RESPONSES OF FABA BEAN (*Vicia faba* L.) TO PHOSPHORUS FERTILIZER RATES AND PLANT POPULATION AT HARAMAYA EASTERN HARARGHE, ETHIOPIA

M. Sc. Thesis

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POSTGRADUATE PROGRAM DIRECTORATE
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We hereby certify that we have read and evaluated this thesis **entitled: "Responses of Faba Bean (*Vicia faba* L.) to Phosphorus Fertilizer Rates and Plant Population at Haramaya Eastern Hararghe, Ethiopia"** which has been prepared under my guidance by Tolamariam Taressa: and we recommend that the thesis be accepted as fulfills the requirement.

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Final approval and acceptance of the Thesis is contingent up on the submission of its final copy to the Council of Graduate studies (CGS) through the candidates department or school of graduate committee (DGC or SGC).

DEDICATION

This thesis is dedicated to my parents who brought me up and to my beloved brother Firaol Taressa for the contribution he made in my training.

STATEMENT OF AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of materials used for thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at Haramaya University and is deposited at the University library to be made available to borrowers under rules of the University library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

Mr. Tolamariam Taressa was born on June 6, 1992 in Oda Gudaya, West Shoa of Oromia, Ethiopia. He completed his elementary school (2000-2008) and high School (2008-2012) at Oda Gudaya elementary school and Ambo secondary high school, respectively. He joined Welloga University in 2013 and obtained the Bachelour of Science degree in Agriculture (Plant Science) in June 2015. He was employed by the Haramaya University (HU) College of Agriculture and Environmental science in 2016. He has been serving the University as a Senior Technical Assistant in the School of Plant Sciences, in Agronomy/Pysiology Program. He has been actively participating in Highland Pulse Research Program of HU. He joined the Postgraduate Progaram Studies of Haramaya University of Agriculture in 2018.

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ACRONYMS AND ABBREVIATIONS

BNF	Biological Nitrogen Fixation
CIMMYT	Centro International Mejoramiento Maize y Trigo
CSA	Central Statistical Authority
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
ICARDA	International Center for Agricultural Research in the Dry Areas
m.a.s.l	Meter above sea level
MoA	Ministry of Agriculture
MoANR	Ministry of Agriculture and Natural Resources
TSP	Triple Super Phosphate
WANA	West Asia and North Africa

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ABSTRACT

A field experiment was conducted to study the responses of faba bean (Vicia faba L.*) to phosphorus fertilizer rates and plant population at Haramaya University, Rare research site during 2019/2020 cropping season. Factorial combinations of four phosphorus (P_2O_5) levels (0, 23, 46, and 69 kg/ha) and six plant populations (133,333; 166,667; 200,000; 222,222; 250,000 and 300,000 plants ha^{-1} respectively were tested. The experiment was laid out in a randomized complete block design (RCBD) replicated three times. Improved faba bean variety (Gachena) was used as a test crop. Phenological parameters, growth, yield and yield components were measured and analyzed using ANOVA. Treatment means with significant differences were separated using least significant difference (LSD) test at 5% probability level. There was highly significant ($P<0.01$) effect of rate of phosphorus on number of days to flowering and maturity, leaf area, leaf area index, effective nodules per plant, plant height, number of primary tillers plant^{-1}, number of seeds pod^{-1}, hundred seed weight, seed moisture content, grain yield, dry biomass yield and harvest index. The shortet period to flowering (54.83 days) after emergence and maximum plant height (189.7 cm), leaf area (58.42 cm^2), number of pods per plant (26.34), number of seeds pod^{-1}(3.378), dry biomass yield (15978 kg ha^{-1}), hundred seed weight (74.22 g) and harvest index (20.32%) were obtained from the highest rate of P (69 kg of P_2O_5 ha^{-1}), but the highest grain yield (2984 kg ha^{-1}) was obtained from 46 kg of P_2O_5 ha^{-1}. For all plant populations, leaf area index, number of primary tillers~~,~~ and pods plant^{-1}, number of seeds pod^{-1} and hundred seed weight increased as the rate of phosphorus increase and the highest leaf area index (3.376), number of primary tillers per plant (3.278) and hundred seed weight (73.88 g) were recorded for the widest spacing (50 x 15 cm) or for a population density of 133,333 plants ha^{-1} while the highest total number of nodules (155.2) and number of effective nodules (16.67) resulted from 250,000 plants ha^{-1} (40 x 10 cm). On the other hand, the interaction of plant population and phosphorus significantly influenced number of seeds per pod^{-1}, above ground dry biomass yield, hundred seed weight, grain yield and harvest index. A population density of 300,000 plants ha^{-1} (30 x 10 cm) gave the highest dry biomass yield (15676 kg ha^{-1}) and grain yield (2893 kg ha^{-1}), whereas the highest harvest index (22.07%) and number of pods plant^{-1}(26.9) were obtained from 133,333 plants ha^{-1} (50 cm x 15 cm). Partial budget analyse was also used to analyze the economic benefit gained from the treatments. Thus, it can be concluded that application of 46 kg of P_2O_5 ha^{-1} at 30 x 10 cm plant spacing proved to be superior with respect to grain yield on fluvisols of Haramaya area. However, further study is required at least for one more cropping season on different soils to reach at a conclusive recommendation.*

