EFFECT OF PLANT DENSITY ON GROWTH, YIELD AND YIELD COMPONENTS OF COMMON BEAN (*Phaseolus vulgaris* L.) VARIETIES AT CENTRAL RIFT VALLEY OF ETHIOPIA

MSc THESIS

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HAWASSA UNIVERSITY

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APPROVAL SHEET

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We, the undersigned, members of the Board of Examiners of the final Open defense by **Shanko Bakure** have read and evaluated his/her thesis entitled **"Effect of Plant Density on Growth, Yield and Yield Components of Common Bean (*Phaseolus vulgaris* L.) Varieties at Central Rift Valley of Ethiopia**" and examined the candidate. This is therefore to certify that the thesis has been accepted as partial fulfillment of requirements for the degree **Master of Science** in Plant Sciences with specialization in **Agronomy**.

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I dedicate this thesis manuscript to my favorite families: Buno Ontora, Alemitu Eda'o and Abdela Bakure for their support and encouragement during the whole study period.

STATEMENT OF AUTHOR

I sincerely declare that this thesis is my own work. I have followed all ethical and technical principles of research in the preparation, data collection, data analysis and compilation of the Thesis. All sources of materials used for this thesis have been properly acknowledged and any intellectual matter that is included in the thesis has been given recognition through citation. This thesis has been submitted in partial fulfillment of the requirements for MSc. degree in Hawassa University and deposited at the University's Library to be made available to borrowers under the rules of the Library. I solemnly declare that this thesis is not submitted to any other learning institution anywhere for the award of any academic degree, diploma, or certificate. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the Head of the Major Department or the Dean of the School of Graduate Studies when in his or her judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author.

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ABBREVIATIONS

BNF	Biological Nitrogen Fixation
CIMMYT	International Maize and Wheat Improvement Center
CSA	Central Statistical Agency
EIAR	Ethiopian Institute of Agricultural Research
ERCA	Ethiopia Revenue and Customs Agency
FAO	Food and Agriculture Organization
ICTA	International Center of Tropical Agriculture of United Nation
IFPRI	International Food Policy Research Institute
MARC	Melkassa Agricultural Research Center
MoARD	Ministry of Agriculture and Rural Development
NPS	Nitrogen, Phosphorus, Sulfur
PABRA	Pan African Bean Research Alliance
RCBD	Randomized Complete Block Design

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Effect of Plant Density on Growth, Yield and Yield Components of Common Bean (*Phaseolus vulgaris* L.) Varieties at Central Rift Valley of Ethiopia

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ABSTRACT

Common bean (*Phaseolus vulgaris* L.) *is one of the major grain legumes grown in various parts of Ethiopia. Despite, the productivity and quality of bean crops was determined due to lack of improved varieties, poor soil fertility, lack of optimum planting date, row and plant spacing, weed and disease control, and weather conditions. Hence, two field experiments were conducted at Arsi Negele and Melkassa Agricultural Research Center during 2019 main cropping seasons to evaluate the effect of plant density on growth, yield and yield components of common bean varieties. The treatments includes: three plant spacing (5, 10, and 15cm), three row-spacing (30, 40, and 50cm) and three released common bean (Dame, SER-119 and KAT-B9) varieties laid out in factorial arrangement with RCBD design in three replications. The results revealed that plant height, leaf area, leaf area index, number of primary branches, shoot dry weight, initial and final stand count as well as nodulation parameters such as nodule number and dry weight were significantly (P < 0.05) affected by plant spacing, row spacing and varieties at both study sites. Similarly, pods plant^{-1}, seeds pod^{-1}, total dry biomass and grain yield were significantly influenced by plant spacing, row spacing and varieties at both locations. Hundred seed weight was affected by all factors at both sites. Harvest index was affected only by varieties at MARC, whereas all factors affected the harvest index at Arsi Negele. The narrower row and plant spacing (30 x 5, 40 x 5 and 50 x 5) had higher total dry biomass. The economic analysis indicated that the highest net benefits (32417.1, 31117.72, 30303.47 and 32233.61 ETB) were obtained from the treatment combinations of (50 cm x 10 cm and 30 cm x 15 cm) with SER-119, (40 cm x 5 cm) with dame and (50 cm x 5 cm) with KAT-B9 at both studied sites respectively. In addition to these treatment combinations of (40 cm x 10 cm, 40 cm x 15 and 50 cm x 15 cm) were also worth's better yield for all the three given varieties. From this research output varieties SER-119 and KAT-B9 performs better yields ha^{-1} at Arsi Negele and MARC, whereas; Dame achieves better yield at Arsi Negele than MARC. Finally, repeated researches have been conducted to confirm the outcomes on similar agro-ecological zones in depth.*

Key Words: *Common bean varieties, crop growth, plant spacing, row spacing, nodulation and yield.*

1. INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the most commonly consumed legume worldwide. It is the most important legume produced for direct human consumption, with a commercial value exceeding that of all other legume crops (Broughton *et al.*, 2003). In Ethiopia, it is used as a source of food and cash crops and has considerable national economic significance traditionally ensures food security (PABRA, 2014). It ranks third as an export commodity, contributing about 9.5% of total export value from agriculture (Demelash, 2017).

Common bean productivity depends on good weather condition and use of appropriate agronomic practices (fertilizer, improved seed, and herbicide) with recommended rate and time (Teshale *et al.*, 2008). The national agricultural system has generated a number of improved agricultural technologies and recommendations such as crop variety, agronomic practices, crop protection measures as well as other technical advices and practices. The technology promoted includes; improved varieties, recommended fertilizer types and rates, appropriate agronomic practices, and weed control practices.

Despite its importance the national average yield is 1.7 $t.ha^{-1}$ relative to a potential yield of 3.5 $t.ha^{-1}$ (CSA, 2013). The low level of productivity of this crop by the farmers field are attributed due to several factors: poor crop management practices, continuous use of varieties with low genetic potential, poor soil fertility with little or no use of fertilizers, high incidences of diseases and pests as well as lack of optimum plant density (Tefera *et al.*, 2012).

The average white and red common bean productivity is 1.41 and 1.56 t ha^{-1} respectively. It is predominantly produced in Oromia, Southern and Amhara regions with their area coverage of 146,452.41 (41%), 117,969.97 (33%) and 81,235.07 (22.74%) ha, respectively. The rest 3.25% is produced in other regions of Ethiopia (CSA, 2016). Generally, pulses covered 13.24% of the grain crop area; where common bean, faba bean and chickpea accounted for 2.9%, 3.6% and 2.1%, respectively (Idris, 2008)**.**

Plant density defines the number of plants per square meter, which in turn determines the area available to each individual plant. (Albayrak *et al.*, 2011; Ciampitti and Vyn, 2011). Plant densities affect the utilization of environmental resources (radiation interception and utilization of moisture from soil) which influences inter-row and intra-plant competitions (Ihsanullah *et al.,* 2002).

These competitions may occur when common recourses are limited for all the plants of a similar species, such as between the established crop plant with a given crop canopy. Individual plant productivity is typically limited by competition for light, water, soil nutrients or competition of each (Abuzer *et al.,* 2011).

To avoid nutrient competition sufficient spacing between plants and rows is vital to get maximum yield in a given plot of land. For instance, crops grown in too narrow rows may result in severe inter-row competition. Row spacing also modifies plant architecture, photosynthetic competence of leaves, and dry matter partitioning in several field crops (Hussain *et al.,* 2012).

Therefore, selecting optimal row spacing is important to improve crop productivity as plants growing in too wide of a row may not efficiently utilize light, water, and nutrient resources. In Ethiopia a standard spacing of 40 x 10 cm has been adopted; irrespective of the growing conditions and locations but it had a gap on growth, nodulation, yield and yield components to be used considered as the standard spacing without having detailed study on the subject.

As a result, there were problems of appropriate planting density to be used in improving production and productivity of legume crops including common bean which consequently results in poor grain yield in quality and quantity (Melaku, 2012). Hence, optimization of plant density for higher crop yield with suitable row and plant spacing is crucial in order to increase common bean productivity per unit area (Melaku, 2012).

In Ethiopia there were diverse common bean varieties that differ in terms of growth habit, seed and pod characteristics, agronomic features, and response to biotic and a biotic stresses (Kay, 1979). These wider ranges of growth habits had enabled the crops to fit in the many growing situations. However, optimum plant density varies depending on crop species or varietal differences in vigor, height and branching, time of sowing, and the nature of the season (Anderson *et al.,* 2004).

Therefore, using only one plant density of 40 x 10 cm; irrespective of rain-fed or irrigated conditions, soil type, varieties, climatic conditions can directly or indirectly affect the production potential of common bean varieties. Thus, there is an urgent need to identify site and variety specific recommendation on the plant spacing of common bean varieties in Ethiopia.

General objective:

- ✓ To define the effects of different spacings on growth, yield and yield components of common bean varieties at central rift valley of Ethiopia.

Specific objectives:

- ✓ To determine the influence of row and plant spacing on growth, nodulation, yield and yield components of common bean varieties at central rift valley of Ethiopia..
- ✓ To determine the economic feasibility of the plant density for common bean production at central rift valley of Ethiopia.

2. LITERATURE REVIEWS

2.1. Common bean: Origin, Distribution and Botany

Common bean (*Phaseolus vulgaris* L.) is a species of the genus *Phaseolus* and family fabaceae (Raemaekers, 2001). It is believed to have originated in the highlands of Central and Southern America (Aguilar *et al.,* 2004). Those common bean accessions domesticated from Ecuador south are considered as the Andean gene pool, whereas those domesticated from Colombia northwards belongs to the Central American gene pool (Kelly, 2010). It was taken to Europe, Africa and Asia in the 16th century by the Spanish and Portuguese travelers. Now a day it's widely grown in many parts of the tropics, sub-tropics, and temperate regions (Purseglove, 1987). Among the most cultivated pulses crops grown for their seeds the common bean is by far the most important (Singh, 1999).

Common bean is a highly polymorphic warm-season, herbaceous annual. It has two types of growth habit: erect herbaceous bushes, up to 20 – 60 cm high; and twining, climbing vines up to 2 – 5 m long (Ecocrop, 2013). The stems of bushy types are rather slender, pubescent and many-branched. In twinning types, the stems are prostrate for most of their length and rise toward the end (Ecocrop, 2013). The leaves, borne on long green petioles, are green or purple in colour and trifoliate. Leaflets are 6 – 15 cm long and 3 – 11 cm broad. The inflorescences are axillary or terminal, 15 – 35 cm long racemes. The flowers are arranged in pairs or solitary along the rachis, white to purple and typically papillonaceous (Wortmann, 2006).

Once pollinated, each flower gives rise to one pod. Pods are slender, green, yellow, black or purple in colour, sometimes striped. They can be cylindrical or flat, straight or curved, 1 – 1.5 cm wide and up to 20 cm in length (Wortmann, 2006). The pods may contain 4 – 12 seeds. The seeds are 0.5 – 2 cm long, kidney-shaped and highly variable in colour depending on the variety: white, red, green, tan, purple, gray or black. It has a taproot-based root system with lateral roots typically located within the top 15 cm of soil. The roots are colonized by Rhizobium bacteria, resulting in irregular root nodules (Purseglove, 1968).

2.1.1. Effect of plant density on growth and nodulation

Plant density has been recognized as a major factor determining crop yield and is of a particular importance for larger seeded varieties (Matthews *et al.,* 2001). Optimum plant density (i.e. the minimum population that produces maximum yield) and suitable plant arrangement per unit area allow crops to exploit resource optimally and produce high yields (Squire, 1993).

However, optimum plant density varies depending on crop species or due to varietal difference in vigor, height and branching, time of sowing, and the nature of the season (Anderson *et al.,* 2004). The response of crops to plant density tended to be less in the low land as compared to the high yielding environments (Matthews *et al.,* 2001). This can also depend on soil type, management practices like seedbed conditions and soil moisture, sowing depth, sowing time, plant density, fungicide dressings of seeds, presence of weeds and seasonal rainfall (Matthews *et al.,* 2001). Research findings confirm that plant height increased significantly with increase in plant population (Khalil *et al.,* 2010).

Similar findings were achieved by Thalji (2010), who indicated that the denser plant population increased the plant height due to competition among plants. Plant height increases as inter- and intra-row spacing decreased due to inter-plant competition which resulted to taller plants which were sparsely branched (Gebremedhin, 2015). When the plants are sown closely together, their stems are shaded from light resulting in accumulation of auxin which is a major growth hormone that stimulates cell division and enlargement (Holshouser and Joshua, 2002).

In sparsely spaced plants, auxin destruction by light occurs resulting in plants being shorter (Mureithi *et al.*, 2012). Lower plant height at low plant population density can also be due to excessive branching. There was an increment of leaf area from 918.1cm^2 to 1012.8 cm^2 irrespective of variety as intra-row spacing increases from 7 cm to 13 cm, while leaf area index decreases from 3.35 to 1.99 (Massa *et al.*, 2017).

The leaf area index (LAI) decreases as row and plant spacing increases. The decline in the LAI at the widest row spacing might be due to wider ground area occupied plant^{-1}. In general, wider row and plant spacing results in higher plant geometric area which reduces LAI plant^{-1} (El-Naim *et al.*, 2010). Similarly, higher light interception in narrow rows results from either larger LAI and/or increased light interception per unit leaf area due to more uniform plant arrangement (Board and Harville, 1992).

In line with this result, Mekonnen (2003), reported that LAI increased as plant population of common bean increased. Similarly, increased plant density resulted in increased leaf area index on faba bean (Idris, 2008). Apart from the environmental variations, plant population density had a major effect on number of branches plant^{-1} (Mtaita and Mutetwa, 2014).

The plants had more branches especially towards the end of the vegetative phase. Lower plant population of 125,000 plants ha^{-1} had the highest number of branches $plant^{-1}$ than higher population density of 320,000 plants ha^{-1} (Dhanjal *et al.*, 2001). At lower plant density, the inter-plant competition seemed to be little, thus plants utilized the available resources with little competition (Bakry *et al.*, 2011).

Common bean is an important legume which is ecologically important because of their ability to establish an efficient symbiotic association with nitrogen-fixing rhizobia, resulting in the formation of root nodules, where rhizobia can fix the atmospheric dinitrogen (N2) in forms that can be assimilated by the plant, in exchange for a carbon source (Shamsi and Kobraee, 2012). Symbiotic nitrogen fixation (SNF) reduces the cost of legume cultivation and is relevant for sustainable agriculture (Venkateshwaran *et al.,* 2013).

Excessive soil moisture levels and low temperature suppress root nodulation and biological fixation in soybean (Shiraiwa *et al*., 2006; Jung *et al.,* 2008). Total plant nitrogen fixation during growth affected by the relative successes of nodulation and the longevity of symbiotically active nodule population. These factors were influenced by plant density due to inter and intra plant competition for water and mineral nutrition. Plant densities have statistically significant effect on faba bean nodulation where increases in plant density increased nodulation (Al-Abduselam and Abdai, 1995).

2.1.2. Effect of plant density on yield and yield components

There was an increment in numbers of pods plant^{-1} as the result of decreasing in plant densities (Khalil *et al.,* 2010). Similalry, Bakry *et al.* (2011) observed that there was increase in pods with increase in the row spacing because of lower populations are more efficient in utilizing the resources of production than the higher plant densities. At low plant density, there is a large quantity of nutrients available for each plant so that more pods can be brought to maturity (Singh *et al.,* 1992).

Coupled with high temperature, higher plant densities tend to create high humidity which leads to more pod abortion (Li *et al.,* 1991). Higher plant densities also create a canopy too dense to allow sufficient light for proper development of the pods (Blackshaw *et al.*, 1999). There is a restriction in the internal supplies of substrates for the growth.

Higher number of pods plant^{-1} is produced from higher number of branches plant^{-1} at lower densities in which higher the number of branches translates assimilates to more sites for flower development which resulted to a prolific pod production (Bakry *et al.,* 2011). The number of seeds pod^{-1} decreased with increasing plant population for all three planting arrangements. According to Osman *et al.* (2010) more nutrients available for fewer plants at lower plant density and higher competition at higher plant density.

On other hand, Allig (2013) reported that the population density did not at all affect the number of seeds produced pod^{-1}. The increase in 100 seeds weight with increase in plant population from 125,000 to 222,222 plants ha^{-1} could be attributed to fewer number of pods plant^{-1} at higher plant density.

The available nutrients were translocated to the growth parts of the seed, hence higher 100 grain weight at higher plant population. Beyond a plant population of 222,222 plants ha^{-1}, the 100 seeds weight decreased probably due to severe competition of the available nutrient resources as reported by (Mehmud *et al.,* 1997). Total biomass yield slightly increase with increased intra-row spacing up to 10 cm, beyond which it significantly decreased (Yacob *et al.,* 2015). Total biomass yield was maximum (17.94 t ha^{-1}) at 10 cm plant spacing, whereas the lowest biomass yield (14.13 t ha^{-1}) was at 20 cm plant spacing (Bakry *et al*., 2011).

The two top narrow intra-rows spacing (5 and 10 cm) were at par among each other and they were significantly different from the other two treatments. A significant response of biomass yield to intra-row spacing was reported by Mtaita and Mutetwa (2014) who observed that there was increase in biomass yield with decrease in the row spacing because of higher populations per unit area. Similarly, Mureithi *et al*. (2012) obtained that the highest plant dry weight (15 g) was recorded from wider plant spacing. Sparse plant population with wider spacing results in higher yield per plant but lower yield per unit area.

Increasing plant population reduced yield of individual plants but increased yield per unit area of common bean (Ball *et al.,* 2000). The yield of common bean crops increased up to an optimum plant population of 222,222 plants ha^{-1}. It was associated with a significant increase in the number of pods per unit area, as indicated by Morgade and Willey (2003) attributed the increase in yield due to increased plant densities per unit area. This confirms the observation by Shirtliffe and Johnston (2002) that high population density contributes to higher seed yield.

