Original Research Article||

Agronomic and symbiotic performances of common bean varieties inoculated with *Rhizobium* species combined with nitrogen fertilizer

Meseret Shifa[1], Tarekegn Yoseph[2]* and Berhanu Abate[2]

[1]*Alliance for a Green Revolution in Africa*
[2]*School of Plant and Horticultural Sciences, College of Agriculture, Hawassa University, P.O. Box 05, Hawassa, Ethiopia*

Abstract

Common bean [*Phaseolus vulgaris* (L)] is an important source of income and protein for farmers in developing countries, including Ethiopia. However, inadequate information about agronomic practices, especially the use of N-source fertilizers, limits its production and productivity. Because of this, a field experiment was conducted in the Meskan district during the 2018 cropping season to evaluate the effect of bio/inorganic fertilizers on growth, nodulation, yield, and yield components of common bean varieties. Factors studied included four common bean varieties [Hawassa Dume, Gegeba, Rori, and Ibado], and four levels of bio/inorganic fertilizers [Control, inoculation with *Rhizobium* strain HB-429, 46 kg N ha^{-1}, inoculation + 46 kg N ha^{-1}]. The experiment was laid out in a randomized complete block design in factorial arrangements with three replications. The results showed significant varietal differences in crop phenology, growth, nodulation, yield, and yield components. Hawassa Dume exhibited superior growth, nodulation, and yields among the varieties except for the hundred seed weight. Similarly, the application of bio/inorganic fertilizers showed significant effects on most studied plant parameters. A higher number of pods plant^{-1}, seeds pod^{-1}, and grain yield were recorded from the combined application of *Rhizobium* strain HB-429 + 46 kg N ha^{-1}. The interaction effect of bio/inorganic fertilizers with varieties significantly affected nodule number plant^{-1} and straw yield. The highest nodule number plant^{-1} and straw yield were recorded from the *Rhizobium* inoculation, and the combined application of *Rhizobium* strain HB-429 inoculation+46 kg N ha^{-1} with variety Hawassa Dume. Grain yield was positively and significantly correlated with plant growth, nodulation, and yield-related parameters. Based on the current findings, the combined application of *Rhizobium* strain HB-429 + 46 kg N ha^{-1} was found to be suitable for the common bean variety Hawassa Dume production in the study site and similar agro ecological areas.

Key words: Bio-fertilizer, grain yield, inorganic fertilizer, nodulation

Original submission: April 25, 2022; **Revised submission**: September 12, 2022; **Published online**: October 23, 2022
***Corresponding author's address:** Tarekegn Yoseph, Email: tareyoseph@gmail.com
Authors: Meseret Shifa: marmarshifa@gmail.com and Berhanu Abate: berhanuabate@yahoo.com

INTRODUCTION

Common bean [*Phaseolus vulgaris* (L)] is an annual crop that belongs to the legume family *Fabaceae*. It is a major grain legume grown and consumed globally for its edible seeds, green pods, and health benefits (Heuzé et al., 2013; Dilis and Trichopoulou, 2009). In addition to its nutritional and health benefits, it can fix more than 160 kg of atmospheric nitrogen per hectare into the soil via interactions with *Rhizobium* bacteria (Beshir et al., 2015).

In Ethiopia, the common bean ranks third as an export commodity, contributing about 9.5% of the total export value from agriculture and with a market value of USD 118.7 million (FAOSTAT, 2019). However, its productivity among smallholder farmers in Ethiopia is very low, ranging from 0.5 to 0.8 t ha^{-1} (EEPA, 2004), which is much lower than the potential yield (4 t ha^{-1}) reported elsewhere (Beebe et al., 2013). The low productivity of the crop in farmer's fields is mainly due to the use of poor quality seeds, poor soil fertility management, biotic and abiotic stresses during plant growth and lack of effective rhizobial inoculants (Ndakidemi et al., 2006; Beebe et al., 2013).

Rhizobial inoculation is an effective way to increase the supply of N to legume crops, especially in soils with low bacterial populations. Under optimal environmental conditions, genetically superior common bean cultivars, efficiently nodulated by *Rhizobium* species, can fix sufficient N to support grain production (Kellman, 2008). On the other hand, the recommended rate of N fertilizers has been reported to enhance early crop growth, allowing the delivery of more carbohydrates for N_2 fixation later in the season (Mesfin *et al.*, 2020). However, farmers have the misconception that the common bean being a legume crop does not require any nutrition and usually grows on marginal land without applying fertilizers. Therefore, to increase the farmers' productivity, it is important to increase the farmers' awareness of the utilization of improved agronomic practices that increase production and ensures accelerated food security through proper implementation soil nutrient management. Hence, this study was conducted with the main objective of assessing the response of common bean varieties to *Rhizobium* inoculant in combination with chemical N fertilizer under silt clay loam soil, in Meskan district, southern Ethiopia.

MATERIALS AND METHODS

Description of the study site

The study was conducted in southern Ethiopia in the Meskan district of the Gurage zone during the 2018 main cropping season. The study site is located 168 km west of Hawassa, the capital of the Sidama region, and 154 km south of Addis Ababa. It is geographically located at 08°03'52" N latitude and 38°23'28" E longitude with an altitude of 1832 m above sea level (Figure 1). The site receives a mean annual rainfall of 1150 mm with minimum and maximum average temperatures of 10.3 and 25.6°C, respectively (SNNPRSMA, 2018 unpublished). The soil of the area is dominated by silt clay loam and maize (*Zea mays* L.) is the dominant crop followed by common bean.