***Keyword**: Crop phenology, dry matter and grain yield, growth, yield components*

1. INTRODUCTION

Pulses are important food crops due to their high protein and essential amino acid content. The seeds of pulse crops are typically made up of 20 to 25% as compared to 6 to 10% protein content in major cereal crops. Pulses are also rich in dietary fiber and usually have only small amounts of oil. The protein of pulse seeds is high in amino acids; lysine and methionine, making pulses nutritionally complementary to cereals, which are deficient in these two essential amino acids. Pulses are the main source of protein in the diet of vegetarians, and feature prominently in the traditional cuisine of virtually every region of the globe (Sitou and Mywish, 2011).

Faba bean (*Vicia faba* L.) is one of the oldest crops in the world most probably domesticated in the late Neolithic period (Metayer, 2004). It is also the important legume crop grown primarily for its edible seeds (beans), which is mainly cultivated for its protein content (on average 30%) in Africa and central Asia. Its popularity has increased recently as its high yield makes it attractive to produce, while its high protein content and low-price makes it attractive to the consumer. It has also a valuable agronomic function of N_2 fixation and the ability to facilitate diversification of the agro-ecosystems by indirectly enhancing associated diversity of wild fauna (Köpke and Nemecek, 2010). Its key environmental service is providing a source of nectar and pollen to pollinators and beneficial insects. The interest in this crop has been renewed, because of decline in the pollinators' worldwide (Duc *et al*., 2014).

Faba bean is one of the most globally important legume crops. Its global acreage declined from 3.7 to 2.1 million ha between 1980 and 2014, and yields are highly variable within specific countries (FAO, 2017). The global production of faba bean grain in 2014 was 4.1 million tons, which was approximately 21% greater than in 1994 (FAO, 2017). In North Africa, the area under faba bean cultivation remains stagnant during the last past five decades, but its production has increased from 405,000 tons in 1961-65 to 605,000 tons in 2011-2014. In North Africa, the major faba bean consuming countries are Egypt, Morocco, and Sudan, which are importing 0.34 MT with a value of 320 million USD and West Asia region imports 93589 tons with a value of 65 million USD in 2013 (FAOSTAT, 2016).

Although global faba bean acreage and production has experienced a steady reduction over the past decades, demand for the crop in the world market led to its increased production in Australia and France (Brown *et al*., 2009). Its production for food and feed was 4.5 million tons worldwide in 2012 and is now widespread in Europe, North Africa, Central Asia, China, South America, the USA, Canada, and Australia. The main faba bean producers are China (1.65 Mt), Ethiopia (0.61 Mt), France (0.44 Mt), Egypt (0.29 Mt), and Australia (0.19 Mt) (FAOSTAT, 2017).

Faba bean is one of the most important grain legumes in Ethiopia in terms of area, production, source of protein and as a rotation crop ameliorating soil fertility. Ethiopia is one of the largest producers of faba bean in the world second only to China (Hawtin and Hebblethwaite, 1983). The country is considered as the secondary center of diversity and also one of the nine major agro-geographical production regions of faba bean (Telaye, 1994). The crop is produced in many parts of Ethiopia and it thrives best in cool, moist areas having an altitude range of 1800-3000 m.a.s.l. However, faba bean utilization and production have been declining in the last decades (by 50% between 1960 and 2010) due to biotic and abiotic factors and replacement of traditional cropping systems by industrialized cereal-based systems (Jensen *et al*., 2010).

