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Full Length Research Paper

Phosphorus mineralisation and agronomic potential of PPB enhanced cattle manure

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Abstract

A study was conducted to determine phosphorus (P) mineralisation and agronomic potential of pelletized phosphate blends (PPB) enhanced cattle manure using incubation and green house experiments for two soils in Zimbabwe. Under incubation, the rate of P mineralization for untreated and PPB treated manures was determined using the Bray 1 method on destructive samples (2 g sub-sample) of the soils collected 3, 7, 14, 28 and 42 days after incubation had commenced. A green house experiment was established to test for direct and residual effect of 10 and 20 t ha^{-1} of untreated and PPB enhanced cattle manure on P uptake and crop growth using maize as a test crop for 5 weeks after crop emergence (WACE). The pots were arranged in a randomized complete block design with each treatment replicated three times. The results of the incubation study showed a significant decrease in the amount of P release into solution for the two soils. The greenhouse results showed no significant ($p < 0.05$) difference in the maize biomass yield at 5 WACE between the untreated and PPB enhanced manures from both soils. However, the maize P uptake differs with soils across all the treatments. There was no significant ($p < 0.05$) difference in the available P in the biomass harvested among all the treatments regardless of soil type used. The study confirmed that if rock phosphate is mixed with cattle manure without composting, there is no improvement in P availability and uptake by maize.

Keywords: Phosphorus availability, cattle manure, PPB enhanced manure, maize establishment.

INTRODUCTION

Household food security is mostly dependent on maize yields as it is the staple food and the most widespread crop grown in Zimbabwe (FAO, 2010). However, efforts to increase maize grain yields beyond the 1 t ha^{-1} in most smallholder farming systems of Zimbabwe are undermined by nitrogen (N) and phosphorus (P) deficiencies in most sandy soils. The persistent N and P supply shortfall remain a challenge and a threat to over 70 % of the rural populations primarily drawing their livelihoods from agriculture, as farmers continually deplete nutrients with no corresponding additions (Smaling *et al.*, 1997). Most of the resource constrained maize farmers in communal areas fail to apply both basal and top dressing fertilizers for crop production (Mano, 2006 cited by Chimhou *et al.*, 2010). Farmers give first preference to top dressing fertilisers (e.g. Ammonium nitrate and urea) yet the basal P fertilizers are critical in crop establishment.

Most smallholder farmers use locally available organic amendments such as cattle manure, crop residues, and leaf litter to improve soil fertility (Bationo and Mokwunye, 1991). However, such amendments can be limited in quantities depending on location (e.g. dry areas where low biomass and litter is produced) and farming systems where there is strong livestock-crop interact-tions (Mapfumo and Giller, 2001). In cases where organic

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resources are available they can supply no more than 15 kg N t^{-1} and 1.5 kg P t^{-1} (Mapfumo and Giller, 2001) and when applied at common rates of 3-5 t ha^{-1} dry matter depending on availability and generally supply 45-75 kg N ha^{-1} and 4.5-7.5 kg P ha^{-1}, against a maize major nutrient requirement of N (200 kg ha^{-1}), P (90 kg ha^{-1}) and K (70 kg ha^{-1}). In such a system, the most limiting nutrient will be P, to sustain grain production (Tanner and Mugwira, 1984; Vanlauwe and Giller, 2006). Cereals will respond to N fertilization only when P deficiencies are addressed, therefore using organic amendments, which can not supply adequate P, may reduce the potential associated with combining organic and inorganic fertilizers (Bationo *et al*., 1990).

Agro-geology involves use of rock parent material to increase soil productivity for agricultural crops. Zimbabwe has abundant rock phosphate deposits in Mashonaland East Province (Dorowa area), which can supply a cheap source a cheap source of P (Akande *et al*., 1998; Dhliwayo, 1999). However, direct use of Dorowa phosphate rock (DPR) as a P source is limited due to low solubility in neutral and alkaline conditions (Dhliwayo, 1999). Given that mineral fertilizers are expensive and farmers' can secure limited quantities, locally available resources are potential sources of fertilizer for most smallholder farmers (Blackie, 1994) and thus there is need to find alternative options to improve phosphate rock quality for utilization. Current efforts have been directed at composting of phosphate rock with agricultural waste, and results have shown an increase in solubility of phosphate rock (Akande *et al*., 1998; Akande *et al.,* 2005). Pelletization of DPR with SSP to produce pelletized phosphate blends (PPB) has also been shown to improve the dissolution of DPR in soil (Menon and Chien, 1990). The availability of rock phosphate gives impetus to look at how we can enhance P availability for uptake by maize. This study investigated the agronomic potential and effectiveness of pelletized phosphate blends enhanced cattle manure on maize establishment. Specific study objectives were to a) determine the P release patterns from PPB enhanced cattle manure; and b) evaluate the effect of PPB enhanced cattle manure on P uptake and maize plant growth during crop establishment.

