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EFFECTS OF COMBINING ORGANIC MATERIALS WITH INORGANIC PHOSPHORUS SOURCES ON MAIZE YIELD AND FINANCIAL BENEFITS IN WESTERN KENYA

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SUMMARY

Due to escalating costs of imported fertilizers, there is renewed interest in the use of local nutrient resources in managing soil fertility in Kenya. We tested the effect of two organic materials, farmyard manure (FYM) and *Tithonia diversifolia* (tithonia), and an inorganic N fertilizer, urea, when applied alone or in combination with three inorganic P sources, triple superphosphate (TSP), Minjingu phosphate rock (MPR) and Busumbu phosphate rock (BPR), on maize yields and financial benefits. The study was conducted for three consecutive seasons, from March 2007 to August 2008 in western Kenya. FYM and tithonia were applied to supply 20 kg P ha^{-1} in treatments where they were used either alone or in combination with the inorganic P sources while 40 kg P ha^{-1} was from the inorganic P sources in the combination. Where urea was used, the inorganic P sources were applied at 60 kg P ha^{-1}. When applied in combination with urea, MPR was a better P source for maize than TSP or BPR. However, when applied in combination with FYM or tithonia, TSP was the best P source. Treatments including tithonia were more effective in increasing maize yields than those without it with a similar total P application rate. The agronomic effectiveness of tithonia did not, however, translate to economic attractiveness, mainly due to very high labour costs associated with its use. FYM when applied alone at 20 kg P ha^{-1} was the only treatment that exceeded a benefit:cost ratio of 2 and, therefore, the most likely, of the tested technologies to be adopted by farmers.

INTRODUCTION

Crop production by the smallholder farmers in the densely populated humid regions of western Kenya is commonly constrained by low soil fertility, particularly phosphorous (P) deficiency (Jama *et al.,* 1997). On such soils, use of other nutrient inputs is not usually effective in increasing crop yields unless P limitations are overcome. Management of P deficiency requires application of inorganic fertilizers, organic inputs or their combinations. However, use of inorganic fertilizers remains negligible among the farmers in western Kenya because of the high cost of purchased fertilizer inputs, the low purchasing power of smallholder farmers and their restricted access to credit (Nziguheba *et al.,* 2002). On the other hand, sole use of organic materials (OMs) to supply P for crop production is not a practical option because most OMs are low in P, thus large amounts would be required to produce moderate yield increases (Palm *et al.*, 2001). There is, therefore, growing interest in integrated soil fertility management in western Kenya, whereby OMs are judiciously combined with inorganic fertilizers (Vanlauwe, 2004). There is also shifting emphasis from reliance on imported fertilizer

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inputs to the use of more local nutrient resources in soil fertility management. In this regard, the use of phosphate rock (PR) as an alternative to soluble inorganic P fertilizers is attracting increased attention (Jama and van Straaten., 2006).

There have been numerous laboratory incubation studies demonstrating positive effects of some OMs and PRs on soil chemical properties such as pH, Al and P sorption (e.g. Iyamuremye *et al.*, 1996; Narambuye and Haynes, 2006; Nziguheba *et al.,* 1998). Such studies have often implied that these positive effects would translate into improved crop yields when the OMs or PRs are used for crop production in P-deficient acid soils. It is also often taken for granted that since these materials are supposedly cheaper than conventional inorganic P fertilizers, their use for crop production would be economically more attractive than the sole use of inorganic fertilizers. However, these concepts have rarely been tested in field experiments in eastern Africa. We hypothesized that combined application of OMs, which are commonly found on smallholder farms in western Kenya, and inorganic P fertilizer inputs would give higher maize yields and financial benefits than the application of such inorganic P inputs in combination with urea.

The objectives of this study were therefore to: i) evaluate the effects of combined application of Minjingu phosphate rock (MPR), Busumbu phosphate rock (BPR) or triple superphosphate (TSP) with urea, *Tithonia diversifolia* green manure (tithonia) or farmyard manure (FYM) on maize yields, and ii) compare the financial benefits of using tithonia or FYM for maize production, when applied alone or in combination with TSP or PRs.

