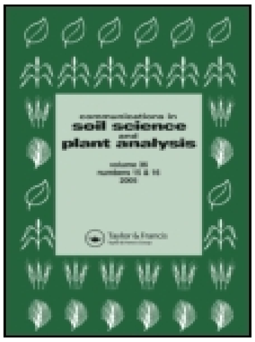

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Communications in Soil Science and Plant Analysis

ISSN: 0010-3624 (Print) 1532-2416 (Online) Journal homepage: https://www.tandfonline.com/loi/lcss20

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Communications in Soil Science and Plant Analysis, 42:2526–2536, 2011

ISSN: 0010-3624 print / 1532-2416 online
DOI: 10.1080/00103624.2011.609260

Effect of Prep-Pac Application on Soil Properties, Maize, and Legume Yields in a Ferralsol of Western Kenya

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High rates of soil depletion, food insecurity, and poverty are widespread in western Kenya, which calls for urgent and affordable solutions. A field experiment was carried out during 2003 short rains and 2004 long rains in western Kenya to study the effectiveness of "PREP-PAC" on soil properties, maize (Zea mays L.), and legume yields of six maize–legume intercrops. The experiment was conducted in a randomized complete block design, with four replications and two levels of fertility (no fertilizer and PREP-PAC). The maize variety, cv 'KSTP' (94), was intercropped with six legume types, namely: Bambaranuts (Vigna subterranean L., Var. Dark brown), Soybean (Glycine max L., Var. TGX 14482E), Yellow grams (Vigna radiate L., local type), Groundnuts (Arachis hypogaea L., Var. Uganda red stripped), Beans (Phaseolus vulgaris L., Var. KK15), and Cowpeas (Vigna unguiculata L., Var. white type). The farm was characterized by low pH of 5.35, low soil available phosphorus (P) below the critical value of 10 mg P/kg, and generally low exchangeable cations. Results indicated a significant ($P < 0.05$) increase in soil pH, soil available P ($P < 0.0001$), maize and legume yields ($P < 0.0001$) throughout the cropping seasons. Intercrops with bambaranuts, beans, and groundnuts produced better legume yields compared to the rest of the legumes. Therefore, the authors of this study concluded that, PREP-PAC is effective with elevated N input (60 kg N ha^{-1}) on restoring soil fertility and improving farm productivity in western Kenya. However, availability and accessibility of PREP-PAC in local markets needs to be improved.

Keywords Maize and legume yields, PREP-PAC, soil available P

Received 29 May 2009; accepted 15 May 2011.
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Introduction

Population increases in Sub-Saharan Africa have put a lot of pressure on natural resources leading to conflicts, land fragmentation, food insecurity, and poverty. Western Kenya population densities ranges from 500 to 1200 persons per km^2 (Hoekstra & Corbett, 1995) with reduced farm sizes to below 0.2 ha/household (Swinkels et al., 1997).

Farmers in this region earn less than $1.00 per day (Obura et al., 2001); thereby use of inorganic fertilizers is generally low, below 20 kg nitrogen (N) and 10 kg phosphorus (P) ha^{-1} (Muriithi et al., 1994) and continuous cultivation of farm lands (Okalebo, 2000). The results are high rates of soil nutrient depletion and crop yield reduction. For example, Woomer, Okalebo, & Sanchez (1997) reported phosphorus losses of 3–13 kg ha^{-1} yr^{-1}. Similarly, corn and soybean average yields remained less than 1.0 t ha^{-1} and about 200–500 kg ha^{-1}, respectively over a decade (Sanchez et al., 1997).

Western Kenya soils are generally characterized as Ferralsols (Oxisols) FAO classification, which are acidic in nature (Kanyanjua et al., 2002). Phosphate rocks (PRs) are insoluble in water but sparingly soluble in citric acid; the solubility depending on the nature of the deposit. Phosphate rock is therefore a suitable direct source of P in soils of low pH, low exchangeable calcium, and low available P (Asea, Kucey, & Steward, 1988). Many deposits of phosphate rock (PR) with varying agronomic value occur in east and southern Africa and estimated reserves of PR for the three East African countries (Table 1) indicates a treasure that can still be used to replenish P depleted soils at a low cost for generations (van Keuwebergh, 1991). Maize–legume conventional cropping system is a common practice in western Kenya (Obura et al., 2001).However, the majority of legumes are shade intolerant and do not do well under this system; hence reducing the food legumes preferences in this region.

