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Original Research

Nodulation and Root Characteristics of Rhizobium Inoculated Common Bean Varieties to Different NPSB Fertilizer levels

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Abstract

Roots and nodulation characteristics of legume crops have wide implication for plant nutrition, growth, and development. This study aimed to explore the combined effect of rhizobium-inoculated common bean varieties and NPSB fertilizer rates on nodulation and root characteristics. Three common bean varieties (Local, Loko, and Nasir) were combined with four rates of blended NPSB fertilizers (0, 50, 100, and 150 kg ha^{-1}) in RCB design with a factorial arrangement in three replications. The results showed that the main effect of common bean varieties and NPSB blended fertilizer rates caused significant effect on nodulation and root growth while the interaction effect on total number of nodules per plant was significant. Maximum tap root length (8.4cm), root fresh weight plant^{-1}(24.22g), root dry weight plant^{-1}(4.2g), nodules fresh weight plant^{-1} (11.84g) and nodules dry weight (1.29g) of common bean were obtained from application of 150 kg NPSB ha^{-1} fertilizer. Loko variety yielded the highest mean value for tap root length (7.5cm), root fresh weight plant^{-1} (18.4g), root dry weight plant^{-1}(3.56g), nodules fresh weight plant^{-1}(10.8g), nodules dry weight plant^{-1} (1.12g) while Nassir gave highest effective nodules plant^{-1} (39.7.) as compared to the rest. The regression line drawn revealed the effect of NPSB fertilizer was significantly higher than the varietal effect on root development and nodulation. Therefore, root and nodulation characters had been significantly increased at 150 kg NPSB ha^{-1}) blended fertilizer while Loko and Nassir variety gave higher root development and nodulation, respectively.

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INTRODUCTION

Common bean is an important source of protein, and micronutrients besides its economic and environmental benefit due to their association with nitrogen-fixing bacteria by contributing in sustainable agriculture (Norma *et al*., 2016). In addition to this, the caloric intake, of common beans also provides minerals, fibre, thiamine, folate, and phytochemicals with analgesic and neuroprotective properties (Blair *et al*., 2013). The red, speckled beans and white beans are the three main haricot bean types grown in Ethiopia, the red bean types are typically grown for food security by the poorer farmers in the southern Rift Valley areas of the country, whereas white beans are produced almost exclusively for the export market in central eastern Rift Valley. All bean production is by small-scale farmers with minimal to zero inputs producing 1.5 t ha^{-1} (Ferris and Kaganzi, 2008). This is low as compared to the yield (2 to 3.6 ha^{-1}) achieved at research fields in Ethiopia (MoANR, 2016)

The nutrient that is in the smallest supply to a plant's requirements stifles its growth. Plant nutrition also needs a constant effort to give balanced nutrition in the ideal range to produce good yields. The high yields achieved were reached because of excellent crop growth conditions, optimal and balanced nutrient management, and the use of best management methods (Goulding *et al*., 2008). Legumes have evolved the remarkable ability to host N_2 fixing bacteria, known as rhizobia, in specialized organs called root nodules and the symbiotic associations between legumes and rhizobia have been estimated to fix ~80% of the biologically fixed N_2 in agricultural areas (O'Hara, 1998). Unbalanced fertilizer use causes increased deficiency of other soil nutrients, leading to reduced yields and profits. Fertilizer deficiencies, such as nitrogen and phosphorus, as well as sulfur, boron, and zinc, are now widespread in Ethiopian soils (Dame and Tasisa, 2019).

Achieving food security and lowering the risk of climate change are among the increasing challenges in the future. Thus, producing sustainably is therefore becoming central in agriculture and food systems. Legume crops could play an important role in this context by delivering multiple services in line with sustainability principles that if introduced into modern cropping systems can increase crop diversity and reduce the use of external inputs. They also perform well in conservation systems, and intercropping systems, which are very important in developing countries as well as in low-input and low-yield farming systems. Legumes fix the atmospheric nitrogen, release the soil high-quality organic matter and facilitate soil nutrients' circulation and water retention (Stagnari and Maggio, 2017). In terms of the effect of host genotype, research on legumes has revealed genetic differences in symbiont choice (Boivin *et al*., 2021). Bean-rhizobia interactions are diverse, as evidenced by a large number of rhizobia species capable of nodulating the common bean (Gurkanli *et al*., 2013). However, in most areas, soil nutrient inadequacy, such as low nitrogen and phosphorus levels, as well as acidic soil conditions, are significant constraints on common bean development (Graham *et al*., 2003) and the decline of soil fertility necessitates the application of some amount of fertilizer which would be also essential in biological nitrogen *fi*xation, Nitrogen is supplied to legume crops such as common bean and soybean through symbiotic nitrogen fixation, which is a sustainable and cost-effective strategy (Thilakarathna and Raizada, 2018). It has the potential to minimize nitrogen fertilizer input prices while simultaneously minimizing the negative environmental impacts of wasted nitrogen (Thilakarathna and Raizada, 2018; Khan *et al*., 2020). The use of nitrogen fertilizer enhances the development of common bean seedlings by causing rhizobia to form. It encourages vegetative development and generates circumstances that favour large yields throughout the early stages of growth (Yin *et al*., 2018).

While phosphorus is involved in a variety of metabolic processes, including photosynthesis, respiration, and signal transduction, it is essential for the growth, development, and yield productivity of common beans (Fageria and Baligar, 2016).

