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Enrichment of municipal solid waste compost through rock phosphate and phosphorus solublizing bacteria and effect of its application on soil and maize growth

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Abstract

Rock phosphate (RP) is a valuable source of plant available phosphorus (P) however its solubility in alkaline soils is negligible when applied directly. We studied the possibility of solubilizing RP by composting it with municipal solid waste (MSW) and P solubilizing bacteria (PSB). The MSW was composted with 5 and 10% charge rates of RP and/or two PSB strains, viz., Klebsiella pneumonia and Burkholderia cenocepacia for 120 days. These composts treatments were analyzed for total and soluble P contents with fifteen days interval. The compost enriched with 10% of RP and both strains of PSB resulting in the highest total P (2%) and soluble P contents (120 mg kg^{-1}) was selected for raising maize in greenhouse conditions. The treatments included 50 and 100% of the recommended dose of P fertilizer (100 kg P_2O_5 ha^{-1}), enriched compost equivalent to 50, 100, 150 and 200% of recommended P rate and a mixture of compost and P-fertilizer (75:25) to supply recommended P rate in soil (25% from P fertilizer and 75% of recommended P from enriched compost). Enriched compost at 200% of recommended P resulted in the highest concentrations of N, P and K (18.2, 7.8 and 162 mg kg^{-1}, respectively) in soil. Uptake of N, P and K by maize plants was also the highest (2.9, 0.47, 1.72%, respectively) with this treatment. However, the plant height of maize was maximum (61.4 cm) with recommended dose of P fertilizer but statistically at par with higher rates of enriched compost (58.9 cm). The highest fresh weight (123.6 g) and dry weight (32.3 g) of maize plants per pot were obtained from enriched compost at 200% of recommended P followed by full dose of recommended P fertilizer. Combined use of enriched compost (75: 25) gave maize yield (114.8 g) comparable to sole application of P-fertilizer (121.1 g) and enriched compost (123.6 g). Combined application of enriched compost and P-fertilizer in 75:25 ratio proved equally effective by giving yield comparable to higher application rates of both enriched compost and P-fertilizer.

Keywords: Rock phosphate, municipal solid waste, phosphorus solubilizing bacteria, maize growth, nutrient contents

Introduction

Phosphorus (P) is one of the major essential macronutrients required for the plant growth. Globally $\geq$ 5.7 billion hectares of land contain very low available P (Hisinger, 2001). Likewise, arid regions of Pakistan are highly deficient in P, and averagely contain $\leq$ 3 mg kg^{-1} of available soil P (Rashid and Qayyum, 1991). Hence, for meeting the crop requirement, farmers have to use costly phosphatic fertilizers. Moreover, the use efficiency of these fertilizers is also low due to many factors including high pH, high Ca activity coupled with the P fixation by clays (Davies *et al*., 2002). Thus, there is a dire need to find a cheaper alternate of P fertilizers for P deficient soil.

Recently, rock phosphate (RP), which is used as a raw material for phosphatic fertilizers, has appeared to be a potential source of plant P nutrition (Yu *et al*., 2012). Unfortunately, phosphorus in RP is not plant available in soils with an alkaline pH and even when conditions are optimal, plant yields are lower than those obtained with soluble phosphate (Khasawnech and Doll, 1978). In Pakistan, there are 26 million tons of RP reserves. Although local RP is being used for the manufacture of SSP however, the presence of Si impurities increases the cost of processing (Mehmood *et al*., 2010). Therefore, large quantity of RP is imported from Jordan and Morocco for the production of P fertilizers, which is another reason of high cost of P fertilizers.

Availability of P from relatively insoluble RP can be improved by integrating it with organic residues (Biswas and Narayanasamy, 2006) and phosphate solubilizing microorganisms (Chi *et al.,* 2007). Phosphate solubilizing bacteria (PSB) can transform the insoluble P to soluble forms of HPO_4^{2-} and $H_2PO_4^{-}$ by acidification, chelation, exchange reactions, and polymeric substances formation (Delvasto *et al*., 2006; Khan *et al.,* 2009). Therefore, use of PSB can not only offset the high cost of manufacturing

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phosphatic fertilizers but also mobilize insoluble phosphorus in the fertilizers (Rodriguez and Fraga, 1999).