The increase in seed yield per plot resulted from increased number of plants per unit area. Another possible reason behind the lower yield under comparable overcrowded situation might be due to lesser and lesser availability of energy to maintain momentum for longer time than in case of availability of abundant energy (Alghamdi, 2002). These results are in line with the findings of (Singh *et al.,* 2009). Similarly, seeds from the highest plant population density 320,000 plants ha^{-1} had the lowest weight signifying the small seeds from these plots; whereas seeds from low plant density had highest 100 seed weight (Naim AMEI, and Jabereldar AA; 2010).

The higher harvest index involves higher partitioning of dry matter into grain yield and the lowest harvest index at highest plant density might be due to interplant competition for resources such as nutrients, water and solar radiation is low as compared to high plant density (Mulatu *et al*., 2001). This result was supported by Solomon (2003) who found that the reduced harvest index with increased plant density on common bean.

2.1.3. Varietal responses to different plant density

The grain yield of common bean is highly affected as a result of many complex morphological and physiological processes occurring during the growth of the crop, which ultimately influence the yield and yield components (Osman *et al.,* 2010). Based on climatic conditions, several researchers obtained different responses of common bean in relation to plant spacing (Simane *et al.,* 1998). The characteristics of different common bean varieties are different with each other in terms of their growth habit, days to maturity, seed color, size and weight, as well as agro-ecological adaptation (Mulatu *et al.,* 1997).

Plant density highly influences common bean growth and development. The degree of the influence generally depends up on the availability and/or scarcity of environmental resources for which plants compete with each other and the growth pattern and morphological characteristics of the competing plants (Matthews *et al*., 2008). High plant density brings out certain modifications in the growth of plants, for example. increase in plant height, reduction in leaf thickness, alteration in leaf orientation, and leaves become erect, narrow and are arranged at longer vertical intervals to intercept more sun light (Singh and Singh, 2002).

This is because in narrow spacing, plants compete more for available resource especially for light and thus result in more height than widely spaced plants. As Lopez *et al*. (2003) described that as plant density increases competition between plants becomes more intense, affecting the growth, development and production of each plant. Under favorable growing conditions, plant growth is large and competition between plants is greater, therefore lower plant densities (20-25 plants m^{-2}) for faba bean may be more profitable because there is normally no additional response to densities over 35 plants m^{-2} (Marcellos and Constable, 1986; Loss *et al.,* 1998).

As James and Singh (1985) reported a significant curvilinear increase in yield for bean varieties with increasing planting density and significant increases in number of nodes per unit area with increasing plant density. However, increase in plant density leading to a significant curvilinear reduction in number of branches per plant and nodes per branch were observed. As Bennet *et al.* (1977) observed that only linear reductions in number of branches per plant and no change in number of nodes on branches as plant density increased from 17 to 63 plants m^{-2}.

The seed yield of bean is the result of many plant growth processes which ultimately influenced the yield components such as number of pods per plant, seeds per pod, and unit weight of seed (Shibles and Weber, 1966). The spatial distribution of plants in a crop community is an important determinant of yield and many experiments have been conducted to determine the spacing between rows and plants within the row that maximizes yield (Egli, 2008).

Two general concepts are frequently used to explain the relationship between row spacing, plant density, and yield. First, maximum yield could be obtained only if the plant community produced enough leaf area to provide maximum light interception during reproductive growth (Tanner and Hume, 1978; Johnson *et al*., 1982).

Secondly, equidistant spacing between plants affected interplant competition (Pedersen, 2008). As Solomon (2003) observed that seed yield increase from 42.44 to 56.89 g plant^{-1} with increasing 7 x 40 and 16 x 40 cm intra-row spacing. 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 × 10 cm. Similalry, the highest grain yield was recorded for row spacing combination of 30 cm × 15 cm on common bean (Melaku, 2015).

However, there is difference in growth habit and seed size among common bean varieties, only one plant density of 40 cm × 10 cm has 250,000 plants ha^{-1} adopted; irrespective of rain-fed or irrigated conditions, soil type, varieties, climatic conditions (Sam-Aggrey, 1987). Spatial arrangement of the plant directly or indirectly affects the production potential of common bean varieties (Bakry *et al.,* 2011). Thus, there is no site and variety specific recommendation on the plant spacing of common bean varieties in Ethiopia (Essubalew *et al.,* 2014).

The pod yield of green been increased consistently from 2473 to 2574 kg ha^{-1} with an increase in plant and row spacing ranging from 7 x 40 – 15 x 40 cm. On the other hand Mtaita and Mutetwa (2014) indicated that seed yield and biomass tends to decrease in wider (40 cm) than narrower (30 cm) row spacing. According to Mehmud *et al.* (1997) indicated that increased row spacing manifested increase in the seed weight plant^{-1}, pod weight plant^{-1}, and 1000 seed weight, but decreased plant height and seed yield per unit area. As Kumar *et al. (*1997) and Mureithi *et al*. (2012) indicated, the highest seed yield (1.09 t ha^{-1}) and plant dry weight (15 g) with plant spacing of 15 cm and 20 cm, respectively.

According to Davi *et al.* (1995) seed yield of common bean increases as plant density increases (narrow spacing), but high plant densities can lead to low aeration, high humidity and prolonged periods of dampness. These are ideal conditions for the development of white mold (Sclerotinia). The environment within a canopy of given plant density were affected both by plant and row spacing.

3. MATERIALS AND METHODS

3.1 Description of the Study Sites

Field experiments were conducted in Arsi Negele (7°35′N latitude and 38°65′E longtude, at an altitude of 1890 m above sea level) and Melkassa Agricultural Research Center (8°30′N latitude and 39°21′E longtude, at an altitude of 1550 m above sea level) in 2019 cropping season in Central Rift Valley which representing the major common bean cultivating areas of Ethiopia.

The areas had an average annual rain fall of 763 and 807mm during the main cropping season, respectively. The average minimum and maximum temperatures were 13.8 and 33.3°C. The rain fall patterns of Arsi Negele and Melkassa Agricultural Research Center sites were mono modal in nature. Common bean requires average rainfall of 500 – 1500mm throughout the growing season (Amare, 1989).

Therefore, the rainfall is ideal for the production of legumes including common bean in the study sites. The average temperature was slightly higher at Melkassa Agricultural Research Center, than the Arsi Negele site (Appendix-2). The soil textures of both experimental sites were silty clay loam (Hawassa Soil Testing Laboratory, 2019). The experiments were conducted between June and October, 2019 main cropping season. The fields had previously cultivated with cereals such maize and sorghum, respectively.

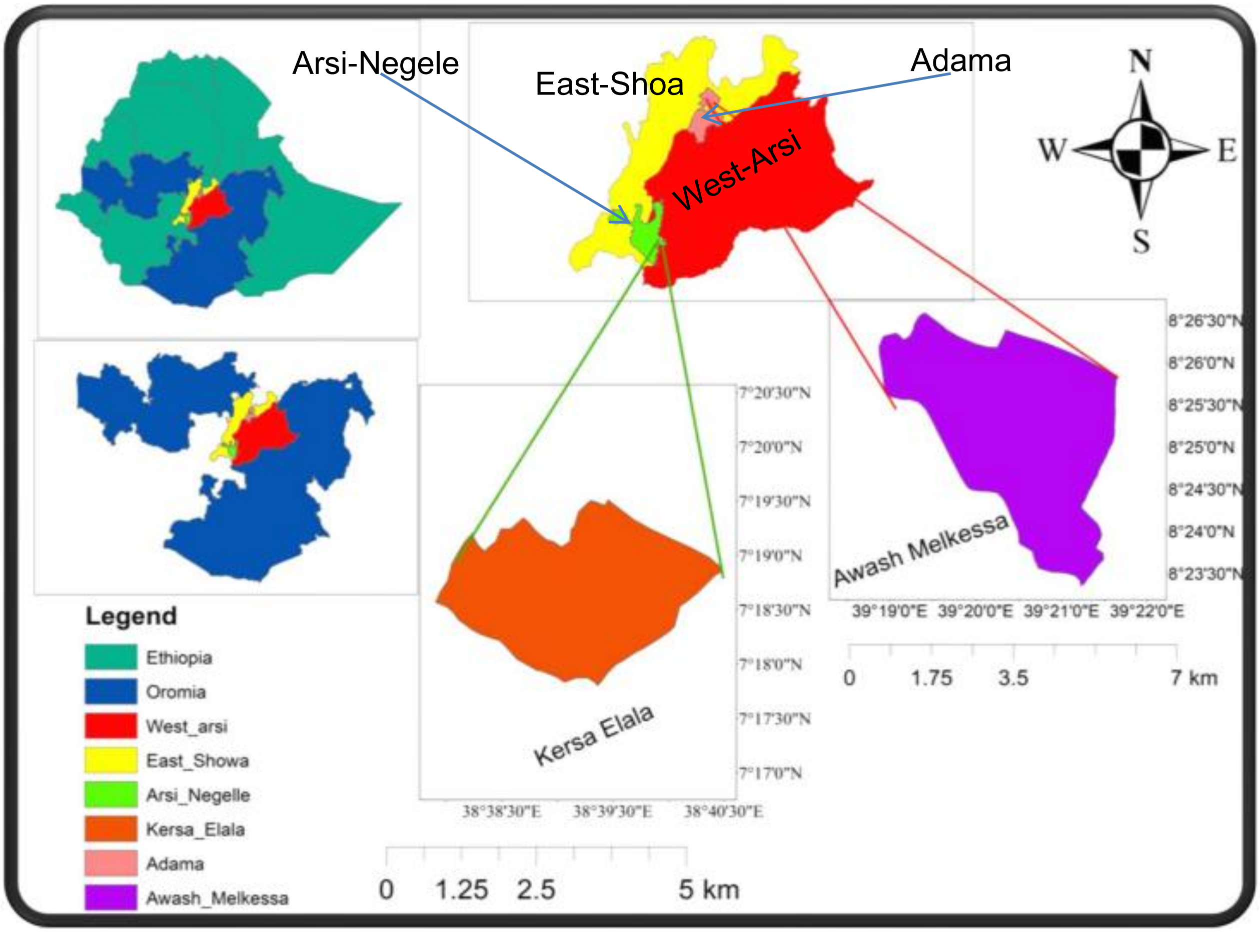


Figure 1: Administrative map of the study sites (Source: ARC GIS, 2019).

3.1. Source of Planting Material

The common bean varieties used in this experiment were: Dame, SER-119 and KAT-B9 which were obtained from the Melkassa Agriculture Research Centre, South Eastern Ethiopia. The three varieties are known for their wider adaptation in different agro-ecologies and have different growth habits, seed size and colour. The growth habits of these varieties were late, intermediate and early maturing (Dame, SER-119 and KAT-B9), respectively. Their seed sizes were large, small and medium respectively. General growth conditions and ecological requirement were indicated on the Appendix Table 1

3.2. Treatments and Experimental Design

The factors studied were three varieties of common bean (Dame, SER-119 and KAT-B9), three row spacings (30, 40 and 50cm) and three plant spacings (5, 10 and 15cm). Treatments were arranged in a factorial combination using randomized complete block design (RCBD) with three replications. Each plot contains six equal numbers of rows and the areas of each plot were different because of the distance between rows were not the same. A single plot size for 30, 40 and 50cm inter-row spacing was 2m x 3m (6m^2), 2.6m x3m (7.8m^2) and 3.2m x 3m (9.6m^2), respectively. The distance between block and plot was 1.5 and 0.8 m respectively.

3.3. Experimental Procedures

Common bean planting required three to four times land preparation for planting during main cropping season. The land was ploughed twice using tractor and plot leveling was done by manually. Numbers of seeds planted per row were 60, 30 and 20 for 5, 10 and 15 cm intra-row spacing, respectively. Numbers of seeds plot^{-1} were 360, 180 and 120 for 5, 10 and 15cm intra-row spacing respectively. The recommended rate of NPS (100 kg ha^{-1}) fertilizer was used for both experimental sites. The seed rates used for sowing were ranged from 75 – 100 kg ha^{-1} for small and large sized seeds of common bean varieties, respectively.

Planting was done on 05 and 09 July, 2019 at Arsi Negele and Melkassa Agricultural Research Center, respectively. Early weed management was done manually after ten (10th) days when the crops were fully emerged from the soil. Then after two times weeding were done in both sites at 22th and 38th days from sowing. Additionally, cultural practices such as; hoeing and weeding were carried out uniformly for all plots from the crop emergence to harvesting.

3.4. Soil Sampling and Analysis

Before planting, twenty surface soil samples (0 – 0cm) were randomly collected from the entire field using augur to determine the physco-chemical properties of each sites. The collected soil samples were mixed well in a plastic bag, sieved and one composite representative sample was taken for analysis of physical (soil texture) and chemical (pH, total N, available P, organic carbon (OC), and cation exchaning capacity (CEC) properties of soils at each site. All intended parameters were analized at Hawassa University College of Agriculture soil laboratory and the analysis was done using the standard procedure of each sample.

The soil texture was determined by the modified Bouyoucos Hydrometer Method and the texture class was designated based on the mass ratio of the three particles (clay, silt and sand) with the help of soil textural triangle (Hillel, 2004). The pH of the soil was measured by glass electrode pH meter using soil: water suspension of 1:2.5 ratios (Jackson, 1973).

Total N was determined by treating the sample with mixture of concentrated sulfuric acid and digestion catalysis following modified Kjeldhal method (Okolebo *et al.*, 2002). Available P contents of the soil were determined by 0.5M sodium bicarbonate extraction solution (pH 8.5) according to the procedure described by Olson and Sommers, (1982). Organic C content of the soil was determined by the wet combustion procedure of Walkley and Black (1954). The CEC was measured after saturating the soil with 1N ammonium acetate (NHOAc) solution by using the modified Kjeldhal 16 method as described by Okallebo *et al.* (2002).

3.5. Data Collected

3.5.1. Growth parameters

Initial stand count: it was recorded by counting the total number of plants per net plot area excluding the boarder rows and destructive samples immediately after thinning.

Final stand count*:* final stand count was taken from the three central rows in net plot area when the plants were attained physiological maturity and the percent of stand mortality was calculated to determine the change in stand count due to competition effect.

Plant height (cm): it was measured from six randomly selected plants from the ground level to the apex of each plant at the time of physiological maturity from the net plot area.

Number of primary branches plant^{-1}: it was determined by counting of primary branches on the main stem from randomly selected six plants from the net plot area.

Leaf area (cm^2): it was recorded from randomly selected destructive sample of six plants from a net plot. It was measured at mid-flowering stage using portable leaf area meter (model=CI-3000A, USA).

Leaf area index: it was calculated as the ratio of total leaf area plant^{-1} to the respective ground area occupied by the crop canopy as described by Marschner (1995).

$$\text{LAI} = \frac{\text{Total leaf area of the sampled plant}}{\text{Ground area occupied by the sampled plant}}$$

Shoot and root dry weight (g): It was done from the up rooted six (6) randomly selected plants for leaf area calculation, then all the leaves were removed from it and the shoots were put under oven dry for 72 hours at 70 ^{o}C temperature. After the shoot oven dried the weight was taken by the use of sensitive balance.

3.5.2. Nodulation parameters

Total number of nodules plant^{-1}: it was determined by counting the nodules from six plants randomly selected from destructive sampling row of each plot at mid flowering. Roots were carefully exposed with the bulk of root mass and nodules. The nodules were separated from the soil, washed and the total numbers of nodules were determined by counting.

Nodule dry weight (g): it was done from total counted nodules from the destructive samples and then put the nodules under oven dry for 48 hours at the 70°C. After the nodule oven dried the weight was taken by the use of sensitive balance.

3.5.3. Yield and yield components

Number of pods plant^{-1}: it was determined by counting the number of pods plant^{-1} of 10 randomly selected plants from each net plot area at harvest.

Number of seeds pod^{-1}: it was counted from 10 randomly selected pods from each net plot at harvest.

Hundred seed weight (g): it was determined by taking weight of 100 randomly sampled seeds from the total harvest from each net plot area and adjusted to 10% moisture level.

Above ground total dry biomass: at harvest, plants from three central rows were manually harvested. The harvested plants straw were sun-dried in an open air until constant weight attained and weighed to determine above ground total dry biomass yield and the average above ground total biomass yield was reported in ton ha^{-1}

Grain yield*:* the three central rows were manually harvested and threshed to determine grain yield $plot^{-1}$ and the average yield was reported in kg ha^{-1}.

Moisture contents: it was determined to calculate adjusted grain yield ha^{-1} using moisture meter of hundred seeds.

Adjusted grain yield: it was calculated by multiplying the actual yield downwards to 10% to meet the field experimental yield to farmers yield. Actual yield*(100-mc)/ (100-Dmc)*100. Where mc=measured moisture contents, Dmc=designated moisture contents (10%) for common bean crops).

Harvest index*:* the harvest index was calculated as the ratio of grain yield to above ground total biomass yield. $\text{HI}\ (\%) = \frac{\text{Grain yield}}{\text{Total above ground biological yield}}\ x\ 100$

3.6. Partial Budget Analysis

The partial budget analysis was done as described by CIMMYT (1988) wherever the variable cost that differ included the cost of fertilizer and labor involved for application. The total costs that vary included the seed rate cost and the field price of the crop. However, for simplicity in estimate in place of field price of the crop, the cost earned for harvesting, threshing, winnowing, packing and transportation was added to the variable input cost.

Actual yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. There was optimum plant population density, timely labor accessibility and better management (e.g. weed control, better protection) under experimental sites.

