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"PREP-PAC": a product for nutrient replenishment in smallhold farms of Western Kenya.

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Abstract

Soil fertility depletion is recognised as a leading cause of food insecurity in sub-Saharan Africa and several approaches are being tested to replenish the fertility of degraded soils. A particular challenge is to develop products formulated for the needs of smallhold farmers who are directly affected by continuous food shortages. These products could be distributed through local farm input supply networks. Thus the Phosphate Rock Evaluation Project (PREP) at Moi University, Kenya, has formulated and field-tested a product, the PREP-PAC, which is an inexpensive product that combines fertilizer, legume seed and rhizobial inoculant techniques, from the University of Nairobi. It is specifically targeted to the low soil fertility patches that are widespread to smallhold farms in the highly weathered and leached soils of Western Kenya, consisting of about 500,000 hectares of mainly Acrisols (Ultisols) and ferralsols (oxisols) and their mixtures. PREP-PAC contains of 2 kg of the reactive/biogenic locally available Minjingu (Tanzania) rock phosphate (PR), 0.2 kg imported urea, 0.13 kg seed of a N-fixing food legume, rhizobial inoculant (Biofix), seed adhesive (gum arabic), lime pellets and instruction sheet for use in English, Kiswahili and other local languages. The pack is assembled at US$ 0.58 per unit and is intended to meliorate of 25 m^2. The product is particularly effective in acid (pH <5.5) and low P (10 mgP kg^{-1}) soils. In PREP-PAC testing in the field, several experiments were conducted form 1998 to date. The general principle is to apply slowly the available PR sufficient for several cropping seasons with readily available nitrogen fertilizer (urea) and to intercrop with a legume that provides residual fixed-nitrogen and organic inputs to the soil. This approach was tested in 52 on-farm experiments where PREP-PACs were tested in symptomatic patches containing maize-bean intercrops with and without an improved variety of climbing *Phaseolus vulgaris* cv. Flora. Unamended patches (25 m^2) produced 1.6 kg maize and 0.08 kg bean. With addition of PREP-PAC containing Flora, yields increased to 4.1 kg maize and 1.1 kg bean ($p<0.001$) for both crops and the improvement in bean yield during the first cropping season nearly offset PREP-PACs' investment costs. A second experiment examined interactions between PREP-PAC components in a maize-soybean intercrop in nutrient depleted soils with sandy and loamy surface horizons at 3 on-farms sites. The treatments were ± PR, ± urea and ± inoculants arranged as a 2^3 factorial with four replicates at each location. The total value of the intercrops ranged between $ 0.83 in the unammended plots and $ 2.44 in those treated with PREP-PAC. Significant positive effects were observed with the addition of PR ($P<0.001$), urea ($P = 0.04$) and inoculant ($P=0.01$) and interactions between PR and urea (P=0.02) or inoculant (p=0.07). The return ratio to PREP-PAC investment was 2.6 in the sandy soil but 3.7 in the loamy soil. A third experiment compared in the field, the responses of dry bean and soybean to rhizobia inoculants with tolerance to acidity, in three acid and low fertility soils. Significant site and PREP-PAC treatment effects were found across sites for both legumes. The effectiveness of inoculants also varied with sites. Presently, PREP-PAC is being field-tested by five developmental organisations and test-marketed by several retailers of agricultural inputs. Efforts are underway to lower the cost of PREP-PAC production by 30% (to $0.41 per unit), primarily through bulk purchases and reduced packaging and transportation costs. Study extension is suggested to accomplish these tasks, however, including an economic and agronomic evaluation of the existing soil fertility amelioration methods along with PREP-PAC.

Keywords: PREP-PAC, nutrient depletion and replenishment, Kenya

Introduction

Food insecurity in sub-Saharan Africa (Kenya included) is of global concern. In this region, food aid has increased exponentially over the past 35 years or so and there seems to be no nearby end to this food crisis (FAO, 1996; World Bank, 1996). Reasons for food deficits are multiple, but include frequent droughts, political unrests and poor or declining economies in most African countries. But, as the countries affected strive to increase agricultural production, they are constrained by the widespread soil fertility depletion on croplands, and to the overall food insecurity (FAO, 1996; Sanchez *et al.*, 1997; Woomer *et al.*, 1998).

Soil fertility depletion is particularly distinct among smallhold farms that comprise a large proportion of the farming community in Africa. At these farms, land is continuously cultivated without or with minimal nutrient inputs in most cases; this results in substantial removals of nutrients from soils, mainly from crop harvests. Other pathways of nutrient losses include: soil erosion, leaching, denitrification and volatilization. Thus the farming systems, for example, in the East African Highlands result in negative nutrient balances or nutrient depletion at rates of 36 kg nitrogen (N), 5 kg phosphorus (P) and 25 kg potassium (K) per hectare per annum, a more rapid loss than in any African sub-region (Smaling *et al.*, 1997). The consequences of this magnitude of nutrient depletion are evident in Western Kenya (current Phosphate Rock Evaluation Project (PREP) study area), where maize (staple) yields on smallhold farms have reached below 500 kg grain/ha/season (Nekesa *et al.*, 1999). This quantity of maize is often consumed within the households in 3 months soon after harvest (Stephen Nandwa, personal communication). Hence food shortages will recur in the region. Moreover, western Kenya is characterized by the highly weathered and leached soils, mainly the acrisols, ferralsols, cambisols and nitisols that are generally acidic and low in available N and P nutrients (Woomer and Muchena, 1996). Fertilizer response trials in this region also suggest that N and P are the two most frequently limiting nutrients (FURP, 1994; Woomer *et al.*, 1997). Farmers are aware of the consequences of low soil fertility and the benefits of fertilizer use (Sanchez *et al.*, 1997) but are discouraged by irregular supply, uncontrolled pricing system, lack of credit, poor distribution and unreliable returns to investment, dictated by low producer prices. Consequently they apply none or less quantities than those recommended to replace losses (Smaling *et al.*, 1997). In addition, smallhold farmers are rarely visited by the Government extension staff for information/instructions on efficient fertilizer use (Mwaura and Woomer, 1999).

