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On Farm Yield Responses of Soybean [*Glycine max* L. (Merrill)] to Fertilizer Sources Under Different Soil Acidity Status in Gobu Sayo District, Western Ethiopia

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ABSTRACT
The study was conducted on fourteen on-farm fields under rain fed in Gobu sayo district to evaluate the responses of phosphorus application with rhizobium inoculations under different soil acidity, available phosphorus and potassium. The experimental sites were purposively selected from three different peasant associations and the trials were laid out on plots of N-deficient sites that were more or less homogenous. The treatments were Didessa (+P+R), Ethio-ugozilavia (+P+R), Didessa (-P-R) and Ethio-ugozilavia (-P-R). The result of soil analysis showed that all experimental sites were strongly acidic and available phosphorus and exchangeable potassium were found to be from low to medium ranges and considerably affected yield and yield traits of the test crop. Significant variations in plant height, pods per plant, grain and husk yield due to the effect of applied inputs. However, there was significant difference between varieties in terms of nitrogen uptake, 100 seed weight and oven dry weight of husk. Even if the inputs revealed significant effects on yield traits, the responses were not consistence across each farmer's plot and resulted in considerable yield variability which ranged from less than 1 t to more than 5.8 t. Variations in Soil pH, available phosphorus and exchangeable potassium across farmers' plots significantly influenced yield variability and the effects of input applications on each variety. Yield was positively and significantly correlated to initial soil pH, available phosphorus and exchangeable potassium. In conclusion, application of 50 kg ha^{-1} DAP in combination with rhizobium inoculation is recommended for in production in areas where soil pH is near to neutral. However, it needs more attention should be given to optimize soil pH as the majority of the farms were strongly acidic. Moreover, revision of phosphorus fertilizer rates and determination of potassium sources of fertilizer is another concern for sustainable production of soybean in the area.

Key words: Soybean, phosphorus, rhizobium strain, soil pH

INTRODUCTION

Soybean is one of the most important oil grain legume crops in the world. In the international trade market, soybean is ranked number one among the major oil crops (Ramteke *et al*., 2010) with an average protein content of 40% on dry matter basis. Soybean has the highest protein content of all field crops and is second only to groundnut in terms of oil content (20%) among the food legumes (Ahiabor *et al*., 2014; Chung and Singh, 2008).

Soyabean in Ethiopia could be grown from sea level up to 2200 m altitude and with annual rainfall as low as 500-700 mm but performs best between 1300 and 1800 m altitude with annual rainfall of 900-1300 mm, an average annual temperature between 20-25°C and a soil pH of 5.5-7 (Gurmu, 2007). In 2013 cropping season of 11.1% of total area nationally covered by pulse crops, about 2% (31,900 ha) was covered by soybean (CSA., 2013). However, more than 44% of soybean production in the country is produced in Oromia region, particularly in Western and Eastern Wollega and Illu-ababor zones (CSA., 2013). The majority of the product is consumed for local processing factories like tasty soya, fafa food factories though local consumptions, particularly in Ilu-ababor zone (Chewaka areas) are also common. The community used as parts of their dish in the form of porridge, milk, local 'Wot', Bread, 'Injera' and other different recipes prepared locally.

Despite the economic and food security importance of this crop, actual smallholder farm yields are by far below the potential production. For instance, the national average yield of soybean varied from 1.8 t ha^{-1} (2012) to 2 t ha^{-1} (2013) while the potential yield at research and farmers' field are 3.5 and 2.6 t ha^{-1} (MARD., 2012), respectively. In spite of this many biotic and a biotic factors contribute to the low yield of these nitrogen and phosphorus are the main factors that significantly reduce the production and productivity of legume crops (Kamara *et al.*, 2007; Tahir *et al.*, 2009). The low availability of phosphorus nutrition in soils has become the limiting factor for plant and root growth (Zafar *et al.*, 2013). Phosphorus has a key role in the energy metabolism of all plant cells and particularly in nitrogen fixation as an energy requiring process (Jones *et al.*, 1977). Legume plants that depend on biological N_2 fixation for their N supply require more P and other macro and micro nutrients than plants receiving fertilizer N since the reduction of atmospheric N_2 by the nitrogenous system is a very energy-consuming process and more P and other nutrients are needed for symbiotic N fixation than for general plant metabolism (Israel, 1987). Nitrogen is the most important nutrient for crop production and its deficiency occurs in most countries of the world (Tahir *et al.*, 2009). Therefore, the efficient use of mineral fertilizers to infertile soil is recognized to be a quick and direct way of boosting crop production (Tarekegne and Tanner, 2001).

