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ORIGINAL RESEARCH

Forms of phosphorus of vermicompost produced from leaf compost and sheep dung enriched with rock phosphate

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Abstarct

Introduction Vermicomposting could increase nutrients availability including phosphorus. During vermicomposting, a decomposition of organic substrates leads to the production of several organic acids, such as malonic, fumaric, succinic acids. Microorganisms both in the intestinal organ of the worms and the organic waste have the ability to convert insoluble P into soluble forms. Little information exists about the effects of vermicomposting on rock phosphate (RP) solubilization. Present study was conducted to evaluate the solubilization of powdered RP during vermicomposting.

Results Vermicomposting and RP application increased $NaHCO_3$-P_i. Rock phosphate application in vermicomposting significantly increased $NaHCO_3$-P_o. Vermicomposting significantly increased NaOH-P_i in all of the treatments. RP application and vermicomposting increased HCl-P_i in both organic sources. Generally, vermicomposting increased HCl-P_o. Vermicomposting decreased pH but its effect was more evident in the presence of RP. Vermicomposting increased EC in both organic sources.

Conclusion Present study showed that vermicomposting helps to enhance the transformation of P from RP into various organic or inorganic P forms, which would be readily or moderately available, thus, increase the availability of P from both RPs.

Keywords *Eisenia fetida* · $NaHCO_3$-P · NaOH-P · HCl-P

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Introduction

The high cost of chemical P fertilizer production has generated considerable interest toward direct utilization of rock phosphate in some countries as well as Iran (Besharati et al. 2001). Most of the RPs are reasonably suitable for direct use in acid soils, but has not given satisfactory results in neutral to alkaline soils (Narayanasamy and Biswas 1998). Some methods for improving the efficacy of RP are mixing with elemental sulfur (Mohammady Aria et al. 2010), partial acidulation with nominal amount of acid, dry compaction with water-soluble P fertilizers (Biswas and Narayanasamy 2006) and mixing RP with organic residues, such as compost, manure, and vermicompost (Odongo et al. 2007; Biswas and Narayanasamy 2006).

Vermicompost is an efficient tool to manage the utilization of organic residues (Garg et al. 2006) and increase nutrients availability including phosphorus (Ghosh et al. 1999; Venkatesh and Eevera 2008). During vermicomposting, a decomposition of organic substrates leads to the production of several organic acids such as malonic, fumaric, succinic acids (Epstein 1997), and soluble humic molecules (Atiyeh et al. 2002). Both assimilation and mineralization of phosphorus are microorganisms mediated processes and application of vermicompost increases the rates of these two processes in soil.

Previous studies have revealed the beneficial effect of mixing rock phosphate with vermicompost. Pramanik et al. (2009) repoted that vermicomposts increased (13–26 %) available P of soil after 90 days of incubation. Available P content of rock phosphate-treated soils increased steadily up to 45 days of incubation, but thereafter it gradually decreased forming a parabolic shaped rate curve for P transformation. Initial decrease in P content in vermicompost-treated soils could be avoided or minimized by

Table 1 Chemical properties of raw organic materials

Organic matter	$NaHCO_3$-P_i (mg kg^{-1})	$NaHCO_3$-P_o	P_t* (%)	O.C	C:P	EC (dS m^{-1})	pH (1:2.5)	WHC (%)
Sheep dung	291	45.5	0.35	38.9	111	8.7	8.5	80
Leaf compost	388	32.4	0.28	21.2	76	1.02	8.1	60

* P_t (%); O.C; EC; WHC represent total phosphorus; organic carbon; electrical conductivity; and water-holding capacity, respectively

application of rock phosphate in combination with vermicomposts (Pramanik et al. 2009). Mohammady Aria et al. (2010) observed that vermicompost had a significant effect on the water-soluble phosphates of hard phosphate rock.

Many studies have been conducted about the changes of biochemical properties and nutrients (including P) availability during vermicomposting, but little information exists about the effects of vermicomposting on RP solubilization, and various organic or inorganic P fractions. Present study was conducted to evaluate the solubilization of RP from Esfordi plant during vermicomposting and the influence of RP on pH and EC of the produced vermicompost.

Methods and materials

Preparation of materials

Two organic matters (leaf compost and sheep dung) were used in the present study. Chemical characteristics of organic sources including pH and electrical conductivity (EC) in a 1:2.5 water mixture, loss on ignition by heating at 550 °C for 4 h, organic and inorganic phosphorus soluble in bicarbonate ($NaHCO_3$-P_o and $NaHCO_3$-P_i), total P after dry ashing (Kou 1996) and C:P ratio were determined. Water-holding capacity was determined following 24 h drainage of saturated organic materials (Table 1). Moisture content of OM was determined by drying a specified weight under 70 °C for 48 h.