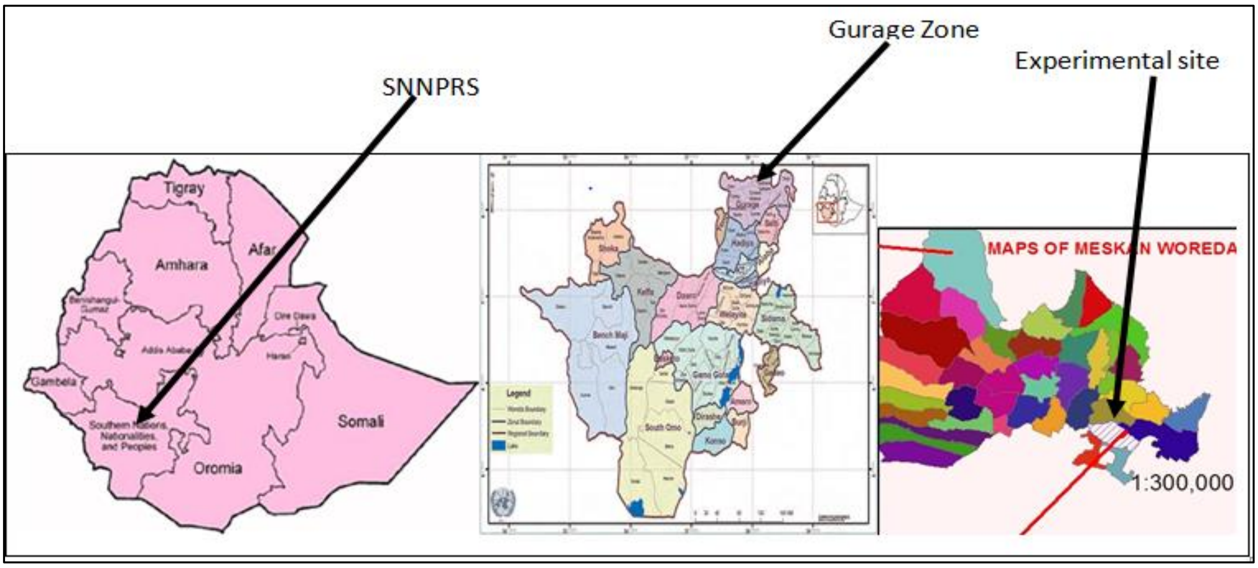

Figure 1. Administrative map of SNNPR where Gurage Zone, Meskan district, and experimental sites are located.
Source: Teka et al., 2020.

Source of variety and *Rhizobium* inoculant

Seeds of the three common bean varieties [Hawassa Dume, Gegeba, and Rori] were obtained from Hawassa Agriculture Research Center. However, the Ibado variety seeds were sourced from Areka Agricultural Research Center. The varieties were selected based on their productive potential, adaptability, and seed availability. On the other hand, the *Rhizobium* inoculant strain HB-429 was obtained from Menagesha Biotech, P.L.C. Ethiopia. The inoculant was selected for its outstanding growth, nodulation, and yield performances under two years of field experiments (Samago et al., 2018).

Rhizobium inoculation

The seeds were inoculated with a peat-based carrier as per the recommended rate (10 g inoculant per kg of seeds containing 6.5×10^8 viable bacterial cells g^{-1} peat) (Rice *et al.*, 2001). Inoculation was done under shade to maintain the viability of bacterial cells. Then the inoculum was mixed thoroughly with moist seeds and allowed to dry in the air for fifteen minutes before planting to prevent fungal growth. Each planting hole received two seeds, which were later tinned to a plant. As a precaution against cross-contamination, the un-inoculated plants were sown first and followed by inoculated treatments. Soil ridges were made to separate inoculated and un-inoculated treatments from each other to prevent cross-contamination through rainwater movement. After sowing, the seeds were immediately covered with moist soil to prevent bacterial cell death due to desiccation.

Experimental design and procedures

The treatments included four common bean varieties [Hawassa Dume, Gegeba, Rori, and Ibado] and four-levels of bio/inorganic fertilizers (control, *Rhizobium* strain HB-429 inoculation, 46 kg N ha^{-1}, and *Rhizobium* strain HB-429 inoculation + 46 kg N ha^{-1}) which were laid out in Randomized Complete Block Design (RCBD) in factorial arrangements with three replications. Each treatment combination was assigned randomly to the experimental units within a block. Thus, the experiment included 16 treatments with a total of 48 plots. The size of each experimental plot was 2.4 m x 3.2 m (7.68 m^2) in six rows. Planting was done using a spacing of 0.4 m between rows and 0.1 m between plants to give a final population density of 250,000 plants ha^{-1}. The pathways between blocks and plots were 1m and 0.5 m, respectively. From each plot, the central three rows (2.88 m^2) were used for the final harvest. The recommended triple superphosphate fertilizer (100 kg TSP ha^{-1} or 76.8 g plot^{-1}) was applied to all plots as a P source during planting. The recommended urea fertilizer was applied manually to designated plots at planting and three weeks after sowing. All recommended agricultural practices have been implemented during the growing season invariably for each treatment.

Soil sampling and analysis

At the onset of the experiment, twenty soil samples (0 – 30 cm) were taken from the site using a soil auger. The samples were mixed thoroughly and reduced to one kilogram of the composite sample, which was then, air-dried and crushed and packed in a polythene bag, labeled, and sent to Hawassa University College of Agriculture soil laboratory for the physicochemical characterization.

The parameter analyzed included soil textural class (percentage of sand, silt, and clay), soil pH, total N, available P, organic carbon, and cation exchangeable capacity (CEC). The soil texture was estimated using the modified Bouyoucos hydrometer method (Day, 1965). Soil pH was determined potentiometrically in the supernatant of 1:2.5 soil: distilled water ratio using a combined glass electrode pH meter (Chopra and Kanwar, 1976). The total N content of the soil was estimated using the wet-oxidation procedure of the Kjeldahl method as described by Dewis and Freitas (1975). The available P content of the soil was determined by 0.5 M sodium bicarbonate extraction solution (pH 8.5) according to the procedure of Olsen (Olsen et al., 1982). The organic carbon content of the soil was determined using the wet combustion procedure of Walkley and Black (1954). The CEC was determined using the Kjeldahl procedure as described by (Ranist et al., 1999) for planting.

Phenological data

Days to 50% flowering: it was recorded as a number of days from emergence to the time when 50% of the plant population in each plot produced flowers.

Days to 90% maturity*:* it was counted as the number of days after seedling emergence to the period when 90% of the plants in a plot were ready for harvest as revealed by a straw color change in the foliage and pod and seed hardening in the pods.

