



Effect of Sources of Phosphorus on Phosphorus Sorption in Cambisols and Ferralsols of Western Kenya

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Author's contribution

This whole work was carried out by author PAO.

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ABSTRACT

The influence of two organic materials (OMs); *Tithonia* and FYM and inorganic materials; triple superphosphate (TSP) and Minjingu phosphate rock (MPR) and Busumbu phosphate rock (BPR), when applied alone or in combination, on P sorption at two sites, Kakamega and Bukura, in western Kenya was investigated. The soil at Bukura was a Ferralsol while that at Kakamega was a Cambisol. A randomized complete block design with 3 replications was used. All the P inputs were uniformly broadcast on the plots and then incorporated into the top soil (0-15 cm) in April 2007. Soils were sampled at 4 and 9 weeks after incorporation of phosphorus inputs (WAI) from each of the treatments and the soil P sorption characteristics determined. The equilibrium P concentration which represents the amount of P in the equilibrium solution at zero P sorbed was $< 0.2 \text{ mg P L}^{-1}$ regardless of the input combination used. The P sorption capacity of the soil at Kakamega was low compared to that at Bukura and was generally not affected by the treatments. None of the P sources significantly reduced the amount of P sorbed at Kakamega. However at Bukura, the amount of P sorbed (q) was significantly lower than the control for only *Tithonia* when applied alone and FYM applied in combination with TSP at 4 and 9 WAI. *Tithonia* applied with TSP

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significantly reduced q at 4 WAI but not 9 WAI while FYM applied alone was able to lower q at 9 WAI. None of the inorganic P sources, when applied alone, reduced the P sorption capacity of the soils. The results demonstrate that OM has the potential to reduce P sorption in soils that are high in P sorption, but where the P sorption is relatively low, the application of OM to reduce P sorption may not be useful.

Keywords: Cambisol; ferralsol; inorganic; organic materials; phosphorus sorption.

1. INTRODUCTION

Phosphorus deficiencies are widespread in western Kenya where they severely limit crop production. Management of P deficiency generally requires addition of organic or inorganic fertilizers or their combinations. Sole use of organic inputs to supply adequate P to meet crop requirements is, however, not a practical option due to their low P content [1]. Phosphorus must, therefore, be added to P depleted soils in concentrated forms either as P-containing fertilizers or locally available phosphate rocks (PRs) [2]. Regardless of its source, P undergoes several chemical reactions that influence its availability to plants upon its application to soil. P availability is largely controlled by adsorption-desorption reactions, which regulate the concentration of P in the soil solution [3,4]. From the agronomic point of view, P sorption is a concern because P that is strongly retained by the soil is less available for plant uptake [5]. Phosphorus sorption is, therefore, a widely researched subject since the use-efficiency of P is likely to be dependent on its source. The challenge then is to identify practices that are able to increase the use-efficiency of applied P inputs to these P-fixing acid soils.

Management practices for amelioration of P-sorption have been a subject of many reviews e.g. [6-8]. Liming and use of organic materials feature prominently in among these practices. The effectiveness of lime in reducing P sorption has been demonstrated in western Kenya [9]. However, due to its high cost and limited supply in most rural areas, its use is not widespread. The potential use of organic materials (OMs) to reduce P-sorption and enhance availability of applied inorganic P inputs has, therefore, received considerable research attention in recent years in western Kenya [10,11]. Organic materials interact with P in soils in a variety of ways that potentially influence P sorption and release reactions. The direct and indirect mechanisms which have been proposed for the increase in P-availability as a result of addition of

organic materials were a subject of reviews by [12] and [13]. If organic materials can decrease P sorption, then farming systems that include additions of green or animal manures may be able to increase availability of P by increasing the solubility of soil P [14]. The objective of this study was therefore to determine the influence of organic materials; *Tithonia*, FYM and inorganic materials; TSP and phosphate rocks, when applied alone or in combination on P sorption of two soil types in western Kenya.

