Alternative Technology of Phosphorus Supplying for Plant: Mycorrhiza Vesicular-Arbuscular (MVA) and Phosphate Solubilizing Bacteria (PSB)

Fany Juliarti Panjaitan[1], Onesimus Ke Lele[2], Rizki Adiputra Taopan[3]
{fanyjait@gmail.com[1], oneskelele@gmail.com[2], rizkimicro@gmail.com[3] }

[1,3]Universitas Katolik Indonesia Santu Paulus Ruteng, Indonesia
[2]Universitas Pertanahan Republik Indonesia, Indonesia

Abstract. The degradation of soil fertility and the issue of healthy agriculture have attracted the attention of many parties today. The latest environmentally friendly technology continues to be developed but its prospects and effectiveness have not been disseminated massively. This study briefly summarizes some of the benefits and roles of soil fertility quality as an important biological agent in agriculture. This review is intended to provide an overview of the role and benefits of MVA and PSB for plant productivity. The role of MVA and PSB for soil and plants independently has been widely reported, especially as biological agents providing phosphorus nutrients. The synergistic role between the two biological agents is an interesting study considering the many benefits of its role for plants. PSB can provide phosphorus and depends on the carbon released by MVA obtained from plant photosynthesis. MVA extraradical hyphae were also used by PSB to reach further areas to reach insoluble P. PSB has the ability to synthesize important hormones that play a role in the development of MVA. Nevertheless, there is a need for research related to the sensitivity of the synergistic effect of the two biological agents on improving the quality of soil fertility quality.

Keywords: mycorrhizae vesicular arbuscular, phosphate solubilizing bacteria, phosphorus

1 Introduction

Soil is one of the important components of the carrying capacity of the land for plant growth. Soil specifically in agriculture functions as a place to grow and develop roots and enforce plant growth. In addition, soil also plays an important role in supplying the needs of water and air for plants. Therefore, the soil is considered as a storehouse of all the resources needed by plants. The ability of the soil to provide these various resources will determine the level of fertility of the land. Fertile land is characterized by a state of physical, chemical, and biological properties that are ideal for plant growth. One of the important chemical properties of soil that plays a role in plant growth is phosphorus (P).

Phosphorus is one of the essential macronutrients for plants, so its presence is very important in the soil. Phosphorus plays an important role in the process of photosynthesis and root development, especially in the period of flower and fruit development. The limitation of phosphorus in this phase can cause losses in crop production. Other studies have also proven that a phosphorus deficit at the time the plants enter the flowering period can reduce crop

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yields [1]. Phosphorus greatly determines fruit quality because of its role in the fertilization process. P deficiency reduces orthophosphate concentrations in the chloroplast stroma to levels that inhibit ATP synthase activity [2].

Currently, there have been many studies on phosphorus, especially the problem of its limitations in the soil. The main factor in the occurrence of phosphorus limitations is the high concentration of aluminum and iron elements in a field [3]. Phosphorus in the soil is largely determined by the solubility of these two elements when the soil is in low pH conditions. Likewise, if the soil is in a high pH condition, the concentration of magnesium and calcium elements tends to be high. This situation causes the phosphorus element to become bound so that it will be in a state not available to plants. Answering these obstacles, in the last decade, there have been many technological innovations to supply phosphorus nutrients for plants, one of which is the use of biotechnology in the form of potential microorganisms found in the soil. Important soil microbes in question include Mychorriza Vesicular-Arbuscular (MVA) and Phosphate Solubilizing Bacteria (PSB).

Soil microorganisms play an important role in supplying insoluble or unavailable nutrients to plants through functional soil processes which are the main drivers in the biogeochemical cycle of nutrients, especially elemental phosphorus [4]. In the plant rhizosphere, there are very wide and varied soil microorganisms, both beneficial and not. Important microbes that have attracted the attention of researchers are Mychorriza Vesicular-Arbuscular (MVA) and Phosphate Solubilizing Bacteria (PSB).

