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Full Length Research Paper

Farmer evaluation of phosphorus fertilizer application to annual legumes in Chisepo, Central Malawi

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Building from the perception that farmers have an intimate knowledge of their local environment, production problems, crop priorities and criteria for evaluation, an on-farm experiment was conducted with farmers in 2003/4 in Chisepo, central Malawi, to evaluate the response of six annual legumes to phosphorus (P) (20 kg P ha^{-1} or no P fertilizer) application. The legumes were velvet bean, pigeonpea, soyabean, groundnut, bunch-type cowpea and Bambara groundnut. Twelve farmers hosted the experiments and each farmer formed a group of at least 4 other farmers to evaluate the legumes. Farmer participatory monitoring and evaluation of the legume and P combinations was conducted during the experiment to determine farmer preferences and acceptance of the technology. Measured grain yields, returns to labour and total costs of the P-fertilized legumes were compared with those for the unfertilized legumes. The application of P fertilizer significantly (P = 0.05) increased legume grain yields, particularly with velvet bean, and soyabean. However, use of P was not financially attractive and farmers were not interested to use P at the time. Farmers were more interested to maximize legume food production from their labour investment. Soyabean, groundnut and pigeonpea, grain legumes with high value as food, were considered to be priority crops by farmers over velvet bean, cowpea and Bambara groundnut.

Key words: Grain legume, farmer participation, soil fertility, phosphorus, monitoring and evaluation, financial analysis.

INTRODUCTION

The incorporation of legume residues is often proposed as a way to improve the productivity and sustainability of cereal-based cropping systems in smallholder fields in Africa (e.g. Giller, 2001; Snapp et al., 1998; Mafongoya et al., 2006). In Malawi, common annual grain legumes include pigeonpea, groundnut, soyabean and common bean (*Phaseolus vulgaris*) and examples of green manure legumes are velvet bean and fish bean (*Tephrosia vogelii*). Soil fertility is in a slow general decline in sub-Saharan Africa and this poses a special threat to the future of smallholder agriculture where limited options to improve soil fertility are available (Smaling, 1998). To arrest the decline in soil fertility and improve crop yields in southern African smallholder agriculture, research has widely promoted the use of annual grain legumes that also provide food for humans (Waddington, et al., 2004; Whitbread et al., 2004). Nevertheless, in Malawi, many farmers grow few legumes, and on small land areas (Phiri, 1999; Snapp et al., 2002). The improvement of soil fertility therefore requires an integrated approach that includes increased production of legumes by farmers using inputs, such as mineral fertilizers, that help the legumes to grow well. One way to do that is for farmers to work together with research and extension staff to learn about various legume and fertilizer options and benefits.

The maintenance of soil organic matter (SOM) is crucial to the management of soil fertility in the tropics

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(Woomer et al., 1994). Therefore farmer's perceptions about biomass and SOM from legumes (and cereals) and the management of legumes, are relevant to improving soil fertility. In addition, legumes improve soil fertility through biological N_2-fixation, additional carbon inputs and by conserving nutrients (e.g. Giller, 2001). However, farmers may neglect the effect of these legumes as the benefits often are not obvious in the short run. Farmers have an intimate knowledge of their local environmental conditions, production problems, crop priorities and criteria for evaluation, and many actively engage in experimentation as part of their farming routine (Sumberg et al., 2003).

However, this knowledge, experience and experimentation are often ignored by researchers, who commonly give farmer perceptions little attention in their research (Bellon, 2001; Tripathi and Ellis-Jones, 2005). At the same time, the results of formal research are often not accessible and inappropriate for resource-poor farmers. To bring these components of knowledge together requires that the local knowledge with farmers be taken as a basis or keystone for a collegial relationship between farmers and researchers where significant extra benefits may accrue to both (Quansah et al., 2001; Sumberg, et al., 2003).

While legumes can improve soil fertility, prevailing low soil fertility limits N fixation by legumes and the overall growth and yield of legumes grown on many smallholder farms. Phosphorus (P) deficiency is one often important factor (Whitbread et al., 2004). P is needed in relatively large amounts by legumes for growth and nitrogen fixation and their effectiveness in soil improvement is hindered by P deficiency (Giller and Cadisch, 1995). P deficiency can limit nodule, leaf area, biomass and grain development in legumes.

The application of P fertilizer can overcome the deficiency on soils that do not strongly adsorb P (Giller, 2001). In Malawi, low yield of legumes grown by smallholder farmers may be strongly linked to minimal use of P fertilizer (Mwalwanda et al., 2003) among other factors, and this was also identified during simulation modelling of the response of maize to legumes and N fertilizer in central Malawi (Robertson et al., 2005).

In recent efforts to increase the production of legumes by smallholder farmers, the notion of 'trialability" has been emphasized where end users (farmers) contribute their knowledge and experiences effectively and modify where necessary the innovations during the process of adoption (Sumberg et al., 2003).

It is important that participatory assessment is used to capitalize on farmer knowledge to identify opportunities and constraints, understand farmers' use of technologies, and assist technology adoption. To evaluate the response of six annual legumes to P fertilizer application, we conducted an on-farm experiment with 12 Malawian host farmers in 2003 - 2004. To increase ownership and the usefulness of results from the experiment, farmers provided land and labour for all activities on the plots and made frequent visits as a group to the experiments. This paper presents results from that study which established the response of the legumes to P fertilization, identified constraints and farmer concerns about the technologies, and recorded farmer modifications to the use of P fertilizer on the legumes.

MATERIALS AND METHODS

Profile of the study site

The study was conducted in Chisepo, Dowa District in the Central Region of Malawi (13'32'' S and 33'31'' E), located 140 km northwest of Lilongwe City at an average elevation of 1100 m above sea level. Annual rainfall in Chisepo ranges from 600 - 800 mm (Figure 1) with an annual mean temperature of 24°C. In the 2003 - 2004 growing season, rainfall was well distributed from November to April although the annual total (670 mm) was below the long term average of 748 mm. Below average rainfall adversely affects crops such as long duration pigeonpea which requires more residual soil moisture before maturity in July. Soils in the area are generally sandy and ferralitic clay loams (Young and Brown, 1962). Most of the area was formerly a miombo woodland ecosystem. Agriculture dominates the farmers' livelihood strategies in the area. Maize is the predominant food crop and tobacco the most important cash crop.

