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Bio-priming with *Arbuscular mycorrhizae* for Addressing Soil Fertility with Special Reference to Phosphorus

Suryakant Dhawal, Deep Ranjan Sarkar, Ranjeet Singh Yadav, Manoj Parihar and Amitava Rakshit

Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Science, BHU, Varanasi, India

Corresponding author: amitavar@bhu.ac.in

ABSTRACT

Phosphorus (P) is an indispensable element in agriculture whose contribution is enormous in food production. The sources and availability of P has always been a great concern for humans because of the limited fossil reserves from where the mineral P fertilisers are processed, and alongside its low accessibility for plant uptake suggest the requirement of appropriate techniques which can enhance P use efficiency. Microorganisms being the integral component of P cycle can solve the P-related problems. Beneficial microbes like arbuscular mycorrhizae if used as seed treatment can yield strong and healthy plants and induce significant effects in rhizosphere soils. Thus, the concept of bio-priming are very important for carrying out the practices of sustainable agriculture.

Keywords: Phosphorus, *Arbuscular mycorrhizal* fungi, symbiosis, phosphorus acquisition

Phosphorus (P) is a major growth-limiting macronutrient often associated with its low availability in most agricultural soils. Its unique chemistry makes it a least accessible nutrient for plant uptake. P when applied to soils reacts with Fe^{3+} and Al^{3+} in acidic soils and Ca^{2+} and Mg^{2+} in calcareous soils through precipitation, causing immobilisation of P (Sanyal and DeDatta, 1991). Excessive use of phosphatic fertilisers leads to transportation of P from agricultural fields causing eutrophication in aquatic systems (Sims *et al.*, 1998). In soil inorganic form of P is the predominant form, although organic forms of P may also contributes ubstantially (20–80%) to the total P content (Sanyal *et al.*, 2015).

It has been reported that more than 40% of the world soils are deficient in P (Balemi and Negisho, 2012) and efficiency of P fertilizer throughout the world is around 10-25 % (Isherword, 1998). Depletion of global P reserves is occurring very fast but the fact that P is essential for the intensive agricultural production system.

Importance of phosphorus in plant nutrition

P is a non-substitutable plant nutrient required for growth and development of plants and without it no plant can complete its life cycle. The master key element (P) is known for plethora of functions in the plant growth and metabolism (Mahdi *et al.*, 2011). It has a key role in all major metabolic processes and physiological activities of plants viz. cell division, photosynthesis, energy transfer, signal transduction, macromolecular biosynthesis, respiration, root development, stalk and stem strength, flower and seed formation, crop maturity and production and nitrogen fixation in legumes (Nisha *et al.*, 2014). P acts as energy currency in plants as it is involved in the supply, transfer and storage of energy for all biochemical processes inside the plant (Kaviyarasi *et al.*, 2011). It is an important constituent of nucleic acid, phytin and phospholipids. It not only helps plants to survive winter rigors but also induces resistance to various diseases (Sagervanshi *et al.*, 2012). Deficiency of P results in browning of leaves accompanied by small leaves, weak stem and slow development and consequently the yield of crops is hampered (Dhankhar *et al.*, 2013). Shortage of P supply in the future will raise the question of food security and thus P has unique position in the progress of agriculture.

Reservoir of P is depleted

The present mining rate indicates that global P stock (71 billion tonnes) will diminish in about 100 years or less (Herrera-Estrella and López-Arredondo, 2016). Phosphatic rocks being the only source of P fertilizers, P reserves has received a worldwide attention as unlike N, the atmosphere does not provide soluble P to plants. The high-quality sources of rock phosphate (RP) are finite and their continuous extraction has led the alarming situation. The world phosphate stocks are mostly distributed in marine phosphorite deposits and very few countries have high reserves i.e. it is a geographically restricted resource. India ranks 17 in world phosphate production. Exploitation of these resources would lead to P scarcity. India has very limited known resource of RP which is mostly low to medium grade in quality andis the largest importer of RP in the world (about 30% of global trade) (Subba Rao *et al.*, 2015). About 98% of Indian soils contain insufficient amount of available phosphorus and intensive cropping pattern during this green and white revolution has led to widespread deficiency of phosphorus (Sharma *et al.*, 2013). Agriculture sector alone results in the depletion of approximately 19Mt $a^{-1}$of P from RP for fertilizer production (Hefferand Prud'homme, 2008). A steady increase(approximately 6 MMT per year) from 139.3 MMT in 2000 to 207.5MMT in 2012 indicate that global mine production is likely to increase in future (Biswas Chowdhury *et al.*, 2016). For this non-renewable resource,recycling of P is very important which could postpone depletion costs and maintain a minimum consumption forever but at rising marginal costs (Seyhan *et al.*, 2012).

