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The potential of underutilized phosphate rocks for soil Fertility replenishment in Africa: case studies inWestern Kenya

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Abstract: Most sub-Saharan African countries continue to have slow development rates, mainly resulting from food insecurity, poverty and poor health of the majority of the populations. With regard to food insecurity, soil fertility depletion is well-known to contribute to low and declining crop yields. In particular, the macronutrients N and P are predominantly deficient in the highly weathered and leached soils. Substantial researches have tested the use of the widely distributed phosphate rocks (PRs) in Africa with an overall aim to replenish the P status of soils, towards improved and sustained crop productivity. Thus, in the populous western Kenya region, the direct applications of the reactive Minjingu (Tanzania) PR and the use of blended Busumbu PR (Uganda) with soluble triplesuperphosphate (TSP) at rates from 20 to 150 kg P/ha, have resulted in significant maize (staple) yield increases from 0.5 t/ha/season at smallholder farm level to 5 t/ha/season. In this paper we report specific case studies in western Kenya where positive effects of PR use have been obtained with respect to crop yield increases, economic viability and residual effectiveness. The PR tested compares favorably with soluble TSP. The question is: "What ails the smallholder farmers from adopting the use of PRs that have been demonstrated to be affordable and effective?" We however, stress that the PRs (with concurrent main effects of P and lime) are effective on acid (pH<5.5), low available P (<5 mg P/kg) soils.

Key words: Soil fertility depletion, replenishment from phosphate rocks, technology adoption problem.

Introduction

The problems of hunger, poverty and poor health are well-known globally and are widespread among the rural populations in Africa. These constraints have significantly had a negative impact on development and success for an African Green Revolution, particularly so in sub-Saharan African (SSA) region which continues to receive world food aid (World Bank, 1996; Voss, 2006). SSA is characterized with constraints such as frequent crop failures from long droughts, widespread infertile soils, poor economies, which include low and unstable markets from no value added products (Sanchez *et al.*, 1997). With regard to infertile soils, there is strong evidence of widespread nitrogen (N) and phosphorus (P) deficiencies in arable soils that are highly weathered, leached and acidic across the continent (Woomer and Muchena, 1960, but particularly so in western Kenya region (Kanyanjua *et al.*, 2002; Woomer *et al.*, 2003; Okalebo *et al.*, 2006).

Western Kenya has a human population of about 5 million and an arable land area of about 0.9 hectares. Smallholder farmers, who constitute about 95% of total farming community in this region, grow mixed or intercropped maize and beans (staples) in the same fields, season after season, but with minimal to no nutrient returns to the land. These practices have largely contributed to the low and declining crop yields in the region to the levels below 0.5 t/maize/ha/season and below 0.2t/bean/ha/season (Nekesa *et al.*, 1999; Gudu *et al.*, 2005). However, there is strong evidence in this region, where striking crop responses to applied nutrient inputs to soils have been found. Thus increased crop yields and positive economic returns have been documented through use of inorganic fertilizers (FURP, 1994), organic resources of varying qualities (Gachengo *et al*, 2004), improved leguminous short fallows (Jama *et al*, 1997, Ndungu *et al.*, 2006) and combined use of inorganic and organics (Woomer *et al.*, 2003; Okalebo *et al*, 2006). However, in spite of these demonstrated positive crop responses to nutrient inputs, the smallholder farmers across Africa use very negligible quantities of fertilizers, averaging 9 – 12 kg/ha of fertilizer/year across Africa (A. Bationo, pers. Communication). The costs of fertilizers are high and even increasing yearly in many African countries.

Substantial research work has been done in Africa to find alternative sources of affordable but effective sources of major nutrients to increase agricultural productivity for resource poor farmers (e.g. Jama *et al.*, 1997; Sanchez *et al.*, 1997; Woomer *et al.*, 2003; Okalebo *et al.*, 2005). These attempts have focused the direct use of PRs or acidulated partially phosphate rocks (PRs) which are widely distributed in Africa and the trapping of the abundant nitrogen from the air through cropped legumes in the well-known biological nitrogen fixation process (through nodule-rhizobium associations).

In this paper, we recognize major characteristics of PRs available in Africa and worldwide. For example, PRs vary in hardness or softness and hence in their agronomic effectiveness (Buresh *et al.*, 1997). Further, PRs are known to be effective on crop yield increases on acid (pH <5.5) and on low P and calcium soils (Smyth and Sanchez, 1982). In addition, the solubility and hence P availability is improved through acidulation processes (Terman, 1971). In our approach, towards affordability and nutrient replenishment strategy in poor soils of western Kenya, we took into consideration these characteristics of PRs. We therefore, chose two promising PRs in East Africa (Minjingu and Busumbu PRs form Tanzania and Uganda respectively).