Genetic diversity and phenotypic plasticity were discovered in taproot depth, root dry weight, specific root length, and average root diameter across soybean genotypes, with the large-rooted genotype having a better harvest index than the small-rooted genotype (Salim *et al*., 2022) and in common bean, nodulation characters were positively correlated with yield components, shoot and root parts, and flowering duration (Santalla *et al*., 2001). Moreover, nodulation may be influenced by the varietal differences and the fertility level. However, loss of soil fertility and unbalanced fertilizer application were among production constraints in crop production (Ahmed *et al*., 2007). Therefore, the knowledge on the nodulation and root characteristics of the crop would have an important implication on predicting the crop growth and yield potential and soil fertility management options. Thus, this research was conducted to explore the information on the interaction effect of rhizobium inoculated common bean varieties and NPSB fertilizer rates on the nodulation and root characteristics of common bean.

METERIALS AND METHODS

Description of the study area

The experiment was carried out in the Bako Agricultural Research Center (BARC), Western Showa Zone, Oromia Regional State, during the 2020 main cropping season. Geographically, Bako Agricultural Research Center is located at 37 09' East longitude and 09 06' North latitude, The location is at low elevation (about 1650 meters above sea level). The climate in the region is warm and humid, with annual minimum and maximum temperatures of 13 and 34.2 ^{0}c, respectively. The area receives 1,024.30mm of annual rainfall, mostly from April to October, with the most precipitation falling between May and October (Figure 1). The area's major soil type is Nitisols brown and clay in texture with a pH that falls in the range of very strongly acidic.

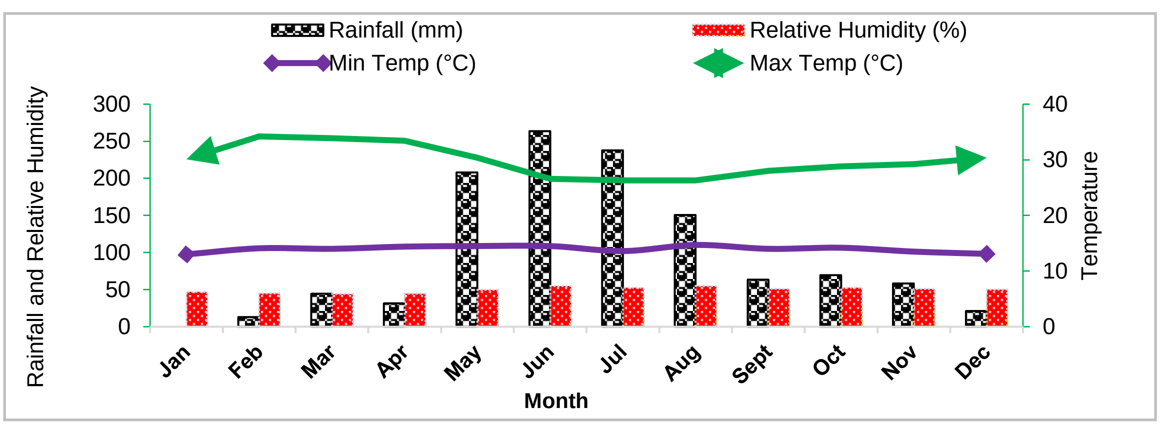

Figure 1: Monthly total rainfall (mm), relative humidity (%), mean minimum and maximum temperature (°C) of Bako research station during 2020.

Description of Experimental Materials

Variety: a common bean Nasir, Loko and one local variety which are adapted to the agro-ecology of the area where the study was conducted.

Bio-fertilizer: *Rhyzobium* strain known as *R. leguminosarum phaseoli* (HB-429) was used for inoculation of common bean varieties (Tarekegn *et al*., 2018).

Treatments and Experimental Design

The experiment was conducted using four levels of blended NPSB fertilizer (0, 50, 100, and 150 kg ha^{-1}) and three common bean varieties (Nasir, Loko and local). The experiment was organized in a 4x3 factorial combination with a total of 12 treatments in a randomized complete block design with three replications. Blended fertilizer was applied as basal and it contains 18.7% N, 37.4% P_2O_5, 6.9% S, and 0.25% B (Tolera *et al*., 2020). The gross plot area was seven (7) rows and each row accommodated 30 plants of 3 m length (7 x 0.4 m x 3 m = 8.4m^2) or (width is 2.8 m x 3 m = 8.4m^2). One row each from both sides of the plot was left as a border row and again one row of both sides of the plot was used for destructive sampling. Thus, the central three rows (3 x 0.4 m x 3 m 3.6 m2) were used for data collection. All the treatment combinations are described in Table 1.

Table 1. Description of treatment combination.

No	Treatments	Varieties	Blended NPSB (kg ha^{-1})
1	LVR + f_1	Loko	0
2	LVR + f_2	Loko	50
3	LVR + f_3	Loko	100
4	LVR + f_4	Loko	150
5	NVR + f_1	Nasir	0
6	NVR + f_2	Nasir	50
7	NVR + f_3	Nasir	100
8	NVR + f_4	Nasir	150
9	LoVR + f_1	Local	0
10	LoVR + f_2	Local	50
11	LoVR + f_3	Local	100
12	LoVR + f_4	Local	150

Experimental Procedures

The field was ploughed, disked, and harrowed. Plots were levelled manually and sowing was done on June 27, 2020. Planting space between rows (40 cm) and within rows (10 cm) were employed, respectively. Blended fertilizer NPSB was applied as a starter dose to all treatments uniformly at the time of sowing. Furthermore, 1m and 0.5 m paths between blocks and plots, respectively, were also applied. After ten days, the two seeds sown per hill were thinned to one and other recommended agronomic and management practices were uniformly applied.

