Original Research Article||

Effect of plant density on common bean (*Phaseolus vulgaris* L.) varieties at Jinka, South Omo Zone, Ethiopia

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Abstract

Common bean is an important pulse crop in Ethiopia. However, its yield is primarily limited by the lack of appropriate plant density for different varieties. Therefore, this experiment was conducted to assess the effect of plant density on the growth, yield, and yield components of common bean varieties during the 2018 main cropping season in Jinka, South Omo Zone, Ethiopia. The experiment consisted of six common bean varieties (Hawassa Dume, DAB-277, SER-125, SCR-26, Wajo and Remeda) and three plant densities: 333,333; 250,000 and 200,000 plants ha^{-1} with inter-row spacing (cm^2) of 30 x 10; 50 x 10; and 40 x 10, respectively. The experiment was organized using a factorial arrangement in randomized complete block design with three replications. Growth parameters, yield and yield components data were collected and analyzed using SAS software program. The result revealed that, the highest leaf area, number of primary branches, pods and seeds plant^{-1} were obtained from variety SCR-26 at the lowest plant density of 200,000 plant ha^{-1} and the highest plant height was recorded for the Wajo variety at the highest plant density of 333,333 plant ha^{-1}. The highest above-ground biomass corresponded to SCR-26 variety at plant density of 250,000 plants ha^{-1}. The highest grain yield (3.51 t ha^{-1}) was recorded for SCR-26 variety at the lowest plant density, followed by SER-125 (3.33 t ha^{-1}) at the plant density of 250,000 plants ha^{-1}. The optimum plant density for SCR-26, Wajo and Remeda were 200,000 plants ha^{-1} while for SER-125, DAB-277 and Hawassa Dume were 250,000 plants ha^{-1}. In conclusion, sowing variety SCR-26 at 200,000 plant density ha^{-1} and variety SER-125 at 250,000 plant density are agronomically optimal for the study area. However, this tentative generalization, based on one season and one location, requires further studies over multiple years and locations to provide valid recommendations.

Key words: inter-row spacing, growth parameters, yield, yield components

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INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is an annual herbaceous dicot plant belonging to *Fabaceae* family and an autogamous diploid species with a total chromosome number of 2n=2x=22 (Kay, 1979). In Ethiopia, the agro-ecology of common bean growing locations is diverse, ranging from 1,200 to 2,212 meters above sea level, with annual rainfall varying from 580 to 1,950 mm. The length of growing period also varies from 70 to 220 days. Accordingly, the seasonal rainfall during the growing period ranges from 120 to 1636 mm (Belay et al., 1998). The optimum temperature for the growth of common bean is between 15-27°C (Salcedo, 2008). Moreover, common bean performs best on deep, friable and well aerated soil types. The ideal soil pH is between 6.0 and 7.5. The pH should not be below 5.0 or above 8.0 (Worku, 2015)

The major common bean-producing regions in Ethiopia are as follows: 43.8% for Oromia, 32.2% for the Southern Nations, Nationalities, and Peoples' Region (SNNPR), and 23.9% for Amhara (CSA, 2017). Common bean is the most important pulse crop in the SNNPR and is grown both as sole crop and in association with other crops. Common bean is grown in rotation crops as well as intercropped with cereals (maize and sorghum). The CSA (2017) report showed that 290,202.43 ha of land was cultivated with common bean yielding 483,922.65 tons, with average national yield of 1.65 t ha^{-1} in Ethiopia.

The world demand for common bean is highly increasing because of its significance to human nutrition as a source of proteins, complex carbohydrates, vitamins and minerals. It is also important in reducing blood cholesterol level, cancers, diabetics and chronic heart diseases (Bennink, 2005). It has been known as an export crop for long period contributing to the foreign exchange earnings. It is also grown as a food crop and consumed as traditional dishes. Dry beans are mostly prepared as *nifro* (boiled grain), mixed with sorghum or maize and also with kocho. It compliments cereals and other stable foods in the diet (Beshir et al., 2005).

