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On-farm Yield variability and Responses of Common bean (*Phaseolus vulgaris L.*) Varieties to Rhizobium Inoculation with Inorganic Fertilizer Rates

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1 ABSTRACT

The experiment was conducted on fourteen farmers' fields to evaluate the responses of common bean varieties to rhizobium (R) inoculation (HB-429) and phosphorus (P) application in Bako Tibe district, Ethiopia. The treatments consisted of two varieties only with phosphorus (+P) and rhizobium (+R) inoculation and without phosphorus (-P) and rhizobium (-R) inputs. On the other hand, one separate input trial comprised of four treatments (+P+R, +P-R,-P+R & -P-R) with three replications was conducted for comparison purposes. Initial soil analysis showed the soils at all plots were strongly acidic, and very low to medium range in soil organic carbon, total nitrogen, available phosphorus and exchangeable potassium, thus expected to considerably affect crop growth and yield across plots. Significant increase in grain yield was attained from Nasir (144%) and Angar (33%) varieties due to uses of the inputs (+P+R). However, the higher dry weight of husk was recorded from Angar. Moreover, the result of input trial revealed application of P with inoculants significantly increased the yield than the use of either of the two treatments. Despite the significant positive effects of inputs(+P+R) in bean yield performances and overall differences between the varieties, the responses across farmers' plots were not consistent and yield variability ranged from less than 0.3 t ha-1 to 3.86 t ha-1. In addition to differences in farmers' agronomic practices, which might significantly affect crop performances, variations in initial soil pH, OC, N, P and K across farmers' plots significantly caused confounding effects on responses of the crop to applied inputs. Thus, grain yield were positively and significantly correlated to the soil OC, N and K contents indicating these were the main drivers for the observed yield variability across farmers. In addition, the availability of K and P was influenced by the level of soil pH and OC content. While the use of rhizobium and P are recommended for bean production, more attention should be given to optimizing pH near to neutral level. In addition, determination of optimum K rate and revision of P fertilizer application rate are mandatory for sustainable production of common bean.

2 INTRODUCTION

Grain legumes occupy about 13% of cultivated land in Ethiopia and their contribution to agricultural value addition is around 10 %(CSA, 2012). Pulses are the third-largest export crop of Ethiopia after coffee and sesame, contributing USD 90 million to export earnings in 2010(IFPRI, 2010). In addition, pulses are the second most important element in the national diet, providing the principal protein source and important dietary supplement to cereal consumption. Common Bean (*Phaseolus vulgaris* L.) is the most important food legume worldwide, providing the chief source of dietary protein for more than 300 million people (CIAT, 2001). It is also widely grown in Ethiopia and is an increasingly important commodity in the cropping systems of smallholder farmers for food security and income generation. The major production areas are in the Rift Valley areas and Southern parts of Ethiopia (SNNPR). Farmers grow a wide range of bean types, in terms of colour and size, but the most common types are the pure red and white beans. Most of the beans produced, traded and consumed in the domestic Ethiopian bean markets, are the medium and small red beans whereas white beans are virtually all exported. These market types of beans are a valued source of foreign exchange with an annual value in the range of USD 25-30 million (Ferris and Kaganzi, 2008). Despite the economic and food security importance of these crops, actual smallholder farm yields are by far below the potential production. For instance, the national average yield of common bean is 1.15 t/ha (2011 cropping season) while the potential yield at research stations and researcher managed farmers' field is 3.4 t/ha (CVR, 2012). While many biotic and abiotic factors contribute to low yield, soil nitrogen and phosphorus deficiencies are the main factors that significantly reduce the production and productivity of legume crops (Tahir *et al.,* 2009). Legume plants depend on symbiotic N_2 fixation for their N supply. Since the reduction of atmospheric N_2 is an energy-consuming process, the symbiotic system requires more P and other nutrients than non-N fixing plants for general plant metabolism (Israel, 1987). Moreover, acidic soils cause poor plant growth resulting from aluminium (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 depends 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 is enhanced (Jensen *et al.,* 2012). Therefore, restoring, maintaining and optimizing the soil fertility is major importance to ensure food security and to satisfy the rapidly increasing demand for feed and agricultural raw materials. Nitrogen is the most important nutrient for crop production and deficient in most tropical regions (Fageria and Baligar, 2001). The main reasons for N deficiency include losses by leaching, volatilization, and denitrification, lower rates of N applied compared to rates of N removed in the harvested portion of the crop, low N use efficiency and soil degradation with successive crop cultivation (Fageria 2002). Therefore, the efficient use of mineral fertilizers to the infertile soil is recognized to be a quick and direct way of boosting crop production. However, most of the smallholder farmers in tropical Africa, including Ethiopia, are resource limited and use an insufficient amount of inorganic fertilizers. On the other hand, continuous use of mineral N fertilizer may have detrimental effects on soil properties. Thus, integrated approaches to N management such as the use of bio-fertilizer and other organic N sources have been suggested to be better alternative economically and environmentally (Giller, 2001). Next to nitrogen, phosphorus is the most important element for adequate grain production (Brady and Weil, 2002). P plays an important role in N-fixing process, as adenosine tri-phosphate (ATP) is required in large quantities for legumes to undergo N2 fixation (Sinclair and Vadez, 2002). Its deficiency in legume plants results in reduced nodule mass, N fixation, and low yield. In western parts of Ethiopia, low soil P availability, due to soil acidity and its high fixation, is a limiting factor to crop production. Stoorvogel and Smaling (1990) reported that losses of the major nutrient elements in Ethiopia were in the order of > 40 kg N, over 6.6 kg P, and more than 33.2 kg K ha^{-1} $year^{-1}$, which are much greater than the net average losses for soils in sub-Saharan Africa. The significance and extent of such losses are judged to be of sufficient importance to intervene through application of P fertilizer. In addition, nodules of bean plants act as strong sinks of P and sufficient amount should be available to the plant to realize the potential rates of N_2 fixation. Cognizant of these gaps, the work reported here has been conducted to evaluate on farm yield variability and response to P-fertilizer application and rhizobium inoculation and to elucidate their relationships with initial soil fertility status.