Combating problems related to P fertility

P is the least mobile element in soil due to its high fixation and slow diffusion nature. In Indian soils, the total P ranges from 44 to 3580 ppm (Tomar, 2000) but P content in an average soil is found to be 0.05% only. Anthropogenic influences suchas excessive mining, growing demand, increasing price, geopolitical constraints, excessive wastage and high discharge to water bodies provides a barrier to the sustainable management of the global P resource (Biswas Chowdhury *et al.*, 2016). Enhancing P use efficiency is a big concern all over the world which can be achieved through improving P acquisition and/or utilization (Wang et al., 2010). Alternative methods for exploitation of soil P resources to optimize P bio-availability through either the selection of efficient cultivars or microbial strains used in smart practices like bio-priming (Rakshit *et al.*, 2015; Kartikay *et al.*, 2015) are important and need to be focussed on. Management strategies must be undertaken from knowledge and technologies emerging in the modern era, which should be easy to adapt for farmers. Bio-priming is one of the seed enhancement techniques that integrate controlled seed hydration and inoculation of seeds with microbial agents. Priming is employed to improve the vigour and seedling establishment, thereupon plant efficiency in the fields (Entesari, 2013). Primed plants are better able to cope up under adverse environmental conditions.

Microbial mediated P management are considered to be holistic approach, being eco-friendly and cheapest way of soil P nutrition as they are the key factors in biogeochemical cycles. Various phosphate solubilising microorganisms (PSM) are known today as efficient P-solublisers viz. phosphate solublising bacteria (PSB), vesicular arbuscular mycorrhizae (VAM). P-efficicient cultivars may be the alternate strategy for enhancing the P use efficiency (PUE) of the plants (Shenoyand Kalagudi 2005) but this requires identification and deployment of plant traits that limit or enhance the uptake and utilization of P (Narang *et al.*, 2000). Organic amendments are a sustainable tool to improve soil organic C stock andsoil fertility in intensive agriculture (Scotti *et al.*, 2015). Band application especially of mono-and di-ammonium phosphate fertilizers enhance root proliferation due to both N and Peffect, consequently improving the P uptake capacity of plants (Balemi and Negisho, 2012).

However, integrated use of organic manures along with phosphatic fertilizers not only improves the efficiency of the P but also increase in the availability of P (Mahajan *et al.*, 1997).The use of beneficial microbes in agricultural practices started 60 years ago (Wu *et al.*, 2005) and selective utilization of the existing diversity of microbial species and functions provides many opportunities to improve the production (Shen, 1997). Bio-priming is a new technique of seed treatment exploiting beneficial microorganisms for yielding strong and healthy plants. The system integrates the biological and physiological aspects of enhancing growth, disease control and increase in yield (Karthika and Vanangamudi, 2013). Seed priming induces several biochemical changes in the seed (Khalil *et al.*, 2010), improves the physiological responses and tolerance capacity to various environmental stresses (Khan, 2008), could be one-way to increase the P availability and reduce the needfor fertilizer P in subsequent crop growth (Sekiy *et al.*, 2009).