MATERIALS AND METHODS

Site description

A field experiment was conducted for three consecutive seasons, from March 2007 to August 2008, at Bukura Agricultural College in western Kenya (0°7′N, 34°30′E). The average annual rainfall at this site is 1700 mm, which is distributed over two main cropping seasons, the long rainy season, from March to July, and the short rainy season, from September to December. The soil is classified as an orthic Ferralsol (FAO/UNESCO, 1988) with the following characteristics; pH = 4.8; exchangeable acidity = 0.89 cmol kg^{-1}; total soil organic carbon = 20.9 g kg^{-1}; exchangeable potassium (K) = 0.1 cmol kg^{-1}; exchangeable Mg = 1.0 cmol kg^{-1}; exchangeable Ca = 1.9 cmol kg^{-1}; effective cation exchange capacity (ECEC) = 3.89 cmol kg^{-1}; Al saturation = 23%; Olsen extractable P = 5.6 mg kg^{-1}. The soil had a moderate P-fixing capacity with a soil P concentration of 0.2 mg l^{-1} corresponding to 260 mg P kg^{-1} adsorbed by the soil.

Experimental layout and management

The experiment was established in March 2007 and laid out as a randomized complete block design with three replications with plots measuring 5 m × 3 m. The treatments consisted of three inorganic P sources (TSP, MPR and BPR), each applied in combination with two OMs (FYM or tithonia) or with urea, a commercial nitrogen

(N) fertilizer. Other treatments included a control with no P input but with urea, 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 the inorganic P sources. The inorganic P sources were applied to provide 40 kg P ha^{-1} in the OM/inorganic P source combinations, but when they were used in combination with urea, they were applied at 60 kg P ha^{-1}. This P rate was chosen based on earlier observations which showed that it gave maximum benefits to maize crops in most soils in western Kenya (FURP, 1987).

Initial characterization of the OMs showed that on average, the tithonia biomass had 3.0% N, 0.3% P and 3.8% K, and the FYM had 1.8% N, 0.4% P and 1.2% K. At the P application rate of 20 kg P ha^{-1}, both FYM and tithonia therefore provided adequate N for the maize crop (>80 N kg ha^{-1}) as per the recommendations for the study area (FURP, 1987). Urea was applied to provide 100 kg N ha^{-1} where it was used. The nutrient inputs were evenly spread within the appropriate experimental plots and incorporated to a depth of 0–15 cm at the time of planting in each season. However, urea was applied at only a third of the full rate and the rest was applied five weeks after planting. Muriate of potash (KCl) was applied at a rate of 60 kg K ha^{-1} to all plots without an application of tithonia or FYM at the time of planting maize. The intention was to supply sufficient amounts of N and K to ensure that the two nutrients were not limiting factors on plant growth when studying the P effects. Maize was grown using the recommended agronomic practices for the area.

Analyses of soils and the organic materials

Tithonia was obtained from the hedges bordering the experimental site while the FYM was from the Bukura Agricultural College farm. Characterization of the OMs and soils was performed using the following laboratory analyses. Organic C was determined by Walkley and Black sulphuric acid–dichromate digestion followed by back titration with ferrous ammonium sulphate (Nelson and Sommers, 1982). Total N and P were determined by digesting 0.3 g of the soil/OM sample in a mixture of Se, $LiSO_4$, H_2O_2 and concentrated H_2SO_4 (Anderson and Ingram, 1993). The N and P contents in the digests were determined colorimetrically. The particle size distribution was determined by the Bouyoucos hydrometer method, and the available P was determined by the Olsen method as described by Okalebo *et al.* (2002). Soil pH was determined using a glass electrode pH meter at 1:2.5 soil:water ratio (McClean, 1965). The basic cations (Ca, Mg and K) were extracted using ammonium acetate at pH 7 (Anderson and Ingram, 1993). Exchangeable Ca and Mg in the extract were determined using atomic absorption spectrophotometry, and exchangeable K by flame photometry. Exchangeable acidity and exchangeable Al were extracted using unbuffered 1M KCl (Anderson and Ingram, 1993).

Economic analysis

The net benefits of each treatment were computed using partial budgeting, which included only costs and benefits that varied from the control. The prices of maize,

Table 1. Values used for cost benefit analysis.

Parameter	Actual values (USD) First and second seasons	Third season
Price of TSP kg^{-1}	0.62	1.23
Price of MPR kg^{-1}	0.35	0.69
Price of BPR kg^{-1}	0.31	0.61
Price of urea kg^{-1}	0.54	0.80
Transport of fertilizers to the farm 100 kg^{-1}	1.75	1.75
Labour for applying fertilizers ha^{-1}	1.67	1.67
Price of FYM 100 kg^{-1} ‡	0.80	1.00
Cost of application of FYM ha^{-1}‡	26.00	26.00
Cost of cutting and application of 6.7 t of tithonia‡	605.00	605.00
Price of maize kg^{-1}	0.32	0.39
Price of maize stover 100 kg^{-1}	12.00	12.00

‡Values of FYM (farmyard manure) and tithonia are expressed on dry matter basis.