2. MATERIALS AND METHODS

2.1 Site Description

The study was conducted from April to July 2007 at two sites i.e. Bukura and Kakamega, in western Kenya. Bukura is at an altitude of 1400 m above sea level, 0°30'N latitude and 34°30'E longitude while Kakamega, is 1330 m above sea level, 0°08'N latitude and 34°22'E longitude. Farming in the region is largely undertaken by smallholder farmers, practicing a mixture of food, cash crop and tree production. Maize and beans are the most common food crops grown in the area mainly as intercrops. The main livestock kept are both indigenous and improved breeds of cattle, sheep, goats and chicken. The soil at Bukura was an orthic Ferralsol while the soil at Kakamega was a Ferralic Cambisol [15]. The initial soil properties at the sites are presented in Table 1.

The treatments consisted of three inorganic P sources; TSP, MPR and BPR each applied alone or in combination with FYM or *Tithonia* in a randomized complete block design with three replications. Other treatments included a control with no P input and FYM and *Tithonia*, each applied alone. FYM and *Tithonia* were applied to supply 20 kg P ha⁻¹ in treatments where they were used either alone or in combination with inorganic P sources. The inorganic P sources were applied to provide 40 kg P ha⁻¹ in OM/inorganic P source combinations. However, when they were used in combination alone, they were applied at 60 kg P ha⁻¹. *Tithonia* had 3.0%

N, 0.3% P, 3.8% K, 42% C, pH 6.5, whereas FYM had 1.8% N, 0.4% P, 1.2% K, 36% C, pH 7.7

1. Control (no P)
2. *Tithonia* (20 kg P ha⁻¹)
3. FYM (20 kg P ha⁻¹)
4. MPR (60 kg P ha⁻¹)
5. BPR (60 kg P ha⁻¹)
6. TSP (60 kg P ha⁻¹)
7. *Tithonia* (20 kg P ha⁻¹) + MPR (40 kg P ha⁻¹)
8. *Tithonia* (20 kg P ha⁻¹) + BPR (40 kg P ha⁻¹)
9. *Tithonia* (20 kg P ha⁻¹) + TSP (40 kg P ha⁻¹)
10. FYM (20 kg P ha⁻¹) + MPR (40 kg P ha⁻¹)
11. FYM (20 kg P ha⁻¹) + BPR (40 kg P ha⁻¹)
12. FYM (20 kg P ha⁻¹) + TSP (40 kg P ha⁻¹)

All the inputs (both organic and inorganic) were uniformly broadcast on the plots and then incorporated into the top soil (0-15 cm) by a hand hoe.

Table 1. Initial surface (0-15 cm) soil properties at the study sites

Parameter	Bukura	Kakamega
	Value	
pH (H ₂ O) (1:2.5)	4.80	5.10
Exchangeable acidity (cmol _c kg ⁻¹)	0.88	0.35
Exchangeable Al (cmol _c kg ⁻¹)	0.63	0.13
Exchangeable bases (cmol kg⁻¹)		
Ca	1.94	2.1
Mg	1.01	1.8
K	0.12	0.2
ECEC	3.95	4.85
Al saturation (%)	22	7.2
Organic C (%)	3.2	2.7
Total N (%)	0.3	0.3
C:N ratio	10.6	9.0
Total P (%)	0.04	0.03
Olsen P (mg kg ⁻¹)	5.6	2.5
Phosphate sorption (P sorbed at 0.2 mg kg ⁻¹)- P requirement	260	45
Sand (%)	52	54
Silt (%)	18	28
Clay (%)	30	18
Textural class	Sandy clay loam	Sandy loam
Soil classification	Orthic Ferralsol	Ferralic Cambisols

2.2 Soil Sampling and Analysis

To determine the soil P sorption characteristics, soils were sampled at 4 and 9 weeks after

incorporation of phosphorus inputs (WAI) from each of the treatments. The soil samples were collected at 0 to 15 cm soil depth from nine randomly selected locations per plot and thoroughly mixed in a bucket before taking a composite sample of about 200 g that was prepared for subsequent laboratory analyses. The method of [16] was used to determine the P sorption characteristics of the soils. Three gram samples of soil plus 30 mL of different P standards (0, 10, 20, 30, 40, 50 and 60 mg P L⁻¹) prepared in 0.01 M CaCl₂ solution were shaken in a reciprocal shaker for a 30 minute period, twice a day, for 6 days at ambient temperature. A drop of 0.1% HgCl was added per sample suspension to retard microbial growth. On the sixth day, the equilibrated samples were filtered through a Whatman no. 5 filter paper. An aliquot of 20 ml was used to determine P in the supernatant solution using the molybdate ascorbic acid blue method of [17]. Phosphorus which disappeared from solution was considered to have been sorbed. Phosphorus sorbed was plotted against P concentration in the supernatant solution to construct the P sorption isotherms. Non-linear regression using the Genstat statistical package [18] was used to fit the adsorption data obtained to the non-linear form of the Langmuir equation;

