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A comparative analysis of phosphorus fertilizer regimes on seed production of Lablab in East and Central Africa

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Abstract

Lablab purpureus is an important forage legume in smallholder crop-livestock systems of East and Central Africa. Seed yields of *L. purpureus* are generally low owing to limited phosphorus levels in most soils. Amendment of soil with phosphorus fertilizers is thus critical in enhancing lablab seed production. The objective of this study was to investigate the effect of varying levels of Phosphorus fertilizers on seed yields and the resulting net benefits associated with each level. The paper examines results from three studies conducted in Uganda (treatments: 0, 15, 30, 40, 60, 80 and 100 kg$P_2 0_5$ ha^{-1}), Sudan (treatments: 0, 94 and 188 kg SSP/ha) and Burundi (treatments: 0, 20, 40, 60 and 80 kgDAP/ha). Generally, amendment of soil with P enhanced seed yield by 27, 18.4 and 4% in Uganda, Burundi and Sudan respectively. The highest increments in seed yield of 40, 27 and 5.3% were obtained at 30 kgP_2O_5, 60 kgDAP and 188 kgSSP Uganda, Burundi and Sudan respectively. Results from dominance analysis indicated that treatments 80 and 100 $kgha^{-1}$ were dominated and their net benefits were lower than that of the control. In Uganda, marginal analysis showed that the marginal rate of return (MRR) from 0 to 15 and 30 kgP_2O_5 was 500 and 700% respectively, while moving from 15 to 30 kgP_2O_5 resulted into a MRR of 274%. The study concluded that the rate of 30kg $P_2 0_5 ha^{-1}$ was the most economically viable rate for seed production in Uganda.

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Introduction

Lablab (*Lablab purpureus* L.) is an important forage legume used to supplement animals fed on low protein grass-based diets in many animal production systems of East and Central Africa (ECA). The nutritive value of the legume is high with crude protein content and digestibility of the leafy component ranging between 21-38 and 55-76% respectively (Cameron, 1988). This makes the legume a suitable option to supplement livestock fed on low protein grass diets. In Uganda, results from a household survey conducted within three districts (Masaka, Mityana and Wakiso Districts) indicated that Lablab was the main forage legume used to supplement lactating animals fed on Napier based diets in smallholder dairy production systems.

Recognized for its drought tolerance (Cameron, 1988), lablab has the potential to offset drought induced feed scarcity, sustain animal physiological processes and increase milk production during drought. This makes the legume a suitable fodder for animal production systems threatened with escalating levels of feed insecurity attributed partly to the increased frequency and severity of droughts. Incorporation of Lablab into farming systems particularly in smallholder crop-livestock systems therefore offers a continuum of benefits ranging from improved crop productivity due to enhanced soil fertility (Maobe et al., 1998) to improved animal productivity emanating from sufficient animal nutrition (Schaaffhausen, 1963).

However, sustaining the production of the legume is greatly constrained by inadequate quantity of good quality seed amongst farmers. This is attributed to the limited understanding of the appropriate agronomic practices, particularly, fertilizer requirements for optimum seed production. Leguminous crops require adequate supply of readily available nutrients, particularly, phosphorus (P) for optimum growth and yield (Yemane and Skjelvag, 2003). Among the essential plant nutrients, P is the most important for seed production. P helps in the formation of an efficient and sound root system which is essential in the uptake of nutrients from the soil. P also plays a key role in plant cell division, flowering, fruiting including seed formation, crop maturation and nodulation (Berg and Lynd, 1985; Pacovsky et al., 1986; Kasturikrishna & Ahlawat, 1999).

Despite its importance in seed production, the appropriate P regimes for optimum production of lablab seed have not been investigated. Scientific investigations on yield responses to various fertilizer regimes usually focus on fertilizer treatments that lead to highest responses in yields with little emphasis on the net economic benefits associated with such treatments. Such studies may be misleading to farmers since increase in yields does not necessarily lead to increase in incomes (net benefits) as high investment may be needed to achieve additional yields. It is therefore necessary for farmers to know how much additional income can be generated by investing more resources into a given technology. Farmers are often willing to adopt new forage technologies only when they can see a financial benefit in the short to medium term. Researchers need to provide supporting evidence that investment in new forage technologies makes a difference not only to livestock production but also to household income. The objective of this study was to investigate the influence of varying levels of phosphorus fertilizers on lablab seed production as well as to establish the net benefits associated with each level.