3 MATERIALS AND METHODS

3.1 Site selection and land preparation: The experiments were conducted on the farms (on fourteen farm plots) under rain fed conditions from May to November during the 2013 growing season. The study area is located in Bako Tibe district between 9.027 to 9.13862°N and 37.0125 to 36.9806°E and within altitude ranging from 1595 m to 1907 m above sea level (Fig 1).

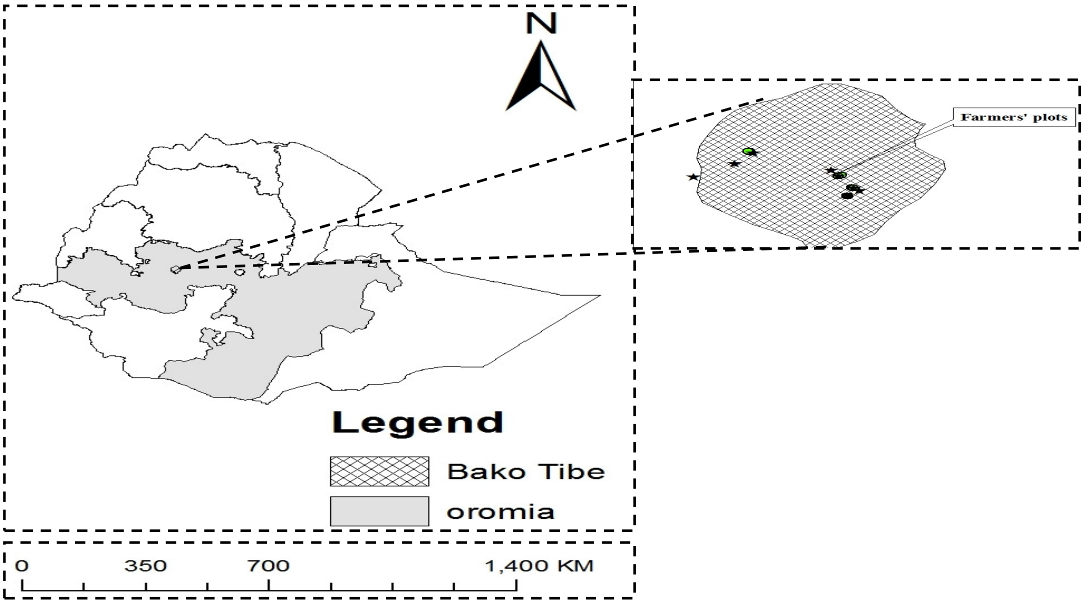


Fig 1: Location map of study area (Bako Tibe) in Ethiopia indicating farmers' plots

The experimental area receives an average annual rainfall amount of 1237 mm with maximum precipitation (85%) received in the months of May to August while the annual rain fall in the 2013 cropping season was 1431mm (Fig 2). It has a warm humid climate with annual mean minimum and maximum air temperatures of 13.5 and 29.7°C, respectively. The area is a mixed farming zone and is one of the most important maize (*Zea mays L.*) growing belts of Ethiopia, in which cultivation of field crops such as common bean (*Phaseolus vulgaris L.*), soybean [*Glycine max (L.) Merrill*], finger millet (*Eleusine coracana*) and teff (*Erogratis tef*) are also most popular. The experimental plots were selected from three different peasant associations (PA) and five farmers from each PAs based on cropping history and topographical similarities (slopes).