3.7. Statistical Analysis

The data collected were subjected to analysis of variance (ANOVA) using the Statistical Analysis System Software (SAS, 2002) version 9.1.3. Significant treatment means were compared using least significant difference test (LSD) at 5% probability level.

4. RESULTS AND DISCUSSIONS

4.1. Soil Physico-chemical Properties of Study Sites

The results of soil analysis revealed that the textural class of experimental sites belongs to silty clay loam with the proportions of 20 and 12% sand, 34 and 32% silt, and 46 and 56% clay for Arsi Negele and Melkassa Agriculture Research Center (MARC), sites respectively (Table 1). The pH values of both sites were 6.00 and 6.75, making them slightly acidic and suitable for common bean production (Liebenberg, 2009). Total N in the experimental soils were 0.06 and 0.05%, respectively. It was rated as very low (<0.1), low (0.1 – 0.15), medium (0.15 – 0.25) and high (>0.25) (Havlin *et al.*, 1999). Hence, total N of the soil of the experimental fields were in very low ranges.

This shows that the importance of applying external N sourced fertilizers to improve crop growth and productivity (Yoseph *et al.*, 2017). According to Jackson (1958) and Herrera (2005), the soil OC content was rated as very low (< 2%), low (2 – 4%), medium (4 – 10%), high (10 – 20%) and very high (>20%). Thus, the soil at experimental sites had very low OC content. According to Olsen *et al.* (1954), P content (mg kg^{-1}) <5 is very low, 5 – 15 is low, 15 – 25 is medium and >25 is high.

Therefore, the available P in soils at the experimental sites (24.6 mg kg^{-1} and 27.3 mg kg^{-1}) were medium at Arsi Negele and high at MARC. The cation exchange capacity (CEC) is a major controlling factor of stability of soil structure, nutrient availability for plant growth, the soil's reaction to fertilizers and other ameliorants.

The soil CEC content ranges 5 – 15, 15 – 25 and 25 – 40 cmol kg^{-1} are rated as low, medium, and high, respectively. Based on these ratings, the CEC values of 27.3 cmol kg^{-1} at Arsi Negele and 24.6 cmol kg^{-1} at MARC, before planting of the experimental field was in the high ranges, respectively.

Table 1: Soil physical and chemical properties of the experimental sites

	Parameters							
	Particle size distribution (%)			pH	Total N	OC	Available	CEC
Sites	Sand	Silt	Clay	H_2O	(%)	(%)	P (mg kg^{-1})	(cmol kg^{-1})
Arsi Negele	20	34	46	6.0	0.06	0.98	24.6	27.3
MARC	12	32	56	6.7	0.05	0.97	27.3	24.6

MARC= Melkassa Agricultural Research center

4.2. Effect of Different Spacing on Growth Parameters of Common bean Varieties

4.2.1. Initial and final stand counts (%)

The analysis of variance revealed that the main effect of plant spacing had highly significant (P<0.05) effects on initial and final stand counts at Arsi Negele and MARC sites. On the other hand, the interaction effects of row spacing x varieties were significant (P< 0.05) at the Arsi Negele site (Table 2). However, the main effect of row spacing and varieties, as well as all other interactions, were not significant (P> 0.05) on initial and final stand counts.

Regarding the main effect of plant spacing, the initial and final stand counts of common bean varieties increased significantly with the increasing plant spacing in both sites. The highest initial stand count was recorded from the plant spacing of 15cm followed by 10cm. However, the lowest was recorded from 5cm plant spacing (Table 2).

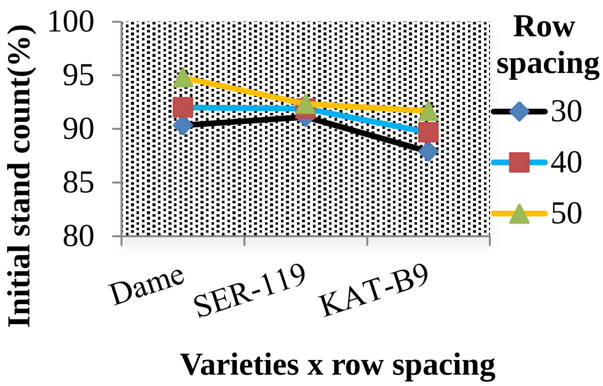
The increase in initial and final stand counts of common bean over the wider plant spacing may be due to the availability of growth resources (water, air, and minerals) at crop demand levels as a result of low competition between plants in the studied areas. This finding is concomitant with the finding of Mahama (2011) who reported an increased initial stand count with increased plant spacing. Regarding the interaction effect, only the row spacing x variety was significant ($P < 0.05$) at the Arsi Negele site for the initial and final stand counts.

The maximum mean initial and final stand counts were recorded from the variety Dame with 50 cm row spacing. However, the lowest was recorded from the variety KAT-B9 with 30 cm row spacing (Figure 2A & B). The reason for the increment of initial and final stand count due to wider spacing might be attributed due to the increasing availability of growth promoting resources with less competition between and among plants.

On the other hand, the differences among common bean varieties in the initial and final stand counts may be due to the plant's genetic makeup. This finding is consistent with Maluku's (2012) study, which states that the highest and lowest initial and final stand counts were obtained from, Chercher and Roba-1 varieties from the lowest and highest plant densities respectively.

A)

B)



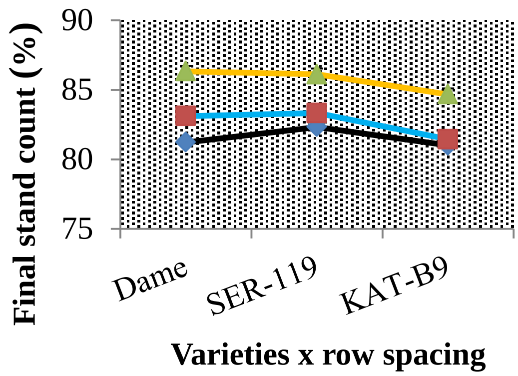


Figure 2: Interaction effect of A) Varieties x Row spacing; and B) Varieties x Row spacing at Arsi Negele on initial and final stand count. Vertical lines on bars represent standard error of the statistical means.

4.2.2. Plant height

The analysis of variance indicated that plant height showed significant difference ($P < 0.05$) due to the different spacing on plant height among common bean varieties at Arsi Negele and MARC experimental sites (Appendix 3 and Table 2). Similarly, all the two-way and three-way interaction effects at the Arsi Negele site and row spacing x variety at the MARC site showed a significant effect on plant height (Appendix 3 and Table 2).

At Arsi Negele, the tallest plants were recorded from the variety Dame with the 5 cm x 30 cm plant spacing and row spacing. While the lowest plant height was recorded from wider spacings between plants and rows (Figure 3A & B). The overall increase in plant height in the narrow inter-row spacing may be due to light and space competition. Similar observations were reported in a study by Abuzar *et al.* (2011) who observed that an increased plant height of maize with increasing plant densities.

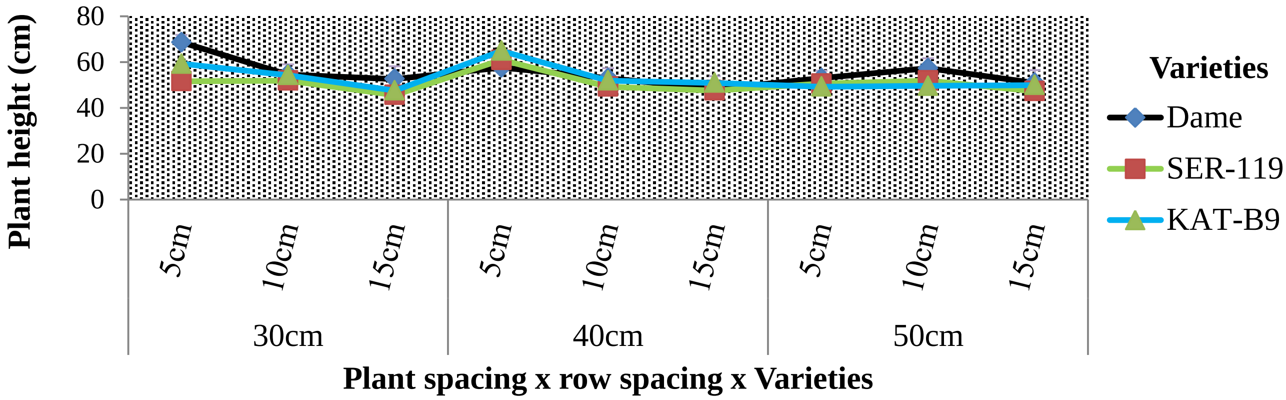
On the other hand, a decrease in plant height at wider spacing might also be due to excessive branching, which leads to lateral growth while suppressing apical growth. In line with this result, Mureithi *et al*. (2012) reported that in widely spaced plants auxin destruction by sun light takes place resulting in plants being shorter in height. At MARC, plant height showed decreasing trends with increasing plant and row spacings. Relatively the highest values were recorded from narrower spacing than the wider spacings (Table 2).

Regarding the main effect of variety, the tallest plants were recorded from variety Dame followed by KAT-B9. However, the shortest plant height was recorded from the SER-119 variety (Table 2). At this site the only interaction which showed a significant ($P < 0.05$) effect on plant height was row spacing x variety. Regardless of the row spacing, the tallest plant height was recorded from the variety Dame than the other varieties

However, the shortest plants were recoded from the varieties SER-119 and KAT-B9 (Figure 3A & B). Increasing the number of plants per unit area associated with plant competition and a lower amount of light intercepted by a single plant resulting in increased inter node length caused a great variation in plant height. Similar findings were reported by Derya *et al. (*2013) who indicated that denser plant population of pea increased plant height due to competition among plants.

On the other hand, the observed differences among the common bean varieties might be attributed due to the varietal growth habit and the nature of crop genetic makeup. Similar results have been reported by Yoseph *et al.* (2017) where the effects of cowpea varieties were statistically significant on the height.

A)



B)

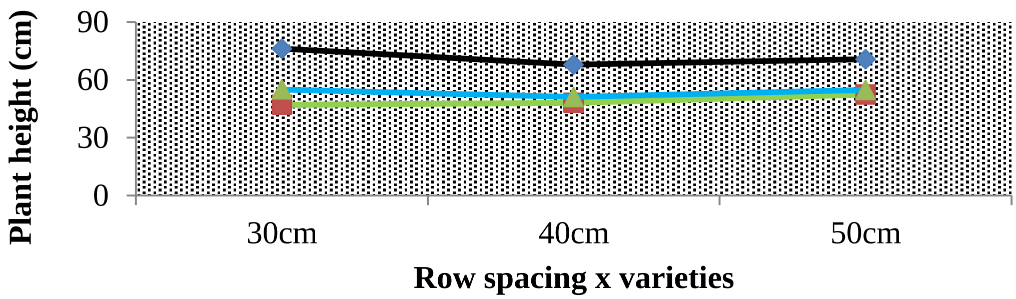


Figure 3: Interaction effect of A) Plant spacing x Row spacing x Varieties at Arsi Negele, B) Row spacing x Varieties at MARC on plant height. Vertical lines on bars represent standard error of the statistical means.

Table 2:Effect of plant and row spacing on growth parameters of common bean varieties at central rift valley of Ethiopia.

Parameters	Initial stand count (%)		Final stand count(%)		Plant height (cm)		Leaf area (cm^2)	
Locations	**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**
Plant spacing (cm)								
5	82.57±0.61^{c}	81,58±0.65^{c}	79.05±0.46^{c}	78.30±0.52^{c}	57.37±0.09^{a}	60.62±1.44^{a}	1851.39±35.30^{b}	1843.8±41.33^{b}
10	88.37±0.52^{b}	87.55±0.42^{b}	83.13±0.54^{b}	81.43±0.51^{b}	52.70±0.55^{b}	58.07±1.4^{ab}	1934.10±32.40^{a}	2011.6±43.00^{a}
15	94.77±0.50^{a}	92.97±0.41^{a}	88.18±0.47^{a}	86.13±0.43^{a}	49.03±0.51^{c}	55.69±1.07^{b}	1963.28±35.00^{a}	2060.9±62.15^{a}
Row spacing (cm)								
30	86.28±0.92^{ns}	86.52±0.68^{ns}	80.84±0.85^{ns}	81.13±0.7^{ns}	54.07±0.86^{a}	59.41±1.60^{a}	1864.96±33.48^{c}	1865.2±42.13^{b}
40	87.84±0.98^{ns}	87.90±0.51^{ns}	80.27±0.96^{ns}	81.38±0.66^{ns}	53.89±0.79^{a}	55.70±1.12^{b}	1904.73±37.43^{b}	1877.8±47.85^{b}
50	86.61±0.99^{ns}	85.54±0.76^{ns}	79.26±0.97^{ns}	79.35±0.79^{ns}	51.15±0.56^{b}	59.27±1.20^{a}	1979.08±31.66^{a}	2173.3±53.93^{a}
Varieties								
Dame	87.37±0.99^{ns}	86.42±0.52^{ns}	80.10±0.94^{ns}	79.05±0.59^{ns}	55.15±0.79^{a}	71.57±0.99^{a}	1845.37±33.20^{b}	1875.6±39.95^{b}
SER-119	87.57±1.03^{ns}	86.85±0.83^{ns}	81.09±0.99^{ns}	81.25±0.89^{ns}	50.82±0.74^{b}	49.19±0.66^{c}	1975.11±36.20^{a}	2041.9±47.79^{a}
KAT-B9	85.78±0.87^{ns}	88.69±0.62^{ns}	79.18±0.85^{ns}	80.56±0.66^{ns}	53.15±0.67^{ab}	53.61±0.55^{b}	1928.30±32.97^{ab}	1998.8±60.67^{a}
LSD	**2.5949**	**2.4318**	**2.3709**	**2.3294**	**0.3071**	**2.6779**	**38.589**	**69.885**
CV	**5.47**	**5.14**	**5.42**	**5.31**	**1.06**	**8.44**	**3.69**	**6.49**

*Values (Mean ± SE) followed by dissimilar letters in column are significantly different at *: p<0.05; **: p<0.01; ***: p<0.001; Ns=Non-significant.*

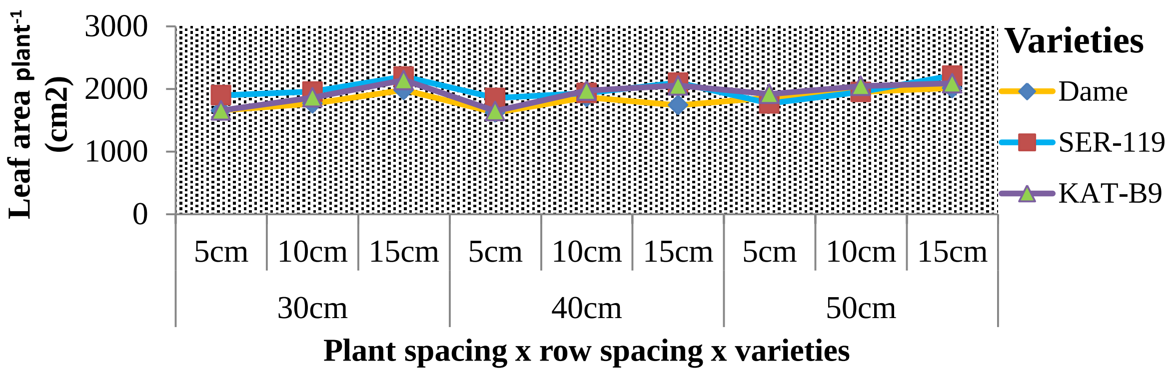
4.2.3. Leaf area plant^{-1}

The analysis of variance revealed that the main effect of plant and row spacing, as well as variety, had a highly significant effect ($P < 0.05$) on leaf area at Arsi Negele and MARC sites. Likewise, both the two and three-way interactions were revealed highly significant ($P<0.05$) effects on leaf area (Appendix 3). At Arsi Negele and MARC sites, the highest leaf area was recorded from the wider 15cm between plant and 50cm between row spacing (Table 2). This may be due to the fact that there was lesser competition for the resources and light interception between plants at the wider spacing (Mekonnen, 2012).

Furthermore, the increasing or decreasing an inter and intra row spacing increased or decreased in leaf area which was a critical part of green plants used for light interception, and another several related physiological processes such as leaf addition, expansion, and senescence. In line with this result, Soltani *et al. (*2006) had found that physiological processes including leaf area development can be varied by genotype and affected by management factors such as sowing density.

Similarly, Purcell *et al.* (2002) found that common bean at higher sowing densities tends to limit individual plant branch formation, node numbers and consequently individual plant leaf area and vegetative mass. Regarding the varieties, the growth habit and nature of varieties had their own effects on the leaf area of the given crops in which SER-119, KAT-B9 and Dame, had higher, medium and lower leaf areas, respectively (Fig 4A & B). In line with this result, Hampton *et al.* (2008) stated that grain legumes including common beans were affected by genotypes and various management practices including sowing density (inter and intra row spacing).

A)



B)

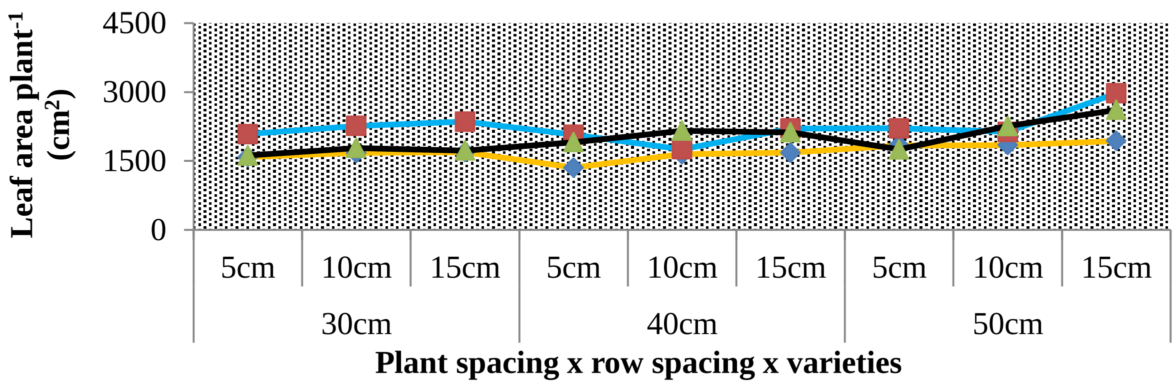


Figure 4: Interaction effect of Plant spacing x Row Spacing x Varieties, A) at Arsi Negele, and B) at MARC on leaf area. Vertical lines on bars represent standard error of the statistical means.