Moreover, acidic soils cause poor plant growth resulting from aluminum (Al^{+3}) and manganese toxicity (Mn^{+2}) or deficiency of essential nutrients like phosphorus, calcium and magnesium. Suitability of soils as a medium for crop growth and development considerably depend on its reaction. Availability of essential nutrients and biological activity in soils are generally the greatest at intermediate pH at which organic matter break down and release of essential nutrients like N, P and S are enhanced (Jensen *et al.*, 2012). Therefore, restoring, maintaining and optimizing soil properties to improve fertility of this soil are major priorities as a demand of food and raw materials are increasing rapidly. The objective of this study was, therefore, to determine the effect of phosphorus application and strain inoculations on yield of soybean under different soil acidity condition and its influence on input application.

MATERIALS AND METHODS

Site selection and land preparation: The experiment was conducted on fourteen farmers'' field under rain fed conditions starting from May 2013. The study area is located in Gobu sayo district and geographically found between 09.0227-9.13361°N and 036.98643-037.01599°E with an altitude ranged from 1592-1907 m above sea level. The area receives an average annual rainfall of 1237 mm with maximum precipitation (85%) being received in the months of May to August while the annual rain fall in the 2013 cropping season was 1431 mm (Fig. 1). It has a warm humid climate with annual mean minimum and maximum air temperatures of 13.5 and 29.7°C, respectively.

The experimental plots were purposively selected from 3 different Peasant Associations (PA) and 5 farmers from each PA on the basis of the previous years cropping history, soil fertility status and similarities on slopes and other features. Particularly, the trials were laid out mostly on plots of N-deficient sites not very steep.

Experimental plot preparation and layouts: The experimental plots were finely prepared by the host farmers through the supports of Development Agents (DA). The plots were plowed three to four times at different time intervals. An area of 10×10 m of four plots per farmer's plot was delineated and the distance between each plot and block was 1 m apart. Plot arrangements were done depending on the slope of the selected sites, upper parts were allocated for uninoculated plots where as the lower parts were allocated for the inoculated plots.

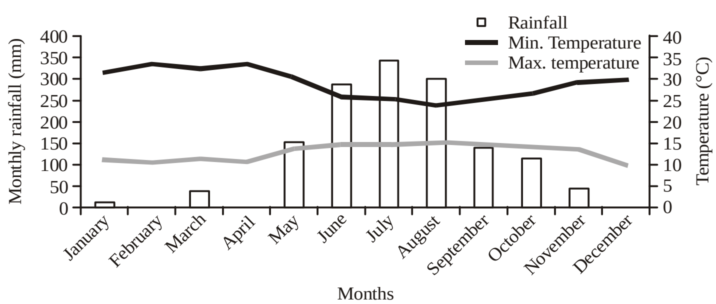

Fig. 1: Monthly weather data of Bako Agricultural Research Centre (BARC) in 2013 cropping season

Released soybean varieties, Didessa and Ethiop-ugozilavia were used for the experiment. Rhizobium inoculation was used for each variety in addition to application of 50 kg ha^{-1} DAP where as the control plot (negative inputs) for each variety was also planted on each farmer's field. The treatments were Didessa (+P+R), Ethio-ugozilavia (+P+R), Didessa (-P-R) and Ethio-ugozilavia (-P-R). The fertilizer was banded 10 cm away from seed rows at the time of planting. The inoculants were applied using recommended rates and procedures just at the time of planting. The uninoculated seeds were first sown in the prepared rows while the inoculated seeds were also immediately planted by avoiding exposure to sunlight. Farmers were considered as blocks.