Growth parameters

Plant height (cm): it was measured at 50% flowering and physiological maturity by measuring the main stem height from the ground up to the canopy height using a ruler from five randomly selected plants per plot, and the average height was used for analysis.

Number of primary branches plant^{-1}: it was determined by counting the primary branches of the main stem of five randomly selected plants per plot and average values were considered for analysis.

Shoot dry weight plant^{-1}: was determined at the mid-flowering stage of the crop from plants that were sampled for nodulation. The plant samples were placed in labeled perforated paper bags and oven-dried for 48 hours at 70°C to a constant weight to determine the dry weight yield. The average shoot dry weight of five plants was recorded as shoot dry weight plant^{-1}.

Nodulation parameters – nodule number and dry weight plant^{-1}

The collected nodules were labeled and placed in perforated paper bags. The number of nodules was determined by counting the number of nodules from five randomly selected plants and the mean value of the five plants was recorded as the number of nodules plant^{-1}. The nodule dry weight plant^{-1} was measured after drying the collected nodules in an oven with a temperature of 70°C for 48 hrs (until constant weight was obtained). The average of five plants was taken as a nodule dry weight plant^{-1}.

Yield and yield components

Number of pods plant^{-1}: was recorded from ten randomly selected plants from the net plot area at the harvest and averaged to ten plants.

Number of seeds pod^{-1}: was determined from randomly selected ten pods from the plant used for pod number count and the average of ten pods was used as a number of seed pod^{-1}.

Hundred seeds weight: was recorded by weighing 100 randomly selected dry seeds from the net plot harvest using a sensitive balance.

Grain yield (t ha^{-1}): was recorded after threshing and adjusting the grain yield at the appropriate standard grain moisture content of 10% for pulses.

$$AGY\ (t\ ha^{-1}) = \frac{PY(kg) \times (100 - AMC) \times 1000m^2}{2.88\ m^2 \times (100 - SMC) \times 10000m^2}$$

Where AGY = adjusted grain yield; PY = plot yield; AMC = actual moisture content and SMC = standard moisture content

Biological yield (t ha^{-1}): at physiological maturity, ten plants were selected randomly and independently from each plot and the straws were placed in an oven with a temperature of 70°C for 48 hrs (until constant weight was obtained) to determine above-ground total biomass yield, and the average above-ground total biomass yield was reported in t ha^{-1}.

Harvest index (HI, %): was computed as the ratio of dry grain yield to the total above-ground biomass yield.

$$HI\ (\%) = \frac{Dry\ seed\ yield}{Total\ above\ ground\ biomass} \times 100$$

Statistical analysis

The collected data were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) of the Statistical Analysis System software (SAS, 2002) version 9.0. Whenever the effects of the factors were found to be significant, the means were compared using the Least Significant Differences (LSD) test at 5% level of significance. Correlation analysis was done using Pearson's simple correlation coefficients for the parameters with meaningful associations.

RESULTS

Physicochemical properties of soil at the study sites

The results showed that the soil particle size distribution [22.4% sand, 46% silt, and 31.6% clay] was silt clay loam in texture. Soil texture is a fundamental property of the soil that a farmer can hardly modify. Moreover, it is closely related to soil nutrient and water retention capacity, as loam and clay soils hold more nutrients and water than sandy soils (Brady, 2002). The soil was slightly acidic (pH = 6.2) in soil reaction and hence, suitable for crop production, including common beans (Havlin *et al*., 1999). Except for the CEC (24 cmol kg^{-1}), which was rated as medium, total N (0.15%), available P (6 mg ka^{-1}), and organic carbon (1.56%) were low in the soil before planting. This may be due to poor farm management practices and continuous cropping with little or no fertilizer input, which resulted in a decline in the soil fertility of the area (oral communication with the local farmers). Thus, the experimental site needs the addition of organic or inorganic fertilizers to support the potential crop production. It may be because these common bean varieties responded to the combined application of *Rhizobium* inoculation and recommended N fertilizer under this experiment.

Effect of bio/inorganic fertilizers on phenology and growth of common bean varieties

The results showed that the phenological and growth parameters were significantly influenced (p<0.01) by the main effect of variety and bio/inorganic fertilizers (Table 1). However, the interaction effect of variety by bio/inorganic fertilizers did not show a marked effect on the phenological and growth parameters. Among the varieties, Ibado took longer days to flower and reach physiological maturity, followed by Gegeba and Rori. The shortest days to flowering and physiological maturity, on the other hand were recorded for the Hawassa Dume variety. Better growth performance in terms of plant height, number of primary branches, and shoot dry weight were also recorded for the Hawassa Dume variety. However, the lowest primary branches and shoot dry weight corresponded to the Gegeba variety.

Regarding bio/inorganic fertilizers, the longest days to flowering and physiological maturity as well as higher plant height, primary branches, and shoot dry weight were recorded for the treatment of combined application of *Rhizobium* strain HB-429 and 46 kg N ha^{-1}, followed by separate applications of strain HB-429 inoculation and 46 kg N ha^{-1}, respectively. The control treatment exhibited lower values of these parameters.

Table 1. Common bean varieties and fertilizer treatment levels during the 2018 cropping season

Treatment	Days to 50% flowering	Days to 90% maturity	PH (cm)	Number of primary branch	Shoot DW (g plant^{-1})
Variety					
Hawassa Dume	43.4^{c}	81.0^{c}	102.7^{a}	2.9^{a}	80.0^{a}
Gegeba	44.8^{ba}	85.8^{ba}	88.0^{b}	2.4^{c}	57.3^{d}
Rori	44.2^{bc}	83.3^{cb}	88.4 ^{b}	2.6^{b}	71.9^{b}
Ibado	45.5^{a}	87.8^{a}	82.3 ^{b}	2.5^{cb}	64.5^{c}
LSD0.05	1.3	2.8	6.3	0.19	5.08
Bio/inorganic fertilizers					
Control	42.3^{d}	80.6^{c}	77.6^{c}	2.1^{d}	51.8^{d}
HB-429 (Ino.)	45.2^{b}	85.0^{b}	91.8^{b}	2.7^{b}	72.4^{b}
46kg N ha^{-1}	43.8^{C}	83.8^{cb}	86.2^{b}	2.4^{c}	63.1^{c}
46 kg N ha^{-1}+Ino.	46.6^{a}	88.5^{a}	105.8^{a}	3.2^{a}	86.4^{a}
LSD 0.05	1.3	2.8	6.3	0.19	5.08
F-Statistics					
Variety	**	**	**	**	**
Bio/inorganic fertilizer	**	**	**	**	**
Var. x fertilizer	NS	NS	NS	NS	NS
CV (%)	3.4	4	8.4	9.1	8.9