MATERIALS AND METHODS

Study site

The study was conducted over one season (2007/8) in two parallel experiments: (a) laboratory P release incubation tests and (b) investigation of agronomic potential of the PPB enhance manure under greenhouse conditions. The incubation tests were conducted in Soil Science and Agricultural Engineering Department laboratories while the green house was established at Crop Science Department facilities at the University of Zimbabwe. To determine the P release patterns from PPB enhanced manure, soil samples (0-20 cm) were collected from Buhera and Marenga villages in Buhera District ($19^{0}04^{1}$S; $31^{0}46^{1}$E) of Zimbabwe. Buhera District lies in agro-ecological region III, where average rainfall is 650 mm a^{-1}, mostly restricted to the summer season from November to April (Surveyor General, 2002). The soils are classified as Typic Kandiustaff derived from granitic parent material with relatively low water holding capacity and consists of sandy to loamy sands (Vogel *et al.,* 1994).

Sampling and chemical characterisation of soil, manure and PPB enhanced manure

A total of five sub-samples of soil (10 kg each) were randomly collected from five different farmers' fields within a village. The sub-samples were thoroughly mixed in a polystyrene bucket to make a 50 kg composite sample. The two composite samples (Buhera and Marenga) were air-dried, sieved through a 2 mm sieve and followed by determination of texture, mineral N, available P, organic carbon, exchangeable bases (Ca, Mg, K) and micronutrients as described by Anderson and Ingram (1993). The manure and enhanced PPB manure used for the both laboratory and greenhouse studies were collected from the two study sites. Ten sub-samples of manure and enhanced PPB manure were randomly taken from different positions of the respective heaps to make a composite 20 kg sample. The collected composite samples for each manure type (PPB treated and untreated manure) were ground and sieved to pass through a 0.2 mm sieve before being analysed for total N and P using the modified micro-Kjeldahl procedure (Anderson and Ingram, 1993). To a mass of 0.02 g of the sample, 5 ml of concentrated sulphuric acid and selenium mixture was added. The mixture was digested at about 70 ^{o}C until the solution was clear to pale yellow and then cooled for 10 minutes. The contents of the digestion flask were transferred into the distillation flask by rinsing twice with distilled water and the sidearm replaced. To the distillate, 20 ml of 50 % NaOH was steadily introduced to liberate NH_3 from the solution which was cooled and absorbed in 5 ml of boric acid indicator until the solution reached the 50 ml mark. Total N was then determined by titration with standardised sulphuric acid (H_2SO_4). The titre value was taken as the N content of the sample. As for the total P, 1 g of the ground material was saturated with calcium acetate and ashed in a muffle furnace at 450 ^{o}C for twelve hours. After the ash had cooled, 3 drops of distilled water was added and followed by 2 ml of 50 % hydrochloric acid before being heated to dryness. Five (5) ml of 25 % nitric acid were added to dissolve the contents and transferred quantitatively into a 50 ml volumetric flask which was filled to the mark with distilled water. After

Table 1. Chemical characteristics of soils (0 - 20cm) from Buhera and Marenga used in the study

Site	Organic C (%)	Total N (%)	Available P (mgkg^{-1})*	pH ($CaCl_2$)	Ca	Mg (me %)	K	Fe	Mn (ppm)	Zn	Cu
Buhera	0.28	0.03	7.2	4.4	0.62	0.18	0.12	35	8	4	28
Marenga	0.34	0.05	12.4	4.9	0.67	0.16	0.14	42	12	7	23

*Bray 1 P method

diluting the solution, 10 ml of vanadomolybdate reagent was added and the total P was determined colorimetrically by spectrophotometry (Bremner and Mulvancy, 1982).