Materials and methods

Study sites

Three experiments to evaluate varying Phosphorus regimes on Lablab seed production were conducted in Uganda, Sudan and Burundi. In Uganda, the study was conducted at the National Crop Resources Research Institute (NaCRRI) located at 00 32'' N of the Equator and 320 37'' E. NaCRRI is at an elevation of 1150 meters (3780 ft) above sea level and has a tropical wet and mild dry climate with slightly humid conditions (average 65%). The area gets fairly uniform temperatures throughout the year with the highest mean monthly temperature of 27.7ºC during the dry season and the lowest of 21.3ºC during the wet season. NaCRRI is located within the bimodal rainfall region with the first and second rains occurring between February to June and August to December respectively. In Bulundi, The experiment was conducted at Moso, ISABU Research Station located in the southern part of Burundi. The site experiences a sub-humid tropical type of climate and a bimodal rainfall pattern. The short and lighter rains start from October to January and the long and heavy rains start from February to May with a peak in April. In Sudan, the study was carried out at the Gezira Research Farm of the Agricultural Research Corporation, Wad Medani, Sudan ("latitude 14º 24′N and longitude 33º 29′ E). The altitude is 406.9 m above sea level with average annual rainfall of 200-300 mm falling during July to September. Maximum temperature ranges from 33 ºC in January to 42 ºC in May, while minimum temperature ranges from 14 ºC in January to 25 ºC in June. The relative humidity is low during most of the year. Wind speed is slow as it is generally 2-3 m/s at 2 m height.

Experimental setup, data collection and analysis

In Uganda, the experiment involved twenty one experimental plots (5 x 5m each) arranged in a completely randomized block design with three replications. Phosphorus fertilizers in form of single supper phosphates (SSP) constituted the treatment at seven levels: 0, 15, 30, 40, 60, 80 and 100kgP_2O_5 ha^{-1}. The fertilizers were applied by broadcast and incorporated into the soil at sowing and the plants were sown at a spacing of 1 x 1 meter. The experiment in Burundi involved fifteen plots (5 x 5m each) also arranged in a completely randomized block design with three replications. Phosphate fertilizers in form of Di-ammonium phosphate (DAP: 18% - 46% - 0%) constituted the treatment at five levels: 0, 20, 40, 60 and 80 DAP kg ha^{-1} and were applied by broadcast and incorporated into the soil at sowing. In Sudan, the effect of P on seed production was evaluated using three P levels: 0, 94 and 188 kgSSP ha^{-1} arranged in a completely randomized block design with four replications. The fertilizers were applied at sowing and plants were irrigated every 10-14 days. Data was collected on days to first flowering, days to 50% flowering, number of flowers per plant, number of pods per plant, number of seeds per pod and seed yield. Days to 50% flowering was estimated by counting the number of days from sowing date to when 50% of plants had flowered. The number of days from sowing date to appearance of the first inflorescence in each plot was used to determine the number of days to first flowering. To determine the number of seeds in pods, 30 pods were selected randomly from a bunch of pods harvested per plot and the number of seeds in each pod counted. Mature lablab seeds were picked by hand. The pods were dried, threshed, and the seed cleaned. The seeds obtained per plot were dried at 12% moisture and weighed to obtain seed yield. The data was analyzed by analysis of variance using the general linear procedure of XLSTAT (2011).

Economic analysis

The net benefits associated with the different phosphorus regimes investigated in Uganda were also quantified to aid farmers' decisions on selection and adoption of appropriate P regimes. The economic analysis involved estimation of costs that vary, gross field benefits and net benefits as discussed in the subsequent sections.

