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Effect Of Phosphorus Fertilizer Rates And Plant Density On Yield And Yield Related Traits Of Common Bean (*Phaseolus vulgaris* L.) In Dangur District, North- Western Ethiopia

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Abstract: Common bean production is constrained partly due to lack of recommendation on the optimum plant density and rate of phosphorus fertilizer. In view of this, a field experiment was conducted in Dangur district during 2016 cropping season to determine the effect of phosphorus rate and plant density on yield related traits and yield of common bean. The experiment consisted of five level of phosphorus (0, 23, 46, 69 and 92 kg P_2O_5 ha^{-1}) and four levels of plant densities (333333, 250000, 222222 and 166667 plants ha^{-1}). The experiment was laid out in randomized complete block design in a factorial arrangement with three replications. Results showed significant main effect of phosphorous rates on days to 90% physiological maturity, leaf area, leaf area index, number of primary branches and total aboveground biomass yield. The highest leaf area (2206 cm^2), leaf area index (5.25), number of primary branches (6.75) and total aboveground biomass yield (10021 kg ha^{-1}) were recorded from 46 kg P_2O_5 ha^{-1}; the highest total nodules (52.77) and total effective nodules (50.32) were at 92 kg P_2O_5 ha^{-1}; while highest days to 90% physiological maturity (91.87days) was recorded at the rate of 0 kg P_2O_5 ha^{-1} (control). Plant density had significant effect on days to 90% physiological maturity, leaf area, leaf area index, number of primary branches, plant height and total aboveground biomass yield. The highest days to 90% physiological maturity (91.49 days), leaf area (2212 cm^2) and number of primary branches (5.63) were recorded from plant density 166,667 plants ha^{-1}; while the highest leaf area index (6.17), plant height (153.6 cm) and total aboveground biomass yield (9283 kg ha^{-1}) were recorded from plant density 333,333 plants ha^{-1}. There was significant ($P<0.05$) interaction effect of phosphorus and plant density on number of pod plant^{-1}, number of seeds pod^{-1}, grain yield and harvest index. The highest number of pod plant^{--1}(28.33), number of seeds pod^{-1} (8.00), grain yield (3333 kg ha^{-1} and harvest index (37.19%) were recorded from combination of 46 kg P_2O_5 ha^{-1}and 166.667 plants ha^{-1}, moreover the highest net benefit (27772 Birr ha^{-1}) was recorded from combination of 46 kg P_2O_5 ha^{-1}and 166.667 plants ha^{-1}. Thus, use of plant density 166.667 plants ha^{-1} with 46 kg P_2O_5 ha^{-1} was found to give highest economic benefit in the study area.

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1. INTRODUCTION

Common bean (*Phaseolus vulgaries* L), locally known as 'Boleqe' also known as dry bean, common bean, kidney bean and field bean is a very important legume crop grown worldwide. It is an annual crop which belongs to the family Fabaceae. It grows best in warm climate at temperature of 18 to 24°C (Teshale *et al*., 2005). Common bean is primarily a crop of small scale producers and generally few inputs are used or no fertilizer or no soil amendments (Wortmann *et al*., 2004). The crop is adapted to a wide range of climatic condition ranging from sea level to nearly 3000 meters above sea level (masl) depending on variety selection. However, it does not grow well below 600 meters due to poor pod setting caused by high temperature (Dev and Gupta, 1997).

In Ethiopia, common bean is grown predominantly by smallholder producers as an important food crop and source of cash. It is one of the fast expanding legume crops that provide an essential part of the daily diet and foreign earnings for most Ethiopians (Girma, 2009). The major common been producing areas of Ethiopia are central, eastern and southern parts of the country (CSA, 2015). The crop grows well between 1400 and 2000 m above sea level (Fikru, 2007) and in areas with annual average rainfall of 500-1500 mm (Wortmann *et al.,* 2004). In 2014/15, total common bean production in the country was about 463008.5 t on approximately 366,876.94 ha of land (CSA, 2015).

The straw is commonly used for fodder. In addition, at present it is commonly used as a folk medicine (Teshale *et al.,* 2005). In the Ethiopian context, 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* (Kristin *et al*., 1997). Farmers also prepare a local stew known as *shiro* wet from some bean cultivars (Mekibib, 1997). Beans are generally characterized by their unstable yields resulting from biological, climate and edaphic factors that affect plant growth and productivity (Kristin *et al*., 1997).

The wide range of growth habits of common bean among varieties has enabled the crop to fit many growing situations (Kristin *et al*., 1997). Among different growth habit of common bean prostrate bush types achieve rapid ground cover, compete with weeds and avoid competition with tiff for labor. Early maturity and moderate degree of drought tolerance led the crop's vital role in farmers' strategies for risk aversion in drought prone lowland areas of the country (Fikru, 2007).

However, yield per unit area is very low especially in Benishangul Gumuz Region (1.14 t ha^{-1}) western part of Ethiopia is low compared to the national average of 1.26 t ha^{-1} (CSA, 2015. This low yield is attributed to various constraints such as moisture stress, absence of improved high yielding varieties, use of inappropriate agronomic practices, poor soil fertility, losses due to insect pests and disease etc (Eden, 2002; Ferris and Kaganzi, 2008; Girma, 2009). Varieties differ for their response to these constraints but are largely influenced by the environmental conditions (Wortmann *et al*., 2004).

Bean productivity is greatly influenced by soil fertility especially phosphorous and nitrogen. They have high nitrogen requirement for expressing their genetic potential and phosphorus plays an important role in biological nitrogen fixation (Kouas *et al.,* 2005; Tiessen, 2008; Fageria, 2009). Phosphorus appears essential for both nodulation (Kouas *et al.,* 2005) and N_2 fixation (Kouas *et al.,* 2005; Tiessen, 2008; Fageria, 2009). It is also the basis for the formation of useful energy, which is essential for sugar formation and translocation. Nitrogen fixation in beans needs more phosphorus and phosphorus availability in soil is considered to be the major constraint to common bean production (Israel, 1987). Before a decade common bean was not well distributed in western part of Ethiopia, although the area has potential for production. At the present time, the production and area coverage of common bean has been increasing from time to time because of the fact that the crop has immense potential for export and risk aversion in hot humid areas of Metekel Zone (Zelalem, 2014).

Management practices can improve the productivity of common bean in such marginal areas; more progress in improving yield will be realized through genetic improvement (White *et al*., 1994; Singh, 1995). Phosphorus availability in soil is a major constraint to common bean production in the tropics (Allen *et al.,* 1997). From the essential plant nutrients, nitrogen and phosphorus are often deficient in many soils of tropical Africa as well as in many Ethiopian soils. In the tropics, the amount of available phosphorus in soils is largely insufficient to meet the demand of legumes and thus phosphorus deficiency is widespread in pulse crops (Rao *et al.,* 2012). To overcome such problem research is needed to know optimum rate of phosphorus nutrient for common bean production. In Ethiopia 69 kg P_2O_5 ha^{-1} was recommended for common bean production in semi-arid zones of Central Rift Valley (Girma, 2009). However, such rates vary with soil and climatic conditions, varieties of crops and management of the crops.

Next to nitrogen, phosphorus is the most important element for adequate grain production (Brady and Weil, 2002). High seed production of legumes primarily depends on the amount of P absorbed (Khan *et al*., 2003). The yield of common bean increased as the phosphorus application rate increased from 10 kg to 40 kg (Gemechu, 1990) and its nodulation and fixation of N can be improved with the application of P (Amare, 1987). Therefore, application of P is very important to maximize the yield of bean. Getachew (2005) reported that lack of optimum fertilizer rate is one of the several factors contributing to the low grain yield of the bean.

Plant density and arrangement of plants in a unit area greatly determines:resource utilization such as light, nutrients and water, the rate and extent of vegetative growth and development of crops particularly that of leaf area index, plant height, root length and density, yield and yield components, development of important diseases and pests and the seed cost (Jettner *et al.,* 1998; Matthews *et al*., 2008). 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 *et al*., 2008).

Optimum plant density is the minimum population that produces maximum yield and suitable plant arrangement per unit area allow crops to exploit resource optimally and produce high yields. 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). The response of crops to plant density tended to be less in the low as compared to the high yielding environments (Matthews *et al*., 2008). This can also depend on soil type, management practices like seedbed conditions and soil moisture, sowing depth, sowing date, fungicide dressings of seeds, presence of weeds and seasonal rainfall (Matthews *et al*., 2008). Since optimum plant density of a crop at one location may not apply at other locations because of variation in soil type, rainfall, nutrient availability, varieties etc, there is a need to develop site specific recommendations.

However, only one plant density, *i.e.* 250,000 plants ha^{-1} (40 cm × 10 cm) is used for common bean production in Ethiopia irrespective of the various growth habits of common bean and locations. Though common bean is becoming one of the most commonly pulse crops in the study area, Dangure District in Benishangul Gumuz Region North-western Ethiopia the necessary recommendations such as fertilizer rates, optimum planting density are lacking.

Thus, this study was conducted with the following objectives:

- to assess the effect of phosphorus fertilizer rates and plant density on growth, yield and yield components of common bean; and
- to determine the economical rates of phosphorus and plant density for common bean in the study area.

2. LITERATURE REVIEW

2.1. Origin and Distribution of Common Bean

Common bean (*Phaseolus vulgaris* L.) belongs to order Rosales, family Fabaceae subfamily Papilionideae, tribe Phaseolinae (CIAT, 1986). The common bean was originated in Mexico, Guatemala, and Peru, but there are also evidences for its multiple domestication within Central America (Kay, 1979). The crop is now widely distributed throughout the world and consequently, it is grown in all continents except Antarctica (Singh, 1999). In Ethiopia, it is most likely to be introduced by the Portuguese in the 16th century (Wortmann *et al*., 2004). It is well adapted to areas that receive an annual average rainfall ranging from 500-1500 mm with optimum temperature range of 16-24 °C, and a frost free period of 105 to 120 days. Moreover, it performs best on deep, friable and well aerated soil types with optimum pH range of 6.0 to 6.8 (Kay, 1979). Major common bean producing regions are Central, Eastern, and Southern parts of the country and in central Ethiopia farmers grow early maturing white pea bean crop for export as their cash crop (CSA, 2015).