Soil sampling and analysis: Before planting, 8 sub-sample of soil were taken from each farmer's plots at 10-15 cm depth and composite sample was made to take representative sample for physico-chemical analysis. The samples were air dried and prepared for the analysis and finally soil pH (1:2.5 H_2O) by using a digital pH meter (Page, 1982) available phosphorus (mg kg^{-1} soil) using Bray-II method (Bray and Kurtz, 1945) and exchangeable K (mg kg^{-1}) of soil were analyzed. Other soil physical and chemical properties were also analyzed though not included in this report.

Collected data

Tissue dry weight: Plant tissues were collected from 10 destroyed plants at the time of flowering. The tissue was oven dried at 70°C for 48 h until constant dry weight and the weight was finally measured using electrical sensitive balance.

Nitrogen in tissue dry weight: Total nitrogen in dried tissue sample was determined by Kjeldahl method in order to determine the nitrogen uptake by each variety under different treatments and farming systems.

Yield and other yield traits: Plant height, pods per plant, grain, husk and hulm yield weight were taken. Finally oven dry weight of husk and hulm were taken after oven dried for 48 h at 70°C to constant dry weight and then sample were measured using electrical sensitive balances.

Statistical analysis: The data was subjected to analysis of variances using GenStat-15 software. Means were separated using Least significant value at p = 0.05 probability level. Sigma plot version 10 was used to sketch bar graphs where as scatter plots and correlation analysis were done using Microsoft excels software.

RESULT AND DISCUSSION

Growth traits: Analysis of variances (ANOVA) revealed that variations in peasant association and history of each farmer's

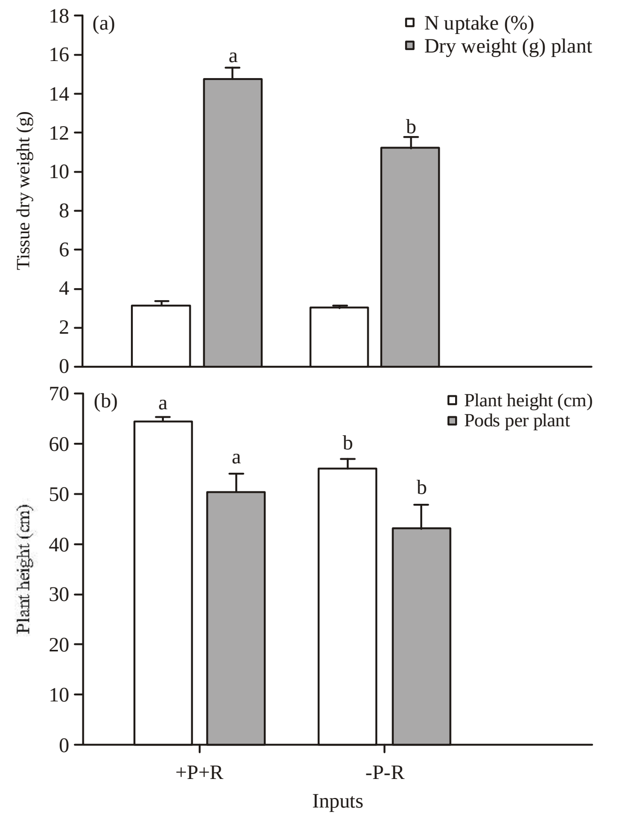

Fig. 2(a-b): Effect of phosphorus application and rhizobium inoculation on nitrogen uptake, (a) Tissue dry weight and (b) Plant height and number of pods per plant of soybean at farmers' field, 2013

Table 1: Analysis of variances for growth and yield components of soybean as affected by different input application on soybean at farmers' field

		F probability values			
Source of variation	df	PH	N-uptake	TDW	PP
PA	2	0.016*	0.219	<0.001**	<0.001**
Inputs (In)	1	<0.001**	0.119	0.008**	<0.001**
Var	1	0.060	<0.001**	0.905	0.628
PA.In	2	0.779	0.072	0.621	0.507
PA.var	2	0.041*	0.448	0.343	0.125
In.var	1	0.846	0.554	0.860	0.573
PA.In	2	0.458	0.768	0.678	0.399
Farmer (rep)	13	0.001**	0.079	<0.001**	<0.001**

*Significant at p = 0.05, **Highly significant at p = 0.001, PA: Peasant Association, Var: Variety, df: Degree of freedom, PH: Plant height (cm), N-Uptake: Nitrogen uptake (%), TDW: Tissue dry weight/plant (g), PP: Pods per plant

field were highly (p<0.001) affected plant height, tissue dry weight and number of pods per plant (Table 1). Application of inputs revealed significant changes in plant height, tissue dry weight and pods per plant where as nitrogen uptake was significantly different between varieties (Table 1).