Calculation of costs that vary

The costs that varied with treatments included costs incurred (per hectare) in purchase, transportation and application of different quantities phosphate fertilizers. The cost incurred in transportation of fertilizers was factored into the cost incurred to purchase fertilizers. Consequently, the costs that varied for the different treatments were of two types: 1. costs incurred (per hectare) in purchase of fertilizers and (2). Costs incurred for labor during application of fertilizers. The total costs that vary for each treatment were then calculated by summing up the two types of cost as described by (CIMMYT, 1989). The average cost of a 50kg bag of SSP from agro-input outlets was Uganda shillings (Ug. shs) 100,000 and the average transportation cost of each 50kg bag to farmers' fields from the nearest agro-input outlets was Ug. shs 5000. Hence the cost of purchasing and transporting a 50kg bag was Ug. shs 105,000. The SSP fertilizer contained 20% of P_2O_5 implying that there were 10 kg of P_2O_5 in the 50 kg bag. The cost (Ug. shs 10,500) of each kilogram of P_2O_5 was therefore obtained by dividing Ug. shs 105,000 by 10. The average cost of applying a 50 kg bag of SSP was Ug. shs 5000 and since each bag contained 10 kg of P_2O_5, it implied that each kg of P_2O_5 was being applied at a cost of Ug. shs 500. We therefore multiplied Ug. shs 10,500 by the amount of P_2O_5 ($kgha^{-1}$) to obtain the costs incurred in purchase of fertilizers. Also, Ug. shs 500 was multiplied by the amount of P_2O_5 ($kgha^{-1}$) to obtain the cost incurred for labor. The two costs were then summed up to obtain the total costs that vary per treatment. To allows comparisons of costs across currencies, the costs were quantified when 1 US$= Ug. shs 2800.

Estimation of gross field and net benefits

Assessment of Lablab yields on farmers' farms within the area revealed that farmers' yields were 20% lower than the yields obtained on experimental sites. We therefore adjusted the yield achieved in the experiment by reducing it by 20% to represent actual yield scenarios experienced by farmers. The average cost of 1kg of Lablab seed was estimated at Ug. shs 4000 and this was multiplied by the adjusted seed yield to obtain the gross field benefits from seed sales. The total costs that vary per treatment were subtracted from the gross field benefits to obtain the net benefits per treatment.

Results

Soil characteristics

The pH in water for experimental sites ranged from 5.6 (weakly acid soil in Uganda), 6.21 (near neural soil in Burundi) to alkaline soils in Sudan (Table 1). The organic matter content of the soils ranged from 0.8 to 3.32 with Burundi and Sudan having low levels of soil organic matter. The amount of soil nitrogen (N) in Uganda and Sudan was below the critical N level (0.2%) required for adequate plant establishment and growth. The amount of available extractable P was low in Uganda and Sudan but moderate in Burundi. The concentration P-fixing ions (Mn^{+2}) was high in Uganda and was far above the average level (200 ppm) of Mn^{+2} reported for most soils in Uganda.

Table 1. Chemical properties of the top soil (0 -20cm) of the experimental site.

Variable	Countries			Method of analysis
	Uganda	Burundi	Sudan	
pH (H_2O)	5.6	6.21	8.7	pH meter
OM (%)	3.21	1.67	0.8	Walkley-Black method
N (%)	0.15	0.34	0.17	Kjeldahl method
Av. P ($mgkg^{-1}$)	2.25	6	3.5	Bray 1
Fe (ppm)	162.2	-	-	AAS
Mn (ppm)	318.3	-	-	AAS

Av.P: Available extractable P

AAS: Atomic Absorption Spectrophotometer

Flowering characteristics, seed yield and yield components

Although addition of varying levels of P did not have a significant effect on the number of days to first and 50% flowering, the mean number of days to flowering (both first and 50%) for plots amended with P were less than those of the control by one day in Uganda and Burundi. P fertilization significantly ($p<0.05$) increased the number of flowers per plant by 13% with the highest number of flowers (19) being obtained at 80 kgP_2O_5 in Uganda. The mean seed yield from all plots amended with P was 1588, 3503 and 450 $kgha^{-1}$ in Uganda, Burundi and Sudan respectively (Table 2).

Table 2. Effect of varying regimes of phosphorus fertilizers on flowering and seed production components of Lablab.

