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Bio-Organo-Phos: A Potential Phosphorus Source for Organic Farming

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Presently phosphorus is being supplied in the form of fertilizers produced exclusively by the mining of high quality phosphate rock (PR) deposits of igneous or sedimentary origin. These minerals are finite and exhaustible resources which pose challenge to sustainable development. For sustainable phosphorus use to ensure food security and environmental safety, integrated use and recycling of all the phosphorus sources along with utilization of low quality raw materials are some alternative strategies. Mechanisms and benefits of the use of phosphorus supplying efficient microbes with organic sources and low grade phosphatic minerals is discussed here under.

Key words: Rock phosphate, apatite, P solubilizers, arbuscular mycorrhiza

Phosphorus (P) is next to nitrogen when it comes to plant growth and development and an adequate supply of P is required for optimum growth and reproduction. Role of phosphorus is well known by its involvement in several key plant functions including energy transfer, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics from one generation to the next. On root uptake P is incorporated into organic compounds including nucleic acids (DNA and RNA), phosphoproteins, phospholipids, sugar phosphates, enzymes and energy-rich phosphate compounds like adenosine triphosphate (ATP). It is in these organic forms as well as the inorganic phosphate ion that P is moved throughout the plant and plays its role in further reactions. It also is involved in many plant processes like photosynthesis, carbon metabolism, membrane formation, energy generation, nucleic acid synthesis, glycolysis, respiration, activation and inactivation of enzymes and nitrogen fixation. Movement of nutrients within the plant depends largely upon transport through cell membranes, which requires energy to oppose the forces of osmosis. Here again, ATP and other high energy P compounds provide the needed energy. Root architecture, seed development and crop maturity are also affected by P deficient conditions. Leguminous crops for symbiotic nitrogen (N_2) fixation generally require high amount of P due to high energy requirement which is mainly contributed through ATP.

Phosphorus's unique attributes of being essential, finite, non-substitutable and having a dissipative use structure makes it major challenging crop nutrient element to address issue of resource limitation to promote sustainable development to include intra- and intergenerational fairness (Mew, 2018). The availability of soil P is optimum at pH ranging between 6.5 and 7.0 for plant absorption. Crop uptake efficiency of fertilizer phosphorus is very low because of the many ways that fertilizer phosphorus (which is 100% water soluble) can change to less available forms. Fertilizer efficiencies are affected by several factors like pH, organic matter, texture of soil, soil temperature, soil moisture, type of crop, root characteristics of crop, degree of soil phosphorus deficiency and method of fertilizer application, etc. It is claimed that depending on type of crop, P-use efficiency ranges between 10 to 30%. The total nutrient use efficiency of phosphorus (i.e., the proportion of P mined from PR deposits being digested in human food) remains at very low levels. Losses of phosphorus along the supply chain from PR-ore to human consumption can amount to up to 95% and we do dissipate the element ultimately into seawater, where concentrations become very low that the element becomes unrecoverable. Recycling of P in the form of animal manure is one of the main agricultural practice due to availability of animal population making manures the secondary source of P. Current activities mostly focus on devising methods of P recovery and recycling from potential sources such as wastewater, manure or food- and slaughter wastes (Mew et al, 2018). Along with efficiency constraints prices of phosphatic fertilizers are high adding to cost of cultivation. Apart from economic concerns the environmental concerns of phosphorus fertilizers is their production technology and the sink or end point of reach of applied P fertilizers. The rock phosphates or apatites, the major sources of P fertilizers reserves are exhaustible (Table 1) and the fact that there is no substitution possible—no other element can perform the same task as phosphorus—leads to the supply of the element being 'essential'. Rock phosphates are not easily soluble and P in them is not easily accessible to plant nutrition, they are first treated with acids to liberate P held and increase the concentration of P in final product through beneficiation. During these processes effluents generated are acidic and contain minor quantities of P which goes to open environment or water bodies. Similarly, phosphatic fertilizer P applied to crop fields sometimes gets along with run surface runoff to reach water bodies causing eutrophication leading to the destruction of the habitat of the aquatic life and cause environmental degradation. Due to both the above processes of factory effluent release from fertilizer manufacturing and surface runoff, there is chance of eutrophication of water bodies harming flora and fauna. The energy consumed in phosphatic fertilizer manufacturing is another environmental aspect as huge energy is invested to manufacture chemical fertilizers. Keeping all the above cited reasons the search for alternate phosphorus sources lead us to either completely organic sources of P or utilization of low grade ores in eco-friendly way.

