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Economic analysis of maize-tepary bean production using a soil fertility replenishment product (PREP-PAC) in semi-arid Eastern Kenya

Chris A. Shisanya[1]
[1]*Kenyatta University, Department of Geography, P.O. Box 43844 GPO 00100, Nairobi, Kenya.*
e-mail: shisanya@yahoo.com or shisanya@avu.org

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Abstract

Continuous cropping without external nutrient inputs to soils has led to the expression of poorly productive patches in farmers' fields in semi-arid Eastern Kenya. The smallholder farmers attempting to correct these conditions are often confused by the spatial and symptomatic irregularity of the affected plants, until recently, no soil management product was commercially available that is specifically formulated to restore soil fertility to these patches. PREP-PAC contains 2 kg Minjingu rock phosphate (RP), 0.2 kg urea, seeds of various symbiotic nitrogen-fixing food legumes (in this case tepary bean (TB)), rhizobial inoculant, gum Arabica seed adhesive, lime for seed pelleting and instructions for the use of these materials. It is intended for addition to 25 m^2 and produced at a cost of US $ 0.56 per unit. The general principle is to apply slowly available RP sufficient for several cropping seasons with readily available nitrogenous fertiliser and to intercrop farmer's maize (*Zea mays*) with a legume that provides residual fixed-nitrogen and organic inputs to the soil. This approach was tested in on-farm trials covering 50 farms, conducted in collaboration with farmers groups. An experiment examined interactions between PREP-PAC components in a maize-TB (*Vigna unguiculata*) intercrop in nutrient depleted Ferralsols of semi-arid Eastern Kenya. The treatments included ±RP, ±Urea, and ±inoculant arranged as a 2^3 factorial with four replicated at each location. Total value of the intercrops ranged between US $ 0.95 in the unamended plots and US $ 2.90 in plots treated with PREP-PAC. Significant positive effects were observed with the addition of RP ($P< 0.001$), urea ($P = 0.04$) and inoculant ($P = 0.01$) and in interactions between RP and urea ($P = 0.02$) or inoculant ($P = 0.07$). The return ratio to PREP-PAC investment was 2.8 in the sandy fields and 4.2 in the clay fields. PREP-PACs were tested on-farm in 50 symptomatic patches containing maize-TB intercrops. Unamended patches (25 m^2 = 0.0025 ha) produced 1.9 kg maize and 0.06 kg TB. With addition of PREP-PAC, yields increased to 4.2 kg maize and 1.6 kg TB ($P < 0.001$, for both crops). PREP-PAC is a strategic approach because all of its components, except for urea, originate from East Africa and are relatively inexpensive; the product is intended for distribution through the existing local retail and rural development networks.

Key words: Eastern Kenya, fertiliser, integrated nutrient management, maize, inoculation, on-farm research, rock phosphate, semi-arid, soil fertility replenishment, tepary bean.

Introduction

Identifying approaches to improve soil fertility management adaptable by smallholder farmers in East Africa is prominent within the subregions agricultural development agenda. Two significant milestones preceded this distinction. Strongly negative estimates of soil fertility imbalances at farm, district, national and subregional scales were estimated [1, 2] suggesting that decades of continuous cultivation without substantial nutrient replacement had reached a critically low threshold. Soil fertility depletion was next identified as a root cause of East Africa's persistent food insecurity that was best addressed through broad-based nutrient replenishment efforts [3], with a variety of strategies undergoing consideration including large-scale fertiliser relief, market-oriented solutions and strengthening of locally developed approaches to integrate nutrient management [4, 5]. Soil fertility replenishment has influenced the agenda of organisations ranging from the grassroots to the international level, but so far little tangible improvement in the livelihood of affected farmers has been realised [6].