Nevertheless, farmers in Western Kenya (and other parts of Kenya) also practice complex nutrient management practices such as the use of on-and off-farm manures and composts, recycling of organic resources (Palm *et al.*, 1997) and the use of agroforestry and short fallow practices (Buresh *et al.*, 1997; Jama *et al.*, 1997). But these practices are not able to give positive nutrient balances (Stoorvogel *et al.*, 1993) and their rates of adoption seem to be negligible. In addition, the common feature of these nutrient amelioration options is that they have broad-based applicability and they reflect increased labour costs, particularly in the biomass transfers (Tithonia, for example) and applications of organic resources. Thus over a long period no specific affordable products have been used to replenish the fertility of low fertility patches that are widespread in smallhold farms (Woomer *et al.*, 1997).

Low soil fertility patches occur from factors such as poor drainage, variability in soil properties, but occur mainly from continuous cultivation of land without nutrient inputs. These patches are shown in areas where crops are stunted and have definite N and P deficiency colorations, namely, the yellow, purplish to reddish leaf and young stem colorations. In a survey on distribution of patches in Western Kenya (Kamau and Okalebo), low fertility patches were estimated to occupy 8 to 30% of each hectare cropped, and available P levels were lower from soils in patchy areas compared with soils from areas very close to the patches, with healthy crop growth (unpublished data). Farmers are aware of the need to cultivate high value crops frequently close to homesteads to facilitate good husbandry and the applications of nutrient resources (mainly as manure and compost). Therefore the fields furthest from homesteads rarely receive nutrient inputs, although these fields are also cropped continuously (Okalebo *et al.*, 1992), and hence develop poor crop growth areas or patches (Figure 1). If properly treated, the low fertility patches could be transformed into the most productive areas of the outfields and better meet the nutrient requirements of the whole farm through nutrient recycling. In view of this, PREP has developed and field-tested a prototype soil fertility product targeted to ameliorate the widespread, symptomatic nutrient depleted patches in smallhold farmers fields. This paper summarizes the achievements and failures resulting from the use of the PREP-PAC product over the past 4 years in Western Kenya.

Materials and Methods

Sources of phosphorus for replenishment

Many agronomineral deposits of rock phosphate (PR) occur in East and Southern Africa (van Kauwenbergh, 1991). The major sources of PR are the igneous and sedimentary rocks with the latter having a francolite structure. These rocks are widely used in refined phosphate fertilizer production, mainly in the developed world (Lehr and McClellan, 1972). PRs differ widely in their mineral constituents, but with the apatite mineral being the most important fertilizer mineral. Of our major concern is the Minjingu PR, of sedimentary origin, located near Lake Manyara in Arusha, Tanzania. This PR has received considerable research attention (Mnkeni *et al.*, 1991; Okalebo and

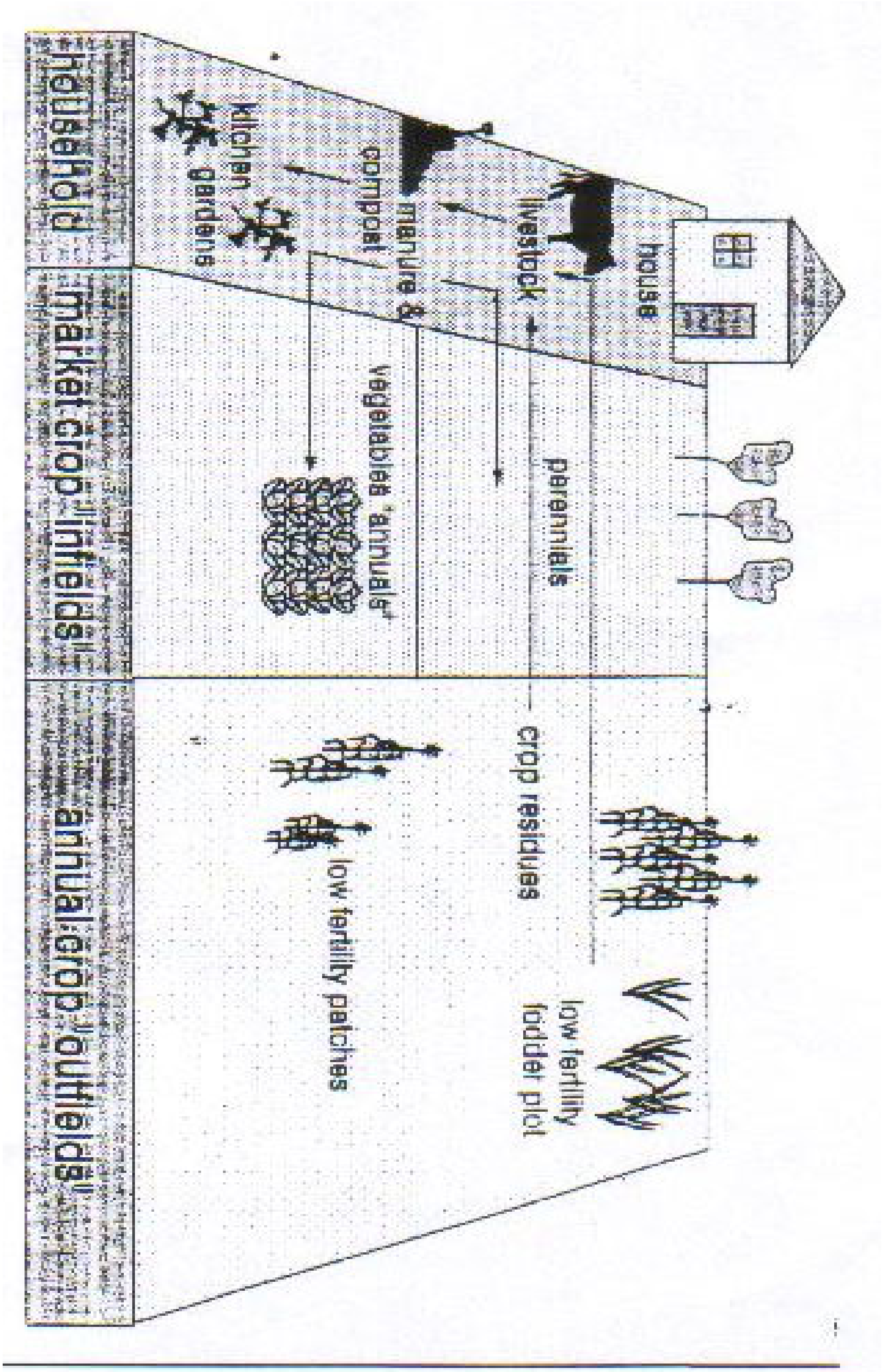

Figure 1 Low fertility patches and plots develop within croplands mined of nutrients for use by livestock and in market enterprises.