$$q = kbc/(1 + kc),$$

Where c (mg P L⁻¹) is the equilibrium concentration, x/m (mg P kg⁻¹) is the amount of P adsorbed per unit mass of adsorbent, b (mg P kg⁻¹) is the P adsorption maximum and k (mg L⁻¹) is the constant related to the energy of adsorption. All the P sorption data were subjected to analysis of variance and treatment means separated by standard errors of difference of means (SED) at p < 0.05.

3. RESULTS AND DISCUSSION

Results of the P sorption study in the field experiment are presented using the Langmuir sorption estimates Tables 2 to 3 and P sorption isotherms Figs. 1 to 4. The equilibrium P concentration which represents the amount of P in the equilibrium solution at zero P sorbed [19] was < 0.2 mg P L⁻¹ regardless of the input combination used. This indicates that the soils at both sites, even after application of the treatments, were P-deficient and would, therefore, respond to further application of P. The P sorption capacity of the Kakamega soil was low, according to the classification scheme [20],

with mean of 43 mg P kg^{-1} of P sorbed at 0.2 mg L^{-1} for control treatment at the two sampling times Table 2. None of the P sources significantly reduced the amount of P sorbed at Kakamega at both sampling times as shown by q (P adsorbed at 0.2 mg P L^{-1}) Table 2. and the P sorption isotherms Figs. 1 and 2. There was a significant reduction in the adsorption affinity, k , by three treatments, i.e. *Tithonia* 20 kg P ha^{-1} , *Tithonia* 20 kg P ha^{-1} + TSP 40 kg P ha^{-1} and FYM (20 kg P ha^{-1} + TSP 40 kg P ha^{-1} at 4 WAI but not at 9 WAI at Kakamega. This reduction in k was however, accompanied by an increase in adsorption maxima, b , relative to the control treatment. At Bukura, the P sorption capacity ($> 200 \text{ mg P kg}^{-1}$ at 0.2 mg P L^{-1}) was much higher than that at Kakamega and would be classified as medium. The amount of P sorbed (q) was significantly lower than the control for only *Tithonia* (20 kg P ha^{-1}) and FYM (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1}) at 4 and 9 WAI Table 3. *Tithonia* (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1}) significantly reduced q at 4 WAI but not 9 WAI while FYM (20 kg P ha^{-1}) was able to lower q at 9 WAI. There were no significant differences in both the adsorption affinity (k) and adsorption maxima (b) among the treatments at 4 WAI at this site. However at 9 WAI, FYM (20 kg P ha^{-1}) significantly reduced k while BPR (60 kg P ha^{-1}) increased it.

The adsorption maxima were also significantly reduced by *Tithonia* applied in combination with

MPR or TSP and BPR applied alone. FYM when combined with TSP consistently sorbed less P than other treatments at all the sampling times at Bukura as shown by the P sorption isotherms Figs. 3 and 4. On the other hand, application of BPR alone, generally increased the amount of P adsorbed and the adsorption affinity as shown by the sorption isotherms and q values Tables 2 and 3. Addition of *Tithonia* or FYM in combination with inorganic P sources, especially TSP and MPR reduced adsorbed P values when compared to addition of inorganics alone at the same P rate, but significance levels were not consistent and depended on the concentration of P in the equilibrating solution.

The P sorption capacity of the soil at Kakamega was low compared to that at Bukura and was generally not affected by the treatments. This is likely due to the lower content of exchangeable Al and the higher soil pH at Kakamega compared to at Bukura Table 1. This is consistent with observations by [7] and [21] that the overall effect of application of materials that can reduce P sorption differs among soils and that it is only in acid soils with high levels of exchangeable Al that a decrease in P sorption can be expected when amendments such as lime are applied to soil. The rest of the discussion is, therefore, confined to the Bukura soil where there were significant treatment effects on P sorption characteristics of the soil.