Mychorriza Vesicular-Arbuscular (MVA) or endomycorrhizal has an effect on both abiotic and biotic stress conditions of plants. The symbiotic association of MVA mutualism with plants is able to increase plant growth, nutrient uptake, drought resistance, production of growth hormones and growth regulators, and protection from root pathogens and toxic elements [5]. The results of research by [6] found that the best dose of mycorrhizae for mung bean plants was 15 g/plant. This dose was able to increase production and increase the P uptake of mung bean plants by 2.74 mg/plant. Similarly, it was reported by [7] that the application of MVA to organic rice plants affected vegetative growth (height and number of vegetative tillers), and production yields (dry weight of pods, dry grain per clump, and per plot).

Endomycorrhizal fungi are known not only to be able to increase plant growth and yield, but through their associations, they can also improve soil quality and overcome pathogen attacks on plants. In several kinds of literature, it has been reported that the successful use of endomycorrhizal in overcoming the problem of land fertility degradation, and rehabilitation of critical lands [8]. Likewise, the benefits of endomycorrhizal in protecting plants from pathogen attacks have been reported [9].

One of the microorganisms having been widely reported to be able to increase the availability of phosphate in the soil other than MVA is Phosphate Solubilizing Bacteria (PSB). These microorganisms are able to naturally dissolve phosphorus that is not available into phosphorus that is available to plants. The existence of PSB is quite diverse in various places which are influenced by environmental conditions. The dissolution mechanism carried out by PSB is a form of chemical and biological dissolution. The findings in the last decade have shown that there is a mechanism of P chelation by siderophores (ferric-specific chelates) produced by these microorganisms. PSB can also produce organic acids that not only function as a chelating agent, but also as a supplier of hydrogen ions for dissolving hydroxylapatite. Besides functioning to increase the absorption of phosphorus nutrients, PSB is also known to be able to stimulate the production of plant phytohormones [10]. PSB can be isolated from phosphate-containing soils, especially in areas of the plant rhizosphere. Seeing the many benefits of MVA and PSB, the author tries to briefly review several related articles to see how much influence and benefits they have for soil and plants. The results of this review article are expected to strengthen the study of the benefits of MVA and PSB in agriculture, especially for plant cultivation entrepreneurs.

2 Method and Materials

The preparation of scientific articles is carried out using the literature study method, where the author determines the title of the article first and then looks for several references in the form of scientific articles, books, or other references that are relevant to the title of the article, namely alternative technology of phosporus (P) supplying for plant: Mycorrhiza Vesicular-Arbuscular (MVA) and Phosphate Solubilizing Bacteria (PSB). The author reviews these references and rearranges them into a new article using his own ideas or opinions.

3 Results and Discussion

3.1 The Response of Plants to Phosphorus Deficiency

The plant adaptation form to suboptimal environmental conditions is indicated by the emergence of various responses in the form of certain changes both biochemically, as well as in morphology and physiology [11]. P nutrient deficiency in soil is one of the unfavorable environmental conditions for plants. Plants will try to obtain the phosphorus element to maintain their existence by allocating preferential carbohydrates to the root area, roots expand the uptake area, root growth will be more massive, change root structure, and even reduce plant growth [12].

Inorganic phosphorus in soil is generally very immobile because it tends to be in the bound state. This causes P uptake in the rhizosphere area to be [13]. As a form of plant response to P deficiency, plants will adjust the composition of carbohydrates needed between source and sink, also in the process of photosynthesis, sugar metabolism, cations in carbon metabolism and alternative respiration pathways, and/or membrane biosynthesis. In addition, plant roots also form a mutualism symbiosis with MVA fungi in the soil to meet plant phosphorus needs.

