Optimizing Phosphorus and Manure Application in Maize-Soybean Rotations in Zimbabwe

By Shamie Zingore and Ken E. Giller

Soybean production in Zimbabwe is limited because farmers give little attention to the crop and prefer to apply fertilizer to the previous crop in the rotation (maize). Our research showed that the combined application of P fertilizer and manure to maize, as is currently practiced by farmers, was more productive and economic under poor soil fertility conditions. However, there is potential to increase income with application of P and manure to soybean on more fertile soils.

Cultivation of maize as a monocrop with little addition of nutrients has contributed to depletion of soil fertility on smallholder farms in sub-Saharan Africa. Soybean varieties with low N harvest indices are commonly promoted for use in small holder farming systems in Africa and have great potential to contribute N to soil through biological N_2-fixation (BNF), while improving the income and nutrition of smallholder farmers (Mpepereki et al. 2000; Giller and Cadisch 1995). However, major challenges exist to enhance the productivity of soybean and other grain legumes under smallholder farm conditions (Snapp et al. 2002). Soils cultivated by smallholder farmers are predominantly infertile and sandy, with low levels of available P. Other factors constraining production of grain legumes are directly linked to farmers' preference to use fertilizer on maize while growing the crop on the most fertile soils (Zingore et al. 2007). Production of grain legumes on poor soils, and with residual fertility, has led to very poor yields (< 0.5 t/ha) and low N_2 fixation (< 5 kg N/ha/yr) (Giller 2001).

This study investigated two key questions related to the effects of farmer management practices on productivity of grain legumes and maize: i) What is the effect of soil fertility status on productivity of soybean and the crop response to P fertilizer? and ii) Is the current practice of targeting nutrient resources to maize and growing grain legumes on residual fertility more productive and economic than targeting nutrients to grain legumes?

Two on-farm experiments were conducted for 3 years (2004 to 2007) in northeast Zimbabwe, a site with a high potential for crop production (i.e. 850 mm avg. annual rainfall). The dominant soils in the area are either infertile sandy soils derived from granite, or more fertile red clay soils derived from dolomitic parent materials. The first experiment was a multi-location experiment to assess soybean response to P fertilizer across fields varying in soil fertility. The experiment was established in 50 fields covering a wide range of soil fertility conditions and textures (sandy to clayey soils). On each field, two plots (5 m x 5 m) were marked out with the following treatments: i) soybean without nutrient inputs; and ii) soybean fertilized with 30 kg P/ha as SSP. All plots were analyzed for soil organic C and available P using the Olsen method.

The second experiment was conducted on two fields: i) sandy soil (3% clay, 5% silt, and 92% sand) with 0.3% SOC, 3 mg/kg available P (Olsen), pH of 4.5 and 3.9 using water and $CaCl_2$, respectively, and CEC of 2 cmol$_c$/kg; and ii) a more fertile red clay soil (34% clay, 18% silt, and 48% sand) with 0.9% SOC, 12 mg/kg available P (Olsen), pH of 5.6 and 4.9 with water and $CaCl_2$, respectively, and CEC of 16 cmol$_c$/kg. At both these sites, soybean and maize were planted in a two-course rotation for three seasons: soybean-maize-soybean for the rotation in which soybean was grown in the first season, and maize-soybean-maize where maize was grown in the first season (**Table 1**). Cattle manure and SSP were applied to crops in the first and third season, while residual effects were assessed in the second season. Control treatments included soybean and maize grown as monocrops.

Single superphosphate was applied at 30 kg P/ha—the regional recommendation for maize. Manure was also applied to provide 30 kg P/ha. Soybean residues were incorporated in the top 20 cm after harvest in the first season. Maize residues were removed, as farmers use the residues for cattle fodder. All the maize plots, except the monocrop control, received 70 kg N/ha applied as ammonium nitrate at about 3 and 6 weeks after emergence. The experiment at each site was set up in a randomized complete block design with three replicates. Data collected for the second experiment included grain and residue yields, N and P contents of grain and residues, and N_2-fixation was estimated using the ^{15}N natural abundance method. The proportion of N fixed by soybeans was calculated as the percentage of total N fixed over total N accomodated

Common abbreviations and notes: N = nitrogen; P = phosphorus; C = carbon; Ca = calcium; Mg = magnesium; Mo = molybdenum; Co = cobalt; SSP = single superphosphate; CEC = cation exchange capacity; SOC = soil organic carbon; $CaCl_2$ = calcium chloride.