Other crops include traditional legumes such as groundnut and common bean. Low soil fertility and erratic rainfall are the major constraints to increased smallholder agricultural production. The soils produce inadequate crops without soil fertility interventions, resulting in relatively high levels of poverty in the area (Snapp et al., 2002).

Selection of farmers hosting legume experiments

Prior to this study, farmers in Chisepo had experience with conducting on-farm experiments on maize-legume technologies beginning in 1998 by working as research groups over four years. These previous participatory studies involved about 52 farmers in the village area. In a pre-season workshop with farmers in 2003, discussions on the results of APSIM crop system simulation model predictions on yield of legumes (Robertson et al., 2005) led to the decision to evaluate P fertilizer application to legume performance under farm conditions. Twelve farmers were randomly selected by the researchers to host the experiments.

Each farmer formed a group of at least four farmers. Although many of the farmers had received previous training on field experiment management, farmers were reminded about the principles of conducting research. Many farmers were familiar with at least the following ten legumes: pigeonpea (ICP 9145) (*Cajanus cajan,* (L.) Millsp.), Magoye soyabean (*Glycine max* (L.) Merrill), groundnut (*Arachis hypogaea* L.), Bambara groundnut (*Vigna subterranea* (L.) Verd), velvet bean (*Mucuna pruriens* (L.) DC), cowpea determinate-habit (*Vigna unguiculata* (L.) Walp.), cowpea indeterminate-habit (*Vigna unguiculata* (L.) Walp.*)*, fish bean (*Tephrosia vogelii* Hook. F.), sunnhemp (*Crotalaria juncea* L.) and grahamiana (*Crotalaria grahamiana* Wight and Arn.*)*.

From these, farmers selected six annual legumes for the experiment based on their expectations of food, soil and financial benefits. Responsibilities for implementing the experiments were discussed during the workshop. The agreement was that researchers would provide P fertilizer, seed and field notebooks while participating farmers would provide land and labour. All farmers would make observations and help with recording, and

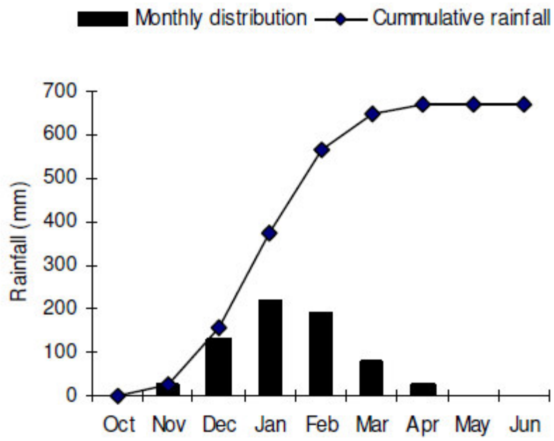

Figure 1. Rainfall distribution in Chisepo, central Malawi during the 2003/04 cropping season.

participate in all activities from planting to harvest with the help of a field assistant. At the end of the experiment all farmers and researchers jointly evaluated the results.

Experimental design and implementation

The experiment consisted of 12 experimental treatments. Plots were allocated to six legumes: velvet bean, pigeonpea, soyabean, groundnut, cowpea bunch-type and Bambara groundnut. Each legume received no P fertilizer or 20 kg P ha^{-1} as triple super phosphate (TSP). The experiment was laid out in home fields adjacent to the homestead buildings (within 50 m) and in middle fields that were over 50 m away from homes. The experiment was hosted by 12 farmers, but one farmer discontinued involvement during the study because the family had to look for a temporary employment on a tobacco estate in the area as a means of finding food. Each farmer had all 12 experimental treatments which were replicated three times in each field in a 6 x 2 x 3 randomized complete block design giving a total of 396 data points. Legumes were planted following standard farmer plant spacing targeting plant population densities of 74,000 ha^{-1} for velvet bean, groundnut, Bambara groundnut, and bunch cowpea, 444,000 ha^{-1} for soyabean and 37,000 ha^{-1} for pigeonpea (GoM, 1996). P fertilizer was applied once at planting at the rates given above, and either banded or dolloped on the soil surface on top of the ridges. All management activities with the experiment were the responsibility of the farmers, field assistant and researchers.

Data and methods for collection

Baseline soil samples were collected from a soil depth of 20 cm just before planting the legumes. The samples were analysed for pH (in H_20), soil texture, % organic matter, % nitrogen and available phosphorus (Bray) using standard methods for tropical soils (Anderson and Ingram, 1993). Legume grain and yield components were measured after crop maturity at the end of the season. Crop samples were harvested for above-ground non grain biomass analysis from the legumes in net plots of 3 x 3 m at the end of the season. Samples were analysed for nitrogen (N) and phosphorus (P) content in DM at Bunda College Soils and Plant Laboratory.

Farmers and the field assistant periodically recorded their practices and observations from the experiments, including operations such as date of planting, weeding, flowering and the incidence of pests and diseases. Labour use on different operations was monitored by the host farmer and the field assistant, and records kept of the time taken for each operation. This included land preparation, planting, fertilizing, weeding, and harvesting. Incorporation of crop residues was left to the host farmers to perform. Training events, farmer workshops, field days, exchange visits and farmer evaluation of the legumes were done with all participating farmers at appropriate times throughout the season. Proceedings of each meeting were recorded by farmers and the field assistant. Because experimental management was left with the farmers, rather than be tightly controlled, management practices and standards were variable as were the fields where the experiments were conducted. This resulted in a large range of yields achieved in the experiments.

Preference ranking of technologies by farmers

Farmers monitored the performance of legume technologies throughout the season and regularly observed and recorded their observations in field notebooks and on resource allocation maps. Crop performance at each stage was evaluated against their criteria for selection of the technology and that was used to judge farmers' final assessment of each technology. In a final evaluation, farmers looked at crop growth parameters like the amount of biomass, grain yields and ease of management, including suitability for intercropping. Intercropping became an important selection factor because it is increasingly used by farmers with legumes that are promising to restore soil fertility and also offer a bonus food crop.

Farmers assigned ranks to each technology in a preference ranking based on their criteria. All observable aspects were aggregated by each farmer for each technology. After all farmers had ranked the technologies, all were summed up for a total rank of the technology and an overall final preference rank was given for each technology. Farmers were grouped into three categories based on how well they participated and responded to the needs of the experiments.