Methods of Inoculation:

The strain's carrier-based inoculants were administered at a rate of 6.25 g per kg of seed (Tarekegn *et al*., 2018), and appropriate inoculation protocols were followed (Tena *et al.*, 2016)

Data collection

Nodulation parameters

Total number of nodules: The nodule population was assessed at the 50% blooming stage. The dirt adhered to ten randomly selected plants was washed away with tap water to clean the roots and nodules from the top and lateral root portions, which were then separated separately and put on a sieve until all the water had drained from the nodules' surface. After that, the number of nodules per plant was counted and the average was rated for each plant Karikari *et al*., 2015) as shown below:

$$\text{Nodulation rating} := \frac{(a*10)+(b*5)+(c*1)+(d+1)}{\text{Total number of plants}} \quad \ldots\ldots\ldots\ldots$$

Where **a**: number of plants showing tap root nodulation, **b**: plants with nodules in secondary roots but close to tap root, **c**: plants with scattered nodulation, and **d**: plants without nodulation.

Effective nodule number: Cutting with a sharp blade revealed the colour inside the nodule, which ranged from pink to dark-reddish; whereas inactive nodules (non-effective nodules) were black, grey or greenish, white on the inside of nodules (Purcell *et al*., 2014). The number of effective nodules per plant was counted and the average per plant was calculated.

Nodule fresh weight: The nodules were collected from ten sample plants and pooled from each plot including the dissected nodules for colour determination and their fresh weight was measured by sensitive balance to constant weight and expressed as an average nodule fresh weight of ten plants samples were taken as nodule fresh weight per plant.

Nodule dry weight: The nodules were harvested from ten sample plants and pooled from each plot, including the dissected nodules for colour analysis, and their dry weight was obtained by oven drying them for 24 hours at 70°C to get a uniform weight.

Root characters

Tap root length: was measured in centimeters (cm) by carefully plucking ten randomly selected plants from destructive rows from the ground level to the tip of the taproot, and the average was calculated.

Root fresh weight: was calculated as an average of ten plants in grams per plant from ten randomly selected plants from each plot of destructive rows using sensitive balance.

Root dry weight: was determined using a sensitive balance after ten sample plant roots were dried in an oven at 70°C for 48 hours and represented as an average of ten plants in grams per plant.

Data analysis

Statistical **a**nalysis of variance and treatment means were compared using 5% and 1% probability levels and box and interaction plots were employed to illustrate the main and interaction effects of both components graphically (R Software, 2015). In examining the distribution of data across data sets, the plot () function of R statistical programme (Shah *et al*., 2019) as a box plot is useful. For the examination of medical data, regression analysis is an essential statistical tool. It allows for the detection and characterization of links between a variety of variables (Schneider *et al.*, 2010).

RESULTS

Analysis of variance

The study results showed that the main effect of rhizobium inoculated common bean varieties and NPSB blended fertilizer rates had a significant effect on phenology, growth, and nodulation parameters considered while the interaction effect of both factors was significant for a total number of nodules per plant (Table 2). The interaction effect indicates how much an effect of a certain factor changes when we vary the level of the other factor. The interaction effects between two factors are commonly determined using two-way ANOVA model which is cruder. However, the graphical display of interaction patterns among the two factors, Rhizobium inoculated common bean varieties and NPSB blended fertilizer rates by interaction plot can clearly illustrate the interaction about the trend and the specific pattern of the interaction at different levels of the other factor.

Table 2: Mean square of variance for nodulation and root characteristics of the common bean as influenced by blended NSPB fertilizer at Bako area. 2019.

Sources of variation	df	Mean square values						
		TNNPP	ENNPP	NFWPP	NDWPP	TRL	RFW	RDW
Block	2	27.66	31.73	4.70	0.10	0.004	3.03	0.28
V	2	633.39**	707.86**	54.12**	0.824**	2.15*	22.69**	1.33*
F	3	514.86**	551.94**	113.9**	1.73**	18.8**	299.30**	6.7**
FxV	6	47.26*	54.45NS	10.13NS	0.07NS	0.33 NS	4.21NS	0.21NS
Error	22	12.93	22.34	6.53	0.06	0.36	2.97	0.27
CV (%)		**11.1**	**15.2**	**30.5**	**27.4**	**8.5**	**10.1**	**16.01**

*and **, significant and highly significant at 5% and 1% probability levels, respectively, NS= non-significant. CV = coefficient of variation, F = blended fertilizer rate, V= *Rhizobium* inoculated varieties, FxV = Interaction of blended fertilizer rate with *rhizobium* inoculated varieties, df= Degree of freedom, TNNPP = Total number nodule per plant, ENNPP = Effective number of -nodules per plant, NFWPP= Nodule fresh weight per plant (g), NDWPP = Nodule dry weight per plant (g), TRL= Tap root length per plant (cm), RFW = Root fresh weight per plant (g), RDW = Root dry weight per plant (g),

NODULATION

Number of Total and effective nodules plant ^{1}

The highest number of total nodules (53.73) was obtained from Nassir with the application of 100 kg NPSB ha^{-1} whereas the minimum total number of nodules per plant (18.97) was obtained from the control (local variety) (Figure 2a). The maximum number of effective nodules per plant (39.71) was obtained from the Nassir variety treated with 100 kg NPSB ha^{-1} fertilizer level and statistically in par with 150 kg NPSB ha^{-1} fertilizer rate. The minimum number of effective nodules (24.82) was obtained from cultivar Local variety not treated with NPSB fertilizer (Figure 2b). To see the extent of the relationship between the common bean variety and blended NPSB fertilizer factors and their influence on the measured characters, regression analysis was conducted. Thus, the regression line of the common bean was flat while the blended NPSB fertilizer was in a linear and positive effect on a total number of nodules per plant Figure 3a) and an effective number of nodules per plant as shown by scatter plot graph (Figure 3b).