Common bean was grown on about 98,324.41 ha in SNNPR from which about 154, 081.89 tons were produced in the year 2017, with the average regional yield of 1.62 t ha^{-1}. In the same year 4,584.52 ha was covered with common bean in South Omo Zone from which about 5,125.25 tones were produced, with the average zonal yield of 1.12 t ha^{-1} (CSA, 2017). However, this grain yield is lower as compared to its genetic yield potential (2.5 to 4.5 t ha^{-1}) under good management conditions (MOANR, 2017). Low productivity of common bean varieties might be associated with inappropriate crop geometry, which can affect yield of different varieties. About 50 common bean varieties were released nationally from different institutes (Universities and Research Centers) in Ethiopia, for which inter and intra-row spacing recommended nationally for different locations is the same (40 cm×10 cm), while the varieties have phenotypic and genotypic variations that might respond differently for crop geometry (Masa et al., 2017). Plant density is the major determinant for crop yield and especially in large seeded crops like common bean, since the logistics and cost of large quantities of seed becomes a significant issue compared to small seeded cereals (Matthews et al., 2011).

Melaku (2012) reported significant variety and plant density interactions on the phenology, growth, yield and yield components of common bean. The characteristics of different common bean varieties are different in terms of their growth habit, days to maturity, seed color, seed size, and seed weight, and agro-ecological adaptation (Matthews et al., 2011). According to Seyum (2014) plant spacing of 40 cm x 7 cm resulted in the highest total pod yield and lowest total pod yield was obtained from a green bean spaced at 40 cm ×1 0 cm. Alemayehu et al. (2015) stated that the highest grain yield for row spacing combination of 40 cm × 5 cm on common bean.

In Ethiopia, a spacing of 40 cm x 10 cm has been adopted; irrespective of the various growth habits of common bean varieties and locations which was not clear how this spacing was considered as the standard spacing without having planting density study (Beruktawit, 2012). In South Omo Zone, most farmers either use very high or very low plant density, which results in poor grain yield in quality and quantity (Mitiku, 2017).

In addition, improved common bean varieties are limited in the South Omo Zone, and farmers primarily use their own local cultivars and Hawassa Dume varieties, along with traditional agronomic practices. Therefore, this study was conducted to assess the effect of plant density on the yield and yield components of common bean varieties.

MATERIALS AND METHODS

Description of the Study Area

The field experiment was conducted at the research farm of Jinka Agricultural Research Center in South Omo Zone during 2018 the main cropping season. The geographical coordinates are 36^0 33'-37^0 67'E and 5^0 46'-6^0 57'N with an altitude of 1450 meter above sea level (Figure 1).

The rain distribution of the area is bimodal with the main rainy season extending from March to May and the second cropping season from July to October. The average annual rainfall of the area for the last ten years was 1326.7 mm with two seasons, while the monthly mean temperatures of 22.4ºC (National Metrological Agency Hawassa Brach, 2018). The soil texture of the experimental site is a sandy loam. It has organic matter content of 5.88%, total nitrogen content of 0.24%, cations exchange capacity of 32.40 cmol kg^{-1}, available phosphorus content of 3.41 mg kg^{-1} soil and soil pH of 6.41 (Yoseph and Worku, 2014).