Smallholder farmers in semi-arid Eastern Kenya produce crops under diverse biophysical and socio-economic conditions. Maize intercropped with a legume is the main crops produced for household food consumption with occasional surpluses sold for cash income [7]. However, these smallholder farmers in this region are now facing a critical challenge. They may either carefully diversify into profitable, mixed enterprise agriculture or they may backslide into the vicious cycle of poverty, with soil fertility management playing a crucial role in either outcome [3, 8-10]. Proven district-level recommendations of fertiliser rates based on several years' field investigation are now in place [11] but rely upon blanket application approaches that are too often readily adoptable by smallholder farmers because they were based upon optimising yield, rather than maximising the use efficiency of scarce inputs. Another flow in blanket recommendations results from intrinsic field-scale spatial heterogeneity [12, 13], where an early symptom of soil depletion is the expression of poorly productive, nutrient-deficient "patches", particularly in more distant areas of the farm away from the homestead [10]. Farmers prefer to manage this heterogeneity to household advantage rather than attempt to overcome it through non-discriminate application of fertilisers [13]. These fertility-depleted "patches" persist because farmers have little opportunity to reverse this trend due to poor access to markets and restricted availability of modern farm inputs [10]. Furthermore, inexpensive soil nutrient management products addressing the specific needs of smallholder farmers are unavailable through existing retail networks as fertilisers tend

Table 1. Formulation and assembly costs of PREP-PAC, a nutrient replenishment product under development for use by smallholder farmers in Western Kenya.

Component	Source	Price per unit US $*	Quantity per PREP-PAC	Cost per PREP-PAC (US $)
Minjingu RP	Arusha, Tanzania	110 t^{-1}	2 kg	0.22
Labels and instructions	Insta Print, Nairobi	125 per 10,000 pages	4 pages	0.05
Plastic bags	Plastics Ltd, Nairobi	0.03 per 50 bags	5 bags	0.07
Packaging	Local manpower	4 per person/day	50 PREP-PACS/day	0.08
Legume seed	Local farmers	550 t^{-1}	0.13 kg	0.07
Urea	Imported	324 t^{-1}	0.20	0.06
Lime	Flourspar Ltd	8.25 per 50 kg	3 g	< 0.01
Legume inoculant	University of Nairobi	8 per kg	1.5 g	0.02
Gum Arabica	Local	12.50 per 25 kg	1.5 g	< 0.01

*1 US $ = Ksh. 80

to be merely repackaged into smaller sizes rather than blended to meet the prevailing soil fertility conditions [14]. The Phosphate Rock Evaluation Project (PREP) combined fertiliser and germplasm technologies initially intended for use in Western Kenya (Table 1). The formulation and field-testing in Eastern Kenya are described in this paper.

Product Formulation

The formulation of PREP-PAC was governed by several principles. The product must be capable of amelioration the severe nitrogen- and phosphorus-deficient "patches" that are common in smallholdings of Eastern Kenya. It must be affordable to client smallholders and its instructions comprehensible. The product must be attractive to local entrepreneurs for local fabrication and retail distribution. Preference was assigned to lower-cost, locally available components that are combined in a manner consistent with developing understanding of integrated nutrient management [15] including the "N from the air, P from the bag" paradigm [3]. Published information on the ability of the inexpensive Minjingu rock phosphate (RP) from Tanzania [16] to react with and ameliorate phosphorus-deficient soils of Western and Eastern Kenya [17] was combined with the importance of intercropped legumes within the predominant maize-based cropping system [7, 18] as a key consideration in product design.

Soils most likely to respond to the application of Minjingu RP were identified as Acrisols, Ferralsols and Acri-Ferralsols complexes forming on acid igneous rock [19], categories which dominate the geomorphic landscape of Eastern Kenya. Underlying the product design and testing decisions was the belief that close collaboration between national universities and grassroots development agencies remains a promising but under-utilised mechanism for agricultural development in East Africa.

Methodology

Field procedures: The study was conducted between October 2003 and November 2004. PREP-PAC was tested on 50 representative farms of smallholder maize-based systems in semi-arid Makueni district, Eastern Kenya. Farm sizes vary between 0.5 and 3.5 ha with a median of 1.4 ha [20]. Average maize yields in farmers' fields range from about 0.4 to 1.5 t ha^{-1} [21]. Soils in the farmer's fields had generally low fertility (Table 2), and farmers considered these the most fertility-depleted areas of their farms. These sites were characterised by nutrient deficiencies often expressed as stunted, yellow and/or purple maize plants. The climate of the study area is described as hot and dry [22]. Rainfall is bimodally distributed, with median monthly maximum in April (126 mm) and November (138 mm). The median annual rainfall is about 582 mm $year^{-1}$. The short rains (SR) (October-January) generally have more rainfall and are more reliable than the long rains (LR) (March-June) [22]. The lengths of the agrohumid periods for drought-adapted crops are 50-55 days (LR) and 65-70 days (SR) [23]. Average monthly temperatures are highest in February (24.3°C) and October (23.4°C) [24], prior to the onset of the rains in March and November, respectively.