Experimental treatments consisted of a factorial combination of organic matter (compost or sheep dung), powder rock phosphate (Zero, 6 % raw RP, and 2 % modified RP) and earthworms of *Eisenia fetida* (zero or 20 adult individuals per pot) with three replications in a completely randomized design. Powder of raw and modified RP was obtained from Esfordi phosphate Plant. The modification procedure contains leaching and floatation and includes no acid treatment, thereupon the water-soluble P of both RP was negligible. Physico-chemical characteristics of phosphate materials are presented in Table 2.

Five hundred g of calculated dry organic matter (based on moisture content) was placed in a suitable plastic bag with appropriate amount of RP. After thoroughly mixing,

Table 2 Chemical characteristics of rock phosphate

Substance	Water-soluble P	Total P_2O_5 %	SiO_2	Fe_2O_3	Cd mg kg^{-1}
Raw	Not detectable	12 ± 1	1.2 ± 0.5	1.4 ± 0.7	3 ± 2
Modified	Not detectable	37 ± 1	3.50 ± 1	3.5 ± 1	10 ± 5

materials were transferred into suitable plastic pots, which contained a three cm layer of rinsed sand beneath. Ten pairs of earthworm species *Eisenia fetida* were placed on each pot and sprayed gently with water. Pots were kept at 70 % water-holding capacity by weighing each 3 days under lab temperatures. After 2 months organic materials was separated by sieving at suitable moisture content and allowed to air dry.

Chemical analyses

Inorganic and organic P fractions was extracted separately with sodium bicarbonate 0.5 M pH 8.5 after 30 min shaking ($NaHCO_3$-P_i and $NaHCO_3$-P_o, respectively), sodium hydroxide 0.1 M after 2 h shaking (NaOH-P_i and NaOH-P_o, respectively), hydrochloric acid 0.5 M after 2 h shaking (HCl-P_i and HCl-P_o, respectively). Reactive P in the supernatant was determined using the ascorbic acid method at 882 nm (Murphy and Riley 1962) and total P of the supernatants was determined after digestion of a suitable aliquot as described by Fan et al. (1999). Organic P was calculated as the difference between total and reactive P in the extracts. pH and electrical conductivity (EC) were determined in a 1:2.5 OM:water mixture.

Statistical analyses conducted using MSTATC software.

Results and discussion

Phosphorus fractions

Vermicomposting increased $NaHCO_3$-P_i from 145 mg kg^{-1} in the control of sheep dung to 215 mg kg^{-1}. Application of 6 and 2 % of raw and modified RP increased

Table 3 Changes in the $NaHCO_3$ extractable P (mg kg^{-1}) of sheep dung and leaf compost ($LSD_{0.05}$ for $NaHCO_3$-P_i = 7.37 and for $NaHCO_3$-P_o = 7.91)

	Vermicomposting		Mean
	−	+	
$NaHCO_3$-P_i			
Sheep dung			
0	145	215	180
6 % Raw RP	220	227	223
2 % modified RP	228	237	232
Mean	197	226	211
Compost			
0	139	203	171
6 % Raw RP	181	226	203
2 % modified RP	199	230	214
Mean	173	219	196
$NaHCO_3$-P_o			
Sheep dung			
0	84	131	107
6 % Raw RP	86	123	104
2 % modified RP	96	150	123
Mean	88.7	134	111
Compost			
0	71	78	74.5
6 % Raw RP	108	115	111
2 % modified RP	119	131	125
Mean	99.3	108	103

Table 4 Changes in the NaOH extractable P (mg kg^{-1}) of sheep dung and leaf ($LSD_{0.05}$ for NaOH-P_i = 3.80 and for NaOH-P_o = 10.3)

	Vermicomposting		Mean
	−	+	
NaOH-P_i			
Sheep dung			
0	31.3	49.9	40.6
6 % Raw RP	39.4	59.1	49.6
2 % modified RP	44.4	53.6	49
Mean	38.3	54.2	46.3
Compost			
0	10.5	29.8	20.1
6 % Raw RP	13.6	33.8	23.7
2 % modified RP	15.7	41.9	28.8
Mean	13.3	35.1	24.2
NaOH-P_o			
Sheep dung			
0	69.5	144	106
6 % Raw RP	72.5	150	111
2 % modified RP	100	192	146
Mean	80.7	162	121
Compost			
0	42.8	83.7	63.2
6 % Raw RP	57.2	105	81.1
2 % modified RP	52.2	109	80.6
Mean	50.7	99.2	74.9