Economic analysis of the technologies

Costs and benefits were calculated on inputs and outputs in the experiments using prices prevalent in the 2003/4 season. Average farm-gate price for legume grain was MK20.00 kg^{-1} (US$0.19 kg^{-1}). Labour cost was estimated using the opportunity cost of labour, based on the minimum agricultural wage rate of MK56 man-day^{-1} (US$0.53) in 2003/4.

Average labour requirement for the production of legumes for each field experiment (not including costs of residue incorporation) was 47 man-days including fertilizing with P, and an average of 36 man-days in some legumes where fertilizer was not applied. Legume seed was priced at US$0.56 kg^{-1}, which is lower than the normal price of US$1.2 kg^{-1}. This was so because normally farmers plant legume seed from their previous harvests. Buying of new seed is not common for many farmers and if they buy it usually is from within the area from other farmers. Triple super phosphate-P was MK249.31 kg^{-1} (US$2.33). Most economic analyses of agricultural experiments use three criteria for evaluation for financial or economic performance: returns to labour, returns to land and the benefit to cost ratio.

These criteria were used to evaluate the eco-nomic legume grain response to P fertilizer application under farmer conditions in Chisepo. Labour is the main asset of smallholder farmers and their goal is to maximize returns to this asset. Returns to labour, calculated by dividing the net benefits by the total man-days, were used to compare the benefits in the economic analysis. Returns to land are represented by the Gross Margins (GM), and GM was calculated as;

$$GM = \sum_{i=0}^{n} (B-C)$$

Where B is the benefits accrued by using the land in that year, C are the costs associated with use of that land in the same period. The benefit-cost ratio (B/C) indicates the rate of return per unit cost. The B/C ratio was calculated as follows;

$$B/C \text{ ratio} = \sum_{i=0}^{n} B \Big/ \sum_{i=0}^{n} C$$

A B/C ratio of greater than 1 indicates that the land use system is profitable.

Data management and analysis

All quantitative data from experimental plots and field based measurements were statistically analyzed using an appropriate analysis of variance model in the Genstat statistical package. Field observations that farmers had recorded throughout the year were presented in a final workshop in June 2004 and were discussed to identify farmer perceptions. Preference ranking data obtained during the final evaluation was presented graphically after calculation of cumulative probabilities of each technology.

RESULTS

Farmers' rationale for selection of legumes used in the participatory evaluation

Farmers described five main criteria for evaluating a legume for their cropping systems (Table 1). Their rationale involved weighing the positive attributes against negative ones. The first positive attribute was the ability of a legume to produce useable grain for either human food or market. Farmers mentioned that although the project emphasized soil fertility improvements, for them the use of legumes for soil fertility improvement was a secondary benefit after food. The second attribute was the ability of a legume to be intercropped with maize. Farmers explained that due to scarcity of land and increased labour demands for other activities, a legume that intercropped well with maize or other main crops was better than one that did not. The third attribute farmers gave was ability to improve soil fertility. This was assessed primarily through the level of biomass production by the legume, which they believed was the most important pathway for legume soil fertility improvements. The fourth attribute was the ability to control weeds. Witchweed (*Striga asiatica*) was one of the most important weeds in the area, and most farmers agreed with researchers that some legumes reduce witchweed incidence on maize. Legumes with those characteristics would be preferred over others. The last attribute mentioned was the labour requirement for management of the legume. Negative attributes that farmers identified for velvet bean included a lack of market for its grain, problems with cooking the toxic seeds and difficulties to intercrop with maize. Late maturity was the main negative attribute for pigeonpea because damage by livestock into the dry season reduces its ability to improve soil fertility or provide seed. Pests and disease were recognized to reduce grain yields of pigeonpea. The method of harvesting soyabean, where the whole crop is uprooted for processing at home, reduces incorporation of biomass. The commonly used CG 7 groundnut was susceptible to pests and diseases and it easily gets mouldy when harvesting was delayed. Bambara groundnut and cowpea had several negative attributes including susceptibility to pests and diseases, limited biomass production, aphid attack and low yield expectation. Farmers however said that they consider both positive and negative attributes for selection of a legume. If in their view, the positive attributes out-weigh the negative attributes then the legume has a higher priority over others. According to Estrella and Gaventa (1998), evaluation of legumes that centres on farmers own criteria reflect the value farmers put on the characteristics of technologies.

Soil properties of experiment sites

Initial soil properties in the farmers' fields where the experiments were hosted indicated that the soils had a slightly acidic reaction, and small concentrations of Bray available P (Table 2). The critical value for Bray available P ranges from 8 - 16 mg kg^{-1} for most soils in central Malawi. There was little difference in soil properties between the home and middle fields.

Legume response to P fertilizer

Effects of P fertilizer on legume grain yields

Grain yields of P fertilized legumes were higher (*P* = 0.05*)* than yields of unfertilized treatments for all legumes in the two field types, except for pigeonpea where yield was the same in the home field (Figure 2). The mean grain yield of P-fertilized velvet bean was 1.0 t ha^{-1} higher than unfertilized. Similarly, P-fertilized groundnut, soyabean, Bambara groundnut and cowpea gave 0.8, 0.5, 1.0 and 0.3 t ha^{-1} extra grain yield (P = 0.05) than unfertilized plots respectively. Velvet bean gave the largest grain yield followed by groundnut, soyabean, Bambara groundnut and then cowpea (Figure 2). Pigeonpea had the poorest yields on both field types. Velvet bean, pigeonpea, soyabean, unfertilized groundnut and Bambara groundnut had larger yields in middle fields (P = 0.05) than home fields. Cowpea and fertilized groundnut had better yields in the home fields than middle fields (Figure 2). Except pigeonpea and cowpea, other legumes performed better than the national average grain yields of 400 - 800 kg ha^{-1}. In terms of percentage response, cowpea had the strongest response to applied P seconded by Bambara groundnut, and then groundnut, velvet bean and soyabean. Pigeonpea showed no response to P in

Table 1. Farmers' reasons for selection of annual legumes for the 2003/04 season in Chisepo, central Malawi.