Effectiveness of these two local P sources was tested in the field (on smallholder farmers) over a wide range of maize-legume intercrops. We further tested the liming effect of PR. In our study approach at Moi University, we collaborated very closely with farmers, the Community Based Organizations (CBOs), Non-Government Organizations (NGOs), Government extension agencies, to name a few. We therefore, highlight findings from some case studies in western Kenya with overall objective to improve food security through use of locally available PRs, which seem to be slighted in most African countries.

Study Approach

Study Area

Response of maize-legume intercrops to phosphate rock applications have been studied in the field on smallholder farms across western Kenya, by Moi University, Kenya, researchers and their collaborators from 1997 to date. Apart from the size of croplands and the magnitude of human population in western Kenya, indicated earlier, this region receives a bimodal rainfall distribution pattern, with long rains (LR) falling between March and July, while the short rains (SR) are received from September to December (Jaetzold and Schmidt, 1983). The rains about 800 to 1400 mm annually, are on the average evenly distributed and hence contribute to two annual maize-legume harvests. The soils of this region are mainly the widely distributed acrisols (ultisols), ferralsols (oxisols), and nitisols (alfisols) or their mixtures (Woomer and Muchena, 1996). These soils are characterized by their acidity, low total N and organic matter contents and also low available P in their plough depth (Table 1)

Table 1: Soil test data (0 – 15 cm depth) across districts in western Kenya (means of 20 farms for each district are given). Source: Department of Soil Science, Laboratory, Moi University.

Soil parameter	District						
	Bungoma	Teso	Mt. Elgon	Busia	Siaya	Vihiga	Mean
pH (H_2O)	5.54	6.10	5.90	5.10	4.73	5.30	5.39
% Carbon	1.37	1.36	1.91	1.32	2.07	nd	1.67
% nitrogen	0.18	0.19	0.21	0.23	0.21	0.36	0.24
Available P (mg/kg) (Olsen extraction)	4.8	9.1	10.2	7.1	3.4	3.0	6.6

Phosphate rocks tested in western Kenya

Phosphate rocks of different origins, local names, reserves, softness or hardness and P contents are widely distributed and are documented elsewhere by Buresh *et al.*, (1997). But the PRs found in East Africa, with potential to replenish P in depleted soils, are presented in table 2. In this paper only the results of case studies for two forms of PR are presented, namely, the Minjingu phosphate rock (MPR) and Busumbu phosphate rock (BPR).

Table 2: Estimated resources of important phosphate rocks (PRs) in East Africa (after Buresh *et al.*, 1997; Van Kauwenburgh, 1991).

Country	Name of deposit	Type of PR	Reactivity	Estimated reserve (10^6 – tones)	Total P content (g/kg)
Tanzania	Minjingu	Sedimentary	Medium to high	10	87 – 109
Tanzania	P and Hill	Igneous	Low	125	26
Uganda	Sukulu	Igneous	Low	230	48 – 57
Kenya	Rangwe	Igneous	Low	-	<48

Guidelines towards affordability of nutrient inputs

From day to day life, consumers tend to choose and purchase products for specific functions on the basis of cost. Therefore, towards PR technology adoption, we assembled prices of low cost MPR at the factory in Tanzania and Kakamega town (the centre of western Kenya) and compared these prices with those of soluble P fertilizers (triplesuperphosphate or diammonium phosphate). On the basis of price differences, field demonstrations on various P sources and economic analytical data from field experiments; it was felt that the farmers would be empowered to select affordable P source inputs. Table 3 presents prices of various P sources in Kakamega town in 1997.

Table 3: Prices of phosphate fertilizers in Kakamega town, western Kenya, from various P sources from various distributors

P form	Quote	Price/ton (US $)	Transport/ton (US $)	Kakamega price (US $)	Unit P price (US $/kg P)
TSP	E. A. Seed Co.	472.73	32.73	505.45	2.73
TSP	Mwaura	416.73	32.73	449.49	2.43
SSP	Minji/KEL	105.00	72.82	177.82	1.69
MPR	MIPCO	235.36	32.73	269.09	2.12
MPR	KEL	127.27	32.73	160.00	1.26
MPR	Factory, Tanzania	50.00	69.09	117.09	0.92

Source: PREP Proposal document, 1997.
Note: TSP = Triplesuperphsophate
SSP = Singlesuperphosphate
MPR = Minjingu Phosphate Rock form Tanzania
KEL = a Chemical Company in Thika, Kenya
E. A. Seed Co. = East African Seed Company, Nairobi
MIPCO = Agent in Nairobi, handling MPR sales.