this fraction to 220 and 228 mg kg^{-1} but vermicomposting did not considerably change it in the presence of RP. Similar to sheep dung, RP application and vermicomposting increased $NaHCO_3$-P_i of leaf compost. In average, vermicomposting increased $NaHCO_3$-P_o by 35 % and the trend was consistent in all of the treatments. Rock phosphate application had a little effect on $NaHCO_3$-P_o in the absence of vermicomposting but when vermicomposted significantly increased $NaHCO_3$-P_o, i.e., vermicomposting of 2 % modified RP treatments caused 54 and 12 mg kg^{-1} increase of $NaHCO_3$-P_o in sheep dung and leaf compost, respectively (Table 3). Among different P fractions, bicarbonate extractable inorganic and organic P ($NaHCO_3$-P_i and $NaHCO_3$-P_o) collectively form the bioavailable or labile P in the soil (Sui et al. 1999). Previous studies have revealed the increase of inorganic available P by vermicomposting. Ghosh et al. (1999) found that saloid-bound P was considerably higher in the earthworm-treated wastes than in the wastes without earthworms, showing that inoculation of earthworms in wastes was useful in increasing the amount of such loosely held and, thereby, easily accessible, forms of P in the organic wastes. Pal Vig et al. (2001) reported that the total available P was significantly higher after vermicomposting than the initial one. In the present study, it was observed that in addition to easily available P_i, easily available P_o will be enhanced by vermicomposting.

Sodium hydroxide extractable P_i (NaOH-P_i) in sheep dung was almost threefold of that in leaf compost (Table 4). Sodium hydroxide (NaOH) is mainly used to remove inorganic Al and Fe–P fraction in soils (Adhami et al. 2006) but when used for OM the origin of inorganic P is undefined and in this case it might extract acidic phosphatase. Rock phosphate application had a little effect on this fraction (Table 4), while vermicomposting significantly increased it in all of the treatments. In average, vermicomposting caused 75 % increase of NaOH-P_i, but the effects of the treatments were more evident on NaOH-P_o. In average vermicomposting cuased about 100 % increase of NaOH-P_o. Application of 2 % modified RP increased NaOH-P_o by 30.5 mg kg^{-1} in sheep dung but the increase was less for leaf compost (Table 4). According to Cross and Schlesinger (1995), soil organic C controls variability of NaOH-P_o pool in the soils. The NaOH extracts P mainly from organic components and some amorphous aluminum-containing compounds in soil (Cassagne et al. 2000) that is; the P associated with humic acids

Table 5 Changes in the HCl extractable P (mg kg^{-1}) of sheep dung and leaf compost ($LSD_{0.05}$ for HCl-P_i = 41.75 and for HCl-P_o = 80.17)

	Vermicomposting		Mean
	−	+	
HCl-P_i			
Sheep dung			
0	888	1,233	1,060
6 % Raw RP	991	1,401	1,196
2 % modified RP	1,097	1,476	1,286
Mean	992	1,370	1,180
Leaf Compost			
0	860	1,265	1,062
6 % Raw RP	971	1,683	1,377
2 % modified RP	1,148	1,746	1,447
Mean	1,026	1,564	1,295
HCl-P_o			
Sheep dung			
0	960	1,016	988
6 % Raw RP	989	1,207	1,098
2 % modified RP	1,048	1,293	1,170
Mean	999	1,172	1,085
Leaf Compost			
0	659	869	764
6 % Raw RP	878	748	813
2 % modified RP	934	867	900
Mean	823	828	825

or chemisorbed to the surfaces of Fe and Al compounds (Schoenau et al. 1989). The products of microbial decomposition of organic materials might solubilize some of the sorbed or recalcitrant P in soil causing an increase in organic P associated with the humic substances (Reddy et al. 2005). Organic P extracted with NaOH (NaOH-P) is introduced as stable organic P compounds (Fan et al. 1999), though this fraction is not readily available for plants, but the high resistance of this fraction could maintain P availability in an intermediate period. Nonlabile P fractions are thought to be tightly bound to soil particles, and unavailable to plants. The nonoccluded phosphorus, including phosphorus that is extracted with NaOH, is considered to be biologically available over an intermediate time scale (Cross and Schlesinger 1995).

Inorganic P extracted with HCl is attributed to the highly stable Ca–P compounds (i.e., various apatite compounds). This fraction was the highest among various P fractions in all of the treatments and showed the highest increase with RP application. Rock phosphate application increased inorganic P extracted with HCl (HCl-Pi) in both organic sources. The increase of HCl-Pi by the RP addition was almost equal for both organic sources in the absence of vermicomposting. In average, HCl-Pi increased by 209 and 288 mg kg^{-1} in 2 % modified RP in sheep dung and leaf compost, respectively. In addition, vermicomposting was associated with a great increase of HCl-Pi in both organic sources. On the other hand, vermicomposting in the presence of RP considerably increased HCl-Pi (Table 5). Vermicomposting of leaf compost increased HCl-Pi around 405 mg kg^{-1} but in the presence of RP the increase was about 598 mg kg^{-1}. In average, vermicomposting increased HCl-Pi by 450 mg kg^{-1}. HCl-P_o increased from 960 mg kg^{-1} in the control of sheep dung to 1,048 mg kg^{-1} by the addition of 2 % modified RP while the increase was higher in the leaf compost and caused 275 mg kg^{-1} increase of HCl-P_o. Generally, vermicomposting increased HCl-P_o in sheep dung and the application of RP caused higher increase of HCl-P_o; the trend, which was not observed for leaf compost (Table 5). The HCl-P_o is considered to be derived from particulate organic matter which is unavailable in its current form but may become bioavailable after microbial decomposition (Tiessen and Moir 1993).