	Positive attributes	Negative attributes	Supporting ethnographic quotes
Velvet bean	High biomass and grain production Good for soil fertility Helps in weed control e.g. *Striga* species Has no pest or disease problem Grows well in all soils Conserves soil	Difficult to cook (need alternative ways of processing) Poisonous Does not grow well with maize Difficult to incorporate	"Our soils are so poor, we can't find fertilizer, and maybe growing these bushes would help improve our maize" "… although we hear that it killed the Ngoni people, its grain helped many families here in Chisepo during the 2001/02 famine; that year we were dying"
Pigeonpea	Excellent grain and relish food Improves soil fertility Grows well with maize, hence labour and land saving Provides firewood Good to feed cattle and goats if wanted	Late maturing hence destroyed by livestock, goats like it Depredation by pests and diseases (beetles)	"*Ndiwo yake ya yiwisi ndiyokoma kwambiri* " (Its grain relish is very good)
Soyabean	Grain for food (flour makes local bread, porridge, milk, mix with relish) Grain for sale Improves soil fertility Grows well with maize, hence land and labour saving Grows well in all soils	Difficult to establish where seed-eating birds are common Difficult to incorporate due to harvesting method Poor germination	"I prefer growing soyabean because I understood from our field officers how to make milk and porridge from soyabean. The milk and porridge have helped keep my family healthy and I guarantee the family health for as long as I grow the crop"
Groundnut	Food Improves soil fertility Good animal feed	Susceptible to diseases and pests Becomes mouldy easily	"The new variety is sweet, although it does not make a good mixture for relish"
Bambara groundnut	Good relish Easy to manage	Limited biomass production Low yielding Susceptible to pests and diseases	"This crop has not been widely grown because we believed that only households who had lost at least one child should grow it. Using it in the experiment helps to clear this myth"
Cowpea bunch-type	Relish Easy to manage Matures faster	Aphid attack	"The traditional cowpea spreads a lot and we fail to plant more of it in maize. This new one maybe would replace that"

Table 2. Soil properties at 20 cm soil depth for selected farmers' fields in Chisepo, central Malawi in 2003.

Farmer	pH	% Sand	% Silt	% Clay	% OM	% N	Bray avail. P (mg kg^{-1})
Home field							
G. Mbingwa	5.6	53	13	33	1.3	0.06	4.1
B. Banda	5.4	63	10	27	1.7	0.08	7.0
L. Mwenda	5.1	67	17	17	0.8	0.04	9.9
M. Samson	5.6	63	10	27	1.9	0.10	9.0
Mean	5.4	61	13	26	1.4	0.07	7.5
Middle field							
P. Biliati	5.4	53	13	33	1.6	0.08	6.2
S. Kalivute	5.9	70	10	20	2.1	0.10	6.6
J. Mafuta	5.2	53	17	30	2.1	0.10	4.9
L. Basela	5.9	67	7	27	1.8	0.09	9.0
M. Jeremani	5.6	63	10	27	1.5	0.07	5.2
Mean	5.6	61	11	27	1.8	0.09	6.4
Overall mean	5.5	61	12	27	1.6	0.08	6.9

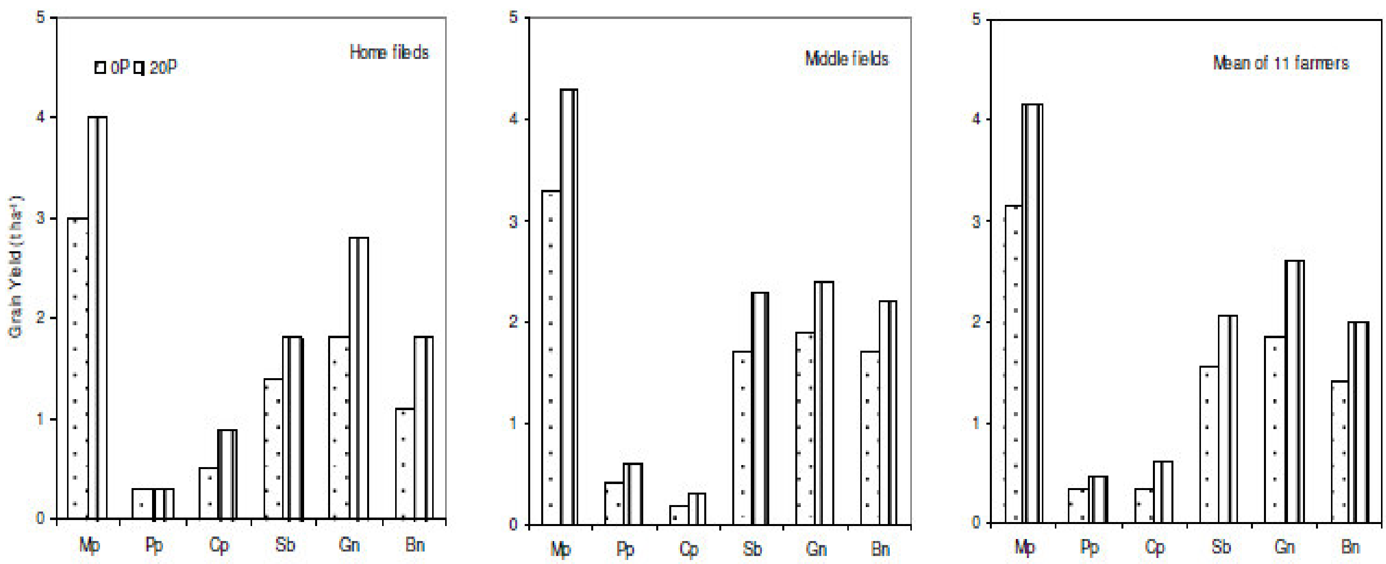

Figure 2. Grain yield (t ha^{-1}) of legumes in Chisepo in 2003/04 (n = mean of 11 farmers).

the home fields. However, pigeonpea and cowpea had the strongest response to applied P fertilizer in the middle fields. Velvet bean and soyabean responded almost the same way to applied P fertilizer. Overall responses (mean of 11 farmers), indicate that cowpea responded more to applied P than any other legume, followed by Bambara groundnut, groundnut and soyabean. Pigeonpea responded least to P fertilizer.