Considerably 18 and 21% increases in plant height and number of pods per plant were recorded when compared with the control (Fig. 2). This result is in agreement with other

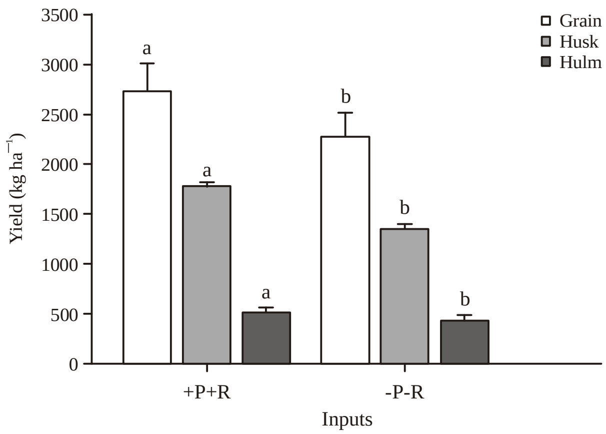

Fig. 3: Effect of phosphorus application and strain inoculation on grain, husk and hulm yields of soybean at farmers' field, 2013

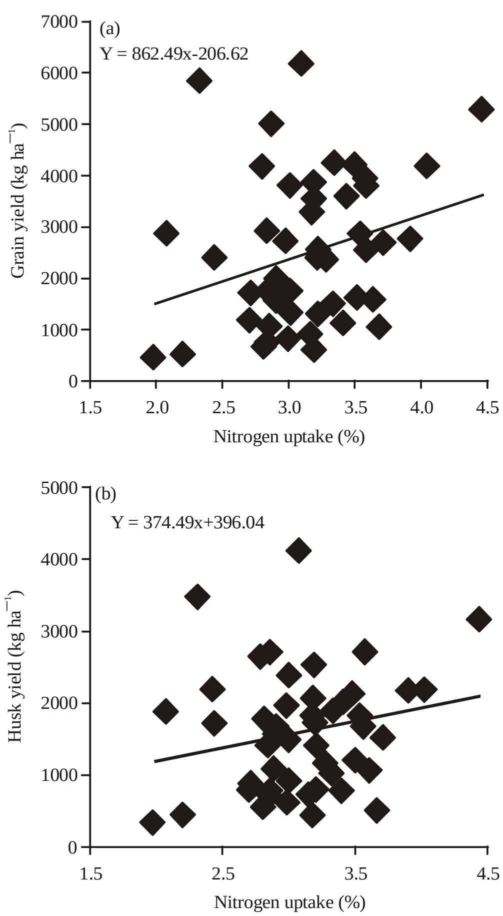

Fig. 4(a-b): Relationship between (a) Nitrogen uptake and grain and (b) Husk yield

reports revealed that the presence of available phosphorus and inoculants results in marked differences in dry matter accumulation between plants (Singleton *et al*., 1985).

Similarly, significant accumulation of tissue dry weight per plant was recorded under applied inputs and the increase was 36% over the control (Fig. 1). Even though N- uptake was not significant due to input application, the uptake is numerically better by 7% than as compared to untreated plot. However, Didessa variety was significantly superior in N uptake as compared to Ethio-ugozilavia regardless of inputs variations (Fig. 2). This might attributed to the differences between varieties in their genetic and other morphological characters particularly root numbers and distribution which might directly contribute for maximum absorption of the nutrients (Vadez *et al*., 1999).

Yield and yield traits: The results of analysis of variances revealed that variations between locations (peasant association) highly ($p<0.001$) affected all traits except hulm weight and dry weight of husk. Both 100 seed weight and oven dry weight of hulm were significantly varied between varieties whereas, grain, husk and hulm yields were statistically at par. However, application of phosphorus in the form of DAP and rhizobium inoculations showed significant increases of grain, husk and hulm yields over the control regardless of varietal differences. However, interaction effects were not significant.