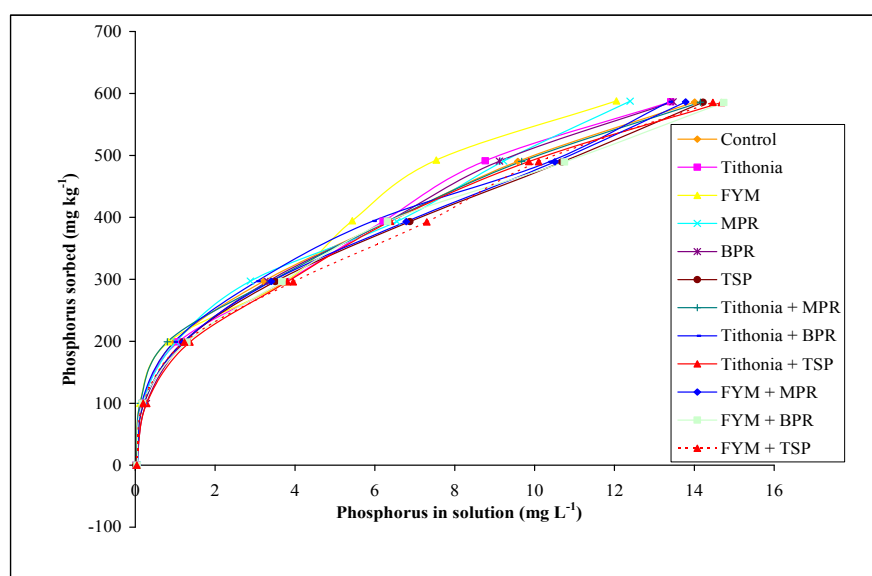


Fig. 1. Phosphorus sorption isotherms for organic and inorganic P sources at 4 WAI at Kakamega. ; FYM= Farmyard manure; TSP= triple superphosphate; MPR= Minjingu phosphate rock; BPR= Busumbu phosphate rock

Table 2. The phosphorus sorption parameters, adsorption affinity (k), adsorption maxima (b), and P adsorbed at 0.2 mg P L⁻¹ (q) obtained from the Langmuir equation for the various treatments at Kakamega

Treatment	4 WAI			9 WAI		
	k (mg L ⁻¹)	b (mg kg ⁻¹)	q (mg kg ⁻¹)	k (mg L ⁻¹)	b (mg kg ⁻¹)	q (mg kg ⁻¹)
1. Control (no P input)	0.29a	683b	36.88a	0.37a	700a	48.1a
2. <i>Tithonia</i> (20 kg P ha ⁻¹)	0.21b	764a	30.15a	0.34a	690a	43.5a
3. FYM (20 kg P ha ⁻¹)	0.22ab	784a	32.42a	0.29a	716a	39.3a
4. MPR (60 kg P ha ⁻¹) + urea	0.30a	684b	38.52a	0.39a	698a	48.4a
5. BPR (60 kg P ha ⁻¹) + urea	0.23ab	735ab	32.43a	0.51a	624a	57.2a
6. TSP (60 kg P ha ⁻¹) + urea	0.24ab	702ab	32.42a	0.37a	686a	46.9a
7. <i>Tithonia</i> (20 kg P ha ⁻¹) + MPR (40 kg P ha ⁻¹)	0.31a	681b	38.29a	0.24a	748a	34.2a
8. <i>Tithonia</i> (20 kg P ha ⁻¹) + BPR (40 kg P ha ⁻¹)	0.30a	675b	38.37a	0.35a	680a	43.9a
9. <i>Tithonia</i> (20 kg P ha ⁻¹) + TSP (40 kg P ha ⁻¹)	0.20b	752a	28.87a	0.33a	686a	42.3a
10. FYM (20 kg P ha ⁻¹) + MPR (40 kg P ha ⁻¹)	0.23ab	713a	31.60a	0.33a	679a	41.9a
11. FYM (20 kg P ha ⁻¹) + BPR (40 kg P ha ⁻¹)	0.22ab	724a	30.64a	0.30a	725a	41.4a
12. FYM (20 kg P ha ⁻¹) + TSP (40 kg P ha ⁻¹)	0.20b	745a	28.85a	0.27a	706a	36.0a
SED	0.04	31	NS	NS	NS	NS
CV%	19	5	13	23	6	17