2.2. Common Bean Production and Its Economic Importance in Ethiopia

The importance of haricot bean as a source of income, nutrition and its role in food security at a household level is very high (Ali *et al*., 2003). There is a wide range of common bean types grown in Ethiopia including mottled, red, white and black varieties (Ali *et al*., 2003). 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 and Kaganzi, 2008).

To support both the growth in domestic and export bean markets, the Ethiopian Institute of Agricultural Research (EIAR) has developed a range of high yielding, multi-disease resistant bean varieties (Ali *et al.,* 2003). The focus of this genetic improvement program has been on the pure red and white beans to support the commercial sector (Ali *et al.,* 2003). Within the red bean types, the most favored and most commercially accepted varieties include Red Melka, a mottled medium sized red; Red Wolaita, a medium sized pure light red; and Nasser, a small pure dark red variety (Ferris and Kaganzi, 2008). According to EPPA (2004) in the year 2000, 2001 and 2002 Ethiopia exported 23994.4, 32932.7 and 42127.0 tons and earned 8.2, 9.98 and 13.2 million US dollar, respectively.

The main destination markets were Pakistan, Germany, Yemen, UK, South Africa, India and Mexico having 12.5, 7.8, 6.9, 5.79, 4, 4, 4% share, respectively (EPPA, 2004). The country's exports of common beans have increased over the last few years, from 58,126 MTs in 2005 to 78,271 MTs in 2007 and Ethiopia got 63 million dollar from common bean market in 2005 (Legese *et al.*, 2006).

Common bean production is very heterogeneous in terms of ecology, cropping systems and yield. It predominantly grows from low lands (300-1100 masl) to mid highland areas (1400-2000 mas) of the country. Majority of the smallholder farmers do not use fertilizer and use local seed instead of improved seeds for planting. Common bean is harvested by hand, heaped and sun dried for a week and then threshed by beating the dried vines with sticks or by chasing oxen on threshing floor. White beans from the Northern Rift Valley were sold into export markets to supply European canning factories and red beans were exported from the southern Rift Valley areas to supply drought affected areas in Northern Kenya (Ferris and Robbins, 2004). The major storage and trading sites in the southern Rift Valley area are concentrated in the towns of Sodo, Awassa and Shashemene while the major collection centers for white beans being in Nazareth, prior to exportation through Djibouti (Ferris and Kaganzi, 2008). There are good prospects that this market will grow as consumers in industrialized countries seek evermore competitive suppliers (Ferris and Kaganzi, 2008). For the major processing companies, Ethiopia is a relatively new source of supply and recent investments by a number of international companies from Italy, UK and Turkey indicate that market prospects are good (CIAT, 1994).

2.3. Phosphorus Use Efficiency of Common Bean

Phosphorus is a critical nutrient element for plant growth, since it is involved in cellular energy transfer, respiration and photosynthesis. P is also a structural component of the nucleic acids of genes and chromosomes and of many coenzymes, phospho-proteins and phospholipids ids. Plants need P throughout their life cycle but most importantly during early growth stages for cell division (Havlin *et al.*, 1999).

Phosphorus deficiency is globally a major constraint to bean production on agricultural soils, and of greater importance in tropical soils because their generally high capacity to fix P in plant unavailable forms. An estimated 60% of beans in Latin America are grown on severely P-deficient soils (CIAT, 1987). Under conditions of high soil-P fixation, use efficiency of applied P fertilizers is often less than 25%, and the economies of bean production in many developing countries discourages wide spread application of P to alleviate deficiency. A viable alternative to use of inorganic P-fertilizers is selecting and developing plants more tolerant of P-deficient soils. Throughout Latin America, researchers have demonstrated genetic differences in tolerance to low P-conditions, defined as the ability to produce economic yields under a P-deficient environment (CIAT, 1994). Work completed in 1993, focusing on the physiological evaluation of 16 selected lines at CIAT, revealed: large genetic variability for p use efficiency, the variation is because of general adaptation to low P-availability interaction, and large seeded germplasm may have superior P efficiency (Yan *et al.,* 1995).

Phosphorus is the second limiting element after nitrogen for plant growth (Tolera *et al.,* 2005) Phosphorus deficiency is also the major constraints to the growth of legumes in many soils (Desta, 1988). Beans respond to the application of phosphorus and production increase proportionally with increase of phosphorus fertilizer (Tolera *et al.*, 2005). Many research on legume indicated that phosphorus availability in the soil is a great limitation for bean production in tropics (Morgado, 2003). Application of fertilizer on common bean production depends on area of production and soil fertility.

Phosphorus influences nodule development through its basic functions in plants as an energy source. Phosphorus plays a vital function in increasing plant tip and root growth, decreasing the time needed for developing nodules to become active and of benefit to the host legume. Furthermore, phosphorus increases the number and size of nodules and the amount of nitrogen assimilated per unit weight of nodules, increasing the percent and total amount of nitrogen in the harvested portion of the host legume and improving the density of *Rhizobium* bacteria in the soil surrounding the root (Bashir *et al.*, 2011). Phosphorus brings about the ability of catalyzing stress in the symbiotic relation between root bacteria and legume plants (Tsvetkova *et al.*, 2003).

Application of fertilizers in a recommended amount is essential for high yield and quality of grains. The use of fertilizers is considered to be one of the most important factors to increase crop yield per unit area basis (Khan *et al.,* 2003). However, the response to fertilizer and rates of applications vary widely with location, climate and soil type (Wortmann *et al*., 2004). According to Kathju *et al.* (1987) and Frizzone (1982), P is among the principal nutrient elements needed for growth of many legumes in arid and semi arid agriculture regions due to low available P in the soils and advantageous effects of P. Amos *et al.* (1999) also indicated that P application is key to enhance bean yield on farmers field in their study on the low fertile Orthic Acrisols of western Kenya. The researchers also indicated that P significantly enhanced the establishment of beans, number of pods per plant, and the bean grain yields. Similarly, Dadson and Acquaah (1984) also reported that the formation of nodes and pods was promoted with the application of P, in P deficient soil. Thus, application of P from external sources/fertilizers/ becomes very essential to obtain optimum yield. Many researchers reported that P is the most limiting factor for pulses production and mostly 8.6-43 kg P_2O_5 ha^{-1} is beneficial depending on the prevailing conditions (Tomers *et al.*, 1985). Similarly, the grain legume project work in central Kenya recommended 36 kg N ha^{-1} and 17.2 kg P_2O_5 ha^{-1} for beans (GLP, 1983).

Studies on nutrient requirement of common bean gave variable recommendations in Ethiopia (Mitiku, 1990). Gemechu (1990) reported highest yield at the rate of 100 kg N ha^{-1} and 43.7 kg P_2O_5 ha^{-1}, but recommended 50 kg N ha $^{-1}$ and 21.8 kg P_2O_5 ha^{-1} for economic purpose at Bako Researcher center. Similarly, results of fertilizer researchers done between 1972-76 on beans in different parts of Ethiopia indicated that 30-50 kg P_2O_5 ha^{-1} gave frequently significant yield response, especially if the soil was low in available P (Ohlander, 1980). Application of 69 kg ha^{-1} P_2O_5 and 27 kg ha^{-1} N and using tie-ridging gave the highest grain yield. However, the highest grain yield (1627 kg ha^{-1}) was obtained at 92 kg ha^{-1} P_2O_5 (Girma, 2009).

2.4. Soil Properties and Phosphorus Availability

Phosphorus exists in the soil as: Calcium phosphate resulting from the weathering of primary-bearing minerals, non-labile or strongly bound P, organic P in humus and organic residue and soluble and adsorbed phosphates which constitute P in solution (0.1 µg P per mL). Of the adsorbed P, only the mononuclear fraction is considered to be in equilibrium with P in solution, and therefore accessible to plants (Jones, 1975).

In the pH range of 5.5 to 7.0, the dominant form is $H_2PO_4^-$, and P availability is highest. Insoluble iron phosphates and aluminum phosphates are formed at low pH, while insoluble calcium phosphates and magnesium phosphates are formed at pH above 7.0. Phosphorus released from decomposition of plant residues can be a relatively significant source of available P. Because P is relatively immobile in the soil, banding P 5 to 8 cm to the side and 3 to 5 cm below the seed is preferable to broadcast application. Flooding from rain or excessive irrigation leaches only P in soil solutions, while erosion is the major means of P removal from the soil. Phosphorus in fertilizer is expressed as phosphate or P_2O_5. The main sources of P are normal, superphosphate (0-20-0), triple superphosphate (0-46-0), mono ammonium phosphate (MAP), and ammoniated superphosphates ($NH_4H_2PO_4$) and potassium phosphate (KH_2PO_4) (Jones, 1975).

Fixation is the problem in phosphate fertilization and the retention depends on the physical and chemical properties of soil particularly pH, temperature, types of cations and anions, texture, extent of P saturation and organic matter (Havlin *et al.,* 1999). At pH lower than 5.5, the retention results largely from the reactions with Fe, Al and their hydrous oxides resulting in low forms of available P, while at pH higher than 7.0, high concentration of Ca, Mg and their carbonates cause precipitation of the added phosphorous (Ahn, 1993; Mengel and Kirkby, 1996; Onwueme and Sinha, 1999). Adsorption of phosphate to soil particle is frequently not an ideal adsorption process but rather a combination of adsorption and precipitation.