FYM, TSP, MPR, BPR, urea and fertilizer transport cost were determined through a market survey of the area (Table 1). Tithonia was costed in terms of labour involved in harvesting, transporting and incorporating it into the soil (Mucheru-Muna *et al.*, 2007). Amounts of labour for application of fertilizer, FYM and tithonia were determined from observation of the performance of the specific activities in each season. Discount rate of capital was estimated at 10% per season (20% per year). This discount rate reflects a farmer's preference to receive benefits as early as possible and postpone costs (Jama *et al.*, 1997).

Mathematical calculations and data analysis

The relative agronomic effectiveness (RAE) of the PRs compared to TSP was calculated as:

$$\mathrm{RAE} = (\mathrm{Y_{PR}} - \mathrm{Y_{control}})/(\mathrm{Y_{TSP}} - \mathrm{Y_{control}}) \times 100$$

Where Y_{PR} is maize grain yield from MPR or BPR applied at the rate of 60 kg P ha^{-1}, Y_{TSP} is maize grain yield from the TSP treatment at the rate of 60 kg P ha^{-1} and $Y_{control}$ is maize grain yield from the control (0 P).

Analysis of variance (ANOVA) was conducted using the Genstat statistical package (GENSTAT, 1993) to determine the effects of treatments on maize grain yields. The standard error of difference between means (*s.e.d.*) was used to compare the treatment means. Mention of statistical significance refers to $p < 0.05$ unless otherwise stated.

RESULTS

Maize grain yields

The maize grain yields varied among the seasons (Table 2). The mean grain yields of the third season (2.9 t ha^{-1}) were higher than those of the second season

Table 2. Effect of organic materials and inorganic phosphorus sources on maize grain yield at Bukura, western Kenya.

Treatment	Total P added (kg-^{1})	Season: First	Second	Third
		Grain yield t ha^{-1}		
1. Control (no P but with urea applied)	0	1.9	0.8	1.3
2. Tithonia (20 kg P ha^{-1})	20	4.3	1.6	3.6
3. FYM (20 kg P ha^{-1})	60	3.2	1.4	2.5
4. MPR (60 kg P ha^{-1}) + urea	60	2.6	1.1	2.4
5. BPR (60 kg P ha^{-1}) + urea	60	2.0	0.7	1.4
6. TSP (60 kg P ha^{-1}) + urea	60	2.2	1.0	1.5
7. Tithonia (20 kg P ha^{-1}) + MPR (40 kg P ha^{-1})	60	4.9	2.3	4.4
8. Tithonia (20 kg P ha^{-1}) + BPR (40 kg P ha^{-1})	60	4.4	1.3	3.9
9. Tithonia (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	60	5.1	2.4	5.3
10. FYM (20 kg P ha^{-1}) + MPR (40 kg P ha^{-1})	60	3.2	1.4	2.7
11. FYM (20 kg P ha^{-1}) + BPR (40 kg P ha^{-1})	60	2.7	1.0	2.4
12. FYM (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	60	2.9	1.4	3.0
s.e.d.		0.49	0.3	0.6
CV%		18.00	28.0	13.0

FYM: farmyard manure; TSP: triple superphosphate; MPR: Minjingu phosphate rock; BPR: Busumbu phosphate rock; *s.e.d.* = standard error of difference between means.
CV: coefficient of variance.

(1.4 t ha^{-1}) but lower than those of the first season (3.3 t ha^{-1}). The highest increase in maize yields, relative to the control, in each of the three seasons was with tithonia applied in combination with TSP, while the lowest was by BPR, when combined with urea. When the total yield of the three seasons is considered, the yield increase by tithonia combined with TSP was 220% and only 12% when BPR was combined with urea.

Maize failed to respond to all the inorganic P sources, when applied in combination with urea in the first two seasons, and responded only to MPR in the third season. All the treatments with tithonia or FYM, when applied alone or in combination with the inorganic P sources, significantly increased maize yields above the control in all the three seasons. The maize yields obtained when tithonia was combined with either TSP or MPR, at the total P rate of 60 kg ha^{-1}, were significantly higher than those of tithonia applied alone at 20 kg P ha^{-1} in both the second and third seasons but not the first season. The combination of BPR with tithonia, however, gave yields that were not significantly different from those obtained with tithonia when applied alone in all seasons. Combining FYM with the inorganic P sources at the total P rate of 60 kg ha^{-1} gave maize yields that were not significantly different from those obtained when FYM was applied alone at only 20 kg P ha^{-1} in all seasons. In general, when applied in combination with urea, MPR was a better P source for maize than TSP or BPR. However, when applied in combination with FYM or tithonia, TSP was the best P source. The RAE for MPR applied in combination with urea ranged from 207% to 300%, but BPR had a much lower RAE ranging from −86% to 33%.