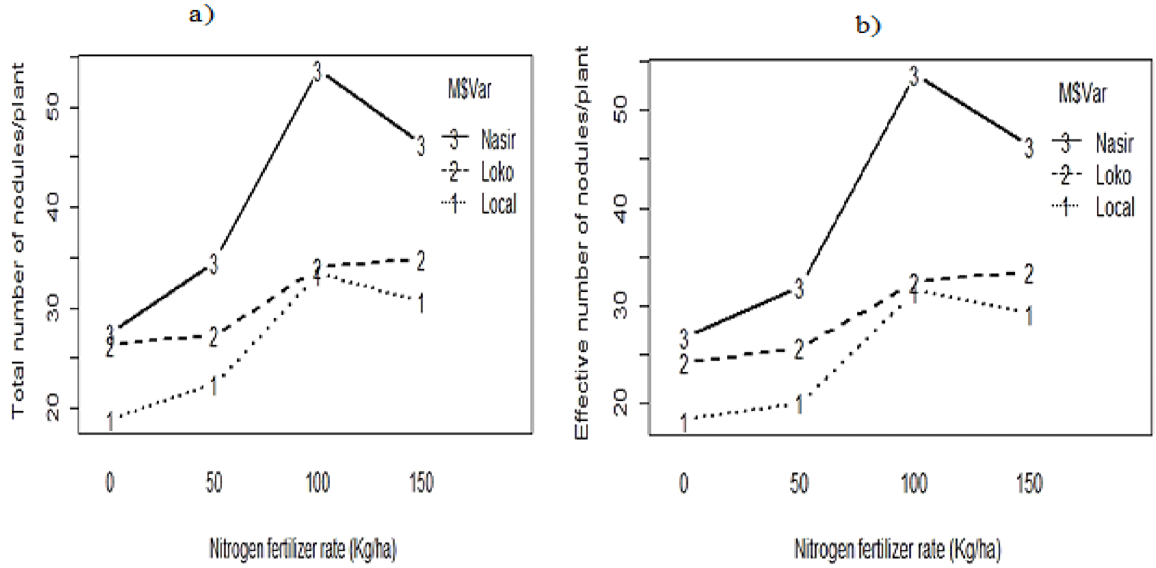

Figure 2. Interaction plot of the total number of nodules (a) and an effective number of nodules/plant (b) of common bean at different NPSB fertilizer levels.

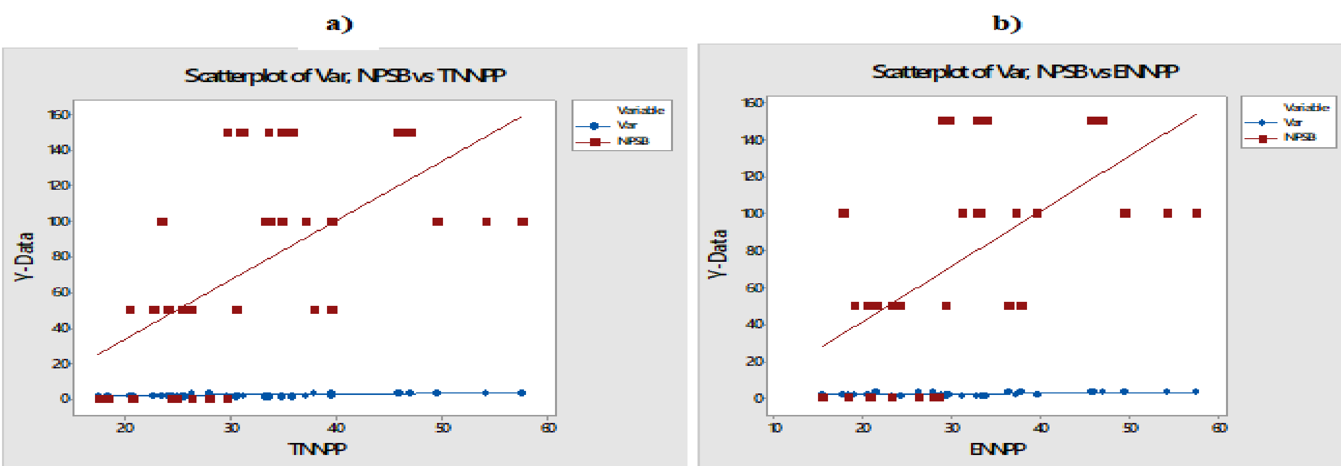

Figure 3. Regression line of the effect of common bean variety and NPSB blended fertilizer on total number nodule per plant (a) and effective number nodule/plant (b).