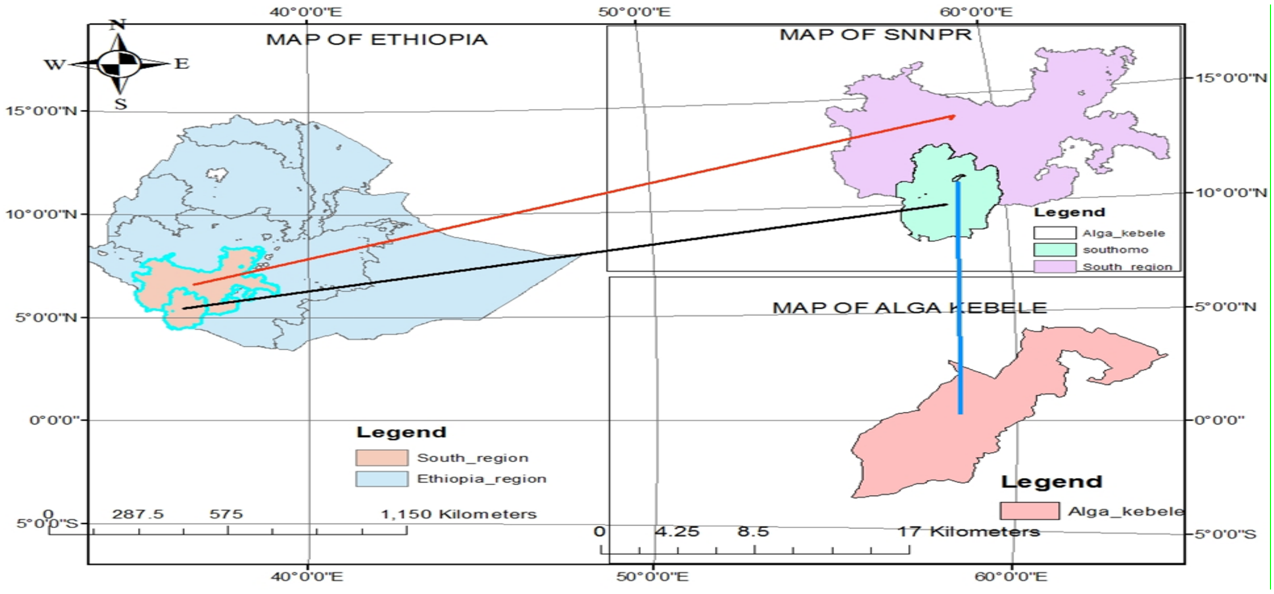

Figure 1: Map of the study area

Treatment and Experimental Design

The treatment consisted of six common bean varieties (SCR-26, DAB-27, SER-125, Wajo, Remeda and Hawassa Dume (as local variety, Table 1) and three plant densities formulated by three inter-rows spacing including 333,333 plant density ha^{-1} (30 cm x 10 cm), 250,000 plant density ha^{-1} (40cmx10 cm, control) and 200,000 plant density ha^{-1}(50 cm x10 cm). Eighteen factorial arrangements of varieties and plant density treatments were laid out in a randomized complete block design (RCBD) with three replications per treatment.

Table 1. Description of common bean varieties used for the research at Jinka, South Omo Zone during 2018 cropping season

Varieties	Seed color	Adaptation area (masl)	Yield t ha^{-1} Research field	Maturity days	Year & Place varieties released	Growth habit
SCR-26	Red	1300-1900	2.5-3.1	75-90	2017 SARI/HARC	determinate bush type
Remeda	Red	1300-1800	2.3	85-90	2017 SARI/HARC	Partial determinate bush type
SER 125	Red	1000-1200	2.0-4.5	70-90	2014 EIAR/MARC	determinate bush type
DAB-277	Red	1300-1900	2.6	75-90	2017 SARI/HARC	Determinant bush type
Wajo	White	1300-1800	2.4	75-100	2017 SARI/HARC	Indeterminate bush type
Hawassa Dume	Red	1000-1800	2.5-3.0	85-90	2017 SARI/HARC	Determinate bush type

Source: MOANR (2017); EIAR = Ethiopian Institute of Agricultural Research; HARC = Hawassa Agricultural Research Center; MARC = Melkassa Agricultural Research Center; SARI = Southern Agricultural Research Institute

Experimental Procedures and Management

The land was plowed, disked, and harrowed by a tractor. Two seeds per hill were sown at 10 cm intra-row spacing and at different inter-row spacing according to the treatment. Thinning of a single seedling per hill was done 12 days after emerged to maintain the target plant densities. The recommended rate of 100 kg ha^{-1} NPS fertilizer was applied as basal dressing along the rows at sowing. A gross plot size of 3 m x 3.6 m was used for 30 cm and 40 cm inter-row spacing and 3 m x 3.5 m for 50 cm inter-row spacing. The spacing between blocks and plots were 2.0 m and 1.0 m, respectively. The number of rows per plot for 30 cm, 40 cm, and 50 cm inter-row spacing were 12, 9, and 7, respectively. All agronomic practices such as weeding and hoeing were performed uniformly across the treatments. The first, second and third weeding were performed 15, 25 and 35 days, respectively after emergence. Harvesting was carried out from October 14/11/2018 up to 28/ 11/2018, based on the inherent maturity differences of the varieties.

Data Collection and Measurements

Growth and Nodulation Parameters

Leaf area (cm^2) was recorded by taking a destructive sample of five plants from rows next to the net plot and measured just before flowering using leaf area meter (Model-lI-3000A-portable Area meter, lI, COR). Plant height (cm) was measured at the time of physiological maturity from central rows as the mean height of five randomly taken sample plants from the ground level to the apex of each plant. The number of primary branches per plant was determined by counting the primary branches on the main stem of randomly selected plants from the central rows.