Highly ($p<0.01$) variable yield and yield traits were also caused by variation in farmers' practices or farmers' land history (Table 2). Pooled mean of grain yield indicated that a significant increase in 21% over the control was obtained when inputs (+P+R) were applied to the test crop (Fig. 3). In other words, a ton could be increased due to the effect of rhizobium and P fertilizer application as compare to control.

The result of correlation and regression analysis also confirmed that there were a strong and positive correlation between nitrogen uptake to husk and final grain yield, indicating that inoculation and application of P fertilizer to the crops significantly enhance the productivity of the crop. For instances, an increase in one unit of nitrogen uptake positively increased by 862 and 374 kg ha^{-1} of grain and husk yields, respectively (Fig. 4).

This result and other similar reports indicate that adequate supply of phosphorus in combination with bio-fertilizer which in turn increased the carboxylation efficiency and the ribulose-1-5-diphosphate carboxylase activity, thus results in increased photosynthetic rate, growth and finally grain yield (Fatima *et al*., 2006; Tahir *et al*., 2009). In addition to grain yield, both husk and hulm yield were significantly affected by inputs applications. It is possible to harvest from 1.6-2 t ha^{-1} of husk yield from treated plots whereas, 1.1-1.6 t ha^{-1} could be obtained from control plot. However, pooled mean revealed that a significant increase by 32% of husk yield was harvested when the inputs were used (Fig. 3). Even though, hulm yield was lower than husk yield as all the leaves were fall down to the ground as litter fall at the time of harvesting, the remaining parts (stem parts) was significantly affected by treatment variations. Statistically significant hulm yield (508 kg ha^{-1}) was recorded when the test crop was supplied by both inputs and the increase was more than 19% over the control.

Table 2: Analysis of variances for growth and yield components of soybean as affected by different input application on soybean at farmers' field, 2013

		F probability value					
Source of variation	df	GY	Husk (wt)	Hulm (wt)	100 (sw)	ODW-hulm	ODW-husk
PA	2	<0.001**	<0.001**	0.155	<0.001**	<0.001**	0.088
Inputs (In)	1	0.044*	0.002*	0.025*	0.370	0.623	0.818
Var	1	0.446	0.796	0.740	<0.001**	0.014**	0.293
PA.In	2	0.267	0.515	0.218	0.754	0.024*	0.843
PA.var	2	0.590	0.914	0.139	0.338	0.304	0.862
In.var	1	0.586	0.494	0.745	0.589	0.291	0.608
PA.In	2	0.738	0.746	0.345	0.609	0.877	0.242
Farmer (rep)	13	0.005*	0.008*	<.001**	0.005**	0.001**	0.019*

PA: Peassant association, Var: Variety, df: Degree of freedom, GY: Grain yield (kg ha^{-1}); Husk Wt: Husk weight (kg ha^{-1}); Hulm wt: Hulm weight (kg ha^{-1}), 100 sw: 100 seed weight (g), ODW hulm: Oven dry weight of hulm (g), ODW husk: Oven dry weight of husk (g)

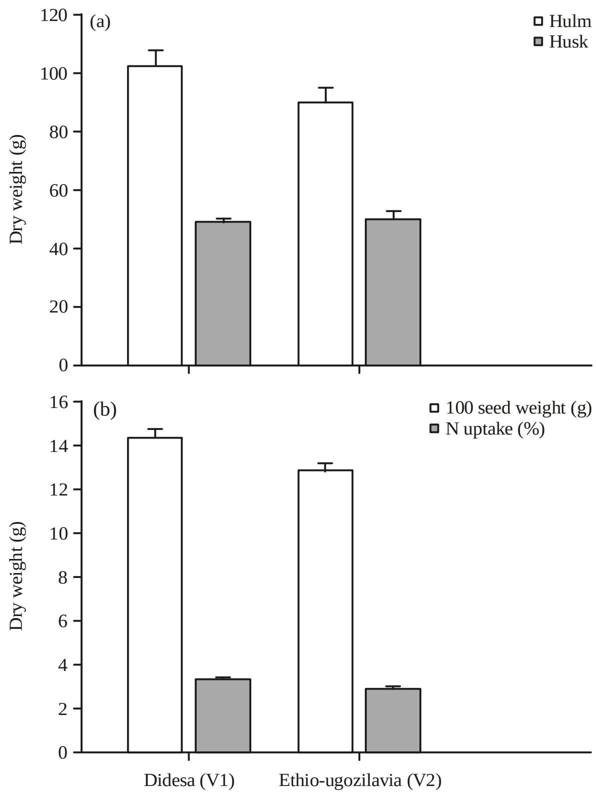

Fig. 5(a-b): Effect of soybean varieties on (a) Hulm and husk dry weight and (b) 100 seed weight and nitrogen uptake soybean at farmers' field