The organic phosphorus sources are generally low in P_2O_5 content. For example in bulky organic manures like farm yard manure it is 0.3-0.9%, in vermicompost 0.1-0.3%, in green manure crops 0.3-0.8%, in green leaf manures 0.1-0.5% and in oil cakes its 1.0-2.0%. So in order to fulfil crop phosphorus needs, farmers need to apply huge quantities (in tons) of these organic manures to fields. If we analyse economics of such addition it comes near to equivalent cost or even more as compared to chemical fertilizer application. The availability of quality bulky organic manure devoid of fertilizer adulteration is also a matter of concern. That leaves us to explore other alternative source of P and low grade ores and rock phosphate gain attention here.

Rock phosphate (RP) is an economical source of P to the crop plants and 200–300 billion tons of RP are available throughout the world. The major issues with RP is having a low available P and its universal availability. Research work is needed to find out a way to enable farmers to utilize this RP as alternative to P-fertilizers to meet nutrient demand and cope with the prices. Price range of RP is INR 6 to 10 thousand per metric tons with mean price of INR 7000 per metric ton in India. Some low quality RP is available for INR 4000 with synonyms like brown rock phosphate, etc. A huge share of foreign exchange is utilized in importing phosphatic fertilizers which is not feasible for developing countries. With current rate of mining it is predicted that by 2050 high quality reserves may get depleted (Ditta and Khalid, 2016). However since chemical fertilizers are not allowed in organic farming practices, reliable phosphorus sources are need to be innovated with technology to exploit RP resources in bioavailable form without compromising on yield.

Table 1. World rock phosphate reserves

Country	RP reserves (in MMTs)	Country	RP reserves (in MMTs)
Morocco & Western Sahara	50000	Russia	600
China	3200	Peru	400
Algeria	2200	Kazakhstan	260
Syria	1800	Tunisia	100
Brazil	1700	Israel	67
South Africa	1500	Senegal	50
Saudi Arabia	1400	India	46
Egypt	1300	Togo	30
Australia	1100	Vietnam	30
United States	1000	Mexico	30
Jordan	1000	Other countries	770
Finland	1000	**Total**	**70000**

In India, the total reserves/resources of rock phosphate (as per NMI data based on UNFC system as on 1.4.2015) have been placed at 312.67 million tonnes. Out of these, the reserves constitute only 45.80 million tonnes while 266.87 million tonnes are under remaining resources category. Grade wise, low-grade account for 37%, followed by beneficiable (29%), blendable (11%), chemical fertilizer & soil reclamation (8% each) and remaining unclassified and not-known grades (about 7%). For, apatite which is also source of phosphorus there is 24.23 million tonnes of reserves in India. Out of these resources, the reserves are only 2.09 million tonnes and 22.14 million tonnes are remaining resources. Of the total resources, the bulk (57%) are located in West Bengal followed by Jharkhand (30%) and Meghalaya (5%). The remaining 8% resources are available in Rajasthan, Andhra Pradesh, Gujarat and Tamil Nadu. Gradewise, soil reclamation grade accounts for 45% followed by beneficiable grade (31%), low and non-beneficiable grade (18%) and blendable, others and not-known grades (6%). The resources of chemical fertilizer grade are over one percent only. The production of apatite at 572 tonnes during 2012-13 decreased considerably by 81% as compared to that in the previous year due to discontinuance of production by WBMDT Corpn.Ltd. The entire production of apatite was of grade 15-20% P_2O_5, which was reported by a private sector mine in Andhra Pradesh. In case of rock phosphate (phosphorite) the total production of 1,474 thousand tonnes in 2015-16 decreased by about 8% as compared to that in the previous year. Rajasthan continued to be the principal producing state, contributing 96% of the total production and the remaining 4% was contributed by Madhya Pradesh. About 62% of the total production of rock phosphate was of grade up to 15-20% P_2O_5, 34% of grade above 30-35% P_2O_5 and 2% of grade above 25-30% P_2O_5 and 2% of grade above 20-25% P_2O_5. Only about 10% requirement of raw material for phosphate fertilizer production is met through indigenous sources. The remaining requirement is met through import in the form of rock phosphate, phosphoric acid and direct fertilizers. In India, most of the existing phosphatic fertilizer and phosphoric acid plants have been designed for high grade imported rock phosphate, mainly from Morocco and Jordan. The Indian deposits are relatively of low grade. Therefore, the fertilizer and phosphoric acid plants that maybe set up as replacement to the existing plants will have to be designed to accept indigenous ores as a feed. Since this is long and capital incurring process to establish infrastructure and all, it will be helpful to develop technology to use these low grade phosphorus sources for organic cultivation practices either with use of microbial solubilisation or with other means.