The total number of nodules was determined from five plants randomly selected from the two central rows at flowering.. The roots were carefully exposed with the bulk of root mass and nodules after which the nodules were separated from the soil, washed and the total numbers of nodules counted and average were recorded. Effective and non-effective nodules were also separated by their colors where a cross section of an effective nodule shows a pink to dark-red color, whereas a green color indicates ineffective nodulation.

Yield and Yield Components

Number of pods per plant was determined from five randomly sampled plants and the average value was considered. The number of seeds per plant was counted from five randomly selected plants, and number of seeds per pod was calculated by dividing the number of seeds by the number of pods. Total above ground dry biomass yield (kg) was determined by taking the total weight of the harvest including the seeds from two central rows and sun drying the biomass to constant weight and converted to t ha^{-1} with adjustment of 10% moisture content.

For grain yield assessment, the two central rows per plot were harvested, sun dried and threshed. The grain yield in kg from each plot was weighed using an electronic balance. Seed moisture content was measured with moisture meter (DRAMINSKI SN: 10-860 Olsztyn) after which the grain weight was adjusted to 10% moisture level and converted to t ha^{-1}. Adjusted yield was calculated using the formula of Kenneth (1995).

$$\text{Adjusted grain yield(kg)} = \frac{\text{Actual yield (kg)} * (100 - \text{Actual moisture content})}{(100 - \text{standared moisture content of pulse (10\%)}}$$

Statistical Data Analysis

The collected data were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in randomized complete block design (RCBD) using SAS software program version 9.2 (SAS, 2008) with a generalized linear model (GLM) procedure. Means were separated using the least significant differences (LSD) test at a 5 % level of significance.

RESULTS AND DISCUSSION

Plant Density by Growth and Nodulation

Yield and Yield Components

The analysis of variance showed that the main and interaction effects of variety and plant density were highly significant ($p < 0.01$) on leaf area per plant (Appendix Table 1). The highest leaf area (1760.5 cm^2) was recorded for variety SCR-26 at the lowest plant density (200,000 plants ha^{-1}) while the lowest (544.3 cm^2) was obtained from variety DAB-277 at the highest plant density (333,333 plants ha^{-1}) (Figure 1). This could be attributed to the inherent varietal characteristics and suitable environment for variety SCR-26 resulting in large leaf size per plant at lowest plant density (200,000 plants ha^{-1}) among tested treatments (Table 2).

In general, as plant density decreased, the leaf area per plant increased from 333,333 to 200,000 plants per hectare among the tested varieties (Table 2). The possible reason for observed higher leaf area per plant in all tested varieties at the lowest plant density might be due to more availability of sufficient levels of growth factors and better penetration of light, consequently increased number of leaves produced and the size of individual leaves in plants at wider row spacing.

The result from the present work was in agreement with those reported by Kueneman (1978) who reported that, lower plant density tended to enhance vegetative growth of common bean plant resulting in the development of large leaf area compared to the high and moderate plant populations resulting in sink limitation to photosynthesis. Similarly, Beruktawit

(2012) found that the highest leaf area per plant of (3678 cm^2) was obtained at the lowest plant density of 133,333 plants ha^{-1} and the lowest leaf area (1350 cm^2) was obtained at the highest plant density of 333,333 plants ha^{-1} in common bean varieties. Masa et al. (2017) also reported higher leaf areas per plant with increased inter-row spacing from 30 cm to 50 cm for common varieties.

Table 2. Mean values of leaf area, plant height and number of primary branches as influenced by common bean varieties and plant densities at Jinka, South Omo Zone during 2018 cropping season

