EFFECT OF PLANT SPACING ON YIELD RELATED TRAITS AND YIELD OF COMMON BEAN (*Phaseolus vulgarism* L.) IN CHIRO DISTRICT OF WEST HARARGHE Zone, EASTERN ETHIOPIA.

MSc THESIS

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Effect of Plant Spacing on Yield Related Traits and Yield of Common Bean (*phaseolus vulgaris* L.) in Chiro District of West Harerge Zone Eastern Ethiopia.

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As Thesis Research advisors, we hereby certify that we have read and evaluated this thesis prepared under our guidance by **Daniel Worku** entitled **"Effect of Plant Spacing on Yield Related Traits and Yield of Common Bean (*phaseolus vulgaris* L.) In Chiro District of West Harangue Zone, Eastern Ethiopia."** and we recommend that it be submitted as fulfilling of the MSc Thesis requirement.

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As members of the board of Examiners of the MSc Thesis open Defense Examination, we certify that we have read and evaluated the thesis prepared by Daniel Worku And examined the candidate. We recommended that the Thesis be accepted as fulfilling the Thesis requirements for the degree of Master of Science in Agriculture (Agronomy).

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Final approval and acceptance of the Thesis is contingent upon the submission of its final copy to the Council of Graduate Studies (CGS) through the candidate's School Graduate Committee (SGC).

DEDICATION

This Thesis manuscript is dedicated to my beloved mother Atinaf Kidane whom I lost on Marche 2018. May God rest her soul in paradise!!!

STATEMENT OF THE AUTHOR

I earnestly declare that this thesis is my bona fide work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of the Thesis. All sources of materials used for this thesis have been duly acknowledged and any scholarly matter that is included in the thesis has been given recognition through citation.

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BIOGRAPHICAL SKETCH

The author was born from his father Mr. Worku Wolde Yohannis and his mother Mis Atinaf Kidane on November 3, 1975 G.C. in Chiro District of West Harangue Zone, Oromia National Regional State, Ethiopia. He attended his education from Grade 1-6 at Chiro Primary number 3 elementary school and from grade 7 to 8 at Chiro junior number 1 Secondary School, from grade 9-12 at Chercher Comprehensive Secondary School. He joined Agarfa Multipurpose Agricultural Training Center in Certificates and graduated with General Agriculture. The author was employed in Chiro District Agricultural Office as Development Agent in Rural area and served for few years and then joined Nedjo ATVET college and graduated in Diploma in the field of Plant Science. He again joined Chiro District Agricultural Office as Development Agent and Site Supervisor from 1997 E.C until 2001 E.C. Then he joined Jimma University and graduated with BSC Degree in Plant Science in 2011 G.C and additionally he was graduated from Haramaya University with BSC degree in RDAE in 2017/18 G.C. The author served the same office in different positions i.e., extension expert, extension team leader and coordinator until the time he joined the Post Graduate Directorate of Haramaya University to pursue his MSc degree in Agronomy in the School of Plant Sciences.

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ACRONOMS AND ABRIVIATIONS

CAR	Center of Agricultural Research
CSA	Central Statistical Authority
DZARC	Debre Zeit Agricultural Research Center
EARO	Ethiopian Agricultural Research Organization
EEPA	Ethiopian Export Promotion Agency
FAOSTAT	Food and Agricultural Organization Statistical Database
FTC	Farmers Training Center
GLM	Generalized Linear Model
IAR	Institute of Agricultural Research
ICARDA	International Center of Agricultural Research in Dry Area
ICRSAT	International Crop Research Institute for Semi-Arid Tropics
ILRI	International Livestock Research Institute
LSD	Least Significant Difference
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rular Development
SNNPR	Southern Nations, Nationalities and Peoples Region
TCA	Technical Center for Agriculture and Rural Cooperation

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ABSTRACT

*One of the basic agronomic practices to improve the yield potential of common bean is identification of optimum plant spacing. Thus, field experiment was conducted to assess the effect of inter-row and intra-row spacing on the yield and yield components of common bean using variety Dursitu (DOR-811) at Chiro District in eastern Ethiopia. The treatment consisted of four inter- row (20, 30, 40 and 50cm) and four intra- row (5, 10, 15 and 20 cm) spacing arranged in factorial combinations in a randomized complete block design (RCBD) with three replications. Data were collected on days of 50% emergence, 50% flowering, physiological maturity, plant height, number of primary branch, number of pod , number seed per pod,100 seed weight, and grain yield and subjected to statistical analysis using Gene State Software version 18. The main effect of inter-row, intra row and their interaction were showed non-significant effect on days to 50% emergence of common bean. The main effect of inter-row and intra- row spacing showed highly significant effect on days to 50% flowering and physiological maturity. The highest days to 50% flowering (63 days) and days to physiological maturity (85.5 days) were recorded at 50 cm inter-row spacing, on the other hand, at 20 cm intra-row spacing, the highest days to 50% flowering (61 days) and days to physiological maturity (84.42 days) were recorded. The main effects of intra-row and inter-row spacing were significant on plant height. The tallest plant height (59.03 cm) was recorded under the interaction of 20cm inter-row spacing and 5cm intra row spacing. The 50 x 20 cm spacing produced the highest number of primary branches (4.5) while, the lowest number (**3.03**) was scored under 20 x 5 cm. Stand count at harvest was increased from 87.5 % to 94.44%.As intra-row spacing increased from 5 to20cm respectively. The 50 cm inter row spacing was produced the highest number of pods (40.71) and 20cm intra raw spacing produced 37.86 pods per plant respectively. The highest number of seeds (6.93) per pod was scored under the interaction of 50cm inter and 20cm intra row spacing. The highest hundred seed weight (24.47g and 24.29 g) were recorded at 50 cm inter-row and 20 cm intra-row spacing respectively. The highest seed yield (3.66 tones ha^{-1}) and (2.683 tone ha-^{1}) was recorded under 40 cm inter-row with 10 cm intra- row spacing and 30cm inter row with 15cm intra row spacing respectively. Thus, based on the results of this study, 40 cm inter-row with 10 cm intra-row spacing can tentatively gave high yield followed by 30 cm inter row with 15cm intra-row spacing as best for production of common bean in the study area as compliment to the current recommendation of 40 x 10 cm. However Conclusive recommendation could be obtained if the study is repeated at more locations and seasons.*

Keywords: *Interaction effects, Inter-row spacing, Intra-row spacing, Main effects*

1. INTRODUCTION

Legume seeds are an important staple foods and sources of dietary minerals that potentially provide all of the 15 essential minerals required by humans. Common bean (*Phaseolus vulgaris*) is the most vital grain legume for direct human consumption. The Species has high diversity as seen in its morphological variability, uses and growth habits and patterns (Baeta *et al*., 2010; Heuze *et al*., 2013). In the study area, common bean is known as Oshongoree in the local Oromiffaa language. Other names of the crop include dry bean, bean, kidney bean, haricot bean, French bean and field bean. It is a particularly important legume crop grown worldwide. It grows best in warm climates at temperatures of 18 to 24°C (Gebre-egziabher Murut *et al.,* 2014).

This crop is currently estimated to be one of the most important legumes worldwide and it is described as a nearly "perfect" food. Nutritionally rich, it is also a good source of protein, dietary fiber and complex carbohydrates (Pachico, 1993) and it is an important source of nutrients for more than 300 million people in parts of Eastern Africa and Latin America, representing 65% of total protein consumed, 32% of energy and a major source of micronutrients, e.g., iron, zinc, thiamin and folic acid (Petry *et al*., 2015). It is also important in Nitrogen fixation thus improving the soil fertility as well as increasing crop production and improving the livelihoods of farmers (Gebre-egziabeher Murut *et al*., 2014). It is described as a non-sensitive crop to soil as long as it is well-drained and Fertile (Rahman *et al*., 2014). It can be grow successfully on most soil types, from light Sands to heavy clays, but friable, deep and well-drained soils are best preferred (Gifole Gidago *et al*., 2011).

According to Margaret *et al*. (2014), common bean in Sub-Saharan Africa (SSA) is an important crop for food-security and nutrition. It plays a big dietary role, supplying proteins, carbohydrates, essential elements and vitamins to both rural and urban households. It is estimated that the crop meets more than 50% of dietary protein requirements of households in SSA. The annual per capita consumption is higher among low-income people who cannot afford to buy nutritious food stuff, such as meats and fish (Arenas *et al.,* 2013).

Common bean is also a major food and cash crop in Ethiopia as well and it has considerable national economic significance. It is often grown as cash crop by small scale farmers and used as a major food legume in many parts of the country where it is consumed in different types of traditional dishes (Kedir Oshone *et al.,* 2014). For a very long time, it has been cultivated as a field crop. Moreover, for more than 40 years it has been an export crop (Rahmeto Negash, 2007). It is cultivated in a wide range of agro ecologies and farming systems including well-watered and drought-stressed areas (Asrat Asfaw *et al*., 2009).

This crop is distributed and grown in different parts of Ethiopia depending on climatic and socio-economic factors and is being part of the diets of the farming households.

In Ethiopia, the major common bean producing areas are central, eastern and southern parts of the country (Hirpa Legesse *et al*., 2013). Common bean production has been practiced in all Regions of Ethiopia. Oromia (43%), Amhara, SNNPR, Benishangul-Gumuz and Tigray Regions are the major producing Regions that contribute more than 99 percent of the total production.

Low yield of common bean in Ethiopia is attributed to several production constraints which include lack of seeds of improved varieties for various agro-ecological zones, poor cultural practices such as untimely and inappropriate field operations, inappropriate plant density, weed infestation, low soil fertility, water stress, diseases and insect pests (Teshale A, 2008).