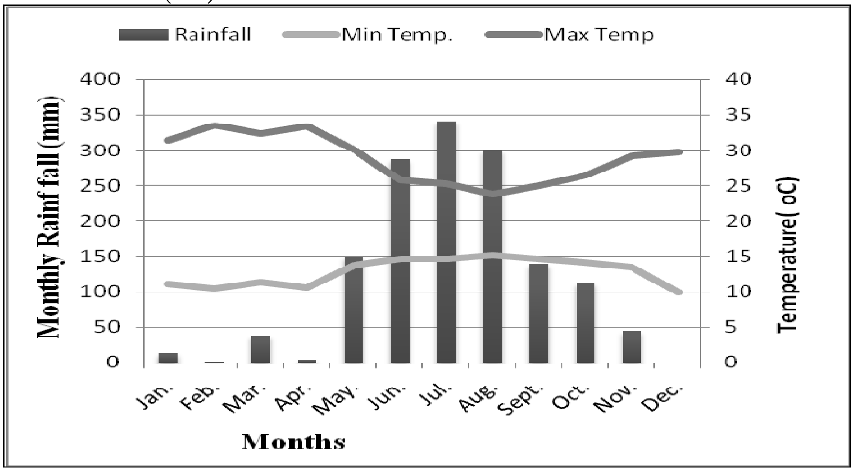


Figure 2: Monthly weather data of Bako Agricultural Research Centre (BARC), in the 2013 cropping season (unpublished data)

3.2 Experimental Design and Layouts: While the frequency of plowing differs depending on the farmers' practices, the plots were finely prepared by collaborating farmers under close supervision of development agents (DA). Four (10mx10m) plots were delineated in each of the collaborating farmers and the distances between each plot and blocks were 1m apart. The plots were arranged for the different treatments in such a way that inadvertent contamination from inoculated to uninoculated plots would not occur. Released common bean varieties, Angar and Nassir were used for the demonstration trials. Rhizobium inoculation (+R) was used for each variety in addition to application of 25 kg ha^{-1} DAP as sources of phosphorus (+P) and the control plots (no inputs) for each common bean variety were also planted on each farmer's plot. Thus, the treatment combinations were Nassir (+P+R), Angar (+P+R), Nassir (-P-R) and Angar (-P-R).The rhizobium inoculant (HB-429) was obtained from national soil testing laboratory. The fertilizer DAP was banded 10 cm away from seed rows at the time of planting. The inoculants were applied using recommended rate (10g $1kg^{-1}$ seed) and following inoculation procedures just before planting. Other separate input trials that consisted of four treatments (+P+R,-P+R, +P-R & -P-R) with three replications were conducted on two farmers' field in the 2013 cropping season on one variety(Awasa Dume) of the common bean as mother trial. The P fertilizer source was DAP, 25 kg ha^{-1}, and rhizobium inoculation (HB-429). Only bean yield parameter was analyzed and presented in this paper for comparison purposes.

3.3 Soil Sampling and Analysis: Before planting, eight samples of soil were collected from each farmer's plot at 10-15 cm depth and composite samples were made to take representative samples for physicochemical analysis. The samples were analyzed for soil pH (1:2.5 H_2O) by using a digital pH meter (Page, 1982). Organic carbon (OC) content of the soil was determined based on oxidation of OC with acid dichromate medium. Total nitrogen percentage (N) in the soil was determined by the micro-Kjeldahl method and soil cation exchange capacity (meq/100mg) by ammonium acetate method (Cottenie, 1980). Available phosphorus (mg kg^{-1} soil) was determined using Bray-II method (Bray and Kurtz, 1945). Exchangeable acidity (meq/100g of soil), exchangeable K (cmol (+)/kg of soil), Ca (meq/100g) and Mg (meq/100g) were also analyzed at soil laboratory of Bako Agricultural Research Center (BARC).

3.4 Data collection: Nodule and tissue data were collected from 10 plants, growing in 2m x 0.5m quadrant within the plots, at the time of flowering. The plants were carefully uprooted and the roots were washed with gently running tap water on a sieve, a number of nodules were counted and collected. Ten nodules from each of two plants were cut into two equal parts in order to inspect the internal nodule colour, depending on which the nodules were designated as active and inactive nodules per plants. Finally, plant tissues were collected from 10 plants harvested for scoring nodules. The tissue was oven dried at 70ºC for 48 hours to constant dry weight and the weight was finally measured using electrical sensitive balance.

3.5 Total N in tissue dry weight and yield traits: Total N in dried tissue sample was determined by the Kjeldahl method in order to determine the N-uptake by plants of each variety grown under different treatments and farmer's plots. Grain yield and husk weight were measured from samples collected from each plot using sensitive balance. Husks were oven dried to constant weight (at 70ºC for 48 hours) before weighing.

3.6 Statistical Analysis: The data were subjected to analysis of variances using GenStat-15th edition software. The different farmers' plots were treated as replicates and the three peasant associations as blocks. Statistically different means were separated using Least significant value at P=0.05 probability level. Sigma plot version 10 was used to sketch bar graphs whereas scatter plots and correlation analysis were done using Microsoft excels.

4 RESULTS AND DISCUSSION

4.1 Initial soil Chemical Properties: The soil pH of the farmer's plots where the experiment was conducted ranged from 4.5 to 5.9, 47% of the total targeted farm plots being below 5.0 (Table1).