Soils dominated by calcium carbonates adsorb phosphate, which is then slowly converted in to apatite and in such a process, some phosphate of the labile pool is continuously being rendered immobile and so transferred to the non-labile phosphate fraction (Parfitt, 1997). Therefore, pH should be corrected in order to alleviate the effect of P fixation and thereby to increase its availability.

The effect of pH on P availability can be improved by cropping system. The simple mechanism that cropping system can improve soil pH is the buffering effect through organic matter (James and Richa, 1986). Curtin *et al.* (1996) found that organic carbon buffers soil pH much more than clay though most soil contains much more clay than organic carbon. Addition of organic matter to soil may increase or decrease soil pH based on the chemical nature of the soil (Yan *et al.,* 1996; Summer, 1997). Addition of organic matter increases soil pH in acid soil but decreases it in alkaline soil (Nelson and Oades, 1998). Liming can also increase the pH of acid soils (Havlin *et al*., 1999).

The retention of P can also be affected by the types of cations and anions. Compared to monovalent cations, the divalent cations enhance P adsorption, by making positively charged edge sites of clay minerals more accessible to P anions. For example, clays saturated with Ca^{2+} retain greater amounts of P than those saturated with Na^{+} or other monovalent ions. Similarly, anion can also affect P fixation. Both inorganic and organic anions can compete with P for adsorption sites, resulting in decreased adsorption of added P.weakly held in organic anions such as NO_3^- and Cl^- are of little consequences, whereas adsorbed OH^-, H_3SiO_4, and SO_4^{-2}, and MoO_4^{-2} can be competitive. The strength of bonding of the anion with the mineral surface determines the competitive ability of that anion. For instance, SO_4^{-2} is unable to desorb much $H_2PO_4^-$, since $H_2PO_4^-$, is capable of forming a stronger bond than is SO_4^{-2}. Organic anions such as oxalate and citrate can reduce P retention by forming stable complexes with Fe and Al (Havllin *et al.*, 1999).

Soil textures particularly the content and type of clay generally governs nutrient retention (Mclntosh *et al.,* 1999). In modeling soil and plant P dynamics in calcareous and highly weathered soils, Sharpley *et al.* (1989) found that for highly weathered soils clay content explained the greatest amount of variation in sobbed or fertilized phosphorus availability index. Phosphorus tends to accumulate in the finer fractions of soil and thus its content increases as the clay content increases (Hesse, 1994). Yagadin (1984) reported the effect of texture on the adsorption of phosphate, and concluded that particles larger than 0.01 mm in size do not adsorb phosphate. It was also found that at optimal moisture content the diffusion of P in clay soil might be more pronounced than in sandy soil. Furthermore, phosphate sorption and fixation parameters are above all significantly correlated with clay content and type of soil (Evans, 1985). Sandy soils generally retain less P than finer textured soils because of deficiency of mineral components such as mineral oxides and Phyllosilicates having high surface affinity for orthophosphate (Harris *et al.,* 1996).

Retention of P can also be influenced by extent of P saturation. Soils with little P adsorbed to mineral surfaces have greater tendency for adsorption than soils with more P adsorbed to the surfaces (Havlin *et al.,* 1999). To lessen the effect, higher amount of P fertilizer should be added to soils with little P adsorbed than those with more P adsorbed (Mengel and Kirkby, 1987; Havlin *et al.*, 1999).

Soil organic matter also influences the concentration of inorganic phosphorus in solution by different mechanisms. It influences as compound transporting phosphorus by complexion inorganic P in water and there by stabilizing its concentration in solution, complex with P for adsorption sites in ligand exchange and increase the mobility of inorganic P/Pi/ particularly in acidic soils by decreasing chemical activity of iron or aluminum**,** which would otherwise precipitate phosphorus from solution (Holford, 1989). In addition to its indirect effect on soil physical and chemical properties, soil organic matter influences P availability too directly by contributing to P pools (Clark *et al.*, 1998).

Usually, annual crops absorb about 5-10% of phosphate fertilizer added to the soil though high recovery can be obtained when P demanding crops are grown on soils that are poor in content. Addition of P to soils of high P status, its uptake is limited by factors other than, results in low P uptake (Russel, 2008). Crops in any one season are generally able to recover only a small fraction of the added fertilizer P, usually less than 25% (Havlin *et al.*, 1999).

2.5. Effect of Plant Density on Resources Utilization

Plant density defines the number of plant per unit area, which determines the size of the area available to the individual plant. 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, 2000). 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, by planting seeds singly or in groups, or by changing row direction (Robinson *et al*., 2002). Plant spacing should be thought of as 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, as plant density increases the plant spacing within the row decreases and interplant competition increases. Obviously, both factors can be adjusted to provide optimal plant spacing and typically plant density increases as row spacing decreases (Pedersen *et al*., 2008).

For a low density of plants of a single species, increasing the density increases yield per unit area and intra specific competition becomes more intense, because greater numbers of individuals compete for the same common limiting resources. In pure stands, increase in the intensity of competition manifests itself by the reduction of the performance of the individual, for example biomass of single plant and/or reduction of grain weight per plant (Sobkowicz and Podgorska, 2007). Reddy (2000) described that both too narrow and too wide spacing do affect grain yields through competition and due to the effect of shading. 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.

Closely spaced and quick growing crops like soybean which can intercept more light within a short period give higher yield as compared to wider spaced crops. As such for the proper light interception at various growth stages, optimum plant density is necessary. The greater interception increases photosynthesis and reduces evaporation of water from the soil (Robinson *et al*., 2002). Plant density must be adjusted to available soil moisture levels, either with in rows or between rows (Gobeze, 2015). Planting arrangement alters both the spatial and temporal pattern of interception or retrieval of the limiting resource, especially in dry land cropping where the soil water is rarely adequate throughout the growing season. In such cases, inter and intra row spacing are normally a matter of compromise (Bora *et al*., 2001).

2.6. Effects of Plant Density on Yield and Yield Components of Pulse Crops

Common bean is considered as one of the most important members of pulses. Access to resources used by a plant such as solar radiation, usable water, and food has a great relationship with plant density; adjustment of plant density, to increase the yield per unit, will be based on the degree of the availability of resources and other factors of production. Plant density is one of the factors that affect the morphological and physiological characteristics, yield and yield component of crops (Koochaki and Soltani, 1988).

Nowadays, it is recommended that plant spacing should be reduced as much as possible. The density of common bean planting is very different; farmers do not use a specific density in planting. The density of planting, with respect to the dry farming of common bean can be very important and the appropriate planting density can help in better production of this plant (Koochaki and Soltani, 1988).

Plant density per unit area has great effects on the yield of products and like other agricultural inputs; it is important (Torabi, 2005). Plant density is one of the most important factors in determining the level of competition between plants (Khajepour, 1987). Optimum plant density is the one that as a result of which all the environmental factors (water, air, light, and soil) have been fully used and at the same time the competition within the plant is at its least degree to obtain maximum yield with desired quality. On the other hand, this density should provide enough space for the operations of harvesting (Khajepour, 1987). Optimal density depends on various factors such as the characteristics of the plant, plant height, growth period, the time and method of planting, soil fertility, plant size, available moisture, solar radiation, planting pattern, and weed status (Shirtliffe *et al*., 2002).

Crop plant should have to cover the soil as early as possible to intercept maximum sunlight to produce high dry matter as the intercepted solar radiation and dry matter production are directly related as plant density increase the amount of dry matter in vegetative part also increases. By maintaining optimum plant population under suitable environment it is possible to get more than ten quintals of common bean per hectare (Adamu *et al*., 2008).

Stem thickness showed inverse relationship with sowing density (Amaducci, 2008; Hall *et al.,* 2014; Lisson and Mendham, 2000). Another report by Van der Werf (1996) indicated that increasing plant density results in thinner stemmed plants. Stem dry weight followed a linear trend for plant spacing and as plant spacing decreased stem dry weight of pulse crops diminished (Jovicich *et al*., 1998).

At a close spacing the branches develop less in number than at wider spacing (Abuzar, 2011). Weber *et al.* (1966) also found that, plants produced at highest densities were taller and more sparsely branched. The rate of nodes of faba bean appearance was relatively constant within and across seasons whereas the number of branches per plant declined with increasing plant density, and fewer branches survived through to maturity at high density (Loss *et al*., 1998). The increased number of branches at the wider plant spacing could also be attributed to more interception of the sunlight for photosynthesis and at high density there might also be comparatively low light interception through crop canopy as compared to wider spacing that might have resulted in lesser auxiliary buds leading to lower number of branches per plant. This indicated the plasticity response of plants to various plant spacing that is increased in plant population is associated with a progressive decline in number of branches whereas, plants at lower density produce higher number of branches in order to compensate the dry matter per unit area of higher densities (Mehmet, 2008).

As plant population increase the number leaf decrease where as the leaf number increases as the number of population decreases. Studies by Lazim, (1972) also showed that, increasing plant population decreased the number of leaves per plant. In contrast, Ahmed *et al.* (2010) indicate intra-row spacing had no significant effect on number of leaves per plant. The higher leaf per plant with in the lower plant density might be due to more availability of sufficient levels of growth factors and better penetration of light, consequently increased number of leaves produced and the size of individual leaves in plants at wider row spacing, Kueneman (2008) also reported that the low plant population tended to enhance vegetative growth of dry bean plant resulting in the development of large leaf as compared to the high and moderate plant populations resulting in sink limitation to photosynthesis.

Plant numbers compensate almost exactly for reduction in the production of individual plant (Girma and Hunt, 1975). Intra-row spacing had no significant effect on plant height in common bean (Ahmed *et al.,* 2010). Mohamed (2002) also reported that intra row spacing had no significant effect on most of the growth attributes. Plant density had no significant effect on plant height. In the other case, Abuzar *et al.* (2011) reported that due to crowding effect of the plant and higher intra specific competition for resources, plant height decreased as population number increases. This trend explains that as the number of plants increased in a given area the competition among the plants for nutrients uptake and sunlight interception also increased (Sangakkara *et al*., 2004).

