Vol. 14(25), pp. 1051-1057, 20 June, 2019
DOI: 10.5897/AJAR2018.13089
Article Number: 5A3BB1561238
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

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African Journal of Agricultural Research

Full Length Research Paper

Composting coffee pulp with Minjingu phosphate rock improves phosphorus availability for tomato uptake

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Received 28 February, 2018; Accepted 25 July, 2018

A glasshouse experiment was conducted to evaluate the effect of composting coffee pulp with phosphate rock on phosphorus (P) availability for plant uptake. Coffee pulps composted with or without phosphate rock and Minjingu phosphate rock applied alone were evaluated as source of P for tomato growing on a Chromic Acrisol. All P sources were applied at varying rates of 0, 20, 40, 60, 80 and 100 mg P kg^{-1} and all other limiting nutrients were adjusted to recommend levels using industrial fertilizers and/or reagent grade laboratory salts. Phosphorus uptake of tomato plants receiving coffee pulp composted alone, Minjingu phosphate rock alone and coffee pulp composted with Minjingu phosphate rock increased 11, 13 and 18 times above the control. Observed P concentrations in tomato plants receiving external P sources were 23, 36%and 110% of the concentrations in control plants. Composting coffee pulp with Minjingu phosphate rock was concluded as a potential technique for improving phosphorus availability and uptake by tomato.

Key words: phosphate rock, coffee pulp, phosphate rock enriched compost, tomato, phosphorus uptake.

INTRODUCTION

Most of the tropical agricultural soils are highly weathered, leached and consequently acidic. These soils are highly deficient in phosphorus (P) thus require substantial P inputs for optimum crop production (Buehler et al., 2002). Phosphorus deficiencies are mainly corrected via application of water soluble P fertilizers and manures. However, water soluble P fertilizers are of limited availability and unaffordable to most small holders in developing countries (Kpomblekou and Tabatabai, 2003; Mowo et al., 2006)

Farmyard manure is similarly not readily available for most smallholder crop producers and where available is of poor quality (Buresh et al., 1997). Continuous cropping associated with low levels of fertilizers and manure applications results into soil degradation and subsequently season after season decline of small holder crop productivity.

Promoting the use of locally available Minjingu phosphate rock (MPR) has been considered as the most promising alternatives to the expensive mineral P fertilizers in Tanzania. However, slow dissolution of the MPR results into limited availability of P for plant uptake, hence limited first season crop response to applied MPR. Production of phosphate rock enriched composts has been reported as an alternative way for improving phosphorus release from low value phosphate rocks and

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crop response to applied PRs (Ditta et al., 2017; Meena and Biswas, 2015; Mihreteaba et al., 2015; Ikerra et al., 2006). Availability of P for plant uptake from PR enriched compost is thus a product of the quality of composted plant biomass and the PR used to enrich the compost. High quality plant biomass is therefore a prerequisite for enhancing P availability from PRs through composting.

Coffee pulp is a readily available crop residue in all the coffee producing areas of the world, including Tanzania. Its direct application as a soil amendment in coffee fields is restricted by the presence of toxic compounds like phenols, local heat generation and coffee berry disease spread risks (Pandeya et al., 2000; Preethu et al., 2007). Different technologies have been applied to manage coffee pulp for the purpose of minimizing the challenges associated with direct application of coffee pulp and environmental pollution risks. Reported technologies include composting coffee pulp and using as a growing media in greenhouse crop production (Berecha et al., 2011); soil application of composted pulp as a fertilizer material or soil conditioner (Dzung et al., 2013); using coffee pulp as feedstock in heat energy or biogas production (Cubero-Abarca, et al. 2014); as well as using dried coffee pulp as supplement in ruminant diets (Núñez et al., 2015). Although application of composted coffee pulp as soil organic amendment is documented, the effect of composting coffee pulp with PRs on P release and availability for plant uptake is still unknown. This study was therefore based on this knowledge gap and evaluated the effect of composting coffee pulp with MPR on P availability and uptake by tomato.