Table 1: Initial soil chemical properties of the experimental plots in Bako Tibe district, 2013

Farmers	pH	Ex. Ac	P	OC	TN	CEC	Exch.K	Ca	Mg
Dambi Dima(PA)									
FCN.1	5.4	0.13	6.5	1.74	0.117	11.23	0.595	6.15	8.05
FCN.2	5.9	0.24	4	2.38	0.204	15.66	0.787	9.1	6.5
FCN.3	5.0	0.69	7	2.26	0.195	15.92	0.767	6.6	16.6
FCN.3	5.0	0.79	6	1.74	0.120	13.64	0.448	13.2	7.52
FCN.4	4.9	0.52	6	1.53	0.162	14.84	0.793	11.6	1.1
Mean	5.0	0.66	5.4	2.44	0.179	23.70	0.760	13.0	5.14
Oda Haro(PA)									
FCN.5	5.2	0.16	7	2.40	0.204	24.72	0.732	16.1	1.9
FCN.6	4.8	1.53	6	2.49	0.161	21.90	0.614	8.1	5.5
FCN.7	5.1	0.52	6	2.70	0.153	21.80	0.844	14.4	4
FCN.8	4.9	1.07	7	2.49	0.162	25.86	0.396	10.2	9.9
FCN.9	4.8	0.01	5	2.12	0.216	24.22	1.215	16.4	4.4
Mean	4.8	1.3	8	2.32	0.141	20.48	0.678	10.3	5.9
Tulu Sangota (PA)									
FCN.10	4.5	3.3	6	2.58	0.125	24.00	0.486	7.3	4.9

FCN.11	5.1	0.29	8	2.92	0.168	31.96	0.787	9.1	11.1
FCN.12	5.1	0.51	5	2.43	0.182	33.44	0.550	12.8	8.3
FCN.13	4.6	3.06	6	2.43	0.151	23.26	0.537	7.5	5.4
FCN.14	4.9	1.37	6	2.44	0.196	10.40	0.563	9.4	5.3
Mean	5	0.92	5.8	2.28	0.163	20.26	0.67	10.3	6.73

Notes: PA= Peasant association, FCN=farmer's code number, pH ((1:2.5 H_2O),Ex.Ac= Exchangeable acidity(meq/100g of soil), P= Available P(mg kg^{-1}soil),OC=organic carbon(%),TN=total nitrogen(%),CEC=Cation exchange capacity(meq/100mg) Exc. K= Exchangeable potassium (cmol(+)/ kg of soil), Ca= Calcium(meq/100g soil), Mg= Magnesium (meq/100 g soil)

Thus, the soils at almost all the experimental farm plots can be classified as strongly acidic as per the standard classification procedure (FAO guide lab analysis, 2008). According to Havlin *et al*. (1999) classification, 27% and 73% of the selected farm plots were found to be in the low and low to medium ranges in total nitrogen contents, respectively. However, the overall average total nitrogen content was 0.16%, which was found under low range. Available phosphorus content for all plots was ranged from 4 to 8 (mg kg^{-1}), falling in the very low range (5-15 mg kg^{-1}). The analysis of soil organic carbon (OC) indicated contents varied from 1.53 to 2.92%, which is also found to be in the very low to medium range. The cation exchange capacity (CEC) of the soil across farm plots was also variable ranging from 10.4 to 33.44, where 87% of the total plots were found to be in medium range (Table 1).

4.2 Yield and yield traits: The analysis of variance revealed that active nodule number, tissue dry weight and final grain yield were highly ($P<0.001$) affected by locations (PA) and application of inputs whereas varieties were not significant (Table 2). On the other hand, significant effects ($P<0.05$) on nitrogen uptake, husk dry weight, and grain yield were observed due to the interaction effect of variety by input ($P<0.05$). Highly significant differences among farmers' plots were also observed for yield and yield parameters except for N uptake.

Table 2: Analysis of variances for common bean varieties, Rhizobium Inoculation and phosphorus applications and their interactions on farmers' plots in Bako Tibe, 2013

	F probability					
Source of variation	**d.f.**	**ANN**	**TDW**	**N uptake (%)**	**DW husk**	**GY**
PA	2	<.001	<.001	0.587	<.001	<.001
Inputs(I)	1	<.001	<.001	0.066	0.131	<.001
variety(V)	1	0.349	0.733	0.221	0.353	0.739
PA*I	2	0.876	0.061	0.09	0.672	0.11
PA*V	2	0.429	0.691	0.623	0.99	0.676
I*V	1	0.26	0.309	0.002	0.027	0.027
PA*I*V	2	0.952	0.327	0.177	0.547	0.259
Farmers(rep)	13	<.001	<.001	<.001	<.001	<.001

Note: PA= Peasant associations, d.f=degree of freedom; ANN=Active nodule number per plant, TDW=Tissue dry weight/plant, DW husk=dry weight of husk (g), GY=grain yield; PA=Peasant Association.

Significantly higher active nodule number and plant tissue dry weights were recorded from combined application of rhizobium inoculants and phosphorus fertilizer (Fig 3), which resulted in more than 69% nodulation and 62% dry matter accumulation compared to the untreated controls.

