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RESIDUAL EFFECTIVENESS OF MINJINGU PHOSPHATE ROCK AND FALLOW BIOMASS ON CROP YIELDS AND FINANCIAL RETURNS IN WESTERN KENYA

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SUMMARY

In western Kenya, severe nutrient depletion, especially that of nitrogen and phosphorus, has drastically reduced crop yields over the past two to three decades. The potential effects of P application, with a single direct application of Minjingu phosphate rock (MPR) at 20, 40 and 60 kg P ha^{-1}, and fallow biomass in terms of nutrient replenishment on maize and bean yields were investigated on N and P deficient soils of western Kenya for six cropping seasons (three years). The agro-forestry shrubs tested were one season (six months) *Crotalaria grahamiana* and *Tephrosia vogelii* followed by maize monocrop. These fallow species were intercropped with beans in the 2000 long rains season to provide a food benefit to the farmer. Soil samples were taken at the end of each season and analyzed for soil pH and extractable P. The results showed that soil available P increased significantly following application of MPR. Significant increases in bean yields were obtained when 60 kg P ha^{-1} as MPR were applied, and contributed to a 260 % increase above the control. Significant maize grain yield increases were obtained when MPR was applied alone or in combination with fallow biomass as compared with treatments with either no external nutrient addition (control) or with fallow biomass alone in all seasons. The 60 kg P ha^{-1} MPR rate gave the highest cumulative maize grain yields (9.6 t ha^{-1}) over the five consecutive maize growing seasons, followed by 40 kg P ha^{-1} (8.8 t ha^{-1}). The residual benefits of MPR at modest rates of application (60 kg P ha^{-1}) were found to persist in the soil for only three cropping seasons. Thereafter, there was a steady decline in soil chemical properties (pH and available P), grain yields and net benefits. The study demonstrated the need for frequent additions of P especially in the fourth consecutive season to ensure sustained availability of P, favorable pH, and increased crop yields and net benefits on the nutrient-depleted soils of western Kenya.

INTRODUCTION

In the highly populated areas of western Kenya, where continuous cropping with minimal external nutrient addition has been practiced for decades, nutrient depletion of soil is widespread and seasonal grain yields of the staple maize crop rarely exceed 1 t ha^{-1}. Phosphorus deficiency is of primary concern: more than 90 % of farm soils tested had less than 5 mg P kg^{-1} of bicarbonate-extractable P (Lijzenga, 1998). As a

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result of heavy rainfall, nitrogen leaches and accumulates below the crop root zone as the rate of N mineralization also exceeds the requirement of poorly growing crops, particularly in the absence of P (Mekonnen *et al.*, 1997). In many high potential areas, smallholder farms are depleted of both N and P, necessitating the use of both organic and mineral fertilizers (Palm *et al.*, 1997).

The use of different cereals, herbaceous (green manure) and forage legumes in cropping systems, either as intercrops or in rotations with other crops for improving soil fertility is a well known practice in the tropics. These short duration fallows improve soil fertility through pathways such as biological nitrogen fixation and recycling of nutrients from the subsoil and contribute to increased crop yields. Incorporation of short term fallows of 6–8 months duration, namely, *Tephrosia vogelii* and *Crotalaria grahamiana*, is an effective and profitable way of adding about 100 kg N ha^{-1} and recycling other nutrients in the N-depleted soils of western Kenya; this practice is reported to triple maize yields (Niang *et al.*, 1998; Sanchez, 1999). In a separate study, Jama *et al.* (1997) reported an increase in yields of the subsequent maize crops after incorporation of 1.5-year-old *Sesbania sesban* biomass into soils compared with crops that did not receive any input. Addition of P in the form of mineral fertilizer greatly increased the benefit of these fallows.

In P deficient and acidic soils, Minjingu phosphate rock (MPR) from northern Tanzania has proven to be as effective as imported water-soluble triple super phosphate as well as being more profitable to farmers (Sanchez *et al.*, 2000). This phosphate rock contains 8.7 to 10.9 % of total P, 38 % CaO, 2.6 % MgO, 12.5 % SiO_2 and 1.3 % Fe_2O_3 (Buresh *et al.*, 1997). Addition of P from MPR to the fallow–cereal intercrop is required to exploit the potential of these fallows, with respect to fast fallow growth, hence contributing to increased biomass production over a shorter duration. Numerous studies involving the use of MPR show increased maize and legume grain yields and improvement of soil properties (e.g. bicarbonate P) in the acid soils of western Kenya (Jama *et al.*, 1997; Ndung'u *et al.*, 2003). In some of these studies (Jama *et al.*, 1997; Rao *et al.*, 1993), high rates of P (135–500 kg P ha^{-1}) have been tested as a capital investment with an expected residual effect of five years. However, these rates are far too expensive for most small-scale farmers.