Phosphorus mineralisation

Phosphorus release patterns of untreated manure, PPB enhanced manure and unamended soils (control) were determined in an incubation experiment (Robinson and Syers, 1990). The incubation method estimates the potential release of P into solution under suitable field conditions (adequate moisture and temperature) for mineralisation of soil organic matter (McClellan and Gremillion, 1980). The sampled soils from Buhera and Marenga villages were mixed with manure and PPB enhanced manure at a rate equivalent to 10 t ha^{-1} in petri dishes with 200 g of soil. The Petri dishes were arranged in a complete randomised design (CRD), with each treatment replicated three times. The petri dishes were put in 1L jars and incubated in the dark at 28 ^{0}C in a constant temperature room. The moisture content of the petri dishes was maintained at field capacity by weekly adjustments. Destructive sampling (2 g sub-sample) of the soils was done at 3, 7, 14, 28 and 42 days after the incubation commenced to determine available P using the Bray 1 method.

Agronomic potential experiment

To evaluate the agronomic potential of PPB enhanced cattle manure on P uptake and maize growth, a pot trial was established under greenhouse conditions. Buhera and Marenga soils were used for this greenhouse experiment with both manure and PPB enhanced manure applied at 10 and 20 t ha^{-1}. Thus the following treatments were tested: (i) Soil + 10t ha^{-1} manure, (ii) Soil + 10t ha^{-1} PPB enhanced manure, (iii) Soil + 20 t ha^{-1} manure, (iv) Soil + 20 t ha^{-1} PPB enhanced manure and (v) unamended soil (control). The pots were arranged in a randomized complete block design (RCBD) with each treatment replicated three times. Supplementary fertilizers were added to optimize levels of other nutrients to create a suitable environment for maximum P uptake. Maize (SC 513 variety) was grown as a test crop, with 4 plants per pot, for five weeks following plant germination. The plants were thinned to 2 pot^{-1} at two weeks after crop emergence (WACE). The above–ground plant material was harvested 5 WACE, dried in an oven at 60 ^{0}C, ground and weighed for dry mass determination (Okalebo *et al.,* 2002). The plant material was analysed for total P as described in Okalebo *et al.* (2002). After harvesting the biomass, the soil available P was analyzed using the Bray 1 method.

Data analysis

Data was analyzed using GENSTAT (2005) statistical package. Analysis of variance was used to separate treatment effects on available P, biomass yield and P uptake. All mean comparisons were considered at 95 % significance level.

RESULTS

Soil and manure characterisation

The soils were acidic (pH < 5.0 i.e. 4.4 for Buhera and 4.9 for Marenga), low in total N, acute deficient in available P and light textured with loamy sands in Buhera while sandy loams in Marenga. Generally, the selected analysed soil fertility parameters were higher for Marenga compared to Buhera, except for Mg which was high in Buhera soil. Micronutrient levels followed the order Fe > Mn > Zn > Cu for the two study sites (Table 1).

Overall the untreated manure from Buhera was of better nutrient composition than Marenga manure despite all being of poor quality (Table 2). There was no significant ($p < 0.05$) difference in the nutrient composition. Both manures had ~0.70 % N, 0.061 % P, 0.79 % K and high in Ca %. Manure enhanced with PPB from Marenga was of better P nutrient value compared to that from Buhera. Moreover, most nutrient composition was better for Marenga PPB enhanced manures compared to Buhera. However, N and Mg levels were higher for PPB enhanced manure from Buhera. There was no significant ($p < 0.05$) difference in the nutrient composition. Both manures had; 0.77 % N, 0.15 % P, 0.95 % K and high in Ca % (*Table 2*). However, there

Table 2. Chemical composition of the organic nutrient resource used for the study

Organic nutrient resource	Site	Nutrients N (%)	P (%)	K (me%)	Ca (me%)	Mg (me%)	Zn (ppm)	Cu (ppm)
Cattle manure	Buhera	0.69	0.063	0.80	1.18	0.14	30	17
	Marenga	0.72	0.059	0.77	1.23	0.12	23	14
PPB enhance manure	Buhera	0.78	0.143	0.92	1.24	0.17	37	12
	Marenga	0.75	0.155	0.97	1.35	0.15	32	11