Country	Trts	D-1	D-50	NBP	NFP	NPP	NSP	SY (kg/ha)
Uganda	0	76^{a}	90^{a}	4.2^{a}	16^{cd}	134^{a}	3.7^{a}	1253^{a}
	15	74^{a}	90^{a}	4.5^{a}	16^{cd}	149^{a}	3.9^{a}	1560^{a}
	30	75^{a}	89^{a}	5.6^{b}	17^{bc}	150^{a}	3.9^{a}	1753^{a}
	40	76^{a}	90^{a}	4.2^{a}	18^{ab}	141^{a}	3.9^{a}	1380^{a}
	60	74^{a}	88^{a}	4.4^{a}	18a^{b}	146^{a}	3.9^{a}	1560^{a}
	80	75^{a}	89^{aa}	4.7^{a}	19^{a}	156^{a}	4.0^{a}	1680
	100^{a}	76^{a}	90^{a}	4.6^{a}	15^{d}	150^{a}	3.9^{a}	1593
	Mean	75	89	4.6	17	147	3.9	1540
Burundi								
	0	105^{a}	126^{aa}	5.3^{b}	-	154^{a}	3.3^{a}	2960
	20	103^{a}	124^{a}	4.3^{ab}	-	161^{a}	3.5^{a}	3360^{a}
	40	103^{a}	124^{a}	4.2^{ab}	-	157^{a}	3.3^{a}	3147^{a}
	60	106^{a}	124^{a}	4.3^{ab}	-	169^{a}	3.4^{a}	3760^{a}
	80	103^{a}	126^{a}	4.6^{a}	-	167^{a}	3.5^{a}	3747^{a}
	Mean	104	125	4.17	-	163^{a}	3.4	3395
Sudan								
	0	90^{a}	105^{a}	3.3^{a}	-	16.1^{a}	3.4^{a}	433^{a}
	94	89^{a}	107^{a}	3.7^{a}	-	14.8^{a}	3.6^{a}	444^{a}
	188	89^{a}	106^{a}	3.8^{a}	-	15.9^{a}	3.4^{a}	456^{a}
	Mean	89	106	3.6	-	15.6	3.47	444.3

D-1 day to first flowering, D-50 days to 50% flowering, NBP number of branches per plant, NFP number of flowers per plant, NPP number of pods per plant, NSP number of seeds per pod, SY seed yield. a,b,c,d Means with different superscripts in the same column per country are significantly different ($p<0.05$).

Amendment of soil with P therefore enhanced yield by 27, 18.4 and 4% in Uganda, Burundi and Sudan respectively. The highest increments in seed yield of 40, 27 and 5.3% were obtained at 30kgP_2O_5, 60kgDAP and 188kgSSP in Uganda, Burundi and Sudan respectively. However, the yield improvements in all countries were not significant. P fertilization also increased the number of pods per plant by 11% in Uganda with plots amended with 80kgP_2O_5 producing the highest increment (16.4%). Conversely, P fertilization led to a decline in number of pods per plant by 5% in Sudan. The number of seeds/pod was noted to increase with P fertilization but the responses was non-significant. Correlation analysis indicated significant positive relationships between seed yield with the number of branches per plant ($r=0.41$, $p = 0.004$), number of pods per plant ($r=0.29$, $p = 0.049$) and number of seeds per pod ($r= 0.39$, $p = 0.007$) in Sudan (Table 3). The same trend was observed in Uganda but the relationships were non-significant except for the correlation between seed yield and number of seeds per pod ($r=0.444$, $p = 0.044$). Seed yield, however, showed a negative but non-significant correlation ($r= -0.38$, $p = 0.17$) with the number of branches per plant in Burundi.

Table 3. Correlation tests between seed yield and seed yield components.

Country	Variables	Variables			
		No. of branches	No. of pods/plant	No. of seeds /pod	Seed yield (kgha⁻¹)
Sudan	No. of branches	r=1	r=0.62***	r=0.16	r=0.41*
	No. of pods/plant	r=0.62***	r=1	r=0.01	r=0.29*
	No. of seeds /pod	r=0.16	r=0.01	r=1	r=0.39**
	Seed yield (kgha⁻¹)	r=0.41**	r=0.29*	r= 0.39*	r=1
Uganda	No. of branches	r=1.	r=0.18	r=0.071	r= 0.38
	No. of pods/plant	r=0.18	r=1	r=0.053	r=303
	No. of seeds /pod	r=0.071	r=0.053	r=1	r=0.444*
	Seed yield (kgha⁻¹)	r= 0.38	r=0.303	r=0.444*	r=1
Burundi	No. of branches	r=1	r=0.071	r=0.071	r=0.38
	No. of pods/plant	r=0.17	r=1	r=0.071	r= 0.58
	No. of seeds /pod	r=0.071	r=0.071	r=1	r=0.41
	Seed yield (kgha⁻¹)	r= -0.38	r= 0.58	r= 0.41	r= 1

*Significant at $p<0.05$, ** Significant at $p<0.005$, ***Significant at $p<0.0001$

Economic analysis

The highest net benefits of Ug. shs 5,279,000 and Ug. shs 4,827,000 were obtained at 30 and 15 kgP_2O_5 respectively (Table 4). The net benefits at 30 and 15 kgP_2O_5 were 32 and 20% higher than the benefits at 0 kgP_2O_5. Dominance analysis indicated that the net benefits of treatments 40 (3,976,000) and 100 kgP_2O_5 (3,997,600) were lower than the net benefit of treatment 0 kgP_2O_5 where the total costs that vary were actually zero. Raising the amount of P from 0 to 30 kgP_2O_5 led to an increment in net benefits beyond which further increment in the amount of P resulted in a decline in net benefits. The marginal rate of return (MRR) from 0 to 15 and 30 kgP_2O_5 was 500 and 700% respectively, while moving from 15 to 30 kgP_2O_5 resulted into a MRR of 274%.