Woomer, 1994). The characteristics of this PR are described elsewhere (along with other PRs), but it contains 11-13.2%P and 38.2% CaO as main ingredients (Van Kauwenbergh, 1991; Table 1).

Table 1 Estimated resources of some phosphate rocks in East Africa (after Buresh *et al*., 1997; van Kauwenbergh, 1991).

Country	Name of deposit	Type of PR	Reactivity	Estimated reserves (10^6 tonnes)	Total P (g kg^{-1})
Tanzania	Minjingu	Sedimentary	Medium to high	10	87 - 109
Tanzania	Panda Hill	Igneous	Low	125	26
Uganda	Sukulu Hill	Igneous	Low	230	48 - 57
Kenya	Rangwe	Igneous	Low	-	<48

[1]About 51,000 tonnes of Minjingu PR were mined in 1995. Total P contents of this PR vary rather widely.

In general, PRs are insoluble in water but sparingly soluble in citric acid, with solubility, depending on the nature of the deposit. Hence phosphate rock is a suitable direct source of P in soil conditions that will alter the equilibrium reaction to dissolution. These factors include low pH, low exchangeable calcium, low solution P, adequate soil moisture and an increase in the PR-soil contact time (Asea *et al*., 1988). In addition, solubility of PR may be increased by maintaining higher organic matter levels in soils, through the reaction of organic acids formed in the process of decomposition (Bangar *et al*., 1985). Environmentally, PR may offer a solution to eutrophication in surface waters mainly associated with P as a result of its lower solubility when compared to soluble P sources (Robinson and Syers, 1990).

Development of the PREP-PAC

The development of PREP-PAC dates back to 1997 at a Workshop held at Moi University with an overall goal to develop a technology for replenishing the fertility of depleted soils in Western Kenya. The strategy suggested was the Fill-in-the-Gap approach, whereby two test strips of 0.1 ha each, separated by 0.3 ha were selected. Researchers would ameliorate these two strips through application of 100 kg P ha^{-1} (1 tonne of Minjingu PR) and grow maize and legume on the strips and in the area between them. Based on the yield results of the first application season, the smallhold farmer could himself decide to Fin-in-the-gap at his own expense (Figure 2). This approach could result in nutrient replenishment in 0.5 ha increments with farmers meeting 60% of the cost. The participants at this Workshop did not accept this gap-filling approach.

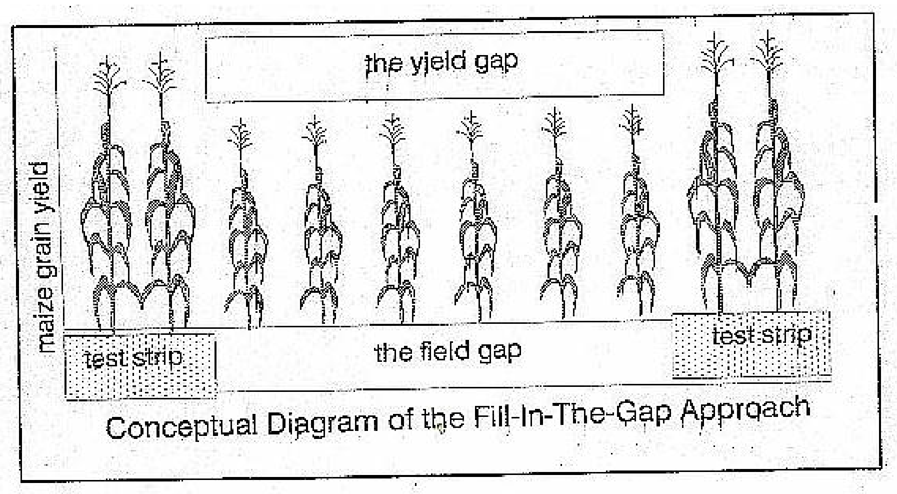

Figure 2 A schematic representation of Fill-in-the-Gap approach on P replenishment.

An alternative strategy was proposed which relied on smaller incremental investment by farmers, targeting the low soil fertility patches. Repackaging of fertilizers in small amounts affordable to farmers was suggested and farmer experimentation suggested. The PREP-PAC was then proposed and demonstrated at the CGIAR conference on "Approaches to Replenishing Soil Fertility in Africa - NGO Perspective" (ICRAF Nairobi, 3 - 9 June 1997).

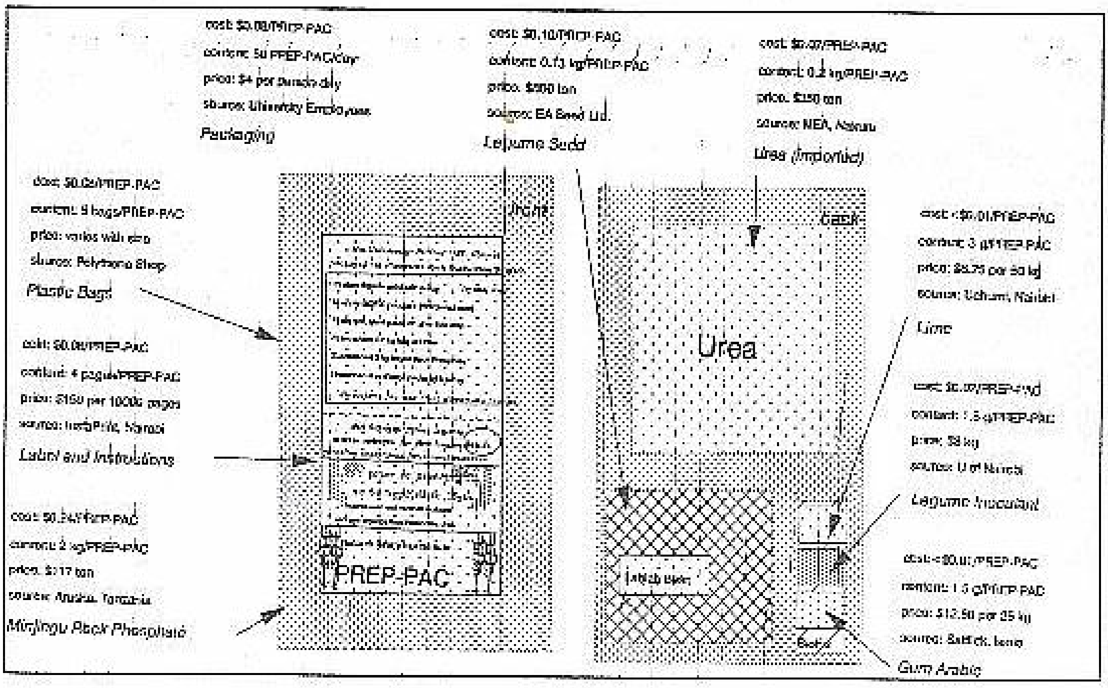

Figure 3 The PREP-PAC with its components and costs.