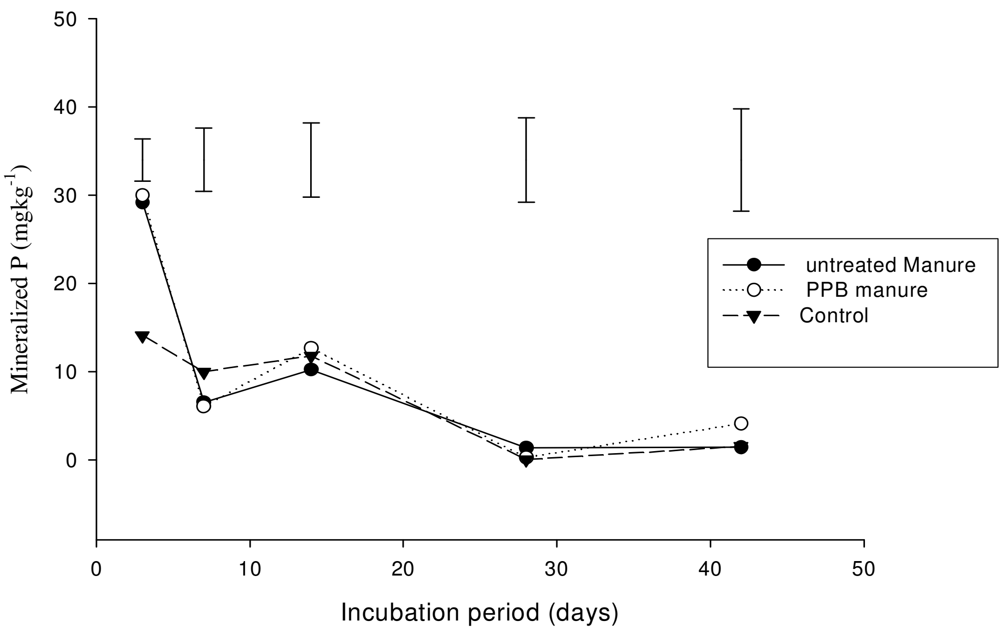

Figure 1. Phosphorus mineralization patterns of untreated and PPB treated manures for Buhera soils.

was a significant (p >0.05) difference in P levels between the untreated and PPB enhanced manures for both Buhera and Marenga sites. The high P values in the PPB enhanced manures could be attributed to the short term release potential of single superphosphate (SSP) which is a component of PPB amendment. Pelletized phosphate blend is made up of blending and pelletizing or compacting of Dorowa mine waste (at a rate of 50 - 90 %) with triple or single super phosphate (at a rate of 10 - 50 %).

Phosphorus release patterns of the organic amendments

At the beginning, there was a significant (p > 0.05) difference in the mineralized P from the cattle manure and PPB enhanced manure with the unamended soil. Overtime, there was a general decrease in the amount of P release into solution for the Buhera soil (Figure 1). Furthermore there was no significant (p < 0.05) difference between all the treatment over time. Manure enhanced with PPB and untreated cattle manures released less P than unamended soil, indication of immobilization of P at 7 days after incubation (DAI); followed by a net P mineralization at 14 DAI for PPB manure while untreated manure immobilized the mineralized P at the same level. On the 28th day after incubation, there was a slight net P mineralization form both the manure and enhanced PPB manure. At the end of the incubation period (42 DAI), PPB enhanced manure produced more mineralized P compared to control and cattle manure (*Figure 1*). At the end of the incubation the mineralized P was highest for PPB enhanced manure followed by the manure which was equal to the control.

Similarly for the Marenga soil, there was a general decrease in the mineralized P over time in all the treatments (Figure 2). At first, there was a significant (p < 0.05) difference in the mineralized P from PPB treated manure with the untreated manure and unamended soil.