MATERIALS AND METHODS

Coffee pulp collection and characterization

The coffee pulp was collected from Malonji village primary processing center in Mbozi District and transported to the Tanzania Coffee Research Institute, Mbimba station for composting. Fifteen random samples were taken from a pile of fresh coffee pulp mixed into a homogenous representative sample, weighed and dried to constant weight at 60°C. The oven dried sample was ground to pass through a 0.5 mm sieve for laboratory total analysis. The moisture content, pH, total organic carbon, total N, P, Ca, and K in the coffee pulp were determined following the procedures described by Okalebo et al. (1993).

Compost preparation

Coffee pulp was composted in pits both alone and mixed with MPR. Four pits (3x2x1 m^3 each) were opened and the floor of each pit was lined with polythene sheets to avoid underground seepage. One tone of fresh coffee pulp at 70% moisture content (equivalent to 300 kg air dry weight) were mixed with 100 kg of air dry surface soil to get 400 kg of air dry mixture which was filled into the first pit. Another portion of 400 kg air dry mixture prepared in the same fashion was mixed with 100 kg of MPR (4:1) (FAO, 1987) on air dry weight basis to fill the third pit. The two pits 1 and 3 were covered with banana leaves followed by a layer of dry soil while pits 2 and 4 remained empty for the turning of the compost materials. Composting lasted for 4 months with turning of material at 4 weeks intervals to allow optimum aeration. Water was sprinkled onto the compost materials at every turn to maintain the moisture around 60% for optimum microbial activity (Graves and Hattemer, 2000).

Compost sampling and analysis

At the end of the composting period, ten random samples were taken from each of the two composting sets, homogenized and reduced by quartering into two separate 0.5 kg representative samples. Moisture content of the representative compost samples was determined following the procedures described by Graves and Hattemer (2000). Thereafter, the samples were air dried ground and sieved through 2 mm sieve for determination of the pH, total organic carbon, nitrogen, phosphorus, potassium and calcium following the standard procedures compiled by Okalebo et al. (1993).

Soil sampling and analysis

Soil sampling was done at Magadu farm located on the western part of SUA Main campus in Morogoro Tanzania. The process was preceded by a preliminary survey to identify an area with a Chromic Acrisol that has neither been under cultivation nor received any fertilizer or manure treatment for the past ten years. Ten representative surface samples (0-20 cm), 50 kg each were randomly collected and thoroughly mixed to constitute a representative composite soil sample. The soil was air dried and sieved through 8 mm for the pot experiment. One kilogram representative sample was drawn from the entire soil reduced by the quartering procedure to 0.5 kg ground and sieved through 2mm for laboratory analysis.

The Chromic Acrisol was analyzed for physical and chemical properties in the Department of Soil Science laboratory, at Sokoine University of Agriculture, Morogoro Tanzania. Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986) while pH was electrometrically determined in 1:2.5 (soil: water) suspension (Mclean, 1982). Organic carbon was determined by the Walkley and Black method (Nelson and Sommers, 1982). Total N was determined by the micro Kjeldahl method (Bremner, 1996). Available P in the soils was extracted by the Bray 1 procedure (Kuo, 1996). CEC was determined by the ammonium acetate saturation method (Rhodes, 1982). Exchangeable bases, that is Ca^{2+} and Mg^{2+} in the CEC determination filtrates (NH_4-acetate filtrates) were determined by atomic absorption spectrophotometer, while K and Na were determined by the flame photometer method (Thomas, 1982). Plant extractable Cu, Zn, Mn and Fe were extracted by DTPA and measured by atomic absorption spectrometer (Lindasy and Norvell, 1978).

Glasshouse pot experiment

A glasshouse pot experiment was carried out at the Sokoine University of Agriculture (SUA), Morogoro Tanzania. The experiment was arranged in a 3 x 8 completely randomized block design using three different P sources (CP, MPR and CPMPR) all applied at 0, 20, 40, 60, 80 and 100 mg P kg^{-1} in three replicates. Following application of all P sources; the soils were equilibrated with two liters of water/pot for 24 h to bring the soil moisture to field capacity before sowing the seeds. After 24 h of equilibration five tomato seeds were sown in each pot and thereafter, soil moisture content was maintained around field capacity by replacing equivalent amount lost through evapotranspiration. All emerging weeds were uprooted to keep weed competition at minimum level possible. Thirty days after planting, two seedlings were thinned out leaving three seedlings per pot followed by the second split of nitrogen uniformly applied to all pots except absolute controls.