Results and Discussion

In this paper, we present and discuss the results from selected case studies in western Kenya. These are related to the direct and residual effectiveness of PR on maize productivity; strategies to improve the solubility of PR for enhanced P availability and crop uptake (through combinations with organics and blending with a soluble P source) are also presented. In addition, the potential for adoption of a small PR unit, the PREP-PAC package, is highlighted; but above all, the PRs have both positive P and liming effects.

Direct and residual responses to Minjingu phosphate rock (MPR)

In a field study by Ndungu *et al.*, (2006), the use of low cost MPR as a P source to increase maize-short fallow yields in depleted soils, also aimed at the provision of low cost N to succeeding maize crops through N fixed by the legume improved fallows, (tephrosia and crotalaria) and through fallow biomass decomposition and subsequent N release in soils. Apart from soil fertility replenishment, the fallows tested have other uses, such as the provision of poles, fuel wood and pest control (tephrosia). In this study, three on-farm trials in Busia, Siaya and Bungoma districts of western Kenya were selected to test the effectiveness of MPR at 0, 20, 40 and 60 kg P/ha (considered affordable) on maize-bean and maize – short fallow intercrops. The fallow biomass was incorporated into the soils during successive maize and bean intercropping in five successive seasons. Significant ($p<0.05$) maize grain yield increases were obtained when MPR was applied alone or in combination with fallow biomass as compared to treatments with either no nutrient inputs (control) or with fallow biomass alone in all seasons. The 60 kg P/ha MPR rate gave the highest cumulative maize grain yield of 9.6 t/ha over the five consecutive growing seasons, followed by 40 kg P/ha MPR (8.8 t/ha maize), in only one site in Busia district. There was however a trend in soil fertility decline as implied by decreasing maize yields from third to fifth consecutive cropping of maize (Table 4). In addition, significant ($p<0.05$) increases in bean yield (data not shown) were obtained when 60 kg P/ha MPR was applied and this gave a 200% bean yield increase above the control. The residual effects of MPR at the rate of 60 kg P/ha were found to persist in the soil for only three cropping seasons. This was shown in the progressive decline in soil chemical properties (pH and available P measured during cropping), in grain yields and net benefits from economic analysis. This study demonstrated the need for frequent additions of P at modest rates, especially in the fourth consecutive cropping season to ensure sustained availability of P, favourable soil pH from liming effect of MPR, and increased crop yields and net economical benefits on nutrient depleted soils of western Kenya (Ndungu *et al.*, 2006).

Table 4: Maize grain yields from direct and residual MPR and incorporated fallow biomass during five seasons of continuous cropping with only first season 2000 LR MPR addition in Busia district, western Kenya (Ndungu *et al*, 2006**)**

Rates of MPR applied (kg P/ha)	Maize grain yield (t/ha)					
	2000 SR	2001 LR	2001 SR	2002 LR	2002 SR	Cumulative grain yield
0	1.8	1.9	1.1	0.9	0.8	6.3
20	2.0	2.5	1.1	0.6	1.0	7.2
40	1.8	2.9	1.5	0.9	0.8	8.8
60	1.8	4.3	1.8	0.9	1.3	9.6
Mean	(1.85)	(3.13)	(1.39)	(0.86)	(0.93)	(7.97)
SED	0.13	0.35	0.13	0.16	0.24	-

Note: LR = long rains; SR = short rains. The 2000 LR was the first season with MPR additions but with no maize yields, only bean yields and improved fallow yields (not shown) were obtained.

Attempts to improve solubility and hence P availability of PRS

Practices which have been made worldwide to enhance solubility of PRs include: partial to complete acidulation through PR treatment with H_2SO_4 mainly (or H_3PO_4) (Terman, 1971); incorporation of PR into soils or into composts together with acid forming organics (crop residues, tree prunings, hedge shrubs) and microorganisms that accelerate the process of decomposition of organics (Bolan and Hedley, 1989; Nahas and Asis, 1996); and blending the PRs with various quantities of soluble P sources (Buresh *et al.*, 1997; Ngoze, 2000). However, towards the access and affordability of PR technology by smallholder farmers in western Kenya, MPR and BPR were incorporated to plough depth soils with various quantities of organics (crop residues, hedge shrubs through biomass transfer, agribusiness wastes, mainly sugar bagasse and pyrethrum wastes farmyard manure). Results from these practices are now summarized.