In Pakistan, there is abundant production of municipal solid waste (MSW) in urban areas. Solid waste generation is estimated to be 55,000 tons/day (JICA and Pak-EPA, 2005). Government agencies are unable to handle this huge amount of solid waste and only 60% is collected and dumped in open places away from city. Compost prepared from the decomposition of MSW is being used the world over as organic source to improve soil properties. Application of compost in soils increases the availability of P by reducing its fixation (Kwabiah *et al*., 2003). The research work on improving the quality of municipal solid waste compost (MSWC) is lacking. Composting of municipal solid waste along with rock phosphate and PSB may help in managing huge volume of solid waste. It may also result in better quality compost with high P content to meet P deficiency in arid soils.

This research study was carried out with the objectives to improve the phosphorus content of municipal waste compost by treating it with rock phosphate and phosphorus solublizing bacteria and to study the effects of enriched municipal waste compost application on maize growth and soil.

Materials and Methods

Preparation of P-enriched compost

About 1000 kg municipal solid waste was collected from different dumping sites of the city. This waste was homogenized by thorough mixing and segregated to determine its physical composition which was: plastic, 17.3; paper, 10.7; cloth pieces, 5.6; metals, 2.9; animal residues, 3.2; glass, 1.5; stones, 3.4; wood, 0.4; miscellaneous decomposable material, 55 (all in %). Chemical composition of MSW included N, 0.97; P, 0.48; K, 0.93 (all in %); and Zn, 127; Cu, 67; Fe, 988; Mn, 197; Cr, 62; Cd, 0.96; Pb, 113 (all in mg kg^{-1}). Buffalo dung was added at 5% of MSW to serve as a natural inoculum/starter. This MSW-buffalo dung mixture was used as a base material for making P-enriched compost. Rock phosphate (RP) was collected from Abbotabad district with P_2O_5 content 24%, extractable P, 190; water soluble P, 3; K, 43; Zn, 4.0; Cu, 6.8; Fe, 28; Mn, 8.4; Ca, 190; Mg, 6.0; Pb, 150 (all in mg kg^{-1}). Average Si content of RP from this area is 10.86% (Mehmood *et al.,* 2010).

Nine enriched composts (EC) were prepared aerobically by mixing MSW, RP and PSB in different combinations. Treatments included: control/compost (MSW-dung mixture, base material), MSW with 5 and/or 10% RP, MSW with 5 and/or 10% RP along with two PSB strains (*Klebsiella pneumoniae* and/or *Burkholderia cepacia)*. Sources of *Klebsiella pneumoniae* and *Burkholderia cepacia* were rhizospheric soils collected from Kahuta soil series (Haplargids) and Balkasar soil series (Ustochrepts), respectively. These species were isolated from the soil samples in the Department of Soil Science, PMAS Arid Agriculture University Rawalpindi by culturing on Pikovskaya's agar medium (Pikovskaya, 1948), and characterized through biochemical tests (API Kit) and 16S rRNA gene sequencing in an earlier study (Khan *et al*., 2015). Moisture and aeration were maintained in all the treatments by regular monitoring of water content at 50% and turning the composting mixture.

Subsamples were drawn biweekly and analyzed for macronutrients (N, P, K), micronutrients (Cu, Zn, Fe, Mn), and C/N ratio. Composting was continued till constant temperature of the heaps. Compost enriched with 10% RP and both strains of PSB had the highest total P (2%) and water soluble P (120 mg kg^{-1}) contents, and it was selected for use in greenhouse experiment. Nutrient and mineral contents in the selected EC were: N, 1.3; P, 2; K, 1.2 (all in %); and Zn, 155; Cu, 100; Fe, 1298; Mn, 350; Cr, 87; Cd, 1.43; Pb, 142 (all in mg kg^{-1}).

Analytical procedures

Total P in rock phosphate was determined by digesting it with $HClO_4$ (Jackson, 1958) while water soluble P was determined by shaking a mixture of soil, water in 1:10 ratio and then determination of P spectrophotometrically (Olsen and Sommers, 1982). Total nitrogen in representative compost and plant samples was determined by digesting it with a mixture of sulfuric and salicylic acid (Buresh *et al.,* 1982). Total P in compost was determined by digesting compost samples with di-acid mixture of nitric and perchloric acid, and using ammonium vanado molybdate as colour developing solution (Jackson, 1973). Total K was measured in the digested filtrate directly by using flame photometer. For micronutrients and heavy metals, samples were digested with HNO_3, $HClO_4$ at 210 °C and then determination by atomic absorption spectrophotometer (Burau, 1982). Nitrate-N, P and K in soil were measured by using AB-DTPA method (Soltanpour and Workman, 1979). Soil pH and electrical conductivity were determined by the methods described by McLean (1982) and Richards (1954).