Faba bean ranks first in its production volume and cultivated land among pulse crops cultivated in Ethiopia and it is valuable as the cheap source of protein in most Ethiopian diet (Hailu *et al*., 2014). According to the Central Statistical Agency (CSA, 2017/18) reported, faba bean is the first among pulse crops cultivated in Ethiopia. Pulses covered 12.61% (1,598,806.51 hectares) of the grain crop area and 9.73% (about 29,785,880.89 quintals) of the grain production was drawn from the same crops. Faba beans, haricot beans (red), and chick peas were planted to 3.45% (about 437,106.04 ha^{-1}),1.71% (about 216,803.91 hectares) and 1.91% (about 242,703.73 hectares) of the grain crop area respectively (CSA, 2018).

In East Africa, Ethiopia is the major consumer and producer of faba bean. The area under faba bean grains has increased from 348,400 ha in 1993-1995 to 471,700 hectares in 2011-2014 with yield increase from 1 t ha^{-1} to 1.9 t ha^{-1} respectively. Although many countries in

North Africa and the Nile valley region imports faba bean, Ethiopia exported 0.04 MT of faba bean with a total of 25 million USD in 2013 (FAOSTAT, 2016). Despite its immense economic and ecological merits, productivity of faba bean in Ethiopia is far below the potential due to a number of biotic and abiotic constraints, and inadequate use of improved production technologies. Productions have been constrained by several yield limiting and reducing factors. The limiting natural resources of land and water, in addition to climate change, also have put high pressure on ongoing breeding programs of faba bean (Pandey *et al*., 2016).

An appropriate plant density is a factor, which affects growth, development and grain productivity per unit area in almost all crops, including faba bean. Plant density has a remarkable capacity to exploit the environment with varying competitive stresses. High plant density may cause lodging, less light penetration in the crop canopy, reduced photosynthetic efficiency and can reduce the yield drastically. In contrast, low plant density may result in low yield, more weed infestation, and poor radiation-use efficiency (Lemerle *et al*., 2006). It has been reported that among the various package of improved production technologies, proper plant populations with appropriate adjustment of inter and intra-row spacing play a key role in enhancing faba bean production (Gezahegn *et al*., 2016). Optimum plant density varies across locations have as different location has different soil types, soil moisture, soil fertility and relative humidity (Elhag, 2014).

Faba bean is able to fix nitrogen and it is used in crop rotation. Like the other members of Fabaceae, faba bean also increases the humus in the soil. Depending on the plant density and field management, the crop is able to fix up to 40 kg/ha nitrogen annually. Despite the importance of the crop in the traditional farming systems, the yield is generally low due to several factors, including poor soil fertility and inadequate plant nutrition, sub-optimal weed control, and lack of improved varieties (Getachew, 2011).

Phosphorus is, in fact, the most important growth-limiting nutrient for pulses including faba bean (Amare *et al*., 1999). Phosphorus deficiency leads to a general reduction in most metabolic processes, including cell division, cell expansion, respiration, and photosynthesis

(Epstein, 1972). Besides, in Vertisols of Ethiopian highlands, phosphorous is fixed and its non-availability is a limiting factor for better crop growth and development.

Soil fertility is sub-optimal for the production of faba bean in Ethiopian highlands. Phosphorus deficiency has also been shown to be the major yield limiting nutrients in the highlands of Ethiopia (Bereket *et al*., 2011) particularly soils of many areas in highlands that receive high rainfall suffer from remarkable phosphorus deficiencies due to phosphorus fixation at low pH. Phosphorous fertilizer application at an optimum level is necessary to improve the yield of faba bean. Indeed, there is a need to evaluate the performance of faba bean in varying plant populations and determine optimum density as well as optimum phosphorus fertilizer rates of the crop for maximum yield. So far, no works have been conducted on the determination of optimum phosphorus fertilizer rate for the production of faba bean at Haramaya University, Ethiopia.