WAI= Weeks after planting; FYM= Farmyard manure; TSP= triple superphosphate; MPR= Minjingu phosphate rock; BPR= Busumbu phosphate rock; SED = standard error of difference between means. NS = not significant at $p < 0.05$

Table 3. The phosphorus sorption parameters, adsorption affinity (k), adsorption maxima (b), and P adsorbed at 0.2 mg P L⁻¹ (q) obtained from the Langmuir equation for the various treatments at Bukura

Treatment	4 WAI			9 WAI		
	k (mg L ⁻¹)	b (mg kg ⁻¹)	q (mg kg ⁻¹)	k (mg L ⁻¹)	b (mg kg ⁻¹)	q (mg kg ⁻¹)
1. Control (no P input)	2.36a	859a	269a	3.25a	681a	265a
2. <i>Tithonia</i> (20 kg P ha ⁻¹)	1.54a	854a	192b	2.28b	684a	214b
3. FYM (20 kg P ha ⁻¹)	2.24a	823a	236a	1.68b	710a	178b
4. MPR (60 kg P ha ⁻¹) + urea	2.50a	842a	261a	2.68a	685a	233ab
5. BPR (60 kg P ha ⁻¹) + urea	3.13a	759a	285a	5.65c	590b	308c
6. TSP (60 kg P ha ⁻¹) + urea	1.94a	892a	223a	2.86a	675a	234ab
7. <i>Tithonia</i> (20 kg P ha ⁻¹) + MPR (40 kg P ha ⁻¹)	2.21a	755a	222a	3.19a	610b	237ab
8. <i>Tithonia</i> (20 kg P ha ⁻¹) + BPR (40 kg P ha ⁻¹)	2.75a	744a	255a	2.76a	676a	235ab
9. <i>Tithonia</i> (20 kg P ha ⁻¹) + TSP (40 kg P ha ⁻¹)	1.67a	838a	207b	3.60a	594b	242ab
10. FYM (20 kg P ha ⁻¹) + MPR (40 kg P ha ⁻¹)	2.38a	729a	229a	2.45ab	719a	234ab
11. FYM (20 kg P ha ⁻¹) + BPR (40 kg P ha ⁻¹)	2.35a	769a	238a	2.62ab	659ab	224ab
12. FYM (20 kg P ha ⁻¹) + TSP (40 kg P ha ⁻¹)	1.50a	807a	175b	2.17b	649ab	195b
SED	NS	NS	29.7	0.56	32.7	21.6
CV%	38	13	16	23	6	11

WAI= Weeks after planting; FYM= Farmyard manure; TSP= triple superphosphate; MPR= Minjingu phosphate rock; BPR= Busumbu phosphate rock; SED = standard error of difference between means. NS = not significant at $p < 0.05$