Greenhouse study

A greenhouse experiment was carried out following completely randomized design (CRD) to assess the effect of different rates of enriched compost (EC), selected in above study, on maize growth, nutrient content in soil and their uptake by plants. Ten kilogram air-dried, ground and sieved soil was filled in each pot. Characteristics of the soil were:

texture, sandy clay loam; EC, 0.43 dS m^{-1}, pH, 7.3; NO_3-N, 7.6 mg kg^{-1}; extractable P, 2.8 mg kg^{-1}; extractable K, 111 mg kg^{-1}; and organic matter, 0.76%. Treatments included: control (no compost), application of half (50 kg) and full dose (100 kg ha^{-1}) of P fertilizer (SSP), enriched compost for providing 50, 100, 150 and 200% of recommended P rate and combination of enriched compost and SSP (75:25) with 75% of recommended P from enriched compost and 25 % from SSP. Five maize seedlings were retained in each pot. Two seedlings were used for nutrient analysis after 45 days while remaining three seedlings were maintained in pots for 90 days. Soil samples drawn before sowing and after the harvest of crop were analyzed for N, P, K. Plant samples obtained after 90 days were analyzed for N, P, K along with crop parameters, viz. plant height, fresh and dry biomass.

Statistical analysis

Data regarding the effect of enriched compost treatments on plant growth attributes, nutrient contents in soil and plants were subjected to analysis of variance (ANOVA), and comparison of mean values was undertaken by LSD test (Steel *et al.*, 1997).

Results and Discussion

Effect of composting on total P dynamics

At the start of composting, total P content varied from 0.55% in simple MSW compost to 1.13% in 10% RP+PSB1+PSB2 (Figure 1). Total P content increased during composting. In simple compost it increased from 0.55 to 0.7%, a change of 27% over initial value. In 10% RP+ PSB1+PSB2 total P changed from 1.13 to 2%. Improvement in total P content to different extent was also noted in other treatments. In control, change in total P was more initially however, after 45 days change was very slow which could be due to the lack of decomposable organic material. Change in the volume of compost heaps was also prominent and within two weeks the volume reduced to almost half in many treatments. This loss of carbonaceous material could be one reason to increase total P content on weight basis (Bernal *et al.*, 2009). RP-amended compost resulted in higher total P as compared to control. However, this increase in total P was slow and gradual. So the compost mixture treated with 10% RP had higher total P compared to compost mixture treated with 5% RP. Highest total P (2%) was noted in 10% RP+PSB1+PSB2. Slow increase in total P content is beneficial as such compost can provide P to the crops gradually for a longer period of time. These results are supported by the previous findings of Nishanth and Biswas (2008). They composted rice straw along with RP, waste mica and P solublizing fungus. They reported higher total P content (3.9%) in the treatment receiving high application rate of RP with P solublizing fungus.

Effect of composting on soluble P dynamics

Water soluble P content was also affected prominently during composting (Figure 2). At the start of composting, soluble P ranged between 37 and 43 mg kg^{-1} while after the completion of composting, soluble P ranged from 61 to 120 mg kg^{-1} which accounted for a very significant increase of 65 to 179%. The highest soluble P content (120 mg kg^{-1}) at the end of composting was noted in 10% RP + PSB1 + PSB2, while the lowest (63 mg kg^{-1}) was recorded in control. At the beginning, there was a little difference among the treatments however, after two weeks, there was a noticeable change regarding soluble P in all treatments. Gradual change in soluble P was noted in the treatments where rock phosphate had been added. Among two rates of rock phosphate (5 and 10%), 10% RP accounted for higher soluble P. Moreover, greater changes were noted in the treatments where single strain of PSB or mixture of two strains of PSB had been applied compared to the treatments where no PSB had been applied. Soluble P improved significantly in the treatments where a mixture of rock phosphate and P solubilizing bacteria had been applied and in such cases slow release continued for longer period of time.