Quantification of dry matter yield and nutrient uptake

Sixty days after planting, two seedlings were harvested from each pot by cutting all above ground parts at the soil surface for the determination of dry matter yield and nutrient uptake. Harvested plants were cleaned using distilled water and oven dried to constant weight at 55°C for 72 h, and weighed using a chemical balance. After weighing, dry plant samples were chopped into small pieces then ground using a motor and pestle into a fine powder to pass through 0.5 mm sieve. A 0.5 g of fine ground sample was digested by the H_2SO_4 - H_2O_2 and HNO_3 - H_2O_2 procedures and the digests were analyzed for N and P, K, Ca and Mg contents respectively, following procedures compiled by Okalebo et al. (1993).

Data analysis

Dry mater yields, P uptake and plant tissue P concentration data was subjected to analysis of variance (ANOVA) and the means were separated at $P \leq 0.05$using Duncan's New Multiple Range Test.

RESULTS AND DISCUSSION

Physico-chemical properties

Selected physico-chemical properties of the soil used is as shown in Table 1.

Properties of the chromic acrisol

Selected properties of the surface (0-20 cm) Chromic Acrisol analyzed before applying P sources were as presented in Table 2. The soil pH was low (< 5.5) with a very strong acid reaction and very low level of organic carbon (< 4%) and Bray I extractable phosphorus (< 7 mg kg^{-1} soil) (Landon, 1991). Low pH could be attributed to the nature of the parent material (acidic parent material), extensive weathering, loss of basic cations and anions through the processes of plant uptake and most probably due to leaching. Low levels of extractable P on the other hand could be attributable to the low inherent P in the soil's parent material and transformation of plant available P into unavailable Fe –P and Al-P to of P as influenced by Fe^{3+} and Al^{3+}.

Exchangeable K is categorized as < 0.2 cmol (+)/kg (low), 0.2-0.4 cmol (+)/kg (medium) and > 0.4 cmol (+)/kg (high); exchangeable Ca < 1 cmol (+)/kg as moderately low, 1-2 cmol (+)/kg as moderately high and 2-3 cmol (+)/kg as high. Critical values of Mg on the other hand are categorized as ≤ 0.2 cmol (+)/kg (low), 0.2-0.5 cmol (+)/kg (medium) and > 0.5 cmol (+)/kg (high). Based on this categorization, the Chromic Acrisol requires substantial N, P, K and Ca inputs for successful tomato production. Its pH was less than the optimum pH range of 6.0 to 7.0 recommended for successful tomato production thus requires liming. The use of MPR and composts rich in Ca was thus expected to improve the soil pH and this would be as a secondary effect to plant nutrient supply.

Properties of Minjingu phosphate rock

Selected chemical properties of the Minjingu phosphate rock **(**MPR) used in the study are as presented in Table 3.

The concentration of total P is high enough (> 5%) thus MPR qualifies as a fertilizer based on the criteria set by FAO (2000). However, Ca content of MPR is also high implying that P exists as Ca-P which is a complex form not easily released for plant uptake. Direct application of MPR as P fertilizer is therefore only feasible in acidic soils with large number of Ca sinks where MPR could have some liming effects as well.

Properties of composts used in the study

Selected properties of compost materials used in the study were as presented in Table 3.

The moisture content of the coffee pulp composted alone was slightly lower than that of the coffee pulp composted with MPR (26.42 and 29.08%, respectively). Differences in moisture contents of the two composts were attributed to minor differences in drainage of the composting pits. Graves and Hatteemer (2000) recommended 30-40% moisture content to be the optimal for finished or mature composts ready for soil application. Based on this criterion, both CP and CPMPR had moisture contents close to the recommended moisture content range. Minor difference in moisture contents could not have significant effect on tomato plant response since all soils were equilibrated to field capacity moisture content before sowing the tomato seeds and irrigation water was applied to maintain moisture content at field capacity.