Effect of phosphorus on legume biomass yield and N and P leaf content:

Legume biomass yields (DM) shown in Figure 3 were significantly different at P = 0.05. Fertilized treatments gave higher biomass yield than unfertilized treatments for all legumes planted on both field types. Mean yield showed the same trend, with the fertilized velvet bean treatment yielding 2.2 t ha^{-1} higher biomass than the unfertilized treatment (P = 0.05). Fertilized soyabean had 1.5 t ha^{-1} of biomass on top of the unfertilized treatment. The least difference was from pigeonpea where the fertilized treatment raised yields only by 0.3 t ha^{-1} compared with the unfertilized treatment. Velvet bean gave the highest biomass yield of all legumes followed by groundnut, soyabean, Bambara groundnut and cowpea; pigeonpea was least (Figure 3). In home fields, velvet bean still produced the most biomass, followed by cowpea, groundnut,

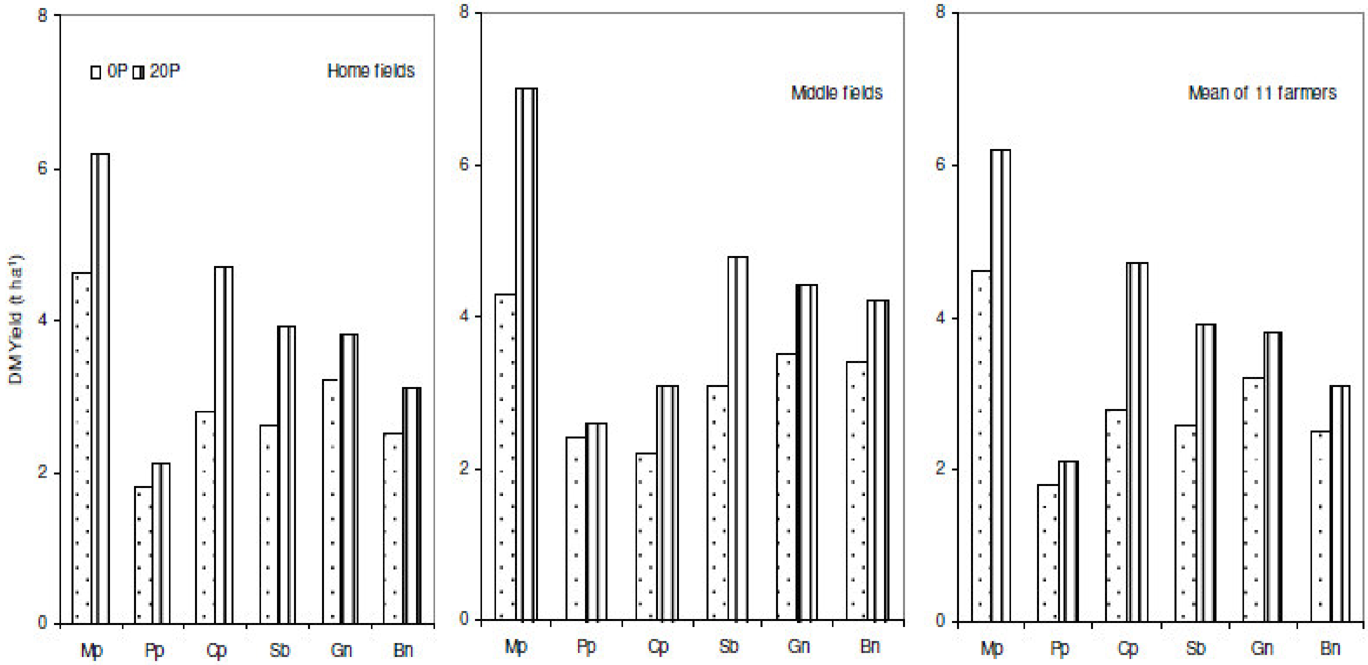

Figure 3. Dry matter (DM) biomass (t ha^{-1}) of legumes in Chisepo in 2003/04 (n = 11 farmers).

soyabean, Bambara groundnut and the pigeonpea, while velvet bean was followed by soyabean, groundnut and Bambara groundnut, cowpea and then pigeonpea in middle fields. The differences between home and middle fields were variable, with velvet bean, pigeonpea, soyabean, ground-nut and Bambara groundnut giving better yields in middle fields than home fields.

The effect of P fertilizer on legume leaf N and P content is shown in Figure 4. There was a consistent increase in N content in all legumes with P fertilizer application with the highest response observed in velvet bean followed by soyabean, cowpea, groundnut, Bambara and pigeonpea. Mean % N content ranged from 2.0 to 3.2 across the legumes but was slightly higher within treatments that had received P. Leaf P content also increased with P fertilizer for all legumes with the exception of pigeonpea. The highest response came from Bambara groundnut followed by soyabean, velvet bean, cowpea and groundnut.

Participatory evaluation of legumes

Farmers' evaluation and preference ranking of the technologies

Farmers were asked to assess the legumes for different attributes with P fertilization. Soyabean was the most preferred legume by farmers, followed by groundnut and cowpea. Velvet bean, pigeonpea and Bambara groundnut had lower scores (Table 3). Farmers observed that soyabean showed a better response to P for grain and biomass yields. They observed that it had the highest contribution to food security, had good germination and the grain is marketable. However, soyabean scored poorly on drought resistance. The second highest preferred legume by farmers was groundnut, which scored high on seed availability, marketability, storage and contribution to food security. Cowpea was preferred to velvet bean, pigeonpea and Bambara groundnut. Farmers were able to link legume response to its potential for soil fertility improvement and capacity to smother weeds. Farmers also noted that pigeonpea, velvet bean and soyabean grew well during the dry spells in the season. Labour for P fertilization was perceived to be high for all the legumes except pigeonpea.