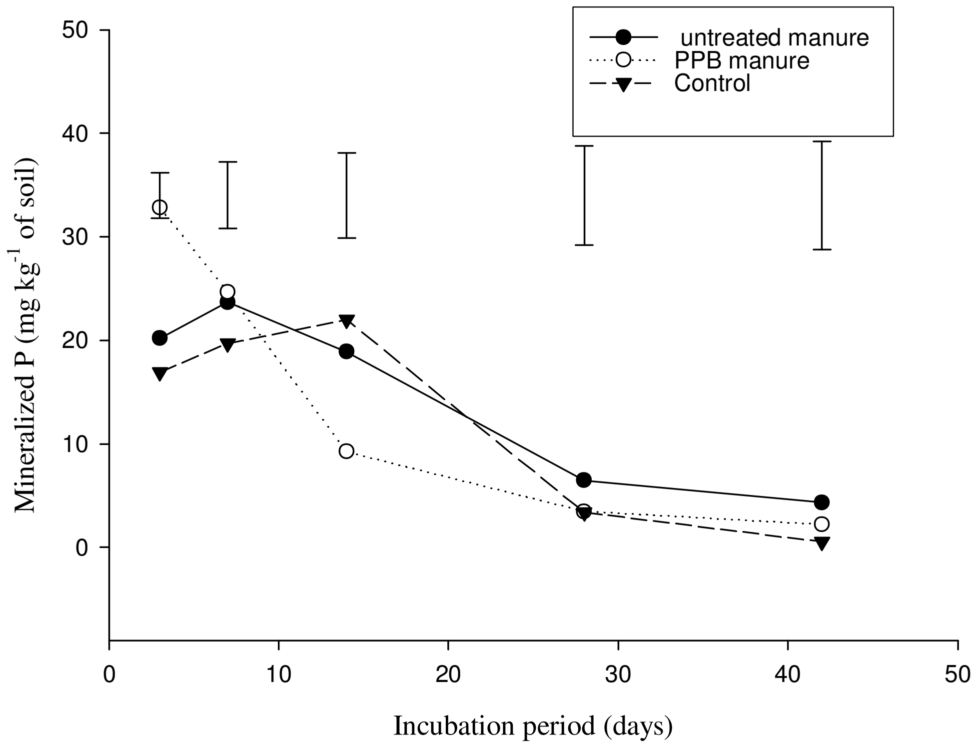

Figure 2. Phosphorus mineralization patterns of untreated and PPB treated manures for Marenga soils

Table 3. Maize dry matter yield at 5 WACE in the greenhouse for Buhera and Marenga soils

	Maize biomass productivity at 5 week after emergence (g pot^{-1})				
Application rate (t ha^{-1})	**Buhera manure**	**Buhera enhanced PPB manure**	**Marenga manure**	**Marenga enhanced PPB manure**	**SED**
0	1.38	1.38	2.20	2.20	0.29
10	1.37	1.38	2.29	2.37	0.32
20	1.67	1.66	2.10	2.43	0.32
SED	0.26	0.22	0.35	0.40	

SED = standard error of the difference between treatment means

For PPB enhanced manure, there was gradual decrease in the mineralized P from the start of the incubation to 28th DAI followed by a slight decrease to 42 DAI. However, at 3rd and 42 DAI, there was net P mineralization. As for the untreated manure, there was an increase in the mineralized P to the 3rd DAI and then a gradual immobilization of the mineralized P up to 21 DAI when it net gave net positive mineralized P to the last day of incubation. There was an increase in the mineralized P from the control up to the 12th DAI and it fall up to ~ 7 mg kg^{-1} soil at 42 DAI (Figure 2). At the end of the incubation the mineralized P was highest for the manure > PPB enhanced manure > control.

Maize dry matter yield and P uptake

Generally there was no significant ($p < 0.05$) difference in the maize biomass yield at 5 WACE between the manure and PPB enhanced manure from both soils. The lowest maize biomass yields were attained in controls, with Buhera soil giving 1.38 g pot^{-1} while Marenga producing 2.20 g pot^{-1}. For the Buhera soil, the yield ranged from 1.38 g pot^{-1} to 1.67 g pot^{-1} with highest yield attained in the treatment with 20 t ha^{-1} of manure. The maize biomass yield for the Marenga soils ranged from 2.2 g pot^{-1} to 2.43 g pot^{-1}. There was a proportional incremental benefit to the maize biomass yield as the application rate

Table 4. Soil available P after maize harvest at 5 week after emergence

Site	Initial soil available P (mg kg^{-1})	Soil available P after maize harvest at 5 week after emergence (mg kg^{-1})					
		Unamended soil	Buhera manure	Buhera enhanced PPB manure	Marenga manure	Marenga enhanced PPB manure	LSD
Buhera	7.2	5.33	10.21	18.28	11.5	20.08	8.6
Marenga	9.4	6.18	11.84	22.33	12.3	22.16	7.3
SED	2.6	0.24	0.06	3.28	2.88	1.76	