Table 3. Effect of organic materials and inorganic phosphorus sources on added costs (USD ha^{-1}) at Bukura, western Kenya.

Treatment	Added input cost: Each of the first two seasons	Added input cost: Third season	Added labour costs: Each of the three seasons	Total added costs: Each of the first two seasons	Total added costs: Third season
1. Control (no P but with urea applied)	–	–	–	–	–
2. Tithonia (20 kg P ha^{-1})	0	0	605	605	605
3. FYM (20 kg P ha^{-1})	72	86	26	98	112
4. MPR (60 kg P ha^{-1}) + urea	295	585	3	298	588
5. BPR (60 kg P ha^{-1}) + urea	270	541	3	273	544
6. TSP (60 kg P ha^{-1}) + urea	344	607	3	347	610
7. Tithonia (20 kg P ha^{-1}) + MPR (40 kg P ha^{-1})	108	260	607	715	867
8. Tithonia (20 kg P ha^{-1}) + BPR (40 kg P ha^{-1})	91	230	607	698	837
9. Tithonia (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	141	275	606	747	881
10. FYM (20 kg P ha^{-1}) + MPR (40 kg P ha^{-1})	154	354	28	182	382
11. FYM (20 kg P ha^{-1}) + BPR (40 kg P ha^{-1})	137	316	28	165	344
12. FYM (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	187	360	28	215	388

FYM: farmyard manure; TSP: triple superphosphate; MPR: Minjingu phosphate rock; BPR: Busumbu phosphate rock.

Economic analyses

Total added costs for the tithonia treatments were generally high (Table 3). Tithonia applied in combination with TSP had the highest added costs while FYM applied alone had the least added costs in all the seasons. The added costs for the first two seasons were similar, but in the third season the added costs were higher, mainly due to increased cost of inorganic P fertilizers. The higher costs for the tithonia treatments resulted mainly from the high labour cost associated with its use. Labour costs constituted 100% of the total added costs (input + labour) when tithonia was applied alone and ranged from 69 to 87% of the total added costs when it was combined with inorganic P sources. Labour costs for the inorganic P sources, when not combined with OMs, were small and on average represented < 1% of the total added costs in all seasons.

The highest net financial benefits in the first and third seasons were obtained with tithonia when combined with TSP while the lowest net benefits, in all seasons, were obtained with BPR when applied with urea (Table 4). In the second season, net benefits were negative for all the treatments apart from FYM when applied alone or in combination with MPR (Table 4). The net benefits for combination of the OMs and inorganic P sources depended on the input combinations. Combining FYM with any of the inorganic P sources resulted in net benefits that were lower than FYM applied alone, but higher than the inorganic P sources applied without integration. Combining tithonia with TSP or MPR resulted in net benefits that were higher than the sole application of tithonia or the two inorganic P sources applied with urea but the combination of tithonia with BPR was superior to tithonia alone only in the first season. The benefit cost ratios (BCR) were generally low (< 1) for all the treatments, apart from those with FYM, in all the seasons (Table 4).

Table 4. Net financial benefits (USD ha^{-1}) and benefit-cost ratio (BCR) at Bukura, western Kenya.

	First season		Second season		Third season	
Treatment	Net benefit	BCR	Net benefit	BCR	Net benefit	BCR
1. Control (no P but with urea applied)	–	–	–	–	–	–
2. Tithonia (20 kg P ha^{-1})	144	0.2	−351	−0.6	306	0.5
3. FYM (20 kg P ha^{-1})	323	3.3	130	1.3	379	3.4
4. MPR (60 kg P ha^{-1}) + urea	−51	−0.2	−188	−0.6	−196	−0.3
5. BPR (60 kg P ha^{-1}) + urea	−248	−0.9	−399	−1.5	−514	−0.9
6. TSP (60 kg P ha^{-1}) + urea	−228	−0.7	−284	−0.8	−512	−0.8
7. Tithonia (20 kg P ha^{-1}) + MPR (40 kg P ha^{-1})	327	0.5	−232	−0.3	377	0.4
8. Tithonia (20 kg P ha^{-1}) + BPR (40 kg P ha^{-1})	172	0.3	−506	−0.7	232	0.3
9. Tithonia (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	405	0.5	−234	−0.3	711	0.8
10. FYM (20 kg P ha^{-1}) + MPR (40 kg P ha^{-1})	223	1.2	25	−0.2	161	0.4
11. FYM (20 kg P ha^{-1}) + BPR (40 kg P ha^{-1})	100	0.6	−95	−0.8	114	0.3
12. FYM (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	138	0.6	−10	−0.1	302	0.8