Means in columns followed by the different superscript letters are significantly different as judged by the LSD test at a 5% level of significance; DW = dry weight; CV = Coefficient of variation; PH = Plant height; Ino. Inoculation by HB-429; Var. = Variety; NS = not significant (p<0.05); ** means that the factors were significant at p<0.01

Effect of bio/inorganic fertilizers on nodulation of common bean varieties

The analysis of variance indicated that the main effects of variety and bio/inorganic fertilizers had a highly significant (p<0.01) effect on the nodule number and nodule dry weight (Table 2). The interaction effect of variety by bio/inorganic fertilizers also significantly affected nodule number but not nodule dry weight. The highest number of nodules and nodule dry weight were obtained from the Hawassa Dume variety; with the lowest values corresponding to the Gegeba variety. Statistically significant differences were not detected in nodule numbers between the Ibado and Rori varieties and in nodule dry weight among the varieties Ibado, Rori, and Gigaba.

Looking at the fertilizer treatments applications, the highest nodule number and nodule dry weight were recorded from plants inoculated with *Rhizobium* strain HB-429. Whereas, the differences in nodule dry weight between the 46 kg N ha^{-1} alone and the combined application of 46 kg N ha^{-1} + *Rhizobium* strain HB-429 were not statistically significant. The lowest nodules and nodule dry weight was recorded for the control treatment. Regarding the interaction effect, the highest nodules plant^{-1} were recorded for the Hawassa Dume variety receiving the *Rhizobium* strain HB-429 inoculation. A statistically significant difference in the nodule number was not detected between the varieties Hawassa Dume and Rori. However, the lowest number of nodules were recorded from the variety Gegeba without inoculation (Figure 2).

Table 2. Effect of bio/inorganic fertilizers on nodulation of common bean varieties at Meskan, during the 2018 cropping season

Treatment	Nodule number (plant^{-1})	Nodule DW (g plant^{-1})
Variety		
Hawassa Dume	29.7^{a}	0.32^{a}
Gegeba	22.7^{c}	0.26^{b}
Rori	26.2^{b}	0.28^{b}
Ibado	25.8^{b}	0.27^{b}
LSD 0.05	2.9	0.02
Bio/inorganic fertilizers		
Control	17.4^{d}	0.2^{c}
HB-429	36.8^{a}	0.4^{a}
46kg N ha^{-1}	22.8^{c}	0.3^{b}
46kg N ha^{-1}+HB-429	27.3^{b}	0.3^{b}
LSD 0.05	2.9	0.02
F-Statistics		
Variety	**	**
Bio/inorganic fertilizer	**	**
Variety x Bio/inorganic fertilizer	**	NS
CV (%)	13.4	12.1

Means in columns followed by the same letter/s are not significantly different as judged by LSD test at a 5% level of significance; DW = dry weight; CV: Coefficient of variation; NS = not significant ($p<0.05$); ** means that the factors were significant at $p<0.01$.

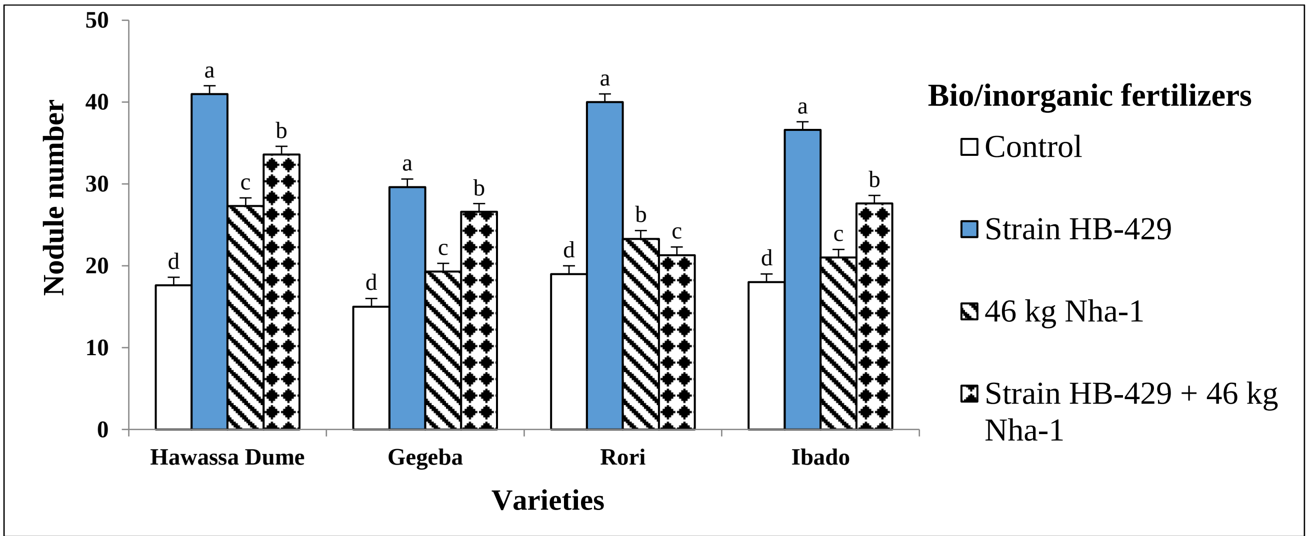

Figure 2. Interaction effects of variety by bio/inorganic fertilizers on nodule number plant^{-1} Bars with different letters are significantly different ($p<0.05$).