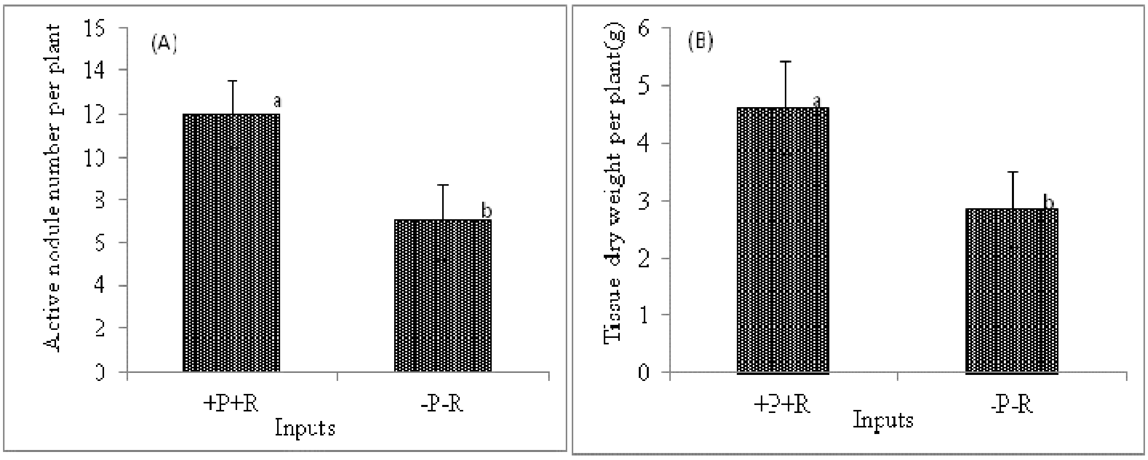
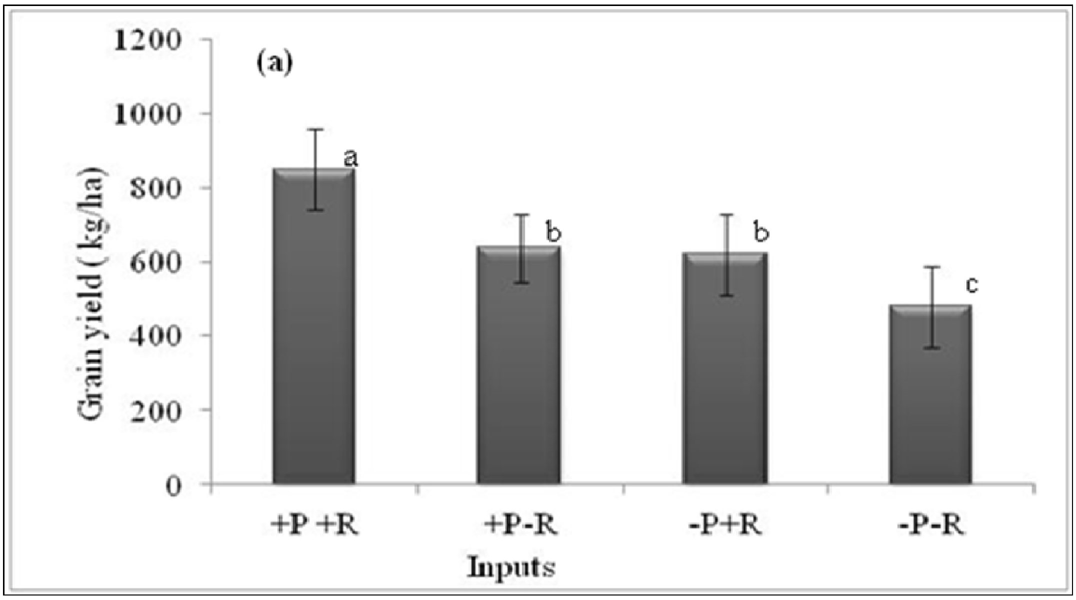


Figure 3 (a-b): The effect of rhizobium inoculation and phosphorus application (P+R+) on active nodule numbers and tissue dry weight (g) per plants on common bean at farmers' plots in Bako Tibe, Western Ethiopia.

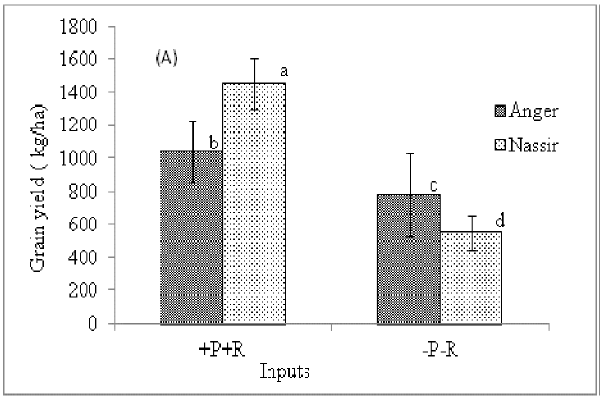
These results are in agreement with output of input trials (Fig 4) and other reports indicated that available phosphorus and inoculants show marked differences in rhizobial effectiveness for more nitrogen fixation as well as dry matter accumulation (Singleton *et al.*, 1985). Nodules are known to be strong sink for P (Weisany *et al.*, 2013). Similar study (Ndakidemi *et.al.*, 2001) indicated that inoculation and P application enhanced nutrient uptake, dry matter accumulation and final grain yield as compared to control plots with no inputs.