A field experiment (Kifuko *et al.*, 2007) was conducted in a smallholder farm in Bumala division, Busia district, Kenya, for 3 consecutive maize cropping seasons: 2000 SR, 2001 LR and 2001 SR. Treatments consisted of no nutrient inputs (control), three sources of organic residues, chicken manure (CM), maize stover and sugar bagasse (SB) applied at 2 t/ha each separately or combined with MPR at 0, 30 and 60 kg P/ha. MPR and organic residues were broadcast evenly and incorporated to plough depth soils before planting maize (cv H 614 D and H 513 for LR and SR respectively). This experiment tested the effects of maize cropping and also on P sorption characteristics of soils, on maize yield and economic considerations. Maize yields were recorded at harvesting.

To monitor the residual effects of treatments applied only once in the first season (2000 SR), maize crops in the subsequent 2 season above were planted without addition of extra nutrient inputs, except for basal or maintenance nitrogen at 30 kg N/ha in all plots. The maize yields for 3 consecutive seasons as affected by MPR combined with organic residues are shown in Fig. 1. On the average, P applied alone as MPR during 2000 SR, gave positive residual effects and significant ($p<0.05$) increases of maize grain yields compared to the control for 2 consecutive cropping seasons (2001 LR and SR). Application of organic materials with or without MPR had variable effects on maize grain yields. Chicken manure and FYM gave significant ($p<0.05$) higher grain yields compared to sugar bagasse and control treatments during the first cropping season. However, in the second season, all the organics had positive residual effects and gave significantly ($p<0.05$) higher yields compared to the control. Applications of MPR at 30 kg P/ha combined with FYM at 2 t/ha gave the highest cumulative yield (12.4 t/ha) over the 3 consecutive maize cropping seasons. Maize yields showed a significant positive relationship with available P obtained from MPR at harvesting of the first, second and third crops ($r = 0.89$, 0.82 and 0.97 respectively). Applications of CM at 2 t/ha plus MPR at 60 kg P/ha produced the highest incremental net benefit of US \$657/ha and return to land of US \$752/ha in the three maize cropping seasons.

Another parallel field experiment on solubilization of MPR and BPR (Busumbu phosphate rocks) was conducted on – farm in Nyabeda division, Siaya district, Kenya in 2004 LR (Thuita *et al.*, 2004). These two PRs differ in characteristics and hence in agronomic effectiveness. BPR is sparingly soluble and it has to be demagnetized before use. Both PRs, at modest rate or 40 kg P/ha each, were incorporated to plough depth soils with 2 t/ha each of the hedge shrubs, lantana camara and tithonia diversifolia, residue maize stover and pyrethrum waste. These were compared with FYM at 2 t/ha and soluble TSP fertilizer at 40 kg P/ha.

Maize (cv H 614 D) and soybeans were intercropped and their grain yields obtained at harvest, to assess yield differences from treatments. Effectiveness of different organics combined with PRs varied with the PR and the organic material (Thuita *et al*, 2004), but we present only the mean yields of each PR combined with lantana camara, tithonia, maize stover and pyrethrum wastes (at 2 t/ha each), in Table 5.