West Hararghe Zone is one of highly common bean producing Zones in Oromia Regional State for a long period of time. Due to presence of bi-modal cropping season in the area, common bean is normally grown twice a year under rain fed agriculture. The first production is during the short rainy season called *Belge* (April to June) and second is during the long rain season called *Mehere* (July to October) (Simane B, 1998).

About (25,994.67 hectares) was covered by common bean during the '*Meher'* season of 2014/2015 cropping season and produced 37,712.213 tons with average productivity of 1.45 tons ha-^{1} (CSA , 2015). This yield is far less than the achievable production potential value of the crop which is 2-3 tons ha-^{1} (MoARD, 2009).

Increase in yield can be ensured, by maintaining appropriate plant population through different planting patterns. Planting pattern influences radiation interception and utilization of moisture from soil Ihsanullah, (2002). Main role of planting pattern on plant growth is due to differences in distributing and dispersion of light energy quality and quantity among plants which induced improving grain yield and biological yield with increasing ratio uptake (Orcutt DM, 2000).

Plant density affects early ground cover, competitive ability of crops with weed, soil surface evaporation, light interception, lodging and development of an optimum number of fruiting sites in a crop canopy. It also affects canopy development, plant architecture and distribution of pods Matthews PW, (2008). 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 WK, 2004).

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. However, 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 M, 2012).

The characteristics of different common bean varieties are different with each other in terms of their growth habit, days to maturity, seed color, seed size, and seed weight, and agro ecological adaptation (Mulatu E, 1997). The seed size of common bean varies considerably, but most commercial cultivars of common beans have a seed size in the range of 200 to 350 mg (Davis JH, 1997). Moreover, the optimum plant population differs with the availability of soil moisture, relative humidity and nutrients. Spatial arrangement of the plant directly or indirectly affects the production potential of common bean varieties. Thus, there is no site and variety specific recommendation on the plant spacing of common bean varieties in Chiro District.

In view of the above facts the present study was undertaken with the following objectives:

To assess the effects of plant spacing on yield and yield related traits of common bean variety.

2. LITERETURE REVIEW

2.1. Botanical Description of Common Bean

The growth forms are of the annual climber type or sub erect herbs, leaflets are ovate or ovate-rhombic, 4.5-15 x 2.5-10 cm, acuminate and pubescent. The inflorescence is several-flowered; bracteoles ovate-lanceolate, 5-6 mm long. Calyx 4-5 mm long. Corolla white, yellowish, purple or pink; standard 1-1.5 cm long; keel spirally incurved. Pod linear-lanceolate, c10-20 x 1-1.5cm, compressed, puberulous or glabrous, c 5-10-seeded. Native in America now cultivated throughout the world; in Ethiopia commonly grown at intermediate altitudes and perhaps locally naturalized (Thulin, 1989).

Seeds variable in size, shape and color, as a rule oblong but also ellipsoid, globular or kidney-shaped, laterally compressed, (6-)8-17(-20) x (4-)5-7(11) mm, white, purple, black, ochre, brown, white, black mosaic, brown, black mosaic, light colored, purple mosaic, light colored, red-purple mosaic, light colored, brown mosaic, light colored, orange mosaic, and grey-brown, very small light spots, usually glossy. Hilum oblong, sometimes elliptic, about 2-3.5 mm long, central, covered by a layer of white detachable tissue, brownish, often surrounded by a darker colored hilum ring, with a darker colored, often conspicuous twin-bump situated near the hilum at the opposite side of the micropyle (Westphal, 1974; Thulin, 1989).

2.2. Origin and Domestication of Common Bean

Common bean originated from the New World; two centers of origin were identified Andean and Mesoamerican (Hornakova *et al*., 2003; Logozzo *et al*., 2007).

The domestication occurred independently in South America and Central America/Mexico, leading to two different domesticated gene pools, the Andean and Mesoamerican, respectively (Papa and Gepts, 2003; Petry *et al*., 2015).

This crop is native to Mexico and Guatemala where the greater part of the diversity of varieties is found (Arenas *et al*., 2013).

Common bean is the most widely distributed of the related species and has the broadest range of genetic resources (Gomez, 2004) and is frequently used as food crop throughout the world, especially in Latin America and Africa. Different races have been described in both gene pools differentiated for morph-agronomical traits. Common bean was introduced to Europe probably from Cuba immediately after Columbus's voyage/ since the first half of the sixteenth century. It was distributed widely in all parts of Europe and the Mediterranean area where many landraces and varieties evolved that were grown to provide dry seed or fresh pods (Logozzo *et al*., 2007).

The species was perhaps introduced to the eastern part of Africa by Portuguese traders in the sixteenth century (Wortmann *et al*., 2004).

2.3. Taxonomy and Description of Common Bean

2.3.1. Taxonomy of Common Bean

Common bean is the best-known species of the genus *Phaseolus* in the family *Fabaceae* of about fifty plant species, all native to America. After the Asteraceae and Orchidaceae, the *Fabaceae* is the third largest family of flowering plants in the world and the first in Ethiopia (Arenas *et al*., 2013).

It is a family of great economic importance and very unique in having members that can form associations with symbiotic bacteria to fix atmospheric nitrogen (Karagkiozi *et al*., 2012). The wide range of growth habits of common bean varieties has enabled the crop to fit in the many growing situations. Among the different growth habits of common bean, the prostrate and the bushy types achieve rapid ground cover, compete with weeds and avoid competition (Zelalem Zewdu, 2014). Moreover, common bean is an important understory companion crop in various intercropping systems throughout the world (Rahmeto Negash, 2007).

It is planted in pure stands of single landrace, as mixed plantings of several farmers‟ varieties, and intercropped with maize, sorghum, sweet potato, cotton, coffee and other crops. Typically, when planted for use as vegetables, common bean is planted as a monoculture crop (Negash Hailu *et al*., 2015).

Under Ethiopian condition, the crop is normally grown twice a year, the first production is during the short rainy season (April to June) and the second is during the long rain season (July to October) (Kedir Oshone *et al*., 2014).

2.3.2. Description of Common Bean

Common bean is the most commonly consumed legume worldwide, and it is the most important legume produced for direct human consumption, with a commercial value exceeding that of all other legume crops combined (Broughton *et al.*, 2003; Porch *et al.*, 2013; Graham and Vance, 2003).

Although low in methionine and cysteine, the dried seeds, or "pulses", of *P. vulgaris* are an important source of dietary protein for millions of people throughout the tropics, supplementing those amino acids lacking in diets based on maize, rice or other cereals (Broughton *et al.*, 2003; Wortmann, 2006).

Beans are an especially valuable source of the amino acids lysine and tryptophan; the minerals iron, copper and zinc; and beneficial phytochemicals, antioxidants and flavonoids (FAO, 1999).

Dry beans are typically processed before consumption, usually by cooking in water, but some beans are consumed after roasting or after milling into flour (Tohme *et al*., 1995; Siddiq and Uebersax, 2012; FAO, 1999).

Immature seed pods, called snap beans, are consumed as vegetables in some regions, and straw from the plants is used as forage (Purseglove, 1968; Broughton *et al.,* 2003). The leaves of some specially selected varieties are consumed as a vegetable, usually when better quality food is not available (Wortmann, 2006).

In developing countries of Latin America and Africa, most beans are produced by smallholder farmers (Broughton *et al.,* 2003), and a significant portion of the crop is consumed on-farm, so it is difficult to accurately estimate global production. The widespread practice of producing beans through intercropping also leads to an overestimation of the total area planted and an underestimation of global yields (Akibode and Maredia, 2011).The FAO reported that total dry bean production in 2014 was over 26 million tons, although this number includes other bean species as well and possibly other minor food legumes. Due to extensive plant-breeding efforts, *P. vulgaris* comprises numerous cultivars with a wide range of morphological and agronomic characteristics, including differences in seed size and color as well as growth habit (Purseglove, 1968; Singh *et al*., 1991).

The stems are typically hairy, with the length and density of the hairs dependent on the cultivar. However, short, hooked hairs (uncinate hairs) are always present on the younger portions of the stems (Debouck and Hidalgo, 1986; Singh *et al*., 1991; Lackey, 1981; Freytag and Debouck, 2002). The hairs have a role in both disease and insect resistance. There is evidence that the hairs interrupt the production of fungal spores, thereby reducing secondary inoculums (e.g. bean rust, Uromyces appendiculatus) and can physically wound insects (such as leafhoppers, Empoasca fabae), resulting in reduced predation (Mmbaga and Steadman, 1992; Pillemer and Tingey, 1978). When the climate is sufficiently warm to allow a semi-perennial growth habit, the stems of wild *P. vulgaris* can grow to a diameter of 1.5 cm and may develop a corky outer layer (Gentry, 1969).

The leaves are trifoliolate and alternate on the stems. The leaflets are entire and somewhat hairy, 8-15 cm x 5-10 cm, with small stipules (Purseglove, 1968; Wortmann, 2006).

Leaflet shape differs among the cultivars, but leaflets generally have broad bases and pointed tips (Singh *et al.*, 1991). Flowers are borne on auxiliary or terminal racemes, in colors of white, pink or violet, depending on the cultivar.

The bisexual flowers are keeled, and the keel terminates in a coil, with one to two turns (Purseglove, 1968; Bailey, 1975; Wortmann, 2006). The seed pods are narrow, 8-20 cm x 1-2 cm, with up to 12 seeds per pod, but most varieties have 4-6 seeds. Seeds are produced in a wide variety of colors, depending on the cultivar (Purseglove, 1968; Wortmann, 2006), and the seeds vary considerably in size, with a range of 150-900 g per 1 000 seeds (Brink and Belay, 2006; Wortmann, 2006).