FYM: farmyard manure; TSP: triple superphosphate; MPR: Minjingu phosphate rock; BPR: Busumbu phosphate rock.

Sensitivity analyses revealed that net benefits for use of FYM and tithonia were strongly influenced by labour wage rate, price and their P content (Figures 1 and 2). The net benefits calculated for this study valued labour cost for collection, transportation and application of tithonia (0.3% P) at 0.09 USD kg^{-1}. The labour cost could be lower for farmers using family labour, especially at non-peak periods with limited opportunity for off-farm employment (Jama *et al.*, 1998). The labour cost, on the other hand, could also be higher in environments with greater opportunity for off-farm employment. Thus in the sensitivity analyses, both scenarios were considered where labour wages for tithonia use were varied from 0.067 (a reduction in labour wage rate by approximately 25%) to 0.185 USD kg^{-1} (if the labour wage is increased by about 100%). The P concentration of tithonia also varies from 0.24 to 0.56% (Jama *et al.*, 2000), therefore this range of P concentrations was considered in the analyses. The net benefits for tithonia with a P concentration of 0.50% were positive at all the wage rates considered in the first and third seasons. The break-even wage rate, below which financial returns were negative in the first season, was 0.09 and 0.11 USD kg^{-1} for tithonia with a P concentration of 0.24% and 0.30% respectively (Figure 1). In the third season, the break-even wage rates were higher than in the first season, i.e. 0.11 and 0.14 USD kg^{-1} for tithonia with a P concentration of 0.24% and 0.30%, respectively (Figure 1). In the second season, financial benefits for use of tithonia were negative under all the scenarios considered (Figure 1).

The sensitivity analysis considered situations whereby the price of FYM increased from 0.8 to 4.6 USD 100 kg^{-1}. Phosphorus concentrations of FYM within the medium range of 0.2–0.6% were used in the sensitivity analysis. In the first and third seasons, it was economically attractive to use FYM of 0.4 or 0.6% P concentration at all the prices considered (Figure 2). Use of FYM with a P concentration of 0.2%, however, gave net negative financial benefits when the price of FYM exceeded 2.9 and 3.3 USD 100 kg^{-1}, in the first and third seasons respectively. While use of FYM with a 0.6%

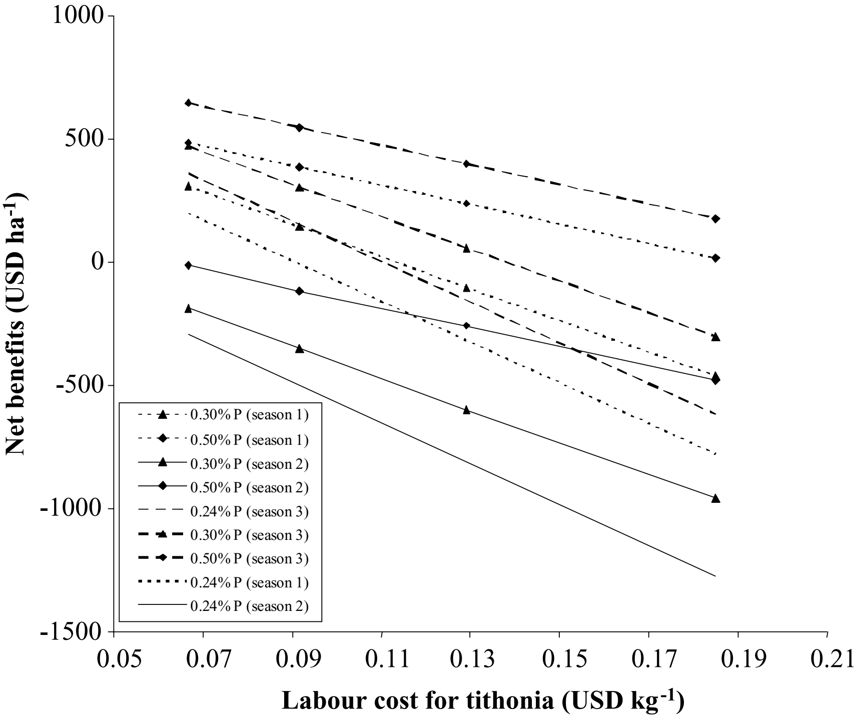

Figure 1. Effect of change in labour cost and P concentration of tithonia on net benefits at Bukura, western Kenya.