Varieties	Population density (plant ha^{-1})	Leaf area per plant (cm^2)	Plant height (cm)	Number of primary branches
SCR-26	333,333 (30cmx10cm)	1283.4^{d}	73.20^{cd}	6.47^{hi}
	250,000 (40cmx10cm)	1443.5^{c}	68.40^{de}	9.00^{f}
	200,000 50cmx10cm)	1760.5^{a}	62.07^{fgh}	12.00^{a}
SER-125	333333 (30cmx10cm)	1117.5^{fgh}	67.33^{e}	8.57^{fg}
	250,000 (40cmx10cm)	1440.8^{c}	60.60^{gh}	10.33^{cde}
	200,000 (50cmx10cm)	1639.3^{b}	55.67^{ij}	11.73^{ab}
DAB-277	333333 (30cmx10cm)	544.3^{k}	33.33^{k}	6.40^{i}
	250,000 (40cmx10cm)	633.9^{j}	31.33^{k}	6.60^{hi}
	200,000 (50cmx10cm)	780.0^{i}	31.20^{k}	8.67^{fg}
Wajo	333,333 (30cmx10cm)	1047.4^{h}	106.13^{a}	6.33^{i}
	250,000 (40cmx10cm)	1117.1^{fgh}	82.13^{b}	7.53^{gh}
	200,000 (50cmx10cm)	1191.8^{ef}	79.67^{b}	9.67^{def}
Remeda	333,333 (30cmx10cm)	879.3^{i}	78.00^{bc}	9.33^{ef}
	250,000 (40cmx10cm)	1032.7^{h}	66.40^{ef}	9.67^{def}
	200,000 (50cmx10cm)	1180.5^{fg}	64.00^{efg}	10.67^{bcd}
Hawassa Dume	333,333 (30cmx10cm)	1097.2^{gh}	64.97^{efg}	9.03^{f}
	250,000 (40cmx10cm)	1152.6^{fg}	58.13^{hi}	10.40^{cde}
	200,000 (50cmx10cm)	1272.9^{de}	51.93^{j}	11.20^{abc}
LSD (0.05)		88.84	4.84	1.14
CV (%)		4.69	4.63	7.60

Means in column followed by the same letters are not significantly different at 5% level of significance. LSD (0.05) = Least significant difference at 5% probability level; CV= Coefficient of variation.

Number of Total and Effective Nodules Per Plant

The main effects variety and plant density were significant ($p < 0.01$) on the number of total and effective nodules per plant while, the interaction effect was not significant (Appendix Table 2). SCR-26 variety showed the highest numbers of total and effective nodules per plant (46.02) and (20.31), respectively, whereas variety DAB-277 had the lowest (6.00) and (3.61), respectively (Table 3).

The increase in the number of total and effective nodules for the variety SCR-26 may be attributed to its genetic traits, such as an extensive root system architecture. Fenta et al. (2014) suggested that the distribution of roots, particularly those penetrating deeper in the soil, play a crucial role in determining the ability of plants to capture key resources such as water and mobilize nutrients to maintain the water supply to the nodules which is an important trait that would facilitate higher rates of symbiotic nitrogen fixation (SNF).

Results of this study showed that, the highest plant density (333,333 plants ha^{-1}) gave the lowest number of total nodules (16.56) while the lowest plant density (200,000 plants ha^{-1}) gave the highest number (19.38) of effective nodules (Table 3). On other hand, the highest plant density (333,333 plants ha^{-1}) gave the highest number of effective nodules (10.83) while the lowest plant density (200,000 plants ha^{-1}) had the lowest (8.83) number of effective nodules (Table 3). Generally, increasing plant density from (200,000 to 333,333) plants ha^{-1} showed increasing number of effective nodules (8.83 to 10.8) and decreasing total number of nodules per plant with increasing plant density from 200,000 to 333,333 plants ha^{-1}. This result was in line with ranges reported by Dereje

(2014) and Lemlem (2011) where the number of effective nodules was decreasing with decreased plant density on soybean. Similarly, Al-Abduselam and Abdai (1995) reported statistically significant increase on faba bean nodulation with increased plant density.

Table 3. Mean of the number nodules and effective number of nodules per plant as influenced by varieties and plant densities at Jinka, South Omo Zone during 2018 cropping season

Treatments	Total number of nodules	Effective number of nodules
Varieties		
SCR-26	46.02[a]	20.31[a]
SER-125	19.84[b]	11.09[b]
DAB-277	6.00[d]	3.61[e]
Wajo	12.29[c]	8.34[c]
Remeda	12.53[c]	6.47[d]
Hawassa-Dume	12.88[c]	9.26[c]
LSD (0.05)	2.28	1.31
Plant density ha^{-1}		
333,333 (30cmx10cm)	16.56[b]	10.8[a]
250,000 (40cmx10cm)	18.84[a]	9.88[b]
200,000 (50cmx10cm)	19.38[a]	8.83[c]
LSD (0.05)	1.61	0.92
CV (%)	13.05	13.88

Means in column followed by the same letters are not significantly different at 5% level of significant. LSD (0.05) = Least significant difference at 5% probability level; CV= Coefficient of variation.