4.2.4. Leaf area index

The analysis of variance revealed that a significant effect of plant and row spacings at (P<0.05) on leaf area index at Arsi Negele site. However, both factors did not show a significant (P> 0.05) effect on leaf area index at MARC site. But the main effect of varieties had significant at (P < 0.05) effects on leaf area index at Arsi Negele and MARC sites, respectively (Table 3).

Regarding the interaction effects, plant spacing x variety and row spacing x variety at Arsi Negele site and plant spacing x row spacing x variety at MARC site showed a significant effects on leaf area index (Appendix 4). Leaf area index is important in both canopy structure and function, which is one of the main drivers of net primary production, water and nutrient use, and carbon balance. Comparing the model-estimated canopy light use efficiency between the predicted optimum leaf area index and the observed leaf area index, the light-use efficiency is higher under optimal leaf area index by 9% and 7% under current and elevated CO_2 concentration, respectively (Srinivasan *et al.*, 2017).

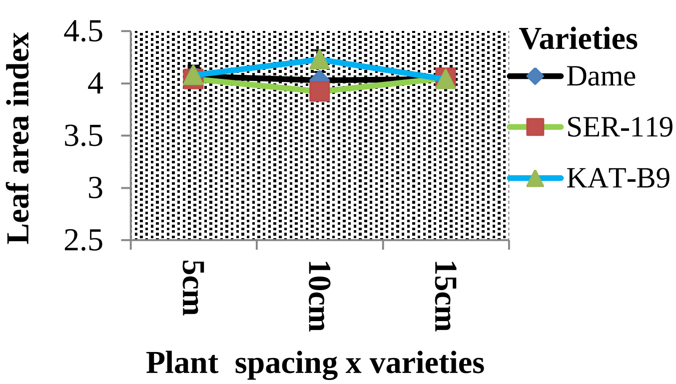
Regarding the main effect of varieties, the highest leaf area index was recorded from the SER-119 followed by the Dame variety. However, the lowest leaf area index was recorded from the variety KAT-B9 in both sites (Table 3). The differences in leaf area index among the common bean varieties might be attributed due to the genetic difference among the varieties. In line with this results Mulatu *et al.* (2017), reported that differences in leaf area index among the Tole-1, Fayo and NC-4x varieties at Abeya district from Borana zone of southern Ethiopia with highest leaf area index from highest plant densities (30 cm x 10 cm=333,333 plants ha^{-1}) and the lowest leaf area index obtained from lowest plant densities (70 cm x 10 cm=142,857 plants ha^{-1}) on ground nut crops.

This result agrees with the findings of Mercy (2010) who stated that the highest leaf area index was recorded at the highest population density of 100,000 plants ha^{-1} than 50,000 plants ha^{-1} in Bambara groundnut (*Vigna subterranea* L). Likewise, Abdel (2008) also reported that increased plant density increased leaf area index on faba bean.

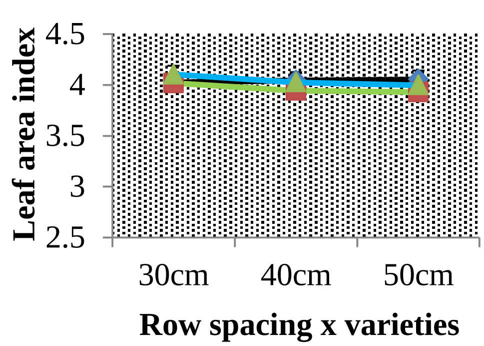
Regarding the interactions at Arsi Negele site, the highest leaf area index was recorded from the variety KAT-B9 at the spacing of 10cm between plants. However, the lowest leaf area index was recorded from the variety SER-119 at the spacing of 10cm between plants (Fig 5A). On the other hands, the highest leaf area index was recorded from the variety KAT-B9 at the spacing of 30cm between rows. However, the lowest leaf area index was recorded from the variety SER-119 at the spacing of 50cm between rows (Fig 5B).

At MARC site, the highest leaf area index was recorded from the variety SER-119 at the spacing of 10cm between plants and 30cm between rows. However, the lowest leaf area index was recorded from the variety KAT-B9 at the spacing of 10cm between plants and 30cm between rows (Fig 5C).

A)



B)



C)

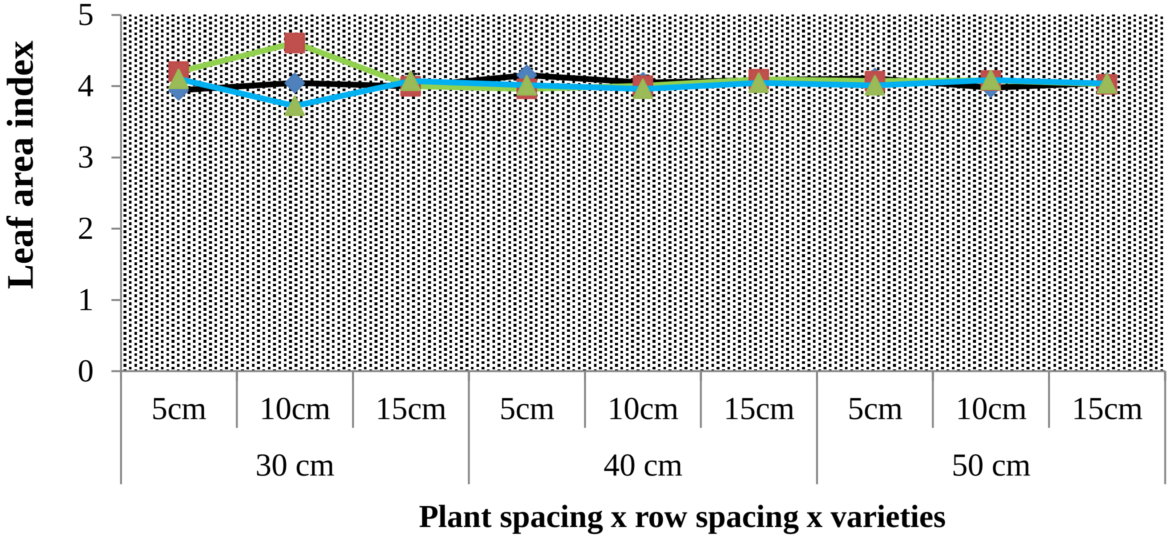


Figure 5**:** Interaction effect of A) Plant spacing x Varieties, and B) Row spacing x Varieties, at Arsi Negele, C) Plant spacing x Row Spacing x Varieties at MARC on leaf area index. Vertical lines on bars represent standard error of the statistical means.

4.2.5. Shoot dry weight

The analysis of variance revealed that the main effects of plant spacing, row spacing and varieties had significant ($P < 0.05$) effect on common bean shoot dry weight at both sites. Similarly, the interaction effects of row spacing x varieties at Arsi Negele site and plant spacing x row spacing x varieties at MARC site, revealed significant at ($P < 0.05$) effects on shoot dry weight, respectively (Table 3).

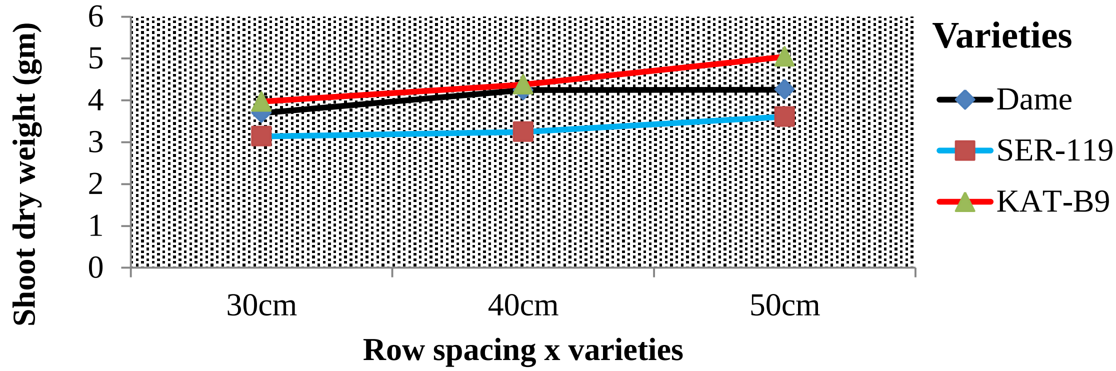
The shoot dry weights of common bean varieties showed increasing trends with increasing intra and inter row spacing (Table 3). This might be due to higher food accumulation in plant tissues as a result of less competition for resources.

In agreement with this result, Hall *et al.* (2014) reported that increased plant density results in thinner stemmed plants that lead to lower shoot dry weight. Furthermore, Amaducci (2008) reported that a direct relationship of shoot dry weight with stem thickness and inverse relationship with higher plant density. At Arsi Negele site, the highest shoot dry weight was recorded from the variety KAT-B9 at the spacing of 50cm between rows. However, the lowest shoot dry weight was recorded from the variety SER-119 at the spacing of 30cm between rows (Fig 6A). Regardless of the common bean varieties, shoot dry weight showed an increasing trend with the increasing row spacing.

This might be attributed due to the slow growth of the plants due to low inter and intra-specific competition as a result of low plant density. In line with these results, Lisson and Mendham (2000) stated that stem dry weight followed a linear trend for plant spacing and as plant density increased stem dry weight diminished. At MARC site, the highest shoot dry weight was recorded from the variety KAT-B9 at the spacing of 10cm between plants and 50cm between rows.

However, the lowest shoot dry weight was recorded from the variety Dame at the spacing of 5cm between plants and 30cm between rows (Fig 6B). The differences might be occurred due to genetic differences of common bean varieties and environmental factors of the experimental sites. This result was in line with the finding of Singh *et al*. (2011) who reported that some varieties have the capacity to better yield than other varieties and show higher plant growth. Addo-Quaye *et al*. (2011) also found that cowpea varieties have different capacities for shoot dry matter accumulation.

A)



B)

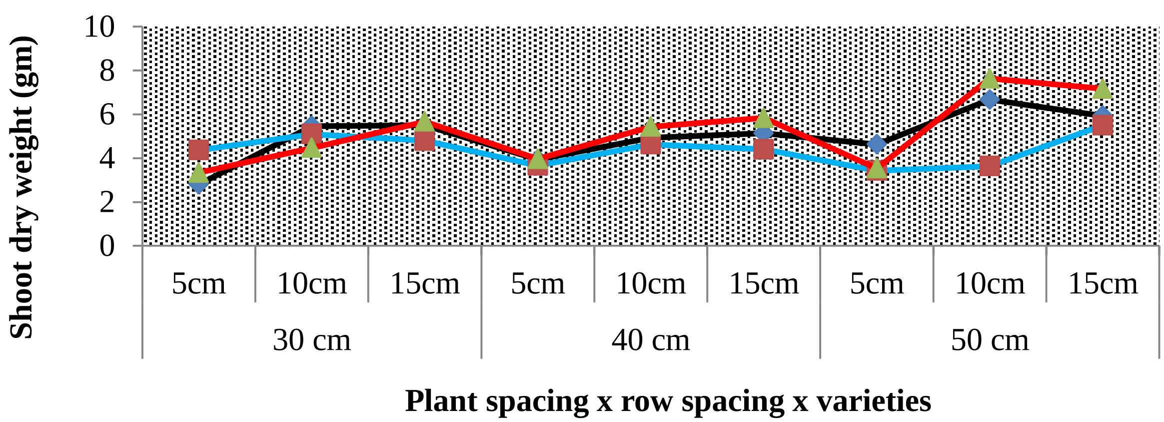


Figure 6: Interaction effect of A) Row Spacing x Varieties, at Arsi Negele, B) Plant spacing x Row spacing x varieties at MARC on shoot dry weight.

Table 3: Effect of plant and row spacing on growth parameters of common bean varieties at central rift valley of Ethiopia

Parameters	Leaf area index		Shoot dry weight (gm)		Primary branches plant^{-1} (no)	
Locations	Arsi Negele	Melkassa	Arsi Negele	Melkassa	Arsi Negele	Melkassa
Plant spacing (cm)						
5	4.05±0.08^{a}	4.06±0.08^{ns}	3.55±0.09^{b}	3.74±0.10^{b}	3.71±0.07^{c}	2.92±0.05^{c}
10	4.02±0.08^{ab}	4.06±0.078^{ns}	4.06±0.15^{a}	5.33±0.17^{a}	4.14±0.08^{b}	3.35±0.06^{b}
15	3.98±0.08^{b}	4.04±0.08^{ns}	4.25±0.10^{a}	5.55±0.16^{a}	4.69±0.08^{a}	3.97±0.05^{a}
Row spacing (cm)						
30cm	4.08±0.011^{a}	4.08±0.08^{ns}	3.60±0.09^{b}	4.43±0.15^{c}	3.89±0.09^{c}	3.18±0.06^{c}
40cm	4.01±0.01^{ab}	4.05±0.08^{ns}	3.96±0.11^{ab}	4.66±0.17^{b}	4.24±0.08^{b}	3.42±0.08^{b}
50cm	3.99±0.01^{b}	4.04±0.07^{ns}	4.31±0.02^{a}	5.64±0.19^{a}	4.42±0.09^{a}	3.64±0.06^{a}
Varieties						
Dame	4.04±0.08^{a}	4.04±0.08^{ab}	4.07±0.12^{a}	5.00±0.16^{a}	3.99±0.07^{c}	3.23±0.07^{b}
SER-119	4.05±0.08^{a}	4.12±0.08^{a}	3.33±0.09^{b}	4.39±0.01^{b}	4.37±0.10^{a}	3.58±0.06^{a}
KAT-B9	3.96±0.09^{b}	4.01±0.07^{b}	4.46±0.12^{a}	5.23±0.21^{a}	4.17±0.09^{b}	3.54±0.08^{a}
LSD	**0.039**	**0.0769**	**0.399**	**0.439**	**0.1327**	**0.088**
CV	**1.77**	**3.48**	**18.48**	**16.49**	**5.81**	**4.72**

*Values (Mean ± SE) followed by dissimilar letters in column are significantly different at *:p<0.05; **:p<0.01; ***: p<0.001; Ns=Non-significant.*

4.2.6. Number of primary branches plants^{-1}

The statistical analysis revealed that the main effects of plant spacing, row spacing, and varieties had significant effects on the number of primary branches plants^{-1} at both locations. Likewise, their three way interactions showed significant ($P< 0.05$) effects on number of primary branches plants^{-1} at both locations (Appendix 4).

The highest number of primary branches plant^{-1} were recorded from SER-119 with spacing of 40cm x 10cm and 40cm x 15cm, whereas the lowest were from Dame variety at the spacing of 30 cmx 5cm on Arsi Negele site. On other hand at MARC the highest number of primary branches plants^{-1} were recorded from SER-119 at spacings of 40 cm x 15 cm and 50 cm x 15 cm and the lowest were recorded from Dame variety at 40 cm x 5 cm.

Regardless of the common bean varieties, number of primary branches plants^{-1} showed an increasing trend with increasing inter- and intra-spacing at Arsi Negele and MARC sites (Figure 7A & B). The increasing number of primary branches plant^{-1} with increasing spacing between plants and rows could be attributed due to less competition between plants in the wider plant spacing for soil nutrients and moisture at a given experimental sites (Mehmet, 2008).

This result is in agreement with the works of Pawar *et al.* (2007) and Mureithi *et al.* (2012) who reported that increase in branches plant^{-1} at an increased spacing in haricot bean and French bean, respectively.