When organic matter are passed through gut of earthworms, some phosphorous being converted with more availability to plants (Lee 1985), which might be the cause for the increase in available phosphorous content of the vermicompost in the present study. The increase in phosphorus is due to both direct action of worm gut enzymes and indirectly by stimulation of the microflora (Lee 1985).

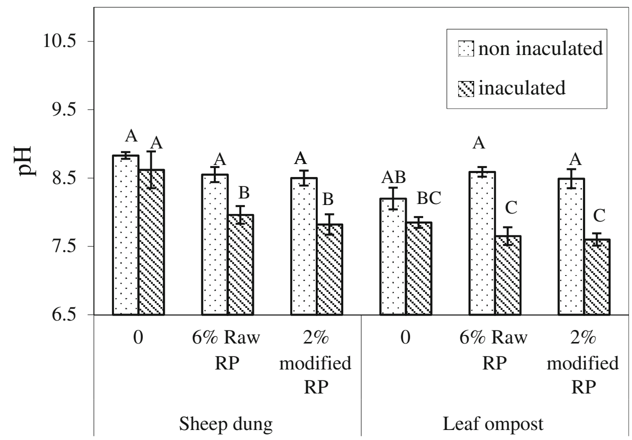

Fig. 1 Changes in the pH value of sheep dung and leaf compost in presence and absence of *Eisenia fetida*. Means within the same organic sources followed by the *same letter* are not significantly different at $P < 0.01$

pH and EC

Changes of pH by RP application was low and not consistent for the both organic sources (i.e., RP application decreased pH of sheep dung slightly but not in leaf compost). Vermicomposting decreased pH but its effect was

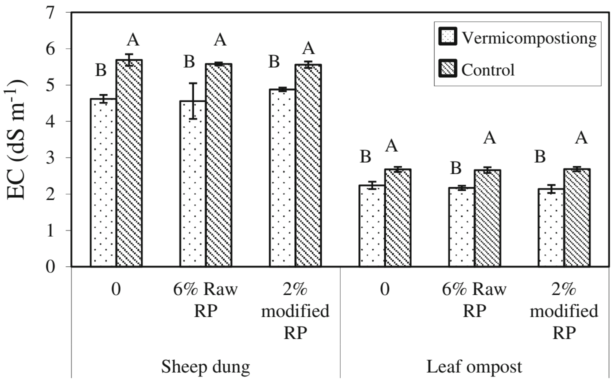

Fig. 2 Changes in the EC (dS m^{-1}) value of sheep dung and leaf compost in presence and absence of *Eisenia fetida*. Means within the same organic sources followed by the *same letter* are not significantly different at $P < 0.01$

more pronounced in the presence of RP. Vermicomposting decreased pH of sheep dung from 8.82 in control to 8.62 in the absence of RP, but decreased to 7.96 and 7.82 in the presence of 6 and 2 % of raw and modified RP, respectively. Similar results were observed in leaf compost (Fig. 1). This is in accordance with the results of Atiyeh et al. (2000) and Venkatesh and Eevera (2008) and Raphael and Velmourougane (2011). pH decrease may be due to the accumulation of organic acids from microbial metabolism or from the production of fulvic and humic acids during decomposition (Albanell et al. 1988).

Vermicomposting caused the highest changes of EC in both organic sources and its effect seemed to be independent of presence or type of RP. In average, the EC of sheep dung and leaf compost were 4.69 and 2.18 dS m^{-1} and increased to 5.61 and 2.68 by vermicomposting, respectively (Fig. 2). RP application or type did not cause considerable and consistent changes of EC. The electrical conductivity reflects the salinity of an organic amendment. The increase of EC during vermicomposting is also reported by others (Venkatesh and Eevera 2008; Pal Vig et al. 2001). The increase in EC could be due to loss of organic matter and release of different mineral salts in available forms, such as phosphate, ammonium, potassium, etc. (Venkatesh and Eevera 2008; Pal Vig et al. 2001; Kaviraj and Sharma 2003).

Conclusion

Present study showed that vermicomposting helps to enhance the transformation of P from RP into various organic or inorganic P forms, which would be readily or moderately available. Thus, increase the availability of P from both RPs. RPs application helped the decrease of pH through vermicomposting which would cause higher nutrients availability. EC increased by vermicomposting but RP addition had a little effect on it.

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