Effect of bio/inorganic fertilizers on yield and yield components of common bean

The results revealed that the main effect of variety and bio/inorganic fertilizers had significant ($p<0.01$) effects on yield and yield components of common bean. However, the interaction effects of variety and bio/inorganic fertilizers did not show significant influences (Table 3). Among the varieties, Hawassa Dume showed superior performances in yield and most yield-related traits except the hundred seed weight. Gegeba variety on the other hand exhibited the heaviest seed weight all varieties.

Regarding the bio/inorganic fertilizers, combined application of 46 kg N ha^{-1} and *Rhizobium* inoculation resulted in higher values for all the parameters followed by the separate applications of *Rhizobium* inoculation and 46 kg N ha^{-1} alone. The control treatment exhibited the lowest yield and yield-related parameters of all.

Regarding the interaction effects, the highest straw yield was recorded for the variety Hawassa Dume and combined application of *Rhizobium* inoculation with strain HB-429 and 46 kg N ha^{-1}, followed by the variety Gegeba inoculated with *Rhizobium* strain HB-429.On the other hand, the lowest straw yield was recorded for the variety Rori without any bio/inorganic fertilizer applications (Figure 3).

Grain yield was found to be dependent on the number of nodules $plant^{-1}$, nodules dry weight $plant^{-1}$, plant height, primary branches $plant^{-1}$, shoot dry weight, pods $plant^{-1}$, seeds $plant^{-1}$, hundred seed weight and biomass yield (Table 4). Generally, a strong positive correlation of grain yield with the parameters listed above was observed with the Pearson's coefficient of correlation (r) ranging from 0.48 to 0.83.

Correlation analysis

Table 3. Correlation (r) between grain yield, plant growth, nodulation, and yield components of common bean varieties planted at Meskan, during the 2018 cropping season

Parameters	Pearson's correlation coefficient (r)	p value
Grain yield versus nodule number	0.63	**
Grain yield versus nodule dry weight	0.63	**
Grain yield versus plant height	0.71	**
Grain yield versus number of primary branches	0.79	**
Grain yield versus. shoot dry weight	0.83	**
Grain yield versus pod number	0.60	**
Grain yield versus seed number	0.72	**
Grain yield versus hundred seed weight	0.48	*
Grain yield versus biomass yield	0.67	**

N = 48: *, **, significant at $p \leq 0.05$, $p \leq 0.01$ levels, respectively.

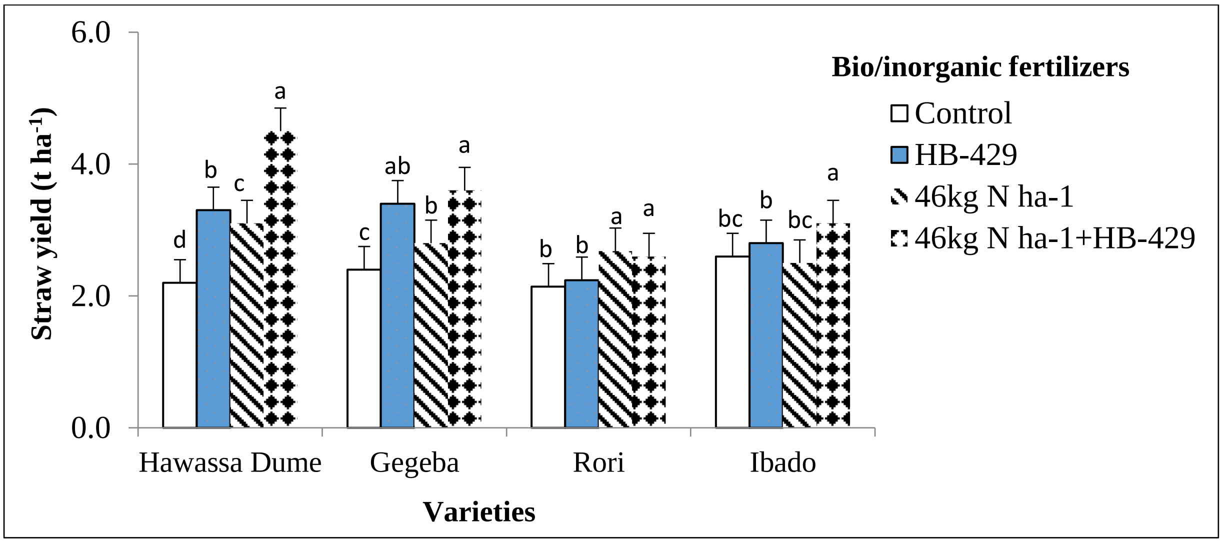

Figure 3. Interaction effects of variety by bio/inorganic fertilizers on straw yield
Bars with different letters are significantly different (p<0.05).

Table 4. Effect of bio/inorganic fertilizers on yield and yield components of common bean varieties at Meskan, during the 2018 cropping season

Treatments	Pod number $plant^{-1}$	Seed number $plant^{-1}$	Hundred seed weight (g)	Grain yield ($t\ ha^{1}$)	Straw yield ($t\ ha^{-1}$)	Biomass yield ($t\ ha^{-1}$)	Harvest index (%)
Varieties							
Hawassa Dume	29.1^{a}	5.6^{a}	23.9^{b}	2.7^{a}	3.3^{a}	5.02^{a}	0.52^{a}
Gegeba	22.4^{c}	4.5^{c}	30.2^{a}	2.0^{b}	3.1^{ba}	4.23^{b}	0.39^{c}
Rori	24.9^{b}	4.9^{b}	25.3^{b}	2.2^{b}	2.4^{c}	4.29^{b}	0.49^{ba}
Ibado	23.6^{cb}	4.3^{c}	26.8^{b}	1.9^{b}	2.8^{bc}	4.09^{b}	0.47^{b}
LSD 0.05	2.4	0.4	3.2	0.2	0.4	0.5	0.04
Bio/inorganic fertilizers							
Control	21.6^{c}	3.8^{c}	17.1^{d}	1.5^{d}	2.4^{c}	3.32^{c}	0.37^{c}
Strain HB-429	26.1^{a}	5.0^{b}	30.3^{b}	2.5^{b}	2.9^{b}	5.02^{a}	0.49^{ba}
46kg N ha^{-1}	24.8^{b}	4.9^{b}	25.3^{c}	2.2^{c}	2.8^{b}	4.12^{b}	0.49^{ba}
46 kg N ha^{-1} + HB-429	27.5^{a}	5.6^{a}	33.5^{a}	2.7^{a}	3.5^{a}	5.19^{a}	0.52^{a}
LSD 0.05	2.4	0.4	3.2	0.2	0.4	0.5	0.04
F-Statistics							
Variety	**	**	**	**	**	**	**
Bio/inorganic fertilizer	**	**	**	**	**	**	**
Var. x fertilizer	NS	NS	NS	NS	*	NS	NS
CV (%)	11.3	9.7	14.4	12.1	14.6	13.3	9.7