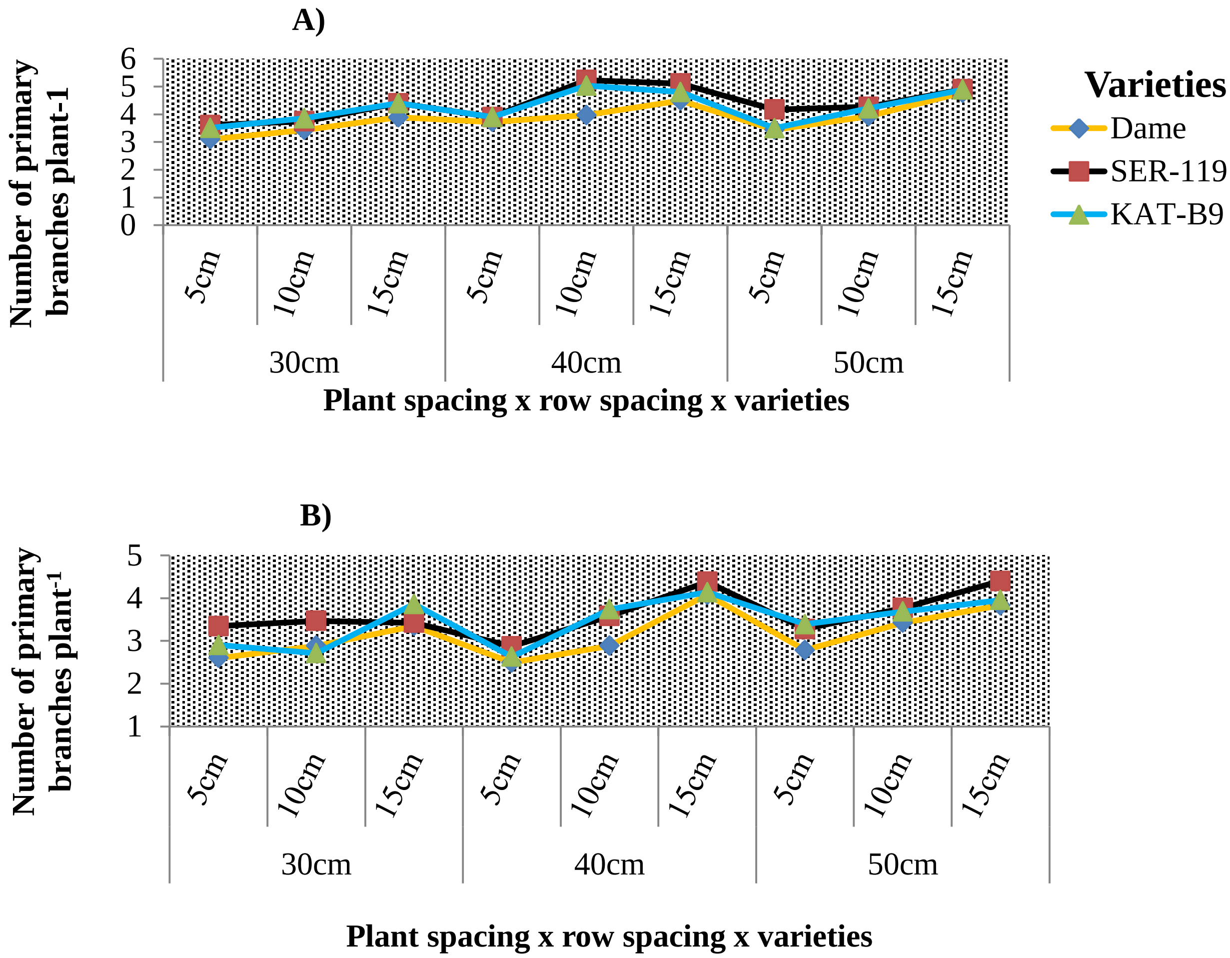


Figure 7: Interaction effect of Plant spacing x Row Spacing x Varieties; A) at Arsi Negele and B) at MARC on number of primary branches plant^{-1} respectively. Vertical lines on bars represent standard error of the statistical means.

4.3. Effect of different Spacing on Nodulation Parameters of Common bean Varieties

4.3.1. Total number of nodules plant^{-1}

The total number of nodules plant^{-1} was significantly influenced by plant and row spacing as well as the varieties ($P < 0.05$) at the Arsi Negele site. However, row spacing did not shown a marked effect on total number of nodules plant^{-1} at MARC site (Table 4). Similarly, their three-way interactions were shown significant effects on total number of nodules plant^{-1} in both sites.

Regarding the main effect, the highest nodules plant^{-1} were recorded from wider spacings (10 and 15cm) between plants than the narrow spacing (5cm). A similar trend was observed for row spacing in both sites. Total plant nitrogen fixation during growth affected by the relative successes of nodulation and the longevity of the symbiotically active nodule population. These factors were influenced by plant density due to inter and intra plant competition for water and mineral nutrition.

Plant densities have a statistically significant effect on faba bean nodulation where increases in plant density increased nodulation (Al-Abduselam and Abdai, 1995). Regarding the varieties, the highest nodules plant^{-1} were recorded from the KAT-B9 followed by the variety Dame. In contrast, the lowest nodules plant^{-1} were recorded from the SER-119 variety in both sites (Table 4)

Regarding the interaction effects, the variety Dame performs best at 30cm x 15cm and 50cm x 15cm at both sites. Whereas KAT-B9 and SER-119 produces better nodules plant^{-1} at 30cm x 10cm, 40cm x 10cm and 50cm x 10cm between rows and plants due to their earlier and intermediate growth habits of crop, respectively (Figure 8A & B). Among the varieties, KAT-B9 had highest nodules whereas Dame and SER-119 followed, respectively. The increasing nodules plant^{-1} in both experimental sites might be attributed due to the low availability of soil N and organic carbon (Table 1).

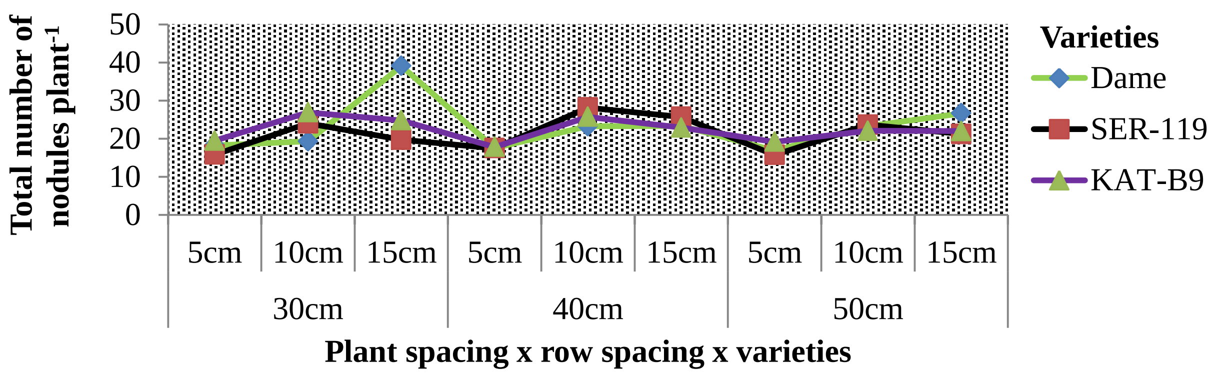
Similar to this result Olivares *et al*. (2013), reported that higher nodule number plant^{-1} were recorded in soils that are low in plant nutrients. On the other hand, the nodule formation in common bean in two experimental sites revealed that the availability of soil indigenous *Rhizobium* which fixes atmospheric N.

When the plant and row spacing increased the competition between and among the plant reduced, as a result, the availability of plant nutrients can be increased. In agreement with this result, Shamsi and Kobraee (2012) reported that at lower plant densities the photosynthetic rate plant^{-1} increased and, consequently, higher carbon (C) supplied to the nodules resulted in an increase in nodulation and in nitrogen fixation rates.

Whereas, this result contradicts the finding of Jibril (2014), who stated that as row spacing increased the number of nodules plant^{-1} decreased due to low competition between plants as a result of wide spaced that leads to easily capture the nutrients from the soil.

On the other hand, the observed differences among common bean varieties for nodule formation might be attributed due to the genetic differences of test varieties. Similarly, Nyemba *et al.* (2009), reported that differences exist among cultivars in their respective abilities to fix N.

A)



B)

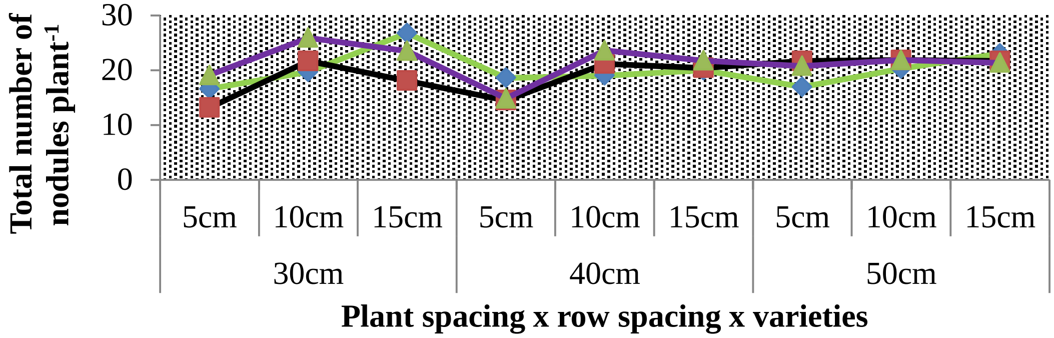


Figure 8: Interaction effect of Plant spacing x Row spacing x Varieties; A) at Arsi Negele and B) at MARC on total number of nodules respectively. Vertical lines on bars represent standard error of the statistical means.

Table-4: Effect of plant and row spacings on nodulation parameter of common bean varieties at central rift valley of Ethiopia.

Parameters	**Total number of nodules**		**Nodules dry weight (gm)**	
Locations	**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**
Plant spacing (cm)				
5	17.59±0.35^{b}	17.46±0.55^{b}	0.36±0.01^{b}	0.27±0.01^{b}
10	24.11±0.63^{a}	21.93±0.54^{a}	0.42±0.01^{b}	0.38±0.01^{a}
15	24.27±0.88^{a}	21.44±0.59^{a}	0.48±0.03^{a}	0.40±0.02^{a}
Row spacing (cm)				
30	21.19±0.63^{b}	20.4907±0.68^{ns}	0.38±0.02^{b}	0.31±0.01^{b}
40	21.72±0.65^{ab}	19.3056±0.51^{ns}	0.44±0.03^{ab}	0.35±0.02^{ab}
50	23.06^{a}±0.91^{a}	21.0278±0.59^{ns}	0.46±0.02^{a}	0.39±0.01^{a}
Varieties				
Dame	23.07±0.91^{a}	20.0741±0.61^{ab}	0.38±0.02^{b}	0.32±0.01^{b}
SER-119	20.57±0.62^{b}	19.3519±0.51^{b}	0.52±0.03^{a}	0.44±0.02^{a}
KAT-B9	22.33±0.64^{a}	21.3981±0.67^{a}	0.37±0.02^{b}	0.29±0.01^{b}
LSD	**1.2655**	**1.6316**	**0.0494**	**0.0384**
CV	**10.53**	**14.73**	**21.35**	**19.99**

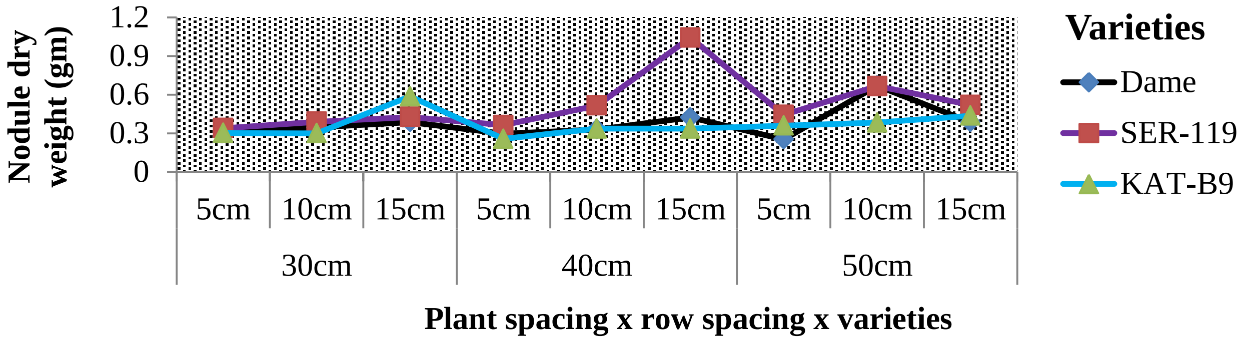
*Values (Mean ± SE) followed by dissimilar letters in column are significantly different at *: p< 0.05; **:p<0.01; ***: p<0.001; Ns= Non-significant.*

4.3.2. Nodules dry weight

The analysis of variance revealed that the main effects of plant spacing, row spacing and varieties had significant effects on nodule dry weight at Arsi Negele and MARC sites (Table 4). Similarly, both the two-way and three-way interaction showed significant ($P < 0.05$) effects on nodule dry weight (Appendix 5). In both sites, the highest nodule dry weight was recorded from the variety SER-119 at the spacing of 15cm between plants and 40cm between rows, respectively. However, the lowest nodule dry weight was recorded from the variety Dame at the spacing of 5cm between plants and 30cm between rows (Fig 9A & B).

Generally, as the spacing increased between plant and rows, there were increasing trends in nodule dry weight. This might be attributed due to a higher amount of growth resources and less competition that involves nodules formation by the transformation of atmospheric N into ammonia by nitrogenase enzymes (Olivares *et al*., 2013). In legumes including common bean, biological nitrogen fixation occurs when N from the atmosphere is transformed to ammonia by an enzyme known as nitrogenase in the reaction ($N_2 + 8H^+ + 8e^- \rightarrow 2NH_3 + H_2$). The reduction of nitrogen into ammonia requires ATP energy for the oxidation of sugars and other compounds (Canfield *et al*., 2010). In line with this report, Fatima *et al.* (2007) reported that high nodule dry weight can be generally a prerequisite for increasing N_2-fixation in legumes rather than a number of nodules.

A)



B)

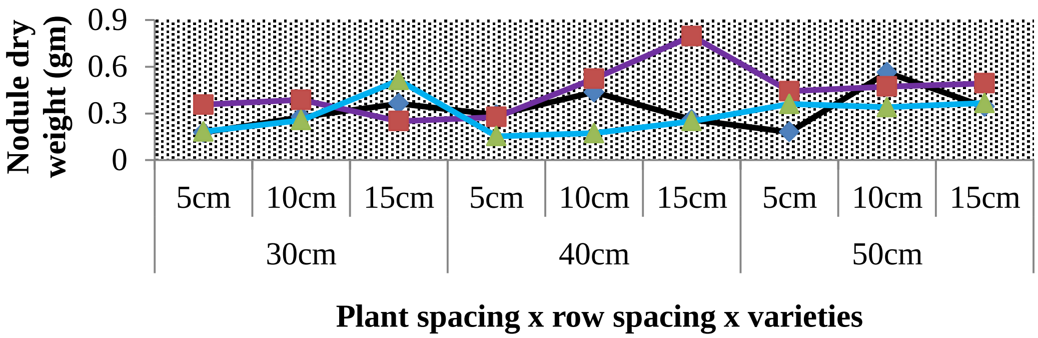


Figure 9: Interaction effect of plant spacing x row spacing x varieties; A) at Arsi Negele and B) at MARC on nodules dry weight.Vertical lines on bars represent standard error of the statistical means.

4.4. Effect of different Spacing on Yield and Yield Components of Common bean Varieties

4.4.1. Number of pods plant^{-1}

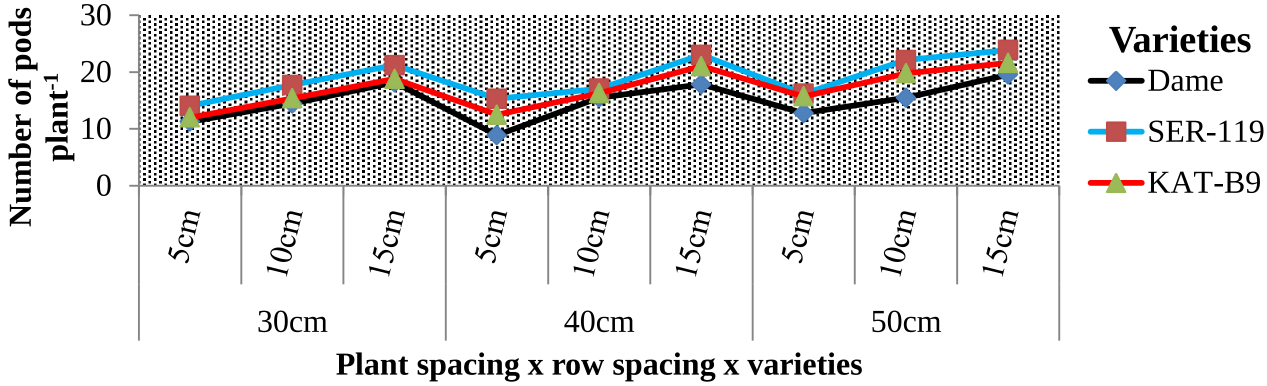
The analysis of variance revealed that plant spacing, row spacing and varieties had significant (P < 0.05) effect on number of pods plant^{-1} in both locations (Table 5). There were also strong interaction effects of plant spacing x row spacing x varieties on number of pods plant^{-1} in both sites (Appendix 6).

At Arsi Negele, the highest number of pods plant^{-1} was recorded from the variety SER-119 with the plant and row spacings of 15 cm x 50 cm followed by the spacings of 15 cm x 40 cm. While the lowest number of pods plant^{-1} was recorded from the variety Dame with the spacings of 5 cm x 40 cm (Figure 10A). On the other hand at MARC, the number of pods plant^{-1} was higher for the variety SER-119 with the plant and row spacings of 15 cm x 40 cm. However, the lowest pods plant^{-1} were recorded from the varieties Dame and KAT-B9 with the spacings of 5cm x 30 cm (Figure 10B).

Generally, as the plant and row spacing increase, the number of pods plants^{-1} increases, because of less competition of plants for growth resources due to high nutrients use efficiencies and light interceptions by the plants. In line with this, result Turk *et al.* (2003) reported that increasing number of pods plant^{-1} when the plant and row spacing increased. This result also in close conformity with the works of Mtaita and Mutetwa (2014) who reported that an increased pod number and dry weight of common bean at the wider intra-row spacing, as compared to closer spacing.

The differences among the varieties might be due to variation in genetic makeup and environmental differences. In line with these results, Tamado *et al.* (2007) and Masa *et al.* (2017) reported the differences among the Hawassa dume and Ibado varieties in number of pods plant^{-1}.