Considering the nutrient depletion problems and the low use of fertilizers in the western Kenya region, this study was undertaken to quantify the effects of modest doses of MPR (affordable for most farmers) on: (i) the yields of bean and short-fallow intercrops; (ii) the duration of any residual effects of MPR and incorporated fallow biomass on maize grain yield; and (iii) the profitability of these soil fertility improvement interventions on small scale farms.

MATERIALS AND METHODS

Site description

The study was conducted in Bumala, Busia district (lat. 0°25′N, long. 33°54′E) from April 2000 to August 2002. This site is representative of the wet highlands of Eastern Africa with an elevation of 1375 m, 1530 mm of annual rainfall, and an

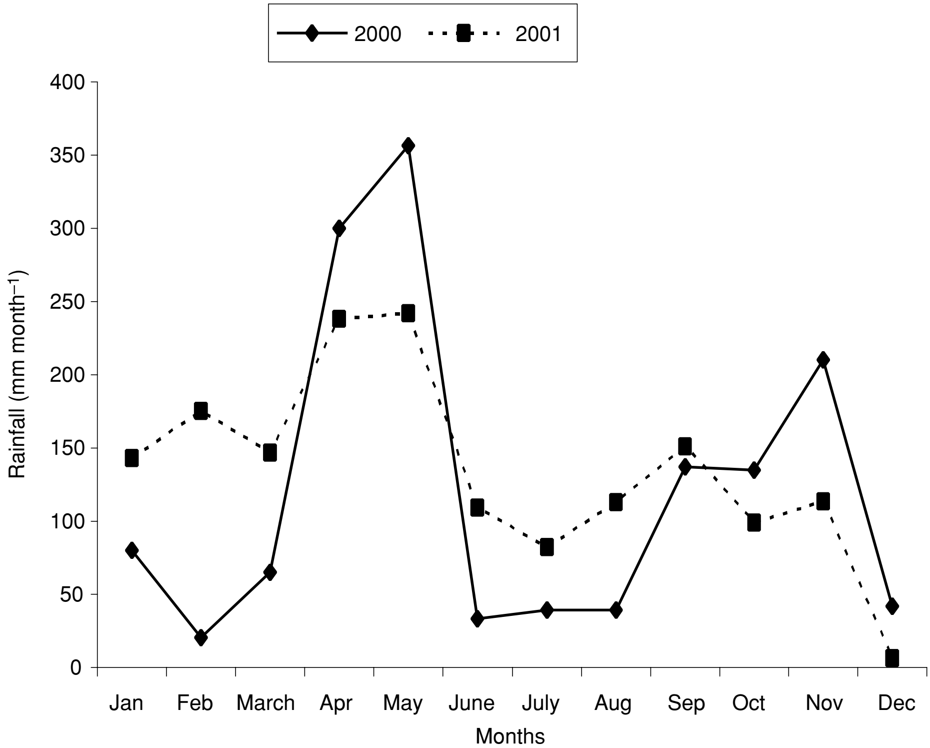

Figure 1. The monthly rainfall pattern in Busia during the study period.

annual mean maximum and minimum temperature range of 26–30 °C and 14–18 °C respectively. The rainfall pattern is bimodal with the first long rains (LR) occurring from mid-March to the end of July and the short rains (SR) from early September to late January (Figure 1). The soils are Ferralsols (Oxisols) covering about 200 000 ha of farmlands in western Kenya (S. M. Kanyanjua, personal communication). They have developed from various parent materials including intermediate and basic igneous rocks, sedimentary rocks and colluvium. These soils are deep, consisting of well-drained red clay of low natural fertility (Republic of Kenya, 1997).

Experimental design and management

The experiment was established in April 2000 during the LR. Treatments included four rates of MPR application (0, 20, 40, 60 kg P ha^{-1}) and three levels of fallow arrangements (no fallow, and crotalaria and tephrosia fallows). These factors were tested in a randomized complete block design arranged in a 3 × 4 factorial experiment with four replicates, in plots measuring 3.2 m × 6 m. After demarcating the area for the trial, composite soil samples (0–15 cm) were collected for site characterization. During the first season, plots were prepared using an ox-drawn plough (the most common practice in western Kenya), but in subsequent seasons, the land was prepared by hand to avoid mixing soils and treatments from adjacent plots. The inorganic fertilizers, namely, starter N in the form of urea at 30 kg N ha^{-1} and MPR were weighed and broadcast evenly across the plots according to the specific treatments in the first season (2000 LR). Western Kenya has widespread N (and P) deficiencies in croplands, necessitating the addition of a starter N dose (TSBF, 1994). Crops require adequate levels of N (and P) for balanced nutrition; enhanced biological nitrogen fixation helps achieve this (Karanja *et al.* 1998). In the second season, the fallow biomass was chopped, weighed, broadcast and incorporated into 0–15 cm soil depth in the same plot. No external nutrient inputs were applied in the succeeding seasons in order to monitor the residual effects of the MPR and fallow biomass applied, with respect to P and N nutrient supply in the soil.