Financial evaluation of legumes

A financial analysis of the legumes (Table 4) revealed that returns to labour were more than the minimum wage rate of $0.53 per day for agricultural labour for all legumes except pigeonpea with fertilizer and cowpea in both types of field. Gross Margins were higher with P fertilizer application. A Benefit/Cost ratio of more than 1 indicates that the practice is profitable. Velvet bean, soyabean, groundnut and Bambara groundnut had positive B/C ratios greater than 1, indicating that production of these legumes under good rains was profitable to the farmer. Application of P however reduced the profitability of the legumes due to the cost of the fertilizer. Pigeonpea gave the lowest returns while velvet bean had the highest returns to labour, GM and also B/C ratios in both types of

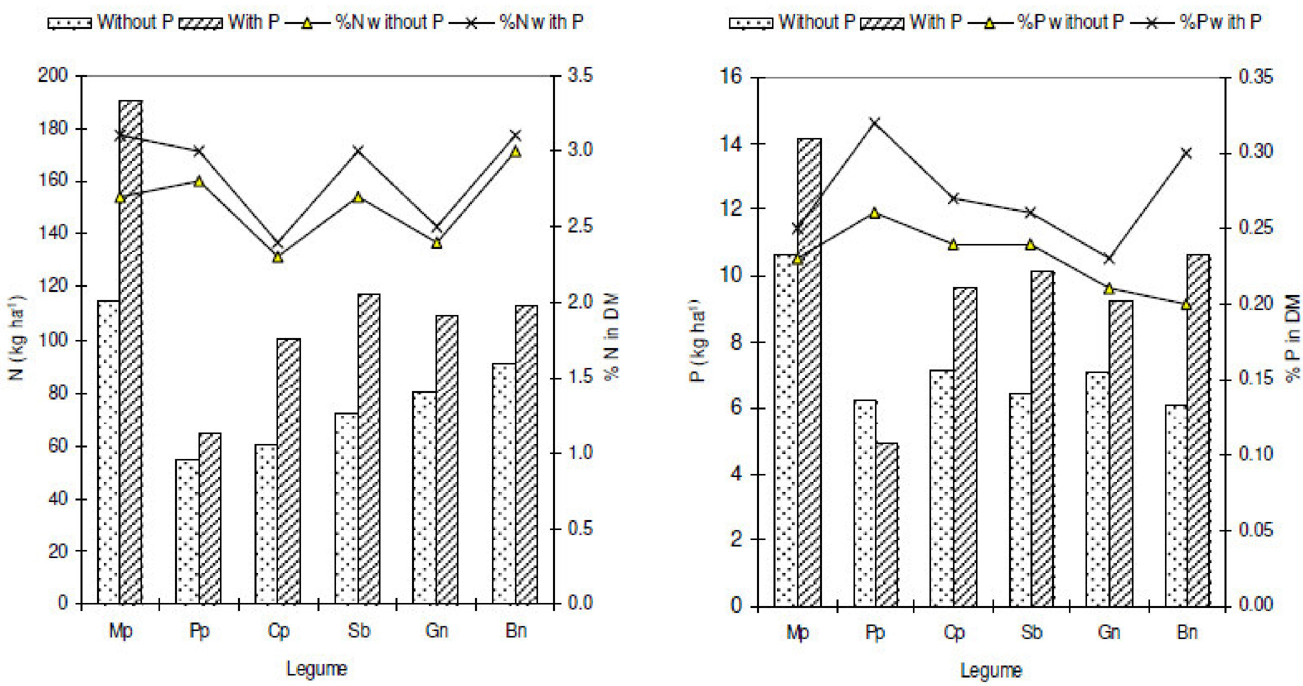

Figure 4. Response of legume leaf N and P content (by difference method) and leaf concentration to applied fertilizer P in Chisepo, Malawi in 2003/04.

Table 3. Farmer score of legume response to P fertilization in Chisepo, central Malawi in 2003/04 (n=48 farmers).

	Velvet bean	Pigeonpea	Cowpea	Soyabean	G/nut	Bambara
Grain yield response to P	3	6	2	1	4	5
Biomass yield response to P	4	6	2	1	3	5
Drought resistance	3	1	6	4	2	5
Germination	3	6	2	1	3	5
Pest attack resistance	1	4	6	2	3	5
Contribution to food security	6	4	3	1	2	5
Marketability	6	5	4	1	2	3
Seed availability	6	5	4	2	1	3
Storage	3	4	5	1	2	6
Overall rank	3.9	4.6	3.8	1.6	2.4	4.7
Rank	4	5	3	1	2	6

Note: 1 = most preferred, 6 = least preferred

fields.

B/C ratios with the fertilized treatments were lower than in unfertilized plots indicating that application of P fertilizer to legumes was not economic to farmers in Chisepo at present, although this assessment does not take into account any residual benefits to subsequent crops.

Farmer learning and participation in legume experimentation and evaluation

Table 5 summarizes what farmers learnt from the participatory evaluation of legumes. There were eleven groups with a total of 56 farmers. The results were divided into three categories of farmers based on their interest to participate, how well they managed the experimentation and their uptake of information. Category 1 had farmers who were very active in all the processes of on-farm experimentation, including recording their observations from the plots. This group also provided good guidance to other farmers. Six farmers from this category hosted the experiments, and provided better management than those in the other two categories. They were not doing this for recognition, but they had considerable interest in

Table 4. Financial returns (US$) from six legumes grown on home and middle fields in Chisepo, central Malawi, in 2003/04.

Legume treatment		Home fields					Middle fields				
		Returns to labour	GM ($ ha^{-1})		B/C ratio		Returns to labour	GM ($ ha^{-1})		B/C ratio	
		$/day	With labour	Without labour	With labour	Without labour	$/day	With labour	Without labour	With labour	Without labour
Velvet bean	-P	10.9	511.5	536.4	8.7	16.0	12.1	568.5	593.4	9.7	17.7
	+P	11.6	650.1	679.8	5.9	8.5	12.6	707.1	736.8	6.4	9.2
Pigeonpea	-P	0.6	27.6	52.5	0.9	11.7	1.0	46.6	71.5	1.6	16.0
	+P	-0.4	-26.4	5.9	-0.3	0.1	0.5	30.6	62.9	0.4	1.2
Cowpea	-P	0.8	36.5	61.4	0.6	1.8	-0.4	-20.5	4.4	-0.4	0.1
	+P	1.1	61.7	90.8	0.6	1.1	-1.0	-52.4	-23.2	-0.5	-0.3
Soyabean	-P	4.4	207.5	232.4	3.5	6.9	5.6	264.5	289.4	4.5	8.6
	+P	3.6	228.4	261.8	2.0	3.3	5.1	323.4	356.8	2.8	4.4
Groundnut	-P	5.6	261.1	286.0	3.2	5.1	6.0	280.1	305.0	3.5	5.4
	+P	5.8	393.4	429.4	2.8	4.2	4.7	317.4	353.4	2.3	3.4
Bambara	-P	3.2	150.5	175.4	2.6	5.2	5.6	264.5	289.4	4.5	8.6
	+P	3.7	228.9	261.8	2.0	3.3	4.9	304.9	337.8	2.7	4.2

Table 5. What farmers learnt from the field experiments (% of total farmers, n = 56) (multiple answers were allowed).