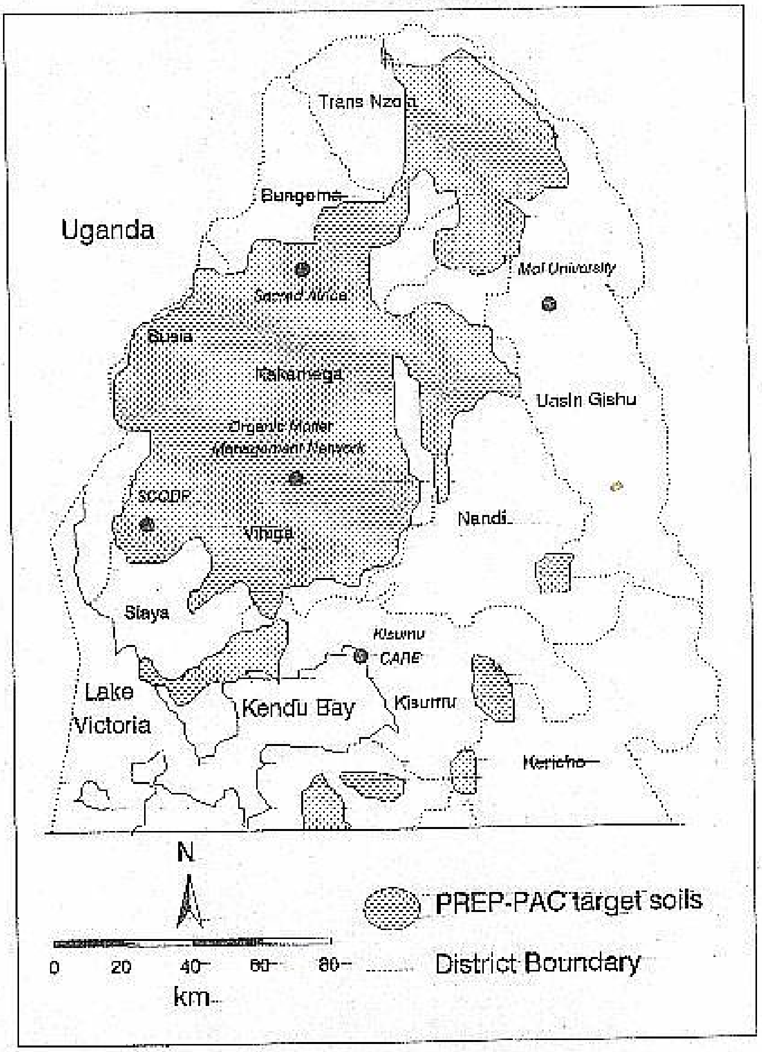

Figure 4 There are approximately 900,000 ha of Acrisols and acidic Ferralsols in Western Kenya that may benefit from PREP-PAC approach to soil fertility restoration.

PREP-PAC consists of 2 kg Minjingu PR, 0.2 kg urea, 125 g legume seed, Biofix, legume seed inoculant (Rhizobium), gum Arabic adhesive and lime for pelleting, along with instructions for use written in English, Kiswahili and other local languages. This product replenishes the fertility of soils in an area of 25 m^2 (Nekesa *et al.*, 1999). The pack costs about US $0.67 to assemble and it is repackaged at Moi University, University of Nairobi and SACRED Africa in Bungoma. Costs for individual components are shown in Figure 3. The researcher - NGO - farmer contact at the initial stages of the project delineated target soils for replenishment into three groups in western Kenya (Figure 4).

(i) Acrisols (Ultisols) with sandy surface horizons and very low inherent soil fertility (common in Siaya and Busia districts)

(ii) Acrisols with clay surface horizons and low to moderate inherent soil fertility (common in Bungoma and northern Kakamega districts)

(iii) Acrisols/Ferralsols complexes with moderate to high, but now depleted inherent soil fertility (common in Vihiga and Kakamega districts).

Thus PREP-PAC was tested on smallhold maize-legume based intercropping systems in the depleted soils and districts above. Soils at the study sites had generally low soil fertility (Table 2), and the farmers considered these the most fertility-depleted areas of their farms (Nekesa *et al*., 1999). These sites were further characterized by nutrient deficiencies often shown as stunted maize plants with yellow and purple to reddish colorations. However, in a separate study, the performance of PREP-PAC components and their interactions was tested at three farms, also in Western Kenya, with low soil fertility (Table 3). Western Kenya is also characterized with two cropping seasons annually, the long rains from March to August and short rains from September to January.

Table 2 Selected soil chemical properties for 52 farms in Western Kenya (Nekesa *et al*., 1999), Surface 0-20 cm soils.

Soil Property	Minimum	Maximum	Mean	sd
pH (1:2.5 soil to water)	4.68	7.26	5.44	0.52
%N	0.15	0.49	0.32	0.08
%C	0.38	4.20	1.89	0.81
Olsen P (mg kg^{-1})	1.00	7.50	2.40	1.50

Table 3 Selected soil chemical properties for three farms (Obura *et al*., 1999) Surface 0-20 cm soils).

Soil Property	Siaya (Nyabeda) Olero Farm	Bungoma (Siritanyi) Masinde Farm	Kakamega (Kabras) Namisi farm
pH (1:2.5 soil to water)	5.36	5.55	5.01
%N	0.23	0.16	0.26
%C	2.20	1.80	2.20
Olsen P (mg kg^{-1})	1.20	2.20	5.20

Experimental design and management

On-farm PREP-PAC evaluation (the survey and economic analysis)

PREP-PAC input was provided to 52 farmers and the prescribed application procedure explained. All farm operations, including application, plant disease/pest control were done by farmers. Two adjacent plots each measuring 5 m by 5 m were marked and treatments applied. The PREP-PAC treatment was applied as described below. Inoculated bean seed and maize were planted immediately. Control plots were beans and maize intercropped without addition of PREP-PAC nutrient sources. Treatments were designed to compare economic returns to PREP-PAC with no fertility amendment practices in the maize-bean intercrops. In both treatments, farmers planted the same maize variety of their choice, and either climbing (cv Flora) or bush variety of *Phaseolus vulgaris* contained in the PREP-PAC. Treatments on each experimental site or farm were subjected to the same management practices determined by the individual farmer. After harvest, sun dried weight of maize grain and bean seed from the two plots were weighed. Statistical analysis of crop yield and economics data was done on the computer using SYSTAT package and FREELANCE package for the graphics.

