative surface charge (Claudio et al., 2017).

Rhizosphere is a subset of soil that is influenced by the presence and metabolism of plant roots. This condition greatly affects the concentration of P in the soil solution around the rhizosphere, which is the most complex area and changes that occur are biological changes, the area is small/narrow ranging from 2–3% of the total soil volume (Mendes et al., 2013). The changes that occur in the rhizosphere are influenced by soil properties, either chemical, physic or biological. Various microorganisms live in the rhizosphere such as fungi, bacteria, alga actinomycetes, and nematodes.

The activity of microorganisms in the rhizosphere and rhizoplan is different from the surrounding soil, this condition depends on the root exudate. Haichar et al. (2014) state that microorganisms together with plant roots interact and stimulate each other influenced by the root exudates, meanwhile the growth and activity of microorganisms in the rhizosphere, rhizoplane, and their surroundings are affected by root exudates (Brahmaprakash et al., 2017). Plant roots release several compounds into the rhizosphere of the soil and usually in the form of organic compounds such as sugars and polysaccharides, amino acids, organic acids, fatty acids, sterols, enzymes, flavonones and nucleotides (Marinari et al., 2014), which are the results is the released about 5−21% from plat root of their photosynthetically fixed carbon (Badri et al., 2013; Chaparro et al., 2013).

The implications of science about P metabolism in soil in general have been developing for a long time, such as efforts to harvest P with various main innovations on acid soils either through the provision of soil improvement or by utilizing phosphate solubilizin microorganisms. This paper aimed to examine the factors that affect the availability of P and efforts to increase its availability in the rhizosphere for plants.

### Factors Affecting P Metabolism in the Rizosphere Region

The processes that occur at the rhizosphere level, including the transformation of nutrients, are generally narrow and limited compared to the soil a whole, but are much more important both qualitatively and quantitatively.

Plants get P in the form of inorganic phosphate (Pi) in the form of anion from soil solution. The P is probably one of the most readily available nutrients to plants in the rhizosphere because it can be treated by inorganic colloids, precipitation as insoluble phosphate in acidic and alkaline pH, and complexed by organic matter. In this context, P deficiency is considered as one of the major limitations for productive crops, particularly in the tropical areas. The ability of plants to obtain P significantly increased in Pi deficiency conditions (Aziz et al., 2014). The factors that influence the P transformation include temperature, humidity regime, oxygen, pH and ion availability, sunlight, and CO2.

**Temperature**

Nutrient metabolism and transformation in the rhizosphere are not directly affected by temperature because the temperature plays a role in plant and microbial growth. The results of the photosynthesis and respiration processes which are one of the activities influenced by the temperature will greatly affect the metabolism and transformation of nutrients in the rhizosphere. In relation to nutrient metabolism, the temperature will affect root exudation both qualitatively and quantitatively.

Dotaniya and Meena (2015) suggest an increase in temperature results in the rate of decomposition and an increased number of mibrobes in the rhizosphere. The temperature that changes suddenly will affect the water content in the root area, there by inhibiting the rate of ion transport.

**Moisture Regime**

Water can affect directly or indirectly. The indirect effect is the effect on microbial and plant activity. If groundwater is deficit, cell expansion will slow down. In the plants having the ability to adapt to such conditions, the roots and shoots will maintain water flow from the root rhizosphere without the simultaneous loss of turgor, while in sensitive plants, the roots will become permanently damaged. The direct effect is on the solution in the soil, which is one of the media for nutrient transportation to plant roots.

**Oxygen**

The nutrient metabolism in the rhizosphere is closely related to the presence of microbes. Lack of oxygen in the soil results in competition for oxygen utilization by plants and microbes. Rieder et al. (2014), oxygen consumption under conditions of abudance of microbes in the soil as well as in conditions of mainteained deficiencies can decrease by more than twofold. Lack of oxygen around the roots causes the root cells to experience decreased respiration. The lack of oxygen will also inhibit the absorption and transport of ions to the top of the plant.