Means in columns followed by the same letters are not significantly different as judged by the LSD test at a 5% level of significance; CV = Coefficient of variation; PH = Plant height; Ino. Inoculation by HB-429; Var. = Variety; NS = not significant ($p<0.05$); *, ** means that the factors were significant at $p<0.05$ and $p<0.01$, respectively.

DISCUSSION

Despite the considerable progress made in agricultural development globally in the 21st century, food security in sub-Saharan Africa (SSA) remains one of the major challenges facing millions of people on the continent (Messerli 2019; Yigezu 2021). In the SSA region, agricultural productivity is low and has declined compared to other developing countries during the past decades (Bjornlund et al., 2020). The problem has been exacerbated by the recent decline in soil fertility due to intensified agricultural activities. One of the alternatives to address such a problem is supplying well-balanced nutrients to meet the crop nutrient requirements. Therefore, a field experiment was conducted in Meskan district, southern Ethiopia to evaluate the effect of bio/inorganic fertilizers on growth, nodulation, yield, and yield components of common bean varieties during the 2018 cropping season.

Plant growth, nodulation, yield and yield components can differ between plant species and varieties. In this study, varietal differences were measured in four common bean varieties [Hawassa Dume, Gegeba, Rori, and Ibado]. Of the four varieties studied, Ibado was found to be a late flowering and maturing variety, followed by Gegeba, while Hawassa Dume and Rori varieties require fewer days to initiate followers and reach maturity (Table 1). Differences in crop phenological parameters among the varieties may be due to their genotypic differences. Such differences among the varieties allow smallholder farmers to select genotypes that mature early and adapt well to moisture deficits. In line with this result, Kilasi (2010) and Habtamu (2019) indicated differences in crop phenology due to the genetic makeup of the varieties or by the environmental conditions existing during the growth and grain filling period of the crop development. On the other hand, Hawassa Dume variety produced more nodules and nodule dry weight than the other varieties (Table 2). The higher nodulation performance of the Hawassa Dume variety when inoculated with an effective bio-inoculant indicates its high biological N_2 fixing capacity. This is important when recommending cultivars to farmers and determining cultivars for use as parental genotypes in breeding programs (Hungria and Bohrer, 2000). The observed differences in nodulation parameters among the common bean varieties could be related to the inherent symbiosis characteristics of the varieties (Habtamu, 2019). In line with this result, Tarekegn et al. (2017) found that the performance of five different varieties of cowpea varied significantly for nodulation parameters. However, this result did not agree with the work of Solomon et al. (2012), who reported non-significant differences among the soybean varieties on nodule number plant^{-1}.

Moreover, plant height, number of primary branches, shoot dry weight, number of pods, number of seeds, grain and biomass yields were higher in the Hawassa Dume variety compared to the other tested. However, the heavier seed weight was recorded from the Gegeba variety (Table 4). Independent of treatment effects, these differences could be attributed to genetic variability which is common among bean varieties (Morad et al., 2013; Awan et al., 2014; Fageria et al., 2014; Tadesse et al., 2014). Moreover, the greater grain yield recorded for the Hawassa Dume variety was due to its ability to produce more pods plant^{-1} and higher seed number pod^{-1}, which increased its economic yield and profitability as a crop (Tarekegn, 2015). The higher grain yield could also be attributed to the better plant growth of Hawassa Dume and perhaps, its increased nodulation or symbiotic performance (Table 2). Moreover, grain yield was positively and significantly correlated with plant growth, nodulation, and yield components, indicating that the improvements in these parameters contributed to the improvement of the final yield (Table 4).

Nitrogen (N) requirement of the legumes can be met by both mineral N_2 assimilation and symbiotic N_2 fixation (Ohyama, 2017). There is usually a positive yield response when N_2 is applied to common bean plants grown in N-poor soils. Studies carried out by Yoseph and Shanko (2017) and Samago et al. (2018) clearly revealed the need for inoculation with rhizobia to improve the yield of common bean under field conditions. In this study, common bean varieties responded positively to the combined application of 46 kg N ha^{-1} and *Rhizobium* strain HB-429 inoculation (Tables 1–3), a finding consistent with previous reports (Fallahi and Peyman, 2020).

Inoculation of common bean varieties with *Rhizobium* strain HB-429 resulted in a higher nodule number and nodule dry weight when compared to the other treatments (Table 2). The improved nodulation performance of common bean varieties due to rhizobial inoculation is a clear manifestation of the poor symbiotic effectiveness of native rhizobia in soils, as well as an indication of the ability of the introduced strain to outcompete the indigenous rhizobia in soils of the study site. On the other hand, applying N_2 fertilizer at 46 kg N_2 ha^{-1} increased the nodule number and nodule dry weight by 23.7 and 33.3% compared to the control. However, Kessel and Hartley (2000) observed a significant decrease in nodulation of several varieties of common beans following the application of 40 kg N ha^{-1}. Such differences might be attributed to the variability in soil N_2 content; where the test site of the present study had very low nutrient contents, including total N_2.

The application of bio/inorganic fertilizers to common bean resulted in prolonged days of flowering and maturity (Table 1) which might be due to the increased vegetative growth with applied N and N_2-fixation. In line with this finding, Nebret and Nigussie (2017) and Habtamu et al. (2017) obtained prolonged days to flowering and maturity in common bean with increased N supply from 0 to 46 kg N ha^{-1}. Similarly, Verma *et al*. (2013) reported delayed days to flowering with effective *Mesorhizobium* inoculation of chickpea. On the other hand, the earlier flowering and maturity of plants in the control treatment might be attributed to plant competition for limited resources.