2.7. Effects of Plant Density on Common Bean Production

An increase of plant density, in spite of the loss of plant weight and weight of seed in plant due to the increased number of plants per unit, plant yield and biological yield is increased. Maximum utilization of the factors required for plant growth can only be achieved when the plant community puts the maximum pressure on these factors (Abuzar, 2011). As a result, because of the plant competition, each of the plants is under relatively severe stress (Koochaki and Soltani, 1988). Improved agronomic practices are used to increase crop yield and are recommended by researchers after testing on the research field and also on farmer field (Alemitu, 2011).

Ethiopian farmers, in general, use lower seed rate than research recommendations which result in lower grain yields (Ali *et al*., 2003). The grain yield of bean is the result of many plant growth processes which ultimately influence the yield components such as pods/plant, seeds/pod, and unit weight of seed. The highest grain yields were obtained when all the above got maximized (Tsubo *et al*., 2004).

2.8. Use of Fertilizer on Common Bean Production

Application of fertilizer in a recommended amount is essential for high yield and quality of grains (Morgado, 2003). The use of fertilizer is considered to be one of the most important factors to increase crop yield per unit area basis, however the response to the type of fertilizer and rate of application vary widely with location, climate and soil type (Marshner, 2002). Nitrogen deficiency occurs almost everywhere unless nitrogen is applied as a fertilizer or manure (Desta, 1988). It has been reported that there was increased yield responses of pulse for nitrogen fertilizer (Morgado, 2003). Phosphorus is the second limiting element after nitrogen for plant growth (Tolera *et al.,* 2005). Phosphorus deficiency is also the major constraints to the growth of legumes in many soils (Desta, 1988). Beans respond to the application of phosphorus and production increase proportionally with increase of phosphorus fertilizer (Tolera *et al.,* 2005) Many research on legume indicated that phosphorus availability in the soil is a great limitation for bean production in tropics (Morgado, 2003).

Application of fertilizer on common bean production varies depending on area of production and soil fertility. According to the regional Agricultural bureau extension program manual (2006) in SNNP Ethiopia, Setegne and Legese (2003) the recommended fertilizer rate, is 100 kg DAP ha^{-1} (18 kg N and 46 kg P_2O_5) and 50 kg ha^{-1} urea (23 kg N).

3. MATERIALS AND METHODS

3.1. Description of the Experimental Site

The experiment was conducted at Manbuk Dangur district in Metekel Zone of Benishangul Gumuz Regional State, which is 573 km away to North west of Addis Ababa and located at the latitude of 11°18’125’’ North and longitude of 36°14’472’’ East longitude. Dangur District situated at an altitude of 1500-2857 masl (BGRSBFED, 2012). The study area has an average annual rainfall range 400-1000 mm with the main growing season (March-November) and receive high rainfall from June-August. The average minimum and maximum temperatures recorded were 20°C and 23°C, in the low land and 10-15°C in the high land (BGRSBFED, 2012). The soil of the experimental site was a clay texture. The major soil chemical properties of the experimental site are indicated in Table 1 of result and discussion.

3.2. Description of Experimental Material

An improved common bean variety; namely Nasir which is released by Hawassa Research Center was used as experimental material. It matures 88 days

(Alemitu, 2011) and at Pawe Agricultural Research Center its yield was 2.1 t ha^{-1} (Personnel communication from the research center). Triple superphosphate (TSP) (46% P_2O_5) was used as source of phosphorus.

3.3. Soil Sampling and Analysis

Surface soil samples (0-30 cm) were collected randomly in a zigzag pattern before sowing from the entire experimental field of five spots, composited, and analyzed in the laboratory for selected physical and chemical soil properties. The soil samples were air-dried and passed through a 2 mm mesh sieve. Soil pH was determined from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (potentiometer) (Page, 1982). Texture of the soil was determined by the hydrometer method. The soil was analyzed for total nitrogen, available phosphorus, CEC, and organic carbon contents. Organic carbon and total nitrogen have been determined by the method of Walkely and Black and Kjeldhal methods, respectively (Jackson, 1973). Available phosphorus has been determined by the methods of Olsen *et al.* (1954).

3.4. Treatments and Experimental Design

The treatments consisted of five levels of phosphorus (0, 23, 46, 69 and 92 kg P_2O_5 ha^{-1}) and four level of plant density [166667 plants ha^{-1} (40 cm x 15 cm), 222222 plants ha^{-1} (30 cm x 15 cm), 250000 plants ha^{-1} (40 cm x 10 cm), and 333333 plants ha^{-1}(30 cm x 10 cm)]. The experiment was laid out in randomized complete block design in factorial arrangement and replicated three times.

3.5. Experimental Procedures and Crop Management

Before the land was ploughed, it was cleared and unnecessary materials were removed. The treatments were assigned randomly to each plot within block. The size of each plot was 4 m long and 3 m wide. The gross plot size for 40 cm x 10 cm and 40 cm x 15 cm were 7 rows x 0.4 m x 3 m = 8.4 m^2 and for 30 cm x 10 cm and 30 cm x 15 cm were 10 rows x 0.3 m x 3 m = 9 m^2. The net plot sizes for 40 cm x 10 cm were 4 rows x 0.4 m x 2.8 m = 4.48 m^2, for 40 cm x 15 cm were 4 rows x 0.4 m x 2.7 m = 4.32 m$^{2.}$ The net plot size for 30 cm x 10 cm and 30 cm x 15 cm were 7 rows x 0.3 m x 2.8 m = 5.88 m^2 and 7 rows x 0.3 m x 2.7 m = 5.67 m^2, respectively. Two rows were left for boarder effect and one row was left for destructive sampling in each plot.

Sowing was done in 22 November 2015 by using supplemental irrigation. Two seeds per hill were planted and thinning was done after two weeks to keep the specified spacing. Nitrogen at the rate of 18 kg ha^{-1} was applied to all treatments as a starter fertilizer. Phosphorous was applied at the time of sowing. Furthermore, all necessary cultural practices such as weeding, cultivation were carried out uniformly for all plots.

3.6. Crop Data Collected

3.6.1. Phenological parameters

Days to 50% flowering: was recorded as the number of days from planting to when 50% of the plants per plot produced flower by visual observation.

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

3.6.2. Growth parameters

Leaf area (cm^2): was recorded by taking a destructive sample of five plants from a destructive row from net plot. Leaf area was measured just before flowering from 2nd, 3rd and 4th mid leaves by using pictorial diagram then the average of the three leaves was multiplied by the total number of leaves per plant. From the leaf area, leaf area index was calculated as the ratio of total leaf area to the respective ground area occupied by the crop depending on the spacing.

The total number of nodules and effective nodules: were determined by counting from five plants randomly taken from the destructive sampling row. 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. Then, effective and non effective nodules was separated by their colors where a cross section of an effective nodule showed a pink to dark-red color, whereas a green color indicated non-effective nodules.

Plant height: was measured as the height of five randomly taken 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 per plant: was determined by counting of primary branches on the main stem from randomly taken five plants from the net plot area at physiological maturity.

3.6.3. Yield components and yield

Stand count: the initial plant stand count was recorded by counting the total number of plants per net plot area immediately after thinning and final plant stand count was taken from net plot area when the plants attained physiological maturity. Then the reduction of the final stand count mortality was calculated and expressed in percentage.

Number of pods per plant: was determined by counting the number of pods per plant of five randomly selected plants from each net plot area at harvest.

Number of seeds per pod: was recorded from ten randomly selected pods from each net plot area at harvest.

Hundred seed weight (g): was determined by taking weight of 100 randomly sampled seeds from the total harvest from each net plot area.

Total above ground dry biomass (kg ha^{-1}): was determined by taking the total weight of the harvest including the seeds from each net plot area after sun drying to 5 days at physiological maturity of the ten plants and converted to kg ha^{-1}.

Grain yield (kg ha^{-1}): was determined after threshing the pods harvested from each net plot and converted to kg ha^{-1}.

Harvest index (HI): was computed as the ratio of grain yield (kg ha^{-1}) to total above ground dry biomass (kg ha^{-1}).

3.7. Statistical Data Analysis

Data were subjected to analysis of variance (ANOVA) according to the Generalized Linear Model (GLM) of SAS (SAS, 2004) version 9.1 and interpretations were made following the procedure of Gomez and Gomez (1984). Significant differences between treatment means were separated using the Least Significance Differences (LSD) test at 5% level significance.

3.8. Partial Budget Analysis

Partial budget analysis is a method of organizing experimental data about the cost benefit of some changes (CIMMYT, 1988). It calculates income and expenses based on variable cost. Partial budget averaged of the 20 treatments is presented (Table 12). The actual yield obtained under different treatments was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. As there were optimum plant population density, timely labor availability and better management under experimental conditions (CIMMYT, 1988). The net benefit (NB) was calculated as the difference between the gross benefit and the total variable cost. The cost of common bean at the time of planting was Birr 1200 per 100 kg while the cost of TSP fertilizer was Birr 1855 per 100 kg. **90 kg seed was used for plant density of 250,000 plants ha^{-1}.** The transportation cost of TSP fertilizer to the field was Birr 20 per 100 kg. The application cost of 23 and 46 kg P_2O_5 ha^{-1} were done by 4 persons (Birr 200), 69 and 92 kg P_2O_5 ha^{-1} by 6 persons (Birr 300). The cost of harvesting, threshing and winnowing (Birr 50 per 100 kg yield). The transportation to the market was Birr 30 per 100 kg produce. Bagging and material cost was Birr 3 per 100 kg yield. The local market price of common bean seed at the time of harvest was Birr 1000 per 100 kg.