**pH and Ion Availability**

pH and ion availability greatly influence changes in the rhizosphere and nutrient ion availability in the soil. Water and low nutrient availability are limiting factors for plant growth (Gomiero, 2016). The movement of nutrients in the soil to the plant roots can be through mass flow or by diffusion. Mass flow is the result of bulk convective motion from the soil solution to the roots, whereas diffusion occurs in response to differences in concentration for a particular ion, which is caused by ion absorption by the roots and depletion of the surrounding soil.

The mass flow process is much faster than absorption by the root surface, this will cause ions to accumulate in the rhizosphere. In agricultural land, the changes in rhizosphere pH often occur which are generally caused by nitrogen which can increase the pH value in the rhizosphere. The changes in pH greatly affect the diversity and richness of the soil microbial community (Kichigina et al., 2017), so this will affect activity in the rhizosphere, especially on root growth due to the toxicity of ions such as $Al^{3+}$, $Mn^{2+}$, and $H^{+}$ at acidic pH.

With the increasing soil pH, the solubility of Fe and Al phosphate increases but the solubility of Ca phosphate decreases (Ruttenberg, 2014). P can be adsorbed on the surface of clay minerals and Fe/Al oxide by forming various complexes such as nonprotonated and protonated bidentate surface complexes (Parvage et al., 2013; Chintala et al., 2014: Xu et al., 2014), whereas innersphere protonated bidentate complexes generally occur in acidic soil conditions. Lack of elements of N, P, K will increase root exudate. In general, the pH in the rhizosphere of different maize genotypes is higher than that in non-rhizosphere soils, regardless of P level (Canarini et al., 2019).

**Sunlight**

Sunlight is closely related to the photosynthetic process, so that roots have an indirect effect on nutrient metabolism in the rhizosphere, especially N and C, because most of the assimilated carbon in these plants comes from photosynthesis, following that changes in light intensity can change the exudation of carbon roots.

**$CO_2$**

The concentration of $CO_2$ affects the photosynthetic process and root exudates. Dotaniya and Meena (2015) point out that changes in microbial function in response to high carbon dioxide without any change in the total viable number of bacteria can affect the nutrient cycle due to changes in rhizodeposition at high $CO_2$. Giving C in high $CO_2$ conditions for rice growth (*Oryza sativa*) will inhibit the mineralization of organic matter at 0−5 cm of the surface layer of rice fields.

**P Metabolism in the Rhizosphere Area**

The rhizosphere is an area near the roots which is a zone of interaction between plants, soil and microorganisms. In the rhizosphere zone, microorganisms interact with root exudates which consist of a complex mixture of organic acid anions, phytosiderophytes, sugars, vitamins, amino acids, purines, nucleosides, inorganic ions, gas molecules, and enzymes (Dotaniya & Meena, 2015). Microorganisms play an important role in the dynamics of P, especially microorganism that are to dissolve P in insoluble.

The plant roots can change the environment of the rhizosphere through various physiological activities, in particulary through the exudation of organic compounds. Chemical and biological processes in the rhizosphere will affect the mobilization and acquisition of soil nutrients, microbial dynamics, and control the efficiency of plant nutrient use (Huang et al., 2014; Sulaiman et al., 2015). This condition is very important, especially in conditions of P deficiency because acidity will increase in the rhizosphere due to the release of $H^+$ and will affect the shape of the roots. The low P mobility in soil can affect its availability for plants, even though the total P amount in the soil is quite high. States that the absorption of Ca in P-deficient soils will affect root induction and also root alkalization. To meet the adequacy of P for plants, the P in the soil solution must always be supplied by the soil to the rhizosphere so that the dynamics of P in the rhizosphere are largely determined by the growth and function of plant roots, soil physical and chemical properties. Plants that have a high degree of adaptation to P deficiency conditions will change their root structure. The root activity can also increase the concentration of inorganic P in the soil through root exudates (Sulaiman et al., 2015). To anticipate P deficiency, in the future it is necessary to develop new plants that can adapt and have strong root clusters and absorption efficiency of P. A symbiosis with microorganisms is one effort that can be made to increase the availability of P by expanding the absorption land through the formation of hyphae in fungi. Lack of P in the soil causes plants to change the root architecture, including morphology, topology, and distribution patterns. Usually, the plants that grow in conditions of P deficiency will trigger an increase in the length and density of root hair and lateral roots as well as reduce the primary root growth (Sulaiman et al., 2015). The structural and functional characteristics of the roots significantly influence the process and contribute to the rhizosphere in terms of the capacity of the roots to absorb nutrients. The root characteristics that support exploration and uptake of the roots also interact extensively with soil microorganisms which have a direct impact on nutrient availability and uptake, especially P and N, indirectly affecting the plant growth (Mohanram & Kumar, 2019). Root structure plays an important role in maximizing P in the root system (Li et al., 2016). The short and little root structure result in the ability of P movement is also very little considering that the P is one element that is very immobile. The availability of P for plants is usually through two events, namely mass flow and diffusion.