Mycorrhizal association is important

Mycorrhizal fungi are widespread in agricultural systems and arbuscular mycorrhizal symbiosis with land plants is the oldest (400 million years) mycorrhizal association. Colonization of roots with arbuscular mycorrhizal fungi (AMF) often improves the P nutrition of plants growing on P deficient soils (Shenoy and Kalagudi, 2005; Pal *et al.*, 2014). Therefore, AM fungi are an eco-friendly and low-cost intensive input in agriculture to reduce the rate of application of P fertilisers. Arbuscular mycorrhizal fungi (AMF) can be used in soil management practices to achieve low-cost sustainable agricultural systems (Hooker and Black, 1995). Several studies (Pan *et al.*, 1998; Mehrotra 2005; Pellerin *et al.*, 2007) have reported that mycorrhizae are involved in transferring water and several macronutrient are primary (N, P, K) Secondary (Ca, Mg, S) and micro (Mn, Fe, Zn, Cu, B) nutrients from soil to the roots of plants. Immobile nutrients like P can be increased for plants uptake by arbuscular mycorrhizae even under low P soils (Rubio *et al.*, 2002).

They also benefit plants by stimulating the production of growth regulating substances, increasing photosynthesis, improving osmotic adjustment under drought and salinity stresses and increasing resistance to pestsand soil borne diseases (Al-Karaki, 2006). Secretion of organic acids and different enzymes act in solubilisation of nutrients. Extension of hyphae of AM fungi into the larger soil volume increases the surface area for nutrient acquisition. Symbiotic benefits on plant physiology like root-to-shoot ratio, nutrient content, and rhizodeposition, have a significant effect on soil aggregate formation (Pal and Pandey, 2014). The better soil structure improve plant root development, water holding capacity, resistance to erosion (both water and wind), microbial activity in soil, maintain soil quality and nutrient recycling (Zimmerman *et al.,* 2009). Mycorrhizal plants are better able to survive than non-mycorrhizal plants in polluted soils which indicated mycorrhiza can be used for the remediation of heavy metals (Hildebrandt *et al.,* 2007). These multi-functional natures of AM fungi have received increased recognition in agriculture.

Management of P nutrition using mycorrhiza

Present status of mycorrhize use in fertilization schedule

The roles of microorganisms in intensive agriculture have been focussed due to consumption of high inputs of inorganic fertilisers, herbicides and pesticides resulting increase in production cost and sudden environmental disturbances. Mass production technology for mycorrhiza has not been widely adapted across the country (Pal *et al.*, 2016). Majority of the research works have been done in screening of strains, their mode of action and their efficacy on pot and field conditions. Moreover, there is a wide gap in dissemination of latest techniques to the farmers. Till now more than 170 species of AM fungi have been recorded with a few screened successful for commercial use. Not only in agriculture but recently theyhave been used in conservation of some valuable medicinal plants where *Glomus* sp. was found to be widely used for the increase yield of important medicinal plants (Chanda *et al.,* 2014). Different mass culturing techniques must be adapted for effective functioning of the fungus. Out of the total production (40324.21 MT per annum) of bioferetiliser in India, mycorrhiza accounted only 7% (2600MT per annum) (Yadav and Chandra, 2013) which indicated creation of awareness of mychorrhizal benefits among cultivators is must.

CONCLUSION

P is one of the slowly available nutrient required for plant growth and development. The depletion