3.2 Mechanism of Phosphorus Uptake and Mobilization by MVA

Mycorrhizae are known as soil fungi and will develop if they are in symbiosis with the host. MVA is highly dependent on the host because it is the only carbon source for sporulation. The symbiosis between the host and MVA is driven by strigolactone compounds that attract MVA to colonize roots [14]. This mutualistic symbiosis results in the transfer of carbon from plants as much as 4-20% of the carbon produced by plant photosynthesis. The benefit for plants is that MVA supplies P to plants [15]. MVA can also help plants obtain micro-nutrients such as Cu, K, Mg, N, and Zn, especially under conditions of deficiency or in less soluble forms in the soil. The nutrient exchange process occurred because MVA managed to penetrate the cell walls of the root cortex and form arbuscules resembling haustoria. These arbuscules facilitate the exchange of metabolites between host cells and fungi [16].

MVA was able to expand the root uptake zone from 10 to 100%. The extensive extraradical hyphae, mycorrhizal roots are able to reach a larger volume of soil than non-mycorrhizal ones, thereby increasing nutrient uptake and translocation. In addition to expanding the absorption area, MVA hyphae and spores are also able to produce and release glycoproteins such as glomalin. Glomalin in the soil helps the absorption of nutrients such as Fe and P which are difficult to dissolve [16].

P uptake by mycorrhizal plant roots occurs in two ways. The first P uptake pathway occurs where P is absorbed directly from the root epidermis. The second pathway, P must enter root cortical cells (intraradical mycelium). Such translocation is known as a rapid form of translocation [15]. The role of hyphae is known to be the most important in MVA symbiosis with plants because they directly play a role in increasing root surface area [15]. MVA is also reported to be able to store P in the form of polyphosphate, so the fungus can maintain relatively low internal Pi levels. Furthermore, MVA effectively transfers P from soil to hyphae to plants via appressoria and from extraradical mycelium to intraradical mycelium [17].

3.3 The role of MVA in improving soil structure and aggregation

MVA besides playing a role in providing nutrients and water are also known through their external hyphae network which is able to repair and stabilize soil aggregates. MVA can secrete polysaccharide compounds, and other organic acids that are able to bind primary soil grains into micro aggregates and can further stabilize macro aggregates. Glycoprotein compounds in the form of glomalin produced by MVA are also known to be able to stabilize soil aggregates. The glomalin compound is produced from the secretion of MVA external hyphae. In addition, MVA also produces various kinds of enzymes and polysaccharide compounds that indirectly help stabilize soil aggregates. Therefore, tillage is one of the important factors that need to be considered in maintaining the existence of MVA.

The role of MVA in strengthening soil structure is very important, especially in soils with high clay and sand content. Improvement of soil aggregates on cultivated land provides production yields and significantly improves soil aggregate quality [18]. Soil conditions that are porous and have good permeability will be able to hold enough water for plant needs. In addition, stable soil aggregates will improve the infiltration rate and increase aeration in the soil. So it can be said that mycorrhizal fungi in addition to playing a role in providing nutrients and water for plants, also directly contribute to conservation and improve soil quality.

3.4 Distribution and diversity of Phosphate Solubilizing Bacteria (PSB)

Phosphate-solubilizing microorganisms naturally exist in the soil at a depth of up to 25 cm with a total population ranging from 0.1-0.5% of the total population of all microorganisms. Phosphate-solubilizing microorganisms of the type of bacteria were much more abundant compared to the group of fungi/mushrooms. The proliferation of these microorganisms is influenced by the presence of soil organic matter. In addition, the type and location of its position against the host also affect the existence of a microorganism. Physiologically, bacteria and/or fungi that are close to the root area of the host plant tend to be more active than those far from the root area [10].

Another factor that causes the diversity of phosphate-solubilizing microorganisms is their own biological nature. Some phosphate-solubilizing microorganisms can live in acidic environmental conditions, but some are able to live in alkaline environmental conditions. Some are hydrophilic, mesophilic, and thermophilic. Likewise, with the nature of its tolerance to oxygen, some can live aerobically and some are anaerobic. Each microorganism has specific properties and different environmental conditions. The difference in these properties then affects its effectiveness in dissolving phosphate [19].