High pH_w for CP and CPMPR was due to high contents of basic cations (Ca, K and Mg) in the raw materials (coffee pulp and MPR) used to produce the composts. Both CP and CPMPR had high organic carbon contents (46.9 and 38.3% respectively) due to elevated carbon contents of coffee pulp used as raw materials for the compost production. However, the two composts had C: N ratio within the range ≤ 30 recommended by Graves and Hatteemer (2000) for successful mineralization of organic materials in soils. Total P and Ca contents were higher in CPMPR than CP suggesting its higher contents in MPR than coffee pulp while total K was in the reverse order for the two composts suggesting the effect of higher K contents in coffee pulp than was in MPR.

Table 1. Selected physico-chemical properties of the soil used.

Soil property	Mean value	Rating	Rating reference
pH (H_20)	4.30	Low	Landon (1991)
Organic carbon (%)	1.10	Very low	Landon (1991)
Total N (%)	0.11	Low	Landon (1991)
Total P (%)	0.10	Low	Dierolf et al. (2001)
Bray I P ($mgkg^{-1}$)	5.59	Low	Landon (1991)
Exchangeable K (cmol(+)/kg)	0.35	Medium	Landon (1991)
Exchangeable Ca (cmol(+)/kg)	1.45	Low	Landon (1991)
Exchangeable Mg (cmol(+)/kg)	1.69	High	Landon (1991)
CEC (pH 7)	16.80	Medium	Landon (1991)
DTPA extractable Cu (mg/kg)	4.64	High	Landon (1991)
DTPA extractable Zn (mg/kg)	1.80	Medium	Landon (1991)
DTPA extractable Mn (mg/kg)	19.04	High	Landon (1991)
DTPA extractable Fe (mg/kg)	69.72	Very high	Landon (1991)
Sand (%)	40		
Silt (%)	7		
Clay (%)	53		
Textural class	Clay		Gee and Bauder (1986)

Table 2. Selected properties of Minjingu phosphate rock (MPR) used in the study.

Property	Average value
pH (H_2O)	8.50
Total P (%)	13.0
Bray I P (%)	0.01
Solubility in NAC (%)	3.60
Ca (%)	35.5
$CaCO_3$ (%)	6.90
K_2O (%)	1.40
MgO (%)	3.40

Table 3. Selected properties of composts used in the study.

Compost type	Moisture	OC	Total N	Total P	Total K	Total Ca	C:N	pH_w
	%							
CP†	26.42	46.91	1.61	0.15	2.87	4.38	29.1	8.26
CPMPR††	29.08	38.3	1.43	1.39	2.28	7.37	26.8	8.54

†, CP = Coffee pulp composted alone; ††, CPMPR= Coffee pulp composted with MPR.

Effect of P source and application rate on P uptake

Generally, P uptake increased with increasing rates of CP, MPR and CPMPR (Figure 1). The differences in P uptake between plants treated with CP, MPR and CPMPR was only significant (p = 0.05) at application rate rates above 40 mg P/kg soil due to high P fixing capacity of the soil. The overall mean plant P uptake values observed for the plants treated with CP, MPR and CPMPR at 20 to 100 mg P kg^{-1} soil were 11, 13 and 18 times P uptake of control plants which did not receive external P.