Fresh and dry weight nodules

The scatter plot graph (Figure 4) revealed that fresh weight and dry weight of nodule performance of inoculated common bean varieties were similar while the NPSB fertilizer application caused a linear response of both nodulation characters measured (Figure 5). Plants applied with greater blended fertilizer had the greatest (11.84g) fresh weight of nodules while control treatment plants had the smallest (4.11g) fresh weight of nodules (Figure 4a). The largest (1.29 g.) dry weight of nodules per plant was recorded by plants inoculated with higher blended fertilizer (150 kg NPSB ha^{-1}) on Nasir varieties, while the lowest 0.29 g)) dry weight of nodules per plant was obtained in control treatment (Figure 4b). The Loko variety recorded the highest dry weight of nodule (1.22) which is par statically with (0.98) and the lowest was recorded on local variety (0.62). The scatter plot graph (Figure 5a and b) showed that the nodule's dry weight performance of inoculated common bean varieties was similar in trend while the nodule's dry weight responded linearly to the application of NPSB fertilizer application

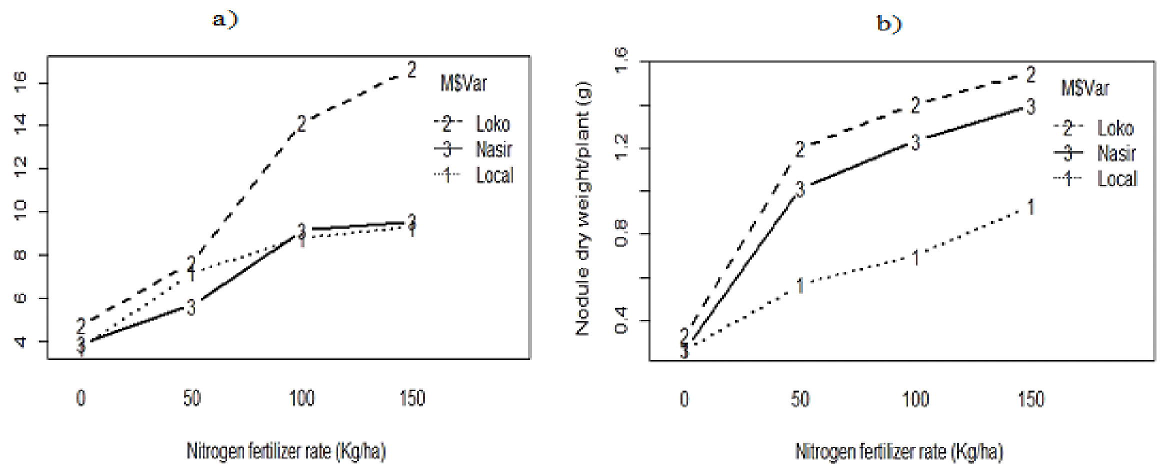

Figure 4. The effect of NPSB blended fertilizer on nodules fresh weight/plant (a) and nodules dry weight/plant (g) (b) of inoculated common bean varieties

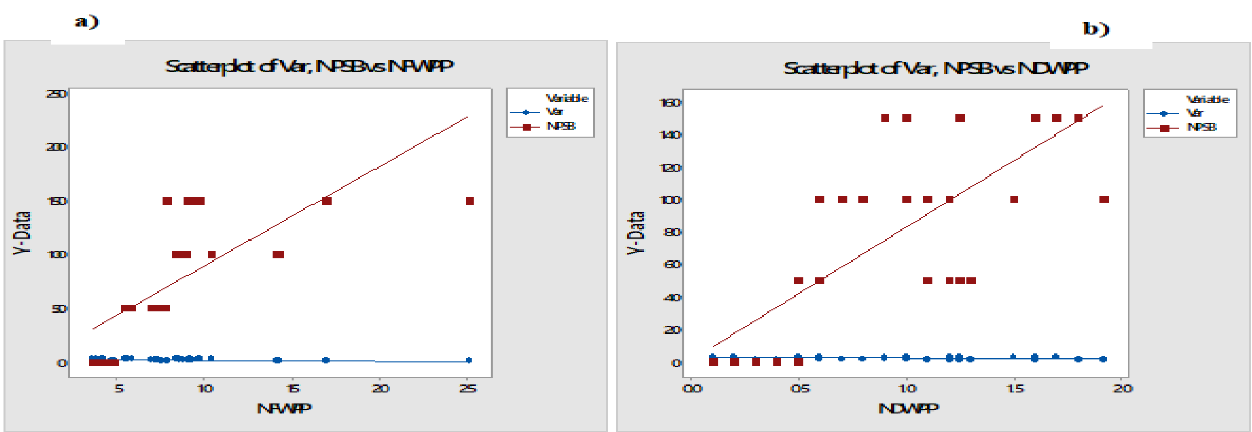

Figure 5. Regression line of the effect of common bean variety and NPSB blended fertilizer on nodule fresh weight per plant (a) and nodule dry weight per plant(b),

Root Characteristics of Inoculated Common Bean Varieties

Taproot length

The highest (8.41 cm) taproot length of common bean was recorded from the application of higher rate (50kg ha [1], of blended fertilizer1as opposed to the lowest (5.22 cm) taproot length from control (Figure 6). All the varieties showed an increasing root length in response to an increased fertilizer rate, however, the Loko variety showed the longest tap root length (7.5 cm) while the shortest tap root length (6.65 cm) was obtained from local variety (Figure 6). The regression graph (Figure 7) of common bean varieties showed a flat line and not varied while the NPSB blended fertilizers had a linear increasing effect on tap root length.

