Effect of Combining Organic and Inorganic Phosphorus Sources on Maize Grain Yield in a *humic*-Nitisol in Western Kenya

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Abstract

The western Kenya soils are typically low in fertility due to continuous cropping with inadequate fertilizer use. A three-year experiment was conducted to investigate the effect of combining organic and inorganic Phosphorus (P) sources on maize grain yield in a P deficient (2ppm) experimental site at the Regional Research Centre, Kakamega, western Kenya. The design was a Randomized Complete Block, replicated three times. Farmyard manure (FYM) and Triple Super Phosphate (TSP) were combined at the ratios: 0:100, 25:75, 50:50, 75:25, and 100:0 to attain 30 kg P ha^{-1} and applied at planting to all plots except the control plot which received no P. To prevent Nitrogen (N) and Potassium (K) deficiencies confounding P responses, N was toped up to 100 kg N ha^{-1} and K to 120 kg K ha^{-1} in all plots. Urea N was top-dressed in equal splits at 3 and 6 weeks after maize emerged, while K (KCl) was applied at planting. Maize grain yield was determined at 13% moisture content and plotted against organic-inorganic P treatments to determine the response pattern. Non-linear regression analysis was then performed to estimate the effects of organic and inorganic P. Grain yield was significantly higher (p=0.05) with P than without and sole organic P was comparable to sole inorganic P. Grain yield responses best fitted quadratic functions and the regression coefficients estimating organic P, inorganic P and the interaction were significant (p=0.05), indicating real FYM and TSP effects and synergy between them. The results demonstrated grain yield benefits of integrating organic and inorganic P sources.

Introduction

The western Kenya region, supporting between 500 and 1200 inhabitants per km^2 (Hoekstra and Corbett, 1995) is one of the most populated rural regions of the world. However, the region is endowed with good agricultural climate and has the potential to produce sufficient food to meet the demand by the population. Despite the high agricultural potential, food production is low. Farming is mainly subsistence, with smallholder farmers growing two crops per year, with little or no fertilizer inputs. This practice has, over the years, resulted in the depletion of native soil fertility and a decline in productivity. A survey in western Kenya (Onim *et al.*, 1986) reported P deficiency in over 90% of the smallholder farms surveyed.

P inputs in smallholder fields consist primarily of inorganic fertilizers and organic sources such as biomass, animal manure, compost and crop residues. However, low quality organic materials such as maize stover, may not supply sufficient amounts of plant-available P (Palm *et al.*, 1997). While inorganic fertilizers can restore the fertility of soils and improve crop yields, their use in the East African highlands is limited (Hoekstra and Corbett, 1995) and alternative strategies for supplying P to the P-deficient smallholder systems are necessary. Studies in western Kenya indicate that the incorporation of higher quality organic manures, like *Tithonia diversifolia* and *Lantana camara,* along with TSP, increases the effectiveness of fertilizer phosphorus (Gachengo, 1996; Nziguheba *et al.*, 1998). Such integration of organic and inorganic resources would have agronomic advantage, if the organic material enhances the availability of added P (Palm *et al.*, 1997).

The processes responsible for better response from the integration of organic and inorganic P sources are not yet clearly established, mainly because of the complex nature of P dynamics in the soil. However, there are suggestions that the interactions resulting from this integration reduces P-sorption capacity of the soil (Palm *et al.*, 1997), thereby increasing P availability to plants. Other benefits include immobilization of excess nutrients that would otherwise be lost through leaching and positive physical effects associated with improved soil structure. Addition of organic residues also enhances microbial pool sizes activity (Smith *et al.*, 1993). These chemical and biological processes influence both availability and utilization of nutrients.

The objectives of this experiment were:

1) To investigate the effect of combining organic and inorganic P sources on maize grain yield
2) To determine the optimum ratio for combining organic and inorganic P, and
3) To assess the synergy resulting from integrated use of organic and inorganic P sources.

Materials and Methods

The experiment was conducted at Kakamega, western Kenya, during the long rain seasons (March to August) of 1997, 1998 and 1999. The experimental site was within the Kenya Agricultural Research Institute's Regional Research Centre, located 00° 16' N (latitude) and 34° 45' E (longitude). The altitude is 1585 m above sea level, mean annual temperature is 18-20°C, the average annual rainfall is 2012 mm and the soil is classified as d*ystro-mollic* Nitisol (Jaetzold and Schmidt, 1983). Characterization previously conducted at the experimental site (FURP, 1987) indicated the soil is well drained, extremely deep, with a thick *humic* top layer. The top soil reaction is in the strong to moderately acid range (pH 4.5) and exchangeable Al is low, while organic matter is high in the top soil (2.4%).