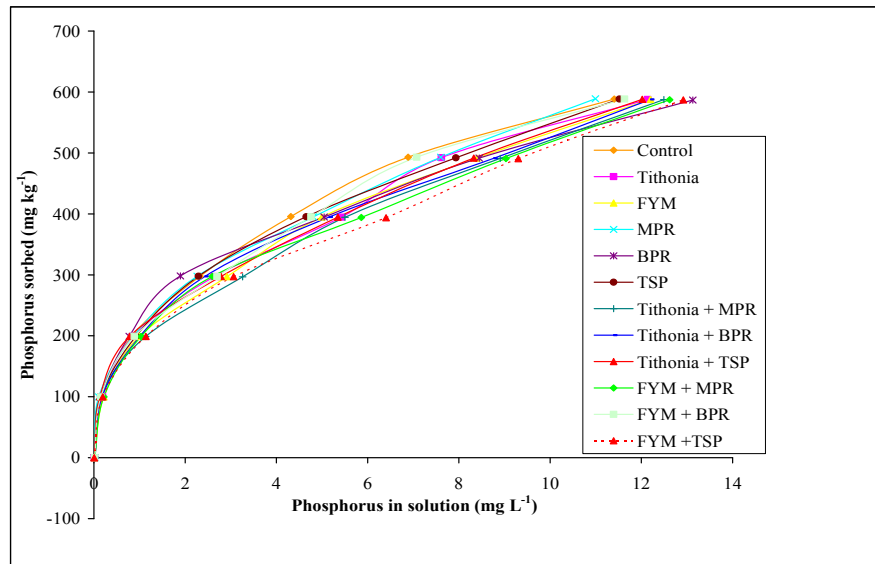


Fig. 2. Phosphorus sorption isotherms for organic and inorganic P sources at 9 WAI at Kakamega. FYM= Farmyard manure; TSP= triple superphosphate; MPR= Minjingu phosphate rock; BPR= Busumbu phosphate rock

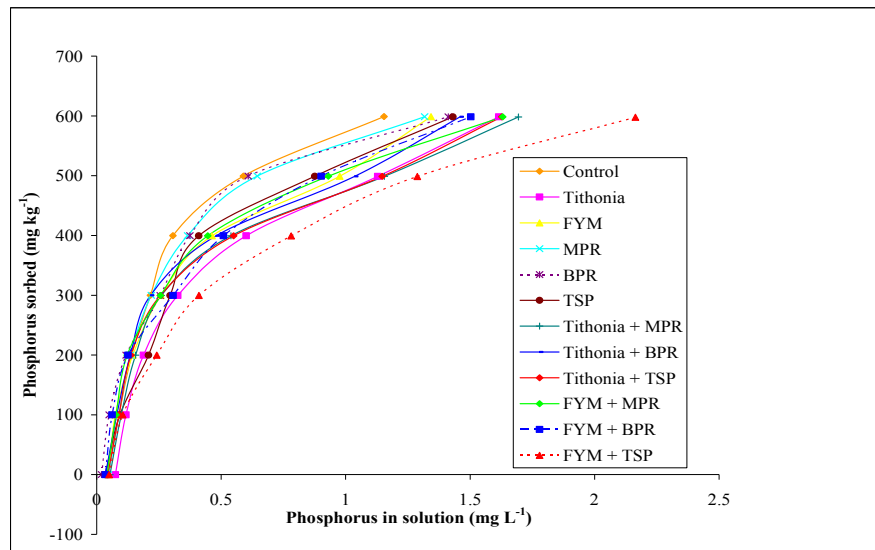


Fig. 3. Phosphorus sorption isotherms for organic and inorganic P sources at 4 WAI at Bukura. FYM= Farmyard manure; TSP= triple superphosphate; MPR= Minjingu phosphate rock; BPR= Busumbu phosphate rock

It was observed in this study that the adsorption maxima (b) of soils treated with OM, especially when applied alone, were in some cases higher than those of treated with inorganics alone. This is contrary to several other studies that have reported reduction in b with addition of OM [e.g. 22-24]. However [25] whose findings were similar

to those reported herein, explained that the addition of organic constituents from the OM or their transformation in the soil possibly led to the creation of additional organic P binding sites but which were of lower binding affinity (k). The rest of the discussion will focus on adsorbed P (q), which is of more agronomic relevance.