Studies on "MBILI" intercropping system (Managing Beneficial Interactions in Legume Intercrops) have indicated a great potential of this spatial arrangement to improve both maize and legume yields (Tungani, Eusebius, & Woomer, 2002; Thuita, 2007). The MBILI intercropping system entails planting a staggered two rows of maize alternated with two rows of a suitable legume, allowing for maximum light penetration and reduced competition for nutrients and water between maize and legumes (Tungani, Eusebius, & Woomer, 2002). Therefore, in view of these facts MBILI intercropping system was adopted by the authors of this study in combination with a nutrient replenishment package, called "PREP-PAC" (Phosphate Rock Evaluation Project Package) developed by Moi University in 1997, in the quest to evaluate PREP-PAC potential to increase crop yields and ameliorated depleted N and P nutrients in western Kenya.

Table 1
Estimated resources of important phosphates rocks (PRs) in East Africa

Country	Name of the deposit	Type of PR	Reactivity	Estimated reserves (10^6 tonnes)	Total P content (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

Source: Sanchez et al., 1997; van Keuwebergh, 1991.

The PREP-PAC package consists of 2 kg (100 kg P ha^{-1}) Minjingu phosphate rock (MPR-source of P), 0.2 kg Urea (40 kg N ha^{-1}), 125 g food grain legume seed (biological N-fixation component), the legume seed inoculant (*Rhizobium*), gum Arabic adhesive, and lime for pelleting (to make the soil reaction favorable for the growth of *Rhizobia*); along with instructions in English, Kiswahili, and a few other local languages. The supplied N in the package is the starter N for the biological N fixing legumes. This package costs $0.54 (40 Kenya shillings) (Obura et al., 2001), which is affordable compared to buying the rather expensive inorganic fertilizers (Smaling, 1993). PREP-PAC replenishes the fertility of soils in low fertility patches of 25 m^2 (Nekesa et al., 1999).

The effectiveness of PREP-PAC to increase crop yields and improve N and P nutrients under different maize–legume intercrops is yet to be explored. This could provide a solution to N and P nutrients depletion widely affecting food production in western Kenya. To be able to establish its potential, this study was initiated to:

i. Assess the effect of PREP-PAC on soil pH and available P in western Kenya soils;
ii. Assess the effect of PREP-PAC application on maize and legume grain yields; and
iii. To identify the best maize–legume combination for increasing crop yields per unit area basis.

Materials and Methods

Site Description

The study was conducted in the Nyabeda area, Siaya District in western Kenya. Siaya district lies between 0° 26’ south to 0° 18’ north latitude, and 31° 51’ east to 34° 31’ west longitude. The altitude is between 1140–1400 m above the sea level. The area receives a bimodal rain distribution pattern with long rains (LR), March–June and short rains (SR), August–December. The average annual rainfall ranges between 800–2000 mm, with temperature of about 27–30 C, and annual minimum temperature ranging from 15–17 C (Jaetzold & Schmidt, 1983). The predominant soil types according to FAO/UNESCO classification in the district are orthic Ferralsols (Oxisols), dystric Nitisols (Alfisols), and Acrisols (Ultisols) (Republic of Kenya, 1994), which are generally acidic and depleted of important plant nutrients.

Experimental Design and Management

The experimental design was a randomized complete block with four replications and the plot size was 4.5 m by 4.0 m. Treatments were factorial combinations of two levels of fertility (no fertilizer and PREP-PAC) and six levels of maize–legume intercropping systems. The maize variety, cv ‘KSTP-94’ (KARI Kakamega) was intercropped with six legume types, namely: Bambaranuts (Var. Dark brown), Soybean (Var. TGX 14482E), Yellow grams (local type), Groundnuts (Var. Uganda red stripped), Beans (Var. KK15), and Cowpeas (Var. white type). All legumes in the PREP-PAC package were inoculated with specific rhizobial (biofix) strains.