Testing the components of PREP-PAC

A 2^3 factorial arrangement with four replications for each of the three sites (Table 3) was used in this experiment. Plot size was again 5 mx5 m (25 m^2, the PREP-PAC size) reflecting the patch target areas for replenishment using one PREP-PAC. Treatments were selected to determine the response of maize and N-fixing soybean intercrops to individual components of the pack: Minjingu PR, urea and inoculant (Biofix); and the interaction of various components of the pack (rock P + urea, rock P + inoculant, urea + inoculant and rock P + urea + inoculant). Rock P (2 kg) and urea (0.2 kg) were broadcast and incorporated 0-15 cm to the seedbed at planting. Soybean seeds were inoculated for specific treatments with Biofix at planting, incorporating the gum Arabic sticker and lime pellets to maintain a favourable pH environment for the survival of the rhizobia. Maize (cv H614D for long rains, but H513 for short rains) was planted with 75 cm row and 25 cm hill spacing, while the soybean (cv Black Hawk) was planted between rows at 75 cm row and 20 cm hill spacing. Both crops were thinned (one and two maize and soybean plants per hill respectively) three to four weeks after planting, giving respective populations of 5.3 and 6.7 plants m^{-2}. Standard crop husbandry practices were maintained for each crop. At maturity, the crops were harvested separately, sun dried and their components weighed.

Assessing response of bean (*Phaseolus vulgaris* and soybean (*Glycine max*) to Rhizobia inoculants in low fertility acid soils of western Kenya.

This field study was conducted at 3 on-farm sites: Siaya, Bumala and Kakamega areas, with low pH and other soil properties and rainfall patterns similar to the above two experiments (a) and (b). Treatments compared the effectiveness of rhizobia strains, namely, the acid tolerant CIAT 899 and USDA 2674 for beans and strains SEMIA 5019 and USDA 110 for soybeans. Starter N and P were applied as basal dressings according to PREP-PAC product specifications, viz, 100 kg P ha^{-1} as Minjingu PR plus 40 kg N/ha urea to all treatments except the absolute control or smallhold no input treatment. Treatments were applied in a RCRD experiment with 4 replicates per site. Broadcast application of these materials, followed by incorporation into soils as for (a) and (b) above, was made. The high quality bean seed, Rosecoco (GLP2) and soybean (NAM 2) were inoculated by coating the inoculants held in filtermud onto the seed surface, using gum arabic sticker and lime pellets, the PREP-PAC instructions (Okalebo *et al.,* 1998). The seeds were then planted as both monocrops and intercrops with spacings of 40 cm between rows and 20 cm between hills. Maize (H614D) spacing for intercrop treatments was 75 cm row and 25 cm hill to hill. Growth measurements taken included the visual assessments of plant vigour, nodulation and yields (as above).

Economic analysis of data

Economic returns to PREP-PAC components and their interactions were assessed in terms of yield, gross field benefits and returns to investment (Hugues and De Leener, 1988) model, which included only costs and benefits that varied from the control (i.e. costs of PREP-PAC and increased maize, bean and soybean yield (CIMMYT, 1988). Costs such as ploughing and weeding that did not differ between treatments were ignored for the purpose of this analysis. The cost of PREP-PAC use by the farmer was KShs. 42 (about US$0.58, the assembly cost of KShs. 37 plus Kshs. 5 application labour cost). The average field price for maize and beans during the harvesting season of 1998 was KShs 10 and KShs. 23 kg^{-1} respectively. Net benefits from PREP-PAC use were compared by subtracting the costs of PREP-PAC use from the gross field benefits (the total value of maize and beans compared between low soil pH <5.2 and moderate soil pH>5.3 because effective dissolution of rock P to release soluble P occurs at soil pH of 5.3 and below (Buresh *et al.,* 1997).

Results

The survey and economic analysis experiment (On-farm PREP-PAC evaluation)

Grain yield

In the survey and economic analysis study covering 52 farms in western Kenya, maize grain yields were lowest in unfertilized treatments (control) under the two pH regimes equivalent to a mean of 0.64 t ha^{-1}. PREP-PAC application increased maize in both lower and moderate pH regimes to a mean of 1.36 t ha^{-1}. The highest maize yield was at the pH >5.3 with a mean of 1.67 t ha^{-1}. There was almost total crop failure for unfertilized bush beans at soil pH<5.2, a yield equivalent to 0.025 t ha^{-1}. PREP-PAC application at lower soil pH<5.2, improved bush bean yield from 0.025 to 0.125 t ha^{-1}. At soil pH<5.2, climbing (cv Flora) beans yielded 0.2 t ha^{-1} and PREP-PAC application increased the yield to 0.35 t ha^{-1}. Flora bean had the highest yield of 0.45 t ha^{-1} under PREP-PAC application and soil pH>5.3. Maize intercropped with Flora bean and treated with PREP-PAC at soil pH>5.3 yielded 1.5 t ha^{-1} compared to 1.2 t ha^{-1} of maize under bush bean intercrop. Maize intercropped with bush bean and without PREP-PAC at pH<5.3 yielded 0.75 t/ha while under Flora intercrop the maize yield was 0.5 t ha^{-1}.

Gross field benefits

The gross benefits for PREP-PAC use were determined for the 25 m^2 experimental plots (Figure 5). Gross field benefit for PREP-PAC was maximal at soil pH >5.3 amounting to KShs. 68, resulting in net benefits of KShs. 26. Gross field benefits from low pH soils <5.2 was KShs. 25 for the control and KShs 47 for PREP-PAC. In moderate soil pH>5.3, gross field benefit was KShs. 31 for control and KShs. 68 for PREP-PAC (p=0.05).