At the initiation of the experiment, the fallow species were planted at a spacing of 80 × 40 cm and beans (*Phaseolus vulgaris*) were intercropped between the fallow crops at a spacing of 40 × 20 cm. This resulted in a population of 31 250 and 125 000 plants ha^{-1} for fallows and bean crops respectively, after thinning to one plant per hill. The food crop (bean) was intercropped between the fallow shrubs to ensure that the farmer benefited from the land in terms of the bean yields. The beans/fallow intercrops were weeded three times, and pests and diseases were controlled by spraying the bean crop with dimethoate and Milraz. During the bean harvest (June 2000), the bean grain and trash weight were recorded after threshing, but the fallows were left to grow in the field for two more months (up to August 2000). The fallows were then harvested, chopped and incorporated into the soil to provide N and to increase levels of organic matter in the soils for the benefit of the subsequent maize crop. Since the study area has two cropping seasons within one year, the timing of fallow introduction and incorporation was manipulated to match the cropping calendar. Maize cv. H614D was then planted in five consecutive seasons starting from the 2000SR to 2002SR at 0.75 m row by 0.30 m hill spacing (44 000 plants ha^{-1}). In each season, the maize crops were weeded twice, while maize stalk borers (*Buseola fusca*) were controlled by the application of Diptrex to the maize funnels, six weeks after crop emergence. At harvest time, the total maize cob weight was measured from an effective area of 15 m^2 and cob samples were taken, air dried, shelled and weighed to determine the total grain weight. The maize stover was chopped and incorporated into each plot at 2 t ha^{-1}, at the end of each season, a rate shown not to immobilize N in soils (Okalebo *et al.*, 2003).

Soil sampling, laboratory and statistical analysis

Soil sampling was done before the application of treatments for site characterization and at the end of every season (at harvesting) to monitor the changes in soil chemical properties as affected by the treatments and their residual effects. The soil was analyzed for pH, organic carbon, total N and available P according to standard procedures outlined in Okalebo *et al.* (2002). Soil pH (1:2.5 soil to water ratio) was measured using a glass electrode, while organic C was determined by wet digestion using the dichromate method (Walkely and Black, 1934). Total N for both soil and plant tissues was estimated by the Kjeldahl method whereby the distilled NH_4 was titrated with N/140 HCl for the soil samples and N/70 HCl for the plant tissues. Available P was extracted using Olsen extractant (sodium bicarbonate) and P was determined

Table 1. Average monetary values (US$) used for the cost- benefit analysis.

Parameters	Values (US$)†
Inputs (kg)	
Bean seed	0.54
Crotalaria seed	2.02
Tephrosia seed	2.02
Hybrid maize	1.41
Minjingu phosphate rock	0.135
Urea	0.32
Diptrex	2.02
Labour costs (ha^{-1})	
Land preparation	27.02
Planting	20.27
‡Weeding	30.40
Harvesting maize (90 kg bag^{-1})	0.27
Incorporating fallow biomass	26.67
Threshing beans	20.27
Shelling maize (90 kg bag^{-1})	0.81
Diptrex application	13.51
Outputs (kg)	
Maize grain price	0.14
Bean grain price	0.54

†Kshs 74/ US $).
‡The experiment was weeded twice per season.

by a spectrophotometer after developing a deep blue colour using the ascorbic acid molybdate method (Olsen *et al.*, 1954). P content in the plant tissues was determined using procedures highlighted by Okalebo *et al.* (2002).

The resultant soils and crop yield data were analyzed using Genstat and means were separated using the standard error of difference (*s.e.d.*).

Economic analysis

Data for this analysis were based on these long-term (six seasons) on-farm experiments. Qualitative data were gathered by interviewing participating farmers using structured questionnaires, while the input and output prices were obtained through a market survey in the area (Table 1). Labour was valued at the wage rates of hired farm labourers. Amounts of labour for the application of fallow biomass were determined from (i) average labour inputs to the area planted without nutrient inputs and (ii) estimates of extra labour required with the use of inputs (Jama *et al.*, 1997). Application of fertilizer (MPR and urea) was assumed to take 7 % more labour when broadcast and incorporated (Jama *et al.*, 1997). Bean and maize prices were an average of the market value during harvests (August and January of each year) in two rural markets in the area. Maize yields on an air-dry basis (14 % moisture content) were used in the economic analysis. Maize stover was assumed to be of no economic value, although in some areas of western Kenya, it is fed to livestock. The opportunity cost of capital was estimated at 10 % per season. The discount rate was adopted from Rommelse (2000), as it is the rate commonly used for studies involving resource-poor smallholder farms. All monetary values were converted to US dollars

Table 2. Initial physical and chemical properties of Busia Ferralsol (surface 0–15 cm soils).