P concentration was economically attractive at all the FYM prices considered in the second season, reducing its P concentration to 0.2% resulted in net negative benefits across most of the prices considered (Figure 2).

In general, net benefits increased with increasing P concentration in tithonia and FYM because of the proportional decreases in the quantity of the OM required to achieve the desired P application rate of 20 kg P ha^{-1}. This reduction in quantity of required OM also resulted in reduced labour costs for collection and application of the OM. Net benefits, as would be expected, were always higher at the lower prices of manure or reduced labour wages for tithonia because of the resultant lower costs.

DISCUSSION

Maize grain yields

The variation in maize grain yields observed among the seasons is attributed mainly to the differences in rainfall. In the first season, the rainfall was adequate (>1400 mm) during the growing period of maize and the uptake of nutrients by the crop was thus not inhibited leading to high grain yields. In the second season, the rainfall was low and poorly distributed. A total of 459 mm of rainfall was recorded in this season with only 48 mm being received in November, when the crop was tasselling. Uptake of nutrients was therefore constrained by low available moisture in this season. In the

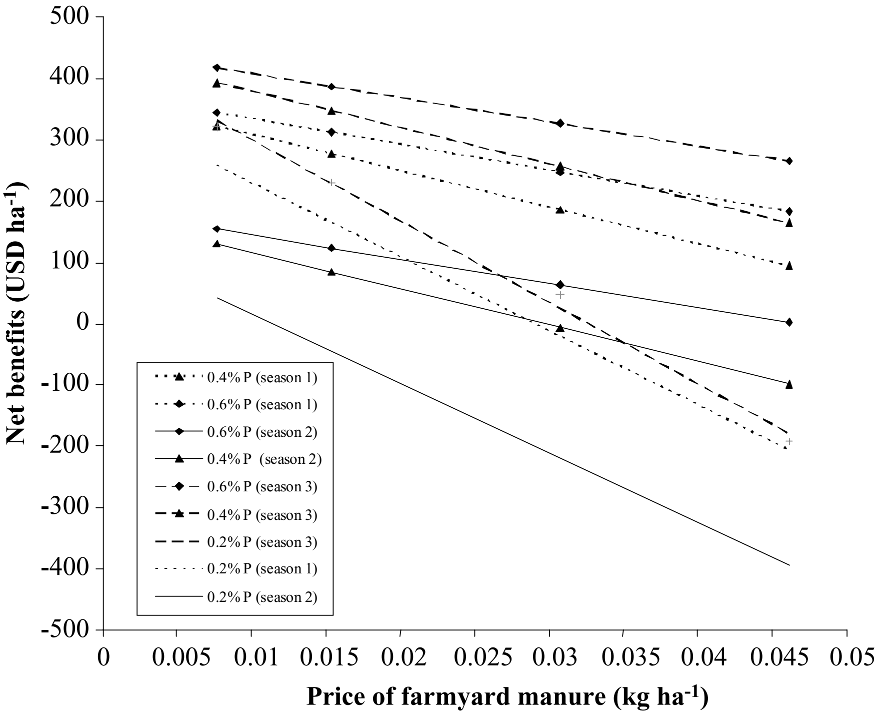

Figure 2. Effect of change in price and P concentration of farmyard manure on net benefits at Bukura, western Kenya.

third season, the grain yield was higher than in the second season but lower than the first season. There was little rainfall (230 mm) received in June and July in the third season. This coincided with the tasselling period of maize and, therefore, led to a reduction in grain yield compared to the first season when rainfall was higher (700 mm) during the two months.