Yield and yield components

Number of pods per plant

The main effects of variety, plant density and their interaction had a significant ($p < 0.01$) effect on number of pods per plant (Appendix Table 2). The highest mean number of pods per plant (23.53) was recorded from variety SCR-26 at the lowest plant density (200,000 plants ha^{-1}), followed by variety SER-125 (19.47) with the same plant density (Table 4), While the lowest (5.53) numbers of pods per plant was recorded for variety DAB-277 at the highest plant density (333,333 plants ha^{-1}) (Table 4). The highest number of pods $plant^{-1}$ observed from variety SCR-26 might be due to the highest branches number per plant of variety SCR-26 at the lowest plant density (200,000 plants ha^{-1}) (Table 4). Since the higher number of branches benefits to more sites for flower development, this attributed to a prolific pod production.

This result is consistent with the work of Tuarira and Moses (2014), who reported that the number of pods per plant increased as inter-row spacing increased from 50 to 30 cm in common bean varieties. Similarly, Dereje (2014) and Kibiru (2017) reported that a higher number of pods per plant of soybean varieties was obtained at a wider inter-row spacing (60 cm) and the lower pods per plant corresponded to narrower inter row spacing (30 cm).

Table 4. Mean values of yield and yield related parameters as influenced by common bean varieties and different plant densities at Jinka, South Omo Zone during 2018 cropping season

Varieties	Plant density (plants ha^{-1})	Pods plant^{-1}	Seeds plant^{-1}	Dry biomass (t ha^{-1})	Grain yield (t ha^{-1})
SCR-26	333,333	15.13^{de}	80.76^{e}	6.88^{cd}	2.74^{d}
	250,000	18.57^{bc}	103.98^{c}	7.79^{a}	3.11^{bc}
	200,000	23.53^{a}	131.33^{a}	7.45^{ab}	3.51^{a}
SER-125	333,333	15.00^{de}	78.18^{ef}	6.67^{d}	2.73^{d}
	250,000	16.67^{cd}	93.28^{d}	7.64^{ab}	3.33^{ab}
	200,000	19.47^{b}	116.97^{b}	7.21^{bc}	3.21^{b}
DAB-277	333,333	5.53^{k}	27.27^{m}	4.31^{g}	1.20^{i}
	250,000	7.07^{jk}	35.33^{klm}	3.58^{h}	1.40^{i}
	200,000	8.67^{ij}	41.60^{jkl}	3.16^{h}	1.31^{i}
Wajo	333,333	6.40^{k}	31.29^{lm}	4.60^{g}	1.90^{h}
	250,000	10.07^{hi}	48.40^{ij}	4.61^{f}	2.10^{gh}
	200,000	12.60^{fg}	63.55^{gh}	5.29^{f}	2.38^{ef}
Remeda	333,333	12.67^{fg}	43.80^{k}	4.46^{f}	1.80^{h}
	250,000	11.47^{gh}	54.74^{hi}	4.72^{g}	1.90^{h}
	200,000	13.73^{ef}	67.73^{fg}	5.30^{f}	2.28^{fg}
Hawassa Dume	333,333	14.60d^{ef}	75.84^{ef}	6.06^{e}	2.57^{de}
	250,000	16.53^{cd}	91.25^{d}	6.80^{cd}	2.85^{cd}
	200,000	19.27^{b}	108.33^{bc}	6.12^{e}	2.71^{de}
LSD (0.05)		2.25	10.46	0.52	0.28
CV (%)		9.88	8.77	5.59	7.06

Means in column followed by the same letters are not significantly different at 5% level of significant. LSD (0.05) = Least significant difference at 5% probability level; CV= Coefficient of variation.