In 2004 SR, full PREP-PAC addition (100 kg P ha^{-1} +40 kg N ha^{-1}) was made through broadcasting fertilizer components evenly to marked plots. During this period, no addition of N was applied as a top dress. This led to yellowing of some plants in PREP-PAC plots, suggesting a possible N deficiency (Barber, 1984), hence the N rate in the PREP-PAC package was increased to 60 kg N ha^{-1} in 2004 LR, applied in two equal splits of 30 kg N ha^{-1} at planting, and as top dress at the vegetative stage, close to the Fertilizer Use

Recommendations Project (FURP) rate of 75 kg N ha^{-1} (KARI, 1994). The experiment was weeded two times per season and pests and diseases were controlled by application of Ridomil Gold® (Syngenta group company, USA) and Dudutrin 5EC (Twiga chemicals company, Kenya).

At maturity, maize was harvested from 11.5 m^2 area and weighed. The maize cobs and stover were separated, weighed, and sample maize cobs were taken for sun drying to 13% moisture content. The maize cobs were shelled to obtain the grains and weighed to determine the total grain weight in kg ha^{-1}. Likewise, cowpeas, beans, yellow grams and soybeans were uprooted from 10.85 m^2 area and total grain and trash weights taken. The pods were then separated from trash, weighed, and samples from trash and grain were sun dried. Following the drying, weights of samples of legume and trash were taken to determine the total grain and trash weight. The bambaranut and groundnut legumes were carefully dug out using a hoe from plot area of 10.85 m^2 for each treatment. The pods were separated from total biomass by hand and pod fresh weight was recorded. Sample pods of 200 g per plot were sun dried and shelled to determine the total grain in kg ha^{-1}.

Soil Sampling, Laboratory, and Statistical Analysis

Soil sampling was done before the application of treatments for site characterization and at the end of every season (at harvest) to monitor the changes in soil chemical properties as affected by the treatments and their residual effects. Soil samples from all plots were taken at random, using a soil auger from 12 points per plot and mixed well to get a composite soil sample across each plot. Soil samples were analyzed for soil pH, organic carbon, total N, and available P according to standard procedures outlined in Okalebo, Gathua, and Woomer (2002). Plant tissues were also analyzed for total P using procedures in Okalebo, Gathua, and Woomer (2002).

The results were statistically analyzed using the General Linear Models (GLM) procedure of SAS version 9.1 (SAS Institute, 2003) to determine treatment effects on yields, soil pH, and available soil P. The results for each season were analyzed individually and means separated using Fishers protected Least Significant Difference (LSD).

Results and Discussion

Chemical and Physical Characteristics of Soil in the Study Site

Some characteristics of the plough depth soils in the study area are presented in Table 2. The soils in this study area were acidic, with a soil pH of 5.35, as classified by KARI's National Agricultural Research Laboratories (NARL), in Nairobi (Kanyanjua et al., 2002). This suggests that, MPR could undergo considerable dissolution as reported by Gahoonia and Nisden, (1992) that PR dissolution is enhanced in soils with pH < 5.5. In acid soils, P is fixed by oxides or sequioxides of aluminum (Al), iron (Fe), and manganese (Mn), hence making it unavailable to the growing plants. It is in this soil acidity condition that basic cations in the soil are less readily available, as reflected in the low to medium amounts of exchangeable bases given in (Table 2) which contributes to reduced crop yields in western Kenya. Soil available P was 1.12 mg P kg^{-1}, far below the critical level of 10 mg P ha^{-1} (Okalebo, Gathua & Woomer, 2002) suggesting need for supplemental P addition for increased crop yields (Ndung'u et al., 2006). Crop responses to P are dependent on suitable soil pH for maximum availability to crops (Tisdale, Nelson, & Beaton, 1990). The soils of Nyabeda would therefore respond to P and Lime applications, the main components in MPR.