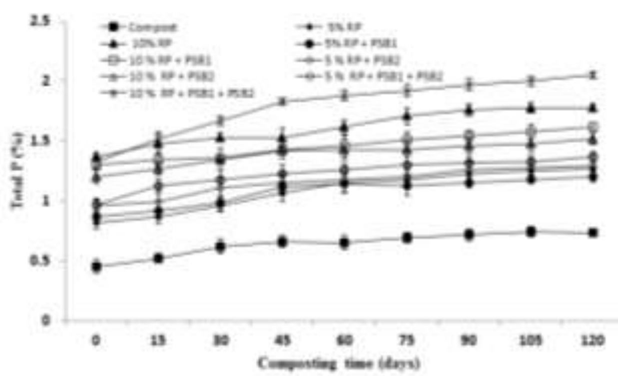

Figure 1: Total P dynamics during composting as affected by the addition of various levels of rockphosphate and P solublizing bacterial cultures

Due to the decomposition/mineralization of organic compounds, improvement in the soluble P content was expected. However, initial improvement in the level of soluble P in control was unexpected and could be due to the fact that decomposition of simple municipal waste material was very fast due to the favorable conditions however, in other treatments involving rock phosphate solubilization of phosphorus by microbes was not so fast rather it progressed gradually. In rock phosphate amended compost reaction of released inorganic soluble P with other cations could be another reason for reduced availability of soluble P (Singh *et al*., 1982). However, the advantage of RP amended compost could be consistent provision of soluble P for a longer period of time because even at 120 days of composting release of soluble P was relatively higher. Applying manures along with inorganic P fertilizer has been reported to be a good practice which not only reduces loss of inorganic P fertilizer but also makes it available for a longer period of time. Phosphorus solubilizing bacteria and fungi are well known to produce organic acids of various types like citric acid, tartaric acid, oxalic acid, gluconic and lactic acid (Babana and Antoun, 2006). These acids produce H^+ ions which solubilize inorganic phosphates and bring them in to soluble forms. Production of alkaline, acid phosphatase and phytase enzyme by PSB also contributes in the solubilization of rock phosphate. Level of phytase enzyme in the medium shows activity of P solubilization (Richardson *et al*., 2000.

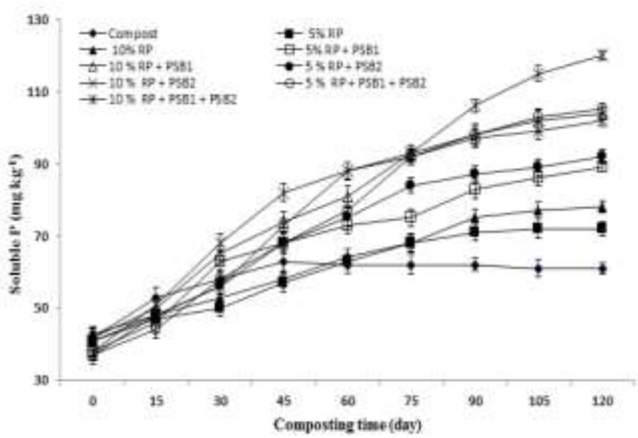

Figure 2: Soluble P dynamics during composting as affected by the addition of various levels of rock phosphate and P solublizing bacterial cultures

Macronutrient contents in soil

In the greenhouse experiment Nitrate-N, P and K contents in soil were affected significantly by the application of various treatments (Table 1). The lowest N, P and K contents in soil were noted in control. Among compost treatments, EC-200 gave the highest NO_3-N (18.7 mg kg^{-1}) and it was statistically at par with EC-150 (16.3 mg kg^{-1}). Results for NO_3-N in EC100 (15.6 mg kg^{-1}), EC-150 (16.3 mg kg^{-1}) and EC75+P25 (13.8 mg kg^{-1}) were statistically comparable. Highest soil P content was noted in EC-200 (6.8 mg kg^{-1}) however it was statistically similar to P100 (6.2 mg kg^{-1}) and EC150 (6.1 mg kg^{-1}). With increasing doses of enriched compost, P content in soil also improved.

According to critical limits given by Soltanpour and Workman (1985), above 7 mg kg^{-1} AB DTPA-P in soil is considered to be sufficient while 4 to 7 mg kg^{-1} as marginal. As soil was highly deficient in P so even the application of full dose of P fertilizer and high dose of enriched compost (EC-200) have not made soil sufficient in available P. Combined treatment (EC+P fertilizer) also resulted in good soil P content (5.3 mg kg^{-1}). This value is close to the recommended P fertilizer application but less than that with highest dose of enriched compost (EC-200).