4. RESULTS AND DISCUSSION

4.1. Soil Physical and Chemical Properties

According to the soil analysis test, the soil pH of the experimental site was 7.3. Herrera (2005) classified soil pH as strongly acidic (3-5.6), moderately acidic (5.6-6.2), slightly acidic (6.2-6.7), neutral (6.7-7.3), slightly alkaline (7.3-7.9), moderately alkaline (7.9-8.5) and strongly alkaline (>8.5). Based on this classification, the pH of the experimental soil was slightly alkaline, which is satisfactory for growth of common bean and most crops (Havelin *et al*., 1999).

The laboratory result of analysis showed that the available P level in the experimental site was 8.99 kg kg^{-1} of soil (Table 1). According to Hazelton and Murphy (2007) rating the available soil phosphorus level is very low (<9 ppm). This low available phosphorus could be due to fixation in such alkaline soils.

Total nitrogen measures the total amount of nitrogen present in the soil, much of which is held in organic matter and is not immediately available to plants. It may be mineralized to available forms. However, total nitrogen cannot be used as a measure of the mineralized forms of nitrogen (NH_4^+, NO_3^- and NO_2^-) as much of it is held in the organic matter in the soil. The result of laboratory analysis showed that the total nitrogen percentage (0.013%) was low (Table 1) as per the rating of Bruce and Rayment (1982).

Cation exchange capacity is the capacity of the soil to hold and exchange cations. It provides a buffering effect to changes in pH, available nutrients, calcium levels and soil structural changes. The result showed that the cation exchange capacity of the experimental soil to be 24 cmol (+) kg^{-1} (Table 1) is rated as moderate according to Landon, (1991).

The laboratory analysis of the experimental soil showed the total carbon content in the soils was 1.998% (Table 1) which was rated as medium as per the classification of Hazelton and Murphy (2007).

Table 1. Selected soil physical and chemical characteristics of experimental site before planting

Soil characteristics	Value	Rating	References
Physical properties			
Sand (%)	24		
Silt (%)	17		
Clay (%)	59		
Textural class		Clay	
Chemical analysis			
Soil pH	7.3	Slightly alkaline	Herrera (2005)
Organic carbon (%)	1.997	Low	Hazelton and Murphy (2007)
Total N (%)	0.013	Low	Bruce and Rayment (1982)
Available phosphorus(mg kg^{-1})	8.998	Low	Hazelton and Murphy (2007)
CEC (cmol (+) kg^{-1})	24	medium	Landon (1991)

4.2. Phenological Parameters

4.2.1. Days to 50% flowering

Analysis of variance revealed that the main and interaction effect of phosphorus and plant density was not significant on this plant parameter (Appendix table 1).

Phosphorus fertilizer rate application had slightly reduced the days to 50% flowering (Table 2), the effect was statistically not significant. Similarly, increase in plant density had slightly reduced the days to 50% flowering (Table 2) as compared to control; however, the effect was statistically not significant.

4.2.2. Days to 90% physiological maturity

Analysis of variance indicated that phosphorus ($P < 0.01$) and plant density ($P < 0.05$) was significantly affected days to physiological maturity (Appendix table 1).

Table 2. Main effect of phosphorus and plant density on days to 50% flowering and 90% physiological maturity of Common bean

Treatment	Days to 50% flowering	Days to 90% physiological maturity
Phosphorus (kg P_2O_5 ha^{-1})		
0	50.60	91.87^{a}
23	50.50	89.83^{b}
46	50.43	88.00^{b}
69	50.30	87.21^{b}
92	50.21	84.83^{b}
LSD $_{(0.05)}$	Ns	3.78
Plant density		
166,667	50.42	91.49^{a}
222,222	50.41	86.91^{b}
250,000	50.40	86.80^{b}
333,333	50.40	86.28^{b}
LSD $_{(0.05)}$	NS	3.39
CV (%)	5.6	5.2

Means in column followed by the same letter(s) are not significantly different at 5% level of significance; LSD= Least Significance Difference; NS=Non-significant; CV = Coefficient of Variation

Phosphorus application at 23, 46, 69, and 92 kg P_2O_5 ha^{-1} had significantly reduced days to 90% physiological maturity as compared to control treatment (Table 2). The maximum days to reach physiological maturity (91.87days) were recorded from control treatment while the minimum (84.83 days) were recorded from 92 kg P_2O_5 ha^{-1}. This might be due to that application of phosphorus fertilizer rate initiate the plants to grow early and set Phenological components and mature with in short period of time. This result was in line with result of Havlin *et al*. (1999) who indicated that ample phosphorus nutrition could reduce the time required for grain ripening. The result was in agreement with the finding of Brady and Weil (2002) who reported hastening of crop maturity due to increasing phosphorus supply. In the same manner, the result was in consistent with the result of Marschner (2002) who reported that phosphorus could reduce the days to physiological maturity by controlling some key enzyme reactions that involve in hastening crop maturity.

Increased plant population density decreased days to physiological maturity. The maximum days to reach physiological maturity (91.49 days) was recorded from 166667 plants ha^{-1} while the minimum (86.28 days) was recorded from plant density of 333333 plants ha^{-1} (30 cm x 10 cm) (Table 2). The decreased days to physiological maturity with highest population density might be due to high competition for the available resource to ripen early. This result is in contrast with that of Mundel *et al*. (1994) and Oad *et al*. (2002) who reported that the closer row and plant spacing increasing maturity days of safflower, but in contrast with that of Holshouser and Joshua (2002) who found no significant effect of row spacing on maturity of soybean.

4.3. Growth Parameters

4.3.1. Leaf area and leaf area index

The analysis of variance revealed that the main effects of phosphorus ($P < 0.05$) and plant density ($P < 0.01$) had significant effect on leaf area and leaf area index. However, there was no interaction effect on this parameter of the plant (Appendix Table 1).

Phosphorus application to all treatments resulted in statistically significant higher leaf area than the control one (Table 3). The highest leaf area (2206 cm^2) was recorded at phosphorus application of phosphorus 46 kg P_2O_5 ha^{-1} and was statistically at poor with 23, 69 and 92 P_2O_5 ha^{-1} while significantly lowest (1849 cm^2) was recorded from no application. This might be due to the application of optimum phosphorus fertilizer rate increased leaves size which leads to increment of leaf area. This result was in agreement with Shubhashree (2007) who reported that application of optimum fertilizer was significantly increased leaf area over the other treatments. However, decrease in leaf area, at application rate of phosphorus 92 kg P_2O_5 ha^{-1} might be due to phosphorus effect dependence on available phosphorus in study site where it were above the optimum level it may interrupt other nutrients, which in turn can bring decrease in growth of common bean (Meseret *et al*., 2014).

Table 3. Main effect of phosphorus and plant density on leaf area, leaf area index and number of branches of common bean

Treatment	Leaf area plant^{-1} (cm^2)	Leaf area index	Number of primary branches plant^{-1}
Phosphorus (kg P_2O_5 ha^{-1})			
0	1849^{c}	4.37^{b}	4.04^{d}
23	2106^{ab}	5.04^{a}	4.83^{c}
46	2206^{a}	5.25^{a}	6.75^{a}
69	2070^{ab}	4.98^{a}	5.79^{b}
92	1985^{ab}	4.81^{ba}	4.92^{c}
LSD $_{(0.05)}$	195.9	0.55	0.34
Plant density			
166,667	2212^{a}	3.71^{c}	5.63^{a}
222,222	2116^{ab}	4.7^{b}	5.43^{a}
250,000	1994^{bc}	4.98^{b}	5.07^{b}
333,333	1851^{c}	6.17^{a}	4.93^{b}
LSD $_{(0.05)}$	175.3	0.49	0.30
CV (%)	11.6	13.6	7.8

Means in column followed by the same letter(s) are not significantly different at 5% level of significance; LSD= Least Significance Difference; CV= Coefficient of Variation

The highest leaf area per plant of (2212 cm^2) was obtained with the lowest plant density of 166667 plants ha^{-1} (40 cm × 15 cm) while the lowest leaf area of (1851cm^2) was recorded with the highest plant density of 333,333 plants ha^{-1} (30 cm × 10 cm) (Table 3). The higher leaf area per plant with in the lower plant density might be due to more availability of sufficient levels of growth factors and better interception of light, which consequently increased number of leaves produced and the size of individual leaves in plants at wider row spacing. This was an important character to increase the yield per plant as the vigorous and ample amount of leaves at the early stage of development are crucial to improve the photosynthetic capacity of the crop. This result was in agreement with the result of Kueneman (2008) who 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.

As it was true for leaf area, analysis of variance showed that plant density had statistically significant ($P < 0.01$) effect on leaf area index (Appendix Table 1). Highest leaf area index (5.25) was recorded with phosphorus application of 46 kg P_2O_5 ha^{-1} and the lowest (4.37) was recorded from the controlled treatments (Table 3). This might be due to the effect of phosphorus fertilizer rates on leaves size with in plant density. When plant density decreased, the leaf area per plant was increased.

The leaf area index was increased with increase in plant density where the highest leaf area index (6.17) was recorded from the highest plant density of 333,333 plants ha^{-1} (30 cm × 10 cm) while the lowest leaf area index (3.71) was recorded from the lowest density of 166,667 plants ha^{-1} (40 cm × 15 cm) (Table 3). This increase in leaf area index with increased density might be due to more number of plants per unit area and reduced smaller area per plant. This result was in agreement with Costa *et al.* (1980) and Solomon (2010) who reported that that leaf area index increased as plant population increased. The result is also in agreement with result of Abdel (2008) who reported that increased plant density increased leaf area index on faba bean.

4.3.2. Total nodules and effective nodules

Analysis of variance showed that the main effect of phosphorus significantly ($P < 0.01$) affected total nodules and effective nodules. However, the main effect of plant density as well as the interaction effect did not significantly ($P < 0.05$) affected this parameter (Appendix Table 1).