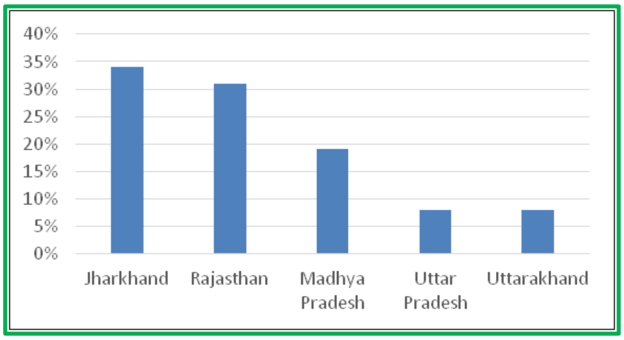

Fig 1. Rock phosphate reserves in India

Direct Application of Rock Phosphate as Fertilizer

In India, the finely-ground rock phosphate containing 16% P_2O_5 is used for direct application to the soil for soil amendment. This application is dependent upon the structure and chemical composition of the rock. Direct application is suited mostly for pastures and forage crops and for acidic soils. According to Pyrites, Phosphates & Chemicals Ltd. (PPCL) specifications considered for utilising any rock phosphate as phosphatic fertilizer for direct application in acidic soils include (i) Absolute citrate solubility index of 7% (max.), (ii) Apatite to carbonate ratio (CO_2% : P_2O_5%) of 0.035, (iii) Sedimentary origin of rock phosphate, (iv) Mesh size of 100, (v) Rock phosphate grade (citrate soluble fraction) of 16% P_2O_5, (vi) Iron as Fe_2O_3 of 5% and (vii) CaO to P_2O_5 ratio of 1.8. The use of rock phosphate for direct application as fertilizer depends on its level of solubility in acidic soil. Phosphate is the component of agronomic interest in these rocks. The higher the phosphate (P_2O_5) content as apatite, the greater the economic potential of the rock. Factors that are important in the chemical conversion of PRs to fertilizer (free carbonates, iron, aluminium, magnesium and chloride) are often not important where the rock is to be used for direct application (Van Kauwenbergh and Hellums, 1995). Figure 2 shows consumption of RP by direct application throughout the world over the years. It can be observed that over the years the direct application has been reduced owing to availability of phosphatic fertilizers.

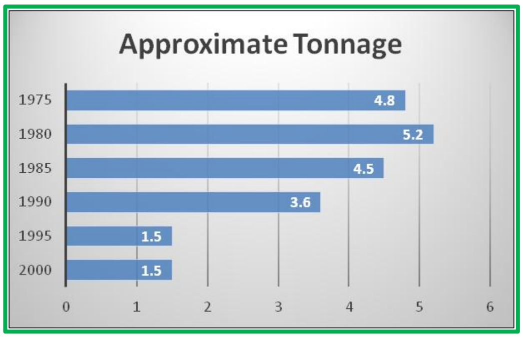

Fig 2. World consumption of direct application phosphate rock (Data: Van Kauwenbergh, 2003)

However, direct application of RP as a P source to the soils is feasible for the acidic soils having low pH and in neutral or alkaline soils, the technology has to be refined to make P solubilisation in these pH conditions. So the helpful approach which could help solubilize the fixed P in RP could be to use the bio-inoculants, which through the release of organic acids (acetate, lactate, oxalate, tartarate, succinate, citrate, gluconate, ketogluconate, glycolate, etc.) reduce the pH of the micro-environment of soil region and thus solubilize P making it bioavailable to crop plants. Such microbes are reknowned by the names as phosphorus solubilizing microbes (PSMs) and the plant growth promoting rhizobacteria (PGPR). They are not mutually exclusive and PSM have PGPR effect or PGPR show PSM activity. These PGPR/PSM include all the bacteria found in the rhizosphere which directly or indirectly enhance plant growth.

The approaches to provide P nutrition in organic farming conditions through low grade rock phosphates is by (1) mixing such phosphate rock with PSMs or PGPRs, (2) mixing phosphate rock during composting to form enriched compost, (3) mixing phosphate rock with both compost and PSMs/PGPRs and (4) enriching compost with PSMs/PGPRs. So by using these components (rock phosphate, compost, PSM/PGPR) in different combinations we can prepare a product rich in plant available P.