Extractable potassium in soil was also affected significantly by various treatments. The mean minimum K content (114 mg kg^{-1}) was recorded in control, while the mean maximum K content (167 mg kg^{-1}) was recorded with EC-200. Soil potassium content improved with increased application of enriched compost. Increase in NO_3-N, P and K content in soil with compost treatments could be due to enhanced activity of microbes in soil (Iyamuremye and Dick, 1996) resulting in more mineralization and thereby availability of these nutrients. The rise in soil P might be because of higher P contents of the compost (Biswas and Narayanasamy, 2006). It also confirmed earlier studies suggesting MSWC to be a good source of plant available P (Cooperband *et al*., 2002). However, Gil *et al.* (2008) found statistically similar available phosphorus content in soil from mineral P fertilizer and a combination of compost and P fertilizer. Increased availability of P might also be due to the property of compost to decrease phosphorus retention by increasing competition between organic ligands and phosphates for fixation sites on metallic oxides (Iglesias-Jimenez *et al.*, 1993). Similarly, Iglesias-Jimenez and Alvarez (1993) concluded that application of MSWC at the rate of 40-50 Mg ha^{-1} provided nitrogen similar to inorganic fertilizer. Increased soil potassium and its uptake by the application of municipal solid waste have also been reported by Montemurro *et al*. (2006) in alfalfa and in red clover by Zheljazkov *et al.* (2006).

Macronutrient contents in plants

Comparatively lower N concentration in leaves (1.8%) was observed in control, while it improved both by the application of inorganic P fertilizer and increasing doses of enriched compost (Table 2). The highest nitrogen concentration (2.9%) was observed with EC200. However, the treatments viz. P100, EC100, EC150, EC200 and EC75+ P25 were statistically non significant in their effect on total plant nitrogen. Similar trend was also noted for total K concentration in maize leaves.

Table 1: Extractable N, P and K content of soil as affected by the application of different rates of P-enriched compost and P fertilizer

Treatment	NO_3-N	P	K
	mg kg $^{-1}$		
Control	9.5 d	2.6 e	114 e
P50	10.2 d	4.3 d	116 e
P100	11.3 cd	6.2 ab	119 e
EC50	11.8 cd	3.1 e	140 d
EC100	15.6 b	5.6 bc	152 bc
EC150	16.3 ab	6.1 abc	158 ab
EC200	18.7 a	6.8 a	167 a
EC75 + P25	13.8 bc	5.3 c	143 cd

Means with same letters are statistically non significant at *p* 0.05; P25, P50 and P100 represent P fertilizer for 25, 50 and 100 kg P_2O_5 ha^{-1}, respectively; EC 50, EC 100, EC 150 and EC 200 indicate P-enriched compost for 50, 100, 150 and 200 kg P_2O_5 ha^{-1}, respectively

In control, total P concentration (0.16%) was in deficient range (Walsh and Beaton, 1973). With the application of full dose of P fertilizer, total P was 0.42%, which was in sufficient range. Among the enriched compost treatments, the highest P concentration (0.47%) in plants was obtained with EC200. Phosphorus concentration from EC150 (0.38%), P100 (0.42%) and EC75+P25 (0.37%) were statistically similar. It is evident from the data that EC-200 produced highest P concentration which was statistically different from all other treatments. Nishanth and Biswas (2008) reported increased P uptake by wheat by the application of rice straw compost enriched with rock phosphate and phosphorus solubilizing fungus. On the other hand, Mkhabela and Warman (2005) reported non-significant difference in P uptake among various rates of MSWC and recommended NPK treatment.

Table 2: Total N, P and K content of maize plants as affected by the application of various rates of P-enriched compost and P-fertilizer

Treatment	Nitrogen	Phosphorus	Potassium
	%		
Control	1.8 c	0.16 e	1.2 e
P50	2.1 bc	0.22 d	1.48 bcd
P100	2.8 a	0.42 b	1.7 ab
EC50	1.9 c	0.24 d	1.33 de
EC100	2.6 a	0.32 c	1.45 cd
EC150	2.8 a	0.38 b	1.67 abc
EC200	2.9 a	0.47 a	1.73 a
EC75 + P25	2.5 ab	0.37 bc	1.67 abc