The experimental design was a Randomized Complete Block with three replicates. Plots were 4.5 by 5.0 m (22.5 m^2), in which 6 rows of maize were planted with a row spacing of 75 cm. Five P treatments were evaluated alongside a control that received no P. In each treated plot, P was applied at the rate of 30 kg P ha^{-1} by combining FYM and TSP in different ratios as follows:

1. 30 kg P ha^{-1} (100% inorganic P)
2. 30 kg P ha^{-1} (100% organic P)
3. 15 kg P ha^{-1} (50% inorganic P) + 15 kg P ha^{-1} (50% organic P)
4. 7.5 kg P ha^{-1} (25% inorganic P) + 22.5 kg P ha^{-1} (75% organic P)
5. 22.5 kg P ha^{-1} (75% inorganic P) + 7.5 kg P ha^{-1} (25% organic P)
6. Control (no P)

A sample of the FYM was analyzed each planting season to determine the P content, which was then used to compute the amount of the material to add to the respective plots. Since FYM also supplied up to 73 kg N ha^{-1} and 120 kg K ha^{-1} to the organic P treated plots, urea and muriate of potash (KCl) were applied to all plots, including the control, to balance N and K at 100 kg N ha^{-1} and 120 kg K ha^{-1}, respectively. Apart from correcting the N and K imbalances, the high rates were intended to prevent N and K deficiencies, which could confound P responses. Urea was applied as top-dress in two equal splits. The first split was applied at 21 days after emergence and the second one 42 days after emergence. KCl was broadcast applied at planting. Soil was sampled in all plots (0-15cm depth) for P determination prior to application of treatments. The plots were maintained throughout the trial duration.

Maize grain yield was determined at harvest. Yield was adjusted to 13% moisture content and grain yield data plotted against treatments to determine the P response pattern. To fit the curves, treatments were arranged in order of increasing proportion of inorganic P (decreasing proportion of organic P). Both linear and quadratic functions were fitted in turn, to determine the best-fit model, based on the correlation coefficient (R^2) value. The model with the highest R^2 value was selected as the best function describing grain yield response pattern. Grain yield data was then subjected to the Analysis of Variance (ANOVA). A non-linear regression model: ($Yield=a+bX_1+gX_2+dX_1*X_2$) was fitted to the data to test the effects of inorganic P, organic P and the interaction between them, on maize grain yield. The regression coefficients in the model are described below:

a = intercept
b = coefficient estimating inorganic P (X_1) effect
g = coefficient estimating organic P (X_2) effect
d = coefficient estimating inorganic P and organic P interaction (X_1*X_2) effect.

The effects of organic P, inorganic P, and the interaction between them, were evaluated by testing the null hypothesis (H_O) that the coefficient estimates were equal to zero. This was done by t-tests.

Results and Discussion

Maize grain yield response to P

Significant (p=0.05) grain yield responses to both organic and inorganic P were observed in 1997, 1998 and 1999 (Table 24.1). The highest response was recorded in 1997 when application of P increased grain yield by 3.2 t ha^{-1} compared with 2.8 and 2.3 t ha^{-1} in 1998 and 1999, respectively. Generally, yield following sole addition of FYM was equivalent to those from sole inorganic P. The FYM used was of relatively high quality (Table 24.2). The difference in grain yield between sole inorganic P and organic P was highest in 1997 (0.8 t ha^{-1}) but the difference was not significant. In 1999, grain yield from sole organic P was slightly higher than that from sole inorganic P. Grain yield responses were more variable in 1999 due to poor rainfall distribution that year (Figure 24.1). Much of the rainfall in 1999 long rain season was received during the February to April period, the beginning of the season. Rainfall sharply declined between April and June before picking up in July, which was towards the end of the growing season.