2.4. Adaptability of Common Bean

Common bean production is heterogeneous in terms of ecology, cropping system and yield Simane B, (1998) Common bean is grown predominantly in low land area (300-1100 m) mainly in the rift valley and some mid highland areas (1400-2000 m) of the country and in areas with annual average rainfall of 500-1500 mm.

It ideally needs moist soil throughout the growing period. However, rainfall towards the end of the growing periods is unwanted. It can be grown successfully on most soil types, from light sands to heavy clays, but friable, deep and well-drained soils are best preferred (Gifole Gidago *et al*., 2011).

In warm climate that shows greater development in environments with average temperature of 18 to24°C during the growing season and a precipitation of 300 to 500 thousand millimeters throughout the crop cycle (Agete Jerena, 2014) and excessive temperatures cause flowers to abscise, and low temperatures delay pod production and can result in empty pods. Common bean prefers well-drained, sandy clay or sandy loam soils, with balanced fertility and moderate acidity pH 5.8-6.5 (Ensor, 2009).

In Ethiopia, common beans are concentrated in the dry and warmer parts of the country mainly along the rift valley (IFPRI, 2010).

2.5. Cultivation of common bean

Common bean is cultivated in a broad variety of environments, in terms of altitude, temperature, soil type, and moisture regime, however it is grow mainly in dry land and rain fed conditions. It is well known that local farmers have selected farmers" varieties collections that best adapt to the soil and climate conditions of the region(Aguilarbenítez, 2014).

The crop is grown by subsistence farmers either as a sole crop and/or intercropped with either cereal or tree crops. Shade tolerance and early maturity contributes to common beans prominent position as understory intercrop for sorghum, maize, and coffee in the eastern zones of the country in which 85 % of all sorghum is intercropped with beans. Therefore, these characteristics make it an ideal crop for intensification of existing farming system (Rahmeto Negash, 2007).

2.6. Distribution of Common Bean in the World and in Ethiopia

Common bean is distributed in different parts of the world, mainly in east Africa, in east Asia, in south Asia, Europe Central America and the Caribbean, southern Africa, Southern and the Andean area. The world major common beans producers are India, Brazil, Myanmar, and China. Ethiopia is the third largest producer of common beans in Eastern and Southern Africa and the leading exporter in Africa. The country exported 40 percent of its common beans out of the total production in 2010 (FAOSTAT, 2015).

Common beans are increasingly becoming an important food security commodity particularly among the smallholders. For instance, consumption has increased from 98,065 tons to 242,100 tons between 2004 and 2009. In addition, it is important in the county's balance of payments (Gepts, 1991; Agete Jerena, 2014). The distribution of beans in Africa is extremely dependent on rural population density and mean temperature during the growing season (Wortmann *et al*., 2004).

Different varieties of common beans grow in different parts of Ethiopia, white beans, grow in the central Ethiopia (Shoa) as cash crop, colored beans grow in the southern part of Ethiopia for local consumption and climbing beans grow in the North West (Metekel) and western Ethiopia (Wollega), climbing type of common bean are planted along fences and on the borders of maize fields (Rahmeto Negash, 2007).

2.7. Agro- Ecological Requirement of Common Bean

Common bean is widely grown in low land and mid altitude areas. It has a wide range of adaptations and grows well between 1400 to 2000 meters above sea level and also does well in some areas as low as 500 m and as high as 1900 m that receive a well distributed average rainfall of 500 to 1500 mm throughout the growing season .Having short maturity period of about three months; it is available for family consumption during the period when other crops are immature (Amare Abebe, 1989).

Common beans are adapted to a wide range of soils. They grow most successfully on drained soils of medium texture (loams). The soil should be at least one meter deep. In humid areas, they are growing on acidic soils. The optimum temperature for their growth is about 16-24℃. These crops grow throughout the cooler tropics, but not in hot semiarid or humid Regions. Common bean requires a minimum frost free period of 105-120 days, as they are killed by frost. In general, high temperature (20-30 0C) during flowering causes the dropping of buds and flowers, which reduces yield (Amare Abebe, 1989).

Full maturity for dry bean seed type was attained from 45 to 150 days after emergence, depending on growth habit type and location (Singh, 1982). Maturity of bean increased with the altitude increase. Due to low temperature prolonging the maturity period of beans and it was more pronounced in indeterminate than determinate types (Amare Abebe, 1987)

2.8. Importance of Common Bean

Common bean is the most commonly consumed legume worldwide, and it is the most important for direct human consumption, with a commercial value exceeding that of all other legume crops combined (Ssekandi *et al*., 2016).

Extractions of common bean as well as some of its individual components have been reported for their effects in reducing appetite and body weight and blood glucose in rats. Common bean is gaining increasing attention as a functional or nutraceutical food, due to its rich variety of phytochemicals with potential health benefits such as fiber, polyphenolic compounds, lectins, unsaturated fatty acids, trypsin inhibitors, phytic acid, among others (Guzman-Maldonado *et al*., 2000). This crop is essential in Nitrogen fixation to improve the soil fertility as well as increase crop production and livelihoods of farmers (Gebre-egziabher Murut *et al*., 2014).

In Ethiopia, common bean has been one of the most important crops grown by small scale farmers in different parts of the Region, in the central rift valley of Ethiopia; the crop is used as one of the cheapest source of protein apart from being the major source of cash income. It is usually consumed in the form of boiled grain, which is locally known as Nifro farmers also prepare a local stew known as shiro wot from some bean cultivars (Zelalem Zewdu, 2014).

2.9. Current Production Status of Common Bean

2.9.1. Current production status of common bean in the world

Common beans are important for direct consumption because they grow all over the world and are consumed as dry and snap beans (Asrat Asfaw & Blair, 2014).

The world major common beans producers are India, Brazil, Myanmar, China, Turkey and Ethiopia taking significant steps to encourage grain legume production. Ethiopia is the third largest producer of common beans in Eastern and Southern Africa and the leading exporter in Africa (Blair *et al.,* 2007).

Common beans are mostly consumed in countries where they are produced. Countries with the highest rates of consumption per capita (in Central America, Caribbean, East

Africa and some Asian economies) produce beans and also import them at varying levels, depending on the harvest, for meeting the internal demand. Considering the global imports and exports of dry beans between 2008 and 2012, it seems that 15 to 20% of the world annual production (around 4 MT on average) is traded internationally. Myanmar, China and the United States are the main exporters, with India and the European Union being the largest importers (FAOSTAT, 2015).

Globally, the annual production of green and dry beans is 17 Million tons (FAO, 2010), which makes the crop the most widely utilized of legumes. It is produced for its green pod and dry seed which are both edible.

In 2014/15, total common bean production in Ethiopia was about, 5,137,348.07 quintals (1.9% of the grain production) on approximately 323,327.27 hectares of land (2.58% of the grain crop area) and yield Quintal/Hectare is about 31.83 (CSA, 2015).

2.9.2. Current production status of common bean in Ethiopia

Almost all common beans were produced by smallholder farmers (CSA, 2015). The average farm size for smallholder farmers is between 0.25 and 0.5 hectares. There is a wide range of common bean types grown in Ethiopia including mottled, red, white and black varieties Frehiwot M (2010). The most commercial varieties are pure red and pure white colored beans and these are becoming the most commonly grown types with increasing market demand Ferris S, Kaganzi E (2008).

To support both the growth in domestic and export bean markets, Ethiopian Institute of Agricultural Research (EIAR, 2014) has developed a range of high yielding, multi disease resistant bean varieties. The focus of this genetic improvement program has been on the pure red and white beans to support the commercial sector Ali K, Gemechu A, Beniwal S, Makkouk S, Halila M (2003).

Within the red bean types, the most favored and most commercially accepted varieties include Red Melka, a mottled medium sized red; Red Wolayita, a medium sized pure light red; and Nasser, a small pure dark red variety Ferris S, Kaganzi E (2008). Among the country pulse crops common bean is the second both cultivated area and in volume of production accounting 21% and 19% respectively (CSA, 2015).

2.9.3. Productivity of common bean in Ethiopia

Common beans productivity depends on good weather condition and use of appropriate technologies (fertilizer, improved seed, and herbicide) with the recommended rate and time. The national agricultural research 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 technologies promoted include improved varieties, recommended fertilizer rates and types, improved agronomic and weed control practices. The average common bean productivity was about 1.6 tons ha-1 (CSA, 2015). However, the experience from experimental plots indicates that 2.5-3.0 tons ha-1 can be obtained (EIAR, 2014).

2.10. Constraints of Common Bean Production in Ethiopia

Mostly, production of common bean is highly constrained by environmental stresses such as drought, pests, diseases, and low input farming methods that have resulted into declined soil fertility and productivity (Asrat Asfaw *et al.,* 2013).

Socio-economic factors related to farmer adoption of new technologies, seed distribution, and market requirements may also restrict bean production. The small-scale farmer's main cost and biggest problem is often the purchase of high-quality seed, production inputs such as fertilizer, pesticide, etc. and adoption of new technology (Frehiwot Mulugeta, 2010).

Soil fertility status, recurrent water stress, insect pests, weeds and diseases are considered as the principal abiotic and biotic constraints of common bean production in Africa (Tesfay Amare and Amin Mohammed, 2014; Yitayal Abebe & Adam Bekele, 2015). There are several serious insect pests that attack the common bean, depending on the geographic location, but predation by a wide range of arthropods aphids, beetles, caterpillars, leafhoppers, whiteflies, mites and thrips is seen worldwide (Beebe *et al.,* 2009; Fire Mulusew *et al*., 2010).