Soil parameter	Value
Soil pH (1:2.5 soil:water)	4.89
Organic C (%)	2.30
Olsen P (mg P kg^{-1} soil)	1.18
Total N (%)	0.34
†SPR (mg P kg^{-1} soil)	889
Clay (%)	32
Silt (%)	22
Sand (%)	46
Soil texture	Sandy clay loam
Soil type	Orthic Ferralsol

†SPR: Standard phosphate requirement.

(US$) at the mean exchange rate of the Kenya shilling (KSH) during the time of the field experiments (74 KSH = 1 US$).

Returns to land from investing in the different rates of MPR and fallow species in maize and bean production were determined because, in these areas, land is relatively more scarce than labour. Few opportunities exist for a farmer to hire his or her labour or to engage in off-farm employment. Sensitivity analysis was conducted to assess the stability of the results with changing prices of MPR and maize.

The sensitivity analysis assumed that the maize yield was constant across the rates of MPR and fallow biomass applied, but that the prices of maize/MPR increased or decreased by 20 %.

RESULTS

At the beginning of the study, the Bumala soil (Table 2) showed low levels of bicarbonate P (less than the critical value of 10 mg P kg^{-1} soil [Okalebo *et al.*, 2002]) and high P sorbing capacity as shown by the high standard phosphate requirement. The soil was acidic, with pH values ranging from 4.4 to 5.2, and had moderate organic C and total N contents (Tekalign *et al.*, 1991). For comparison, surface (0–20 cm) soils across 900 000 ha of croplands in western Kenya are generally acidic (pH 4.8 to 5.8); their available P levels are also low, ranging from 3 to 6 mg P kg^{-1} (Okalebo *et al.*, 2003).

Fallow yields

The effects of MPR application on fallow biomass yields during the 2000 LR season is illustrated in Figure 2. Crotalaria accumulated the highest biomass (1.75–4.13 t ha^{-1}), while tephrosia produced significantly less (0.55–1.53 t ha^{-1}). By comparison, Mwaura (2003) obtained a crotalaria biomass yield of 1.0 to 2.8 t ha^{-1} in fallow bean intercrops in the same area (western Kenya) when 40 kg N plus 100 kg P ha^{-1} were applied. Puru (2000) grew sole crotalaria fallows on a highland Ferralsol of Uasin Gishu district and found yields of 1.3–2.0 t ha^{-1} biomass, resulting from an application of 30 kg N plus 40 kg P ha^{-1}. In the present study, it was