Table 24.1: Effect of organic and inorganic P on maize grain yield at Kakamega Research Station, western Kenya, in 1997, 1998 and 1999

Treatment combination		Maize grain yield (kg ha^{-1})			
% Inorganic P	% Organic P	1997	1998	1999	Mean
100	0	6.22	5.38	2.84	4.81
75	25	6.25	3.83	2.92	4.33
50	50	6.67	4.34	4.38	5.13
25	75	5.75	5.13	4.35	5.07
0	100	5.39	3.12	2.97	3.82
0	0	3.45	2.57	2.05	2.69
LSD (0.05)		1.50	0.95	1.2	1.30
CV		18.2	15.6	24.8	20.2

Table 24.2: Nutrient and lignin content of the FYM used in the trial (%) in 1997, 1998 and 1999

Year	N	P	K	Lignin
1997	1.31	0.35	2.14	10.95
1998	1.45	0.37	2.16	10.05
1999	1.25	0.39	2.11	11.05
Mean	1.33	0.37	2.13	10.68

Combination of fertilizer P with FYM in different proportions did not result in significant grain yield differences in 1997 (Table 24.1). However, in 1998, the treatment combination receiving 25% inorganic P and 75% organic P (25:75) performed similar to the 50:50 treatment but significantly better than the 75:25. In 1999, the 50:50 combination performed significantly better than the 75:25.

The grain yield results were particularly significant in 1999 given that it was the driest of the three trial years. Grain yield sharply declined compared to the two previous years. However, significant and synergistic effects of combining FYM and P fertilizer were demonstrated by the highest yields obtained with the 50:0 and 25:75 combinations (Figure 24.2). The superior performance may have been due to added benefits of the organic material (FYM). Besides the direct benefits of nutrient supply, organic materials have effect on soil physical properties that in turn influence nutrient acquisition and plant growth (Palm *et al.*, 1997). Principal among these, is the soil moisture holding capacity. By influencing moisture storage and promoting root growth, FYM may have greatly improved the efficiency with which the available P was used during the drier 1999 season. Based on analysis of combined data over the three years, no significant differences were detected between the different organic and inorganic P combinations but the 50:50 treatment combination was significantly better than sole organic P treatment (0:100).

The results indicated that the optimal organic to inorganic P combination is close to the 50:50 ratio. Combining fertilizer P with FYM at this ratio is likely to be beneficial to smallhoder farmers, who have limited access to inorganic fertilizers and are typically unable to generate sufficient quantities of high quality organic materials for fertility improvement. Suggestions for integration of fertilizer P with available organic resources have been made in the past by Janssen (1993) and Palm *et al.* (1997).

Figure 24.1: Rainfall distribution at Kakamega Research Station in 1997 , 1998 and 1999 growing seasons

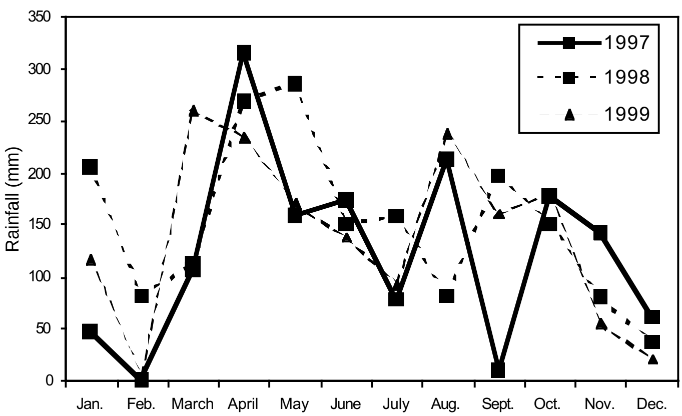
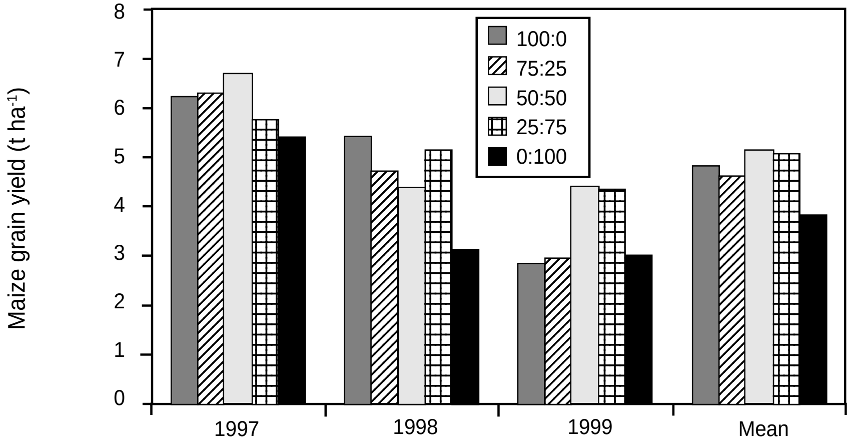


Figure 24.2: Performance of organic and inorganic P combinations across three growing seasons at Kakamega Research Center, western Kenya



Assessment of organic and inorganic P effects

The grain yield responses were best described by quadratic functions (Figures 24.3 - 24.6). The R^2 values for the functions were greater than 0.6 and were much higher than the values obtained when linear functions were fitted to the data. This indicated that the effects were largely quadratic in nature. The apparent non-linearity (curvature) in grain yield responses indicated some degree of interaction or synergistic effects between organic and inorganic P.