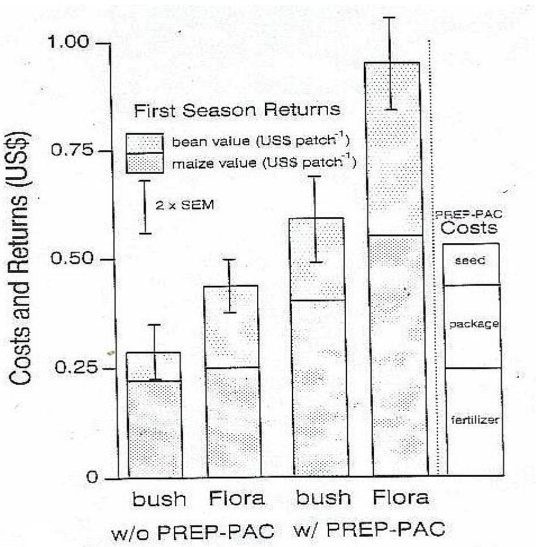

Figure 5 Costs and returns of PREP-PAC applied in conjunction with either local bush varieties or climbing variety (cv Flora) of *Phaseolus vulgaris* based on field trials of 52 farms in western Kenya.

Returns on investment

Use of PREP-PAC in soil pH<5.2 increases financial return on land from KShs. 8720 to KShs. 19920 ha^{-1}, with a return ratio to PREP-PAC of 1.27 (Table 4), thus for every shilling spent on PREP-PAC the farmer gets back the shilling invested plus 0.27 shillings. In moderate pH soils>5.3, PREP-PAC use increases financial returns on land from KShs. 12,400 to KShs. 27,240 ha^{-1} with a return ratio to PREP-PAC of KShs. 1.61.

Table 4 Returns on investment from no fertility amendment and PREP-PAC at low and moderate soil pH.

Soil condition and economic parameter	Without PREP-PAC	With PREP-PAC
Low soil pH<5.2		
Maize grain value (Kshs.)	16.50	32.00
Bean seed value (KShs.)	9.00	15.30
Total Value (KShs.)	25.50	47.30
Return on PREP-PAC		NA
1.27		
Return on land (KShs./ha)	8,720	19,920
Moderate pH soils>5.3		
Maize grain value (Kshs.)	18.40	38.90
Bean seed value (KShs.)	12.20	9.20
Total Value (KShs.)		30.60
68.10		
Return on PREP-PAC		NA
1.61		
Return on land (KShs. ha^{-1})	12,240 27,240	

NA = Not applicable

Source: Nekesa *et al.* (1999)

Components of PREP-PAC experiment

Grain yield

Maize grain yields for 1999 season are presented in Table 5. The yields varied with the treatments and sites and ranged from 1.1 to 4.8 t ha^{-1}. Thus, although the main PREP-PAC components (PR, urea and Biofix) applied individually or separately increased maize yields, the PR sole application gave the highest yield increases across the 3 sites, but particularly so in Kakamega with red soil of a high clay content, where a grain yield increase of 162% above control treatment was found (Table 5). On the average, PR combinations with biofix and urea resulted in significant maize yield increases, but the complete pack (PR + urea + biofix) gave the largest yield increase of 205% above the control at Siaya. Individual urea and biofix applications and the urea + biofix combination depressed maize grain yields in Bungoma with soils of sandy texture; but PR combinations with urea or biofix were associated with high yields.

In Table 6, the grain yields of soybean were 45 to 320 kg ha^{-1} in maize-soybean intercrop in 1999 from 2 sites only (Siaya and Bungoma). This yield magnitude is disappointingly low and may be due to the large shading effect of big maize plants at the tasselling to maturity periods. Nevertheless, there were only small grain yield increases from the individual PR, biofix and urea applications, while significant yield increases were found from combinations of PR with urea and biofix (Table 6). On the average, the PR + biofix combination gave good yields whereby grain increases of 289 and 485 kg ha^{-1} (above control yield) were observed in Siaya and Bungoma respectively. The farmer in Kakamega harvested the soybean crop prematurely.

Economic returns

For economic analysis, both maize and soybean grain data were used. However, for the sake of uniformity in site comparison, Kakamega site was omitted in this analysis due to lack of data from soybean harvest, as explained above. Total crop values were derived form the grain yield for every plot (soybean and maize as intercrops) and the prevailing market prices at the time of harvesting. The total returns and return ratios were calculated for each using the input prices and crop values obtained. Table 7 gives the input costs and returns on investment for each treatment. In terms of total crop value, ANOVA revealed significant effects of location (p=0.000), rock P addition (p=0.000), inoculation of soybean with rhizobia (p=0.01) and urea application (p=0.03). Interactions were observed between rock P addition and both urea (p=0.03) and legume inoculant (p=0.000), return ratio (p=0.01), value of maize (p=0.000) and value of soybean (p=0.062). Even though soybean grain yields were generally low, below 500 kg ha^{-1}, significant responses were observed as a result of application of the following treatments: rock P (p=0.000), urea (p=0.021), inoculation (p=0.000) and interaction between rock P and biofix (p=0.038).

Table 5 Maize grain yield from the three farms in western Kenya under maize-soybean intercrop, 1999 (Obura, 2001).

Treatment	Siaya	Grain Yield (kg ha^{-1}) Bungoma	Kakamega
Control	1578	1619	1595
Biofix	2228	1247	2257
Urea	1930	1183	2614
PR	2510	2435	4174
Urea + Biofix	2281	1083	2889
PR + Biofix	3930	2406	2949
PR + Urea	3741	3028	2298
PR + Urea + Biofix	4814	2711	3151
SED	735	475	648
LSD (p=0.05)	1529	988	1348
cv%	26	24	24

PR = Minjingu rock phosphate

Table 6 Soybean grain yield from two farms in western Kenya under maize-soybean intercrop (Obura, 2001).

Treatment	Siaya	Grain Yield(kg ha^{-1}) Bungoma	Kakamega
Control	57	45	-
Biofix	86	67	-
Urea	71	71	-
PR	77	54	-
Urea + Biofix	72	83	-
PR + Biofix	222	261	-
PR + Urea	137	225	-
PR + Urea + Biofix	175	320	-
SED	26	49	-
LSD (p=0.05)	54	-	-
cv%	23	-	-

PR = phosphate rock (Minjingu)

Table 7 Components and their returns on investment (Obura, 2001).

Input	Cost	Total return from each farm (KShs. 25 m^2) Masinde's	Olero's
Seeds only (S)[1]	10.70	49.50	49.60
Seed + inoculant (I)	14.00	41.03	70.50
Seed + Urea (U)	16.50	40.00	60.70
S + I + U	19.80	38.40	70.60
Seeds + rock P (P)	32.10	73.00	77.40
S + I + P	35.40	92.90	131.30
S + U + P	37.90	106.60	117.60
PR + Urea + Biofix	41.20	107.30	151.20
LSD (p = 0.05)	N/A	26.50	41.80

[1]includes the cost of 100 g of maize seed

Bean and soybean responses to rhizobia strains and to PREP-PAC

Nodulation of beans and soybeans was enhanced by the rhizobial inoculants, namely, the standard strain USDA 2674 and the acid tolerant strain CIAT 899 for beans, but the strains SEMIA 5019 and USDA 110 for soybeans. There was an increased bean nodulation particularly from strain USDA 2674, as reported elsewhere (Okalebo *et al.*, 2001).