Table 4. Main effect of phosphorus and plant density on total nodules, total effective nodules and plant height

Treatment	Total nodules $plant^{-1}$	Total effective nodules $plant^{-1}$	Plant height $plant^{-1}$ (cm)
Phosphorus (kg P_2O_5 ha^{-1})			
0	44.94^b	43.12^b	143.9
23	46.32^b	43.91^b	147.4
46	50.85^a	48.78^a	147.5
69	50.95^a	48.99^a	146.7
92	52.77^a	50.32^a	145.9
LSD $_{(0.05)}$	2.17	2.19	Ns
Plant density ha^{-1}			
166,667	47.72	45.57	143.4^b
222,222	50.09	47.79	144.1^b
250,000	49.99	48.79	144.1^b
333,333	49.69	47.40	153.6^a
LSD $_{(0.05)}$	Ns	Ns	7.88
CV (%)	5.3	5.6	7.3

Means in column followed by the same letter(s) are not significantly different at 5% level of significance; NS= Non-significant; LSD= Least Significance Difference; CV= Coefficient of Variation

This might be due to that phosphorus increased the numbers and size of nodules and the amount of nitrogen assimilated per unit weight of nodules that increasing the percent and total amount of nitrogen in the harvested portion of the host legume and improving the density of *Rhizobium* bacteria in the soil surrounding the root.

Total nodules increased as phosphorus application rate increased when compared to control treatments (Table 4). The highest total nodules (52.77) were recorded from the phosphorus application of 92 kg P_2O_5 ha^{-1} and the lowest (43.12) was recorded at the control treatments (Table 4). The mean value of the analysis revealed that maximum number of effective nodules (50.32) was recorded from application 92 kg P_2O_5 ha^{-1} while the lowest numbers of effective nodules (43.12) were recorded from control treatment. This might be due to that phosphorus increased the numbers and size of nodules and the amount of nitrogen assimilated per unit weight of nodules that increasing the percent and total amount of nitrogen in the harvested portion of the host legume and improving the density of *Rhizobium* bacteria in the soil surrounding the root.

4.3.3. Plant height

Analysis of variance showed that the main effect of plant density significantly ($P < 0.05$) affected plant height. However, the main effect of phosphorus as well as the interaction effects did not significantly ($P < 0.05$) affected this parameter (Appendix Table 1).

Plant height increased with increased plant density and the highest plant density of 333,333 plants ha^{-1} (30 cm × 10 cm) gave the maximum plants height (153.6 cm) while the lowest plant population of 166667 plants ha^{-1} (40 cm × 15 cm) gave the shortest plant height (143.4 cm) (Table 5). This increase in plant height might be justified on the bases of increase in the number of plants per unit area coupled with high plant to plant competition. Due to this lower amount of light intercepted by a single plant resulting into increased inter node length and also under higher plant density there might be comparatively low solar interception through crop canopy and under increased inter and intra row spacing probably the reduced interplant competition for light might have resulted in such variation in plant height. This result was in line with the finding of Taj *et al*. (2002) who reported on mung bean that, competition for light in narrow spacing that resulted in taller plants while at wider spacing light distribution was normal. The result was also in agreement with the finding of Shamsi and Kobraee (2009) who reported that increasing the density of plants led to significant increases in plant height. In contrast to this result, Shahein *et al*. (1995) reported that plant height was not affected by increasing plant density on faba bean. Similarly, Turk *et al*. (2003) reported on lentil negative correlation of plant height with plant density.

4.3.4. Number of primary branches per plant

The analysis of variance revealed that the main effects of phosphorus and plant density had significant ($P < 0.01$) effect on number of primary branches $plant^{-1}$. However, there was no interaction effect on this parameter (Appendix Table 1).

The number of branches per plant increased with increased phosphorus application rates up to 46 kg P_2O_5 ha^{-1}. The highest number of branches per plant (6.75) was recorded from rate of 46 kg P_2O_5 ha^{-1} (Table 3). This might be due to that phosphorus initiates cell division and elongation. This result was in line with Shubhashree (2007) who reported that higher number of branches per plant was recorded with high application of phosphorus on common bean. On the other hand the lowest number of branches per plant (4.04) was recorded at control treatments. The increment in number of branches per plant might be importance of P for cell division activity, leading to the increase number of branches (Tesfaye *et al*., 2007).

The number of branches per plant was increased with decreased plant density where the highest (5.63) number of branches was produced from the lowest plant density of 166,667 plants ha^{-1} (40 cm × 15 cm) and the lowest (4.93) number of branches was produced from the highest plant density of 333,333 plant ha^{-1} (30 cm × 10 cm) (Table 3). This is might be due to the fact that, as plant density decreased ample resources become available for each plant that enhances the lateral vegetative growth of the crop. The increased number of branches at the wider plant spacing could also be attributed to more interception of sunlight per plant for photosynthesis and at high density there might also be comparatively low light interception through crop canopy as compared to wider spacing that might have resulted in lesser axillaries buds leading to lower number of branches per plant.

This also indicated the plasticity response of plants to various plant spacing, that is increased in plant population is associated with a progressive decline in number of branches whereas, plants at lower density produced higher number of branches in order to compensate the dry matter per unit area of higher densities. This result was in line with the finding of Mehmet (2008) who reported increased number of branches at the wider plant spacing for soybean and attributed this to more interception of sunlight for photosynthesis, which may have resulted in production of more assimilate for partitioning towards the development of more branches. In agreement with this result, Loss *et al.* (1998) obtained that number of branches per plant declined with increasing plant density and less number of branches survived throughout maturity in faba bean. Moreover, Amato *et al.* (1992); Aydogdu and Acikgoz (1995) and Loss *et al.* (1998) also reported similar findings where in, faba bean, soya bean and common vetch, respectively, reduced the number of branches with increased plant population.

4.4. Yield Related Traits and Yield

4.4.1. Plant stand count mortality per ha^{-1}

Analysis of variance showed that the main effect of phosphorus rates and plant density had significant ($P < 0.01$) effect on plant stand count mortality. The result also showed that there was significant ($P < 0.01$) interaction effect of phosphorus and plant density on this parameter (Appendix table 2).

The highest (12.06%) plant stand count mortality was recorded from the combined no application of phosphorus and plant density of 250,000 plants ha^{-1} while the lowest (0.7%) plant stand count mortality was recorded from the combined application of phosphorus 92 kg P_2O_5 ha^{-1} and plant density of 166,667 plants ha^{-1} (Table 5). This decreased in number of of plant stand count mortality might be due to application of phosphorus fertilizer tends to form nutrient interaction valuable and makes nutrients essential for growth of the common bean.

At the lowest plant density of 166667 plants ha^{-1} (40 cm × 15 cm) lowest numbers of plants died while at the highest plant density of 250, 000 and 333,333 plants ha^{-1}. The highest numbers of plants died as compared to initial plant stand count (Table 6). This might be due to that from lower population density comparatively availability of more space might have resulted in less competition for resources (nutrients, moisture and light) whereas at high density due to more intra-specific competition the weaker plants might have died by the time the crop approached maturity. This result was in agreement with Njok (2001) who reported increased plant mortality rate as density of plant increased in common bean. The result was also in line with the finding of Abdel (2008) who reported reduced plant competition and plant mortality at lower plant population of faba bean.

Table 5. Interaction effect of phosphorus and plant density on plant stands count mortality

Phosphorus (kg P_2O_5 ha^{-1})	Plant density ha^{-1}			
	166,667	222,222	250,000	333,333
0	7.64^{cd}	11.19^{ab}	12.06^{a}	11.76^{a}
23	6.25^{d}	10.94^{ab}	11.57^{ab}	11.66^{ab}
46	3.47^{ef}	10.84^{ab}	11.21^{ab}	11.59^{ab}
69	2.78^{fg}	10.7^{ab}	10.53^{ab}	11.32^{ab}
92	0.70^{g}	5.56^{de}	9.59^{ab}	10.65^{ab}
LSD $_{(0.05)}$	2.13			
CV (%)	14.2			

Means in column followed by the same letter(s) are not significantly different at 5% level of significance; LSD= Least Significance Difference; CV = Coefficient of Variation

4.4.2. Number of pods per plant

Analysis of variance revealed that the main effect of phosphorus rates, plant population and interaction effect of phosphorus and plant density had significant ($P < 0.01$) effect on number of pods per plant (Appendix Table 2).

Highest number of pods per plant (28.33) was recorded with phosphorus fertilizer rates of 46 kg P_2O_5 ha^{-1} and plant density of 166,667 plants ha^{-1} while the lowest (18.33) was recorded from control and phosphorus application of 23 kg P_2O_5 ha^{-1} at plant density of 333,333 plants ha^{-1}over rest of the other levels. The lowest pods per plant (19.67) were recorded at control (Table 6). Thus, increase in number of pods with the increased P levels might possibly be due to adequate availability of P which might have facilitated the production of primary branches and plant height which might in turn have contributed for the production of higher number of pods. The result was in agreement with that of Shubhashree (2007) who reported that applications of different rates of phosphorus fertilizer increased number of pod per plant. Similarly, Veeresh (2003) who reported significantly more number of pods per plant of common bean at higher application rate of phosphorus (20 kg P_2O_5 ha^{-1}). Singh (2000) also reported significant increase in number of pods per plant, due to increased phosphorus fertilizers. The increment of number of pods per plant due to application of phosphorus fertilizer confirms with study by Buttery (1969) where phosphorus fertilizer promotes the formation of nodes and pods in legumes.

Number of pods per plant increased with decrease in plant density. The decrease in the number of pods per plant with the increased in plant density could be due to increased intra space competition which eventually might have caused reduction in the number of pods per plant.