1. Rock Phosphate and PSMs/PSBs/PGPRs consortia

In acidic soils such as oxisols, inceptisols, and utisols, the added P quickly reacts with Fe and Al oxides as these are the dominant cation oxides in these types of soils and make it unavailable to the plants. In case of alkaline soils, Ca and Mg salts are abundantly present, so these cations react with phosphatic compounds thus making them unavailable to the plants. Precipitation and adsorption of P with the soil colloids are the main responsible mechanisms/reactions for the removal of P from the soil solution. The former is induced by the presence of Ca^{2+} ion in the soil solution while latter depends on the chemical properties of the soil colloids. There is high probability of having the precipitates of calcium phosphate in the soils rich in exchangeable cations. Calcareous soils are poor in plant available P compared to the limed acid soils. It has been found that most of the phosphate rocks or RPs yield better results in the acidic soils like that of oxisols and ultisols compared to alkaline and neutral soils with high pH, high P sorption capacity, low cation exchange capacity (CEC), low rainfall, low organic matter, low microbial activity, etc. because in acidic conditions P in rock phosphate gets solubilized releasing it for plant uptake. Phosphate rocks have significant proportion of isomorphic substitution in the crystal lattice and variable proportion of impurities and accessory minerals. Thus, it has been found to be more beneficial if applied in acidic soil conditions as compared to the neutral and alkaline conditions. The strategy to use phosphate rocks in alkaline and neutral soils is by mixing these rocks with phosphate solubilizing bacteria (PSBs) and/or plant growth-promoting rhizobacteria which not only improve the physicochemical properties of the soils, but also help in the solubilisation of RP, which leads to increased availability of P to the crop plants. Certain mechanisms employed by these PGPR and PSMs have been identified regarding the solubilization of RP. These includes: 1) lowering the pH of microclimate by production of organic acids acetic, propionic, lactic, gluconic, fumaric, butyric, formic, and succinic in the rhizosphere (Table 2 and 3), 2) chelation of cations and competing with phosphate for adsorption sites in the soil. The hydroxyl and carboxyl groups of the acids chelate the cations bound to phosphate, thereby converting it into soluble forms. These acids may complete for fixation sites of Al and Fe insoluble oxides, on reacting with them, stabilize them, and are called "chelates". For example ketogluconic acid is a powerful chelator of calcium. 3) Mineralization of organic phosphate by transformation into utilizable form by PSM through process of mineralization which occurs in soil at the expense of plant and animal remains, which contain a large amount of organic phosphorus compounds such as nucleic acids, phospholipids, sugar phosphates, phytic acid, polyphosphates, and phosphonates. Phosphatases like phytase hydrolyse organic forms of phosphate compounds, thereby releasing inorganic phosphorus that will be immobilized by plants. Alkaline and acid phosphatases are produced by number of soil microbes. The following are among the commonly reported phytase-producing fungus: *Aspergillus candidus*, *Aspergillus fumigatus*, *Aspergillus niger*, *Aspergillus parasiticus*, *Aspergillus rugulosus*, *Aspergillus terreus*, *Penicillium rubrum*, *Penicillium simplicissimum*, *Pseudeurotium zonatum*, *Trichoderma harzianum* and *Trichoderma viride*. Hence one strategy is the use of rock phosphate raw material, the cheaper source of P, directly in the field with use of PSMs and getting the benefit of phosphatic fertilizers.

Table 2. P solubilizing microorganisms

PSMs group	Organisms		
Bacteria	*Bacillus circulans*	*B. polymyxa*	*B. pulvifaciens*
	B. megaterium	*B. subtilis*	*B. coagulans*
	B. fusiformis	*B. pumilus*	*B. chitinolyticus*
	B. sircalmous	*Thiobacillus ferrooxidans*	*Pantoea agglomerans*
	Pseudomonas putida	*P. calcis*	*P. fluorescens*
	P. striata	*P. canescens*	*Rhizobium meliloti*
	R. leguminosarum	*Mesorhizobium mediterraneum*	*Acinetobacter rhizosphaerae*
Fungi	*Aspergillus niger*	*A. clavatus*	*A. awamori*
	A. candidus	*A. parasiticus*	*A. fumigatues*
	A. rugulosus	*A. foetidus*	*A. nidulans*
	A. flavus	*A. wentii*	*A. sydawi*
	A. terreus	*A. tubingensis*	*A. ochraceus*
	A. versicolor		
	Penicillium citrinum	*P. bilaii*	*P. digitatum*
	P. lilacinium	*P. balaji*	*P. funicolosum*
	P. oxalicum	*P. simplicissimum*	*P. rubrum*
	Arthrobotrys oligospora	*Trichoderma viride*	
Actinomycetes	*Streptomyces albus*	*S. cyaneus*	*Streptoverticillium album*
Cyanobacteria		*Calothrix braunii*	

Adapted from Kalayu G (2019)

Table 3. Organic acids produced by PSMs

PSMs	Organic acids
Bacillus sp.	Citric acid, malic acid, succinic acid, fumaric acid, tartaric acid, gluconic acid
Pseudomonas	Citric acid, succinic acid, fumaric acid, gluconic acid, 2-ketogluconic acids
Proteus sp.	Citric acid, succinic acid, fumaric acid, gluconic acid
Aspergillus	Citric acid, gluconic acid, oxalic acid, succinic acid, malic acid, glycolic acid
Azospirillum sp.	Citric acid, succinic acid, fumaric acid, gluconic acid
Penicillium sp.	Gluconic acid, glycolic acid, succinic acid, malic acid, oxalic acid, citric acid
Erwinia herbicola	Gluconic acid, 2-ketogluconic acids
Acetobacter, Gluconobacter	Thermotolerant acetic acid