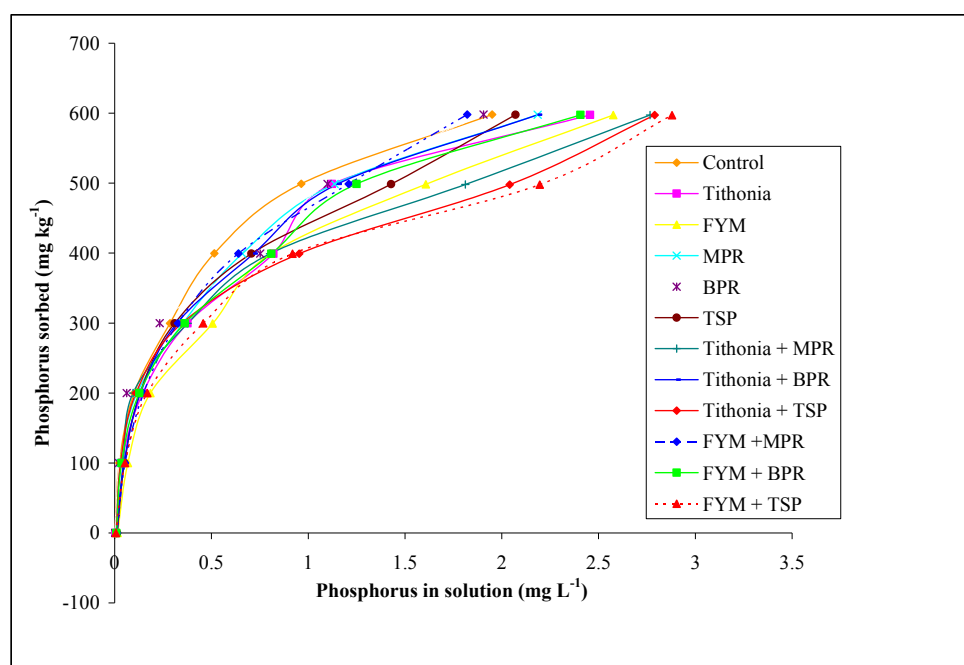


Fig. 4. Phosphorus sorption isotherms for organic and inorganic P sources at 9 WAI at Bukura. FYM= Farmyard manure; TSP= triple superphosphate; MPR= Minjingu phosphate rock; BPR= Busumbu phosphate rock

The reduction in P sorption, q , following application of organic amendments to soils, as was observed in the present study, is now thought to be a cumulative result of several mechanisms [12,13]. These include release of inorganic P from the decaying residues, blocking of the P adsorption sites by organic molecules released from the residues, a rise in soil pH during decomposition and the complexation of soluble Al and Fe by organic molecules [26]. MPR, TSP and BPR were unable to reduce P sorption due to their inability to increase the soil pH or decrease exchangeable Al in soils [9].

4. CONCLUSION

The equilibrium P concentration which represents the amount of P in the equilibrium solution at zero P sorbed was $< 0.2 \text{ mg P L}^{-1}$ regardless of the input combination used. This confirms that these soils were deficient in P and would benefit from application of P inputs. None of the P sources significantly reduced the amount of P sorbed on the cambisol at Kakamega likely due to its already low sorption capacity. However at Bukura, the amount of P sorbed was significantly lowered by application of *Tithonia* when applied alone and FYM applied in

combination with TSP. *Tithonia* applied with TSP significantly reduced the P sorbed at 4 WAI but not 9 WAI while FYM applied alone was able to lower the amount of P sorbed at 9 WAI. None of the inorganic P sources reduced the P sorption capacity of the soils. The results demonstrate that effect of OMs on P sorption is site specific and depends on soil type. Organic materials have the potential to reduce P sorption in soils that are high in P sorption such as Ferralsols, but where the P sorption is low as in Cambisols, the application of OMs to reduce P sorption may not be useful.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Palm CA, Gachengo CN, Delve CN, Cadisch G, Giller KE. Organic inputs for soil fertility management in tropical agroecosystems: Application of an organic resource database. Agric. Ecosyst. Environ. 2001;83:27-42.