The increased plant growth as a result of *Rhizobium* inoculation also resulted in a greater number of pods $plant^{-1}$, seeds pod^{-1}, and grain yield (Table 2). It was therefore not surprising that nodule number and nodule dry weight were correlated positively with common bean grain yield in this study (Table 4). The significantly increased plant growth, nodulation, and grain yield of the common bean varieties as a result of inoculation with *Rhizobium* strains HB-429 provide direct evidence for the poor symbiotic competitiveness and effectiveness of native rhizobia nodulating beans in Ethiopian soils, while affirming the symbiotic superiority of the introduced strain (Samago et al., 2018). This finding is also consistent with a recent report by Samago et al. (2018) and strongly supports the use of rhizobial inoculants for increased common bean growth, nodulation and yield related parameters (Argaw 2016; Yoseph and Shanko, 2017).

CONCLUSION

The experiment was conducted to evaluate the effect of bio/inorganic fertilizers on growth, nodulation, yield, and yield components of common bean varieties. For this purpose, a treatment consisting of four common bean varieties and four bio/inorganic fertilizers was carried out under field conditions. The findings of the experiment indicated the significant effects of bio/inorganic fertilizer application on the growth, nodulation, and yield performance of the tested common bean varieties. Based on the results of the current experiment, it can be suggested that the combined application of *Rhizobium* strain HB-429 + 46 kg N ha^{-1} was found to be suitable for the variety Hawassa Dume in the study site and may be applied to this site and elsewhere with similar agro ecological conditions.

Conflicts of interest

Authors declare no conflicts of interest regarding the publication of this paper.

REFERENCES

Argaw, A., 2016. Effectiveness of Rhizobium inoculation on common bean productivity as determined by inherent soil fertility status. J. Crop Sci. Biotechnol. 19, 311–322. [Scholar Google]

Awan, F.K., Khurshid, M.Y., Afzal, O., Ahmed, M., Chaudhry, A.N., 2014. Agro-morphological evaluation of some exotic common bean (Phaseolus vulgaris L.) genotypes under rainfed conditions of Islamabad, Pakistan. Pak. J. Bot. 46(1), 259–264. [Scholar Google]

Beebe, S.E., Rao, I.M., Blair, M.W., Acosta Gallegos, J.A., 2013. Phenotyping common beans for adaptation Kessel C.V. and Hartley C. 2000. Agricultural management of grain legumes: has it led to an increase in nitrogen fixation. Field Crops Res. 65,165–181. [Scholar Google]

Beshir, H.M., Tesfaye, B., Bueckert, R., Taran, B., 2015. Pod quality of snap bean as affected by Nitrogen fixation, cultivar and climate zone under dryland agriculture. Afr. J. Agric. Res.10, 3157–3169. [Scholar Google]

Bjornlund, V., Bjornlund, H. and Van Rooyen, A.F., 2020. Why agricultural production in sub-Saharan Africa remains low compared to the rest of the world–a historical perspective. *International Journal of Water Resources Development*, *36*(sup1), pp.S20-S53. [Scholar Google]

Brady, N.C., Weil, R.R., 2002. The Nature and Properties of Soils, 13th Edition. Printice Hall, New Jersey, p. 960. [Scholar Google]

Chopra, S.H., Kanwar, J.S., 1976. Analytical Agricultural Chemistry. Kalyani Publisher Ludhiana, New Delhi, India.

Day, R.P., 1965. Pipette method of particle size analysis. In: Methods of soil analysis. Agronomy 9. ASA USA. p. 553–562. [Scholar Google]

Dewis, J., Freitas, P., 1975. Physical and chemical methods of soil and tissue analysis. FAO Bulletin No. 10. Rome. Pp. 275. Education Asia. Delhi, India. p. 960. [Scholar Google]

Dilis, V., Trichopoulou, A., 2009. Nutritional and health properties of pulses. Mediterr. J. Nutr. Metab. 1(3), 149–157. [Scholar Google]

EEPA, (Ethiopian Export Promotion Agency). 2004. Ethiopian pulses. Product Development and Research Directorate. Addis Ababa, Ethiopia.

Fageria, N.K., Melo, L., Ferreira, E., Oliveira, J., Knupp, A., 2014. Dry matter, grain yield, and yield components of dry bean as influenced by nitrogen fertilization and rhizobia. Commun. Soil Sci. Plant Anal. 45(1), 111–125. [Scholar Google]

Fallahi, S., Peyman, S., 2020. Effect of Nitrogen Fixing Bacteria and Nitrogen Rate on Yield and Growth of Common Bean. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 68(3): 491–496. [Scholar Google]

FAOSTAT (Food and Agricultural Organization Statistics). 2019. Agricultural trade statistics. Fao.org/site/291/default.aspx, (http://www. faostat.fao.org).

Habtamu Assefa, Berhanu Amsalu and Tamado Tana., 2017. Response of common bean (Pharsalus vulgaris L.) cultivars to combined application of Rhizobium and NP fertilizer at Melkassa, Central Ethiopia. Int. J. Plant Soil Sci. 14(1), 1–10. [Scholar Google]

Habtamu Kassa., 2019. Growth, Symbiotic and Yield Performance of Common Bean (Phaseolus vulgaris L.) Varieties in Response to Rhizobium Inoculation, and Phosphorus Application at Assosa, Western Ethiopia. MSc Thesis. p. 1–81.

Havlin, L.J., Beaton, D.J., Tisdale, L.S. and Nelson, L.W., 1999. Soil Fertility and Fertilizers: An introduction to nutrient management, p.552–574. [Scholar Google]

Heuzé, V., Tran, G., Sauvant, D., Bastianelli, D. and Lebas, F., 2015. Lima bean (Phaseolus lunatus). [Scholar Google].