The least effect of CP on P uptake as compared to MPR and CPMPR (Figure 1) was due to low amounts of

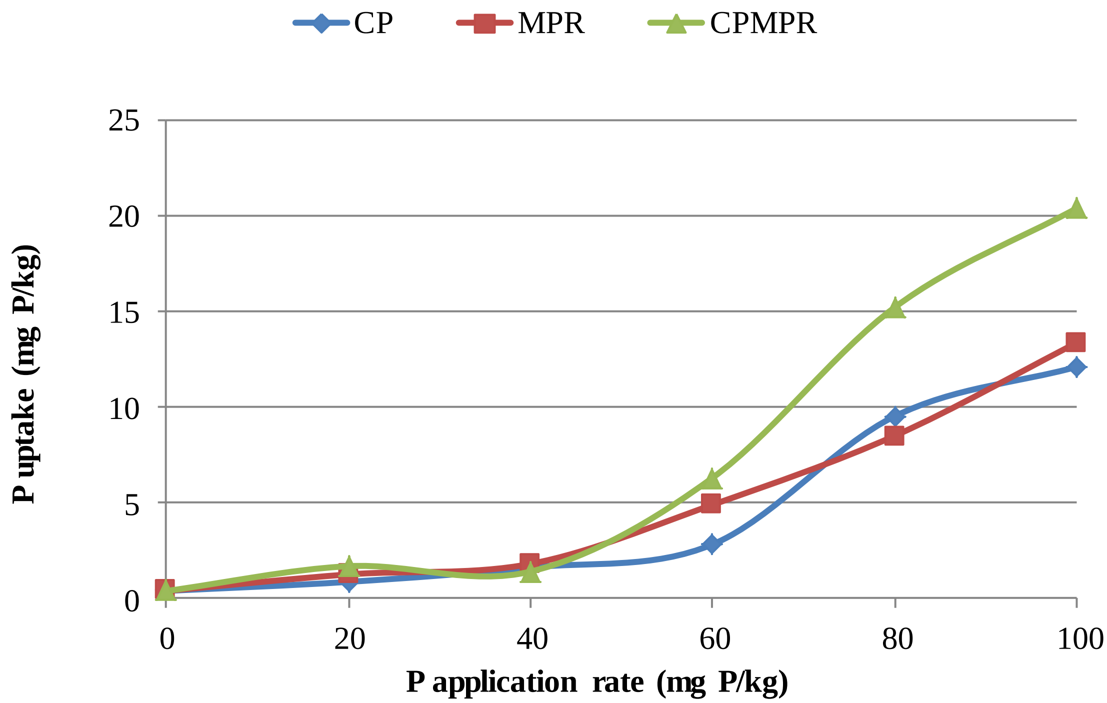

Figure 1. The effect of P sources and application rates on P uptake.

plant available P in the coffee pulp composted alone when compared to plant available P in MPR and CPMPR. Observed increase in P uptake from CP could be attributed to P released after mineralization of the coffee pulp and competition of the humic substances for P fixation sites of the soil, thus increasing P availability for plant uptake. Decomposition products are also reported to have effect on soil structure and moisture retention which enhances microbial activities and ultimately soil P turn over (Ikerra et al. 2006; Olumuyiwatogun et al., 2004). Although MPR increased P uptake; the increase was less than what was observed following application of CPMPR due to slow and continuous dissolution of singly applied MPR as transformation of some P released from MPR into plant unavailable forms.

The highest increase in P uptake observed for CPMPR treated plants was attributed to increased MPR dissolution rate and hence P availability as influenced by the effect of low molecular weight organic acids and humic substances released during microbial decomposition of coffee pulp. Extra P released in plant available from upon decomposition and mineralization of the coffee pulp and reduction of P fixation sites on the soil colloidal surfaces also contributed on increased P uptake. Based on the observed variations in P uptake among CP, MPR and CPMPR treated plants, it was worth to conclude that composting coffee pulp with MPR increased the availability of P for plant uptake as compared to singly composted coffee pulp and MPR applied alone.

Effect of P source and application rates on plant tissue P contents

Application of 20 to 100 mg P kg-1 in the form of CP, MPR and CPMPR had positive and significant effect on plant P concentration (Figure 2). The general effect of P source on plant P concentration was in the order CP < MPR < CPMPR. The increase in P concentration in CP, MPR and CPMPR treated plants were 23%, 36% and 110%, respectively above the control. Observed increase in plant tissue P concentration further implied that, composting coffee pulp with Minjingu phosphate rock increased the dissolution of MPR hence the release of P in plant available form for plant uptake uptake.