Number of Seeds Per Plant

The main effect of varieties and plant densities as well as their interaction had significant ($p < 0.01$) effects on number of seeds per plant (Appendix Table 2). The highest mean number of seeds per plant (131.33) was recorded for variety SCR-26 at the lowest plant density of (200,000 plants ha^{-1}) and followed by variety SER-26 (116.97) at the same plant density (Table 4). On other hand the variety DAB-277 produced the lowest seeds per plant (27.27) at the highest plant density (333,333 plants ha^{-1}) (Table 4). The highest number of seeds plant^{-1} which was observed from varieties SCR-26 and SER-125 at the lowest plant density (200,000 plants ha^{-1}) might be due to the highest branches per plant and number of pods plant^{-1} at lowest plant density. The two varieties can therefore, be recommended for the study area with production data to be collected from other similar areas over multiple cropping years.

This result generally showed that, the number of seeds per plant was increasing from 32 to 130 with decreasing population density (333,333 to 200,000) plants ha^{-1} although the responses of common bean varieties to plant densities are varied (Table 4). This result is in line with that reported by Ermias (2013), who stated that the highest number of common bean seeds per plant was obtained under wide inter-row spacing, ranging from 50 cm to 30 cm.

Aboveground Biomass Yield

The main effects of varieties and plant densities as well as their interaction had significant ($p < 0.01$) effect on above ground dry biomass yield (Appendix Table 2). The highest above-ground biomass (7.79 t ha^{-1}) was recorded from variety SCR-26 at a plant density of 250,000 plants ha^{-1} followed by variety SER-125 (7.76 t ha^{-1}) at the same plant density. However, the lowest above-ground dry biomass yield (3.16 t ha^{-1}) was recorded for variety DAB-277 at the lowest plant density (200,000 plants ha^{-1}) which was statistically similar to (3.58 t ha^{-1}) for the same variety at a plant density of 250,000 plants ha^{-1} (Table 4). Thus, the presence of significant differences for the interaction of varieties and plant densities in above-ground dry biomass yield indicated the differential response of varieties to plant population density.

The current result showed that, slight increased total above-ground biomass yield (3.3 to 8.1) t ha^{-1} with decreasing plant density from 333,333 up to 250,000 plants ha^{-1} among tested varieties (Table 4). The possible reason for the highest biomass yield at low plant densities could be due to interplant competition for growth resources such as nutrients, water and solar radiation is low as the result of thick and well-performed stem and branches as compared to high plant density (Edwards and Purcell, 2005). On the other hand, at the widest inter-row spacing, the space is not fully exploited to give higher biomass yield. The other possible reason could be that as the number of plants per unit area keeps on increasing, but the above ground dry biomass yield decreases due to lodging problem and lower photosynthetic efficiency in highly crowded plant population. The result of this study is in agreement with the report of Alemayehu et al. (2015) who indicated an increased biomass yield at plant density of 250,000 plants ha^{-1} in common bean varieties. Similarly, Dereje (2014) reported highest above ground dry biomass yield at plant density of 250,000 plants ha^{-1} compared to plant density of 333,333 plants ha^{-1} on soybean varieties.

Grain Yield

Grain yield of common bean varieties was significantly ($p < 0.01$) affected by the variety and plant density, separately and in combination, which means that grain yield was significantly ($p < 0.05$) influenced by the main and interaction effect of variety and plant density (Appendix Table 2). Among the treatments, the highest grain yield (3.51 t ha^{-1}) was obtained from variety SCR-26 at the lowest plant density (200,000 plants ha^{-1}) and nearly followed by variety SER-125 (3.33 t ha^{-1}) at the medium plant density (250,000 plants ha^{-1}) while the lowest grain yield (1.20 t ha^{-1}) was obtained from variety DAB-277 at the highest plant density (333,333 plants ha^{-1}) (Table 4).

The result of this study showed that the highest grain yield (3.51 t ha^{-1}) was obtained from variety SCR-26 with determinate growth habit at the lowest plant density (200,000 plants ha^{-1}), variety Wajo with indeterminate growth habit gave the highest grain yield (2.38 t ha^{-1}) at a plant density of 200,000 plants ha^{-1}, variety SER-25 with determinate growth habit gave the highest grain yield (3.33 t ha^{-1}) at a plant density of 250,000 plants ha^{-1}, variety DAB-277 with determinate growth habit gave the highest grain yield (1.20 t ha^{-1}) at a plant density of 250,000 plants ha^{-1}, variety Remeda with partial determinate growth habit gave the highest grain yield (2.28 t ha^{-1}) at a plant density of 200,000 plants ha^{-1}, while variety Hawassa Dume with determinate growth habit gave the highest grain yield (2.85 t ha^{-1}) was obtained at a plant density of 250,000 plants ha^{-1} (Table 4).