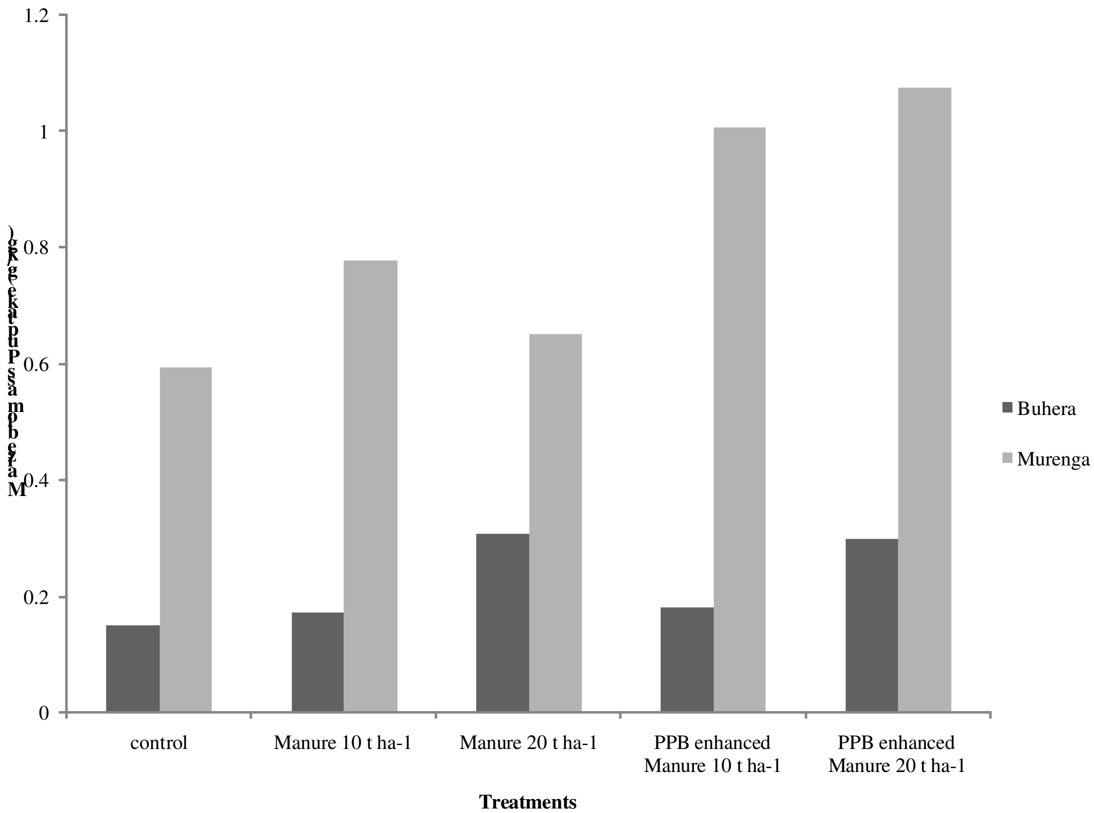

Figure 3. Maize P uptake under Buhera and Marenga soils in greenhouse conditions at 5 weeks after maize crop emergence.

increased to 20 t ha^{-1} of PPB enhanced manure for Marenga soil. As for the manure, the peak maize biomass yield (2.29 g pot^{-1}) was attained at 10 t ha^{-1} which then declined to 2.10 g pot^{-1} at 20 t ha^{-1} for Marenga soil (Table 3).

Generally the maize P uptake under Marenga soil was higher than that attained under Buhera soils across all the treatments (Figure 3). The maize P uptake under Buhera soil ranged from 0.18 g kg^{-1} in the control to 0.31 g kg^{-1} when 20 t ha^{-1} of manure was applied. Application of PPB enhanced manure in Buhera soil had no significant effect when compared with treatments with untreated manure. For instance, at 20 t ha^{-1}, untreated manure out-yielded the PPB enhanced manure in the same soil (Figure 3). The maize P uptake under Marenga soil ranged from 0.60 g kg^{-1} in the control to 1.08 g kg^{-1} when 20 t ha^{-1} of PPB enhanced manure was applied. The P uptake from the manure were lower than attained from enhanced PPB manure at both 10 and 20 t ha^{-1} application rate (Figure 3). The peak maize P uptake under Marenga when using manure was attained at 10 t ha^{-1} while for PPB enhanced manure it was at 20 t ha^{-1} (Figure 3).