2.11. Concepts of Plant Density and Planting Arrangement

For sole cropping, the different aspects of plant density and spatial arrangement are well understood. Plant density defines the number of plant per unit area, which determines the size of the area available to the individual plant. Willey and Osiru (1982) stated that an essential component of plant density is a spatial arrangement. Spatial arrangement is defined as the pattern of plants over the ground, which determines the shape of the area available to the individual plant Reddy, R.S., (2000.). Particularly in annual or row crops the arrangement is rectangular in which the between row spacing is greater than the with-in row spacing David, R.K., A.A. Bruce and W.M. Richard, (1983). Planting arrangement in the field is very important and plays a significant role in determining plant growth and development. Arrangement of a population is altered by changing row spacing, planting seeds singly or in groups, or changing row direction Robinson, (2002). Plant spacing should be thought of an existing in two directions, within row spacing and between row spacing. At a given plant density , as row spacing decreases, the plant spacing within the row increases and results in a more equidistant plant spacing. At a fixed row width, plant density increase the plant spacing within the row decreases and inter plant competition increases. Obviously, both factors can be adjusted to give ideal plant spacing and typically plant density increases as row spacing decreases Pedersen, P., (2008).

2.11.1. Effect of Plant Density on Resource Utilization

Plants show extreme plasticity, responding remarkably in size and form to environmental condition. One of the most potent of these external forces is the presence of competing neighbors, which may reduce a plant to diminutive size. The factors for which completion may occur among plants are water, nutrient, light, oxygen and carbon dioxide and in the reproductive phase, agents of pollination and dispersal. Water, nutrient and light are the factors most commonly deficient. When the immediate supply of single necessary factors falls below the combined demand of the plants, competition begins Norman, A.G., (1963).

For a low density of plants of a single species increasing the density increases yield per unit area and intra-specific completion becomes more intense, because greater number of individuals compete for the same common limiting resources .In pure stands, increase in the intensity of completion manifests itself by the reduction of the performance of the individual, e.g biomass of single plant and/or reduction of grain weight per plant Sobkowicz, P. and M.L. Podgorska, (2007). According to Reddy R.S., (2000) both narrow and too wide spacing, yield reduction can occur due to in efficient utilization of the growth factors. Normally, as density increases yield also increases proportionally but after a certain level, it declines Azam-Ali, S.N. and G.R. Squire, (2002).

An establishment of optimum density per unit area is essential to get maximum yield. Under conditions of sufficient soil moisture and nutrients, higher density is necessary to utilize all the growth factors efficiently. Each growth factor for which the plant competes has limitation to support a crop beyond the optimum plant density level per unit area. The level of plant density should be such that maximum solar radiation is utilized. The full yield potential of an individual plant is fully exploited when sown at wider spacing Singh and Singh, (2002).

Equidistant spacing of inter and intra rows produces an earlier and more complete soil cover than other spacing. As a result, more sunlight is intercepted by the foliage .The more complete soil cover also intercepts more rainfall and may reduce runoff and soil erosion Robinson (2002). In theory, plants arranged in a square should make more efficient use resources than those in rectangle Reddy, R.S., (2000). Singh and Singh, (2002) reported that the crop plants should cover the soil as early as possible to intercept maximum sun light to produce higher dry matter as the intercepted solar radiation and dry matter production are directly related .Closely spaced and quick-growing crops like soybean which can intercept more light within a short period gives higher yield as compared to wider spaced crop. As such for the proper light interception increases photosynthesis and reduces evaporation of water from the soil Robinson (2002).Similarly , completion for soil resources is greater with the more crowded row systems in wide rows.

2.11.2. Effect of Plant Density on Yield and Yield Component

The spatial distribution of plants in a crop community is an important determinant of yield Egli, D.B., (1988) and many experiments have been conducted to determine the spacing between rows and between plants within the row that maximizes yield. 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. Secondly, equidistant spacing between plants affected interplant competition Johnson,. Green and C.W. Jordan, (1982). Hence, it will be imperative to adjust the spatial distribution of the recommended population in order to have maximum yield.

According to the study conducted by Alemayehu, (2016) respective increase in inter-row and intra-row spacing from 20 to 40 cm and 10 to 15 cm increased days to 90% physiological maturity. Similar study conducted by Valimohammadi *et al*; (2007) who reported as there is a steady increase in the number of days to maturity with increased intra-row spacing.

The study done by (Mureithi *et al*., 2012) revealed that higher plant height at narrow spacing could be explained that when the plants are sown closely, their stems are shaded from light resulting in accumulation of auxin (a growth hormone) that stimulates cell division and elongation of internodes, thereby increase in height. While, in widely spaced plants, auxin destruction by light occurs resulting in plants being shorter in height.

The findings of Tuarira M, *et al* (2014) indicated that the highest number of branches (8.56) on the lowest population of 125,000 plants ha^{-1} and the lowest (5.45) on the highest plant population of 320,000 plants ha^{-1} of green bean. Higher number of branches with increasing spacing could possibly be due to less competition between plants in the wider plant spacing for soil nutrients and moisture. Besides, higher number of branches with increasing intra-row spacing reflects that wider plant spacing encouraged lateral growth (branching) but not apical growth, and the vice versa.

The research result of, Mtaita and Mutetwa (2014) indicated that lower plant population of 125,000 plants ha-^{1} had the highest number of branches plant-^{1} than higher population of 320,000 plants ha-^{1}.

Chandhla J, (2005). Reported that the highest number of pods per plant (7.2) at 40 cm inter row spacing and the lowest (5.0) at narrowest spacing of 20 cm of dry bean (*Phaseolus vulgaris* L). Likewise, Abubaker S, (2008) reported that wider row spacing of 60 cm gave significantly higher number of pods compared to 30 cm row spacing in common bean.

The finding of Khalil SK *et al*., (2010) also revealed that increase in number of pods with increase in the row spacing because lower populations are more efficient in utilizing the resources of production than the higher plant densities.

Melaku B, (2012) obtained the highest number of seeds per pod (5.9) at the lowest plant population of 133, 333 plants ha-^{1} and the lowest seeds per pod (5.6) at the highest plant population of 333,333 plants ha-^{1} of common bean. The research result of Osman AA, (2010) indicated that the increase on the number of seeds per pod with increase in plant spacing to more nutrients available for fewer plants at lower plant density.

The research result of Osman AA, (2010) indicated that the increase on the number of seeds per pod with increase in plant spacing to more nutrients available for fewer plants at lower plant density.

The research result obtained by Melaku B, (2012) showed that the highest hundred seed weight of 27.47 g at the lowest plant population of 133, 333 plants ha^{-1} and the lowest 24.99 g at the highest plant population of 333,333 plant ha^{-1} of common bean.

Similarly, Amany MA (2014) reported that the increase of planting density from 25 to 33 plant m^{-2} increased plant height while decreased number of branches per plant, number of pods per plant, number of seeds per plant, hundred seed weight and seed yield per plant.

Aslam M *et al* (1993) found that narrow inter-row spacing (30 cm) gave the highest seed yield as compared to wider spacing of 45 and 60 cm on soybean. Sparse plant population with wider spacing results in higher yield per plant but lower yield per unit area.

Kazemi E, *et al* (2012) obtained the highest grain yield (2393 kg ha^{-1}) from plant density of 13 plants m^{-2} and lowest grain yield (2010 kg ha^{-1}) from 22 plants m^{-2} of white beans (*Phaseolus vulgaris* L.)

According to the research result of , Mekonnen SA (2012) highest seed yield per plant with the minimum plant population (150000 plants ha^{-1}) and lowest seed yield per plant with the highest plant population (350000 plants ha^{-1}) of common bean .

Norman (1963) reported that both too narrow and too wide spacing do affect grain yields through competition (for nutrients, moisture, air and radiation, etc) and due to the effect of shading. In the later case (too wide spacing), yield reduction can occur due to inefficient utilization of the growth resources. Normally, as population increases yield also increases proportionally. After, it reached a certain level the yield declines. Singh and Singh (2002) reported that establishment of optimum density per unit area is essential to get maximum yield. Under conditions of sufficient soil moisture and nutrients, higher density is necessary to utilize all the growth factors efficiently. Each growth factor for which the plant competes has limitation to support a crop beyond the optimum plant density level per unit area. The level of plant density should be such that maximum solar radiation is utilized. The full yield potential of an individual plant is fully exploited when sown at wider spacing.

Plant population can be defined as the number of plants per a given known area of land. Optimum numbers of plants are required per unit area to utilize efficiently the available production resources such as water, nutrients, light and carbon dioxide. Maximum productions are obtained from plant populations, which do not allow plants to achieve their individual maximum potential when they are sown at wider spacing. Population density is also dependent on the moisture availability and nutrient status of the soil. Hence, optimum planting density should be determined through research works (Solomon, 2010).

Kueneman (1978) reported that the low plant population tended to enhance vegetative growth of dry bean plant resulting in the development of large leaf area compared to the high and moderate plant populations resulting in sink limitation to photosynthesis.

Costa *et al.,* (1980) and Solomon (2010) indicated that in common bean leaf area index increased as plant population increase. Martin *et al.,* (2006) indicated that the objective of spacing in crop plants is to obtain the maximum yield on a unit area without sacrificing quality. If the plant population is too high, plants will be tall, spindly, and more susceptible to lodging. Yield may decrease because lodging will be resulted in difficulty of harvesting activities, greater harvest loss, disrupts the leaf canopy and often limits grain development and yield. If plant population is too low, there will be fewer plants to contribute to the yield and weeds will be a greater risk. At higher plant population soybean will produce fewer pods per plant and fewer seeds per pod.