Hungria, M., Bohrer, T.R.J., 2000. Variability of Nodulation and Dinitrogen Fixation Capacity among Soybean Cultivars. Biol. Fertil. Soils 31, 45–52. [Scholar Google]

Kellman, A.W., 2008. Rhizobium inoculation, cultivar and management effects on the growth, development and yield of common bean (Phaseolus vulgaris L.). Thesis Ph.D., Lincoln University. [Scholar Google]

Kessel, C.V., Hartley, C., 2000. Agricultural management of grain legumes: has it led to an increase in nitrogen fixation. Field Crops Res. 65, 165–181. [Scholar Google]

Kilasi N.L., 2010. Comparison of selection indices for tolerance to water stress in common bean (Phaseolus vulgaris L.) for the dry environment of Tanzania. MSc thesis. University of Zambia. [Scholar Google]

Mesfin Kassa, Belay Yebo and Abera Habte, 2014. The Response of haricot Bean (Phaseolus vulgaris L.) Varieties to Phosphorus Levels on Nitosols at Wolaita Zone, Southern Ethiopia. Amer. J. Plant. Nutr. 44, 27–32. [Scholar Google]

Messerli, P., Murniningtyas, E., Eloundou-Enyegue, P., Foli, E.G., Furman, E., Glassman, A., Hernández Licona, G., Kim, E.M., Lutz, W., Moatti, J.P. and Richardson, K., 2019. Global sustainable development report 2019: the future is now–science for achieving sustainable development. [Scholar Google]

Morad, M., Sara, S., Alireza, E., Reza, C.M. and Mohammad, D., 2013. Effects of seed inoculation by Rhizobium strains on yield and yield components in common bean cultivars (Phaseolus vulgaris L.). Int. J. Biosci. 3(3), 134–141. [Scholar Google]

Ndakidemi, P., Dakora, F.D., Nkonya, E., Ringo D., and Mansoor, H., 2006. Yield and economic benefits of common bean (Phaseolus vulgaris) and soybean (Glycine max) inoculation in northern Tanzania. Anim. Prod. Sci. 46(4), 571–577. [Scholar Google]

Nebret Tadesse and Nigussie Dachassa, 2017. Effect of Nitrogen and Sulphur Application on Yield Components and Yield of Common Bean (Phaseolus vulgaris L.) in Eastern Ethiopia. Acad. Res. J. Agric. Sci. Res. 5(2), 77–89. [Scholar Google]

Ohyama, T., 2017. The role of legume-Rhizobium symbiosis in sustainable agriculture. In Legume nitrogen fixation in soils with low phosphorus availability (pp. 1-20). Springer, Cham. [Scholar Google]

Olsen, S.R., Cole, V., Walanbe, C.V. and Dean, L.A. 1954. Estimation of Available phosphorus in soils by extraction with Sodium Bicarbonate. USA Circular NO 939. [Scholar Google]

Ranist, V.E., Verloo, M., Demyer, A. and Pawels, J.M. 1999. Manual for soil chemistry and fertility laboratory. Belgium, p.245. [Scholar Google]

Rice, W., Clayton, G., Lupwayi, N., Olsen, P., 2001. Evaluation of coated seeds as a Rhizobium delivery system for field pea. Can. J. Plant Sci. 81(2), 247–253. [Scholar Google]

Samago, T.Y., Anniye, E.W., Dakora, F.D., 2018. Grain yield of common bean (Phaseolus vulgaris L.) varieties is markedly increased by rhizobial inoculation and phosphorus application in Ethiopia. Symbiosis 75, 245–255. [Scholar Google]

Samago, T.Y. 2015. Grain Yield, Symbiotic Nitrogen Fixation, Carbon Assimilation and Phosphorus Nutrition of Common Bean (Phaseolus vulgaris L.) Varieties in Response to Rhizobium Inoculation and Phosphorus Application in Ethiopia. Ph.D. Dissertation Pp 1-225. [Scholar Google]

SAS, 2002. Institute Inc. SAS User's Guide, Statistics Version 9.0 ed. SAS Institute, Cary, NC, USA.

SNNPRSMA (Southern Nations, nationalities and Peoples Regional State Meteorology Agency), 2018. Meteorological data of districts of Gurage Zonal Administration, Ethiopia.

Solomon, T., Pant, L.M., Angaw, T., 2012. Effects of Inoculation by Bradyrhizobium japonicum Strains on Nodulation, Nitrogen Fixation and Yield of Soybean (Glycine max L. Merill) Varieties on Nitisols of Bako, Western Ethiopia. Int. Sch. Res. Notices 12, 1–8. [Scholar Google]

Tadesse, D., Alem, T., Wossen, T. and Sintayehu, A., 2014. Evaluation of improved varieties of haricot bean in West Belessa, Northwest Ethiopia. Int. J. Sci. Res. 3(12), 2756–2759. [Scholar Google]

Tarekegn Yoseph, Bekele Baraso and Tewodros Ayalew, 2017. Influence of Bradyrhizobia inoculation on growth, nodulation and yield performance of cowpea varieties. Afr. J. Agric. Res. 12(22), 1906 –1913. [Scholar Google]

Teka, A., Asfaw, Z., Demissew, S. and Van Damme, P., 2020. Traditional uses of medicinal plants practiced by the indigenous communities in Gurage Zone, south central Ethiopia. *Ethnobotany Research and Applications*, *19*, pp.1-31. [Scholar Google]

Verma, J.P., Yadav, J., Tiwari, K.N., Kumar, A., 2013. Effect of indigenous Mesorhizobium spp. and plant growth promoting rhizobacteria on yields and nutrient uptake of chickpea (Cicer arietinum L.) under sustainable agriculture. Ecol. Eng. 51, 282–286. [Scholar Google]

Walkley A., Black C.A., 1934. An examination of different methods for determining soil organic matter and the proposed modification by the chromic acid titration method. Soil Sci. 37, 29–38. [Scholar Google]

Yigezu Wendimu, G., 2021. The challenges and prospects of Ethiopian agriculture. *Cogent Food & Agriculture*, *7*(1), p.1923619. [Scholar Google]

Yoseph, T., Shanko, S., 2017. Growth, symbiotic, and yield response of N-fertilized and Rhizobium inoculated common bean (Phaseolus vulgaris L.). Afr. J. Plant Sci. 11(6), 197–202. [Scholar Google]