The results of the present research are in agreement with that reported by Tuarira and Moses (2014) who indicated that reduction of grain yield on common bean varieties as plant density increased from 125,000 to 222,222 plants ha^{-1}. Similarly, Beruktawit (2012) found that the highest grain yield was obtained from variety Goffta at plant density of 200,000 plants ha^{-1}, and variety Roba-1 at plant density of 250,000 plants ha^{-1}. Kibiru (2017) also found there the existence of yield increment soybean varieties as plant density decreased from 333,333 to 200,000 plants ha^{-1}.

CONCLUSIONS

The varieties and plant density levels revealed a significant effect on the number of total and effective nodules, with the highest numbers of both total and effective nodules found in the variety SCR-26 among the tested varieties. Likewise, the highest numbers of total and effective nodules were recorded from population density of 333,333 and 200,000 plant ha^{-1}, respectively. On the other hand, the interaction effect of variety and population density was highly significant on leaf area, plant height, number of primary branches per plant, pod $plant^{-1}$, number of seeds $plant^{-1}$, above ground biomass and grain. Variety SCR-26 gave the highest leaf area, number of primary branches, pods per plant and seeds per plant at the lowest plant density of 200,000 plant ha^{-1} and also the highest plant height was recorded from variety Wajo at plant density of 333,333 plant ha^{-1}. While the highest above-ground biomass was recorded from SCR-26 variety at plant density of 250,000 plants ha^{-1}. The result of this finding showed that the mean grain yield of variety SCR-26 exceeded by 7.2, 7.8 and 13.4% as compared to Wajo at plant density of 200,000 plants ha^{-1}, Remeda at plant density of 200,000 plants ha^{-1} and DAB-277 at plant density of 250,000 plants ha^{-1}, respectively. From the results of this study, it can be tentatively concluded that variety SCR-26 is superior in grain yield (3.51 t ha^{-1}) at plant density of 200,000 plants ha^{-1} followed by variety SER-125 (3.33 tha^{-1}) at plant density of 250,000 plants ha^{-1} for the target area.

Figure 2: Pictorial presentation of different growth stages (a-c) and harvested seeds (d) of common bean varieties at Jinka, South Omo Zone during 2018 cropping season (field views).

CONFLICTS OF INTEREST

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

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APPENDICES

Appendix Table 1. Mean square values of crop phenology and growth parameters of common bean varieties

Source of variation	Degree of freedom	Leaf area per plant (cm^2)	Plant height(cm)	Number of primary branches per plant
Rep	2	3512 ^{ns}	11.80 ^{ns}	0.35^{ns}
V	5	800383***	3132.82***	15.21***
Pd	2	431486***	810.70***	39.39***
V x pd	10	20764***	65.28***	2.01**
Error	34	2797	8.52	0.48

*, **, *** indicate significance at P < 0.05, P < 0.01 and P < 0.001, respectively; 'ns' not significant, V = varieties, PD = plant densities and V x PD=varieties with plant densities

Appendix Table 2: Mean square values for nodules, yield and yield components of common bean varieties

Source of variation	DF	TNN	ENN	NPP	NSPD	DBM	GY
Rep	2	27.71*	2.55 ^{ns}	10.63**	0.23*	0.29^{ns}	0.04^{ns}
V	5	1837.76***	295.13***	199.21***	1.32**	19.66**	4.55***
Pd	2	40.29**	17.91**	98.97**	0.16^{ns}	0.62**	0.81***
V x pd	10	4.52^{ns}	2.68 ^{ns}	5.34**	0.07 ^{ns}	0.66**	0.08*
Error	34	5.68	1.87	1.84	0.06	0.10	0.03

*, **, *** indicate significance at P < 0.05, P < 0.01 and P < 0.001, respectively; 'ns' = not significant= varieties, DF = degrees of freedom, PD= plant density, V x PD=varieties with plant density, TNN = total number of nodules, ENN =effective number of nodules, NPP = number of pods per plant, NSPD= number of seeds per pod, DBM=total dry biomass and GY=grain yield