Means with same letters are statistically non significant at *p* 0.05; P25, P50 and P100 represent P fertilizer for 25, 50 and 100 kg P_2O_5 ha^{-1}, respectively; EC 50, EC 100, EC 150 and EC 200 indicate P-enriched compost for 50, 100, 150 and 200 kg P_2O_5 ha^{-1}, respectively

Compost application affected potassium concentration in maize significantly. Maximum K concentration (1.73%) was observed in plants treated with EC200, however it was at par with treatments viz. P100, EC150 and EC75 + P25. Similarly, treatments, viz. P50, EC100. EC150 and EC75 + P25 were also statistically non significant. The lowest K concentration (1.2%) was in control. The increased K concentration by application of enriched compost might be due to better availability of macro and micro nutrients in the compost which ultimately resulted in enhanced uptake of K by plants. It might also be because of more K release from the decomposition of organic compounds (Soumare *et al.*, 2003). Higher uptake of potassium in alfalfa by the application of municipal solid waste compost has been reported by Montemurro *et al.* (2006).

Table 3: Fresh, dry biomass weight and maize height as affected by the application of different rates of P-enriched compost and P-fertilizer

Treatment	Fresh weight	Dry weight	Plant height
	(g)		(cm)
Control	59.7 e	19.1 c	45.2 b
P50	74.2 de	22.9 bc	53.3 ab
P100	121.1 a	32.8 a	61.4 a
EC50	84.2 cd	24.9 abc	52.8 ab
EC100	96.6 bc	27.7 abc	57.4 ab
EC15	108.4 ab	30.8 ab	58.4 ab
EC200	123.6 a	32.3 a	58.9 ab
EC75+P25	114.8 ab	31.6ab	59.9 ab

Means with same letters are statistically non significant at *p* 0.05; P25, P50 and P100 represent P fertilizer for 25, 50 and 100 kg P_2O_5 ha^{-1}, respectively; EC 50, EC 100, EC 150 and EC 200 indicate P-enriched compost for 50, 100, 150 and 200 kg P_2O_5 ha^{-1}, respectively

Plant biomass and height

The perusal of the data regarding effect of different treatments on fresh and dry plant biomass (Table 3) indicated that the lowest fresh weight (59.7 g pot^{-1}) was obtained in control while it increased significantly by the application of P fertilizer at half and full rates where biomass was 74.2 and 121.1 g, respectively. Application of EC75+P25 also showed promising result where average fresh biomass was 114.8 g pot^{-1}. With increased application of enriched compost, the fresh weight was improved correspondingly. The same trend was noted for dry weight. Regarding plant height, all the treatments produced statistically non-significant difference, however the maximum plant height (61.4 cm) was observed in the pots receiving full dose of NPK, while it was minimum (45.2 cm) in control. Greater plant height with full NPK treatments is understandable as nutrients are readily available for plant use resulting in more plant growth. On the other hand compost supplies nutrients slowly but for a longer period of time (Cooperband *et al.,* 2002). As decomposition of compost takes some time so preferably the compost should be applied before crop sowing. He *et al.* (2003) recommended a gap of 6 months after compost application, while Loecke *et al.* (2004) suggested a gap of three months to allow sufficient time for the decomposition of compost. In our study, the compost was applied just two weeks before sowing, which was lesser time for decomposition. Therefore, it could also be a factor for less height of plants compared to that with chemical P fertilizer treatment.

Conclusion

This study suggests that enriched municipal solid waste compost is a good source of plant nutrients. Combined treatment involving enriched compost and phosphate fertilizer (75:25) could be preferable as it gave results comparable with high dose of enriched compost and full dose of chemical P fertilizer.

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References

Babana, A. and H. Antoun. 2006. Effect of Tilemsi phosphate rock-solubilizing microorganisms on phosphorus uptake and yield of field-grown wheat (*Triticum aestivum* L.) in Mali. *Plant and Soil* 287: 51-58.

Bernal, M.P., J. Alburquerque and H. Joosten. 2009. Composting of animal manures and chemical criteria for compost maturity assessment: A review. *Bioresource Technology* 100: 5444-5453.

Biswas, D.R. and G. Narayanasamy. 2006. Rock phosphate enriched compost: An approach to improve low grade Indian rock phosphate. *Bioresource Technology* 97: 2243-2251.

Burau, R.G. 1982. Lead. p. 347-365. *In:* Methods of Soil Analysis. Part 2. 2nd Ed. A.L. Page, R.H. Miller and D.R. Keeny (ed.). Agronomy Monograph 9. ASA and SSSA, Madison, WI, USA.