Therefore, this study was initiated with the following objectives:

- To evaluate the responses of different rates of phosphorus fertilizer and plant population on yield related traits and yield of faba bean and
- To determine economically optimum rate of phosphorus for faba bean production.

2. LITERATURE REVIEW

2.1. Origin and Distribution of Faba Bean

Faba bean (2n=12) belongs to the order Fables and the genus belongs to the Fabaceae family together with *Lathyrus*, *Lens* and *Pisum* (Smýkal *et al*., 2015). Cultivated forms are herbaceous annuals, which are indeterminate in growth habit. Faba bean is also referred to as a broad bean, horse bean or field bean (Sainte, 2011). Faba bean is an ancient crop and numerous studies have been performed on its origin and domestication. The Mediterranean and Central Asian regions are regarded as the probable centers of origin and domestication of faba bean (Singh, 2002). Cubero (2011) suggested a Near Eastern center of origin with four different radiations: to Europe; along the North African coast to Spain; along the Nile to Ethiopia; from Mesopotamia to India. Secondary centers of diversity are postulated to have occurred in Afghanistan and Ethiopia.

The migration of faba bean to South America, probably during the fifteenth century, occurred with the Spanish and Portuguese sailors (Duc *et al*., 2015). The time of introduction of faba bean in China is uncertain (Wang *et al*., 2012). Zong *et al*. (2009) reported that winter faba bean from China "appears to be in a different gene pool from the rest of the world" reproductively isolated from the European, African and Asian gene pools. The relatively recent development of winter faba beans occurred in Europe, in the nineteenth century, as a hybridization result of Russian and French small seeded populations (Duc *et al*., 2015).

Ethiopia is, undoubtedly, considered as one of the important centers of secondary diversity for faba bean (Asfaw *et al*., 1994). However, areas of eco-geographic distribution and the micro-center of genetic diversity are not well known. The existence of more genetic diversity in one region compared to the other could be due to differences in the level of variability among the original introductions to different regions, the nature and degree of both human and natural selections after introduction, and effects of ecological and agricultural conditions as major forces of evolution.

Agricultural biodiversity, comprising all the elements from gene to agricultural ecosystems, is one of the principal components of natural resources (Chahal and Gosal *et al*., 2002; and Singh 2002), even though it is often treated separately from other natural resources in many parts of the world including Ethiopia. It is assumed that the crops were brought to Ethiopia directly from Central Asia immediately after domestication and have been grown since antiquity (Dawit *et al*., 1994).

2.2.Morphological Description of Faba Bean

Faba bean is a cool season annual legume (Bilalis *et al*., 2003) that forms coarse, upright, hollow, and unbranched stem(s) from the base, and grows between 0.1 and 2 m tall (Bond *et al*., 1985; Duc *et al*., 2015; Heuzé *et al*., 2016). Stem growth is indeterminate, and some cultivars are prone to lodging. The leaves are alternate, pinnate, and consist of two to six leaflets, which are up to 8 cm long without tendrils (Bond *et al*., 1985). The flowers have a typically papilionaceous structure and are grouped in inflorescences; they are either pure white in color or with diff use anthocyanin pigmentation on all petals, while black spots are often present on the wing petals (Bond *et al*., 1985; Duc *et al*., 2015; Heuzé *et al*., 2016).

Seeds, which vary considerably in size, are oblong to broadly oval with a prominent hilum at the end; their color can be yellow, green, brown, black, or violet, and sometimes seeds are spotted (Nozzolillo *et al*., 1989; Duc *et al*., 2015). Faba bean plants feature a robust taproot with frequent lateral root branching from the top of the tap-root; nitrogen-fixing nodules containing rhizobia occur on both the tap and lateral roots (Bond *et al*., 1985). Root traits of European accessions veary profoundly (Zhao *et al*., 2018), and are largely influenced by the tillage regime (Muñoz-Romero *et al*., 2011). Faba bean is generally considered day-neutral, while some accessions require long-day conditions in order to flower.