Plant Species	Mycorrhizae Species	PUE	Condition	Reference
Cereals				
Rice (*Oryza sativa L.*)	*Glomus mosseae*	18.42%	Pot experiment in LalinRivernortheast of China (ratio of soil, sand and vermiculite @ 2:5:3)	Zhang *et al.* 2015
	Glomus caledonium	57%	Under field condition(upland rice and mungbean intercropping system)	Li *et al.* (2009)
Wheat (*Triticumae stivum*)	*Glomus sp*	200%	Greenhouse experiment, loamy sand of brown chernozemic soil	Kucey (1987)
Maize (*Zea mays*)	*Glomus sp*	63%	Pots containing sandy loam soil inoculated with mycorrhiza (20g sterilized + 40-50 AMF spore)	Sharif *et al.* (2011)
Pluses				
Mungbean (*Vigna radiata*)	*Glomus sp*	50%	Pots filled with 10 kg soil low in P content	Sharif *et al.* (2011)
	Glomus caledonium	65%	Under field condition(upland rice and mungbean intercropping sysyem)	Li *et al.* (2009)
	Glomus sp	166%	Pots filled with 10 kg soil low in P content	Sharif *et al.* (2011)
Beans (*Phaseolus vulgaris*)	*Glomus sp*	10.69%	Under greenhouse experiment	Kucey (1987)
Coco T (*Phaseolus vulgaris L.*)	*G. intraradices*	40%	1000 ml pots filled with autoclaved sand-soil mixture @ 9:1 v:v	Tajini *et al.* (2011)
Flamingo (*Phaseolus vulgaris L.*)	*G. intraradices*	30%		
Vegetables				
Broccoli (*Brassica oleracea*)	*Glomus intraradices*	53.33%	Glasshouse with sand: low fertile soil @ 1:3 ratio	Tanwar *et al.* (2013)
	Glomus caledonium	30%	Pot experiment with low P soil	Smith *et al.* (2004)
	Glomus intraradices	90%		
Onion (*Allium porrum*)	*S. calospora*	135-324%	Pots containing 700 g @ 1:9 (w/w) inoculum/soil mixture	Dickson *et al.* (1999)
Chilli (*Capsicum annuum*)	*Glomus fasciculatum*	48.14%	Field experiment , red sandy loam soil	Bagyaraj *et al.* 2015
	G. albidum	41%		
	G. macrocarpum	18.51%		
	G. caledonicum	37%		
Melon (*Cucumismelo*)	*Glomus mosseae*	67.56%	Under reduced fertilization dosage	Martinez-medina *et al.* (2009)
	Glomus claroideum	27.02%		
	Glomus claroideum	27%	Under conventional fertilization	
	Glomus intraradices	21.62%	Under reduced fertilization dosage	
	Glomus intraradices	21.62%	Under conventional fertilization	
Oilseed				
Groundnut (*Arachis hypogeal*)	*Glomus sp*	35%	Field experiment on a P fixing soil	Rakshit *et al.* (2008)

Barrelclover (*Medicago truncuIata*)	*Gigaspora margarita*	105%	Pots containing sterilized soil of Switzerland (49% sand, 32%silt, 16%clay), coarse quartz sand (0.7-1.2 mm), and fine quartz soil (0.08–0.2mm) mixed in a ratio of 1:3:1 (v/v/v)	Thonar *et al.* (2011)
	S. calospora	745%		
	Glomus claroideum	390%		

of global P reserves have raised the concerns for global food security. Among the available Smart strategies for improving the efficiency of P as well as supplement the exisisting fertilisation bio-priming is becoming a viable option. The technique not only ensures good crop establishment but also produces good quality seeds with low-budget farming. AM showing regular symbiotic relationships with plant roots can play a great role in soil fertility and plant health. Following the root architectures can significantly alter root morphology, growth, productivity and nutrient dynamics. They are efficient P solubliser and can be used to cope up with the P deficiency and fertility problems.

REFERENCES

Al-karaki, G.N. 2006. Nursery inoculation of tomato with arbuscular mycorrhizal fungi and subsequent performance under irrigation with saline water. *Scientia Horticulture*, **109**: 1-7.

Balemi, T. and Negisho, K. 2012. Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. *J. Soil Sci. Plant Nutri.*, **12**(3): 547-562.

Chanda, D., Sharma G.D. and Jha, D.K. 2014. The Potential Use of Arbuscular Mycorrhiza in the Cultivation of Medicinal Plants in Barak Valley, Assam: A Review. *Current World Environment*, **9**(2): 544-551.

Cordell, D. and Neset, T.S.S. 2014. Phosphorus vulnerability: a qualitative framework for assessing the vulnerability of national and regional food systems to the multidimensional stressors of phosphorus scarcity. *Glob. Environ. Change*, **24**: 108-122.

Dhankhar, R., Sheoran, S., Dhaka, A. and Soni, R. 2013. The role of phosphorus solublizing bacteria (psb) in soil management – an overview. *Int. J. Deve. Res.*, **3**(9): 31-36.