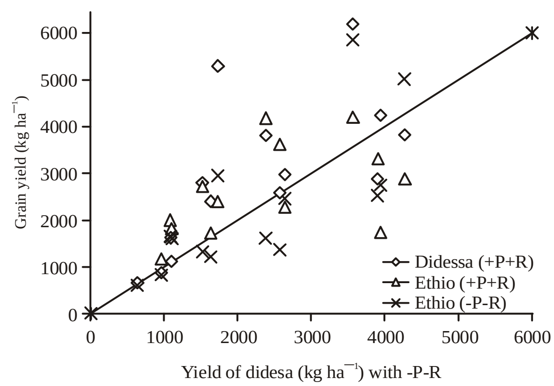

Fig. 6: Response of soybean grain yield (kg ha^{-1}) to inoculation and/or P treatments at farmers' field of Gobu Sayo District

However, oven dry weight of husk and hulm, 100 seed weight and nitrogen uptake was significantly varied between varieties. Didessa varieties produced significantly more hulm dry weight and 100 seed weight as compared to Ethio-ugozilavia (Fig. 5).

Yield variability across farmers' field: Even though mean yield and other traits revealed a significant effect as a result of phosphorus application and inoculation, the responses to inputs were not uniform across farmers' field (Fig. 6). For instance, more than 64% of the farmers obtained lower yield when Ethio-ugozilavia was planted without inputs. In contrast, the highest yield (5.8 t ha^{-1}) was also recorded from the same variety of the crop under the same input applications.

The response of Didesa variety across the farmer's plots was higher as compared to Ethio-ugozilavia, even if at some farmers' fields (15%) showed no response to the applied inputs. Under the same treatment, yield of Didessa variety significantly varied from 551-6206 kg ha^{-1} across the different smallholder farmer's plots, thus indicating differences in soil fertility, pH or agronomic management practices or other factors between farmer's plots (Fig. 6).

On the other hand, the degree of the response to the inputs by different varieties of the crop across different farmers' plots management, in addition to the initial soil pH and fertility status varied from 551 and 672 kg ha^{-1} to 6206 and 4221 kg ha^{-1} yield for Didessa and Ethio-ugozilavia, respectively (Fig. 6).

This variable yield performance might attributed by different factors like the soil fertility status, variation in degrees of farmers' management practices, soil acidity, differences in effectiveness of the inoculant across farms and other related factors. The result of correlation analysis for soil pH and available phosphorus to grain yield of soybean to input application revealed that there is a confounding effect on the response of the crop. The response of the input (+P+R) was linearly increased as the function of increasing soil pH across each farmer's field. Didessa variety was more responsive to the inputs in areas where the soil pH increased to neutral level (Fig. 7). Similar result revealed that variable soil acidity is a major factor limiting nodulation and nitrogen fixation in

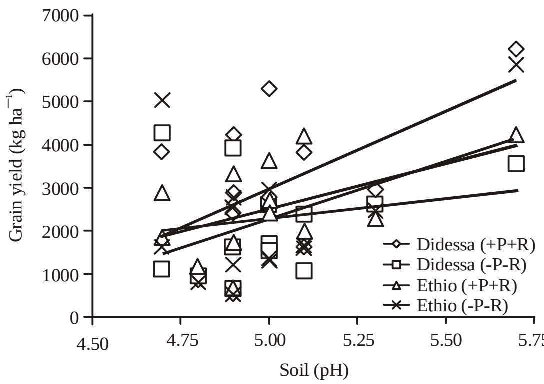

Fig. 7: Relation between initial soil pH and the magnitude of the yield response to different inputs in Gobu Sayo District, 2013