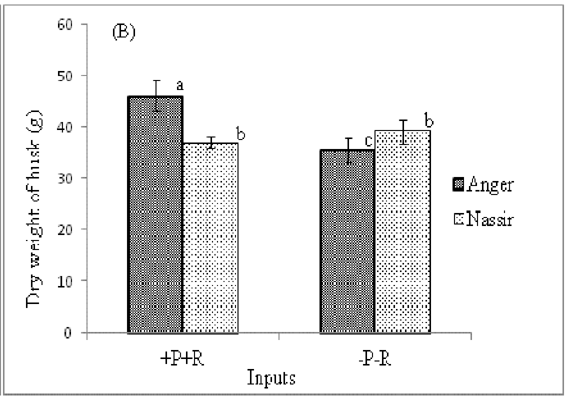


+P+R=25kgha^{-1}DAP+rhizobium,+P-R=25kgha^{-1}DAP+no rhizobium,-P+R=no DAP+rhizobium,-P-R=No DAP and rhizobium(a).

Figure 4: The responses of common bean (Awasa dume variety) to P fertilizer application and rhizobium inoculation on grain yield of common bean, Bako Tibe, 2013

The highest significant yield increase of 144% was obtained when Nasir was treated with P and rhizobium inoculation whereas 33% yield increment was observed for Angar (Fig 5). The result of input trial (Fig 4) on one variety (Awasa dume variety) also revealed that application of both rhizobium inoculations in combination with P application significantly important to enhance productivity than a sole application of either P or rhizobium. More than 33% yield increase could be obtained when a simultaneous application of P and the inoculants than a sole application of P fertilizer or rhizobium inoculations (Fig 4). This result substantiates application of P is crucial for the effective symbiosis of the inoculants since the effective bacterial by themselves need energy in the form of ATP for effective N-fixation for any variety of legume crops. Under the same rates of P and inoculants, Nasir had significantly higher yield increase (by 40%) as compared to Angar. However, with no input application, Angar gave significantly higher yield than Nasir (Fig 5). This confirms that genetic variations significantly affect the effectiveness of symbiotic associations and responses to phosphorus. Other findings also indicated that adequate supply of phosphorus in combination with rhizobium inoculation increased the carboxylation efficiency and thus enhanced the ribulose-1-5-diphosphate carboxylase activity, resulting in increased photosynthetic rate, growth and grain yield (Fatima *et.al.*,2006; Sogut,2006; Tahir *et.al.*,2009). However, several studies revealed that the reaction of the crop to any input is varied among varieties since there are substantial variations in genetic variability in N_2 fixation, morphological characteristics like number and distribution of root hairs and nutrient use efficiencies (Ndakidemi *et.al.,*2001 ;Vadez *et al.,* 1999).





Note: +P+R=25kgha-1DAP+rhizobium and -P-R=No DAP and rhizobium.

Figure 5(a-b): The effect of Rhizobium inoculation and phosphorus application on grain yield and dry weight of husk for common bean varieties at farmers' plot, Bako Tibe, 2013

However, the highest husk dry weight was obtained when Angar variety was treated by both inputs than Nasir. An increment in husk dry weight from 17% up to 50% was recorded from Angar variety as compared to Nasir (Fig 5b). This indicates that assimilation/ partitioning of the nutrient to seed for Angar variety is considerably lower than Nasir, indicating differences between the varieties. Significantly higher husk and hulm biomass yield in kg ha^{-1} (data not shown) were also recorded when Angar variety was obtained when combined phosphorus and rhizobium inoculation were used.

4.3 Yield Variability: Even though the mean yield and other traits revealed a significant effect because of the applied inputs, the response of the inputs on grain yield was not uniform across farmers' plots (Fig 6). The yield was significantly varied from 214 kg ha^{-1} to 3850 kg ha^{-1} under combined uses of P fertilizer and rhizobium inoculation. Some farmers' plots were still non-responsive to the inputs.

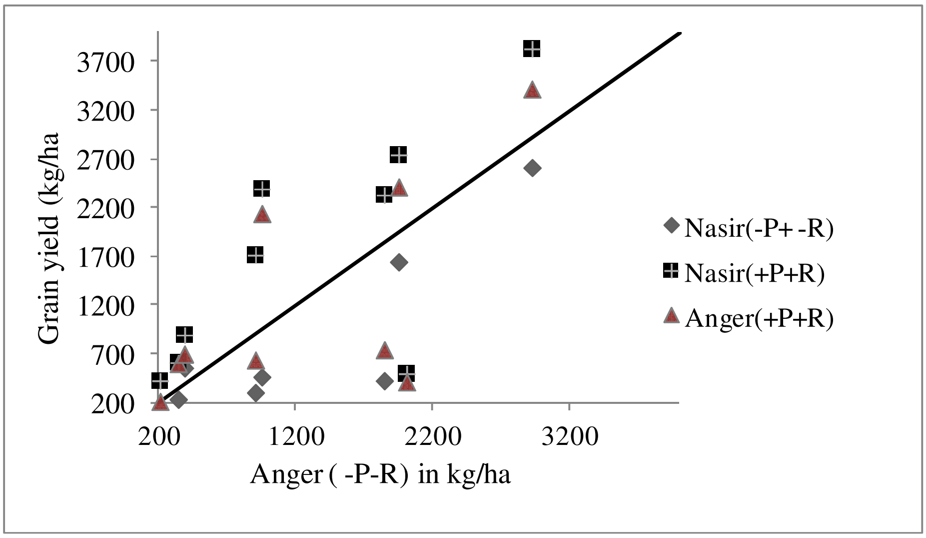


Figure 6: Scatter plots indicating common bean yield under treated (+P+R) versus untreated (-P-R) plots across target farmer plots in Bako Tibe District, Western Ethiopia