Soil available P after biomass harvest

There was no significant ($P < 0.05$) difference in the available P among all the treatments regardless of soil type used (Table 4). The range was 15.33 mg kg^{-1} soil in the control treatment to 22.33 mg P kg^{-1} soil in the treatment where 20 t ha^{-1} PPB enhanced manure was applied for Buhera soils. The available P range for Marenga soils was 16.18 mg P kg^{-1} soil in the control treatment to 22.16 mg P kg^{-1} soil in 20 t ha^{-1} PPB enhanced manure treatment (Table 4). Also there were no significant ($p < 0.05$) differences in the available P at the same application rate of the organic fertilizers under both Buhera and Marenga soils (Table 4).

DISCUSSION

The Buhera and Marenga soils had low P levels of 7.2 mg kg^{-1} and 9.4 mg kg^{-1} respectively suggesting P deficiency in the soils and, hence, the need for phosphorus addition through fertilizer application (Mokwunye and Bationo, 2002). Sahrawat *et al*. (1997) reported an extractable P of 12.5-15 mg P kg^{-1} (Bray 1 P) as critical range for rice and, most likely, for other cereals. Owusu-Bennoah *et al*., (2000) also noted that P deficiency has been identified as one of the major soil fertility constraints in most small-scale farming systems in Africa. However, due to high costs of fertilizers and low availability, the resource constrained farmers are unable to afford water soluble P fertilizers. Instead of expensive phosphorus (P) fertilizers, the use of organic amendments such as cattle manure enhanced with less expensive phosphate rock amendments such as pelletized phosphate blend (PPB) is a possible alternative P source for these soils. The manures have to be enhanced because traditionally farmers produce low quality manure (Mugwira and Murwira, 1997). The low P and acidic soil conditions which are characteristics of Buhera and Marenga soils are suitable for PR amendment dissolution and use (Chien *et al*., 1995), hence used in this study.

The results obtained from the incubation experiment shows low rates of P mineralisation in soils treated with both the unamended and PPB enhanced manures after 42 days incubation. The results show insignificant P availability and uptake. This means the PPB enhancement strategy under incubation studies has proved to be of no agronomic use in providing P to the depleted soils of Buhera and Marenga. The results seemed to agree with those of Mafongoya *et al.,* (2000) who found that manures with P less than 0.2 %, shows prolonged P immobilization. However, the results contrasts Pramanik *et al*., (2009) who in a study to establish phosphorus solubilisation from rock phosphate in the presence of vermi-composts made from cow dung, grasses, aquatic weeds and municipality solid waste reported high rates of P mineralisation in soils treated with rock phosphate, though available P after 60 days incubation. The inference to be drawn from this is to compost the manure and PPB for longer periods, more than 60 days.

The study also showed that there was no significant difference in the maize biomass yield at 5 WACE between the untreated manure and PPB enhanced manure from both soils. This demonstrates that PPB and manure effects were generally not additive. This suggests that there was low P release from the two manure treatments in the early growth stages of the maize. The results support those from the incubation experiment that showed P immobilization of the two manure amendments over a 42 day period. The results can also be explained by Govere *et al*., (1995) who reported that the use of Dorowa phosphate rock (DPR) or its amendments as a P fertilizer in Zimbabwe is ineffective in increasing P uptake or dry matter yield of maize due to its igneous nature (Watkinson and Sinclair, 1996). However, this is in contrast to work done by Waddington and Karigwidi (2001), which gave highest yields to maize when cattle manure was mixed with fertilizers. The results imply for the need to properly manage cow manure through some form of composting. Application of composted manure can enhance the availability of P and promote efficiency of PPB fertilizers. Singh and Amberger (1991) have shown that rock phosphate in composted manure increases both the uptake of P by crops and yield.

Lack of significant differences of soil available P between treatments after biomass harvested at 5 WACE is a reflection of the low release potential of both untreated manure and PPB enhanced cattle manure. It can be assumed that there were no significant differences in P dissolution between the untreated and PPB enhanced cattle manure. This means that PPB amendment did not have a noticeable effect as far as soil extractable P at harvest is concerned. This may reflect that PPB in the cattle manure was very non-reactive and, therefore, the extractable P in the soil may only have come from the soils themselves, manures and insignificant contributions from the relatively insoluble PPB amendment.

CONCLUSION

The study confirms that if rock phosphate is only mixed with cattle manure without composting, there is no increase in P availability in the soil as well as limited (no improved) crop uptake in maize. The combination of aerobically composted cattle manure with PPB needs further investigation. There is need to compost cattle manure with rock phosphate to produce a more complete nutrient source for strongly acidic soils such as the ones found in most communal areas of Zimbabwe.

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