The movement through mass flow is very small of the P demand by plants, while the movement through diffusion is even much smaller, which is about half of the total mass flow movement, on the other hand, nutrient uptake by plant roots can be increased through symbiosis with microorganisms such as fungi and bacteria. The process of nutrient uptake by roots is associated with microorganism through various mechanisms such as increased root growth, changes in nutrient balance, and induction of metabolic processes (Canarini et al., 2019).

If the soil contains sufficient nutrients, especially P and N, the growth of plant roots will be spurred. The root development in P-rich soil layers is associated with decreased root response. The process of chemical and biological changes in the rhizosphere play a role in increasing the bioavailability of P in the soil. This process will release protons, resulting in a more acidic pH around the rhizosphere. This will result in substance changes to the limited use of P (Damon et al., 2014).

The changes in pH in the rhizosphere are mainly influenced by the ratio of cation/anion uptake and nitrogen assimilation. An ammonium supply for roots can cause acidification of the rhizosphere because plants that absorb N in the form of ammonium will release $H^+$ ions so that the rhizosphere area will become acidic, while the supply of nitrate causes alkalization (changes in acidity levels towards alkaline) because plants that absorb N in the form of nitrate will releasing the $OH^-/HCO^{-3}$ ion feed. The changes in rhizosphere pH are also related to soil buffering capacity, microbial activity, and plant genotype (Sulaiman et al., 2017).

Soils that have high buffering power cause the mobility of P ions from the soil matrix to the soil solution to be high. The amount of ion absorbed by the roots can immediately be replaced by the soil solution by the root matrix.

On soil that has high buffering capacity, it will result in sufficient plant nutrients. Generally, the acid soils have low buffering capacity, this is because ions, especially P, will be firmly bound by the soil matrix so that efforts are needed to help reduce P bonds by the soil matrix, one of which is by utilizing the ability of phosphate solubilizing fungal bacteria. Besides being bound by the soil matrix, it is also bound by Al and Fe.

The ability of soil microorganisms to convert some forms of soluble phosphorus to accessible forms is an important factor for bacteria in supporting plant growth. The used of phosphate solubilizing bacteria as inoculants increases the uptake of P by plants, in this case the fungal hyphae will be an extension of the root system which increases soil volume (Figure 1) and also releases organic acids, mobilizing P insoluble P into the plant's available P. The role of phosphate solubilizing bacteria in availability in plants is their ability to change the form of p which is not available to be available for plants.

The mechanisms involved include dissolving the mineral complex directly and chelating $Ca^{2+}$, $Fe^{3+}$, and $Al^{3+}$. Phosphate solubilizing bacteria can dissolve inorganic P complexes by secreting low molecular weight organic acids such as gluconic, acetic, fumaric, and citric acid (Li et al., 2017 and Zeng et al., 2017). The activity of solvent P batteries is associated with the release of organic acids and a decrease in pH.

The understanding of the mechanism of P nutrients in the rhizosphere and its determinants will help manage and improve the efficiency of P use. The utilization of genotypes and P solvent microorganisms is an alternative that can be done to increase the efficiency of P management in acidic soils.