Buresh, R.J., E.R. Austin and E.T. Craswel. 1982. Analytical methods in N-15 research. *Fertilizer Research* 3: 37-62.

Chi, R., C. Xiao, X. Huang, C. Wang and Y. Wu. 2007. Biodecomposition of rock phosphate containing pyrites by *Acidithiobacillus ferrooxidans*. *Journal of Central South University of Technology* 14: 170-175.

Cooperband, L., G. Bollero and F. Coale. 2002. Effect of poultry litter and compost on soil nitrogen and phosphorus availability and corn production. *Nutrient Cycling in Agroecosystems* 62: 185-194.

Davies, T.G.E., J. Ying, Q. Xu, S. Li, J. Li and R. Gordon-Weeks. 2002. Expression analysis of putative high-affinity phosphate transporters in Chinese winter wheat. *Plant, Cell and Environment* 25: 1325-1339.

Delvasto, P., A. Valverde, A. Ballester, J.M. Igual, J.A. Munoz, F. Gonzalez, M.L. Blazquez and C. Garcia. 2006. Characterization of brushite as a recylization product formed during bacterial solublization of hydroxyapatite in batch cultures. *Soil Biology and Biochemistry* 38: 2645-2654.

Gil, M.V., L.F. Calvo, D. Blanco and M.E. Sánchez. 2008. Assessing the agronomic and environmental effects of the application of cattle manure compost on soil by multivariate methods. *Bioresource Technology* 99: 5763-5772.

He, Z.I., D.V. Calvert, A.K. Alva, Y.C. Li, P.J. Stoffella and D.J. Banks. 2003. Nitrogen transformation from biosolids and compost applied to calcareous soil. *Compost Science and Utilization* 11: 81-88.

Hisinger, P. 2001. Bioavailability of soil inorganic P in the rhizosphere as affected by root induced chemical changes: A review. *Plant and Soil* 237: 173-195.

Huang, G.F., J.W.C. Wong, Q.T. Wu and B.B. Nagar. 2004. Effect of C/N on composting of pig manure with sawdust. *Waste Management* 24: 805-813.

Iglesias-Jimenez, E. and C. Alvarez. 1993. Apparent availability of nitrogen in composted municipal refuse. *Biology and Fertility of Soils* 16: 313-318.

Iglesias-Jimenez, E., V. Garcia, M. Espino and J. Hernandez. 1993. City refuse compost as a phosphorus source to overcome the P-fixation capacity of sesquioxide-rich soils. *Plant and Soil* 148: 115-127.

Iyamuremye, F. and R.P. Dick. 1996. Organic amendments and phosphorus sorption by soils. *Advances in Agronomy* 56: 139-451.

Iyamuremye, F. and R.P. Dick. 1996. Organic amendments and phosphorus sorption by soils. *Advances in Agronomy* 56: 139-185.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall, Inc., Englewood Cliffs, New Jersey, USA.

Jackson, M.L. 1973. Soil Chemical Analysis. Pranctice Hall of India, New Delhi. India.

JICA (Japan International Cooperation Agency) and Pak-EPA (Pakistan Environmental Protection Agency). 2005. Guidelines for Solid Waste Management, Pak-EPA, Pakistan.

Khan, A.A., G. Jilani, M.S. Akhtar, M. Islam and S.M.S. Naqvi. 2015. Potential of phosphorus solubilizing microorganisms to transform soil P fractions in sub-tropical Udic Haplustalfs soil. *Journal of Biodiversity and Environmental Sciences* 7(3): 220-227.

Khan, A.A., G. Jilani, M.S. Akhtar, S.M.S. Naqvi and M. Rasheed. 2009. Phosphorus solubilizing bacteria: Occurrence, mechanisms and their role in crop production. *Journal of Agricultural and Biological Science* 1: 48-58.

Khasawneh, F.E. and E.C. Doll. 1978. The use of phosphate rock for direct application to soils. *Advances in Agronomy* 30: 159-206.

Kwabiah, A.B., N.C. Stoskopf, C.A. Palm, R.P. Voroney, M.R. Rao and E. Gacheru. 2003. Phosphorus availability and maize response to organic and inorganic fertilizer inputs in a short term study in western Kenya. *Agriculture, Ecosystems and Environment* 95: 49-59.