Adapted from Kalayu G (2019)

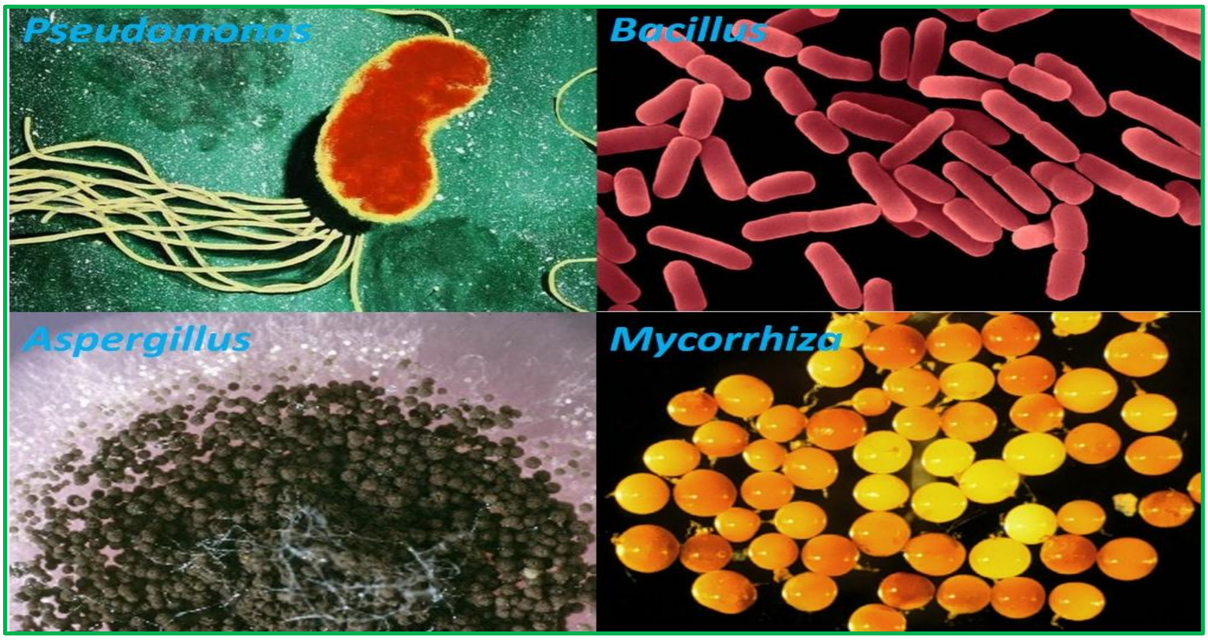

Fig 3. Efficient P Solubilizers and Mobilizers

2. Phosphorus enriched compost/farm yard manure/vermicompost

Organic fertilization through compost application is a common practice for sustainable agricultural production. Compost is rotten product of crop residues and daily waste materials through a process known as composting. If animal residue added to this we can prepare farm yard manure (FYM) and if earthworms are used to convert animal and plant residue to decomposed product it is vermicompost. However, the amount or concentration and type of P compounds depend on the source of the material being used for composting and generally these three above mentioned products are low in P in the range of 0.2 to 0.8% on air dried material. Even with such low concentration, long term application of these organic composts result in build-up of organic P in the soil. The conversion of this organic P into inorganic P or the mineralization depends on the type of compound being mineralized, e.g. orthophosphate di-esters are quickly mineralized compared to orthophosphate monoesters. Mineralization helps in increasing the total available P due to reduction in the P adsorption and increased rates of microbial enzyme activities, which boost up the biologically mediated turnover of organic P into inorganic P.