The finding of Loss *et al.,* (1998) showed that high sowing rates resulted in significantly earlier canopy closure, larger leaf area index, more radiation absorption and dry matter accumulation particularly during the early vegetative stages than in treatments where a low plant density was established in common bean. The lower plant density tended to enhance vegetative growth of the plant resulting in the development of large leaf area. This could most likely be due to more availability of growth factors and better penetration of light, consequently increased number of leaves produced and the size of individual leaves in plants as a result LAI increased.

According to Donald (1963), as the number of plants per unit area increased, competition for growth resources such as nutrients, water and light also increased. Yield response of different plant cultivars to plant spacing need to be known for practical purposes, as planting density is a major management variable used in matching crop requirements to the environmental offer of resources (Smith and Hamel, 1999). Production and productivity of the crop is governed by environmental, genotypic trait of the crop and crop management. Determining appropriate crop geometry is therefore one of the most important crop management activities which improves the performance and productivity of plants (Solomon, 2010).

According to Wilson and Teare (1972) mutual shading of leaves is considered undesirable. It reduce yield directly by reducing light available for photosynthesis and indirectly by allowing light energy to pass directly to the soil, where it may be dissipated as latent heat removing water from the root zone. The spatial distribution of plants in a crop community is an important determinant of yield (Egli, 1988) and many experiments have been conducted to determine the spacing between rows and between plants within the row that maximizes yield. 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 produce enough leaf area to provide maximum light interception during reproductive growth and the second concept could be the spatial distribution of plants within the area as a result of optimum spacing as this determines yield per given area (Tanner and Hume, 1978; Johnson *et al.*, 1982). Hence, it will be imperative to adjust the spatial distribution of the recommended population in order to maximum yield.

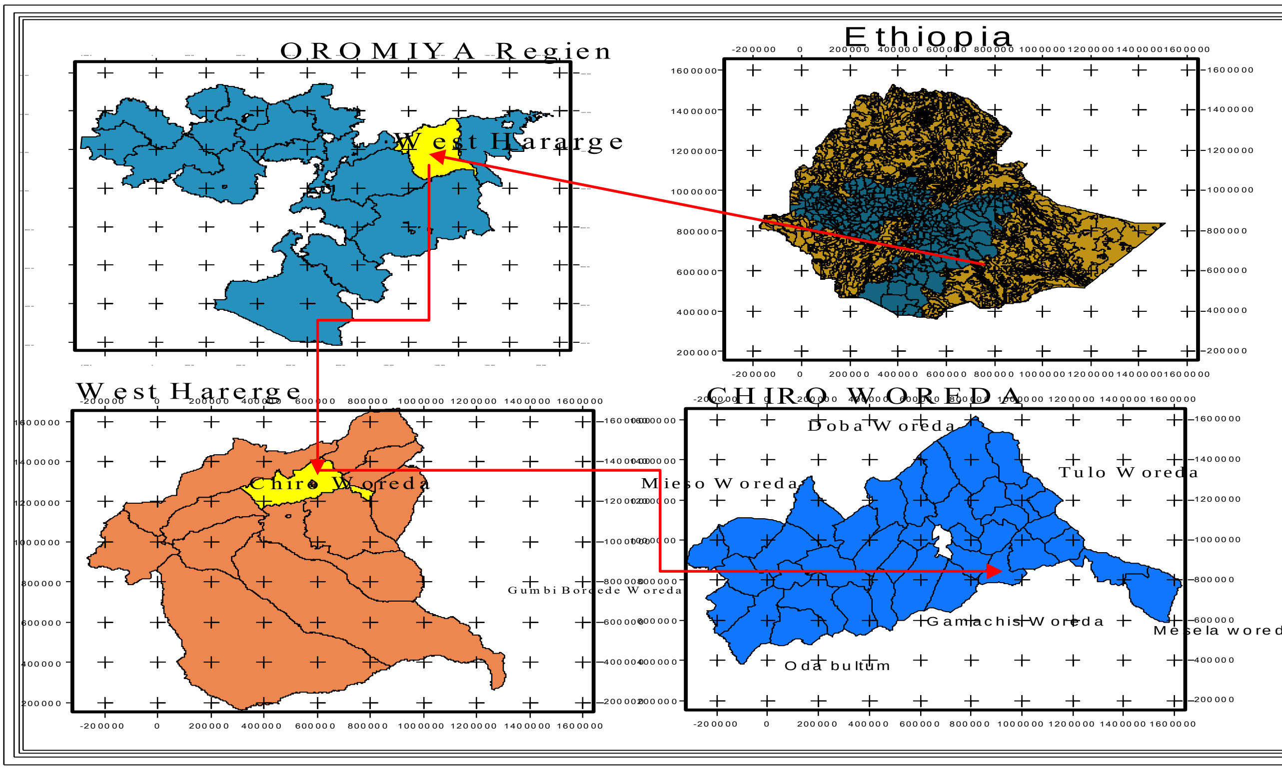
The spatial distribution in a crop community is important determinant of yield. Many experiments have been conducted to determine the spacing between rows and between plants within the rows that maximizes yield. Different experiments were conducted on the spacing of different pulse crops to determine the optimum spacing that would be resulted in optimum population density of such crops. Based on size of the seed, research results indicated that the recommended seed rate for chickpea in Ethiopia ranges from 60-140 kg ha-^{1} (EARO, 2004).

Thus for proper light interception, at various growth stages, optimum plant population is necessary. This indicates establishment of optimum population per unit area of the field is essential to get maximum yield. Under conditions of sufficient soil moisture and nutrients, higher population is necessary to utilize all growth factors. The level of plant population should be such that maximum solar radiation is efficiently utilized. The full yield potential of an individual plant is fully exploited when sown at wider spacing (Solomon, 2010)

3. MATERIALS AND METHODS

3.1. Description of the Study Area

A field experiment was conducted at Arberekete Farmers Training Center (FTC), of Chiro District in West Harangue Zone, Oromia Regional State, during the '*meher'* season from July to October, 2019. The experimental site was located at 335 km in the east of Addis Ababa and 9 km from the capital of West Hararghe Chiro Town. Geographically, the study area is situated at 9°02'51.7.7"N latitude and of- 40°54'47. 0"E longitude and has an altitude ranging from 1501 to 2996 meters above sea level. The District receives annual rain fall ranging from 900-1800 mm and has mean minimum and maximum temperature of 17.5°C and 27.5°C degree Celsius respectively. Source (Chiro District Agricultural and Natural Resource Office).The dominant crop cultivated in the study area includes Sorghum, Maize, Wheat and Common bean**.** The soil type of the study area is clay loam and its map shown as follows.



Legend

West Harerghe . Shp
Ethiopia Map
Oromia Map .Shp

Arberekete PA

3.2. Planting Material and Treatments

3.2.1. Planting material

A Common bean variety called Dursitu was used. The description of the variety is indicated in Table 1.

Table1: Description of common bean Dursituvariety used for the study:

Characteristics	
Year of release:	2008
Adaptation	1600- 2200m.a.s.l
Seed Size	Small
Seed Color	Red
Days to maturity	105
Sowing time:	Mid June to early July
Rain fall adaptation (mm)	500-1500
Yield on station (t/ha)	2.4 -4.0t/ha
Yield on farmers field (t/ha)	1.8-3.0t/ha
Breeding Center	Haramaya University
Resistant to	ALS (Angular leaf spot) Rust HB (Halo blight)
Seed source	Haramaya University low land pulse research programme

Source: Haramaya University lowland Pulse Research programmers

3.2.2. Treatments and experimental design

The experiment consisted of four inter row spacing (20, 30 cm, 40 cm and 50 cm) and four intra row spacing (5 cm, 10 cm and 15 cm 20 cm). The treatments were arranged in a factorial combination using randomized complete block design (RCBD) with three replications where a total of sixteen treatment combinations were obtained (Table 2). Each block (replication) consisted 16 treatments resulted in total of 48 treatment combinations/plots. The width of the plot varied based on inter-row spacing and it was 2.4, and 2.5 m for inter- row spacing of 20, 30 ,40 cm and 50cm respectively. However, the length of the plot was 3 m for all the plots. The distance between two blocks and plots were 1 m and 0.5 m respectively.

The net area from where data were collected and the detail of treatment combination was given in table 2 below.

Table2: Description of the treatment combinations of the experiment.

No	Inter×Intra row combinations	Net- plot size (m^2)	Total number of rows/plo	Net- plot size (m^2)	Harvested rows/plo	Harvestable Area (m^2)	Plant population/ ha
1	20 cm x 5 cm	7.2	12	7.2	8	4.64	1,000,000
2	20 cm x 10 cm	7.2	12	7.2	8	4.48	500.000
3	20 cm x 15cm	7.2	12	7.2	8	4.32	333,333
4	20 cm x 20 cm	7.2	12	7.2	8	4.16	250,000
5	30 cm× 5 cm	7.2	8	7.2	6	5.22	666,000
6	30 cm×10 cm	7.2	8	7.2	6	5.04	333,000
7	30 cm×15 cm	7.2	8	7.2	6	4.86	222,000
8	30 cm× 20 cm	7.2	8	7.2	6	4.68	166,500
9	40 cm× 5 cm	7.2	6	7.2	4	4.64	500,000
1	40 cm×10 cm	7.2	6	7.2	4	4.48	250,000
1	40 cm×15 cm	7.2	6	7.2	4	4.32	166,666.7
1	40 cm×20 cm	7.2	6	7.2	4	4.16	125,000
1	50 cm× 5 cm	7.5	5	7.5	3	4.35	400,000
1	50 cm×10 cm	7.5	5	7.5	3	4.2	200,000
1	50 cm×15 cm	7.5	5	7.5	3	4.05	133,400
1	50 cm×20 cm	7.5	5	7.5	3	3.9	100,000

3.3. Experimental Procedure and Crop Management

The land was plough and disked by a tractor, and leveled manually and layout was prepared against soil fertility gradient and slope. The field layout was, divided in to blocks, and again each blocks divided into plots.