A)



B)

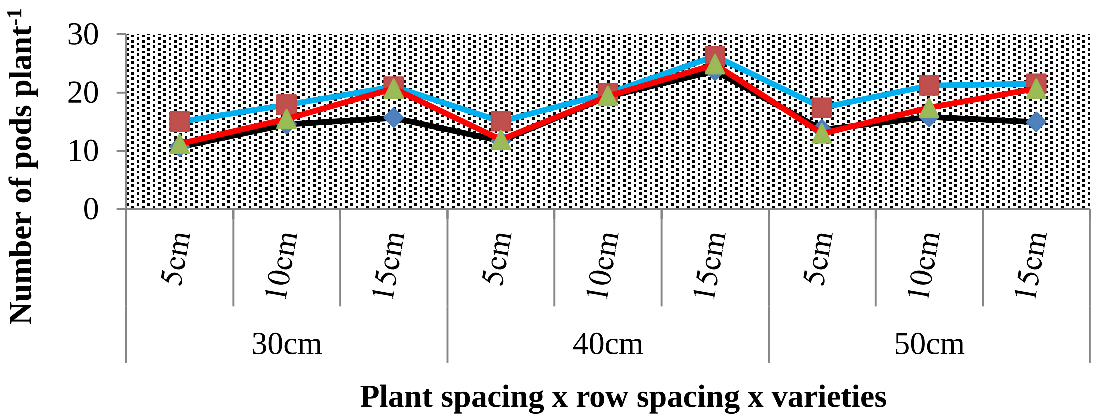


Figure 10: Interaction effect of plant spacing x row spacing x varieties; A) at Arsi Negele and B) at MARC on number of pods plant^{-1}.Vertical lines on bars represents standard error of the statistical means.

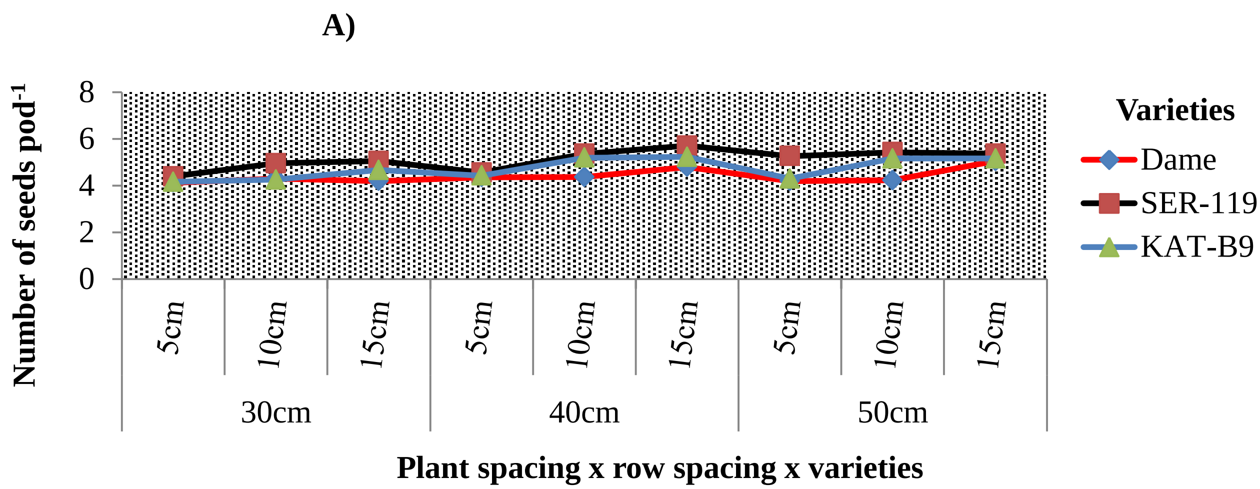
4.4.2. Number of seeds pod^{-1}

The analysis of variance revealed that the number of seeds pod^{-1} were significantly (P< 0.05) influenced by the main effects of inter- and intra-row spacings and varieties at the Arsi Negele site (Appendix 6).

However, row spacing did not influence the number of seeds pod^{-1} at the MARC site (Table-5). There were also significant three-way interaction effects on a number of seeds pod^{-1}at both locations (Table 5).Regardless of the inter- and intra-row spacings, the variety SER-119 outperforms at both locations followed by KAT-B9. However, relatively the lower values for a number of seeds pod^{-1} were recorded from the Dame variety. Regarding the spacings, the numbers of seeds pod^{-1} were higher at wider spacings of 40cm x 15cm, 50cm x 15cm than the narrow spacings 30cm x 5cm (Figure 11A & B).

The differences in a number of seeds pod^{-1} among the common bean varieties might be attributed to the genetic differences. In agreement with this result, Fageria and Santos (2008) stated that differences among the common bean on seeds pod^{-1}. On the other hands, the differences on seeds pod^{-1} due to wider plant and row spacings might be due to lower competition between plant and row spacing for growth resources and other crop assimilation rate also increases due to higher light penetration to the bottom layer of the given crops.

In line with this result, Osman *et al*. (2010), reported that the increased number of seeds pods^{-1} and pods plant^{-1} with increasing plant spacing due to more nutrients available for fewer plants at lower plant density. Moreover, Melaku (2012) obtained the highest number of seeds pod^{-1} at the lowest plant population ha^{-1} and the lowest seeds pod^{-1} at the highest plant population ha^{-1} for common bean.



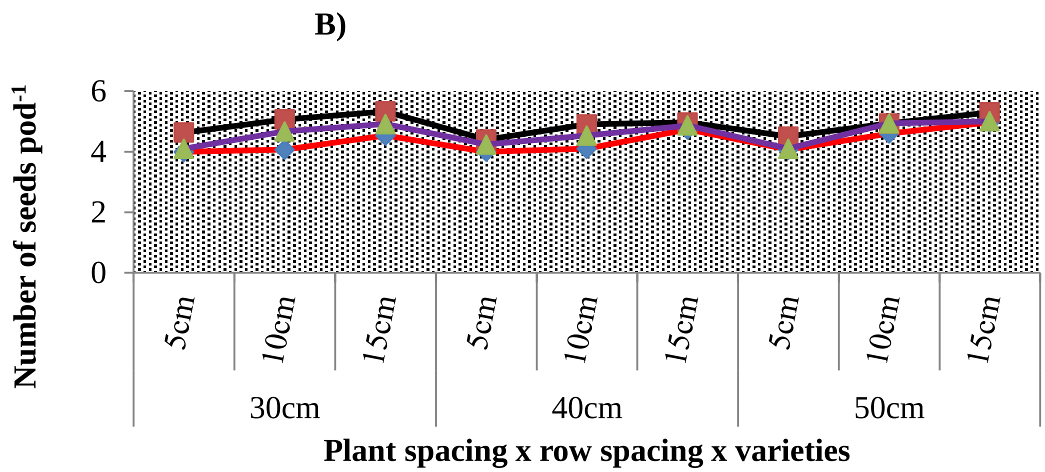


Figure 11: Interaction of Plant spacing x Row spacing x Varieties; A) at Arsi Negele and B) MARC on numbers of seeds pod^{-1}. Vertical lines on bars represent the standard error of statistical means.

Table-5: Effect of plant and row spacings on yield and yield components of common bean varieties at central rift valley of Ethiopia

Parameters	Number of pods plant^{-1}		Number of seeds pods^{-1}		Hundred seeds weight (gm)		Grain yield (kg/ha)	
Locations	**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**
<u>Plant spacing (cm)</u>								
5	14.91±0.53^{b}	13.66±0.61^{c}	4.47±0.12^{b}	4.28±0.10^{b}	43.84±1.15^{b}	41.52±1.20^{b}	2234.83±42.3^{a}	2085.36±47.1^{a}
10	15.46±0.52^{b}	17.39±0.59^{b}	4.83±0.13^{a}	4.70±0.11^{a}	43.30±1.15^{b}	42.59±1.20^{ab}	2195.70±42.4^{a}	1979.15±49.4^{a}
15	20.49±0.50^{a}	21.12±0.72^{a}	4.98±0.12^{a}	4.83±0.12^{a}	46.65±1.40^{a}	44.44±1.20^{a}	2049.31±42.6^{b}	1830.20±44.6^{b}
<u>Row spacing (cm)</u>								
30	15.89±0.53^{b}	16.34±0.71^{b}	4.64±0.11^{b}	4.69±0.10^{ns}	42.65±1.13^{b}	40.52±1.10^{c}	2168.30±39.4^{ns}	1985.44±54.6^{ns}
40	16.39±0.60^{b}	18.56±0.88^{a}	4.73±0.12^{ab}	4.51±0.12^{ns}	45.15±1.38^{a}	42.93±1.10^{b}	2171.34±42.4^{ns}	1981.14±48.2^{ns}
50	18.57±0.58^{a}	17.27±0.55^{ab}	4.91±0.13^{a}	4.61±0.11^{ns}	46.00±1.15^{a}	45.11±1.40^{a}	2140.21±47.9^{ns}	1928.13±41.7^{ns}
<u>Varieties</u>								
Dame	15.74±0.52^{b}	15.94±0.72^{b}	4.63±0.11^{b}	4.38±0.10^{b}	53.948±0.8^{a}	50.63±0.73^{a}	2086.54±36.9^{b}	1814.51±45^{b}
SER-119	18.50±0.52^{a}	19.55±0.69^{a}	4.97±0.12^{a}	4.75±0.11^{a}	33.231±0.6^{c}	30.11±0.52^{c}	2230.52±41.8^{a}	2198.83±41^{a}
KAT-B9	17.79±0.68^{a}	17.65±0.74^{ab}	4.69±0.13^{b}	4.67±0.11^{a}	46.619±0.9^{b}	47.82±0.67^{b}	2162.77±49^{ab}	1881.37±48^{b}
LSD	**0.52**	**1.6329**	**0.152**	**0.2327**	**1.1497**	**1.7737**	**95.773**	**111.63**
CV	**5.62**	**17.19**	**5.85**	**9.26**	**4.72**	**7.58**	**8.00**	**10.42**

*Values (Mean ± SE) followed by dissimilar letters in column are significantly different at *:p<0.05; **:p<0.01; ***: p<0.001; Ns=Non-significant.*

4.4.3. Hundred seed weight

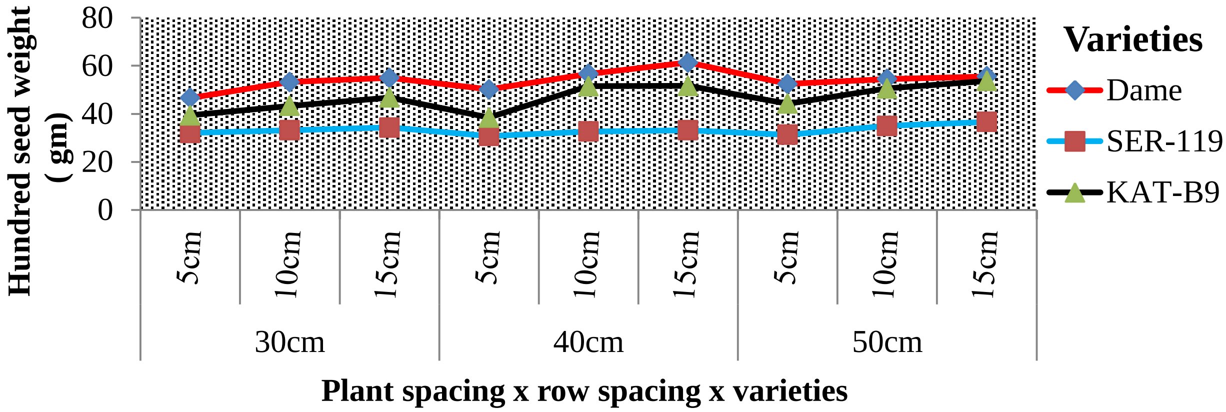
Hundred seed weight was significantly influenced by plant and row spacing as well as the varieties at ($P < 0.05$) for both sites. Similarly, their three-way interactions were shown significant effects on hundred seed weight (Appendix 6). Regardless of the plant and row spacings, the variety SER-119 produced a lighter seed weight than the other varieties.

However, the variety Dame produced heaver seed weight followed by the variety KAT- B9 (Figure 12A & B). The highest hundred seed weights were recorded from varieties Dame and KAT-B9 at the spacings of 40 cm x 15 cm and 50 cm x 15 cm and the lowest were recorded from SER-119 at spacings of 30 cm x 5 cm at both sites.

The differences in seed weight among the variety might be attributed due to the genetic make of the crops. In agreement with this result, Masa *et al*. (2017) also found significant differences in the hundred seed weight among bean genotypes. On the other hand, less competition for resources among plants resulted in higher hundred seed weight as a result of translocation of stored food to the economic parts of the seeds (Dahmardeh *et al.*, 2010).

Moreover in wider spaced plants, the improved supply of assimilates to the seeds resulted in enhanced seed weight. Similarly, Melaku, (2012) reported the highest hundred seed weight from the lowest plant population ha^{-1} of common bean.

A)



B)

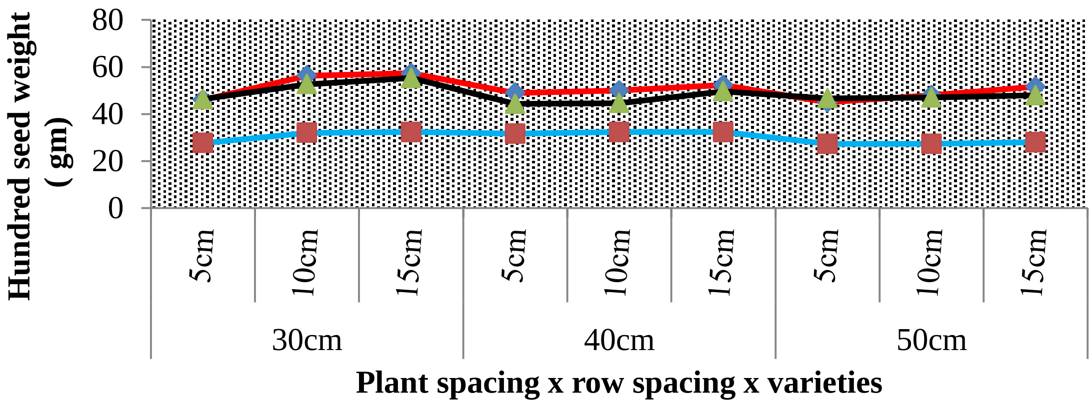


Figure 12: Interaction of Plant spacing x Row spacing x Varieties; A) at Arsi Negele and B) at MARC on hundred seed weight. Vertical lines on bars represent the standard error of statistical means.

4.4.4. Grain yield

The analysis of variance revealed that grain yield of common bean was significantly (P < 0.05) influenced by the main effects of plant spacing and varieties at both locations. However, the row spacing showed non-significant (P > 0.05) effects on grain yield at a given experimental sites (Appendix 6).

At Arsi Negele, the highest grain yield was recorded from the variety SER-119 with the plant and row spacings of 5 cm x 50 cm. However, relatively the lower grain yield was recorded from the variety Dame with the spacings of 10 cm x 30 cm (Figure 13A). At MARC, the highest grain yield was recorded from the variety SER-119 with the plant and row spacings of 5 cm x 50 cm. While the lower grain yield was recorded from the variety Dame with the plant and row spacings of 15 cm x 30 cm (Figure 13B). Generally among the varieties, SER-119 produced higher grain yield followed by KAT-B9. However, the variety Dame was the low yielder than the others.

The observed differences among the common bean varieties might be attributed due to genetic differences (Fageria and Santos, 2008). In line with the current findings, Masa *et al*, (2017) reported that the marked differences among common bean varieties on grain yield. Denser plant population per unit area had the ability to convert biological yield to economic yield. Thus, the grain yield ha^{-1} increases as plant and row spacing decreased due to increased plant population per unit area for common bean crops. In line with this result, Egli (2008) reported that high plant population ensured early canopy coverage and maximizes light interception, greater crop growth rate and crop biomass resulting in increased yield in soybean.

The grain yield had inverse relationships with the number of primary branches and pods $plant^{-1}$ increases as a result of wider inter and intra row spacing and low yielder when compared with that higher plant densities per unit area for a given crop. This points out that the number of plants per unit area seems to be more critical than the number of branches and/or pods $plant^{-1}$, in influencing grain yield.

This result agrees with the work of Essubalew *et al*., (2014) and Mtaita and Mutetwa (2014) who reported that bean yields increased linearly as the spacing reduced due to better yield in the case of high plant populations over that of low plant population of beans.