More than 47% of farmers' plots were not responded to input applications (Fig 6).Moreover, 85% of the host farmers obtained less than 450 kgha^{-1}. The most probable reason for yield variability across farmers' field in addition to farmers' management practices were variations in initial soil fertility status of the plots.

4.3 The effect of initial soil fertility status: In agreement with other results, the initial soil OC was highly and positively correlated to grain yield and the responses were varied as per treatment variations (Lucas and Davi,1961). The higher response was observed when Nasir variety was planted with P application combined with inoculants as the function of increasing the initial soil OC across farmers' plots (Fig 7). Similarly, positive correlation of available soil P with grain yield was observed and higher yield was attained from Nasir variety treated with combined inputs in soils with higher initial available soil (Fig 7)

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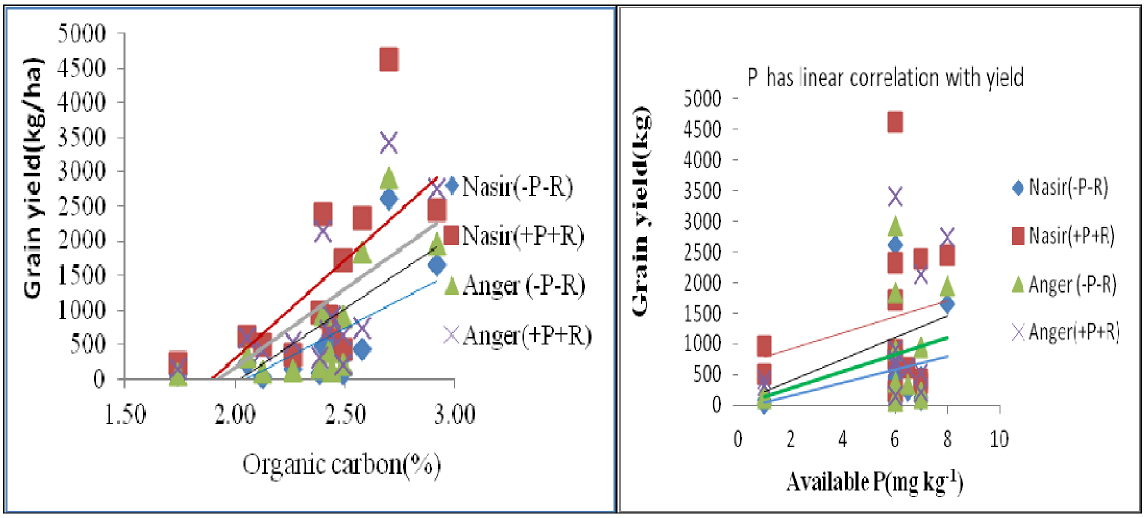

Figure 7: Relationship between organic carbon and Available P to grain yield of common bean under different treatments at farmers' plots in Bako Tibe district, 2013

This result indicated that the amount of P applied to the soil was not optimum to achieve optimum yield, particularly in low available P areas. This might be the nature of soil acidity of the experimental areas that significantly governed P-fixation and other biochemical reactions for the availability of the nutrients (Hernández *et al.,* 2007; Ayub *et.al.,* 2012). Exchangeable K had also a positive correlation between grain yield and the response of varieties due to application of the inputs was different under variable initial exchangeable K. Considerably higher and positive yield response was recorded when Nasir variety was sown with both P application and inoculants as the function of increasing initial available K while the lowest response was recorded in low K areas (Fig 8).

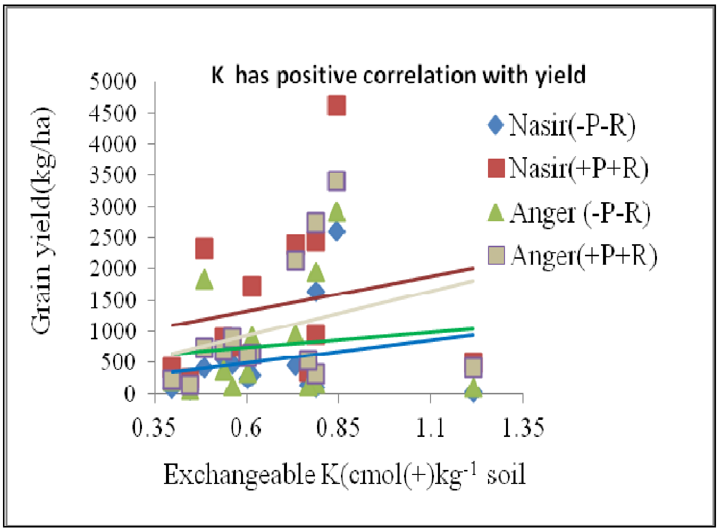

Figure 8: Relationship between organic carbon, Available P and exchangeable K to grain yield of common bean under different treatments at farmers' plots in Bako Tibe district, 2013