Discussion

Flowering characteristics, seed yield and yield components

P fertilization increased seed yield. Numerous studies have also reported similar findings for a number of legumes (French, 1990; Bolland et al., 2001). The increment in the seed yield in response to increasing P levels was attributed to an increase in the number of branches which subsequently increased the number of reproductive nodes. The increased number of reproductive nodes is associated with an increase in the number of pods per plant and hence seed yield. Yemane and Skjelvag (2003) also reported a strong positive correlation between seed yield and number of branches m^{-2} in *Pisum sativam var. abyssinicum*. The high concentration of P-fixing ions (Mn^{2+}) in Ugandan soils is partly responsible for the non-significant response of Lablab to phosphorus fertilizers. Brady (1990) noted that presence of high concentration of P-fixing ions (such as Mn^{2+}) in acidic soils results in fixation of inorganic phosphorus rendering it unavailable for plant uptake. During the P-fixation process, the ions and/or hydrous oxides of Mn^{2+} adsorb P ions forming insoluble compounds. In Sudan however, the alkaline conditions (pH>8) have been reported to favor P-fixation by calcium compounds rendering it unavailable for plant uptake despite amendment of alkaline soils with inorganic phosphorus. Further, the limited soil moisture and the low levels of soil nitrogen could have limited plant response to P in Sudan.

Table 4. Cost-benefit and dominance analysis table for varying P levels.

	Treatments (kgP_2O_5)						
	0	15	30	40	60	80	100
Seed yield ($kgha^{-1}$)	1253	1560	1753	1380	1560	1680	1593
Adjusted yield ($kgha^{-1}$)	1002	1248	1402	1104	1248	1344	1274
Gross field benefits	4,009,600	4,992,000	5,609,600	4,416,000	4,992,000	5,376,000	5,097,600
Cost of fertilizer (Ug. Shs ha^{-1})	0	157,500	315,000	420,000	630,000	840,000	1,050,000
Cost of application	0	7500	15000	20,000	30,000	40,000	50,000
Total costs that vary	0	165,000	330,000	440,000	660,000	880,000	1,100,000
Net benefits	4,009,600	4,827,000	5,279,000	**3,976,000D**	4,332,000	4,496,000	**3,997,600D**

[D] Dominated treatments, 1 US$=2800 Uganda shillings

Economic analysis

CIMMYT (1989) noted that the minimum marginal rate of return acceptable to farmers before making a decision to change from an old practice to a new practice is 50%. In this current study, the MRR from 0 to 15 and 30 kgP_2O_5 were 500 and 700% respectively, all far beyond 50%. This implied that when a farmer invested one shilling as an additional cost to change from 0 to 15kgP_2O_5, the farmer would recover the one shilling and an additional five shillings as profit. Likewise, when a farmer invested a shilling as an additional cost to change from 0 to 30 kgP_2O_5, the same farmer would recover the one shilling and an additional seven shillings as profit. This is to say, when a farmer invested Shs 330,000 as costs incurred in buying and application fertilizers at a rate of 30 kgP_2O_5, the farmer would obtain Shs 2,310,000 (330,000 * 7) as profit in addition to recovering the invested Shs 330,000. The results of dominance analysis revealed that it is not profitable to apply P fertilizers beyond 30 kgP_2O_5 since the achieved net-benefits are lower than those achieved at 30 kgP_2O_5 but involve investment of more inputs and hence costs.

Conclusion

From the results obtained, it can be concluded that presence of high concentration of P-fixing ions (particularly Mn^{2+}) possibly limited Lablab response to P-fertilizers in acidic soils of Uganda. In such soils, amendment with organic materials (manures) would enhance availability of phosphorus. Organic materials form complexes with P-fixing ions rendering phosphorus available to plants. In Sudan, a combination of factors including soil alkalinity, limited N and moisture limited Lablab response to P fertilization. The application of P at 30 kgP_2O_5 is most profitable and hence recommended since it is associated with higher net benefits and Marginal rate of returns.

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