Differences in bean grain yield (473 to 3,478 kg ha^{-1} in the first rains 2000) were significant among sites (p = 0.000) and treatments within sites, with Siaya giving the lowest yields while Kakamega had the highest yields (Table 8). The rhizobial strain CIAT 899, an acid tolerant strain, gave low bean yield in Siaya and Bumala under bean sole crop in particular. Low bean yields were associated with maize-bean intercrops in all three sites and are attributed to shading of beans by maize and possible soil moisture and nutrient competition by two crops (Chui *et al.,* 1984).

Soybean grain yield ranged from 383 to 2,329 kg ha^{-1} in Siaya and Bumala sites where differences in yields were mainly significant from site and treatment differences (Table 9). There was a significant reduction in soybean yield from seed inoculation at Siaya, but a significant yield in Bumala, due to rhizobia inoculants. Like beans, low soybean yields occurred from intercropping maize with soybeans. The PREP-PAC products increased legume yields, but particularly so at Bumala, the site with possible improved use efficiency for added N and P inputs, including the effects of inoculants.

Table 8 Effects of rhizobial inoculants on bean grain yields (kg ha^{-1}) in Western Kenya, long rains 2000.

Site	Bean sole crop Rhizobia inoculant			Maize - bean intercrop Rhizobia inoculant			SE
	Control	899	2674	899	2674	Mean	
Siaya	1052	831	1484	473	847	937	239
Bumala	1458	2462	3060	1737	1555	2054	
Kakamega	3479	3018	2592	1978	1305	2474	
S. E.	309						

$p < 0.001$ sites; $p = 0.09$ treatments; $p = 0.10$ sites x treatments.

Table 9 Effects of rhizobial inoculants on soybean grain yield (kg/ha), long rains 2000.

Site	Soybean sole crop Rhizobia inoculant			Maize - soybean intercrop Rhizobia inoculant			SE
	Control	5019	110	5019	110	Mean	
Siaya	1286	946	524	597	383	747	186
Bumala	884	2141	2022	1571	2329	1789	
Kakamega	1082	1548	1273	1081	1357	1268	
S. E.	415						

$p < 0.001$ sites; $p = 0.28$ treatments; $p = 0.07$ sites x treatments.

The nitrogen accumulated in bean grain at three sites in the long rains of 2000 ranged from 19 to 119 kg N ha^{-1}, whereas the range was higher (18 to 168 kg N ha^{-1}) for soybean grain (Tables 10 and 11). There was a significant ($p < 0.001$) site effect on the N taken up in the seed of both beans and soybeans, reflecting differences in soils and their properties and other environmental factors such as rainfall and temperatures.

The Bumala and Kakamega sites with high clay and organic matter contents (not reported here) had particularly high grain yields (Tables 8 and 9) and subsequent increased N accumulation (Tables 10 and 11). On the average there was a significant site x treatment interaction on the levels of N taken tot he grain, implying differences in effectiveness of rhizobia strains between sites. Further work is being undertaken to confirm observations reported in this paper. There was also reduced accumulation of N in grain from maize-legume intercrops as mainly a result of plant competition for moisture and nutrients, as reported above for grain yields.

Table 10 Effects of rhizobial strains on total nitrogen uptake (kg N ha^{-1}) by beans in Western Kenya, long rains 2000.

Site	Bean Sole Crop			Maize-bean intercrop			SE (site)
	Rhizobia inoculant			Rhizobia inoculant			
	Control	899	2674	899	2674	Site Mean	
Siaya	44	38	61	19	35	39	11
Bumala	50	102	115	72	57	79	
Kakamega	119	101	60	78	50	82	
SE (treatment)	15						

$p < 0.001$ sites; $p = 0.12$ treatments; $p = 0.09$ sites x treatments.

Table 11 Effects of rhizobial strains on total nitrogen uptake (kg N ha^{-1}) by soybeans in Western Kenya, long rains 2000.

Site	Bean Sole Crop			Maize-bean intercrop			SE (site)
	Rhizobia inoculant			Rhizobia inoculant			
	Control	5019	110	5019	110	Site Mean	
Siaya	104	82	42	49	18	59	14
Bumala	63	161	148	118	168	132	
Kakamega	83	122	95	84	93	95	
SE (treatment)	17						

$p < 0.001$ sites; $p = 0.21$ treatments; $p = 0.00$ sites x treatments.

Marketing of PREP-PAC

PREP-PACs were test-marketed in Western Kenya prior to the year 2000 long rains. The study was conducted in two stages. First, 42 retailers in four districts (Bungoma, Busia, Siaya and Vihiga) were invited to participate and provided PREP-PACs and product information free of charge. After one month, the retailers were revisited and asked to respond to a short, formal survey. A total of 245 PREP-PACs were delivered to the retailers with 136 of these sold to farmers for an average retail price of \$0.54 (range \$0.27 to \$1.08). Among those interviewed, all retailers sold fertilizers, with diammonium phosphate, DAP (98%), calcium ammonium nitrate, CAN (74%) and urea (60%) being the most frequently marketed types. A large majority of retailers routinely repackage fertilizers into smaller (1 kg) sizes (79%) suggesting some familiarity with the PREP-PAC approach. Fertilizers were a very important retail line, with 83% of respondents describing them as the first - or second - most sales item alongside pesticides, seeds and livestock supplies. Only 60% of the respondents were owners as their family members creating difficulty in responding to queries concerning business strategies and future plans.

Most of the retailers (63%) considered PREP-PAC a promising product although concerns were expressed over complicated packaging instructions (27%). The potential demand for PREP-PAC was calculated by asking the retailers how many packages they would order at various prices (Figure 6). Only 7% of those queried had no interest in marketing PREP-PAC. Linear regression of this relationship suggests that the current cost of production and retailers suggested wholesale prices are out of line and that either reduced cost of production, higher retail prices or both are necessary before the product can be robustly marketed. Retailers demand will increase by 4% for each KShs. 1 (+ \$0.014) reduction in price (r = 0.93). Retailers may have undervalued PREP-PAC because its benefits are poorly understood and, following positive feedback from customers (Mwaura and Woomer, 1999), they will market the product for a higher price. If wholesale prices were lowered by 30% and sales prices raised by 20%, then the wholesale price, retail price and profit from each PREP-PAC would be \$0.39, \$0.65 and \$0.26 (67%) per unit, respectively.