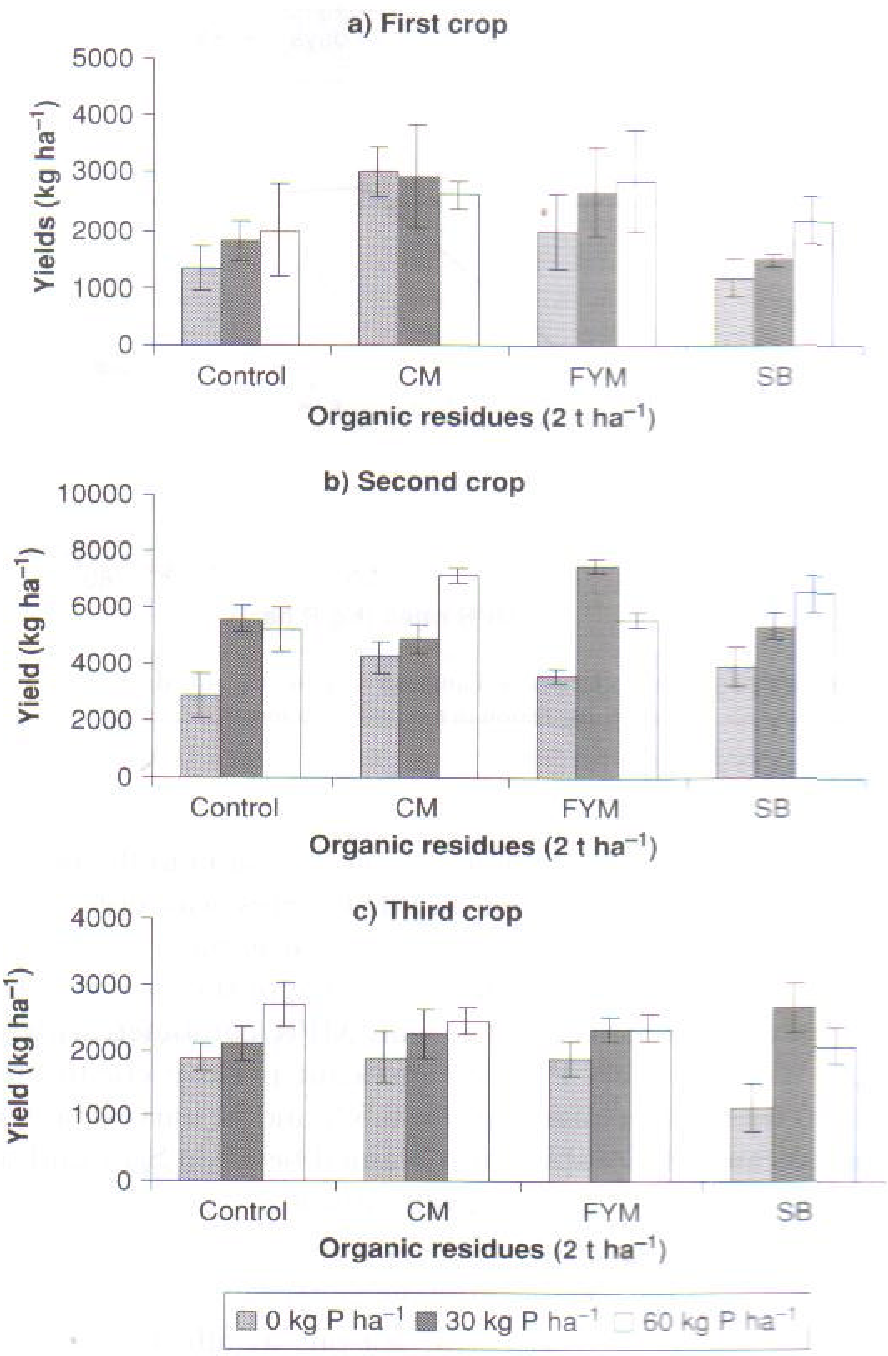

Figure 1: Residual maize grain yield as affected by combination of MPR and organic residues in western Kenya during year 2001 cropping seasons (a) short rains 2000, (b) long rains 2001, (c) short rains 2001. CM: chicken manure (2t ha^{-1}); FYM: farmyard manure (2 ta^{-1}); SB: sugar bagasse (2 t ha^{-1}). Error bars show *s.e.d.*

Table 5: Maize and soybean yields (t/ha) from incorporation of PRs with organics at Nyabeda, Siaya 2004 LR (adapted from Thuita *et al*, 2004)

Treatment	Maize	% Relative yield	Soybeans	% relative yield
Control	0.18	5	0.33	30
BPR with organics	1.69	46	0.33	30
MPR with organics	2.77	75	0.73	66
FYM (2 t/ha) alone	1.14	31	0.55	50
TSP (40 kg P/ha) alone	3.70	100	1.11	100
Overall means	(2.08)	-	(0.57)	-
SED treatments	0.76	-	0.05	-
LSD (P = 0.05)	1.54	-	0.10	-

NB: BPR = Busumbu phosphate rock from Mbale, Uganda, 5 – 12 % total P
MPR = Minjingu phosphate rock from Tanzania, 11 – 13% total P
TSP = Triplesuperphosphate (imported), 20% total P.

This experiment confirmed superiority of MPR over BPR as reported elsewhere (Ngoze, 2000) and particularly low yields on control treatment. The farmer had reported earlier that "nothing grew in the experimental field".

The Liming effect of Minjingu Phosphate Rock

As indicated above, soil acidity, the prevalence of H^+ and Al^{3+} cations, is widespread in the highly weathered and leached tropical soils, Kenya included (Kanynajua *et al.*, 2002). On highly acid soils (pH <5.5; Table 1), Al levels are generally high and contribute to toxicity, whereby the plant root elongation is particularly impeded, resulting in stunted plants with low yields (Kochian, 1995). Over a long period, it was held that in the tropics, because of the low reactivity of the predominant kaolinitic clays, lime applications were not necessary but with exception of very acid soils (Russell, 1973). However, over the past decade, soil tests on lime requirements and crop responses to lime pot tests (P. Opala, unpubl), have suggested the need to apply lime to favour the availability of P, Mo and other elements. Against this background, we examined the liming effect of MPR in the North Rift and western Kenya regions, characterized by acid soils (Table 1). We felt that crop production costs could be reduced through the application of the locally available and affordable MPR, which is a source of both P and lime, compared to separate cost additions of P and DAP (commonly used in these regions) with agricultural lime, whenever needed. Thus to delineate the effects of P alone from MPR, DAP and TSP were applied at similar incremental rates of MPR at 0, 30, 60 and 90 kg P/ha, while agricultural lime (20% CaO) from Koru, Kisumu, Kenya, was applied alone or in combination with DAP and TSP to the corresponding levels of CaO added in MPR (38% CaO), viz, 0, 96, 192 and 288 kg CaO/ha (Nekesa, 2007).