The second approach, besides using RP+PSMs is enriched compost preparation by mixing of RP with a well rotten compost/FYM/vermicompost and this technique is well tried and tested. Many researchers have reported increased availability of P to the plants by increasing the solubility of RP in the soil through composting. The mechanisms behind this is similar to using RP+PSM mixture as the basic changes responsible for P solubilisation are same in case of composting too. Here solubilisation induced by the release of organic acids during the decomposition of organic residues which helps solubilize RP by lowering the pH, and by the conversion of inorganic P in RP into organic P which might become available to the plants after mineralization in the soil. A phosphocompost/N-enriched phosphocompost technology developed by various research organizations/fertilizer manufacturers by varying raw materials, different grade of rock phosphate, consortia of P solubilizing microbes. However, the common aim/feature of final product is enhanced P compared to conventional compost material. For example, phosphocompost developed by IISS, Bhopal using phosphate solubilizing microorganisms (*Aspergillus awamori*, *Pseudomonas straita* and *Bacillus megaterium*), phosphate rock, pyrite and bio-solids to increase the manurial value compared to ordinary FYM and compost. The pyrites addition will enhance sulphur content so that final product's manorial value gets enhanced. Here, raw materials required for the production of one tonne of phosphocompost are: about 1900 kg organic/vegetable wastes/straw, 200 kg cow-dung (dry weight basis) and 250 kg phosphate rock (18% P_2O_5) apart from PSMs. In terms of nutritional quality of the final product/ phosphocompost, it contains 2-3.5% P and 17-18 C:N ratio (Table 4). The huge quantities of crop residues, particularly rice straw, which is generally burnt in the field for sowing wheat in northern India, can be effectively recycled to agriculture by converting them into good quality manure. Detailed enriched compost preparation technique is given in ICAR newsletter (2008, volume 14-3). Economics of enriched compost: cost of retail price of 1 kg P_2O_5 from diammonium phosphate (DAP) is Rs 16.22. And cost of preparation of enriched compost using rock phosphate and waste mica is only Rs 7 (Biswas, 2008). The final P content of enriched compost will be more than 3.5% and generally its range is 4-5% depending on initial raw material used like cow dung or poultry manure, etc. The supply of P through enriched compost will be 110 to 220 kg/ha on application of 2.5 tons to 5 tons of compost, respectively (Bordoloi *et al*, 2015).

Table 4. Nutrient composition of manure and phosphocompost

Manure	Total N (%)	Total P (%)	C:N ratio
FYM	0.5-0.8	0.32-0.55	22.0-25.0
Ordinary Compost	0.6-0.8	0.55-0.60	22.0-25.0
Phospho-compost	1.2-1.4	2.00-3.50	17.0-18.0

Source: IISS, Bhopal

RP-enriched compost increase the total P in the soil compared to compost without RP, but the quantity of water soluble P in the RP-enriched compost is decreased compared to compost without RP or RP alone due to the dilution effect of RP when mixed with a large amount of composting material and reaction of soluble P with $CaCO_3$ present in RP. The extent of P solubilisation depends on many factors like that of the ratio between the RP and compost, time and rate of application to the soils. It has been reported that P from this RP-enriched compost is available even at high pH of 8.5 or more, so it would serve well under alkaline or neutral conditions as RP performs well to considerable extant in acidic soils.

During composting, apart from organic acids listed in table 4 the other high molecular weight organic acids like humic and fulvic acids are also released, which decreases the pH of the material being composted and increases the solubility of fixed P in the soils with high pH. These composts act like plant growth regulators when applied to the soil. The effect of these humic acids isolated from the cattle vermicompost was tested on the earliest stages of lateral root and on the plasma membrane H^+-ATPase activity in an experiment using maize as a test crop. From the results, it was clearly found that the humic acids significantly increased the overall root growth of maize seedling in conjunction with lateral root emergence. Also a significant stimulatory effect on the activity of H^+-ATPase was observed, which implies that the humic acids enhance the expression of this enzyme. Moreover, exchangeable auxin groups in the macrostructures of humic acid-containing compost, as revealed through structural analysis, shows that the hormonal activity is enhanced by the application of organic wastes containing humic acids. On field application these acids have a stimulatory effect on the growth and yield of crop plants and also increases the microbial population of beneficial microorganisms.

The RP-enriched compost has low microbial biomass carbon compared to the straw compost due to the dilution of carbon over a large biomass of compost material. The levels of organic P are also higher in case of RP-enriched compost compared to the straw compost as evidenced from the higher amount of alkaline phosphatases activities and acids. The level of citrate soluble and organic P increases with increasing the addition of RP but up to a certain level and then decrease. So overall, during this organic matter decomposition, the available P and calcium contents are increased to the plants.

3. Integrated application of PSMs, RP and compost (bio-organo-phos)

The third approach apart from using RP+PSMs and RP+Compost/FYM/Vermicompost is integrated use of RP with PSMs and composted material. The difference of this method from preparation of enriched compost is addition of PSMs is requisite here. Whereas in case of enriched compost if RP is added in beginning of composting process then the conventional microflora (mesophilic and thermophilic) will only help in solubilisation of P of phosphate rock. If even after composting residual rock phosphate remains, it will be solubilized when applied to field. The other difference is for enriched compost preparation some manufacturers prefer single super phosphate over rock phosphate because of easy availability of latter. Here the main purpose is increasing P content of final compost. Some farmers or manufacturers additionally mix urea also to increase nitrogen content. But for organic farming practices the use of urea, SSP or DAP are not recommended in any form and hence rock phosphate is used as alternative. The package of practices for organic cultivation under NPOP (National Programme for Organic Production) under national standards for organic production enlists rock phosphate use for organic farming in restricted category. Therefore rock phosphate can be added for enriched compost preparation for organic practices.