Collaboration

A large number of PREP-PACs have been distributed by Moi University to farmers through cooperating agencies (Table 10) since 1998. To date, 5334 PREP-PACs were distributed. In the year 2000, 620 packages were sent to neighboring Uganda for testing by CIAT and the Uganda National Agricultural Research Organization (NARO). To a large extent, the demand for PREP-PACs rapidly outpaced the capacity of project researchers to supervise cooperators' field trials and anticipated data collection efforts by quasi-scientific grassroots organizations have met with limited success. Therefore PREP needs extended funding mainly to tackle Outreach activities and to refine the PREP-PAC through research collaboration. The main objective of the proposed project extension is therefore to replenish the fertility of nutrient depleted soils in smallhold farms in western Kenya using the PREP-PAC product that targets low fertility patches common in the fields. This product is effective, affordable to most farmers and environmentally friendly.

Table 12 Distribution of PREP-PACs, 1998/2000.

Contact Person and Destination	1998	1999	First rains 2000
Joseph Agunda, CARE(K) Siaya and Homa Bay	175	25	100
Dismas Okello, SCODP, Siaya	80	150	50
J.E.Mukhwana[1], SACRED Africa, Bungoma	200	250	500
Fr. Ben Omuse, Catholic Church, Kocholia, Teso	105	-	50
P. Nekesa, ABLH, Kakamega	230	80	-
E. Mwangi, FRESHCO, Pioneer Seed Co; Kitale	245	100	-
P. Nekesa, Resource Projects Kenya, Mbale, Vihiga	-	-	200
A.O.Esilaba, CIAT, Kampala, Uganda	-	-	420
A. Byamugisha, Min. of Agriculture, Uganda	-	-	200
Nganga, NGO in Nairobi	-	-	50
PREP research trials/sites by students	120	250	400
Others	229	625	600
Totals	1384	1480	2470

[1]SACRED Africa and Resource Projects Kenya are now repackaging and distributing their own PREP-PACs in Bungoma, Teso and Vihiga districts.

Extended collaboration is welcome.

Discussion

The findings from three on-farm trials indicate that the combination of PREP-PAC components behave in a synergistic manner, particularly where both soil N and P limit crop production such as at Ambrose Olero's farm in Siaya. At this farm, the small investment in seeds (Kshs. 10.70) also results in modest net returns (Kshs. 388.5), but a high return ratio on investment (4.6). Investing additional KShs. 21.40 in rock phosphate slightly increases net economic returns to KShs. 45.30 and reduces the return ratio to 2.4. Combining all the PREP-PAC components (KShs. 42.10) results in net return of Kshs. 101.60 and raises the return on investment to 3.7. At Masinde's farm in Bungoma, a lower but quite attractive return ratio of 2.6 was achieved.

The economic return from PREP-PAC is equivalent to US \$553 ha^{-1}, which is greater than Kenya's per capita annual income. These data offer convincing evidence that PREP-PAC effectively replenishes soil fertility in soils with two very different textures and that its ingredients have been strategically combined. This integrated approach to replenishing soil fertility clearly indicates that crop yields especially those of maize, the main crop, are comparable to those of imported fertilizers reported elsewhere by other researchers. (e.g. FURP, 1994).

In a separate study incorporating a survey and economic analysis of agronomic and soil test data from 52 farms in western Kenya (Nekesa *et al.*, 1999), the benefit of PREP-PAC application is highlighted by the dramatic response of maize and bean yield under low and moderate soil pH despite the apparent low yield potential of maize and beans at low soil pH. Economic analysis of both treatments showed that, despite the extra costs associated with PREP-PAC use, there was financial gain resulting from its use in both pH regimes. Out of the 52 farms studied, 28 of them had moderate soil pH> 5.3, therefore PREP-PAC effectively improved yields on 54% of the fertility depleted soils.

Gross field benefits differed markedly between low and moderate soil pH under PREP-PAC application. A factor other than P and N apparently limited maize and bean yield response to PREP-PAC at soil pH<5.2, phosphate ions coming from rock P dissolution are taken away from the soil solution and sorbed by Fe and Al oxides and hydroxides (Sanchez *et al.*, 1997). These sorbed phosphate ions are unavailable to plants in the short run hence the lower response to PREP-PAC observed at low soil pH. But the sorbed phosphate ions are slowly desorbed and released to the soil solution during a period of several years (Sanchez *et al.,* 1997). At soil pH 5.0 and below, Al is fairly soluble thereby causing Al-toxicity to crops. Al-toxicity reduces PREP-PAC's effectiveness at low pH, implying that PREP-PAC does not have s strong limiting effect that can reduce Al-toxicity in the first season. Low bush bean yields (25 kg ha^{-1}) in acid soils pH<5.2 is an illustration of the importance of soil fertility management. Thus, Nderitu *et al.* (1997) noted that bean stem maggot and bean root rot are constraints to bean production in low soil fertility. Nutrient application enhances tolerance to bean stem maggot and root rot because a bean crop supplied with nutrients grows vigorously and is able to tolerate bean stem maggot and bean root rot attack (Otsyula *et al.*, 1998) therefore, PREP-PAC application also offers opportunity to address the two biotic constraints to bean production in fertility depleted soils.

Conclusion

Soil nutrient depletion poses a serious threat to the welfare of the smallhold farmers in western Kenya. The deficiency of P in most western Kenya soils must be addressed in any strategy so as to increase crop production in the region. It is therefore important to note that PREP-PAC is basically intended as a nutrient replenishment mechanism (Sanchez *et al*., 1997) through market distribution (Woomer *et al.*, 1998). The economic return realized during the season where PREP-PAC was applied was significant (75% return). However, the phosphorus applied through PREP-PAC is sufficient to replace 10 to 30 years of nutrient loss (Sanchez *et al*., 1997) and returns during following cropping seasons are anticipated too. One important future development is the reduction of costs that may be possible by purchasing the package's components in bulk and through gaining greater efficiency in its assembly. In addition, the full benefits from applying PREP-PACs are yet to be established from the parallel economic survey being conducted in the same region.

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