Table 1. Experimental treatments for analysis of effects of SSP and manure in soybean/maize rotations.

Treatment	First season	Second season	Third season
1	Soybean	Soybean	Soybean
2	Soybean	Maize + 70 kg N/ha	Soybean
3	Soybean + 30 kg P/ha (SSP)	Maize + 70 kg N/ha	Soybean + 30 kg P/ha (SSP)
4	Soybean + 14 t manure/ha	Maize + 70 kg N/ha	Soybean + 14 t manure/ha
5	Maize	Maize	Maize
6	Maize + 70 kg N/ha	Soybean	Maize + 70 kg N/ha
7	Maize + 30 kg P/ha (SSP) + 70 kg N/ha	Soybean	Maize + 30 kg P/ha (SSP) + 70 kg N/ha
8	Maize + 14 t manure/ha + 70 kg N/ha	Soybean	Maize + 14 t manure/ha + 70 kg N/ha

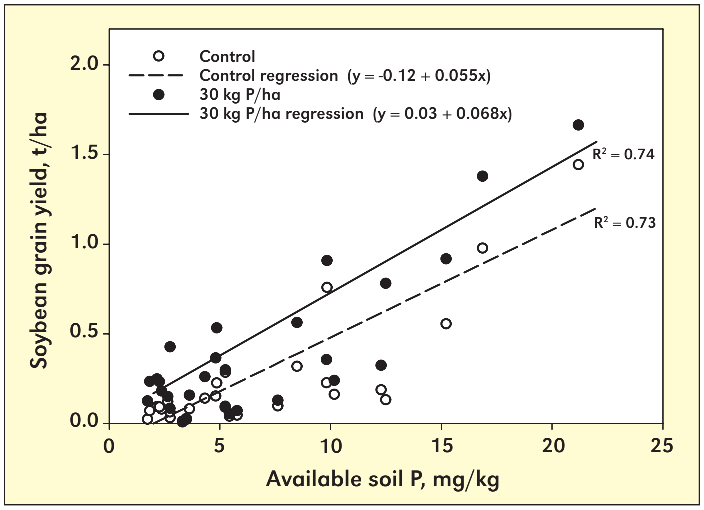

Figure 1. Relationships between soil available P and soybean yields for P fertilized and unfertilized crops.

Field experiments comparing the effects of P application in maize and soybean production in eastern Zimbabwe. Dr. Shamie Zingore, on the left, alongside the cooperating farmer.

Table 2. Average yields of soybean and maize as affected by direct P and manure application in the first and third seasons, northeast Zimbabwe.

		First and third season yield, t/ha	
Treatment	Crop	Sandy soil	Clay soil
1. Control soybean - sole crop	S	0.16	0.57
2. Control soybean - rotation	S	0.15	0.59
3. Soybean + 30 kg P/ha (SSP)	S	0.26	0.79
4. Soybean + 14 t manure/ha	S	0.52	1.18
5. Control maize - sole crop	M	0.44	2.18
6. Control maize rotation + 70 kg N/ha	M	0.64	2.26
7. Maize + 30 kg P/ha (SSP) + 70 kg N/ha	M	1.32	2.92
8. Maize + 14 t manure/ha + 70 kg N/ha	M	2.53	3.41
SED*		(0.05^S; 0.32^M)	(0.06^S; 0.38^M)

*Standard error of difference for comparison of treatment effects on soybean (S) and maize (M) yields.

Table 3. Residual effects of SSP and manure on soybean and maize in the second season, northeast Zimbabwe.