Table 2. Selected soil chemical properties for the 50 on-farm experimental locations.

Soil property	Minimum	Maximum	Mean	s.d.
Olsen P (ppm)	1.1	7.0	2.2	1.4
% N	0.16	0.50	0.30	0.06
% C	0.35	4.10	1.90	0.61
pH (1:2.5 soil/water)	4.70	7.40	5.50	0.46

Experimental design and management: The test input PREP-PAC was tested in two sets of field experiments; one examining the effects and interactions between its individual fertiliser and inoculant (R3254) component with tepary beans. The effects and interactions of RP, urea and R3254 were tested as a 2^3 factorial arrangement in a randomised complete block design with four replications at two different on-farm locations. These locations examined contrasting soil conditions in Eastern Kenya [25]; a sandy Acrisol (Ndilinge Farm in Makueni district); a clayey Ferralsol (Kiteme Farm in Machakos district). Before treatment applications, surface soils (0-20 cm) were sampled as bulked composites of 10 randomly selected soil cores and characterized accordingly [26]. In the Acrisol, soil pH was 5.5, total N 0.16%, and Olsen-extractable P was 2.2 mg kg^{-1}. In the Ferralsol, the results were pH 5.4, total N 0.23% and extractable P was 1.2 mg kg^{-1}. The PREP-PAC was provided to farmers and recommended application procedures explained. All farm operations, including application, planting density, weeding intensity, participating farmers performed pest and disease management. Two adjacent plots each measuring 5 m x 5 m were marked and treatments applied. In the PREP-PAC treatment, rock phosphate and urea were evenly spread then incorporated into the soil to a 15 cm depth; inoculated tepary bean seed and maize were immediately sown. The control plot had tepary beans and maize intercropped without addition of external nutrient sources. Treatments were designed to compare economic returns to PREP-PAC with no fertility amendment practices in the maize-TB intercrops. In both treatments, farmers planted the same maize variety of their choice and tepary bean contained in the

PREP-PAC. Treatments on each experimental site were subjected to the same management practices determined by the individual farmer. After harvest, sun-dried maize grain and TB seed from two plots were weighed and prevailing local market prices used to establish their economic values.

Economic analysis: Economic returns to PREP-PAC were assessed in terms of yield, gross field benefits and returns to investment (Table 3). Costs and benefits of each treatment were compared using a partial budgeting model, which included only costs and benefits that varied from the control (i.e., costs of PREP-PAC and the increased maize and TB yield) [27]. 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 $0.5 (assembly cost of $0.46 plus $0.06 application labour cost). The average field price for maize and TB during harvesting season of 2004 was $0.25 and $0.35 per kilogram, respectively. Net benefits from PREP-PAC use were calculated by subtracting the cost of PREP-PAC use from the gross field benefits (the added value of maize and TB). Crop yields and net benefits were compared between low soil pH (<5.2) and moderate soil pH (>5.3) because effective dissolution of rock phosphate to release soluble P may differ at soil pH 5.3 and below [17].

Table 3. Returns on investment from PREP-PAC at low and moderate soil pH.

Soil condition	Without PREP-PAC	With PREP-PAC
Low pH soils (< 5.2)		
Maize grain value (US $)	0.2	0.4
TB seed value (US $)	0.1	0.2
Total value (US $)	0.3	0.6
Return on PREP-PAC	n.a[1]	1.27
Return on land (US $ ha^{-1})	109	249
Moderate pH soils (> 5.3)		
Maize grain value (US $)	0.23	0.49
TB seed value (US $)	0.15	0.37
Total value (US $)	0.38	0.85
Return on PREP-PAC	n.a	1.61
Return on land (US $ ha^{-1})	153	340.5