Entesari, M., Sharifzadeh, F., Ahmadzadeh, M. and Farhangfar, M. 2013. Seed biopriming with *Trichoderma* species and *Pseudomonas fluorescent* on growth parameters, enzymes activity and nutritional status of soybean. *Int. J. Agro. Plant Prod.*, **4**(4): 610-619.

Herrera-Estrella, L. and López-Arredondo, D. 2016. Phosphorus: The Underrated Element for Feeding the World. *Trends in Plant Sci.*, **21**(6): 461-463.

Heffer, P. and Prud'homme, M. 2008. Medium-Term Outlook for Global Fertilizer Demand, Supply and Trade 2008–2012. 76th IFA Annual Conference Vienna (Austria), 19–21, May 2008.

Hildebrandt, U., Regvar, M. and Bothe, H. 2007. Arbuscular mycorrhiza and heavy metal tolerance. *Phyto Chem.*, **68**: 139–146.

Hooker, J.E. and Black, K.E. 1995. Arbuscular mycorrhizal fungi as components of sustainable soil-plant systems. *Crit. Rev. Biotechnol.*, **15**: 201-212.

Isherword, K.F. 1998. Fertilizer use and environment. In: N. Ahmed and A. Hamid (eds.), Proc. Symp. Plant Nutrition Management for Sustainable Agricultural Growth. NFDC, Islamabad, pp. 57-76.

Kaviyarasi, K., Kanimozhi, K., Madhanraj, P., Panneerselvam, A. and Ambikapathy, V. 2011. Isolation, identification and molecular characterization of phosphate solubilizing actinomycetes isolated from the coastal region of Manora, Thanjavur (Dt.). *Asian J. Pharmacy and Tech.*, **1**(4): 119-122.

Khalil, S.K., Khan, S., Rahman, A., Khan, A.Z., Khalil, I.H., Amanullah, Wahab S., Mohammad, F., Nigar, S., Zubair, M., Parveen, S. and Khan, A. 2010. Seed priming and phosphorus application enhance phenology and dry matter production of wheat. Pak. *J. Bot*., **42**(3): 1849-1856.

Kartikay Bisen, Chetan Keswani, Sandhya Mishra, Amrita Saxena, Rakshit, A. and Singh, H.B. 2015. Unrealized potential of seed biopriming for versatile agriculture. In A. Rakshit *et al.* (eds.), Nutrient Use Efficiency: from Basics to Advances, DOI: 10.1007/978-81-322-2169-2_12.

Khan, A., Shad Khan Kh, Khan, A.Z., Marwat, K.H.B. and Afzal, A. 2008. The role of seed priming in semi-arid area for mung bean phenology and yield. *Pak J Bot.* **40**(6): 2471-2480.

Mahdi, S.S., Hassan, G.I., Hussain, A. and Rasoo, I.F. 2011. Phosphorus Availability Issue- Its Fixation and Role of Phosphate Solubilizing Bacteria in Phosphate Solubilization. *Res. J. Agri. Sci.*, **2**: 174-179.

Mahajan, K.K., Singh, R., Sharma, V.K., Acharya, C.L., Deor, B.S., Goyal, N.K. and Masand, S.S. 1997. Integrated nutrient management in maize (*Zea mays*)- wheat (*Triticumaestivum*) sequence under rainfed condition in Himachal Pradesh. *Indian J. Agri. Sci.*, 67, 560-563.

Narang, R.A., Bruene, A. and Aitmann, T. 2000. Analysis of phosphate acquisition efficiency in Arabidopsis accessions. *Plant Physiol*., **124**: 1786 –99.

Nisha, K., Padma Devi, S.N., Vasandha, S. and Sunitha Kumari, K. 2014. Role of Phosphorous Solubilizing

Microorganisms to eradicate P - deficiency in plants: A Review. *Int. J. Scientific and Res. Pub.*, **4**(7): 1-5.

Pal, A. and Pandey, S. 2014. Role of Glomalin in Improving Soil Fertility. *Int. J. Plant & Soil Sci.*, **3**(9): 112-129.