		Second season yield, t/ha	
Treatment	Crop	Sandy soil	Clay soil
1. Control soybean - sole crop	S	0.23	0.49
2. Control maize - rotation + 70 kg N/ha	M	0.73	2.42
3. SSP residual effects - maize + 70 kg N/ha	M	1.13	2.77
4. Manure residual effects - maize + 70 kg N/ha	M	1.78	2.63
5. Control maize - sole crop	M	0.42	1.84
6. Control soybean - rotation	S	0.21	0.42
7. SSP residual effects - soybean	S	0.29	0.73
8. Manure residual effects - soybean	S	0.54	0.79
SED*		(0.08^S; 0.18^M)	(0.09^S; 0.22^M)

* Standard error of difference for comparison of treatment effects on soybean (S) and maize (M) yields.

in grains and residues. The economic benefits of using SSP and manure in maize/soybean rotations were calculated by subtracting the field value of the output from the field value of inputs (fertilizers and seed).

Soil Available P and Soybean Yields

Soil P levels in farmers' fields were 2 mg/kg and up, and more than 90% of fields had available P status below the critical level of 15 mg/kg in experiment 1. The yields of soybean, and their response to P, were strongly correlated with available P (**Figure 1**). Without P application, soybean yields of < 0.5 t/ha were found in fields that had less than 12 mg/kg available P. With P application, soybean yields increased from 0.5 t/ha in soils with < 5 mg/kg available P to about 1.6 t/ha in soil with the highest available P. The results confirm the low soybean productivity on poor soils, which farmers commonly allocate for soybean production. Still the maximum yields observed are far below the attainable yield for soybean under similar agro-ecological conditions (i.e. 3 to 4 t/ha; Kasasa et al. 1999), possibly due to other limiting nutrients.

Crop Yields

In experiment 2, unfertilized soybean and maize grain yields were low on the infertile sandy soil (**Table 2**). Direct application of SSP led to a marginal increase in soybean yields, but yields were significantly increased (> 300%) with manure application. Maize yield response was also poor with only N fertilization in the first season, but increased with both N and P fertilization. But the largest maize yields were obtained in plots where manure and mineral N fertilizer were applied. For clay soil, yields for all treatments without amendments were significantly higher than in the sandy soil for all seasons. Soybean yields were significantly increased by the addition of either SSP or manure in the clay soil. Maize grain yields for fertilized plots in the first and third seasons decreased in the order N+manure > N+SSP > N alone.

Nitrogen Contents and N_2-Fixation

The total amount of N accumulated by soybean grown on sandy soil without any fertilizer input was very small (< 15 kg N/ha; data not shown). On plots where SSP was applied, total N content in soybean grain and residues averaged 20 kg/ha for the first and third seasons, but increased significantly with manure application. Also, the proportion of N_2 fixed by soybean when manure was applied was significantly higher (83%) than the values obtained for soybean grown without amendments or with application of SSP (61 to 64%) (data not shown). Among soils, the amount of N in soybean biomass was higher on the clay soil than on the sandy soil. For the first and third seasons, when manure and SSP were directly applied, the largest amounts of N were accumulated in plots with manure application (75 kg N/ha on average) followed by SSP application (53 kg N/ha on average), and were least on the plots without any amendment (28 kg N/ha on average). The proportion of soybean N derived from the N_2-fixed on clay soil was greater than 65% across all seasons.

Residual Effect on Crop Yields

On sandy soil and in the second season, maize grain yields following soybean grown without any amendments was only 0.31 t/ha greater than the continuous maize plots, despite application of 70 kg N/ha to the maize following soybean (**Table 3**). Manure applied in the first season led to strong residual effects in the second season resulting in higher maize and soybean yields. Maize grain yields on clay soil in the second season were least on the plots where maize was cropped continuously without fertilizer inputs. Manure or SSP applied to maize in the first season led to significantly greater soybean yields in the second season than those for soybean following maize that had received N fertilizer alone. However, soybean yields on the clay soil were lower when grown with residual fertility (second season) than with direct application of manure in the first and third seasons.