Things farmers learnt	Category 1 (47%)	Category 2 (36%)	Category 3 (17%)
Methods to apply fertilizer to legumes	73.9	21.1	5.0
That legumes grow better with fertilizer	65.6	24.1	10.3
Processing of legumes for consumption	37.0	51.3	11.7
Use of legumes to improve soil fertility	88.2	10.0	1.8
Planting patterns of legumes (incl. intercropping)	54.8	30.2	15.0
Frequent weeding of legumes	60.9	34.3	4.8
Data collection from experiments	55.6	43.4	1.0
Types of legumes and their benefits	67.0	18.3	14.7
Conducting and explaining experiments	67.4	30.6	2.0

learning together to improve their farming. Category 1 comprised just under half (47%) of the participating farmers. Category 2 farmers were those who were neither active nor passive; the average farmers. These were farmers with mixed feelings that did not want to take chances or be seen to be doing things out of nothing. They contributed to the study but were sometimes unavailable or absent. Category 2 consisted of 36% of the farmers; including three who hosted the experimental plots. The last category (Category 3) of farmers comprised those who required to be reminded of their role in the experimentation, contributing little. Their main reason for involvement was an expectation of receiving inputs such as seed or fertilizer. They comprised 17% of the total group and four of these farmers discontinued their participation. One of the farmers who dropped out of Category 3 hosted an experiment but declined to continue after the field was planted. Accordingly we ended up having eleven groups. The other two experiments from this category were poorly managed despite numerous visits and encouragement from the field assistant.

More farmers from Category 1 learned several things from the process as shown by high percentages for several practices especially the use of legumes for soil fertility (Table 5), indicating their confidence in legumes for soil fertility improvements. Percentages were also high for methods of fertilizer application to legumes, and conducting experiments. The average farmers in Category 2 learned more about the processing of legumes for consumption and also about data collection from experiments. Category 3 had few farmers that had understood these things well. They lagged behind in all steps in the process of participatory evaluation. The high confidence that legumes improve soil fertility was emphasized through lessons on management of subsequent crops (including timely planting and weed management) during follow-up meetings with farmers. Timely planting improves the synchronization of nutrient release from incorporated biomass with maize growth. There is a flush of nutrients at the onset of rains and this can be used properly with timely planting of crops and proper weed management (Giller and Cadisch, 1995).

DISCUSSION

Grain yields and farmers' rationale of legume selection for food

The difference in grain yields between home and middle fields (Figure 2) could be attributed to human factors that included reports of consumption of some grain such as pigeonpea and cowpea before yields were measured and accidental feeding by livestock especially goats which were often tethered within the homes during the crop season. Although strong gradients of decreasing soil fertility are found with increasing distance from the homestead within smallholder African farms, due to differential resource allocation (Tittonell et al., 2005), variable management of experiments by farmers is another critical factor. Poorly managed fields had lower overall yields. Pigeonpea yields were consistently low because of poor germination of seeds resulting in poor crop establishment, and this was more a problem in home fields than middle fields. Phosphorus is an essential element for plant growth, and P deficiency is often found to limit legume growth and yield of legumes, depending on the ability of the soil to supply sufficient P. Responses of the legumes in growth and yield and nutrient uptake to P were observed in these experiments in farmers' fields (Figures 2 - 4).

Since food production is the main objective of most of the farmers, food crops were given precedence over other crops. Selection of a crop for inclusion in the farming system therefore depends on whether or not it is a food crop. In addition, the crop has to be a marketable commodity. However, soil fertility was a concern for many farmers, and consequently their third criterion identified was the ability of a legume to restore soil fertility as observed through biomass production. Although crops like velvet bean gave the highest grain yields, they were not given priority over food legumes in the final score of legumes (Table 3). Velvet bean grain had a small market and is considered a "hunger crop" by most families. If the household was self sufficient in maize, very little interest was given to velvet bean grain. On the other hand, groundnut, Bambara groundnut and cowpea were food legumes that were eaten in most households. Soyabean, pigeonpea and velvet bean however, were relatively new legumes in the area and farmers still need more technical support for production and utilization. Soyabean, for example, is commonly used today by farmers to fortify their diets through production of local bread, preparation of porridge and milk extraction from the grain. Tethered livestock often fed on the biomass before harvest, contributing to low biomass yield.

Economic performance and phosphorus fertilizer application

Economic performance of the legumes was directly linked to legume grain yield since grain was the main source of financial return to the farmer in that year. Legumes that gave high yields had better returns than those that had low grain yields. Although velvet bean gave higher returns to labour, GM and B/C ratio in Table 4 the crop had no immediate food and market value. This reduced the importance of the crop to farmers. Other crops such as pigeonpea, soyabean, groundnut and Bambara groundnut were edible and marketable and returns from them were more meaningful to farmers. Application of P to legumes increased the yields and also improved financial returns, but not enough to cover its cost. The high price of P fertilizer and high cost of labour to apply it reduced its profitability with the legumes. Residual effects of the P fertilizer may continue to contribute yield and financial benefits in the following year or two and thus raise its attractiveness. Although its future is not certain, the Government of Malawi input subsidy programme offers an opportunity to farmers to increase fertilizer use as well as increase food production at present (Denning et al., 2009). The program has made fertilizer available to local markets at government subsidized prices for the production of maize and tobacco. Increased use of P fertilizer would directly increase legume food production especially where proper extension advice to farmers is given.