Ditta et al. (2017) reported higher P accumulation in chick pea grains and straws following application of PR enriched composts as compared to P content of similar plant parts from plants receiving non enriched composts. Research findings by Dzung et al. (2013) reported improvement in soil fertility , mineral nutrients in the coffee leaf and growth rate of the coffee plant treated with composted coffee husk as compared with plants on plots which didn't receive the compost. Meena and Biswas (2015) reported 68.8 to 58.7% higher residue Olsen-P in in soils treated with phosphate rock enriched composts over control plots. These research findings are therefore

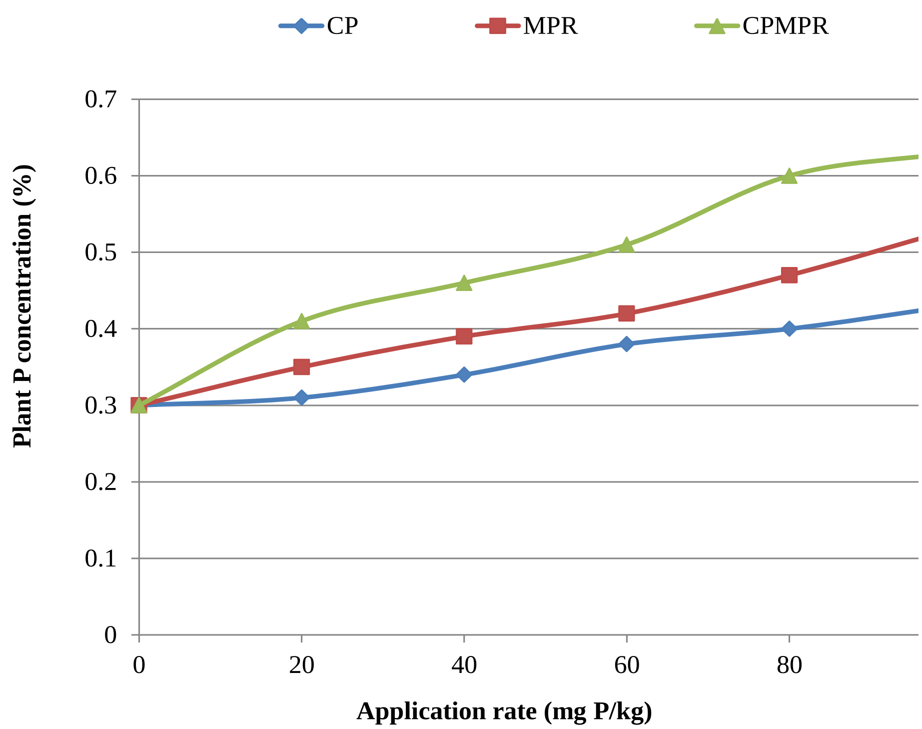

Figure 2. Effect of P sources and application rates on tomato plant P concentration.

in agreement with our findings and support the conclusion that observed higher P uptake and P accumulation in plants treated with CPMPR as compared to plants treated with CP or MPR was due to improved PR dissolution and therefore P availability for plant uptake.

Conclusion

From this study, increased P uptake was observed due to application of coffee pulp compost, Minjingu phosphate rock and coffee pulp composted with Minjingu phosphate rock as source of plant available P. The observed increase in P uptake and its concentration in plant tissue due to CP, MPR and CPMPR application indicate an increased availability of phosphorus for plant uptake. Despite the application of all materials at the same rates of phosphorus, there existed a variation in plant P uptake between different P sources indicative of the differences in P availability. The highest and significant effect observed with CPMPR indicates that composting coffee pulp with MPR is a potential technique for improving the availability of P from MPR and subsequent tomato P uptake.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

ACKNOWLEDGEMENTS

The authors wish to sincerely acknowledge SADC ICART project for the sponsorship which made this study possible. Dissertation development grant received from the Association of African Universities (AAU) through RUFORUM is also highly valued for the accomplishment of this work. Last but not least, our sincere appreciation goes to all members of staff in the Department of Soil and Geological Sciences at Sokoine University of Agriculture for their cooperation and support.

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