Gross Margins

The gross margins from maize and soybean without fertilizer inputs were small on the granitic sandy soil (**Table 4**). Greatest economic benefits for both maize and soybean were obtained with manure. Maize was more profitable than soybean when manure or SSP were applied, despite the extra cost of mineral N added to maize. Overall, gross margins for the three seasons for unfertilized soybean and maize monocrop plots did not differ substantially with rotations without addition of P, which were also small due to poor yields. On the sandy soil, addition of manure to the maize crop led to greater gross margins within the rotation than its addition to the soybean crop, whilst the differences for SSP were marginal. On the clay soil, gross margins were higher for maize than soybean when the crops were grown continuously without fertilizer inputs (**Table 4**). However, within rotations gross margins for the treatment in which manure or SSP were applied to soybean was substantially greater than when applied directly to maize.

The limited productivity and response of soybean to P application on the sandy soil could have been due to a deficiency of Ca, Mg, and/or other micronutrients such as Mo and Co, which are essential for N_2-fixation (Giller, 2001). The soils were also acidic and contained small amounts of organic matter, conditions that are not favorable for soybean production.

Summary

Degraded sandy soils are widespread in Africa and these soils cannot support soybean production without proper fertilizer management. On such soils, current farmer management of applying fertilizer and manure to maize is more viable. The substantial increase in yields and proportion of N_2 fixed with direct application of manure was due to its multiple effects such as supplying multiple secondary and micronutrients, improving moisture availability, and increasing soil pH (De Ridder and Van Keulen 1990). However, low manure availability is a major challenge that limits its wide-scale use to improve crop productivity.

On the clay soil, direct application of manure and SSP to soybean in the first and third seasons led to greater returns than direct application to maize, and this led to the higher returns for the 3-year rotations when SSP and manure were applied to soybean. There are opportunities, therefore, for farmers on the more fertile soils to increase income by targeting manure to soybean rather than maize (Chikowo et al. 1999; Okogun et al. 2005). To maximize benefits from legume production, smallholder farmers need to focus attention on the more fertile plots, although production should be optimized in relation to maize. Longer-term sustainable intensification of maize/soybean systems may however require increased fertilizer use which would allow applying fertilizer directly to each crop, as well as addressing multiple nutrient deficiencies limiting yields on poor soils. BC

Table 4. Gross margin analysis for targeting P and manure with soybean/maize rotations in northeast Zimbabwe.

	Gross margins*, USD/ha	
Treatment	Sandy soil	Clay soil
1. Control soybean - sole crop	176	848
2. Control soybean - rotation	204	1,083
3. Soybean + 30 kg P/ha (SSP)	357	1,213
4. Soybean + 14 t manure/ha	732	1,712
5. Control maize - sole crop	209	1,084
6. Control maize - rotation + 70 kg N/ha	148	891
7. Maize + 30 kg P/ha (SSP) + 70 kg N/ha	309	1,187
8. Maize + 14 t manure/ha + 70 kg N/ha	955	1,413

*The costs (USD; averaged for three years) of inputs were: SSP = $2.25/kg P; manure = $2.25/kg P; ammonium nitrate = $1.35/kg N; maize seed = $0.74/kg; soybean seed = $0.96/kg. Grain prices were $300/t for maize and $753/t for soybean.

Dr. Zingore is the IPNI Director for Sub-Saharan Africa, e-mail: szingore@ipni.net; Prof. Giller is Head, Plant Production System Group, Wageningen University, the Netherlands, e-mail: ken.giller@wur.nl.

References

Chikowo, R., F. Tagwira, and M. Piha. 1999. African Crop Sci. J., 7:383-395.
De Ridder, N. and H. Van Keulen. 1990. Fert. Res. 26:299-310.
Giller, K.E. 2001. Nitrogen Fixation in Tropical Cropping Systems. CAB International, Walliford, UK.
Giller, K.E. and G. Cadisch. 1995. Plant soil, 174:255-277.
Mpepereki, S., F. Javaheri, P. Davis, and K.E. Giller. 2000. Field Crops Res., 65:137-149.
Okogun, J.A., N. Sanginga, R. Abaidoo, K.E. Dashiell, and J. Diels. 2005. Nutr. Cycl. Agroecosys., 73:267-275.
Snapp, S.S., D.D. Rohrbach, F. Simtowe, and H.A. Freeman. 2002. Agri. Ecosys. Environ., 91:159-174.
Zingore, S., H.K. Murwira, R.J. Delve, and K.E. Giller. 2007. Agri. Ecosys. Environ., 119:112-126.