The performance of these treatments was compared in the field at small scale farm level, with four farms in Bungoma, Siaya, Trans Nzoia, and Uasin Gishu districts, Kenya, with acid (pH<5.5 and available P<5 mg P/kg), with main objective to demonstrate technology towards adoption. Maize-bean, soybean and groundnut intercrops were planted in this study (Nekesa, 2007). Table 6 gives mean maize and groundnut yields in Bungoma and Siaya sites in 2005 LR, the sites with rapid crop growth with associated lower altitude effects of higher temperatures and humidity, compared to the Trans Nzoia and Uasin Gishu sites on a much lower elevation. Clearly, soil amendments in this study gave significant ($p<0.05$) increases in maize and groundnut yields from data of Table 6. Maize yields upto 4 – 5 t/ha are very rare in these areas at on-farm level (Nekesa *et al.*, 1999). These crop yield increases are reflected in positive soil pH and available P increases from lime and MPR amendments on acid soils in the four study sites. Figures 2 and 3 show soil pH depressions from DAP added on its own, while all treatments with lime component raised the soil pH. Further, the increases in soil pH are associated with increased P availability in soils (data not shown), resulting in increased crop yields.

Yields from MPR alone were comparable to those found from DAP with lime or TSP with lime. This trend in maize and particularly groundnut yields, is confirmed in the economic analysis of combined crop yield data from intercrops for all 4 sites in 2005 LR (Nekesa, 2007).

Table 6: Maize and groundnut intercrop yields (t/ha) as affected by phosphate and lime application in western Kenya, 2005 LR (adapted form Nekesa, 2007)

Treatment	Maize grain yield		Groundnut kernel yield	
	Mabanga (Bungoma)	Sega (Siaya)	Mabanga (Bungoma)	Sega (Siaya)
Control	0.58	0.52	0.22	0.22
MPR	4.54	4.40	0.59	0.33
DAP alone	4.42	3.90	0.47	0.40
Lime alone	4.48	2.32	0.55	0.31
DAP + Lime	5.40	4.52	0.48	0.40
TSP + Lime	4.62	4.57	0.380.35	
Means	(4.5)	(3.73)	(0.52)	(0.35)
SED treatments	0.77	0.42	0.11	0.08
LSD (P = 0.01)	2.10	1.25	0.30	0.22

Note: MPR = Minjingu Phosphate Rock
DAP = Diammonium Phosphate
TSP = Triplesuperphosphate

In this table, mean crop yields are for treatment rates of 30, 60 and 90 kg P/ha are given for each P source, while mean yields for lime rates of 96, 192 and 288 kg CaO/ha are also given.

In particular, in this study, the gross margins of yield (data not shown; analysis by Dr. M. J. Kipsat, RUFORUM Project Collaborator) indicate profitability from use of MPR as a source of both P and lime on acid and low P soils. In this experiment, we record active participation from CBOs in Bungoma and Siaya districts who are now testing the technologies themselves.