Table 2
Chemical characterization of surface (0–15 cm) soils, at study sites in Nyabeda, Siaya District, before treatment application

Soil parameters	Measured values
pH (1:1 soil:H_2O paste)	5.35
Soil available P (mg P kg $^{-1}$ soil)	1.12
% Nitrogen	0.27
% Carbon	1.84
Exchangeable cations (c mol kg $^{-1}$)	
Potassium (K^+)	0.55
Magnesium (Mg^{++})	2.13
Calcium (Ca^{++})	2.26
Sodium (Na^+)	4.25
Soil Physical properties	
Clay (%)	24
Sand (%)	49
Silt (%)	27
Soil class	Sandy clay loam

Changes in Soil Phosphorus Properties during Growth of Maize–Legume Intercrops Due to PREP-PAC Application in Siaya District, Kenya

Soil pH. The magnitudes and patterns of changes in soil (in 0–15 cm depth) pH due to PREP-PAC application in 2003 SR and 2004 LR cropping seasons are presented in Table 3 and Figure 1. The PREP-PAC fertilizer application significantly ($P < 0.05$) contributed to soil pH increase throughout the two cropping seasons. However, the six intercrop types and interaction between intercrops and fertilizer did not significantly ($P < 0.05$) affect the soil pH changes observed. Throughout cropping season, plots with PREP-PAC had high soil pH compared to that in control plots (Figure 1). These results clearly indicated the potential of PREP-PAC to ameliorate soil acidity through its liming capacity as the

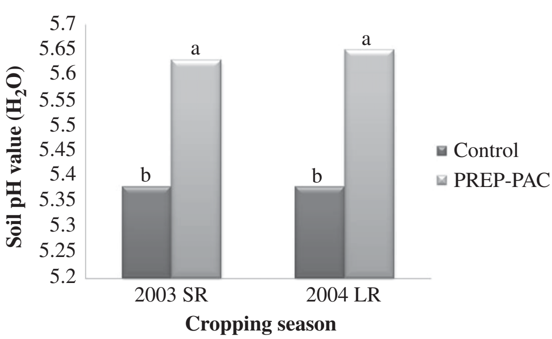

Figure 1. Effect of PREP-PAC on the overall mean of soil pH obtained from a PREP-PAC experiment involving six maize-legume intercrops during 2003 SR and 2004 LR cropping seasons in Siaya district, western Kenya. *Within season, bars followed by the same letter are not different at $P < 0.001$ using Fishers protected LSD. Note: SR= Short rains and LR = Long rains.*

Table 3
Soil pH and available P values as influenced by six maize-legume intercrops during 2003 SR and 2004 LR cropping seasons in Siaya District, Kenya

	2003 SR		2004 LR	
Intercrop	Soil pH (H_2O)	Soil available P (mg P kg^{-1} of soil)	Soil pH (H_2O)	Soil available P (mg P kg^{-1} of soil)
Bambaranuts	5.46a[z]	2.88ab	5.46a	4.31c
Beans	5.58a	2.77ab	5.51a	5.10ab
Soybean	5.48a	2.85ab	5.41a	5.86a
Yellow grams	5.55a	2.96a	5.58a	5.97a
Cowpeas	5.51a	2.79ab	5.64a	5.20ab
Groundnuts	5.45a	2.36b	5.50a	3.40c
SED*	0.15	0.30	0.13	0.75

[z]Means followed by the same letter in a column are not different at $P < 0.05$ using Fishers protected LSD. *SED-Standard error at the difference of two equally replicated means.
Note. SR = Short rains and LR = Long rains.

season progressed. The increase in soil pH due to PREP-PAC addition is explained by the increased MPR dissolution due to low pH of soil in the study area (Table 2). This led to availability of calcium (CaO), which dissociates from the apatite rock during the solubilization process thereby replacing the Al^{3+} and Fe^{3+} ions on the exchange sites; hence increased soil pH (Okalebo et al., 1999). Phosphate rock is sparingly soluble in water and therefore, its complete breakdown toward the release of its components takes long (Sikora & Giordano, 1993), again explaining the slow but steady increase in soil pH due to addition of PREP-PAC. These results concurred with earlier findings by other scientists (Sikora & Giordano, 1993; Okalebo et al., 1999; Nekesa, 2007) who reported that MPR was effective for raising soil pH of an acidic soil.