Pal, S., Singh, H.B. and Rakshit, A. 2014. The Arbuscular mycorrhizal symbiosis: an underground world wide web. Microbial Communities for Sustainable Soil Health and Ecosystem Productivity in Trends in Soil Ecology Studium Press, LLC, USA, 219-253.

Pal, S., Singh, H.B., Farooqui, Rakshit, A. 2016. Commercialization of Arbuscular Mycorrhizal Technology in Agriculture and Forestry In Agriculturally Important Microorganisms: Commercialization and Regulatory Requirements in Asia Springer-Verlag GmbH. Heidelberger Platz 3 14197 Berlin Germany ISBN: 978-981-10-2575-4,97-105pp.

Parewa, H.P., Rakshit, A., Monsefi, A., Lal, B. and Jain, L.K. 2014. Arbuscular Mycorrhizal Fungi: A Way to Improve Soil Quality.

Parihar, M. and Rakshit, A. 2016. Arbuscular Mycorrhiza: A Versatile Component for Alleviation of Salt Stress. *Nature Environment and Pol. Tech.*, **15**(2), 417.

Rubio, R., Borie, F., Schalchli, C., Castillo, C. and Azco′ N.R. 2002. Plant growth responses in natural acidic soil as affected by arbuscular mycorrhizal inoculation and phosphorus sources. *Journal of Plant Nutrition*, **25**(7): 1389-1405.

Rai, A., Rai, S. and Rakshit, A. 2013. Mycorrhiza-mediated phosphorus use efficiency in plants. *Environm. Exp. Biol.*, **11**: 107-117.

Rakshit, A. and Bhadoria, P.S. 2009. Influence of arbuscular mycorrhizal hyphal length on simulation of P influx with the mechanistic model. *African J. Microbiology Res.*, **3**(1): 1-4.

Rakshit, A., Kumai Sunita, Sumita Pal, Akanksha Singh, and Singh, H.B. 2015. Bio-priming mediated nutrient use efficiency of crop species In A. Rakshit *et al.* (eds.), Nutrient Use Efficiency: from Basics to Advances, DOI: 10.1007/978-81-322-2169-2_12.

Sagervanshi, A., Kumara, P., Nagee, A. and Kumar, A. 2012. Isolation and characterization of phosphate solubilizing bacteria from anand agriculture soil. *Int. J. Life Sci. and Pharma Res.*, **2**: 256-266.

Sekiya, N. and Yano, K. 2009. Seed P-enrichment as an effective P supplyto wheat. *Plant and Soil*, **327**: 347-354.

Sharma, S.B., Sayyed, R.Z., Trivedi, M.H. and Gobi, T.A. 2013. Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. *Springer Plus*, **2**(1): 1.

Shenoy, V.V. and Kalagudi, G.M. 2005. Enhancing plant phosphorus use efficiency for sustainable cropping. *Biotechnology Adv.*, **23**(7): 501-513.

Subba Rao, A., Srivastava, S. and Ganeshamurty, A.N. 2015. Phosphorus supply may dictate food security prospects in India. *Current Sci.*, **108**(7): 1253.

Sanyal, S.K., Dwivedi, B.S., Singh, V.K., Majumdar, K., Datta, S.C., Pattanayak, S.K. and Annapurna, K. 2015. Phosphorus in relation to dominant cropping sequences in India: chemistry, fertility relations and management options. *Curr. Sci*, **108**: 7-10.

Sanyal, S.K. and De Datta, S.K. 1991. Chemistry of phosphorus transformations in soils. *Adv Soil Sci*., **16**: 1–120.

Shenoy, V.V. and Kalagudi, G.M. 2005. Enhancing plant phosphorus use efficiency for sustainable cropping. *Biotechnology Advances*, **23**: 501–513.

Sims, J.T., Simard, R.R. and Joern, B.C. 1998. Phosphorus loss in agricultural drainage: Historical Perspective and Current Research. *J. Environ. Qual.* **27**: 277-293.

Wang, X., Shen, J. and Liao, H. 2010. Acquisition or utilization, which is more critical for enhancing phosphorus efficiency in modern crops? *Plant Sci.*, **179**(4): 302-306.