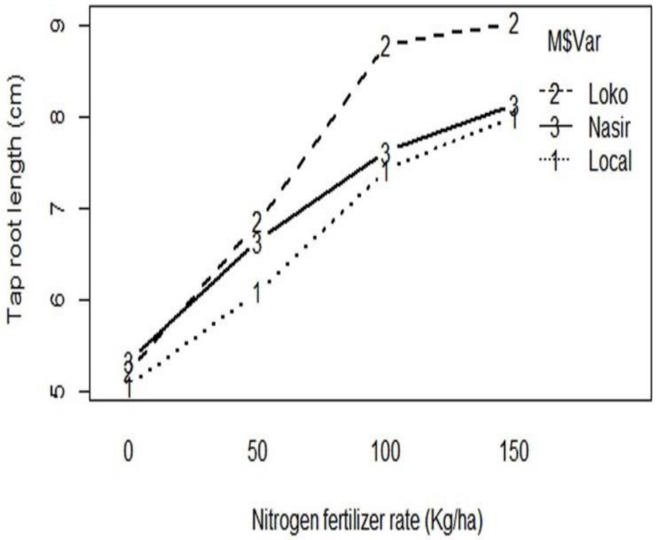

Figure 6. The effect of blended NPSB fertilizer on tap root length of inoculated common bean varieties.

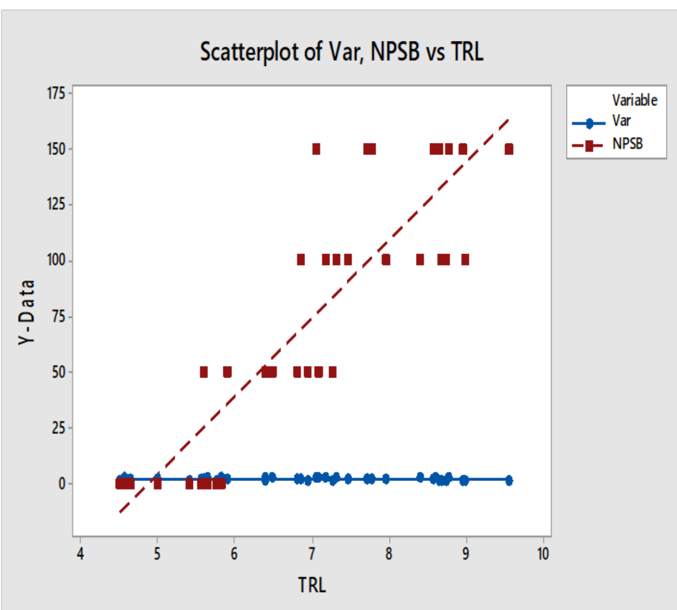

Figure 7. Regression line of the effect of common bean variety and blended NPSB fertilizer on tap root length per plant

Root fresh weight

The largest (24.22 g) root fresh weight was obtained from the highest blended fertilizer rate at 150kg ha$_{-}^{1}$ as compared to the lowest (10.89 g^{1}) mass from control treatment indicating a 122.4% increment over the control. Similarly, Loko variety had the highest root fresh weight (18.42g) while the lowest root fresh weight (15.67g) was obtained from local variety (Figure 8a). The regression line of the NPSB fertilizer effect on root fresh weight was linear in the positive direction (Figure 9a) while the varietal effect of inoculated common bean was horizontal and had not been variable.

Root dry weight

The maximum (4.2g) root dry weight was observed with 150 kg NPSB ha$^{-1,}$ whereas the least root dry weight (2.14 gm) was recorded from control resulting in about 96% increment over control (Figure 8b). The variety Loko had the highest root dry weight (3.56 g) while the lowest root dry weight (2.9g) was obtained from the Nasir variety. This could be attributed to an increase in cell dry matter accumulation with well-developed common bean tap roots during the growth of the plant. To see the relative influence of both factors on root dry weight, the regression analysis was done and accordingly the effect of inoculated common bean varieties was not significantly different while the effect of NPSB fertilizer was the very high and linear relationship with root dry weight recorded (Figure 9b).

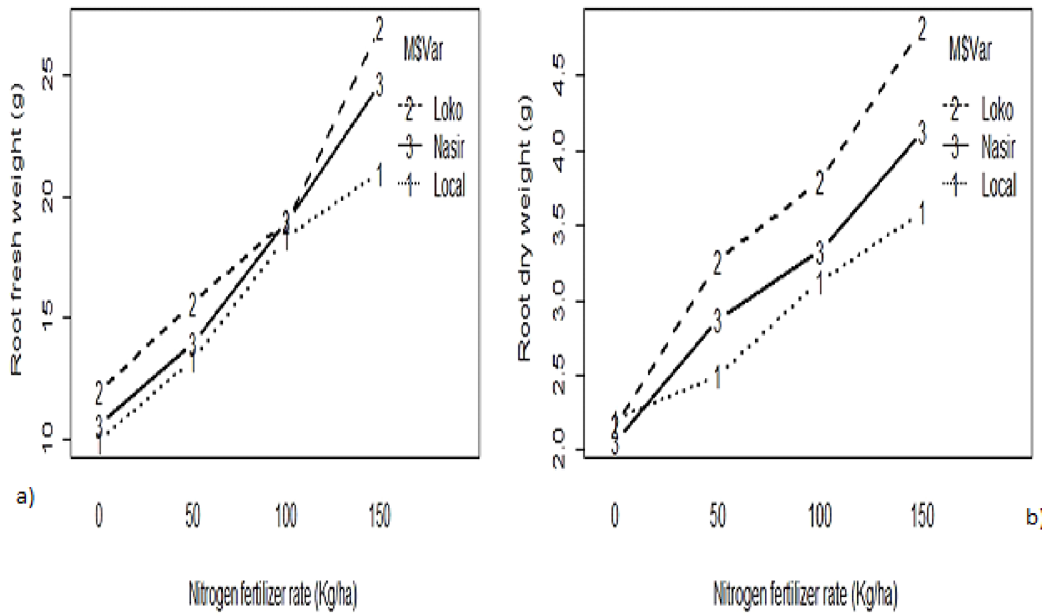

Figure 8. The effect of NPSB blended fertilizer on root fresh weight (a) and dry weight (b) of inoculated common bean varieties.