2. Van Straaten P. Rocks for crops: Agrominerals of sub-Saharan Africa. ICRAF, Nairobi: 2002;338.
3. Curtin D, Syers JK. Lime-induced changes in indices of soil phosphate availability. Soil Sc. Soc. Am. J. 2001;65:147-152.
4. Savdera C, Delgado A. Phosphorus fractions and release patterns in typical Mediterranean soils. In: Soil Sci. Soc. Am. J. 2005;69:607-615.
5. Sui Y, Thompson ML. Phosphorus Sorption, Desorption and Buffering Capacity in a Biosolids-Amended Mollisol. Soil Sci. Soc. Am. J. 2000;64:164-169.
6. Sanchez PA, Salinas JG. Low-input technologies for managing Oxisols and Ultisols in Tropical America. Adv. Agron. 1981;34:279-406.
7. Sanchez PA, Uehara G. Management considerations for acid soils with high phosphorus fixation capacity. In: The role of P in agriculture. Khasawneh FE, Dinauer, CR, Sample EC, Kamprath EJ. (eds). 1980;471-514. Amer. Soc. Agron. Madison, Wisconsin.
8. Buresh RJ, Smithson PC, Hellums DT. Building soil phosphorus capital in Africa In: Buresh RJ, Sanchez PA, Calhoun F (eds.). Replenishing soil fertility in Africa. SSSA special publication no. 51. Madison. Wisconsin. 1997;114-149.
9. Kisinyo PO, Othieno CO, Gudu SO, Okalebo JR, Opala PA, Ng'etich WK, Nyambati RO, Ouma EO, Agalo JJ, Kebeney SJ, Too EJ, Kisinyo JA, Opile WR. Immediate and residual effects of lime and phosphorus fertilizer on soil acidity and maize production in Western Kenya. 2014;50:128-143.
10. Nziguheba G. Overcoming phosphorus deficiency in soils of Eastern Africa: Recent advances and challenges. In: A. Bationo (ed). Advances in integrated Soil Fertility Management in sub-Saharan Africa: Challenges and opportunities. 2007;49-160.
11. Nziguheba G, Merckx R, Palm CA, Mutuo P. Combining *Tithonia diversifolia* and fertilizers for maize production in phosphorus deficient soil in Kenya. Agroforestry Systems. 2002;55:165-174.
12. Iyamuremye F, Dick RP. Organic amendments and phosphorus sorption by soils. Adv. Agron. 1996;56:139-185.
13. Guppy CN, Menzies NW, Moody PW and Blamey FPC. Competitive sorption reactions between phosphorus and organic matter in soil: A review. Aust. J. Soil Sci. 2005;43:189-202.
14. Ohno T, Crannell BS. Green manure and animal derived dissolved organic matter effects on phosphorus sorption. J. Environ. Qual. 1996;25:1137-1143.
15. FAO/UNESCO. Soil Map of the World: Revised legend. World Soil Res. Rep; 1988. No. 60. FAO, Rome, Italy.
16. Fox RL, Kamprath EJ. Phosphate sorption isotherms for evaluating the requirements of soil. Soil Sci. Soc. Am. Proc. 1970;34:902-907.
17. Murphy J, Riley JP. A modified single solution for determination of phosphate in natural waters. Anal. Chim. Acta. 1962;27:31-36.
18. GENSTAT. Gensat 5 Release 3.2 Reference manual. Oxford university press. Oxford, U.K.; 1993.
19. Reddy KR, Overcash MR, Khaleel R, Westerman PW. Phosphorus adsorption-desorption characteristics of two soils utilized for disposal of animal wastes. Environ. Qual. 1980;9:86-92.
20. Juo ASR, Fox RL. Phosphate sorption characteristics of some benchmark soils in West Africa. Soil. Sc. 1977;124:370-376.
21. Smyth TJ and Sanchez PA. Effects of lime, silicate and phosphorus applications to an Oxisol on phosphorus sorption and ion retention. Soil Sci. Soc. Am. J. 1980;44:500-505.
22. Bumaya AH, Naylor DV. Phosphorus sorption and extractability in Andic soil incubated with plant residues of variable P content. Plant and Soil. 1988;112:77-81.
23. Iyamuremye F, Dick RP, Baham J. Organic amendments and phosphorus dynamics. I. Phosphorus chemistry and sorption. Soil Sci. 1996;161:426-435.
24. Bahl GS, Vig, AC, Pal Y, Singh A. Effect of green manure and cropping on P sorption in some soils of Punjab and Himachal Pradesh. Journal of Indian Society of Soil Science. 1998;46:574-579.
25. Brauer D, Turner K, Belesky D. Effects of source and amount of phosphorus on sorption kinetics in the topsoil of a highly weathered soil. Commun. Soil Sci. Plant Anal. 2007;49:841-850.

26. Haynes RJ, Mokolobate MS. Amelioration of aluminum toxicity and phosphorus deficiency in acid soils by additions of organic residues: A critical review of the phenomenon and mechanisms involved. Nutrient cycling in Agroecosystems. 2001;59: 47-63.

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