[1]not applicable

Results

Grain yield: Maize grain yields were lowest in unfertilised treatments under the two pH regimes with an overall mean of 0.65 t ha^{-1}. PREP-PAC application increased maize yield to 1.6 t ha^{-1} (Fig. 1). The highest maize yield was at soil pH>5.3 with a mean value of 1.7 t ha^{-1}. There was almost total crop failure for unfertilised tepary bean at soil pH<5.2, yielding only 0.03 t ha^{-1}. PREP-PAC application at soil pH<5.2 improved tepary bean yield to 0.15 t ha^{-1}. Maize intercropped with tepary bean and treated with PREP-PAC at soil pH<5.2 yielded 1.5 t ha^{-1} compared with 1.2 t ha^{-1} without PREP-PAC application. Maize intercropped with tepary bean with PREP-PAC at pH>5.3 yielded 0.8 t ha^{-1} compared with 0.5 t ha^{-1} without PREP-PAC application. ANOVA of total crop values revealed significant effects of location (P=0.01), RP addition (P<0.001), inoculation with rhizobia (P=0.01) and urea application (P= 0.04). Interactions were observed between RP addition x urea (P=0.03) and with site x legume inoculation (P=0.03). Legume inoculation greatly improved the proportion of crop value derived from tepary bean (P=0.03), particularly in conjunction with RP addition at Makueni (Table 4). Both partial economic analysis and ANOVA suggest that components of PREP-PAC are strategically and synergistically combined.

Table 4. The costs and economic returns to PREP-PAC and its components at tests in two contrasting soils in semi-arid Eastern Kenya.

Input	Costs per unit (US $)	Makueni Acrisol Return (US $)	TB:Ma ($:$)	Machakos Ferralsol Return (US $)	TB:M ($:$)
Seed alone (S)	0.16	0.70	0.12	0.69	0.16
S + R3254 (I)	0.20	0.58	0.22	0.20	0.18
S + Urea (U)	0.24	0.55	0.32	0.84	0.13
S + I + U	0.28	0.50	0.33	0.98	0.12
S + RP (P)	0.40	0.10	0.12	1.15	0.12
S + I + P	0.50	1.40	0.43	1.80	0.28
S + U + P	0.55	1.16	0.36	1.60	0.14
PREP-PAC	0.60	1.48	0.49	2.08	0.14
$LSD_{0.05}$	n.a[b]	0.48[c]	0.26	0.52	0.24

[a]TB:M is the ratio of tepary bean to maize crop values [b]Not applicable as the parameter lacks variance
[c]Comparison applies between field sites

Gross field benefits: The gross field benefits for PREP-PAC use was determined for the 25 m^2 experimental plots (Fig. 2). Gross field benefit for PREP-PAC use was maximum at soil pH>5.3 amounting to $0.85, resulting in net benefits of $0.33. Gross field benefits from low pH soils (<5.2) were $0.31 for the control and $0.59 for PREP-PAC. In moderate soil pH (>5.3), gross field benefit was $0.39 for control and $0.85 for PREP-PAC (P<0.05).

Returns on investment: Use of PREP-PAC in soil pH<5.2 increased financial return on land from $109 to $224, with a return ratio to PREP-PAC of 1.27 (Table 3), thus for every dollar spend on PREP-PAC the farmer received the dollar invested plus 0.27 dollars. In moderate pH soils (>5.3), PREP-PAC use increased financial returns on land from $155 to $340.5 with a return ratio to PREP-PAC of $1.61.

Discussion

The benefit of PREP-PAC application is highlighted by the dramatic response of maize and tepary bean yield despite their low yield potential in acid soils. Economic analysis of both treatments showed that, despite extra costs associated with PREP-PAC use, there was financial gain resulting from PREP-PAC in both soil pH regimes. Out of the 50 farms studies, 28 of them had moderate soil pH (>5.3), therefore PREP-PAC substantially improved yields on 54% of the fertility depleted soils. Gross field benefits differed markedly between low and moderate soil pH with PREP-PAC application. A factor other than P and N apparently limited maize and tepary bean yield response to PREP-PAC at soil pH<5.2. At pH<5.2, phosphate ions coming from rock phosphate dissolution are removed from the soil solution and sorbed by Fe and Al oxides and hydroxides [3]. These sorbed phosphate ions are unavailable to plants in the short term, and this may explain the lower response to PREP-PAC observed at low soil pH. However, the sorbed phosphate ions are slowly desorbed and released to the soil solution during a period of several years [3]. At soil pH 5.2 and below, Al is fairly soluble thereby causing aluminium toxicity to crops. Aluminium