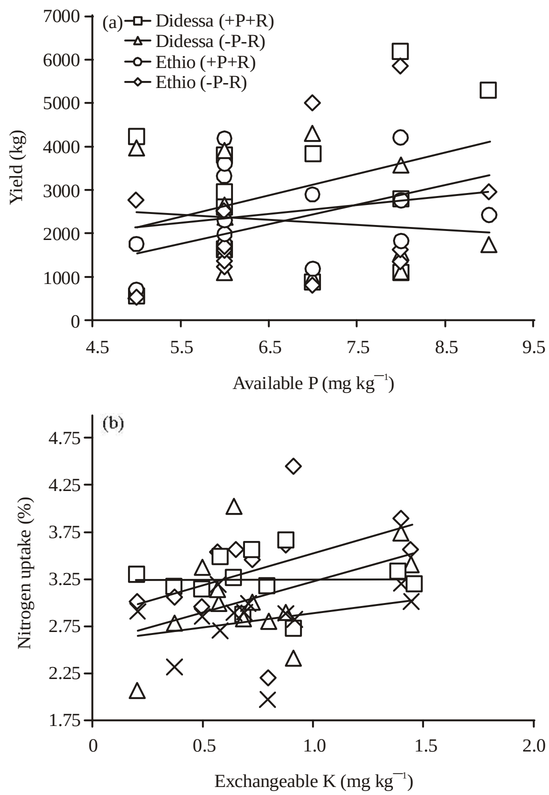

Fig. 8(a-b): Relation between available Phosphorus and potassium and the magnitude of the yield response to different inputs of soybean in Gobu Sayo District

legume crops since it adversely affects legume-rhizobium symbiosis (Legesse *et al*., 2013). The level of both macro and micro nutrient uptake are also highly affected by soil acidity since most of the nutrient is available under more or less neutral conditions. The same author indicated that when the pH drops to below 5, aluminium (Al^{+3}) is released into the soil solution and becomes the single most important factor limiting nutrient availability and uptake.

Similarly, variation in available soil phosphorus contributed to the variations in yield performances across farmers' field. The response to inputs increased as the function of increasing available P, indicating the importance of applied P. For instance, Didessa Variety with inputs (+P+R) linearly increased in its yield performance as the function of increasing the available phosphorus where as the lowest linear increase was observed from the same variety under no input application (-P-R). Similarly, the response of Didessa variety under applied inputs linearly increased as function of exchangeable K increases (Fig. 8).

The report of other finding also indicated that P availability play a significant role in legume production as it highly affects process of biological nitrogen fixation, nutrient uptake and hence, higher amount is required since the process of N fixation is energy intensive (Ali *et al*., 2010). However, plant P uptake is pH dependent with maximum uptake rate being between pH 5.0 and 6.0. Moreover, most of the farm lands do not have enough K that fulfill crop requirements and hence, external K supply is needed in order to maximize the dual role that legume play in the cropping system, increased protein yield and enhanced soil N status via biological nitrogen fixation (Ayub *et al*., 2012).

CONCLUSION

Application of inoculants and phosphorus is significantly improved yield and yield related traits of soybean. Significantly more (19%) yield was recorded when both inputs were applied to the crop. Moreover, statistically a significant number of pods per plant, more husk and hulm yield were obtained when compared with the control. However, the responses of test crop to the inputs are not consistent across farmers' field and yield was varied from less than a ton to 5.8 t ha^{-1}. More than 25% of the tested sites were non responsive to the inputs application and the yield is very variable. In addition to substantial variations in agronomic managements among the farmers, variability in soil pH, available P and K highly affected the degree of responses to input across each test site. In areas where soil pH, available P and K were low, grain yield was significantly reduced, but where availability of these nutrients were high, better yield and yield components were recorded. The level of soil acidity was also significantly and positively correlated to grain yield hence, it needs greater attention to optimize for better nutrient availability. Even though 50 kg ha^{-1} application of DAP and rhizobium inoculations were generally recommended for soybean production, soil acidity management is the main and critical solution for sustainable production of soybean in the area since it improves soil environments for both microbial activities and available nutrients in the soil solutions. Moreover, Revision of phosphorus rates and determination of potassium rates should be considered to produce optimum and sustainable soybean productions, particularly in low P and K deficient areas.

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