Loecke, T.D., M. Liebman, C.A. Cambardella and T.L. Richard. 2004. Corn response to composting and time of application of solid swine manure. *Agronomy Journal* 96: 214-223.

McLean, E.O. 1982. Soil pH and lime requirement. p. 199-224. *In:* Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. A.L. Page (ed.). American Society of Agronomy, Madison, WI, USA.

Mehmood, R., M.A. Bhatti, K.R. Kazmi, A. Mehmood, S.T. Sheikh and S.A. Shah. 2010. Mineralogical and textural characteristics of Kakul (Hazara) phosphate rock, NWFP, Pakistan. *Pakistan Journal of Scientific and Industrial Research* 53**:** 303-310.

Mkhabela, M.S. and P.R. Warman. 2005. The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops grown in a Pugwash sandy loam soil in Nova Scotia. *Agriculture, Ecosystems and Environment* 106: 57-67.

Montemurro, F., M. Maiorana, G. Convertini and D. Ferri. 2006. Compost organic amendments in fodder crops: Effects on yield, nitrogen utilization and soil characteristics. *Compost Science and Utilization* 14: 114-123.

Nishanth, D. and D.R. Biswas. 2008. Kinetics of phosphorus and potassium release from rock phosphate and waste mica enriched compost and their effect on yield and nutrient uptake by wheat. *Bioresource Technology* 99: 3342-3353.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus. p. 403-430. *In:* Methods of Soil Analysis. Part 2. 2nd Ed. A.L. Page and R.H. Miller (ed.). Agronomy Monograph 9. ASA and SSSA, Mdison, WI, USA.

Pikovskaya, R. I. 1948. Mobilization of phosphorus in soil in connection with vital activity of some microbial species. *Microbiology* 17: 362-370.

Rashid, A. and F. Qayyum. 1991. Cooperative research programme on micronutrient status of Pakistan soils and its role in crop production. p. 1983-90. *In:* Final Report. National Agricultural Research Centre, Islamabad.

Richard, L.A. 1954. Diagnosis and Improvement of Saline and Alkaline Soils. USDA Agricultural Handbook 60. Washington, D. C. USA.

Richardson, A.E., P.A. Hadobas and J.E. Hayes. 2000. Acid phosphomonoesterase and phytase activities of wheat (*Triticum aestivum* L.) roots and utilization of organic phosphorus substrates by seedlings grown in sterile culture. *Plant, Cell and Environment* 23: 397- 405.

Rodriguez, H. and R. Fraga. 1999. Phosphate solubilizing bacteria and their role in plant growth promotion. *Biotechnology Advances* 17: 319-339.

Singh, C.P., M.M. Mishra and K.K. Kapoor. 1982. Solubilization of insoluble phosphate by mesophilic fungi. *Revue d'ecologie et de biologie du sol* 19: 17-25.

Soltanpour, P.N. and S. Workman. 1979. Modification of the $NaHCO_3$ DTPA soil test to omit carbon black. *Communications in Soil Science and Plant Analysis* 10: 1411-1420.

Soltanpour, P.N. and S. Workman. 1985. Use of ammonium bicarbonate-DTPA soil test to evaluate elemental availability and toxicity. *Communications in Soil Science and Plant Analysis* 16: 323-338

Soumare, M., F.M. G. Tack and M.G. Verloo. 2003. Effects of municipal solid waste compost and mineral fertilization on plant growth in two tropical agricultural soils of Mali. *Bioresource Technology* 86: 15-20

Steel, R.G.D., J.H. Torrie and M.A. Boston. 1997. Principles and Procedures of Statistics: A Biometrical Approach. 2nd Ed. McGraw Hill Book Co. Inc., New York, USA.

Walsh, L.M. and J.D. Beaton. 1973. Soil Testing and Plant Analysis. Soil Science Society of America, Madison, Wisconsin, USA.

Yu, X., X. Liu, T.H. Zhu, G.H. Liu and C. Mao. 2012. Co-inoculation with phosphate-solubilzing and nitrogen-fixing bacteria on solubilization of rock phosphate and their effect on growth promotion and nutrient uptake by walnut. *European Journal of Soil Biology* 50: 112-117

Zheljazkov, V., T. Astatkie, C.D. Caldwell, J. MacLeod and M. Grimmett. 2006. Compost, manure, and gypsum application to timothy/red clover forage. *Journal of Environmental Quality* 35: 2410-2418.