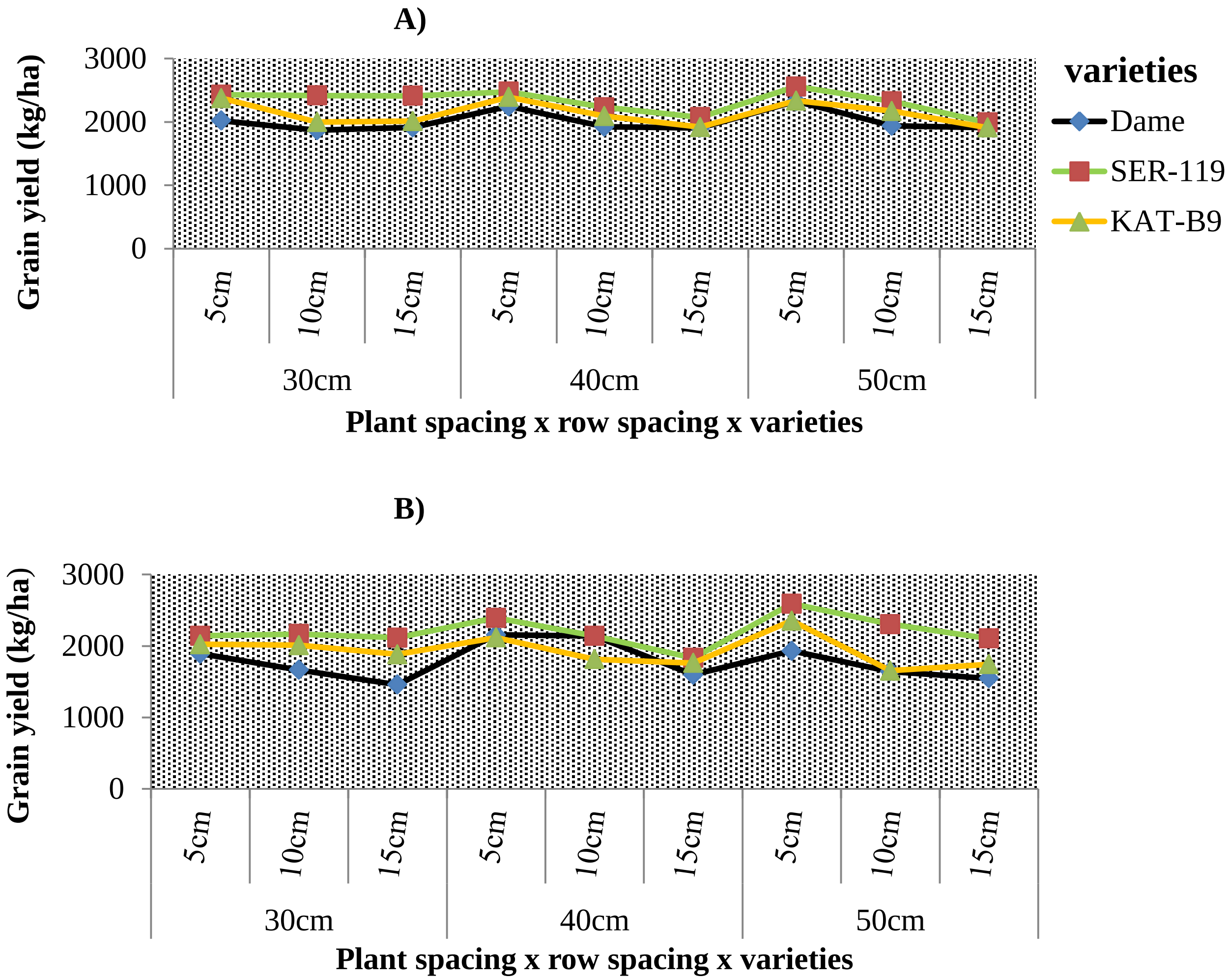


Figure 13: Interaction of Plant spacing x Row spacing x Varieties; A) at Arsi Negele and B) at MARC on grain yield. Vertical lines on bars represent the standard error of statistical means.

4.4.5. Above ground total dry biomass

The analysis of variance showed that the main effects of plant spacing, row spacing and varieties had significant effects on above ground total dry biomass at $P < 0.05$ for Arsi Negele site, whereas only plant spacing showed significant influence on total dry biomass of a given crop and non-significant effects of row spacing and varieties at MARC (Table-6 and Appendix 7). The total dry biomass increases as plant and row spacing decreases from 15-5cm and 50-30 cm, due to higher number of plants hectare^{-1} as a result of narrower inter and intra row spacing.

In line to this result, Getachew *et al.* (2006), found that the higher LAI which provided a larger surface area for light interception resulting in higher net photosynthesis and might have led to greater biomass per unit area. There were also significant differences between varieties on above ground total dry biomass due the variation of genetic and environmental factors (Fig 14A, B & C). In line to this result, Masa *et al.,* (2017) stated that decreasing inter row spacing from 40 cm to 30 cm, increases the above ground total dry biomass for Hawassa dume and Ibado varieties.

Highest above ground dry biomass gained with narrower inter row spacing might be highest vertical vegetative growth with less lateral branching and reproductive organ production before physiological maturity. This implies that at the narrow row spacing there is more number of plants per unit area resulting in higher above ground total dry biomass. In agreement to this result, Rasul F *et al*.,(2012) stated that narrow inter row spacing (30 cm) produced the highest biological yield as compared to wider inter-row spacing (45 cm and 60 cm) on mung bean.

This might be due to the reason that, at higher plant densities crop growth resources are efficiently used and resulted in higher dry matter accumulation and the amount of solar radiation intercepted into the canopy depends on plant density where the higher plant population density speeds up canopy closure and increases interception of photosynthetically active radiation (PAR) needed for carbohydrate production and higher biomass plants^{-1} (Kazemi et al., 2012).

There were significant interaction effects of plant spacing x varieties and row spacing x varieties at MARC and over all interaction effects of plant spacing, row spacing and varieties at Arsi Negele on above ground total dry biomass (Table-6 and Fig 14A, B & C). The highest above ground total dry biomass were recorded from variety SER-119 at spacings of 5 cm x 50 cm whereas Dame and KAT-B9 were at 5 cm x 40 cm for Arsi Negele.

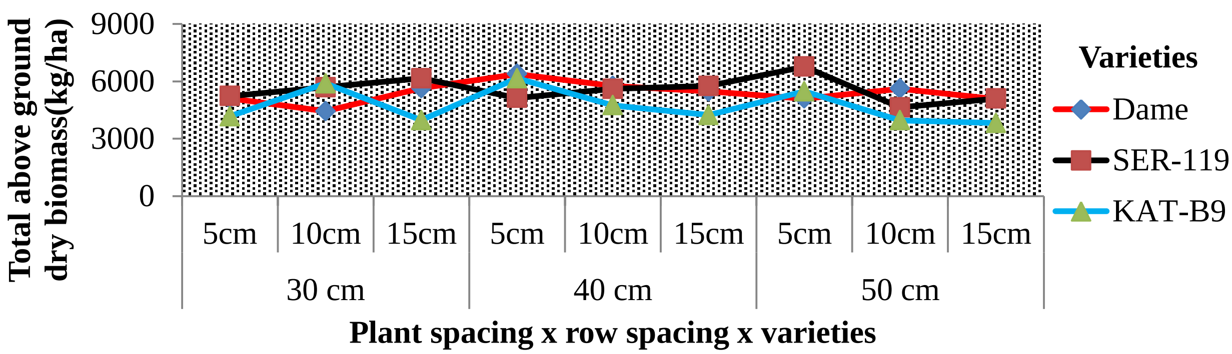
However the lowest were from the variety SER-119 with 10 cm x 50 cm, KAT-B9 with 15 cm x 50 cm and Dame with 10 cm x 30 cm. On other hand at MARC, the highest above ground total dry biomass were obtained from the spacings of 5 cm x 30 cm for SER-119 and KAT-B9 varieties. However the variety Dame had the lowest above ground total dry biomass at the spacings of 15 cm x 30 cm between plants and rows for the given crops.

The highest above ground total dry biomass obtained with narrower inter row spacing might be highest vertical vegetative growth with less lateral branching and reproductive organ production before physiological maturity.

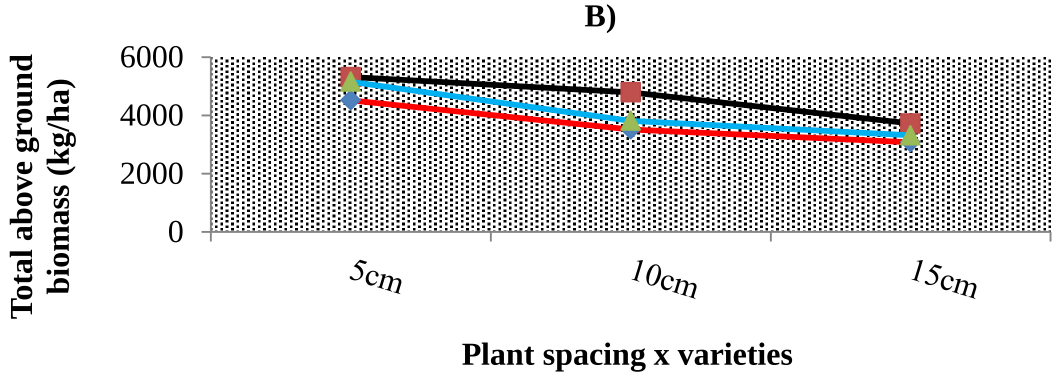
Similar results were reported by Al-Rifaee *et al.* (2004) who observed that at the final harvest of faba bean or the dry matter yield of aboveground parts increased with increasing plant population due to the increase in number of plants per unit area. The highest total dry biomass at the highest plant density might be due to more number of plants per unit area. In agreement with this study, Solomon (2010) and Pawar (2007) reported that total dry biomass hectare^{-1} was significantly increased with increased plant density on haricot bean.

The higher vegetative growth of common bean crops leads to become more competitive for light and increased plant population under narrow intra row spacing. Similarly, Getachew *et al.* (2006), found that increase in above ground total dry biomass of faba bean as a result of increased in plant density.

A)



B)



C)

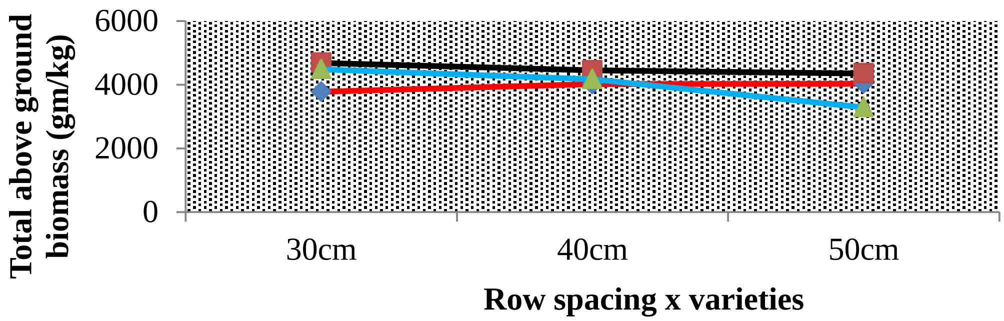


Figure 14: Interaction of A) Plant spacing x Row spacing x Varieties at Arsi Negele, B) Plant spacing x varieties, and C) Row spacing x varieties at MARC on total above ground dry biomass. Vertical lines on bars represent the standard error of statistical means.

Table-6: Effect of plant and row spacings on yield parameters of common bean varieties at central rift valley of Ethiopia.

Parameters	**Total dry biomass (kg/ha)**		**Harvest index (%)**	
Locations	**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**
Plant spacing				
5cm	5503.3±98.10[a]	5026.1±115[a]	41.48±0.64[ns]	42.82±1.10[c]
10cm	5149.3±96.70[b]	4039.4±125[b]	43.71±0.77[ns]	50.30±1.06[b]
15cm	5026.1±127.8[b]	3367.9±111[c]	42.56±0.85[ns]	56.41±1.64[a]
Row spacing (cm)				
30cm	5472.55±108.4[a]	4319.39±137[ns]	39.89±0.6[b]	46.98±1.23[b]
40cm	5144.21±102.5[b]	4217.70±142[ns]	43.29±0.62[a]	48.21±1.08[ab]
50cm	5062.00±116[b]	3896.26±137[ns]	44.57±0.93[a]	54.34±1.73[a]
Varieties				
Dame	4715.3±129.1[b]	3946.5±138.7[ns]	47.15±0.77[a]	52.32±1.1[ns]
SER-119	5563.1±90.70[a]	4341.1±117.2[ns]	39.37±0.55[b]	47.39±2.0[ns]
KAT-B9	5400.4±82.45[a]	4145.8±157.5[ns]	41.24±0.67[b]	49.81±1.0[ns]
LSD	**214.04**	**373.3**	**2.2193**	**5.1775**
CV	**7.49**	**16.49**	**9.54**	**19.02**

*Values (Mean ± SE) followed by dissimilar letters in column are significantly different at *:p<0 .05; **:p<0.01; ***: p<0.001; Ns=Non-significant.*

4.4.6. Harvest index

The harvest index was significantly affected by main effects of row spacing and varieties at (P<0.05) at Arsi Negele site, whereas plant spacing had non-significant (Appedex-7). At MARC plant and row spacing significantly influenced the harvest index at (P<0.05), and varieties had non-significant effects on harvest index. There were three way strong interaction effects of plant spacing, row spacing and varieties at Arsi Negele site, whereas non-significant effects in all the three way interaction for MARC (Table 6).

This is due to the high variation in the genetic makeup of the common bean varieties at the given experimental sites. This might be due to the varietal difference which responds differently for inter-row spacing that enables them more competitive for resources and enhances more translocation of biological yield to economical yield at studied sites. In agreement with this result, Kazemi *et al.* (2012) reported significant interaction between cultivar and plant densities on harvest index of white bean.

The highest harvest index was recorded from the varieties KAT-B9 and SER-119 at the spacings of 10 cm x 50 cm, whereas Dame at 50 cm x 5 cm. However the lowest were from the spacings of 40 cm x 5 cm for all varieties on Arsi Negele site (Figure 15). On other hand higher harvest index implies that higher partioning of dry matter to the grain yield from lower plant density and lower harvest index from higher plant density due to inter plant competition for growth resources for denser plant population as compared to lower plant density (Table 6). This result was in line with Solomon and Mekonnen (2003) who found that harvest index was reduced with an increase in plant density on haricot bean.

A)

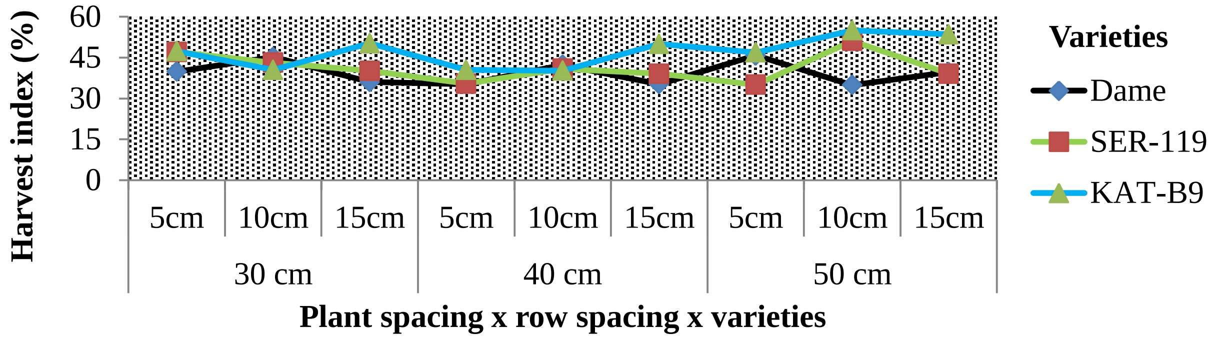


Figure 15: Interaction of Plant spacing x Row spacing x Varieties at Arsi Negele, on harvest index. Vertical lines on bars represent the standard error of statistical means.

4.5 Partial Budget Analysis

The partial budget analysis was done for the experimental sites to assess the cost and benefits for treatments as described in CIMMYT, (1988) on yield obtained. The partial budget analysis was done in reference to the local market price for common bean cultivars for both locations. In this study, the cost of labor and seeds were varied and weeding, cultivation, and other agronomic practices were done equally at both sites. The average grain yield was adjusted downward to 10% to meet the farmer's yield at the field for both locations.

Based on partial budget analysis, the highest net benefit (32417.1 and 31117.72 ETB) were obtained from treatment combination of SER-119 with (50 cm x 10 cm and 30 cm x 15 cm), with a marginal rate of return (8629.53 % and 2110.46 %) at MARC and Arsi Negele sites, respectively (Table 7).

This means for 1.00 birr invested for variety SER-119 with the combination of (50 cm x 10 cm and 30 cm x 15 cm) between inter and intra row spacing used in the field, growers can expect to recover 1.00 birr and added extra 86.30 and 21.10 birr respectively. On the other hand, variety Dame gave higher net benefits (30303.47 and 26729.5 ETB) from the treatment combination of (40 cm x 10 cm and 40 cm x 5 cm) with marginal rate of return (4294.38 % and 3865.4 %) for Arsi Negele and MARC respectively (Table 7). It means that for every 1.00 birr invested for variety Dame with the combination of (40 cm x 10 cm and 40 cm x 5 cm) row and plant spacing used in the field, producers can be believed to improve additional (42.95 and 38.65 ETB).

In the same way variety KAT-B9 produced higher benefits (32233.61 and 29441.5 ETB) with marginal rate of return (3304.02 % and 2329.01 % ETB) for Arsi Negele and MARC respectively. That means for every 1.00 birr invested for variety KAT-B9 with a combination of (50 cm x 5 cm) row and plant spacing used in the field, the growers can assume an additional 33.04 and 23.29 ETB) for both locations respectively.

From these experiments the best net benefits were obtained from the treatment combinations of (50 cm x 10 cm and 30 cm x 15 cm) with SER-119, (40 cm x 10 cm and 40 cm x 5 cm) with Dame and (50 cm x 5 cm) with KAT-B9 at both studied sites respectively (Table 7). Even though the above treatment combinations had higher net benefits, the following treatments combinations (40 cm x 10 cm, 40 cm x 15, and 50 cm x 15 cm) also worth's a better yield for the three given varieties and it is possible to recommend for the given sites, including similar agro-ecological zones at central rift valley of Ethiopia. The marginal rate of return was also greater than 100% which was at the minimum acceptable levels as described by CIMMYT, (1988).