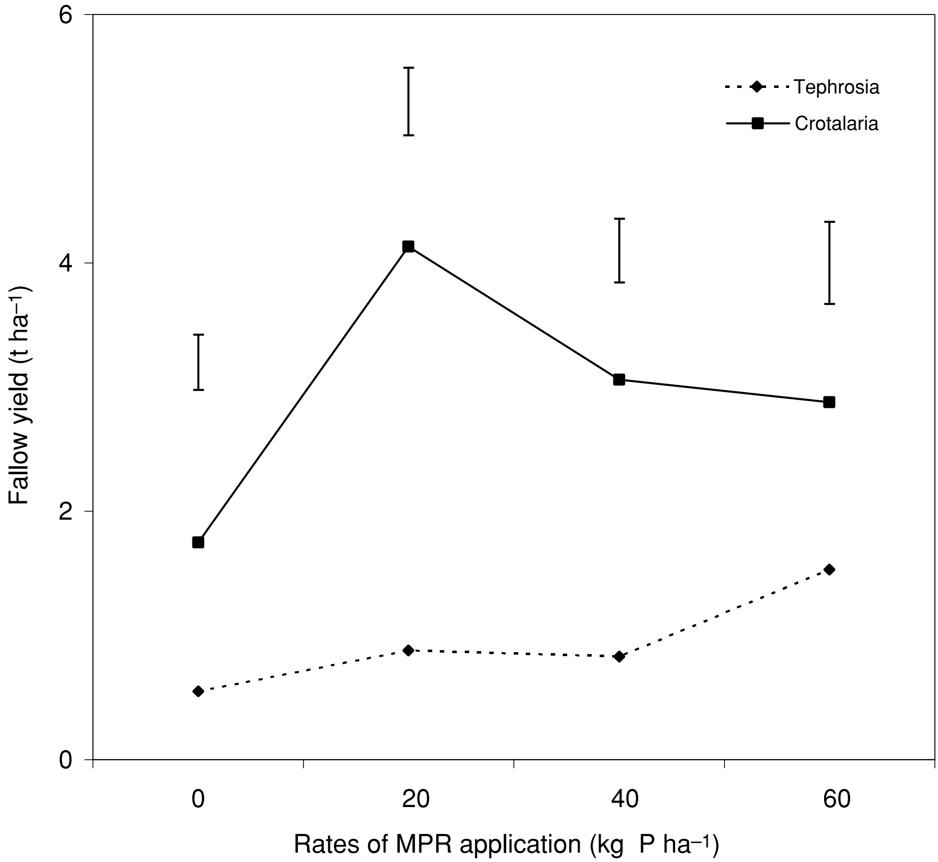

Figure 2. Effect of varying rates of MPR on fallow biomass yield in Bumala, western Kenya (2000LR). Bars represent the *s.e.d.* of means.

observed that the P requirement varied with the fallow species. Crotalaria required only 20 kg P ha^{-1} MPR for maximum yield production (4.13 t ha^{-1}), while for tephrosia, the addition of 60 kg P ha^{-1} MPR produced the highest biomass yield (1.43 t ha^{-1}).

Nutrient contributions resulting from biomass decomposition and nutrient release were 126 kg N ha^{-1}, 6 kg P ha^{-1} and 59 kg K ha^{-1} from crotalaria biomass, but tephrosia, which had lower nutrient concentrations and lower yields, only provided 43 kg N ha^{-1}, 1 kg P ha^{-1} and 17 kg K ha^{-1} from the highest P application rate (60 kg P ha^{-1}). These nutrient accumulations were more than those obtained by Mwaura (2003), where 73 kg N ha^{-1} and 2 kg P ha^{-1} were obtained from crotalaria biomass grown in the same region. These P contents are too low to ensure sufficient crop uptake and growth, necessitating integrated provision of organic and inorganic sources of nutrients because fallow biomass alone is not adequate for provision of plant P requirements (Palm *et al.*, 1997).

Table 3. Effect of Minjingu phosphate rock (MPR) on bean grain yields (kg ha^{-1}) in fallow-bean intercrops during the 2000 LR season in Busia, (Bumala) western Kenya.

	Rates of MPR application (kg P ha^{-1})				
Fallow species	0	20	40	60	Mean
No fallow	165	255	253	595	317
Crotalaria biomass	101	343	249	267	240
Tephrosia biomass	229	174	277	286	242
Mean	165	257	259	383	266
s.e.d. (P rate)			52.4		
s.e.d. (Fallow species)			45.4		

Bean yields

The effects of MPR on bean grain yields during the first season of MPR application are shown in Table 3. Low yields ranging from 101 to 595 kg ha^{-1} were obtained, although these yields are higher than those regularly obtained by farmers in this region, which fall to as low as 88 kg ha^{-1} (Republic of Kenya, 1997). Significant ($p < 0.05$) yield increases due to MPR application were noted. The highest level of P application (60 kg P ha^{-1}) contributed to the highest yields (595 kg ha^{-1}) in this season. By inspection, there was a strong positive correlation between bean yields and crotalaria biomass accumulation (Figure 1 and Table 3). The effects of the bulky crotalaria biomass are non-significant, partly because the beans matured earlier than the crotalaria, so the crotalaria canopy did not contribute to significant shading of the bean crop. Nonetheless, in treatments where MPR was applied to the fallow–bean intercrops, higher bean grain yields and fallow biomass were recorded than in plots where no P was applied.

Effect of MPR and fallow biomass on soil properties

Soil pH. The effect of MPR on soil pH before and after fallow biomass incorporation is shown in Table 4. The addition of fallow biomass contributed to a significant ($p < 0.05$) decrease in the soil pH over the seasons, but a significant ($p < 0.05$) increase was observed in the third season (2001 LR). Thereafter, a gradual decrease in soil pH was noted in the fourth (2001SR) and fifth (2002 LR) seasons. Residual MPR at 60 kg P ha^{-1} contributed to the highest pH, while fallow biomass alone was associated with the lowest pH over the final three consecutive seasons (2001 LR to 2002 LR).

Bicarbonate (available) P. The contributions of MPR and fallow biomass to soil bicarbonate P are shown in Table 5. Significant ($p < 0.001$) increases in soil extractable bicarbonate P from the residual MPR were noted in the second (2000 SR) and third (2001 LR) seasons; the highest increase occurred at the end of the third season, probably due to high rainfall (Figure 1), which enhanced increased moisture levels in soils and hence the dissolution of MPR.

Although the addition of fallow biomass did not contribute significantly ($p > 0.05$) to the availability of P from MPR over the seasons, the treatments with fallow–MPR

Table 4. Influence of residual Minjingu phosphate rock and incorporated fallow biomass on soil pH over four seasons of continuous cultivation in western Kenya.