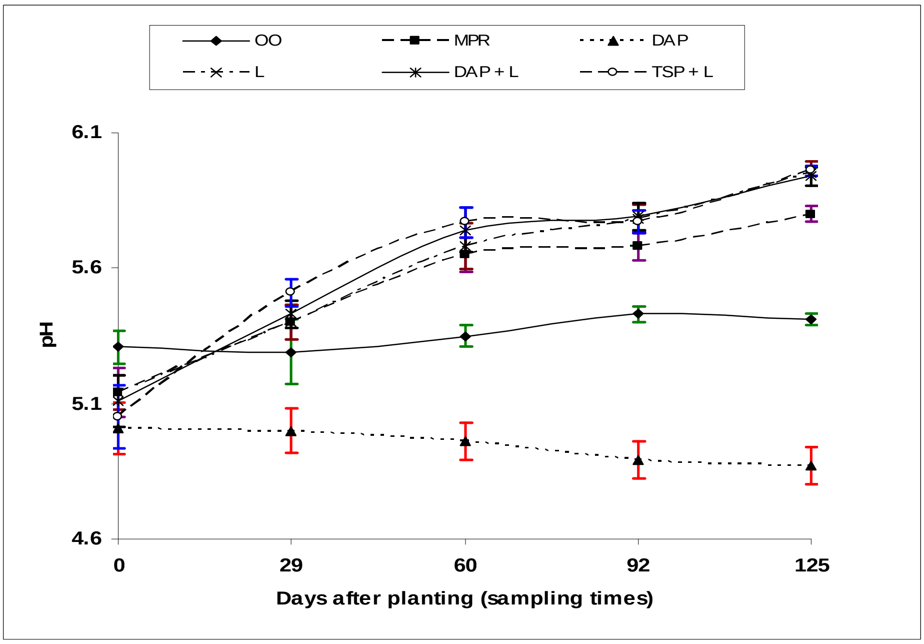

Fig 2: Changes in soil pH as affected by soil amendment material application during the 2005 LR at Mabanga (Bungoma) site.

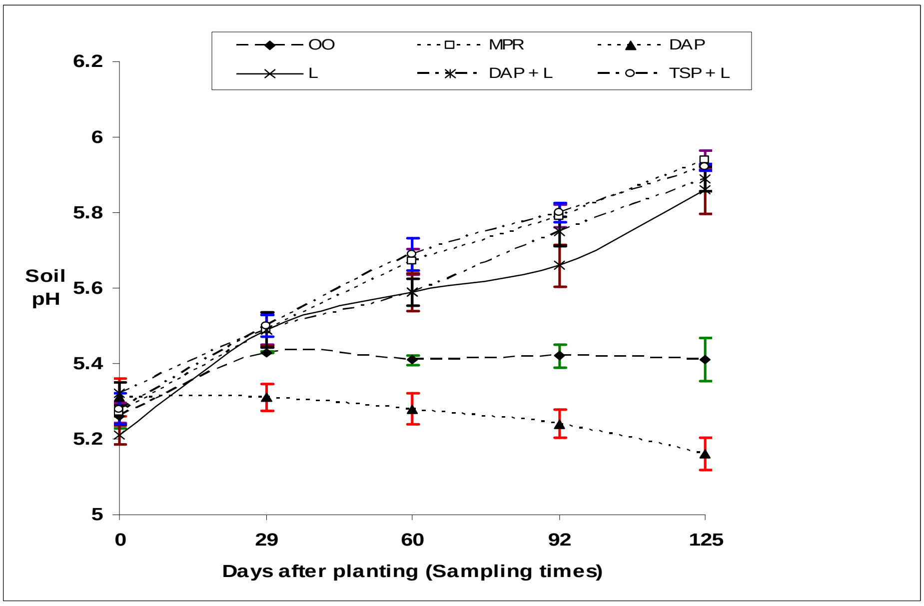

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Fig 3: Changes in pH as affected by soil amendment material application during the 2005 LR at Sega (Siaya) site.

Towards technology adoption: assembling nutrient inputs into small affordable packages

On a global basis, researchers and entrepreneurs have developed and successfully assembled, distributed and sold enhanced crop production packages in forms of nutrient inputs, pests and diseases control and seed genotype packages, including instructions for use. The guiding hypothesis in these endeavours is that farmers or consumers will accept new or promising technologies if the inputs associated with their use are readily available in small affordable units. Thus, increase of soil fertility amelioration, the contents of these units may be used progressively on soils from a nutrient depleted farm. From this guideline, Moi University, Kenya in 1997 developed a simple integrated nutrient package, the PREP-PAC, designed to replenish the fertility of soils in the worst patches common on smallhold farms across western Kenya. PREP-PAC is an acronym for the Phosphate Rock Evaluation Project funded at Moi University by the Rockefeller Foundation, U. S. A. (1997 – 2002); PAC stands for package. PREP-PAC consists of 2 kg of biogenic/reactive MPR from Tanzania, 0.2 kg urea, 120 g of legume (food) seed and Biofix (rhizobial inoculant from MIRCEN Project, University of Nairobi, packaged in filter mud carrier with gum Arabic sticker and lime pellets to create a favourable soil-rhizobium pH environment. Apart from imported urea, all components of PREP-PAC are available in East Africa. Positive maize-legume responses to PREP-AC (with 100 kg P/ha + 40 kg N/ha and BNF source of N) have been reported extensively elsewhere (e.g. Nekesa *et al*, 1999; Obura *et al*, 2001; Woomer *et al.*, 2003; Okalebo *et al.*, 2005; Esilaba *et al.*, 2005). In spite of the great potential of PREP-PAC product to replenish nutrients from infertile soils, it is unfortunate that its adoption hit a snag, in that there has been no funding needed to purchase and repackage inputs and also to distribute and sell the packages on cost-sharing basis. However, while reviewing the shortfalls of our experimentation with the product, we pointed out several limitations. Thus our initial experimentation focused maize-bean and soybean intercrops, whereby these two legumes were planted between maize rows, the so-called conventional intercropping system. Legume yields were disappointingly low, although the PREP-PAC increased these yields significantly (Obura *et al.*, 2001). Therefore, to improve our approach on targeting adoption of the package, we investigated further its applicability over a wide range of seven commonly grown food grain legumes in western Kenya (Table 7). These were intercropped with maize with or without PREP-PAC applications in 2003 SR and 2004 LR and SR consecutive seasons, at Nyabeda, Siaya, on – farm site, where soils are nutrient depleted (Ruto, 2007). However, the improved and profitable "MBILI" system of intercropping (with two staggered alternate maize and legume rows) was adopted in this study.