Bio-organo-phos is made up of three components: 'bio' means microbial component helpful in P nutrition, 'organo' includes organic matter in the form of compost or farm yard manure or vermicompost (either readymade or raw materials intended to prepare compost) and 'phos' means phosphate rock. So it is an integrated application of these three components by carefully selecting consortia of potential phosphorus solubilizing bacteria, fungi and actinomycetes and using this consortia to mixture of organic matter and low grade rock phosphate to prepare P rich final product. The microbial components is known as effective microbes or effective consortia which basically is mixture of phosphorus solubilizing bacteria, fungi, actinomycetes or cyanobacteria (Table 4). Apart from P solubilizing microbes the addition of spores of arbuscular mycorrhizal fungus (AMF) to the product in any stage of preparation or after the preparation of compost will be beneficial owing to role of AMF in P mobilization. Since AMF is another biofertilizer component which mainly helps in absorption or uptake of P from soil by plant root through its large spread mycelium, such addition of spores will help plant to establish strongly. AMF plays a significant role in crop P uptake particularly in P poor conditions like organic cultivation compared to P rich conditions. High levels of colonisation by AMF can occur after addition of sufficient quantity of compost if soil extractable P remains low. The impact of organic matter on colonisation by AMF reflects the ease with which P is mineralised, which is also highly dependent on the quality of the organic matter amendment (Ryan and Tibbett, 2008). Organic sources of nutrients, such as farmyard manure, compost and crop residues and slow release mineral fertilisers such as rock phosphate may stimulate AMF. However, organic amendments rich in P, such as chicken manure, may impact negatively on AMF. Organic matter addition positively stimulates AMF and leads to increased extraradical hyphal length (Gosling et al, 2006). Many ectomycorrhizal fungi (mycorrhiza that colonizes outside root surface) have been shown to be able to release inorganic P from poorly soluble P sources such as apatite. Fungal colonization of apatite grains (Fig. 4) increases weathering rates threefold. The mechanism for apatite dissolution is enhanced acidification and chelation of calcium cations from the apatite through fungal exudation of oxalic acid. Complexation of calcium with oxalic acid would lead to formation of calcium oxalate crystals on the surface of the fungal hyphae in contact with the apatite. The apatite grains introduced into forest soil usually become heavily colonized by ECM hyphae (Jansa et al, 2011). AMF also has other benefits on plant growth too with its improved nutrition support and stress tolerance enhancement.

Fig.4 Apatite grains colonized by ectomycorrhizal fungus [Adapted from Smits et al., 2008]