The spacing between blocks and plots was 1.0 m and 0.5 m, respectively. Treatments (inter and intra row spacing) were randomly allocated to all plots in each replication. Seed of Dursitu common bean variety was obtained from Haramaya Universi low land Research outreach programmed and sowed in end of June 28 / 2019 at the depth of about 5 cm. Two seeds per hole were sown and thinned one plant per hill a week after emergence throughout the plots.

The recommended rate of Urea (50 kg ha^{-1}) and NPS (100 kg ha-^{1}) were applied as the sources of N and P; respectively, during planting. All other necessary agronomic management practices were carried out uniformly as per the research recommendation.

3.4. Data Collection

3.4.1. Phenological parameters***:***

Days to 50% emergence: Was recorded as the number of days from sowing to when 50% of plants were emerged in each plot.

Days to 50% flowering: Was recorded as the number of days from planting to when 50% of the plants produced flower.

Days to 90% physiological maturity: Was recorded as the number of days from planting to when 90% of the plants in each plot showed yellowing of pods.

3.4.2. Growth Parameters

Plant height: Was measured from 10 randomly selected plants from the ground level to the apex of each plant at the time of physiological maturity from the net plot area using a measuring tape.

Number of primary branches: All branches arising from the main stem was counted at the time of maturity from 10 randomly selected plants found in net plot and the average was recorded.

3.4.3. Yield components and yield:

Stand Count at Harvest: Final plant stand count was taken from net plot areas when the plants attained harvest maturity and converted to hectare, and then the percent mortality was calculated to determine the change in stand count due to competition effect.

Number of pods per plant: Total number of seed bearing pods on each plant was counted from 10 randomly selected plants found in net plot at maturity and the average was recorded.

Number of seeds per pod: The total number of seeds per pod was averaged from 10 randomly selected plants in each net plot by counting all the number of seeds for each plant

Hundred seed weight (g): Was counted by taking sample seeds randomly per net plot area at harvest and the weight of hundred seeds was taken and adjusted to 10% moisture level.

Seed yield (kg/ha): seeds harvested from the net plot area were dried for 5 to 6 days in sun and were cleaned, weighed and converted in to seed yield in kg ha^{-1}.The weight was adjusted to 10% moisture level.

3.4.4. Statistical Data Analysis

All measured data were subjected to analysis of variance (ANOVA) following the appropriate statistical procedure described for factorial experiment in RCBD according to the Gen-State version 18 and interpretations were made following the procedure described by Gomez and Gomez (1984). Whenever the effects of the factors were found to be significant, the means were compared using the least significant differences (LSD) test at 5% level of significance.

4. RESULTS AND DISCUSSION

4.1. Phenological Parameters of Common Bean

4.1.1. Days to 50% flowering

The main effect of inter- and intra- row spacing showed significant ($P<0.01$) effect, while their interaction had no significant effect on days to 50% flowering (Appendix Table 1).

Days to 50% flowering was delayed (63.00 days) and hastened (57.50 days) under 50 and 20 cm inter-row spacing respectively. Similarly, days to 50% flowering delayed (61.00 days) and hastened (58.17 days) under 20 cm and 5 cm intra-row spacing respectively. There was no significant difference between 20 and 30 cm inter-row spacing and 10 and 15 cm intra row spacing. (Table 3)

The upper result to the fact that wider inter and intra-row spacing allowed a better light interception as compared to the narrower inter and intra-row spacing resulting in more number of days to reach to 50% flowering stage as common bean needs direct sunlight coverage for its various physiological process. This indicates surface area available in wider row spacing might have caused the crop to flower late as compared to those crops planted in relatively closer spacing. On the other hand, the hastened time of flowering in narrower inters and intra-row spacing might be due to higher competition for nutrients, moisture and space.

4.1.3. Days to 90% physiological maturity

The analysis of variance showed significant ($P<0.01$) effect of inter- and intra- row spacing on days to physiological maturity while their interaction effect was non-significant (Appendix Table 1).

Days to 90% physiological maturity was delayed (85.5 and 84.42 days) under 50 cm inter- and 20 cm intra-row spacing respectively. While it was hastened (82.42 and 83.08 days) under 20 cm inter-row and 5 cm intra-row spacing respectively.

There was no significant difference between 40 and 50 cm inter-row spacing and among 10, 15 and 20 cm intra-row spacing on days to physiological maturity.

These results were in accordance with Valimohammadi *et al*. (2007) who reported a steady increase in the number of days to maturity with increased intra-row spacing.

Similar study conducted by Alemayehu, (2016) indicated a respective increase in inter-row and intra-row spacing from 20 to 40 cm and 10 to 15 cm increased days to 90% physiological maturity.

Table 3: Main effect of inter and intra row spacing on days to emergence, flowering and Physiological Maturity.

Treatment	Days to 50% emergence	Days to 50% flowering	Days to 90% physiological
	Inter row spacing (cm)		
20	9.308^{a}	57.50^{a}	82.42^{a}
30	9.292^{a}	58.00^{a}	82.83^{a}
40	9.367^{a}	61.17^{b}	85.25^{b}
50	9.300^{a}	63.00^{c}	85.50^{b}
LSD (0.05)	Ns	0.592	0.4942
	Intra row spacing (cm)		
5	9.300^{a}	58.17^{a}	83.08^{a}
10	9.292^{a}	60.25^{b}	84.25^{b}
15	9.300^{a}	60.25^{b}	84.25^{b}
20	9.375^{a}	61.00^{c}	84.42^{b}
LSD (0.05)	Ns	0.592	0.4942
CV (%)	**1.2**	**1.2**	**0.7**

Means in columns followed with the same letter (s) are not significantly different to each other at 5% probability level of significance; ns: Non-significant, LSD (0.05): Least Significant Difference at 5%; CV: Coefficient of Variant

4.2. Growth Parameter

4.2.1. Plant height

The Analysis of Variance (ANOVA) result showed highly Significant differences ($p < 0.001$) in plant height among inter and intra row spacing (Appendix Table 1), and plant height decreased significantly with increasing inter and intra-row spacing (Table 4). Maximum plant height (59.03 cm) was produced in the interaction of 20 x 5 cm spacing followed by 58.77 cm in the interaction of 20 x10 cm spacing, whereas minimum plant height (50.83) was recorded from the interaction of 50 x 20 cm spacing (Table 4). Both narrow inter and intra row spacing (20 x 5 cm and 20 x10 cm) significantly enhanced the plant height over the others.

The present study is in agreement with the study done by Mureithi *et al*., (2012) revealed that higher plant height observed at narrow spacing could be explained as that when the plants are sown closely, their stems are shaded from light resulting in accumulation of auxin (a growth hormone) that stimulates cell division and elongation of internodes, thereby increase in height. While in widely spaced plants, auxin destruction by light occurs resulting in shorter plants in height. In line with this, Kumar *et al*., (1997) and Pawar *et al*., (2007) also reported increase in plant height in densely planted French beans. Contrary to our results, the study by Solomon (2003) indicated that plant height was not significantly affected by intra-row spacing. Decrease in plant height at wider spacing might also be due to excessive branching, and this tends to encourage lateral growth while suppressing apical growth.

Table 4: Interaction effect of inter and intra row spacing on Plant Height

	Intra row spacing (cm)			
Inter row spacing (cm)	5	10	15	**20**
20	59.03^{g}	58.77^{g}	58.33^{g}	57.87^{fg}
30	57.00^{efg}	55.37^{cdef}	54.40^{cde}	53.57^{abc}
40	56.73^{def}	54.63^{cde}	54.20^{bcd}	52.90^{abc}
50	54.50^{cde}	51.47^{ab}	51.00^{a}	50.83^{a}
LSD (0.05) Inter×Intra row spacing= 2.744 CV (%) =				

Means in columns followed with the same letter (s) are not significantly different to each other at 5% probability level of significance;, LSD (0.05): Least Significant Difference at 5%; CV: Coefficient of Variations

4.2.2. Number of primary branches

The result of analysis of variance (ANOVA) revealed that, the main, interaction effect of inter and intra row spacing was highly significant (P<0.001) on number of primary branches per plant (Appendix Table 1).

The highest number of primary branches per plant of 4.5 was recorded from combination of the widest inter and intra row spacing of 50 cm with 20 cm followed by 4.47 the inter and intra row spacing combination of 50 cm with 15 cm while the lowest number of branches (3.03) was recorded at the combination of the narrowest inter row (20 cm) and intra row (5 cm) spacing (Table 5).

The narrowest inter and intra row spacing combination resulted in the lowest number of primary branches per plant than wider spacing. The increased numbers of branches at the wider inter and intra row spacing could be attributed to more interception of sunlight and nutrients that favored formation of auxiliary buds and differentiation leading to higher number of branches per plant.

Higher number of branches with increasing spacing could possibly be due to less competition between plants in the wider plant spacing for soil nutrients and moisture. Besides, higher number of branches with increasing intra-row spacing reflects that wider plant spacing encouraged lateral growth (branching) but not apical growth, and the vice versa.