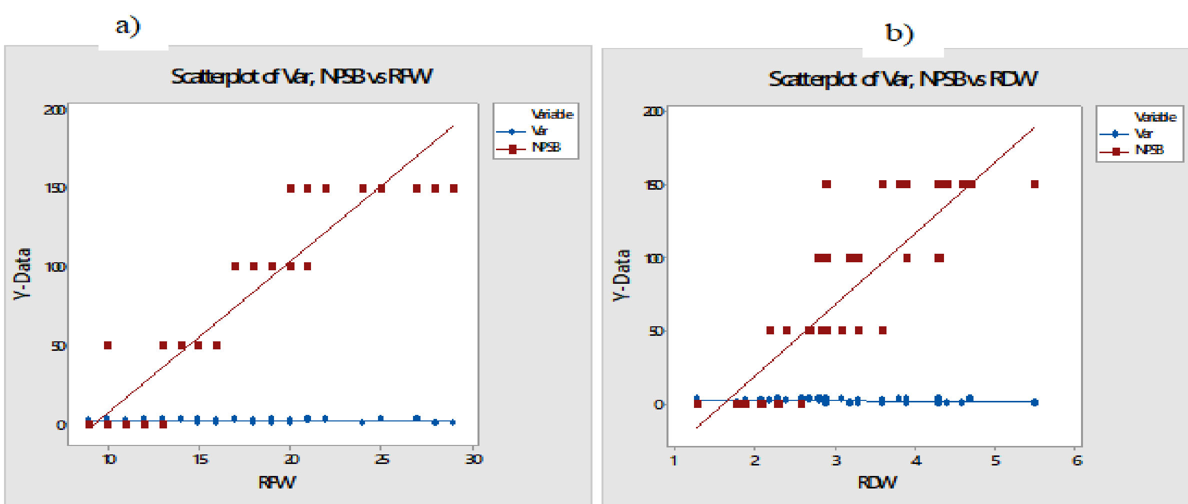

Figure 9. Regression line of the effect of common bean variety and blended NPSB fertilizer on root fresh weight per plant (g), (RFW) (a) and root dry weight per plant (g) (RDW)(

DISCUSSION

The Nasir variety produced the maximum number of nodules per plant (53.73) with the application of 100 kg NPSB ha^{-1} resulting an increase of 183 percent above the control variety's minimal number of nodules (18.97) (local variety) (Figure 2a). This study backs Cardoso *et al*. (2017) who found that the isolates ALSG5A4, JPrG6A8, NVSG11A3, UnPaG11A9, and UnPaG8A12 had considerably higher values ranging from 133 to 174 nodules plant^{-1} on common bean, as well as the largest nodule dry mass (0.27 to 0.384 g). The low nodulation potential obtained could be mainly attributed to the inherent nature of the varieties, the compatibility and the nodulation potential of the strain used, and other environmental factors that may affect nodulation. The common bean varieties responded differently in number of total nodules per plant and showed linearly up to 100 NPSB kg ha^{-1} fertilizer rate beyond which it declines. This result coincides with Merga (2020); Oladzad *et al*.(2020) reported the variation in the number total nodule among common bean varieties. Phosphorus shortage has been shown to impact nitrogen fixation in common beans more than in other legume crops (Fageria and Baligar, 2016). Moreover, the effect of S and B on nodule growth, nodule formation, and functioning were reported (Flores *et al*., 2018). Regarding the effective nodules per plant, the maximum value (39.71) was recorded from the Nassir variety which was also high in the number of total nodules per plant at the application of 100 kg NPSB ha^1 while the lowest was recorded from zero fertilizer application and local variety. This indicates an increment of about 60% (Figure 2b) over the control may have resulted mainly from blended NPSB fertilizer as N initiate nodulation and P increases root development increasing nitrogen fixation in common bean. Similarly, Merga (2020) ; Oladzad *et al*.(2020) reported the presence of significant differences among common bean varieties for effective nodule numbers. Both nodule number $plant^{-1}$ and nodule dry weight were unaffected by bean variety (Ouma *et al*., 2016). However, Arega and Zenebe (2019) found that the highest number of total nodules (137.7), the number of effective nodules (130.7) at the maximum rate of blended NPKSB rate which is higher than these results.

The largest fresh weight of nodules per plant (11.84g) was obtained from the highest level of blended fertilizer as compared to the lowest (4.11g) form control showed a weight gain of about 188% while Loko variety recorded the highest fresh weight of nodule (15.83 g) whereas the lowest was from Nasir variety (7.1 g) which is statistically in par with (7.24) (Figure 4a) with an advantage of about 218%.over the local. This signifies the differences brought by both NPSB fertilizer and varietal responses on nodules fresh weight. Similarly, lower values were 1.98 g $plant^{-1}$ from *japonicum* strain of TAL-379 inoculated and 0.99 g from the un-inoculated plant.by Masresha and Kibebew (2017). **T**he largest (1.29 g. $plant^{-1}$) dry weight of nodules per plant obtained from the maximum blended fertilizer level applied to *the* Nasir variety followed by the Loko variety (Figure 4b) showing the importance of phosphorus in promoting the development of extensive root systems which increase potential nodule development according to Wang *et al*.(202). Application of P significantly improved the number of total and effective nodules and an increasing P rate from nil to 46 kg $P_2 O_5$ ha^{-1} resulted in a 38 and 44% increase in total and effective nodules, respectively, compared to the control (Dereje *et al*., 2018). Cardoso *et al*. (2017) stated the highest nodule dry mass per plant ranging from 0.27g to 0.384 g for the isolates ALSG5A4, JPrG6A8, NVSG11A3, UnPaG11A9 and UnPaG8A12 on common bean.