The general failure of maize to respond to the inorganic P sources, when applied in combination with urea at a P rate of 60 kg ha^{-1}, suggests that some other factor had a more profound effect on maize yields than P availability. In fact, higher maize yields were obtained with tithonia and FYM when applied at a lower P rate of 20 kg P ha^{-1}. The Al saturation (23%) in the soil, which was above the critical value of 20% that has been reported to cause Al toxicity in maize (Farina and Chanon 1991), points to a possibility of Al toxicity at this site. The superior effect of OMs, such as tithonia and FYM, on crop yield when compared to inorganic P fertilizers is likely due to their ability to reduce exchangeable Al in soils, provide micronutrients which are not present in the inorganic fertilizers, and improve soil physical properties such as soil structure and soil moisture holding capacity, which in turn influence nutrient acquisition and plant growth (Haynes and Mokolobate, 2001: Palm *et al.,* 1997).

The RAE of MPR was >200% in all seasons, indicating that although statistically significant differences in maize yields between MPR and TSP were not always attained, MPR is a potentially better source of P than TSP when both are applied in combination with urea in this acid soil. The very low RAE of BPR makes it unsuitable for direct application at this site.

Economic analysis

The added costs of using tithonia were very high because of its bulkiness. Although its P content is considered to be high for a plant material (Jama *et al*, 2000), it had a very high moisture content (80%) at the time of application and therefore a lot of the material had to be applied. At the practical farming level, the labour costs for harvesting, transporting and incorporating it are therefore quite high. Added costs for use of FYM were relatively lower because of its higher P content and lower moisture content (~30%) hence the FYM applied was less bulky. The other advantage of FYM, which it shared with tithonia, compared with inorganic P sources, was its ability to provide N in addition to P, thus no inorganic N was used in the FYM treatments, making use of FYM less costly than the inorganic P sources, where urea had to be purchased to provide N.

The net financial benefits varied with the seasons and among the treatments. Although tithonia when applied in combination with TSP had the highest added costs, it also recorded the highest net benefits in first season, mainly because it had the highest maize yield increases above the control. In the second season, all tithonia treatments recorded negative benefits, despite having the higher yields compared to the non-tithonia treatments. Adequate extra maize yield that would offset the high costs of using tithonia and allow subsequent economic benefit was barely achieved under the prevailing low rainfall conditions of second season. FYM when applied alone gave the highest net benefit in the second season and although its combination with MPR also gave a positive net benefit, this was small indicating that the combination had no financial advantage. FYM when applied alone appears to be a more appropriate intervention during the drier season. Its ability to give higher net benefits than tithonia in this season is attributed to the fact that the differences in absolute maize yields between them were not as high as in the first season while the labour costs for FYM remained lower. In the third season, the net financial benefits for the FYM and tithonia treatments generally improved compared to the first season, despite the generally lower maize yields in the third season. This is because of the better maize price in this season than the first, while the differences in yields between these treatments (FYM and tithonia) and the control treatment remained almost the same in both seasons. Net financial benefits in the treatments where inorganic P sources were applied in conjunction with urea declined in the third season compared to the first season, mainly due the large increase in fertilizer prices in the third season coupled with the fact that maize did not generally respond to the inorganic P fertilizers when applied without tithonia or FYM.

The sensitivity analyses showed that a reduction in the P concentration in the OMs results in a dramatic decrease in net benefits, mainly due to the increased labour costs. This highlights the need for high quality OMs as sources of P on P-deficient soils. Nziguheba *et al.* (2002) concluded that OMs suitable for use as P sources should have a high P content and low cost of production. The P concentration in plant materials such as tithonia is controlled by genetics and environmental factors (Jama *et al.*, 2000) and cannot, therefore, be easily manipulated by the farmer through management. Opportunities for increasing the quality of FYM, however, do exist. Simple practices such as using pits for manure storage and storing manure under a shade (Rufino *et al.,* 2006) can greatly enhance the quality of FYM therefore making its use by the smallholder farmer even more profitable.

The decision by farmers to use fertilizer sources, based on the BCR indicator, depends on their own standard of profitability (FAO, 2006). However, the general rule is that a BCR of at least 2:1, i.e. a return above the cost of fertilizer treatment of at least 200%, is attractive to farmers (FAO, 2006). The BCRs in the present study were generally low, and only FYM when applied alone at 20 kg P ha^{-1} met this criterion in the first and third seasons at the Bukura site. Despite the good agronomic performance by tithonia on maize yields, it is unlikely that farmers would adopt its use as a source of nutrients for maize mainly because of the high labour costs associated with its use. Among the tested nutrient inputs, only FYM, when applied alone at 20 kg P ha^{-1}, is likely to be adopted especially during periods of adequate rainfall.

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REFERENCES

Anderson, J. M. and Ingram, J. S. I. (1993). *Tropical Soil Biology and Fertility: A handbook of methods*. CAB International, Wallingford, U.K.