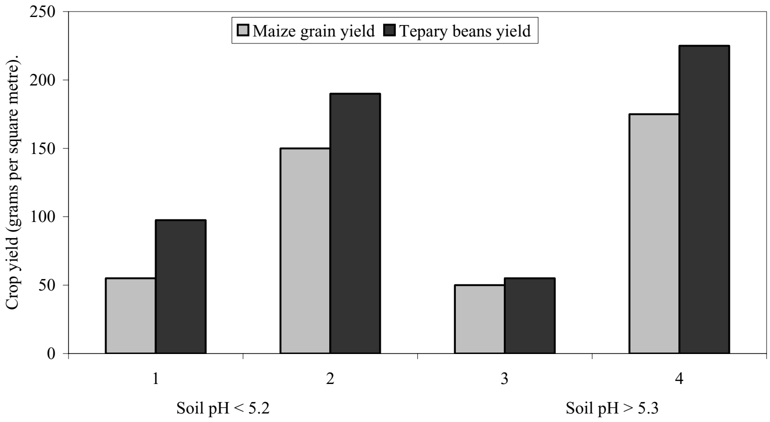

Figure 1. Crop yield (grams per square metre) with and without PREP-PAC under low and moderate soil pH.

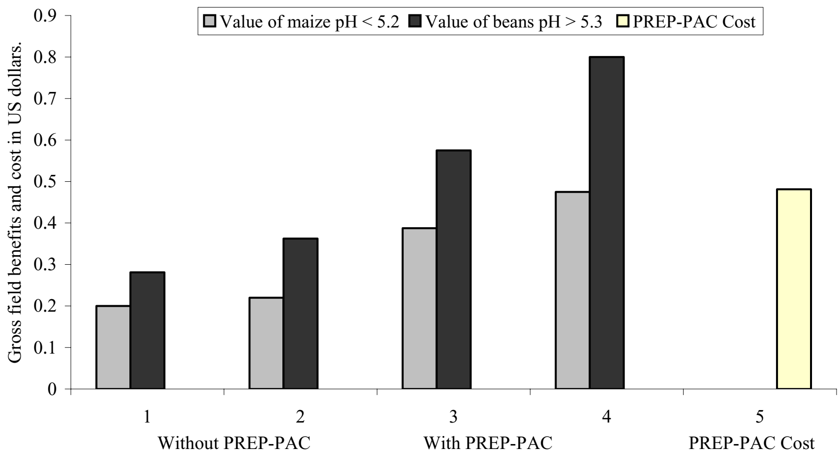

Figure 2. Gross field benefits and cost at low and moderate soil pH with and without PREP-PAC.

toxicity reduces PREP-PACs's effectiveness at low pH implying that PREP-PAC does not have a strong liming effect that can reduce aluminium toxicity in the first season. Low tepary bean yield (25 kg ha^{-1}) in acid soils pH (<5.2) may be related to the importance of soil fertility in pest and disease management. Nderitu et al. [28] noted that bean stem maggot and bean root rot are greater constraints to bean production in low soil fertility. Nutrient application enhances tolerance of beans to bean stem maggot and bean rot because a bean crop supplied with nutrients grows vigorously and is able to tolerate bean stem maggot and bean root rot attack [29]. Therefore, PREP-PAC application may offer an opportunity to address two important biotic constraints to bean production in fertility-depleted soils.

Conclusions

It is important to note that PREP-PAC is primarily intended as a nutrient replenishment mechanism [3, 15] through market distribution [10]. Evidence collected from on-farm experiments suggests that the economic returns realised during the season where PREP-PAC was applied was significant but not spectacular. However, the phosphorus applied through PREP-PAC is sufficient to replace 10 to 30 years of nutrient loss [3] and returns during following cropping seasons are anticipated. Further study of the residual P benefits from applying PREP-PAC are also required as the product is intended for mid- to long-term replenishment but has been valued over a single cropping cycle. In addition, residual benefits of different nitrogen-fixing legumes under maize intercropping requires further examination and those findings must be integrated with farmers' impressions to further refine the legume component of PREP-PAC. 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.

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