The development of phosphate-solubilizing microorganisms is strongly influenced by the level of soil acidity. In acidic soil conditions around 3-5,5, the activity of microorganisms is dominated by the fungi group. Conversely, in soil conditions with a neutral pH and higher, bacterial growth also increases. Bacterial populations, especially PSB, tend to be lower in dry climates than in temperate climates. The effectiveness of PSB in dissolving phosphate is also influenced by the amount and state of phosphate, as well as the composition of organic matter in the soil [2]. Utilization of PSB as an alternative solution to the problem of phosphorus availability also encountered problems from the aspect of soil conditions. Each type of soil has a different phosphate content so it requires a specific phosphate solvent inoculant according to the existing soil conditions.

3.5 Mechanism of phosphorus uptake and mobilization by PSB

Phosphate in the soil exists in two forms, namely organic and inorganic. Organic phosphate is sourced from organic materials such as crop residues and other litter, as well as from organisms in the soil. While inorganic phosphate comes from minerals or parent rock that contains phosphate. The process of dissolving phosphate compounds in the soil carried out by phosphate solubilizing microorganisms takes place chemically and biologically for both organic and inorganic forms of phosphate.

The process of mineralization and solubilization of phosphorus (P) in the soil is very important because it determines its availability to plants [10]. PSB is known to play an important role in the P cycle. Elemental P is known to have three process parts and one cycle namely dissolution-precipitation, mineralization-immobilization, and absorption-desorption. The role of PSB in this regard is to convert insoluble P into soluble P that is available to plants [10]. PSB strains are found in various genera such as *Achromobacter, Actinomadura, Aerobactor, Agrobacterium, Alcaligenes, Arthrobacter, Azotobacter, Azospirillum, Bacillus, Chryseobacterium, Delftia, Enterobacter, Gordonia, Klebsiella, Pantoea, Phyllobacterium, Pseudomonas, Rhomondococcus, Serabucoccus, Rhodococcus, Serabucoccus, Thiobacillus, Xanthobacter, Xanthomonas.* All of these genera are known to be able to dissolve insoluble P compounds into soluble compounds such as dicalcium phosphate hydrosilation, tricalcium phosphate, and rock phosphate and are able to mineralize organic phosphate compounds into forms that can be absorbed by plants such as $H_2PO_4^-$, and HPO_4^{2-} [2].

3.6 The synergistic impact of MVA and PSB on P-availability

In mycorrhizal associations, plants and fungi are reported to be able to interact both in the soil around the roots (rhizosphere) and in the soil around fungal hyphae (mycorrhizosphere) [18]. MVA can interact with other microorganisms in the mycorrhizosphere whose synergistic effect increases plant growth as well as populations of both [18]. In natural ecosystems, the presence of different bacterial taxa is able to colonize the surface of extraradical hyphae and MVA spores that form biofilm-like structures [20]. It is suspected that there is a strong collaboration between MVA and bacteria such as PSB [82]. The synergistic mechanism that is PSB is able to supply phosphorus and depends on the carbon released by MVA.

Many previous studies have shown that MVA and PSB can increase the P acquisition of MVA host plants through their interactions [2]. The synergy scheme developed by MVA and PSB in influencing the utilization of host plants and organic and inorganic phosphorus. It is suspected that PSB uses hyphae to be able to access more soil pore spaces to reach insoluble P. PSB can also obtain root exudate through MVA hyphae which allows it to travel to more distant parts of the plant body. VMAs containing extraradical hyphae can also supply photosynthate for PSB. MVA exudates are also known to change the rhizosphere conditions to be more effective for PSB activity. On the other hand, PSB can increase the availability of nitrogen and phosphorus for MVA and plants through the decomposition of organic matter. PSB is known to produce positive ACC-deaminase hormone. By synthesizing ACC deaminase, it can lower the stress level of ethylene, which is involved in stimulating the growth of MVA. The ability of PSB to hydrolyze organic phosphorus with the secretion of phosphatase and phytase enzymes can increase hyphae growth and provide phosphorus minerals for MVA. In addition to synthesizing ACC deaminase, PSB can also increase positive IAA levels, resulting in many lateral roots which can then become sites of penetration of MVA hyphae. In the presence of positive IAA, PSB can loosen plant cell walls to promote root exudation to provide additional nutrients that support microbial growth. Previous studies have shown that PSB modifies hormonal signals in plants to influence root structure, stimulate shoot and root growth, and increase the uptake of essential nutrients [10].