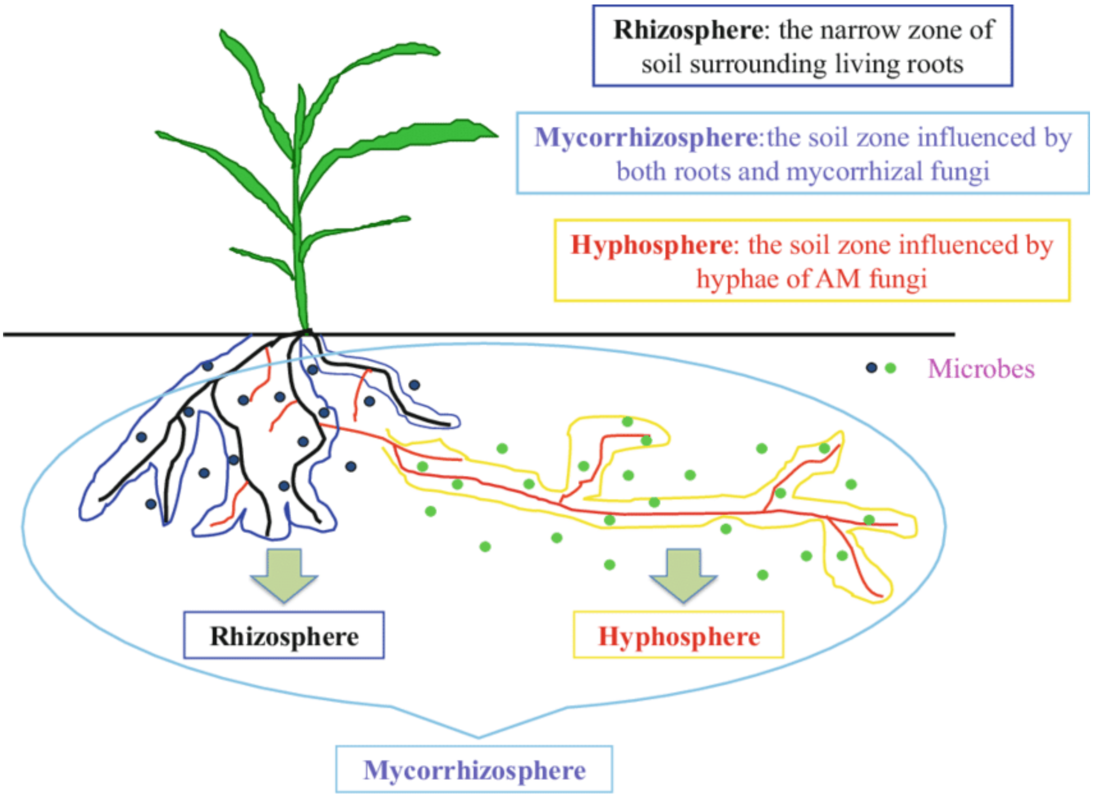


Figure 1. Conceptual diagram of rhizosphere, hyphosphere, and mycorrhizosphere (Wang & Feng, 2021)

## CONCLUSION

P deficiency is considered to be one of the major limitations to crop production resulting in nutrient transformation. The transformation is influenced by the temperature, humidity regime, oxygen, pH and ion availability, sunlight, and $CO_2$. The mechanism of P nutrients in the rhizosphere will determine the dynamics of P in plants. Plant roots play an important role in the absorption of P in the soil, besides that root exudate can affect the level of acidity and also the level of nutrient availability in the rhizosphere. In soil deficient in P, the plant roots undergo adaptation through changes in root morphology so as to increase the solubility and availability of P. The integration of plants with phosphate solubilizing bacteria or fungi can increase P availability in the rhizosphere. The fungal hyphae will serve to extend the reach of the roots for uptake of P in the soil. It is hoped that the understanding of P metabolism in the rhizosphere area can determine a more efficient P management effort.

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