This result indicates that most of the farm plots were deficient in available K to fulfil crop requirement and hence need external application in order to enhance the productivity of the crops. Other findings also indicate that low availability of K significantly reduced yield and yield related traits of legume crops since the requirement of legumes for K as well as P is higher than cereals as these nutrients serve dual purposes in legumes including the growth of host plant and associated biological nitrogen fixing bacteria (Ayub *et.al.*,2012).However, availability of nutrients like N,P, and K are governed by the status of soil acidity. Variable soil pH in different cropping systems considerably affected N and K uptakes. Under strongly acidic condition, total N was very low compared to slightly acidic conditions (Fig 9-b). This result is in agreement with other findings (Legesse *et.al.,*2013) confirmed that availability of N is less than 1% and more than 2% in soils with pH below 4.0 and above 5.0, respectively.

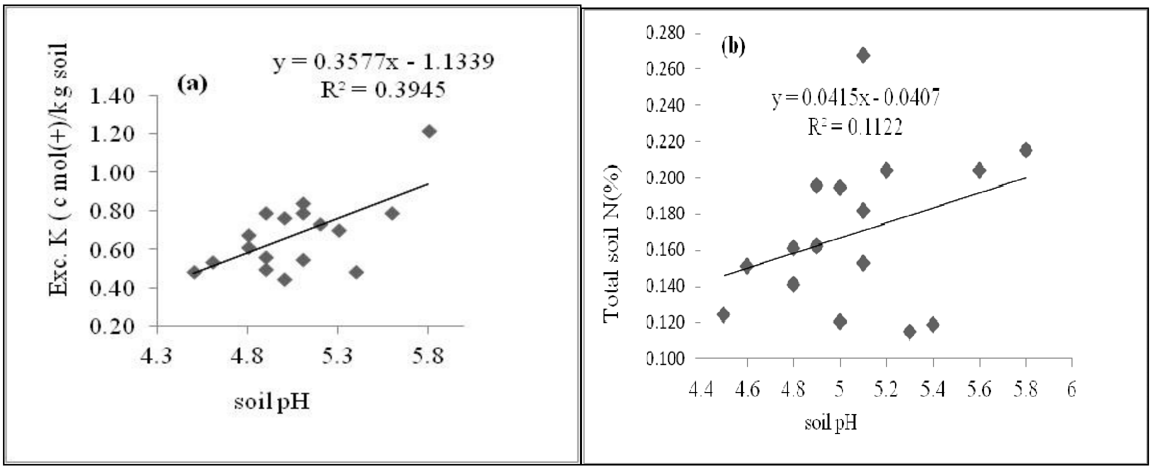

Figure 9(a-b): Relationship between soil pH to exchangeable K (a) and total N (b) on farm plots, Bako Tibe, 2013

The more total or available nitrogen relatively in soils with higher pH is known to improve soil microbial activity showing the nitrate-nitrogen release is adversely affected by the level of soil acidity (Moreira and Fageria,2010; Lucas and Davi,1961). Moreover, availability of potassium in each farm plot was significantly affected by soil pH level. More available K was obtained in soils with pH more than 5.0, but this result was not consistent across all farm plots. The highest exchangeable K was obtained on one farm plot with its pH is 5.9 (Fig 9-a).

5 CONCLUSION

Application of inoculants and phosphorus is significantly improved yield and yield related traits of common bean. More than 144% yield increment for Nasir variety and 33% for Angar variety could be obtained when both inputs were applied to the crop as compared to respective controls. Combined application of P and rhizobium inoculation significantly increased yield performances compared to a sole application of either of the two treatments. In addition, varietal differences highly affected variations in yield performance. However, the responses of each variety to the inputs are not consistent across farmers' field and yield is varied from less than 0.3 t ha^{-1} to more than 3.8 tha^{-1}. More than 47%-tested plots were non-responsive to the application of the inputs and the yield is very variable. In addition to considerable variations in agronomic managements among the farmers, the initial soil fertility status like soil OC, available P and K highly affected the responses of each variety across each test site. In areas with low OC, low available P and K significantly results in lower grain yield while in higher available nutrients higher yield was recorded. Even though applications of 25 kg ha^{-1} DAP as sources of P and rhizobium inoculations were generally recommended, soil acidity management is the main and critical factor for sustainable production of common bean since this improves soil environments for both microbial activities and available nutrients in the soil solutions. Moreover, improvements of soil organic matter through different systems like residue managements and conservation agriculture are other target areas to be considered in order to optimize soil environment for the microbial activities and hence enhance nutrient availabilities for crop growth and developments. Revision of phosphorus rates and determination of potassium rates should also be considered in addition to practicing disease management options to produce optimum and sustainable bean productions, particularly in low P and K deficient areas.

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