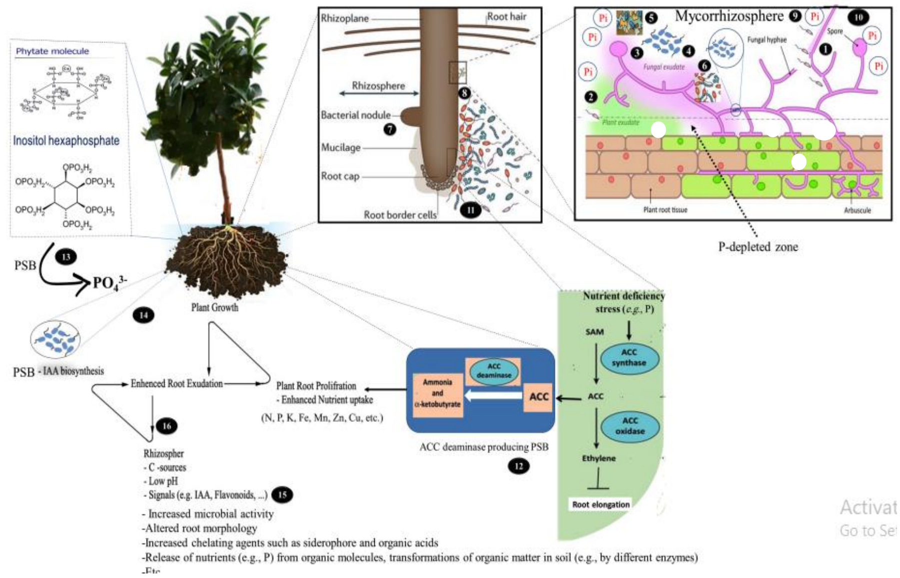

Fig.1. The mechanism of the role of Phosphate Solubilizing Bacteria (PSB) in increasing the ability of plants to obtain phosphorus by changing the absorption balance which can increase net orthophosphate ion transfer into the soil solution *(Source : [21])*.

4 Conclusion

Phosphorus is an essential plant nutrient that cannot be replaced by its role and benefits. As a result, the fulfillment of phosphorus needs has been carried out in various ways, especially the use of synthetic materials which has attracted the attention of environmentalists. The impact of environmental damage that has caused a lot of harm to humans due to the uncontrolled use of synthetic fertilizers has encouraged researchers and scientists from various circles to find approaches to plant cultivation that are sustainable. This can be achieved through various technologies, including the use of MVA and PSB.

Based on the results of various studies on the ability of endomycorrhizal and PSB in improving soil quality and crop production, it can be concluded that these microorganisms can be considered as potential biological agents of marginal land, especially dry land. The presence of endomycorrhizal and PSB is the answer to the classic constraints of crop cultivation on dry land, namely limited water, and especially phosphorus deficiency which is often experienced by almost any agricultural land. As a biological agent, this fungus can also be the best alternative in implementing organic plant cultivation, whose products have recently been favored by consumers. The use of MVA and PSB as biofertilizers needs full attention from various elements, including academics, researchers, fertilizer companies, and related government. This becomes very important considering the increasingly apprehensive soil conditions due to the uncontrolled use of synthetic materials over the last two decades. In addition, it is also a form of support for various government policies in dealing with global warming issues, national food security, and ensuring a healthy and sustainable farming system.

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