Farmer evaluation and acceptance of legumes

Farmer evaluation of legumes was based on the legume response to P fertilizer. Discussions below indicate the overall performance of legumes in relation to farmers' preferences. As with other studies in Malawi (Blatner et al., 2000; Snapp, et al., 2002), this work showed that to enhance the adoption of legumes in central Malawi, promotion should emphasize those legumes that have a dual purpose, such as soyabean, pigeonpea and groundnut. Future research in increasing farmer participation in legume production should concentrate on useable grain legumes that also contribute to soil fertility (Waddington et al., 2004). For example, farmers said that velvet bean seed is quite large and appetising to eat, but no one was doing so because of its troubled history and the poisonous nature of the grain (Gilbert, 2000). One farmer pointed out that velvet bean got a lower rank mainly because of the aggregated effects of its aggressive growth habit suppressing maize, the lack of a market for grain, and they rarely could consume it. The ranking of velvet bean at the fourth position emphasises a point, that research-driven farmer participation reveals a number of barriers to both local experimentation with and adoption of legumes such as velvet bean. Velvet bean has been a priority legume for promotion for soil fertility in Malawi following its undisputed improvement of soils on-station and on farm (e.g. Sakala et al., 2003; Waddington et al., 2004), but it has extremely limited end use by farmers and consumers. This study has confirmed that for smallholder farmers, food production is given first priority over soil fertility issues. In one example of an ethnographic quote, Mr Kamangira said, "*nyemba za kalongonda zabwino mmaso, koma poti sitidya, ndibwino kukolora chimanga chochepa kusiyana ndikubyala nyembazi*" (velvet bean seed is good looking, but since we don't eat it, it is better to harvest little maize than to grow velvet bean). Farmers also noted that fertilizing the legumes with P would require extra labour. It would require more time to fertilize a hectare of the legume crops than maize.

Participating farmers realized from this study that growing legumes on fields with a good history of fertilizer application may increase legume grain yield. This was one reason legumes were evaluated for intercropping with maize, which is more beneficial to smallholder farmers (Willey, 1979). Although food production was the priority, farmers felt that soil fertility was an important issue to look at critically. Their high prioritization of legumes that grow well with maize was based on the thinking that while they obtain legume grain, they also maintain the soil with the same legumes. Again, their choices might be influenced by a fast decline of landholding sizes which may call for intensification of agricultural production including better integration of legumes. Ruthenberg (1980) however found that as the population increases and land sizes decrease, rotations, ley farming, and green manures are not likely to be used. Economic values of the different legume crops are important to the farmers to promote legumes in smallholder agriculture. Farmers also observed that velvet bean, with its heavy spreading biomass, forms living mulch which helped to conserve soil moisture until it was incorporated. They linked that to the fast decomposition of velvet bean leaf which they said was good for the soil. The dense biomass coverage over the soil surface was also reported to be excellent in weed suppression in the fields. While farmers' acceptance of legumes was largely based on their visual evaluation in this experiment, P application has other benefits to farmers. In addition to increasing grain and biomass yield, residual effects on subsequent crops have been demonstrated to be beneficial; e.g. Bationo et al. (1992) observed that the response of pearl millet to fertilizer N was higher where P was applied than where it was not. Osiname et al. (2000) showed significant maize yield response to residual P fertilizer in Cameroon. Thus, the application of P often has beneficial effects which farmers cannot observe in the year of its application.

Farmer's knowledge, participation and adoption of technologies

Farmers' knowledge is essential, and tapping into it leads to understanding farmer participation, and understanding farmers' perceptions about crop technologies (Richards, 1986; Bellon, 2001; Tripathi and Ellis-Jones, 2005). Experiments involving legume effects on soil fertility generate relatively complex systems technologies that require end user (farmer) inputs for their modification and wider adoption. Thus the emphasis of our evaluation was to identify knowledge gaps and promote use of the experimental results by farmers. While soil fertility management remains a constraint to smallholder agriculture, the study showed that farmers seek to obtain a minimum maize harvest first, marketable food legume yield second and then benefits to soils. Their knowledge use was in line with realizing that goal while remaining risk averse, over options that conflict with their goals.

Application of P fertilizer to legumes revealed to farmers that legumes do grow and yield better with fertilizer. An important follow on to this was the realization that legumes would therefore likely do better in fields with a good history of fertilizer use. For example, more benefits would be realised if burley tobacco fields (that generally receive fertilizer) were followed by maize planted together with legumes rather than maize alone. Again although velvet bean was not edible, farmers were convinced that its ability to restore soil fertility was the highest among the legume options tested, suggesting that those with more land, and labour, would easily use it for improving soil fertility. Farmers' perceptions, needs and knowledge of legumes point out that there was a likelihood of more adoption of food legumes such as soyabean and groundnut on larger land areas, for reasons that they intercrop reasonably well with maize in addition to producing grain. For example, Mr. Kalivute observed that his maize was better where he continuously planted legumes with maize, and that encouraged him to incorporate more pigeonpea and soyabean into his cropping system as intercrops. Factors that led a few farmers to stop participating in this study were numerous, but the key one was their failure to observe immediate benefits to their soils or crops. One of these farmers had an extremely poor field, where legume growth was heavily limited by the infertility. His initial interest and participation in the project was in anticipation of improved soils at the end, and when he did not easily see that, he decided to pull out. Poor soils may not have a quick fix solution in smallholder agriculture, but continuous engagement with farmers, exploring their knowledge, perceptions and needs, is the only possible way of identifying alternative long term solutions that they are likely to use.

Conclusion

Phosphorus fertilizer increased legume grain and biomass yields in Chisepo. P fertilizer application to legumes likely would increase legume food production and directly increase food and nutrition security of households besides improve soil fertility. However farmers said that application of P fertilizer to legumes was not an immediate option to them because of the high cost of mineral fertilizer. Other major reasons farmers cited were the unavailability of P fertilizer in local markets, its limited profitability in the short term and the need for extra labour to apply P to legumes. Despite observations that P increased legume grain and biomass yields, farmers expressed little interest to adopt P fertilizer for their legumes at the moment. Low interest to adopt P application to legumes was a major reason that P fertilizer application to legumes had limited relevance to their priorities of maximizing food security from their labour investment.

At present, farmers' priority of legume production is given for legume food production, and legumes that provide multiple benefits are likely essential. However with recent changes in demand for legumes for industrial use in Malawi, the availability of P fertilizer in local markets at a relatively low price would attract some farmers to apply P to legumes to increase income, as well as improve legume food production, soil fertility and overall cereal production. It is important therefore for government to deliberately support the supply of P fertilizer to local markets at attractive prices to increase legume food production. While many annual legumes show potential to improve soil fertility, their use by farmers is affected by many other factors including lack of seed, lack of markets for legumes, lack of improved knowledge for proper production and variable performance of legume technologies. Farmers observed that grain legumes grow better in fields with a history of fertilizer use and this may influence field choice for legumes in the future. Thus farmers' participation in the evaluation of legumes helps to explore their perceptions, needs, knowledge and chances that farmers may increase legume food production.

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