Table 6. Interaction effect of phosphorus and plant density on number of pods plant^{-1}

Phosphorus (kg P_2O_5 ha^{-1})	Plant density			
	166,667	222,222	250,000	333,333
0	19.67^{hij}	19.00^{ijk}	18.67^{jk}	18.33^{k}
23	21.67^{de}	19.00^{ijk}	19.67^{hij}	18.33^{k}
46	28.33^{a}	20.00^{ghi}	20.33^{fgh}	19.33^{hijk}
69	24.33^{b}	21.33^{ef}	21.00^{efg}	21.00^{efg}
92	22.67^{cd}	23.67^{bc}	22.00^{de}	21.33^{ef}
LSD $_{(0.05)}$	1.0350			
CV (%)	3.0			

Means in column and rows followed by the same letter(s) are not significantly different at 5% level of significance; LSD= Least Significance Difference; CV = Coefficient of Variation

Furthermore, the increased in the number of pods per plant with decreased plant density might be due to increase in the number of pods per node as a result of higher net assimilation rate and reduction of competition in wider spacing. On the other hand, increased plant density induced competition between the former and later emerged flowers that could lead to flower abortion. In wider inter and intra-row spacing, however, the growth factors (nutrient, moisture and light) for individual plants might be easily accessible that retained more flowers and supported the development of lateral branches. In agreement with this result, Pilbeam (1991) also noted decrease in the number of pods per plant in the faba bean due to a reduction in the number of stems per plant at the higher densities. The result was also in agreement with Al-Abdselam and Abdi (1995); Hodgson and Blackman (2005); and Abdel (2008) who reported that the development of more and vigorous leaves on low plant density helped to improve the photosynthetic efficiency of the crop and supported large number of pods of faba bean.

4.4.3. Number of seeds per pod

Analysis of variance showed that the main and interaction effect of phosphorus rates and plant density had significant ($P < 0.01$) effect on number of seeds per pod. It was also found that there was significant ($P < 0.01$) interaction effect of phosphorus and plant density on this parameter (Appendix table 2).

Table 7. Interaction effect of phosphorus and plant density on number of seed pod^{-1}

Phosphorus (kg P_2O_5 ha^{-1})	Plant density ha^{-1}			
	166,667	222,222	250,000	333,333
0	5.67^{cde}	5.67^{cde}	5.33^{de}	5.00^{e}
23	6.33^{bc}	5.67^{bcd}	5.33^{de}	6.67^{b}
46	8.00^{a}	6.00^{bcd}	5.67^{cde}	6.67^{b}
69	6.40^{bcd}	6.33^{bc}	6.67^{b}	6.00^{bcd}
92	6.33^{bc}	6.33^{bc}	6.33^{bc}	6.00^{bcd}
LSD $_{(0.05)}$	0.89			
CV (%)	8.9			

Means in column and rows followed by the same letter(s) are not significantly different at 5% level of significance; LSD= Least Significance Difference; CV = Coefficient of Variation

The highest number of seeds per pod (8.00) was obtained from phosphorus rate of 46 kg P_2O_5 ha^{-1} at plant density of 166,667 plants ha^{-1}, whereas the lowest number of seeds per pod (5.00) was recorded from no phosphorus application at the highest plant density of 333,333 plants ha^{-1} (Table 7). The increment of seeds per pod with increased phosphorus fertilizer application up to certain level might be due to that phosphorus fertilizer is for essential nodule formation, protein synthesis, fruiting and seed formation. This result was in agreement with the finding of Shubhashree (2007) who reported that number of seeds per pod of common bean increased significantly to levels of phosphorus added.

The highest mean value for number of seeds per pod was recorded at the lowest plant density while the lowest mean number of seeds per pod was obtained at the highest plant density (Table 7). This might be due to the fact that widely spaced plants encountered less intra plant competition than closely spaced plants and thus exhibited better growth that contributed to more number of seeds per pod. This result was in agreement with Abo El-Zahab(1981); Ayaz *et al*. (2001); and Abdel (2008) who reported that number of seeds per pod increased with decreased plant density of faba bean. Moreover, Oad *et al*. (2002) on safflower reported that higher number of seeds per pod was associated with wider inter and intra-row spacing.

4.4.4. Hundred seed weight (g)

Analysis of variance showed that the main and interaction effect of phosphorus and plant density did not significantly ($P < 0.05$) affected hundred seed weight (Appendix table 2). The hundred seed weight ranged from 19.62 to 20.17 g as density decreased from 333,333 to 166,667 plants per ha^{-1}.

4.4.5. Total above ground dry biomass yield (kg ha^{-1})

The analysis of variance revealed that the main effect of phosphorus and plant density had significant ($P < 0.01$) effect on above ground dry biomass yield. However, there was no significant interaction effect of the factors on this parameter of the plant (Appendix Table 2).

The maximum (10021 kg ha^{-1}) dry biomass yield was recorded at application of phosphorus 46 kg P_2O_5 ha^{-1}; whereas the lowest (7996 kg ha^{-1}) was recorded on control (Table 8). The increase in above ground dry biomass yield at the highest rate of phosphorus might be attributed to the enhanced availability of P_2O_5 for cell elongation and division of the plants. This increment in dry biomass yield with application of phosphorus fertilizer might be due to the adequate supply of phosphorus could result in an increase in number of branches per plant, and leaf area. This in turn increased photosynthetic area and number of pods per plant, which demonstrates a strong effect with dry biomass accumulation and yield.

Table 8. Main effect of phosphorus and plant density on total above ground dry biomass yield and hundred seed weight of common bean

Treatments	Total above ground dry biomass yield (kg ha^{-1})	Hundred seed weight (g)
Phosphorus (kg P_2O_5 ha^{-1})		
0	7996^{d}	20.08
23	8941^{c}	20.08
46	10021^{a}	19.84
69	9351^{b}	19.83
92	8755^{c}	19.81
LSD $_{(0.05)}$	273.3	Ns
Plant density ha^{-1}		
166,667	8525^{b}	20.17
222,222	9056^{a}	20.17
250,000	9187^{a}	19.83
333,333	9284^{a}	19.62
LSD $_{(0.05)}$	244.5	Ns
CV (%)	3.7	12.2

Means in column and rows followed by the same letter(s) are not significantly different at 5% level of significance; LSD=Least Significance Difference; NS=Non-significant; CV=Coefficient of Variation

This result was in agreement with Shubhashree (2007) who reported dry matter accumulation increase with application of phosphorus fertilizer rates. The result was in agreement with the finding of Veeresh (2003) who reported significant increase in total dry matter production of common bean plant due to increased phosphorus. This was also in agreement with the study conducted on soybean indicating that increasing the phosphorus concentration in the soil increased the whole plant dry matter accumulation and total leaf area (Jennifer, 2000).

The highest dry biomass of (9284 kg ha^{-1}) was recorded from the highest plant density of 333,333 plant ha^{-1} (30 cm × 10 cm) followed by plant density of 250,000; 222,222 plants ha^{-1} which were stastically with the highest plant density while the lowest dry biomass yield of (8525 kg ha^{-1}) was recorded at plant densities of 166,667 (40 cm × 15 cm) (Table 9). The highest total dry biomass from the highest density might be due to more number of plants per unit area. Similar with the result, El-Douby *et al*. (1996); Sharaan *et al*. (2003); El-Metwally *et al*. (2003) and Getachew *et al*. (2006) reported increase dry biomass yield of faba bean with increased plant density. Solomon (2010) also reported that dry biomass yield per hectare was significantly increased with increased plant density on common bean.

4.4.6. Grain yield

Analysis of variance showed that the main effect of phosphorus and plant density and interaction effect of phosphorus rates and plant density had significant ($P < 0.01$) effect on grain yield (Appendix Table 2).

Phosphorus application to all treatments resulted in significantly higher grain yield than the control treatment (Table 9). The highest grain yield (3333 kg ha^{-1}) was recorded from the application of phosphorus 46 kg P_2O_5 ha^{-1} and plant density of 166,667 plants ha^{-1}, whereas the lowest grain yield (1996 kg ha^{-1}) was obtained from no phosphorus application and the lowest plant density of 166,667 plants ha^{-1} (Table 9). The increase in yield is therefore, might be attributed to the increased available phosphorus improves availability of P for crops and also external phosphorus fertilizer application improved crop yield performance. This result was in agreement with that of Birhan (2006) who reported that significant response of common bean to application of phosphorus at Melkassa because of phosphorus deficiency in the area. In contrast, Meseret (2006) reported a non-significant yield response of mung bean at Awassa Agricultural Research Center as result of high content of available phosphorus fertilizer. The result of analysis indicated that there was a significant increment of phosphorus application and grain yield, and the yield increased with increasing levels of phosphorus up to the rate of 46 kg P_2O_5 ha^{-1} and then declined afterwards. This tendency of yield decrease at the 92 kg P_2O_5 ha^{-1} might be attributed to imbalance of phosphorus with other nutrients as described by Mengel and Kirkby (1987); and Havlin *et al*. (1999).

Table 9. Interaction effect of phosphorus and plant density on grain yield (kg ha^{-1}) of common bean

Phosphorus (kg P_2O_5 ha^{-1})	Plant density ha^{-1}			
	166,667	222,222	250,000	333,333
0	1996^{j}	2259^{hi}	2401^{gh}	2087^{ij}
23	2940^{bc}	2657^{def}	2576e^{fg}	2552^{fg}
46	3333^{a}	3094^{b}	3048^{b}	2744de
69	3028^{b}	3044^{b}	3026^{b}	2367^{h}
92	2968^{bc}	2965^{bc}	2827^{cd}	2330^{h}
LSD $_{(0.05)}$	183.2			
CV (%)	4.1			

Means in column and rows followed by the same letter(s) are not significantly different at 5% level of significance; LSD= Least Significance Difference; CV = Coefficient of Variation

Increasing plant density significantly decreased individual plant grain yield. The yield reduction at the highest density for all the treatments might be due to intense interplant competition for resources such as nutrients, water and solar radiation as manifested by high plant mortality and low number of pods per plant at the highest plant density. The result of this study was in agreement with Ball *et* *al*. (2000) who reported that increasing plant population from high mean to low mean reduced yield of individual plants and decreased the grain yield ha^{-1}.