Soil Available P. The results indicated a significant ($P < 0.0001$) increase in soil available P due to PREP-PAC fertilizer application in both cropping seasons (Table 3 and Figure 2).

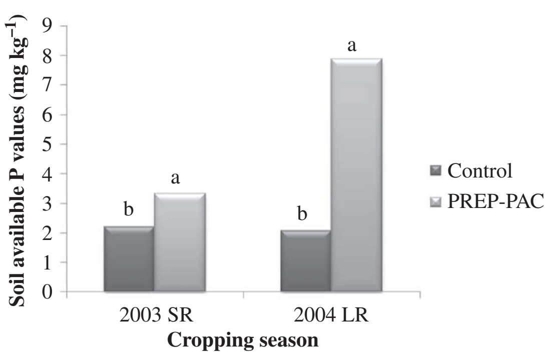

Figure 2. Effect of PREP-PAC on the overall mean of soil available P obtained from PREP-PAC experiment involving six maize-legumes intercrops during 2003 SR and 2004 LR cropping seasons in Siaya district, western Kenya. *Within season, bars followed by the same letter are not different at $P < 0.001$ using Fishers protected LSD. Note: SR= Short rains and LR = Long rains.*

There was a tremendous increase of soil available P due to PREP-PAC addition throughout the cropping season. The results obtained were attributed to positive responses of the soil to added P in the form of MPR, which past studies have found to be observed in acidic soils, thereby resulting in an increase in available soil P. The overall increase in the soil available P confirmed the fact that the reactive MPR component in PREP-PAC has the ability to add readily available P to the soil, a finding that was reported earlier by Mnkeni, Semoka, and Buganga (1991) in Tanzania. The soil available P declined in the control plots throughout the cropping seasons (Figure 2), was in agreement with past findings obtained by Smaling (1993), and Woomer et al. (1998), that continuous cropping without any addition of nutrient input leads to decline of soil fertility.

Changes in maize–legume intercrops grain yields due to PREP-PAC application, in Siaya District, Kenya

Maize Grain Yield. The application of PREP-PAC to the six maize–legume intercrops gave a significant ($P < 0.0001$) increase in maize grain yields during 2003 SR and 2004 LR cropping seasons. However, the maize grain yields among intercrop types did not significantly vary among themselves (Table 4). Generally, average maize grain yields as high as 929 kg ha^{-1} (maize–Bambara nuts intercrop) in 2003 SR to 2229 kg ha^{-1} (maize–Groundnuts intercrop) in 2004 LR were recorded in the plots that received PREP-PAC. The maize–grain yields from control plots were generally low throughout the cropping season (Table 5). In general, the authors of this study found that the addition of both N and P in the PREP-PAC as MRP and urea improved maize–grain yields over the check, which agrees with findings obtained by Obura et al. (2001) and Nekesa et al. (1999). The liming potential of MPR in PREP-PAC also probably reduced P fixation (through soil pH rises), thus the recorded maize–grain yields increase. The maize–grain yields obtained due to PREP-PAC application were far above the farmers' grain yield levels of 0.5 t ha^{-1}, an indication that PREP-PAC is effective to improve land productivity.

Table 4
Response of legumes and maize yields to six maize-legume intercrops during 2003 SR and 2004 LR cropping seasons in Siaya District, Kenya

	Grain yields (kg ha^{-1})			
	2003 SR		2004 LR	
Intercrop	Legume	Maize	Legume	Maize
Bambaranuts	436a[z]	929a	325b	1975a
Beans	547a	807a	516a	2088a
Soybean	180b	848a	219c	1955a
Yellow grams	184b	827a	229c	1889a
Cowpeas	247b	789a	na	2459a
Groundnuts	469a	580a	488a	2229a
SED*	77.31	166.47	69.94	301.85

[z]Means followed by the same letter in column are not different at $P < 0.05$ using Fishers protected LSD. *SED-Standard error at the difference of two equally replicated means.