Lower plant population of 125,000 plants ha-^{1} had the highest number of branches plant-^{1} than higher population of 320,000 plants ha-^{1} (Mtaita and Mutetwa (2014); Tuarira M; *et al* (2014). This result is in agreement with the works of Pawar *et al*. (2007) and Mureithi *et al*. (2012) who reported an increased in branch per plant increased spacing in haricot bean and French bean, respectively.

. Table 5: Interaction effect of inter and intra row spacing on number of primary branches per plant

	Intra row spacing (cm)			
Inter row spacing (cm)	**5**	**10**	**15**	**20**
20	**3.03^{a}**	**3.167^{b}**	**3.267^{bc}**	**3.367^{cd}**
30	**3.200^{b}**	**3.33^{cd}**	**4.267^{g}**	**4.367^{gh}**
40	**3.367^{cd}**	**3.867^{e}**	**4.267^{g}**	**4.467^{hi}**
50	**3.433^{d}**	**4.000^{f}**	**4.33^{g}**	**4.500^{I}**
LSD (0.05) = 0.10268		**CV (%) = 1.6**		

Means in columns followed the same letter (s) are significantly different to each other at 5% probability level of significance ,LSD (0.05): Least Significant Difference at 5% :CV: Coefficient of Variation

4.3. Yield and Yield Components

4.3.1. Stand count at harvest

The analysis of variance (ANOVA) indicated that the main effect of intra-row spacing showed highly significant (P<0.001) effect while the inter-row spacing and interactions had no significant effect on stand count at harvest (Appendix Table 1).

This showed that the competition among the plants grown under varying plant population/densities had no remarkable effect on the survival of the plants at harvest.

The result showed as intra-row spacing increased from 5 to 15 cm stand count at harvest was increased from 87.5 % to 94.44. Similarly, stand count at harvest increased from 88.6% to 93.75% as intra-row spacing increased from 10 to 20 cm (Table 6). This indicates that increasing the spacing between plants within rows has a positive effect on stand count at harvest. The result also indicated that there is statistical parity between 5 and 10 cm and also 15 and 20 cm intra-row spacing in terms of stand count at harvest.

Higher number of survival rate of plants during stand count with increasing intra row spacing could possibly be due to less competition between plants in the wider plant spacing for soil nutrients, sunlight and moisture. On the other hand higher number of mortality rate of plants with decreasing intra-row spacing could possibly due to higher competition between plants in the narrower plant spacing for soil nutrients, sunlight, moisture and lodgings due to the high rain fall during the cropping season.

The current study was agreed with that of Melak (2018) who reported increased percent of stand count as intra-row spacing increased from 5 to 15 cm.

Table 6: Main effects of intra-row spacing on stand count at harvest.

Treatment	Stand Count at Harvest (%)
Intra row spacing (cm)	
5	87.5
10	88.6
15	93.75
20	94.44
CV (%)	41.7
LSD (0.05)	**74.7**

Mean values within columns followed by the same letters are not significantly different from each other; CV= Coefficient of Variation, LSD = Least Significant Difference at 5% level;.

4.3.2. Number of pods per plant:

The Analysis of Variance (ANOVA) result showed that the main effect of inter row spacing and intra row spacing was found highly significant on pods per plant ($P<0.01$). And also the interaction effects were highly significant ($P<0.01$) (Appendix Table 2).

Wider inter row spacing (50 cm) resulted in higher pods per plant (40.71) than narrow inter row spacing of (20 cm) with 28.43 pods per plant. Similarly, wider intra row spacing of (20 cm) resulted in higher number of pods per plant (37.86) which was statistically at parity with intra row spacing of 15 cm (35.99) than closely spacing of 5 cm with 31.62 pods per plant (Table 7).

In general, as row spacing decreases, the number of pods per plant decreases due to increasing population and resource competition. The number of pods per plant is directly related to the number of primary branches per plant. This might be due to the fact that lower resources (nutrients, light and soil moisture) for narrow row spacing resulted in few lateral branching and pod initiation due to its higher population with closely planting which have nutrient scarcity for sink formation.

This result is in conformity with the works of Mtaita and Mutetwa (2014) who reported an increased pod number and dry weight of haricot bean at the wider intra-row spacing (30 cm), as compared to closer spacing (22 cm). Also, a higher value of pod number was reported in a green bean sowed at the lower planting densities as compared to higher planting density. However, this result contradicted the findings of Khalil *et al*. (2010) and Solomon (2003) who reported that pod number plant-1 is significantly reduced with the increase in plant densities. Likewise, Abubaker S, (2008) reported that wider row spacing of 60 cm gave significantly higher number of pods compared to 30 cm row spacing in common bean. Similarly, Chandhla J (2005) reported that the highest number of pods per plant (7.2) at 40 cm inters row spacing and the lowest (5.0) at narrowest spacing of 20 cm of dry bean (*Phaseolus vulgaris* L) and also the present finding is in line with Khalil SK *et al*., (2010). Bakry BA *et al*. and Singh SP *et al*., (2010) observed increase in number of pods with increase in the row spacing because lower populations are more efficient in utilizing the resources of production than the higher plant densities.

Table 7: Main effect of inter and intra row spacing on number of pods per plant of common bean.

	Inter row spacing (cm)	
	20	**28.43[a]**
	30	**33.59[b]**
	40	**38.66[c]**
	50	**40.71[d]**
CV (%)		**5.3**
LSD (0.05)		**1.552**
	Intra row Spacing	
	5	**31.62[a]**
	10	**35.93[b]**
	15	**35.99[b]**
	20	**37.86[c]**
CV (%)		**5.3**
LSD (0.05)		**1.552**

Means in columns followed with the same letter (s) are not significantly different to each other at 5% probability level of significance;, LSD (0.05): Least Significant Difference at 5%; CV: Coefficient of Variation

4.3.3. Number of seeds per pod:

The interaction effect of inter and intra row spacing was highly significant ($P<0.001$), on number of seeds per pod (Appendix Table 2).

The numbers of seeds per pod scored under wider inter and intra row spacing of 50 cm x 20 cm was 6.93, which were the highest as compared to the other row spacing (Table 8). The number of seeds per pod decreased with decreasing row spacing. This might be due to the fact that closely spaced plants encountered more inter plant competition for resources which reduced the number of seeds per pod.

In agreement with this result, Melaku B, (2012) obtained the highest number of seeds per pod (5.9) at the lowest plant population of 133, 333 plants ha-^{1} and the lowest seeds per pod (5.6) at the highest plant population of 333,333 plants ha-^{1} of common bean.

. Similar, Chandhla J , (2005) reported that the highest number of seeds per pod (3.7) at the widest inter and intra-row spacing of 20 cm×30 cm and lowest (3.2) at the narrowest row spacing of 20 cm×15 cm on dry bean.

Table 8: Interaction effect of inter and intra row spacing on number of seed per pod.

	Intra row spacing (cm)			
Inter row spacing (cm)	5	10	15	20
20	4.53[a]	4.67[abc]	4.90[cd]	5.00[de]
30	4.63[ab]	4.80[bcd]	6.50[ij]	6.50[ij]
40	5.17[ef]	5.37[f]	6.10[h]	6.73[jk]
50	5.37[f]	5.77[g]	6.33[hi]	6.93[k]
LSD (0.05) = 0.2436 CV (%) = 2.6				

Means in columns followed with the same letter (s) are not significantly different to each other at 5% probability level of significance; ns: Non-significant, LSD (0.05): Least Significant Difference at 5%; CV: Coefficient of Variation.

4.3.4. Hundred Seed Weight

The Analysis of Variance (ANOVA) result showed that the main effect of inter row spacing and intra row spacing was found highly significant ($P<0.001$). (Appendix Table 2) Wider inter and intra row spacing of 50 cm and 20 cm resulted in higher hundred seed weight of 24.47and 24.29 g, respectively, than narrow inter and intra row spacing of 20 cm and 5 cm with 22.95g and 22.95 g hundred seed weight, respectively (Table 8).

Higher hundred seed weight was recorded for lower plant populations of wider inter and intra row spacing, than denser plant population with narrow inter and intra row spacing. This might be due to enough growth resource availability under wider inter and intra row spacing that converted biological yield to economic yield and stored in seed yield. In addition, in wider spaced plants, the improved supply of assimilates to be stored in the seed, hence, the weight of hundred seeds increased.

The result of this study was agreed with the result obtained by Melaku B, (2012) who obtained the highest hundred seed weight of 27.47 g at the lowest plant population of 133, 333 plants ha^{-1} and the lowest 24.99 g at the highest plant population of 333,333 plant ha^{-1} of common bean. Similarly, Amany MA (2014) reported that the increase of planting density from 25 to 33 plant m^{-2} increased plant height while decreased the number of branches per plant, number of pods per plant, number of seeds per plant, hundred seed weight and seed yield per plant.

Table 9: Main effect of inter and intra row spacing on 100 Seed Weight g of common bean.