Figure 24.3: Mean effect of organic and inorganic P on maize grain yield (1997-1999)

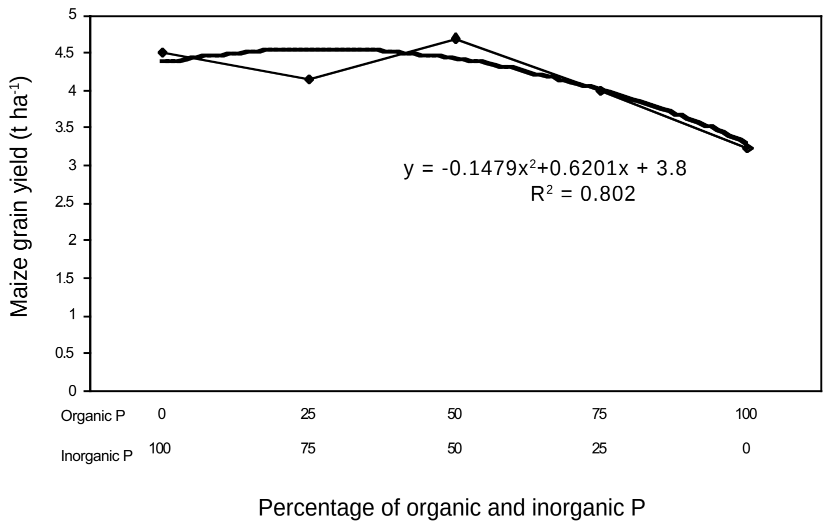


Figure 24.4: Effect of organic and inorganic P on maize grain yield in 1988

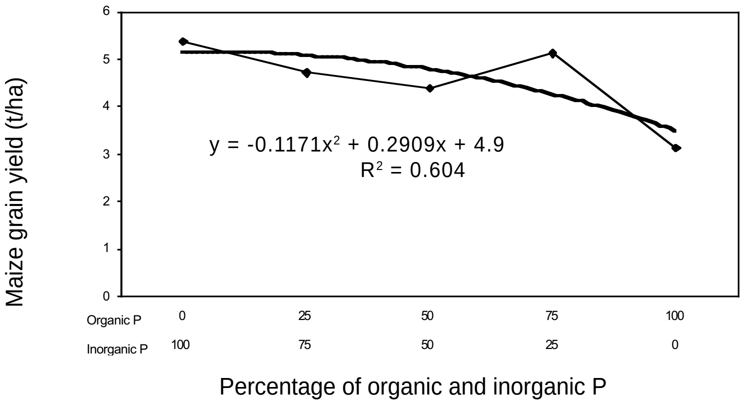


Figure 24.5: Effect of organic and inorganic P on maize grain yield in 1999

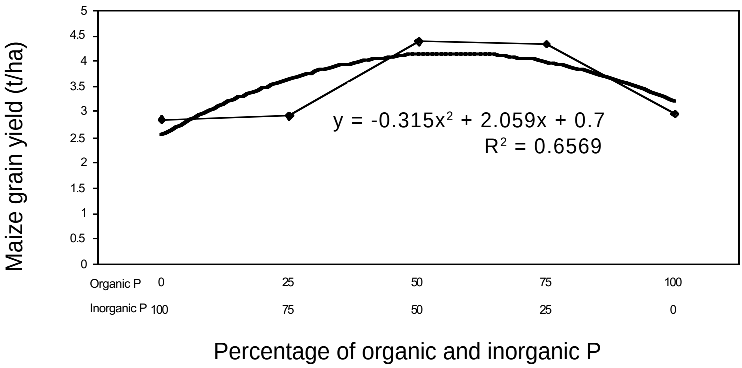
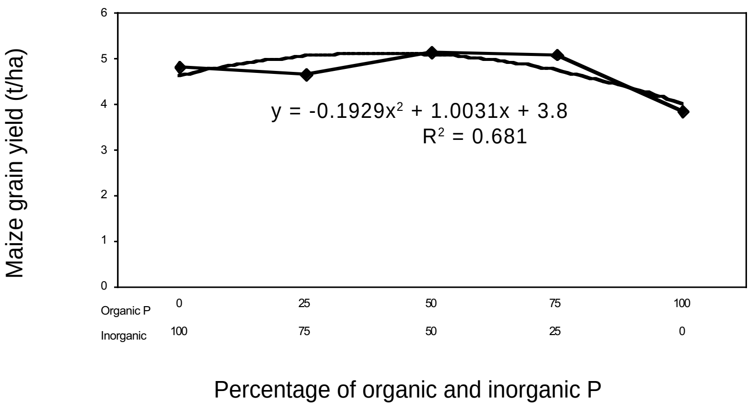