Rates of MPR (kg P ha^{-1})	2000 SR-second season				2001 LR-third season				2001 SR-fourth season				2002 LR-fifth season			
	0	C	T	Av	0	C	T	Av	0	C	T	Av	0	C	T	Av
0	4.90	4.77	4.84	4.84	5.06	5.06	5.08	5.06	4.62	4.67	4.55	4.61	4.20	4.19	4.18	4.19
20	4.70	4.93	4.92	4.85	5.06	5.30	5.00	5.12	5.05	4.56	4.78	4.80	4.29	4.34	4.21	4.28
40	4.96	4.90	5.02	4.93	5.10	5.35	5.06	5.14	4.69	5.22	4.62	4.84	4.30	4.27	4.33	4.30
60	4.90	4.88	4.91	4.90	5.20	5.20	5.18	5.19	4.91	4.64	4.81	4.75	4.35	4.29	4.37	4.33
Mean	4.84	4.87	4.92	4.88	5.10	5.10	5.08	5.12	4.81	4.77	4.69	4.76	4.28	4.27	4.27	4.28
s.e.d(P)	0.085				0.049				0.074				0.051			
s.e.d(F)	0.098				0.057				0.085				0.059			

0: control, no fallow.
Fallow species. C: Crotalaria; T: Tephrosia.

Table 5. Effects of residual Minjingu phosphate rock and fallow biomass on soil bicarbonate P (mg kg^{-1}) in western Kenya.

Rates of MPR (kg P ha^{-1})	2000 SR-second season				2001 LR-third season				2001 SR-fourth season				2002 LR-fifth season			
	0	C	T	Av	0	C	T	Av	0	C	T	Av	0	C	T	Av
0	1.31	0.99	1.05	1.11	1.15	3.27	1.31	1.91	1.78	3.22	2.73	2.58	2.15	1.19	1.73	1.69
20	1.16	1.23	0.91	1.10	1.64	2.10	3.46	2.40	2.61	3.41	2.42	2.82	1.63	1.78	1.68	1.70
40	0.83	0.83	1.57	1.08	2.97	1.88	3.07	2.64	2.05	1.70	1.93	1.89	1.58	2.32	2.45	2.12
60	1.07	1.38	1.97	1.47	4.20	3.01	8.61	5.27	1.82	2.20	1.52	1.84	1.98	2.20	2.42	2.20
Mean	1.09	1.11	1.38	1.19	2.49	2.57	4.11	3.06	2.06	2.63	2.15	2.28	1.83	1.87	2.07	1.93
s.e.d(P)	0.20				0.93				0.28				0.18			
s.e.d(F)	0.23				1.07				0.25				0.15			

0: control, no fallow.
Fallow species. C: Crotalaria; T: Tephrosia.

combinations recorded higher levels of plant available P than those with either fallow biomass or MPR alone.

On average, the extractable bicarbonate P was lower than the critical level (10 mg P kg^{-1} soil) required for P adequacy in all the seasons (Okalebo *et al.*, 2002) and ranged from 1.18 to 3.06 mg P kg^{-1} soil.

Maize grain yields

The residual benefits of MPR were evident in the increased maize grain yields above the control treatment over the seasons, with the highest increases occurring in the third season (Table 6) due to improved soil P content and high rainfall (1020 mm). Long term rainfall data for the study site were not available to present the long term frequencies, but the total seasonal rainfall (66 % reliability) is about 800–900 mm during the long rains and between 700 and 800 in the short rainy season (Jaetzold and Schmidt, 1983). Maize yields in this season (2001 LR) ranged from 1.91 to 5.00 t ha^{-1} compared to 1.24 to 2.40 t ha^{-1} noted in the second season (2002 SR), representing

Table 6. Maize grain yields from residual Minjingu phosphate rock and incorporated fallow biomass after five seasons of continuous cropping with no fertilizer input in a Busia Ferralsol, western Kenya.

Rates of MPR applied (kg P ha^{-1})	Maize grain yield (t ha^{-1})					
	2000 SR	2001 LR	2001 SR	2002 LR	2002 SR	Cumulative grain yield
0	1.8	1.9	1.1	0.9	0.6	6.3
20	2.0	2.5	1.1	0.6	1.0	7.2
40	1.8	3.9	1.5	0.9	0.8	8.8
60	1.8	4.3	1.8	0.9	1.3	9.6
Av	1.85	3.13	1.39	0.86	0.93	7.97
s.e.d	0.13	0.35	0.13	0.16	0.24	

Note: 2000 LR was the first season with no maize yields; only bean and improved fallow yields (Figure 1 and Table 30 were obtained.