This system allows for increased light penetration through the taller and bigger maize plants to the shorter and smaller legume plants, with subsequent yield increases (Tungani *et al.*, 2002). Yields of maize and seven legumes from this experiment are reported elsewhere (Okalebo *et al.*, 2005; Ruto, 2007), but in a nutshell, the PREP-PAC significantly ($p<0.05$) outyielded the control treatments without nutrients. There was an influence of the legume type on maize yields (range 0.29 to 3.00 t/ha). The promising legumes for PREP-PAC inputs under MBILI intercropping system appeared to be cowpeas, common beans, groundnuts, bambara nuts and yellow grams, in low fertility soils. Economic analysis of maize-legume PREP-PAC and MBILI interventions showed the profitability of the production enterprises in the decreasing order of the maize legume intercrops given in Table 7, whereby the below ground yielding legumes (bambara and groundnut) out yielded and were more profitable than the above ground yielding legumes. PREP-PAC is indeed effective and profitable on infertile soils.

Table 7: Gross margin analysis of maize-legume intercrop production under PREP-PAC experiment in Nyabeda, Siaya, for 3 cropping seasons (2003 SR and 2004 LR and SR – Source: Ruto, 2007)

Intercropping type	Returns to factors of production			
	Gross margin labour productivity capital productivity			Value to cost ratio
	(Kshs/ha/yr)	(Ksh/Ksh spent)	(Ksh/Ksh)	
Maize-bambara nuts	118528	430	162	2.45
Maize-dry beans	118398	420	161	2.44
Maize-soybeans	97754	283	132	2.18
Maize-yellow grams	82529	294	114	2.02
Maize-cowpeas	75955	270	104	1.93
Maize-groundnut	24672	90	34	1.31
Maize dolicos (lablab	<17674	-67	-26	0.83

NB: for dolicos beans there was no harvest made on grain because of logistics (financial) associated with the monitoring and payment for labour as this legume flowers and pods continuously (indeterminate).

One US $ exchanged at Ksh. 67 as of April – May 2007.

Conclusions and Recommendations

1. Phosphate rocks (PRs) of diverse origins, reserves and characteristics are widely distributed in Africa. Most of these, when applied directly or modified, have the potential to supply the commonly limiting P nutrient to crops for improved yields and food security.
2. In East Africa, the sedimentary/biogenic Minjingu phosphate rock can be used directly as a source of both P and liming material in the widespread low P and acid soils.
3. Field tests on poor soils of western Kenya have demonstrated positive yield increases from <0.5 to 4 – 5 t/ha maize/season from small scale farm level to applications of PRs from solubilization, blending and other modifications. Similarly, legume grain yields were raised form <0.2 to 0.7 t/ha/season from PR interventions.
4. Economic analyses of maize and legume production and sales from almost all our studies have given positive returns to land, indicating profitability of PRs used, together with associated production practices. Moreover, these PRs have carryover (residual) effects measurable to 5 consecutive cropping seasons. Benefits of residual effects of nutrient inputs are often put aside when economists calculate production and output costs.
5. Short term projects have a negative impact on the adoption of technologies process in that once the farmers start to appreciate and adopt a technology, project funding ends and the technology proprietors remain stranded, unable to purchase and repackage inputs for specific technologies.

From these conclusions, it is recommended that the potential to use PRs in Africa should be revisited as these materials offer promise to replenish the "lost P" in the highly weathered, low P and acid soils.

It is also suggested that long-term projects, with effective monitoring and evaluation processes, should be sought as these are likely to offer an opportunity for prolonged demonstrations and participation in selection of technologies which are likely to contribute to food security, poverty reduction and good health of resource – poor communities in Africa.

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