FAO (2006). Efficiency of soil and fertilizer phosphorus use: Reconciling changing concepts of soil phosphorus behavior with agronomic information. *Fertilizer and Plant Nutrition Bulletin no. 18. Rome, Italy.*

FAO/UNESCO (1988). Soil map of the world: revised legend. *World Soil Res. Rep. no. 60. FAO, Rome, Italy*.

Farina, M. P. W and Chanon, P. (1991). A field comparison of lime requirement indices for maize. *Plant and Soil* 134: 127–135.

FURP (1987). Fertilizer use recommendation project report. A compilation of results from former fertilizer trials in Kenya. *Ministry of Agriculture, Nairobi, Kenya.*

GENSTAT (1993). *Gensat 5 Release 3.2 Reference Manual.* Oxford: Oxford University Press.

Haynes, R. J. and Mokolobate, M. S. (2001). 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* 59: 47–63.

Iyamuremye, F., Dick, R. P. and Baham, J. (1996). Organic amendments and phosphorus dynamics. I. Phosphorus chemistry and sorption. *Soil Science* 161: 426–435.

Jama, B. and van Straaten. (2006). Potential of East African phosphate rock deposits in integrated nutrient management strategies. *Annals of Brazilian Academy of Sciences*. 78: 781–790.

Jama, B., Palm, C. A, Buresh, R. J., Niang, A. I., Gachengo, C., Nziguheba, G. and Amadalo, B. (2000). *Tithonia diversifolia* as a green manure for soil fertility improvement in Western Kenya., A review. *Agroforestry Systems*. 49: 201–221.

Jama, B., Buresh, R. J. and Place, F. (1998). Sesbania tree fallows on phosphorus deficient site: maize yields and financial benefit. *Agronomy Journal* 90: 717–726.

Jama, B., Swinkels, R. A. and Buresh, R. J. (1997). Agronomic and economic evaluation of organic and inorganic sources of phosphorus in western Kenya. *Agronomy Journal* 89: 597–604.

McLean, E.O. (1965). Soil pH and lime requirement. In *Methods of Soil Analysis, Part 2*, 199–223 (Ed. C. A. Black). ASA, Madison, Wisconsin, USA.

Mucheru-Muna, M., D. Mugendi, J. Kungu, J. Mugwe and A. Bationo (2007). Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. *Agroforestry Systems* 69: 189–197.

Narambuye, F. X. and Haynes, R. J. (2006). Short-term effects of three animal manures on soil pH and aluminum solubility. *Australian Journal of Soil Research* 44: 515–521.

Nelson, S. R. and Sommers, L. E. (1982). Total carbon, organic carbon and organic matter. In *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*, 2nd edn. 539–579 (Ed. A. L. Page, R. H. Miller, and D. R. Keeney). American Society of Agronomy, Madison, WI, USA.

Nziguheba, G., Palm, C. A., Buresh, R. J. and Smithson, P. C. (1998). Soil P fractions and adsorption as affected by organic and inorganic sources. *Plant and Soil* 198: 159–168.

Nziguheba, G., Merckx, R., Palm, C. A. and Mutuo, P. (2002). Combining *Tithonia diversifolia* and fertilizers for maize production in phosphorus deficient soil in Kenya. *Agroforestry Systems*. 55: 165–174.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (2002). *Laboratory Methods of Soil and Plant Analysis. A Working Manual*, 2nd edn. TSBF-CIAT, SACRED Africa, KARI, SSEA, Nairobi, Kenya.

Palm, C. A., Myers, R. J. K. and Nandwa, S. (1997). Combined use of organic and inorganic nutrient sources for soil fertility replenishment. In *Replenishing Soil Fertility in Africa*, 193–217 (Eds R. J. Buresh, P. A. Sanchez, and F. Calhoun). Soil Science Society of America Special Publication Number 51, Madison, WI, USA: SSSA.

Palm, C. A., Gachengo, C., Delve, R., Cadisch, G. and Giller, K. E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: Application of an organic resource database. *Agriculture Ecosystems and Environment.* 83: 27–42.

Rufino, M. C., Rowe, E. C., Delve, R. and Giller, K. (2006). Nitrogen cycling efficiencies through resource-poor African crop-livestock systems. *Agriculture Ecosystems and Environment.* 112: 261–282

Vanlauwe, B. (2004). Integrated soil fertility management research at TSBF: The framework, the principles, and their application, In *Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa*, 25–42. (Ed. A. Bationo). Nairobi, Kenya: Academy Sciences Publishers.