Table 7. Net benefits ($ ha^{-1}) accrued from a one-time application of Minjingu phosphate rock and fallow biomass.

Treatments	Net benefits (US $ ha^{-1})						
	2000 LR	2000 SR	2001 LR	2001 SR	2002 LR	2002 SR	Total
Control	−96	−6	82	−36	−15	−73	−144
Crotalaria	−88	−1	63	6	−49	−30	−98
tephrosia	−157	−28	−24	−74	−75	−116	−474
20 kg P ha^{-1} MPR	−74	23	113	−52	−82	−67	−139
20 kg P ha^{-1} MPR + crotalaria	−144	77	124	−44	−102	−40	−129
20 kg P ha^{-1} MPR + tephrosia	−53	56	221	36	−69	0	191
40 kg P ha^{-1} MPR	−102	204	389	−7	−55	−47	381
40 kg P ha^{-1} MPR + crotalaria	−116	136	232	29	−25	−33	223
40 kg P ha^{-1} MPR + tephrosia	−131	188	368	41	−68	−65	334
60 kg P ha^{-1} MPR	56	216	477	67	63	27	906
60 kg P ha^{-1} MPR + crotalaria	−137	266	544	73	−36	43	753
60 kg P ha^{-1} MPR + tephrosia	−148	263	587	64	−47	0	718
Mean	−99.2	116.2	264.6	8.6	−57.2	−33.5	
s.e.d.	49.1	62.3	100.9	33.4	39.3	35.4	

NB: 1 $ = Ksh 74.

a 108 % increase in yield. The grain yields were higher than the average farm yields of 0.5 t ha^{-1} $season^{-1}$ (Nekesa *et al.*, 1999) in this area. Treatments with 60 kg P ha^{-1} MPR gave the highest cumulative yields (9.9 t ha^{-1}) in the five maize growing seasons, followed by 40 kg P ha^{-1} (8.8 t ha^{-1}). However, after the third consecutive season, a continuous decline in yield was noted up to the sixth season (2002 SR). This shows that residual MPR could only sustain maize yields up to the third season after MPR application at modest rates (Table 6).

Economic analysis

Net benefits were negative from all nutrient replenishment strategies in the first, fifth and sixth seasons (Table 7), but positive net benefits were realized from the second to

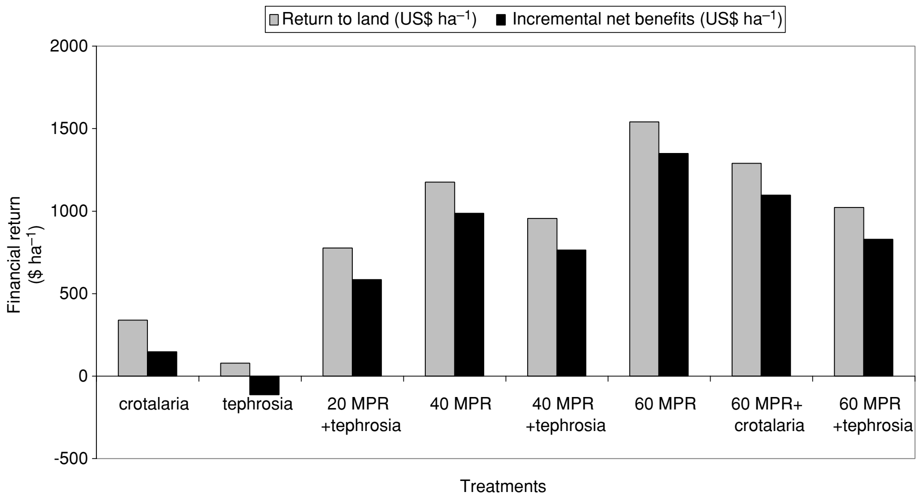

Figure 3. Effect of residual MPR and fallow biomass on incremental net benefits and return to land in Busia, western Kenya.

the fourth seasons, because of the residual yield response to added P and the absence of added fertilizer cost in these seasons. The highest net benefits (477–587 US$ ha^{-1} in the third season) were obtained with an application of 60 kg P ha^{-1} MPR alone and in combination with the fallow biomass. Treatments with no nutrient input (control) and with fallow biomass alone gave consistently negative net benefits, even when all the seasons were considered. Integration of MPR at low rates (20–40 kg P ha^{-1}) with fallow biomass was economically more attractive than either fallow biomass alone or planting with no nutrient input because of the high yields obtained from these treatments, arising from addition of both N and P from fallow biomass and MPR respectively. The sensitivity analysis revealed that increases or decreases of 20 % in MPR and maize prices had little effect on the relative difference in net benefits among the nutrient management options considered in this study. But in the first year of nutrient application, farmers needed to increase their bean production by 43 % or sell their current bean produce at a price twice as high (1US$) at the same cost of MPR in order to break even.