Table 7: Partial Budget Analysis for Arsi Negele and Melkassa Agricultural Research Center

Trts	Trts comb.	Average grain yield		Adjusted grain yield		Total cost	Gross benefit		Net benefit		Dominance & MRR (%)	
		AN	MARC	AN	MARC	(AN+MARC)	AN	MARC	AN	MARC	AN	MARC
1	R1* P1*v1	2045.09	1875.02	1840.58	1687.52	234.07	25768.18	23625.25	25534.11	23391.2	0	0
2	R1* P2*v1	1999.07	1652.83	1799.16	1487.54	214.07	25188.28	20825.62	24974.21	20611.5	2799.47	13898
3	R1* P3*v1	2041.63	1863.15	1837.47	1676.84	204.07	25724.58	23475.69	25520.51	23271.6	11061.92	254397
4	R1* P1*v2	2462.30	2148.12	2216.07	1933.31	234.07	31024.98	27066.31	30790.91	26832.2	11810.26	2251
5	R1* P2*v2	2465.31	2117.50	2218.78	1905.75	214.07	31062.86	26680.46	30848.79	26466.4	10425.03	7853
6	R1* P3*v2	2485.86	2167.31	2237.27	1950.58	204.07	31321.79	27308.15	31117.72	27104.1	2110.46	10035
7	R1* P1*v3	1982.38	2028.86	1784.14	1825.98	234.07	24977.99	25563.68	24743.92	25329.6	D	D
8	R1* P2*v3	2393.32	2017.72	2153.99	1815.95	214.07	30155.87	25423.31	29941.80	25209.2	D	D
9	R1* P3*v3	1927.89	1463.71	1735.10	1317.34	204.07	24291.46	18442.7	24087.39	18238.6	D	D
10	R2* P1*v1	2262.15	2139.96	2035.94	1925.97	234.07	28503.09	26963.54	28269.02	26729.5	2509.13	3865.4
11	R2* P2*v1	2422.03	2004.24	2179.82	1803.82	214.07	30517.54	25253.47	30303.47	25039.4	4294.38	20362
12	R2* P3*v1	1931.53	1582.70	1738.38	1424.43	204.07	24337.32	19941.98	24133.25	19737.9	D	D
13	R2* P1*v2	1833.37	2136.81	1650.04	1923.13	234.07	23100.5	26923.76	22866.43	26689.7	12258.50	30633
14	R2* P2*v2	2301.62	2395.59	2071.46	2156.03	214.07	29000.41	30184.43	28786.34	29970.4	D	7342
15	R2* P3*v2	2249.86	1829.79	2024.88	1646.81	204.07	28348.28	23055.31	28144.21	22851.2	D	D
16	R2* P1*v3	2495.22	2123.09	2245.70	1910.78	234.07	31439.77	26750.93	31205.70	26516.9	9259.07	26962
17	R2* P2*v3	1937.60	1818.33	1743.84	1636.50	214.07	24413.8	22910.96	24199.73	22696.9	20134.93	14971
18	R2* P3*v3	2111.05	1765.40	1899.95	1588.86	204.07	26599.23	22244	26395.16	22039.9	92013.98	31630
19	R3* P1*v1	2348.37	1626.56	2113.54	1463.91	234.07	29589.5	20494.7	29355.43	20260.6	1912.11	D
20	R3* P2*v1	1962.76	1542.17	1766.48	1387.96	214.07	24730.78	19431.38	24516.71	19217.3	15598.00	D
21	R3* P3*v1	2025.01	1917.44	1822.51	1725.69	204.07	25515.13	24159.7	25311.06	23955.6	56330.78	57816
22	R3* P1*v2	2378.53	2302.76	2140.68	2072.48	234.07	29969.48	29014.78	29735.41	28780.7	9075.00	217
23	R3* P2*v2	2385.64	2589.77	2147.08	2330.80	214.07	30059.06	32631.14	29844.99	32417.1	8629.53	2377
24	R3* P3*v2	1955.15	2101.22	1759.64	1891.10	204.07	24634.93	26475.33	24430.86	26271.3	D	D
25	R3* P1*v3	2576.80	2355.21	2319.12	2119.69	234.07	32467.68	29675.6	32233.61	29441.5	3304.20	2329.01
26	R3* P2*v3	2188.33	1656.93	1969.49	1491.24	214.07	27572.92	20877.32	27358.85	20663.2	25355.02	23897
27	R3* P3*v3	2009.30	1743.4	1808.3	1569.11	204.07	25317.1	21967.5	25113.0	21763.4	26289.9	98785

Hint: The average and adjusted grain yield could be measured in (kg) ha^{-1}. *AN=Arsi Negele, MARC=Melkassa Agricultural Research Center*.

5. SUMMARY AND CONCLUSION

Common bean is one of the major important legumes crops produced in various parts of Ethiopia used for food, feed, income generation, and improvement of soil fertility. Even though the crops had economic importance different constraints were affected production and productivity. Among these constraints use of one standard plant densities was the major problem to improve the productivity and quality of common bean crops. This can be solved through maintaining appropriate plant and row spacing and appropriate agronomic practices for a given location.

To achieve this, research was done on the effect of different plant densities on growth, nodulation, yield and yield components at Arsi Negele and MARC from June to October during 2019, and main cropping seasons. The research consisted of three plant spacings (5, 10 and 15 cm), three row spacings (30, 40 and 50 cm) and three common bean varieties (Dame, SER-119 and KAT-B9) in a randomized complete block design (RCBD) in a factorial experiment with three replications.

Use of different spacings and varieties had great importance in improving growth, nodulation, yield and yield components at the given sites. Among the growth parameters: initial and final stand count, leaf area, shoot dry weight and number of primary branches increases at the wider plant and row spacings. Plant height and leaf area index revealed markedly significant increment at narrower plant and row spacings. Regarding the nodulation parameters, there were significantly increment in total number of nodules plant^{-1} and nodule dry as plant and row spacing increased at both sites.

There were markedly an increment in number of pods plant^{-1}, number of seeds pods^{-1}, hundred seeds weight and harvest index as plant and row spacing were increased at given sites. The grain yield and above ground total dry biomass showed significantly increment at narrower plant and row spacing at both sites. The interaction of different spacings and varieties had a significant effect on growth, nodulation, yield and yield components parameters at the given sites.

The highest, intermediate and lowest grain yields were recorded from the row and plant spacing of (50 cm x 5 cm), (40 cm x 5 cm) and (30 cm x 10 & 15 cm) with varieties SER-119, KAT-B9 and Dame for both sites respectively. The highest net benefits (32417.1, 31117.72, 30303.47 and 32233.61 ETB) were obtained from the treatment combinations of (50 cm x 10 cm and 30 cm x 15 cm) with SER-119, (40 cm x 10 cm) with Dame and (50 cm x 5 cm) with KAT-B9 at both studied sites respectively.

Treatment combinations of 40 cm x 10 cm, 40 cm x 15 cm and 50 cm x 15 cm also gave better yield for the given the varieties at the studied sites. Therefore these varieties with the stated plant and row spacings had economic feasibility and recommended to the studied areas and similar agro-ecological zones. However, verification of these results might be repeated in various areas and seasons to established recommendation in a depth.

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7. APPENDICES

Appendix-1

General favorable conditions for common bean production and description of the varieties used for the study.

Characteristics	Common bean verities		
	SER-119	**Deme**	**KAT-B9**
Altitude adaptation (m.s.a.1)	1450-2000	1300-1800	1300-1650
Growth habit	Bush	Bush	Bush
Seed Size	Small	Large	Small
Seed Color	Red	Red speckled	Red
Days of maturity	85-105 (Intermediate maturing)	85-90 (late Maturing)	75-79 (Early maturing)
Rain fall adaptation (mm)	450-700	750	400-750
Yield (t/ha) on station	33	19-22	22-30
Yield (t/ha) on farm	25	18-20	19-23
Center of releasing	MARC	MARC	MARC
Year of released	2014	2008	2013
Recommended seed rate in kg	70-80	80-100	70-80
Favorable agro ecologies	All areas of common bean growing	All areas of common bean growing	Central rift valley of Ethiopia
Recommended NPS fertilizer per hectare in kg	100	100	100

Altitude (m.a.s.l.)	**Amount of Rain fall (mm)**	**Average Temperature(ºC)**	**Soil Types**	**Soil pH**
850-2000	550-1100	18-30	Sandy to sandy loam	5.5-7.5

Sowing season (Time) and Recommended seed rate			
Areas of common bean Production	Rainy Season	Sowing Time	Recommended Seed rate
Southern Ethiopia	Mid of March	End of March	70-80/100-110
Central rift valley, Hararghe and Amhara Region	Beginning of June up to mid-June	From mid-June up to beginning of July	70-80/100-110 (small/Large seed size)
North western Ethiopia	From May to Mid-October	From end of July to beginning of August	70-80/100-110 (small/Large seed size)

Source: (MARC, from Low land pulse crop production team, 2019).

Appendix-2 Mean monthly temperature and rainfall of experimental sites during 2019 cropping seasons

	Precipitation (mm)		Max. Temperature (°C)		Min. Temperature (°C)	
Month	Arsi Negele	Melkassa	Arsi Negele	Melkassa	Arsi Negele	Melkassa
June	87.2	63.1	30.1	30.38	16.0	17.4
July	190.1	158.3	25.2	26.82	14.5	16.6
Aug	91.6	68.6	22.2	26.79	13.5	16.3
Sep	318.3	275.3	20.0	27.45	13.0	14.1
Oct	107.8	73.3	19.0	22.1	12.0	12.1
Mean	**159**	**123.9**	**23.3**	**26.708**	**13.8**	**15.298**
Total	**795**	**619.5**				

(Source: Melkassa Agricultural Research Center and National Meteorological Agency Adama Branch, 2019 cropping seasons).

Appendix-3 Mean square values for growth parameters of common bean varieties as influenced by plant and row spacing at central rift valley of Ethiopia.

		Mean Squares							
Source of Variation	DF	Initial stand count		Final stand count		Plant height (cm)		Leaf area (cm^2)	
Locations		Arsi Negele	Melkassa	Arsi Negele	Melkassa	Arsi Negele	Melkassa	Arsi Negele	Melkassa
Rep	2	0.44^{ns}	0.71^{ns}	1.53^{ns}	1.68^{ns}	2135.86***	23.7***	523.55***	180.97***
PS	2	106.32***	30.55***	90.40***	51.96***	1489.38***	6.85**	18.22***	21.35***
RS	2	0.92^{ns}	1.92^{ns}	0.81^{ns}	4.19*	229.20***	4.95**	18.15***	50.12***
Var	2	1.31^{ns}	0.06^{ns}	1.15^{ns}	1.88^{ns}	401.59***	157.77***	23.35***	12.28***
PS*RS	4	0.75^{ns}	0.89^{ns}	0.84^{ns}	0.55^{ns}	345.50***	1.93^{ns}	14.25***	30.26***
PS*Var	4	1.00^{ns}	2.07^{ns}	0.59^{ns}	1.44^{ns}	15.99***	0.97^{ns}	10.89***	25.17***
RS*Var	4	3.10*	1.57^{ns}	2.73*	0.74^{ns}	203.37***	3.24**	22.62***	11.47***
PS*RS*Var	8	0.43^{ns}	0.80^{ns}	0.93	0.62^{ns}	98.85***	0.40^{ns}	14.21***	18.50***
Error	52	18.85	19.83	22.57	18.192	0.3162	24.04	4993	16374.11
CV		5.42	5.14	5.47	5.31	1.06	8.44	3.68	6.49

*Values (Mean ± SE) followed by dissimilar letters in column are significantly different at *:p<0.05; **:p<0.01; ***: p<0.001; Ns=Non-significant.*

Appendix-4 Mean square values for growth parameters of common bean varieties as influenced by plant and row spacing at central rift valley of Ethiopia.

		Mean Squares					
Sources of Variation	**DF**	**Leaf area index**		**Shoot dry weight (gm)**		**Number of primary branches plant^{-1}**	
Locations		**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**
Rep		4225.71**	949.29***	18.43***	40.55***	175.77***	151.26***
PS	2	5.39**	0.11^{ns}	6.69**	40.66***	109.21***	288.48***
RS	2	4.39*	0.45^{ns}	6.22**	7.10**	32.27***	58.57***
Var	2	10.70***	4.32**	16.65***	7.76**	15.72***	28.58***
PS*RS	4	1.59^{ns}	0.86 ^{ns}	0.96^{ns}	1.23^{ns}	7.26***	20.69***
PS*Var	4	4.11***	3.51**	1.79^{ns}	3.29*	7.07***	3.12*
RS*Var	4	2.59*	4.81**	0.75^{ns}	4.74**	11.15***	5.63***
PS*RS*Var	8	1.35^{ns}	3.77**	0.58^{ns}	2.58**	7.16***	12.45***
Error	52	0.0051	0.02	0.54	0.65	0.059	0.026
CV		1.77	3.48	18.48	16.49	5.81	4.72

*Values (Mean ± SE) followed by dissimilar letters in column are significantly different at *:p<0.05; **:p<0.01; ***: p<0.001; Ns=Non-significant.*

Appendix-5 Mean square values for nodulation parameters of common bean varieties as influenced by plant and row spacing at central rift valley of Ethiopia.

		Mean Squares			
Sources of Variation	**DF**	**Total number of nodules plant^{-1}**		**Nodule dry weight (gm)**	
Locations		**Arsi Negele**	**Melkassa**	**Arsi Negele**	**Melkassa**
Rep	2	128.07 ***	59.09 ***	32.40***	33.42***
PS	2	72.98***	18.12***	12.49***	26.64***
RS	2	4.63*	2.35^{ns}	5.72**	10.81***
Var	2	8.36**	3.26*	6.78***	37.01**
PS*RS	4	6.46***	2.40 ^{ns}	3.91**	2.97*
PS*Var	4	13.26***	0.51^{ns}	5.86***	6.97***
RS*Var	4	3.95**	2.49 ^{ns}	8.92***	12.82***
PS*RS*Var	8	9.95***	2.59*	12.56***	12.83***
Error	52	5.37	8.92	0.0082	0.0049
CV		10.53	14.73	21.35	19.99

*Values (Mean ± SE) followed by dissimilar letters in column are significantly different at *:p<0.05; **:p<0.01; ***: p<0.001; Ns=Non-significant.*

Appendix-6 Mean square values for yield and yield components of common bean as influenced by plant and row spacing at central rift valley of Ethiopia

		Mean Squares							
Sources of Variation	DF	Number of pods plant^{-1}		Number of seeds pods^{-1}		Hundred seed Wt.(gm)		Grain yield (kg/ha)	
Locations		Arsi Negele	Melkassa	Arsi Negele	Melkassa	Arsi Negele	Melkassa	Arsi Negele	Melkassa
Rep	2	561.97***	68.96***	452.31***	135.42***	253.61***	53.30 ***	109.06***	77.58***
PS	2	281.28***	42.04***	24.08***	12.10***	19.70***	5.61**	8.63*	10.56***
RS	2	60.15***	3.77*	6.43**	1.35^{ns}	18.45***	13.51***	0.27^{ns}	0.66^{ns}
Var	2	34.26***	5.39**	11.25***	5.58**	672.34***	316.73***	4.68*	27.11***
PS*RS	4	7.32***	4.10**	0.83^{ns}	0.96^{ns}	11.08***	0.52^{ns}	4.50**	1.87^{ns}
PS*Var	4	50.86***	7.36***	6.60***	3.50*	6.17***	2.10^{ns}	3.04*	5.54***
RS*Var	4	16.34***	2.43*	13.88***	6.11***	7.44***	2.47^{ns}	6.44***	2.62*
PS*RS*Var	8	23.92***	3.83**	9.77***	3.60**	13.25***	3.98**	5.55***	3.79**
Error	52	0.906	8.93	0.077	0.182	4.43	10.55	29907.05	41989.06
CV		5.62	17.19	5.85	9.26	4.72	7.58	8.01	10.43

*Values (Mean ± SE) followed by dissimilar letters in column are significantly different at *:p<0.05; **:p<0.01; ***: p<0.001; Ns=Non-significant.*

Appendix-7 Mean square values for yield and yield components of common bean as influenced by plant and row spacing at central rift valley of Ethiopia.

		Mean squares			
Sources of Variation	DF	Total Dry biomass (kg/ha)		Harvest index (%)	
Locations		Arsi Negele	Melkassa	Arsi Negele	Melkassa
Rep	2	72.83***	36.19***	2.83***	8.41***
PS	2	10.79***	40.20***	2.04^{ns}	13.92***
RS	2	8.29**	2.82^{ns}	9.57***	4.66**
Var	2	35.58***	2.25^{ns}	26.95***	1.83^{ns}
PS*RS	4	12.28***	0.87 ^{ns}	2.49^{ns}	0.82^{ns}
PS*Var	4	8.70***	6.10***	6.64***	2.05^{ns}
RS*Var	4	4.31**	4.41**	2.47^{ns}	1.77^{ns}
PS*RS*Var	8	12.18***	0.58^{ns}	5.47***	1.84^{ns}
Error	52	153596.33	467208.8	16.51	89.87
CV		7.49	16.49	9.54	19.02

*Values (Mean ± SE) followed by dissimilar letters in column are significantly different at *:p<0.05; **:p<0.01; ***: p<0.001; Ns=Non-significant.*

BIOGRAPHICAL SKETCH

The author, Shanko Bakure, was born at Heban Arsi district western Arsi Zone of Oromia Regional State on May 1983 E.C, from his father Bakure Tufa and mother Buno Ontora. He attended his Primary education at Heban Degaga junior School from 1990 to 1997 and Secondary education at Arsi Negele Senior Secondary School from 1998 to 1999 E.C. After completed Secondary School, the author joined Bako ATVET College in 2000 and graduated in July 2002 with diploma in Plant Science. From 2003 to 2004 he joined Arsi Negele Agriculture and Rural development Bureau as development agent. After working for two years as a plant science profession in September, 2005, he joined Adama Science and Technology University Asella School of Agriculture as senior technical assistant working at field and laboratory under plant science department. After working for one year he attended his BSc degree in plant science at Adama Science and Technology University in 2006 and graduated on July 07, 2008 E.C. The author serves his institution for one year & joined postgraduate program in 2010 E.C at Hawassa University, School of Plant and Horticultural Science, to pursue his study for the degree of Master of Science in Agronomy.