4.4.7. Harvest index

Analysis of variance showed that the main effect of phosphorus and plant density and interaction effect of phosphorus rates and plant density had significant ($P < 0.01$) effect on harvest index (Appendix table 2).

Table 10. Interaction effect of phosphorus and plant density on harvest index (%) of common bean

Phosphorus (kg P_2O_5 ha^{-1})	Plant density ha^{-1}			
	166,667	222,222	250,000	333,333
0	25.98^{gh}	29.26^{ef}	29.24^{ef}	22.83^{i}
23	33.77^{bc}	29.59^{def}	28.49^{fg}	28.37^{fg}
46	37.19^{a}	30.18^{def}	29.23^{ef}	28.16^{fg}
69	33.40^{bc}	32.07^{cde}	32.33^{cd}	27.97^{fg}
92	36.26^{ab}	33.54^{bc}	31.96^{cde}	23.31^{hi}
LSD $_{(0.05)}$	2.932			
CV (%)	5.9			

Means in column and rows followed by the same letter(s) are not significantly different at 5% level of significance; LSD= Least Significance Difference; CV = Coefficient of Variation

The mean value of the data showed that the highest harvest index (37.19%) was recorded from 46 kg P_2O_5 ha^{-1} at plant density of 166,667 plants ha^{-1} and this was statistically at propare with phosphorus rates of 92 kg P_2O_5 ha^{-1} and plant density of 166,667 plants ha^{-1} while the lowest harvest index (22.83%) was recorded from no phosphorus application and the highest plant density of 333,333 plants ha^{-1}. The result was also in line of Birhan (2006) who obtained significant response of harvest index to the application of phosphorus fertilizer rates on common bean. The result was in contrast with that of Meseret (2006) who reported a non-significant response of harvest index to phosphorus fertilizer rate on mung bean.

Harvest index increased with decreased in plant density. The highest harvest index **(**37.19%**)** were recorded with the lowest plant density of 166,667 plants ha^{-1} (40 cm × 15 cm) and lowest harvest index **(**22.83%) were recorded with the highest plant density of 333, 333 plant ha^{-1} (30 cm × 10 cm) (Table 11). The highest harvest index at the lowest 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. This result was in line with Solomon (2010) who found that harvest index was reduced with increase in plant density on common bean from 166,667 to 333,333 plants ha^{-1}.

4.5. Partial budget analysis

The result of partial budget analysis showed that the highest net benefit (Birr 27772 ha^{-1}) was obtained from (46 kg P_2O_5 $^{+}$ plant density of 166,667 ha^{-1}) followed by the net benefit (Birr 25339 and 25099 ha^{-1}) from treatment (46 kg P_2O_5 $^{+}$ plant density of 222,222 ha^{-1}) and (23 kg P_2O_5 $^{+}$ plant density of 166,667 ha^{-1}). The lowest net benefit (Birr 13648 ha^{-1}) was obtained from combined application of 92 kg P_2O_5 ha^{-1} with plant density of 333,333 plant ha^{-1}. Based on this analysis it is advisable to apply the combination of 46 kg P_2O_5 ha^{-1} and 166,667 plant ha^{-1} for this specific area to get more profitable.

Table 11. Partial budget analysis of phosphorus and plant density trial during2015/16

Treatment P_2O_5 kg + PD ha^{-1}	Averaged yield (kg/ha)	Net yield (kg/ha) (90%)	Gross filed benefit (ETB)	Total variable cost (ETB)	Net benefit (ETB)
0+166667	2218	1996.2	19962	2377	17585
0+222222	2509.69	2258.721	22587	2835	19753
0+250000	2668.22	2401.398	24014	3073	20941
0+333333	2589.43	2330.487	23305	3374	19931
23+166667	3266.2	2939.58	29396	4297	25099
23+222222	2952.36	2657.124	26571	4303	22268
23+250000	2861.8	2575.62	25756	4355	21401
23+333333	2835.011	2551.51	25515	4695	20820
46+166667	3703.7	3333.33	33333	5562	27772
46+222222	3437.96	3094.164	30942	5603	25339
46+250000	3387.2	3048.48	30485	5685	24800
46+333333	2630.36	2367.324	23673	5480	18193
69+166667	3297.72	2967.948	29680	6296	23384
69+222222	3382.12	3043.908	30439	6599	23840
69+250000	3362.08	3025.872	30259	6704	23555
69+333333	3048.52	2743.668	27437	6830	20607
92+166667	3364.92	3028.428	30284	7284	23001
92+222222	3294.54	2965.086	29651	7471	22180
92+250000	3141.52	2827.368	28274	7477	20797
92+333333	2318.94	2087.046	20871	7222	13648

Cost of TSP 100 kg^{-1} = 1855 birr (18.55 birr kg^{-1}), cost of seed = 1200 birr ha^{-1}, application cost for 23 and 46 kg P_2O_5 ha^{-1}= for 4 person (Birr 200), for 69 and 92 kg P_2O_5 ha^{-1}=for 6 person (Birr 300). The cost of harvesting, threshing and winnowing Birr 50 kg^{-1}. The transportation cost, bagging material cost and sale price cost was 30, 3 and 1000 birr kg^{-1}, respectively.

5. SUMMARY AND CONCLUSIONS

Demand for common bean is highly increasing because of it significance as cash crop and as human nutrition as a source of proteins, complex carbohydrates, vitamins and minerals. Common bean is also one of the most commonly inter cultivated pulse crops in the study area Dangure District in Benishangul Gumuz Region, North-western Ethiopia. However, the necessary recommendations such as fertilizer rates, optimum planting density, etc are lacking.

In view of this, field experiment was conducted to determine effects of phosphorus fertilizer rates and plant density on yield and yield related traits of common bean. The treatments consisted of five levels of phosphorus fertilizer (0, 23, 46, 69 and 92 kg P_2O_5 ha^{-1}) and four plant density ha^{-1} of 333,333 (30 cm × 10 cm), 250,000 (40 cm × 10 cm), 222,222 (30 cm × 15 cm) and 166,667 (40 cm × 15 cm) evaluated in factorial arrangement in randomized complete block design with three replications.

Analysis of variance showed that a day to 50% flowering was non-significantly affected by phosphorus fertilizer rates and plant density where phosphorus application has slightly reduced the days to 50% flowering. Plant density and phosphorus fertilizer rates significantly affected days to maturity. The highest days to maturity (91.87 days) was recorded from control and the lowest (84.83 days) from 92 kg P_2O_5 ha^{-1}. While the highest (91.49) and lowest (86.28) days to maturity was recorded from plant density of 166,667 and 333,333 plants ha^{-1}, respectively.

Main effect of phosphorus fertilizer rates and plant density had highly significant effect on both leaf area and leaf area index. The leaf area per plant decreased as the plant density increased where as leaf area index increased as the plant density increased. The application of phosphorus fertilizer rates and plant density showed significant ($P < 0.01$) effect on the number of branches per plant where the highest mean number of branches (6.75) and the lowest (4.04) were recorded from phosphorus application of 46 kg P_2O_5 ha^{-1} and from no phosphorus application, respectively. Similarly, highest number of branches per plant (5.63) and lowest number of branches (4.93) were recorded from plant density of 166,667 plants ha^{-1} (40 cm x 15 cm) and 333,333 plant ha^{-1} (30 cm x 10 cm), respectively. Phosphorus application had significant ($P < 0.01$) effect on number of total nodules and effective nodules. The highest total nodules per plant (52.77) and effective nodules per plant (50.32) were recorded from phosphorus application of 92 kg P_2O_5 ha^{-1} and the lowest (44.94) and (43.12) total effective nodules, respectively were recorded from no phosphorus application. Plant density had significant ($P < 0.05$) effect on plant height where the highest (153.6 cm) and the lowest (143.4 cm) height were recorded from the plant density of 333,333 plant ha^{-1} (30 cm x 10 cm) and 166,667 plant ha^{-1} (400 cm x 15 cm), respectively.

The interaction effect was significant ($P < 0.01$) on number of pods plant^{-1} and on number of seeds pod^{-1}. The highest number of pods per plant (28.33) and the highest number of seeds per pod (8.0) were obtained from combination of phosphorus application of 46 kg P_2O_5 ha^{-1} and plant density of 166,667 plants ha^{-1}.

Plant density and application of phosphorus fertilizer rates had significant ($P < 0.01$) effect on total dry biomass. The highest dry biomass (10021 kg ha^{-1}) and the lowest (7996 kg ha^{-1}) were recorded from phosphorus application of 46 kg P_2O_5 ha^{-1} and control, respectively. With regard to plant density, the lowest (8525 ha^{-1}) and the highest (9284 kg ha^{-1}) dry biomass were recorded at plant density of 166,667 plants ha^{-1} (40 cm x 15 cm) and 333,333 plants ha^{-1} (30 cm x 10 cm), respectively.

Interaction effect was significant ($P < 0.01$) on grain yield of common bean. The highest grains yield (3333 kg ha^{-1}) was recorded from phosphorus application of 46 kg P_2O_5 ha^{-1} and plant density of 166,667 plants ha^{-1}. While the lowest grains yield (1996 kg ha^{-1}) was recorded from no phosphorus application and plant density of 166,667 plants ha^{-1}.

From the partial budget analysis result, the application of phosphorus fertilizer rate (46 kg P_2O_5 ha^{-1}) with low plant density 166,667 plants ha^{-1} (40 cm x 15 cm) gave the highest net benefit of 27772 Birr ha^{-1}.

In conclusion, the results of the study indicated that most of the yield components and yield of common bean to be superior at phosphorus rate of 46 kg P_2O_5 ha^{-1} and plant density of 166,667 plant ha^{-1} (40 cm x 15 cm) which can be tentatively recommended to be used in the study area for common bean production. However, this study was a one season experiment at one location. Thus, the experiment has to be repeated over locations and seasons to come to a conclusive recommendation.

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