To assess the extent of financial returns made possible by switching from farmers' practice (no nutrient input) to the addition of MPR or fallow biomass, incremental net benefits were calculated. The results revealed that applying MPR at 60 kg P ha^{-1} alone in the first season led to a cumulative incremental net benefit of US$1050 ha^{-1} above the control treatment. But where farmers have less capital to invest in high rates of MPR, applying 40 kg P ha^{-1} could also realize substantial cumulative net benefits of about US$525 above the control over the six seasons. The return to land was relatively low for no input and treatments with fallow biomass alone (Figure 3). However, a one-time application of 60 kg P ha^{-1} MPR to maize could earn a return to land of US$1541 in three years (six seasons) without additional fertilizer. Even at lower rates of 40 kg P ha^{-1}, the average return to land was relatively higher (U$1177 ha^{-1} in three years) than that attained from the control (U$191 ha^{-1}) or under fallow species (U$339 and 77 ha^{-1} for crotalaria and tephrosia respectively).

DISCUSSION

A gradual decline in soil pH was noted after incorporation of the fallow biomass, which was evident especially from the fourth (2001 SR) to the sixth (2002 SR) seasons. Das *et al.* (1982) also found small but insignificant increases in soil pH when they applied organic residues in combination with a Purulia phosphate rock. The decomposition of plant biomass incorporated into the soils is associated with the release of organic acids, thereby contributing to soil acidity (Waigwa *et al.*, 2003).

Below optimum bean yields were realized, particularly in the bean–fallow intercrops, possibly due to competition for space and soil nutrients by these two leguminous species. Although the yields obtained in this study were above farmers' usual production levels (<0.5 t ha^{-1}) in the region, appropriate crops or crop arrangements should be sought which can be intercropped with these improved fallows for increased yields and soil fertility amendment. While previous studies (Ribet and Drevon, 1996) have shown that N-fixing legumes may not require external P addition because of their ability to utilize sufficient P from internal sources, Njeri and Okalebo (1999) found responses to external P fertilization (60 kg P ha^{-1} MPR) in beans in a P-deficient Ferralsol in the Uasin Gishu district. The results of this study also confirm the need for P addition to beans in highly P-deficient soils, although the P requirement may vary with the ability of the legume to fix N.

The organic/inorganic treatment combinations increased P availability in soils, but the addition of sole fallow biomass was associated with reduced bicarbonate P levels in all the seasons, while combining the fallow biomass with MPR led to an increase in available P. This was because the low P content in the fallow biomass lead to immobilization of nutrients in soils by soil microbes. This is consistent with results obtained by Palm *et al.* (1999), who reported that organic materials with less than 3.0 g kg^{-1} P content tie up labile soil P, leading to a continuous yield decline. Addition of organic materials has been reported by different workers to contribute to increased dissolution of MPR and the subsequent release of P (Kifuko, 2002; Okalebo and Woomer, 1994; Ndungu, 2002; Waigwa *et al.*, 2003).

Generally, seasonal maize yields increased upto the third season and then declined in the fourth season, a trend that continued into the sixth season. Similar trends were also observed in the soil properties tested in this study, namely, the soil pH and available P, and also financial returns (net benefits). This shows that the residual benefits from low rates of MPR application were evident only up to the third season after treatment application. Treatments with no nutrient addition continued to show a decline in crop yields, declining levels of available P and lower net benefits in all the seasons. This suggests that land management practices that involve continuous cultivation without external inputs will certainly result in a decline in soil nutrients, especially available P. Declining soil fertility due to little or no nutrient application in western Kenya and other sub-Saharan African soils has been noted by other workers (Smaling, 1993; Stoorvogel, *et al*., 1993). Therefore in soils with high P sorption characteristics, such as the Ferralsol in this study (Table 1), P addition, e.g. from MPR, should be targeted in the fourth consecutive season.

CONCLUSIONS

Residual MPR greatly raised the levels of the measurable soil parameters (soil pH and available P), net benefits and maize grain yields. The residual benefits of MPR at low rates of application were found to persist in the soil only up to the third cropping season; thereafter, a steady decline in soil pH and available P, maize grain yields and net benefits were noted. This trend demonstrated the need for frequent additions of P especially in the fourth consecutive season to ensure sustained availability of soil nutrients and high crop yields. These findings also suggest that farmers could improve the returns from maize production over at least four seasons significantly by applying MPR at 60 kg P ha^{-1} only once. Farmers are, however, likely to have prolonged P effects if they can apply MPR at rates above 60 kg P ha^{-1}. Continuous cropping with little or no nutrient additions will in the long run lead to further depletion of soil nutrients and subsequent decline in yields thus contributing to food insecurity in the region.

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