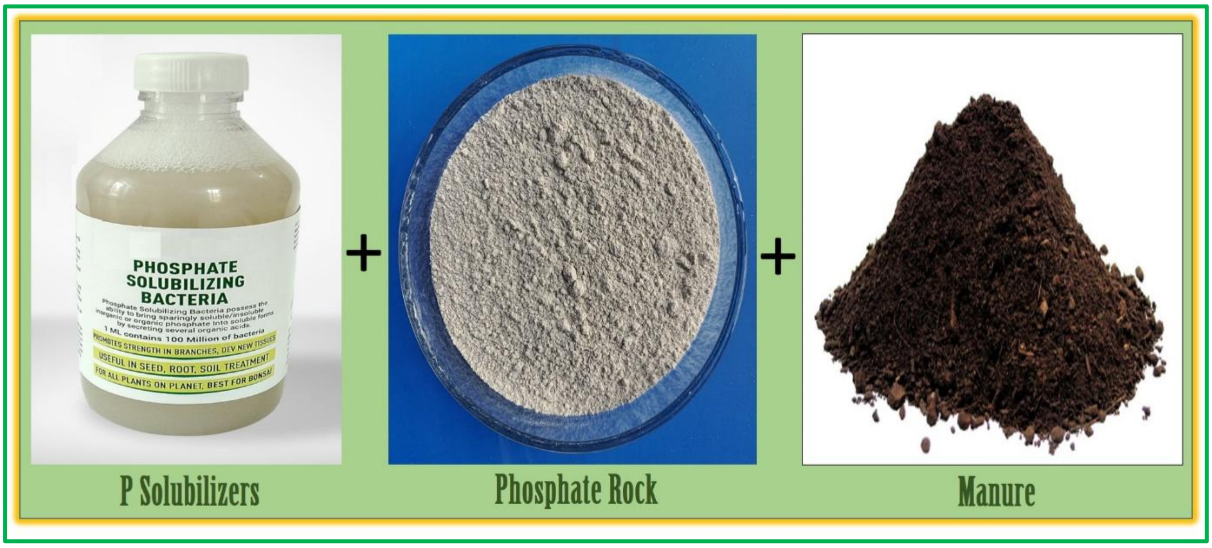

Fig.5 Bio-organo-phos components

The fourth approach is use of PSMs in composting. When certain raw materials like sewage sludge or high C:N ratio straw residues or saw dust or woodchips or kitchen wastes are used for compost preparation it will be helpful if we add free living N fixers and P solubilizers so that the product can be converted/decomposed at faster rate and final product is nutrient rich. Here use of free-living nitrogen fixing bacteria like *Azotobacter*, *Bacillus*, *Clostridium* and *Klebsiella* or associative nitrogen fixers like *Azospirillum* can be used to enhance the nitrogen status of compost prepared. For P solubilisation PGPRs or specific PSMs are used. Lastly, application of phosphatic biofertilizers directly to the soil without RP, compost or additives is well established technology to enhance plant available P status of any soil. This biofertilizer application method is traditional and proven technique owing to its beneficial effects and is generally done with the use of PGPRs, PSMs and AMF application to enhance phosphorus nutrition of crop plants.

Summary

For organic production practices developing a technology or using existing developed technology like a natural and non-polluting way of increasing the solubilization of RP and its use could serve as a valuable substitutional source for chemical phosphatic fertilizers. The use of bio-augmented RP-enriched organic manure would be sustainable approach to meet the needs of crops for P in an environment friendly way. It is also helpful in minimizing organic wastes and converting vast quantity of crop residues that could be composted to make organic manure instead of burning or discarding enabling farmers to use farm resources effectively. The use of indigenous sources of RP would help minimize the energy use during its conversion into chemical phosphatic fertilizers. The product would help the farmers in reducing their cost of cultivation to purchase chemical fertilizers, and would also reduce the import budget on national level.

References

1. Apatite and Rock Phosphate (2015). In: Indian Minerals Yearbook-2013 from Indian Bureau of Mines, Ministry of Mines, Government of India.
2. Apatite and Rock Phosphate (2018). In: Indian Minerals Yearbook-2016 from Indian Bureau of Mines, Ministry of Mines, Government of India.
3. Biswas DR (2008). Production of enriched compost, *ICAR News*, Volume 14 No. 3, p1-2.
4. Bordoloi LJ, Hazarika S, Deka BC, Kumar M, Verma BC and Chatterjee D (2015). Nutrient enriched compost. ICAR Research Complex for NEH Region, Nagaland Centre, Jharnapani (Nagaland), pp34.
5. Ditta A and Khalid A (2016). Bio-Organo-Phos: A sustainable approach for managing phosphorus deficiency in agricultural soils, organic fertilizers - from basic concepts to applied outcomes, Marcelo L. Larramendy and Sonia Soloneski, IntechOpen, DOI: 10.5772/62473.
6. Gosling P, Hodge A, Goodlass G and Bending GD (2006). Arbuscular mycorrhizal fungi and organic farming, Agriculture, Ecosystems and Environment **113:** 17–35.
7. Jansa J, Finlay R, Wallander H, Smith FA and Smith SE. (2011). Role of mycorrhizal symbioses in phosphorus cycling *In* E.K. Bunemann et al. (eds.), Phosphorus in Action, Soil Biology 26, # Springer-Verlag Berlin Heidelberg, 137-168.
8. Kalayu G (2019). Phosphate solubilizing microorganisms: Promising approach as biofertilizers, *International Journal of Agronomy*, **2019:**1-7. Article ID 4917256.
9. Indian Institute of Soil Science Technical Bulletin (Hindi), Nov. 2000.
10. Manna MC and Sahu A (2013). Rapid composting methods, *Indian Institute of Soil Science Leaflet* 1-8.
11. Mew MC, Steiner G and Geissler B (2018). Phosphorus supply chain—Scientific, Technical, and Economic Foundations: A Transdisciplinary Orientation, *Sustainability*, 10 (1087): 1-18.
12. Ryan MH and Tibbett M (2008). The role of arbuscular mycorrhizas in organic farming *In* H. Kirchmann, L. Bergstr¨om (eds.), Organic Crop Production – Ambitions and Limitations, Springer Science+Business Media B.V.
13. Smits MM, Bonneville S, Haward S and Leake JR (2008). Ectomycorrhizal weathering, a matter of scale? *Mineralogical Magazine*, 72(1): 135-138.
14. Van Kauwenbergh, SJ (1995). Mineralogy and Characterization of Phosphate Rock, *In* Direct Application of Phosphate Rock and Appropriate Technology Fertilizers in Asia-What Hinders Acceptance and Growth, pp. 29-47, K. Dahanayake, SJ. Van Kauwenbergh, and D.T. Hellums (Eds.), Institute of Fundamental Studies, Kandy, Sri Lanka.
15. Van Kauwenbergh SJ (2010). World Phosphate Rock Reserves and Resources by the International Fertilizer Development Center (IFDC).