Furthermore, Getachew *et al.* (2017) found that inoculation of rhizobia strains and S fertilizer enhanced volume of nodules, dry weight of nodule, shoot dry weight, and quantity of N2 fixed oi acid soil. Inoculation with MAR-1495 enhanced the quantity of fixed N by 759 % in S applications compared to non-inoculated. Inoculating common beans with a consortium of indigenous strains led to a higher nodule number of $plant^{-1}$ and nodule dry weight when compared to CIAT 899. The following was uncovered, according to one investigation: (1) Shoot growth got 81.5–87.1 % of the nitrogen taken by soybean roots and fixed by root nodules, leaving 12.9–18.5 %for root and nodule growth. Soybeans preferred to apply fertilizer N when there was a supply of NO^{-3} or NH^{4+}. After being transported to the shoots, a portion of the absorbed fertilizer N and nodule-fixed N was redistributed to the roots and nodules. The NO^- ^{3} or NH^{4+} absorbed by the roots and the N fixed by the roots provided the majority of the N necessary for root development (Zhang *et al*., 2020).

The highest (8.41 cm) taproot length of common bean was recorded from the application of higher (50 kg NPSB ha^{-1}) blended fertilizer resulting in a 61% increase due to the nutrient supply which helped more cell division and elongation. All the varieties showed an increasing tendency of root length in response to an increased fertilizer rate, however, the Loko variety showed the relatively longest tap root length (7.5 cm) (Figure 6). Salim *et al. (*2022) reported that large root length implies a higher harvest index than the small-rooted genotype in soybean genotypes. Root length ranging from 8.3 cm to 37.2 cm and the mean fresh root weight of plants ranged from 2.8 to 17.7 g. was recorded from accession PB0025 at the flowering stage (Getachew *et al.*, 2017) which is much larger than the present study may be due to the availability of moisture and varietal differences and/or other environmental factors which forces the root growth for the search of nutrients and moisture in deep in the soil. Also, Akpalu *et al*. (2014) reported a significant root dry weight increases at increased phosphorus rates and *B. japonicum* inoculation strains over non-inoculated treatment. Root biomass per plant increased from 1.40 g to 2.36 g at increasing phosphorous level (Mourice and Tryphone, 2012).

The varietal response of all common bean varieties to NPSB fertilizer rate was correspondingly similar for the root fresh weight and root dry weight performance (Figure 8a and b) indicating both characters showed proportionally. Research indicated that in common bean, nodulation characteristics were favorably linked with yield components, shoot and root parts, and blooming length (Santalla *et al*., 2001). This study partly conforms to Koskey *et al.*(2001).who reported that there was no significant difference in symbiotic efficiency between the MAC13 and MAC64 climbing bean varieties while the results demonstrated a significant improvement in nodule dry weight upon rhizobia inoculation as compared to the non-inoculated control. In addition, inoculation of strains influenced nodule number/plant and nodule dry weight in faba bean considerably ($P_2.0_5$), with inoculation of strain EAL 1018 resulting in greater nodule number (69.40) and nodule dry weight (0.3867 g/plant (Samuel *et al.*, 2021). The biological fixation of bean genotypes can be increased by breeding and selection for the ability of bean genotypes to fix nitrogen at lower fertilizer levels, according to a study on common bean[(Reinprecht *et al*., 2020). The regression analysis showed that the effect of NPSB blended fertilizer had more influence on all the parameters studied than the common bean varieties. The varieties selected for this study might have a similar response to rhizobium inoculation and fertilizer effect. Therefore, genetically diverse varieties would have shown varied responses to rhizobium symbiosis and fertilizer rate which in turn result in a difference of root and nodulation characters. However, from the varieties tested, the Nassir variety had shown better performance in nodulation while the Loko variety was longer in root length and had higher root mass weight.

Therefore, the difference in nodulation and root characteristics response of common bean to the application of various levels of inoculated common bean varieties and NPSB blended fertilizer. This study helps researchers to design experiments to choose the best varieties that can adapt to different environments at the same time with good symbiotic interaction with rhizobia for sustainable fertility management. Therefore, the finding has practical implications in plant nutrition, plant adaptation and soil fertility management.

CONCLUSIONS

The effect of rhizobium inoculated common bean types and blended NPSB fertilizer on root development and nodulation parameters were found to be substantial while the interaction effect was significant for a total number of nodules per plant. The highest number of total nodules (53.7), effective nodules per plant (35.54), taproot length (8.41cm), root dry weight plant^{-1} (4.2g), nodules fresh weight (11.84g) and nodules dry weight (1.29g) were recorded from application of 150 kg NPSB ha^{-}1of blended fertilizer. Nasir variety gave significantly high effective nodules per plant (39.71), while the Loko variety had the highest tap root length (7.5 cm), nodules fresh weight (10.83g), root dry weight (3.56g), and nodules dry weight (3.56g), it also had the shortest tap root length (7.5 cm) (1.22g). Thus, the finding indicated the common bean varieties showed a linear response of root growth and nodulation to an increasing blended NPSB (150 kg ha$^{-1)}$ fertilizer rate. Nassir may be selected for better nodulation whereas Loko variety for root characteristics.

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Competing interest

The authors declare that there is no conflict of interest.

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