	Inter row spacing (cm)	
	20	22.95[a]
	30	23.55[ab]
	40	23.91[bc]
	50	24.47[c]
CV (%)		**3.2**
LSD (0.05)		**0.629**
	Intra row spacing (cm)	
	5	22.95[a]
	10	23.68[b]
	15	23.96[b]
	20	24.29[b]
CV (%)		**3.2**
LSD (0.05)		**0.629**

Means in columns followed with the same letter (s) are not significantly different to each other at 5% probability level of significance:, LSD (0.05): Least Significant Difference at 5%; CV: Coefficient of Variation

4.3.5. Grain yield:

The interaction effect of inter and intra row spacing was highly significant (P<0.001), on grain yield ha-^{1}(Appendix Table 2). The analysis of variance (ANOVA) revealed that the highest grain yield of 3.66 tones ha^{-1} was recorded under the interaction of inter and intra row spacing of (40 cm x 10 cm) to be followed by 2.68 tone ha-^{1} with the combination of 30 cm with 15 cm the inter and intra row spacing; while the lowest grain yield of 1.73 tone ha-^{1} was recorded at the combination of the widest inter row (50 cm) and intra row (20 cm) spacing (Table 10). This indicated as the row spacing increased above the optimum the grain yield was decreased. This might be the optimum plant stand at dense population contributes to high grain yield and effective light interception than sparse population.

The result of this study was agreed with the result obtained by Kazemi E, *et al* (2012) obtained the highest grain yield (2393 kg ha^{-1}) from plant density of 13 plants m^{-2} and lowest grain yield (2010 kg ha^{-1}) from 22 plants m^{-2} of white beans (*Phaseolus vulgaris* L.)

Sparse plant population with wider spacing results in higher yield per plant but lower yield per unit area. This was also in agreement with the study of Ball RA, *et al* (2000) who reported that increasing plant population reduced yield of individual plants but increased yield per unit area of common bean.

The research finding of Mekonnen SA (2012) revealed that highest seed yield per plant with the minimum plant population (150000 plants ha^{-1}) and lowest seed yield per plant with the highest plant population (350000 plants ha^{-1}) of common bean.

Table 10: Interaction effect of inter and intra row spacing on Grain yield tone ha^{-1}.

	Intra row spacing (cm)			
Inter row spacing (cm)	5	10	15	**20**
20	1.73^{de}	1.83^{ef}	1.94^{f}	**2.07^{g}**
30	1.73^{de}	1.85_{ef}	2.68^{j}	**2.11^{gh}**
40	2.13^{gh}	3.66^{k}	2.39^{i}	**2.20^{h}**
50	1.61^{bc}	1.67^{cd}	1.53^{ab}	**1.49^{a}**
LSD (0.05) =0.115	**CV (%) = 3.4**			

Means in columns followed with the same letter (s) are not significantly different to each other at 5% probability level of significance; ns: Non-significant, LSD (0.05): Least Significant Difference at 5%; CV: Coefficient of Variation**.**

5. SUMMARY AND CONCLUSION

Low yield of common bean in Ethiopia is attributed to several production constraints which include lack of seeds of improved varieties for the agro-ecological zones, poor cultural practices such as untimely and inappropriate field operations, use of inappropriate plant density, weed infestation, low soil fertility, moisture stress, diseases and insect pests. Increase in yield of common bean can be ensured, by maintaining appropriate plant population through different planting patterns.

The results of the current study showed that days to 50% flowering and days to physiological maturity were significantly affected by both inter- row and intra- row spacing. Both days to 50% flowering and 90% physiological maturity were delayed due to inter-row spacing of 50 cm (63 days and 85.5 days) and intra-row spacing of 20 cm (61.00 and 84.42 days).

However, days to 50 % flowering was hastened (57.50 days) due to 20 cm inter-row spacing while days to 90% physiological maturity was hastened (82.42 days) at 20 cm inter-row spacing. Likewise, both days to 50% flowering and 90% physiological maturity were hastened due to intra-row spacing of 5 cm (58.17 and 83.08 days). This indicates that wider spacing (50 cm inter- and 20 cm intra-row spacing) delayed flowering and maturity while narrow spacing (20 cm inter- and 5 cm intra- row spacing) hastened flowering and maturity of common bean.

Intra-row and inter-row spacing were highly significantly affected the plant height. Plants were significantly taller at the narrowest combination of inter and intra row spacing of 20 cm and 5 cm (59.03 cm) than the wider inter-and intra row combination of 50 cm and 20 cm(50.83 cm)

Inter-row and intra-row spacing and their interactions showed highly significant effect on the number of primary branches per plant. The highest (4.5) number of primary branches per plant was due to 50 cm inter- row with 20 cm intra-row spacing while the lowest (3.033) number of primary branches per plant was due to 20 cm inter- row with 5 cm intra-row spacing.

Stand count at harvest was significantly affected only by intra-row spacing. As intra-row spacing increased from 5 to 15 cm stand count at harvest was increased from 87.5% to 93.75% .

Similarly, stand count at harvest was increased from 88.6% to 94.44 % as intra-row spacing increased from 10 to 20 cm (Table 6). The result also indicated that there is statistical parity between 5 and 10 cm and also 15 and 20 cm intra-row spacing in terms of stand count at harvest. The result indicates that increasing the spacing between plants within rows has a positive effect on stand count at harvest.

Number of pods per plant and number of seeds per pod were significantly affected by inter-row and intra-row spacing and their interactions. The highest (40.71) number of pods per plant were due to the widest inter row spacing of 50 cm and the lowest (28.43) number of pod per plant were due to the narrowest intra row spacing of 20 cm and the highest (37.86) number of pods per plant were due to the widest intra row spacing of 20 cm and the lowest (31.62) number of pod per plant were due to the narrowest intra row spacing of 5 cm.

Similarly the highest (6.933) number of seeds per pod were due to 50 cm inter-row with 20 cm intra-row spacing. This indicating that wider (50 cm inter- and 20 cm intra-row) spacing produces many pods per plant and seeds per pod than narrower spacing. The lowest (4.533) number of seed per pod was due to 20 cm inter-row with 5 cm intra-row spacing.

Hundred seed weight was significantly affected by inter- and intra-row spacing, but not by their interactions. In terms of inter row spacing, the highest (24.47 g) hundred seed weight was recorded with 50 cm, and the 20 cm intra- row spacing gave the highest (24.29 g) hundred seed weight. The lowest (22.95 and 22.95 g) HSW was recorded with 20 cm inter- row and 5 cm intra- row spacing respectively.

Seed yield was highly and significantly affected by the main effects of inter- and intra-row spacing and their interactions. The highest (3.661 tone ha-^{1}) seed yield was due to 40 cm inter-row with 10 cm intra-row spacing followed by (2.683) tone ha-^{1} was recorded with the inter and intra row spacing combination of 30 cm with 15 cm. The lowest (1.487[a] tone ha-^{1}) seed yield was due to 50 cm inter-row with 20 cm intra-row spacing.

In conclusion both too narrow and too wide spacing do affect grain yields. In the first case (too narrow spacing) affect the grain yield through competition for nutrients ,moisture, sun light and air etc and due to the effect of stem shading. In the later case (too wide spacing), yield reduction can occur due to inefficient utilization of growth resources and more land was left without covering by the crop plants and the weeds may get a chance. On the other hand when the plants grown in the wider spacing increases the yield and yield components per individual crop plants but decreases the yield and the yield components per a given unit area of lands.

Normally , as plant population increases yield also increases proportionally but ,after plant population reached a certain level the yield was declines. Maximum productions are obtained from plant populations which do not allow plants to achieve their individual maximum potential when they are sown at wider spacing. So optimum numbers of plants are required per unit area to utilize efficiently the available production resources.

Generally the results of this study were agreed and confirmed that of the national recommendation of the combination of 40 cm inter row and 10 cm intra row spacing is better yielding than the other spacing. On the other hand the better yield was obtained from the combination of 30 cm inter row spacing and 15 cm intra row spacing were better yielding and recommended by this study next to the national recommendation for the study area.

However, this tentative generalization based on one season, using one variety at one location requires confirmation with further studies over years, locations and different common bean varieties to suggest valid recommendation.

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7. APPENDICES

Table 1: Mean square values of ANOVA for phenological and growth parameters of common bean as affected by inter and intra row spacing.

Source of variation	Mean squares					
	Df	DE	DF	DPM	PH	PB
Block	2	0.13396	0.7708	0.0625	0.0356	0.006458
Intra-row	3	0.01833ns	17.8383**	4.5556***	13.1772**	1.811875**
Inter-row	3	0.01389ns	82.3333**	30.7222**	168.5356**	2.107431**
Inter×Intra	9	0.01222ns	9.8333**	1.7222**	1.6176**	0.147245**
Error	30	0.0859	0.58`0	0.5928	0.5273	0.05028
CV (%)		1.2	1.2	0.7	3.0	1.6

Where, Df: Degree of Freedom; **: Highly Significant; *: Significant; ns: Non-significant; CV (%): Coefficient of Variation; DE: Days to Emergence; DF: Days to Flowering; DPM :Days to Physiological Maturity;; PH: Plant Height; PB: Primary Branches.

Table 2 Mean square values of ANOVA for yield and yield components parameters of common bean as affected by, inter and intra row spacing.

Source of variation	Mean squares					
	Df	PP	SP	%SC	HSW	GYT-h-^{1}
Block	2	34.981	0.27646	0	0.06318	0.015573
Intra-row	3	83.887**	3.99799**	210211**	3.92214**	0.468523**
Inter-row	3	362.355**	4.63465**	89417^{ns}	4.88408**	2.195254**
Inter×Intra	9	36.309**	0.26039**	0	0.34778**	0.570004**
Error	30	1.519	0.1193	37.0	0.0867	0.056
CV (%)		5.3	2.6	41.7	3.2	3.4

Where, Df: Degree of Freedom; **: Highly Significant; *: Significant; ns: Non-significant; CV (%): Coefficient of Variation; PP: Pod per Plant; SP: Seed Per Pod; %SC: Percentage of mortality of stand count at harvest compared to establishment; HSW: Hundred Seed Weight, GYT-h^{-1} Grain yield Tone per hectare.