Note. SR= Short rains and LR = Long rains.

na = data not available.

Table 5
Response of legumes and maize grain yields to a control and PREP-PAC treatment averaged over six maize-legume intercrops during 2003 SR and 2004 LR cropping seasons in Siaya District, Kenya

	Grain yields (kg ha^{-1})			
	2003 SR		2004 LR	
Treatment	Legume	Maize	Legume	Maize
Control	279b[z]	414b	262b	1028b
PREP-PAC	409a	1179a	449a	3171a
SED*	44	96	44	191

[z]Means followed by the same letter in column are not different at P < 0.05 using Fishers protected LSD. *SED-Standard error at the difference of two equally replicated means.

Legume Grain Yields. The results indicated that legume–grain yields for the six legume varieties were significant ($P < 0.0001$) from each other, an indication that they responded differently to the applied PREP-PAC package. However, overall average legume–grain yields in PREP-PAC plots were significantly ($P < 0.0001$) increased above the average farmers' legume–grain yields of < 200 kg ha^{-1} (Table 4). The resultant yields were attributed to added N and P nutrients to the already depleted soils of Nyabeda, through PREP-PAC application. Liming potential of MPR in PREP-PAC contributed to the increased soil pH, leading to release of previously fixed P due to acidic soil, hence available to the growing crops. In 2003 SR; bambaranuts, beans, and ground nuts produced significantly higher yields than soybeans, yellow grams, and cowpeas (Table 4). A similar trend was also observed in 2004 LR, where beans and groundnuts stayed at the top as best performing legumes with average grain yield of 547 kg ha^{-1} and 488 kg ha^{-1}, respectively, while bambaranuts dropped slightly to 325 kg ha^{-1} (Table 4). This demonstrates that groundnuts can perform well as an intercrop if MBILI intercropping system with PREP-PAC is employed. Studies elsewhere have shown that moisture requirement is critical just prior to and during flowering for cowpeas (Holland, Unwin, & Buss, 1991) and yellow grams (Stephens, 1976). Therefore, the low and poorly distributed rainfall patterns (Rutto, 2007) in the study area—especially in 2003 SR—could have led to this response and this may change if adequate rainfall is available. Soybean is a poor performer as an intercrop due to its intolerance to the shading effect of maize (Tungani, Eusebius, & Woomer, 2002). Although this study used the MBILI intercropping system with wider raw spacing and increased light penetration, soybean did not prove to be a suitable maize–legume intercrop.

Conclusions

The chemical analysis of soil samples from the Nyabeda area before nutrient application confirmed that soils in the area are acidic and depleted in N and P nutrients. This explains the low grain yields harvested by farmers from this region year after year as a result of practicing continuous cultivation. PREP-PAC application positively improved the soil pH and available P status of Nyabeda soils, thereby confirming that PREP-PAC has a liming potential, as well as ability to add N and P to depleted soils. Apart from urea in the package, the legumes are also believed to have added N into the soil through biological N fixation as indicated by pink color in the root nodules from PREP-PAC treated legumes (Giller, 1999). There is however a need to raise the N input in the PREP-PAC to 60 kg N ha^{-1} (applied in equal 30 kg N ha^{-1} splits) and applied seasonally. Intercrops with bambaranuts, beans, and groundnuts produced better yields than those with soybeans, yellow grams, and cowpeas; an indication that intercropping these legumes with PREP-PAC application could widen legumes food preferences in this area. To enable farmers to use this soil fertility amelioration product, availability and accessibility of PREP-PAC in local markets needs to be improved through collaboration of the research institutions, the government, non-governmental organizations (NGOs), farmers, and business men.

Acknowledgements

The authors would like to thank TSBF-CIAT and Dr. Martin Wood from the University of Reading U.K. for financing this research project. We also appreciate the support of TSBF-CIAT Maseno staff, Nyabeda farmers, and Moi university laboratory technicians, for helping in laboratory analysis.

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