Figure 24.6: Mean effect of organic and inorganic P on maize grain yield



The curvature and the organic and inorganic P effects on maize grain yield were further tested by fitting a non-linear regression model: ($Yield=a+bX_1+gX_2+dX_1*X_2$) to the data. The regression coefficients estimating the effects of organic and inorganic P and the interaction between them are shown in Table 24.3. In 1997, both organic and inorganic P had significant effects on maize grain yield. These results were in agreement with those of the Analysis of Variance (Table 24.1). However, the inorganic P coefficient was larger than organic P, indicating that inorganic P had greater effect on grain yield. The coefficient for the interaction between organic and inorganic P was the lowest in value and the t-test was not significant. This suggested that there was no real

Table 24.3: Regression coefficients estimating the effects of organic P, inorganic P, and the interaction, on maize grain yield

		1997	
Parameter	Estimate	S.E	t value (for H_o)
a	3.444	0.586	5.878***
b	0.02742	0.00804	3.410**
g	0.01874	0.00804	2.330*
d	0.000241	0.000250	0.96 NS
		1998	
Parameter	Estimate	S.E	t value (for H_o)
a	2.565	0.497	5.160***
b	0.02353	0.00682	3.450**
g	0.01137	0.00682	1.667 NS
d	0.00061	0.000212	0.47 NS
		1999	
Parameter	Estimate	S.E	t value (for H_o)
a	2.048	0.454	4.511***
b	0.00475	0.00623	0.762 NS
g	0.01171	0.00623	1.879 NS
d	0.000499	0.000194	2.572*
		Mean	
Parameter	Estimate	S.E	t value (for H_o)
a	2.253	0.236	9.546***
b	0.01412	0.00324	4.358***
g	0.00997	0.00324	3.077**
d	0.000210	0.000101	2.079 *

*** = significant (p <0.001)
** = significant (p <0.01)
* = significant (p <0.05)
NS=Not significant (p = 0.05)
S.E = Standard Error

a= intercept
b= coefficient estimating inorganic P (X_1) effect.
g= coefficient estimating organic P (X_2) effect.
d= coefficient estimating inorganic P and organic P interaction (X_1* X_2) effect.

interaction between organic and inorganic P and the effects were probably largely additive. Similar to 1997, inorganic P had a significant effect on maize grain yield. However, the organic P and the interaction coefficients were not significant, suggesting no real effect on grain yield. In contrast to 1997 and 1998, the effects of organic and inorganic P on grain yield were small and insignificant in 1999 but the interaction coefficient was relatively large and significant. These results confirmed the conclusions drawn from the analysis of variance that addition of fertilizer P to FYM had synergistic effect on maize grain yield that year.

Based on the results of regression analysis performed on grain yield data averaged over three years (1997 to1999), the coefficients estimating the effects of organic P, inorganic P and the interaction were significant (Table 24.3). However, the coefficient of inorganic P was much larger than that of organic P, indicating greater effect of inorganic P compared to organic P. The significant interaction coefficient demonstrated synergy between FYM and fertilizer P.

Conclusions

The results of this study indicate that applying P at a modest rate of 30 kg P ha^{-1}, either in the organic or inorganic form, can substantially increase maize grain yield. Provided the FYM rate supplies equivalent amount of P, FYM appears to be nearly as effective as TSP. However, since the quality of FYM determines the quantities to be applied to attain the required P rate, low quality material could mean more labour for application, probably making the practice economically unattractive. Combining organic and inorganic P results in synergistic effects, particularly in drier, moisture-stressed growing seasons. This synergy, and other extra benefits of FYM, should be exploited by smallholder resource poor farmers. A 50/50 organic-inorganic combination ratio appears to be the optimum

Acknowledgements

The Authors would like to thank the European Union (EU), the Tropical Soil Biology and Fertility Programme (TSBF) and the Kenya Agricultural Research Institute (KARI) for providing the funds and other resources that made this study possible. All collaborators who contributed to the design and implementation of this study are also greatly acknowledged. We particularly thank Janet Riley of Rothamstead Experimental Station, U.K. for ideas on statistical analysis of similar experimental designs.

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