2.3. Ecology of faba bean

Faba bean is widely grown in mid land and high-altitude areas. It is wide adaptations grows well between 1800-2600 meters above sea level (m.a.s.l). The crop also does a well in some areas as high as 3000 meters above sea level that receive well distributed average rainfall of 700-1000 mm throughout the growing season (Amare, 1990; Tilahun *et al*., 2013). Faba bean requires a cool season for the best development. It is a hardy crop and can withstand rough climates, especially cold ones. It is grown as a winter annual in warm temperate and subtropical areas; hardier cultivars in the Mediterranean region tolerate winter temperatures of -10°C without serious injury whereas the hardiest European cultivars can tolerate up to -15°C (Robertson *et al*., 1996). It can be grown anywhere and does not winterkill. Well-adapted to wetter portions of cereal-growing areas of western Canada and elsewhere. It tolerates nearly any soil type; grows best on rich loams. A moderate moisture supply is necessary (Duke, 1981). It is considered to be the least drought resistant of legume crops; however, cultivars with high water use efficiency have been developed at ICARDA (Robertson *et al*., 1996). Moisture requirement is highest about 9-12 weeks after establishment. Faba bean is more tolerant of acid soil conditions than most legumes. Growing seasons should have little or no excessive heat, optimum temperatures for production range from 18 to 27°C (65-85°F)" (Duke, 1981). The maturity period ranges from 90-200 days depending upon the cultivars and climatic conditions (Bond *et al*., 1985). Faba bean tolerates frost better than other pulses.

2.4. Faba Bean Production in the World and in Ethiopia

Faba bean is the world’s most important legume. In Ethiopia, faba bean is the crop that has the highest absolute production and the largest area cultivated. Ethiopia is also the second largest producer of faba bean in the world next to China (Ronner and Giller, 2012). Faba bean is the most important pulse crop in terms of area coverage and total annual production in Ethiopia. This crop has manifold advantages in the economic lives of the farming community in the high lands of the country. It is a source of food, feed, cash to farmers and also play a significant role in soil fertility practices. However, currently its share in the countries pulse export is small.

Faba bean is one of the major pulse crops occupying about 35% both in terms of area coverage and volume of the annual production of all pulses produced in the country and grown in the highlands (1800 to 3000 meter above sea level) of Ethiopia (Gemechu *et al.*, 2003). Ethiopia is a country of great eco-geographical diversity with high and rugged mountains (EMA, 1988). This eco-geographic diversity might have resulted in diverse crop germplasm in general (Vavilov, 1951), including those of faba bean.

Previous reports show that faba bean diversity in Ethiopia may not be uniformly distributed across eco-geographic regions but rather concentrated in a particular region depending on ecological, agricultural, and socio-cultural conditions in the area (Chahal and Gosal, 2002). According to Singh, (2002) reported that small areas within the large center of diversity, called micro-centers, may exhibit a much greater diversity than the center as a whole.

Faba bean in Ethiopia: widely cultivated throughout the highland areas of the country and requires an altitude of 1800 and 3000 meters above sea level (Senayit and Asrat, 1994). Estimated at 437,106.04 hectares; with a total production of 1,598,806.5 tons and average productivity of 3.01 tons per hectare (CSA, 2018). Over 90% of the total faba bean land is cultivated by small scale farmers using traditional practices and the major producing regions are Amhara, Oromia, Tigray, and some part of Southern Ethiopian highlands (Senayit and Asrat, 1994). Faba bean is also commonly growing in wide regions of Northern Gonder, Northern Wello, Southern Shewa, Northern Shewa, Bale and Arsi region. Even though it is generally believed that the Ethiopian faba bean landraces have valuable genetic diversity (Harlan, 1969; Van der Maesen *et al*., 1988; Engels and Hawkes, 1991), the eco-geographic distribution and micro-centers of genetic diversity are not yet well known.

2.5. Importance of Faba Bean

As a global food crop, faba bean plays an important role in the nutrition of millions of people in the world particularly in the Middle East, the Mediterranean region, China, and Ethiopia. Ethiopia is second to China in faba bean production area but fourth in productivity per unit area after Egypt, Sudan and China in the world (Abdalla *et al*., 2014).

Cultivated faba bean is used as human food in developing countries and as animal feed, mainly for pigs, horses, poultry and pigeons in industrialized countries. Faba bean seed, generally recognized of good nutritional value, has a long history of uses in human foods or animal feeds. This is the result of its valuable and digestible major seed components, starch, and proteins. It offers a low-cost alternative to beef and milk because the seed is rich in protein, iron, fibers, and complex carbohydrates (Torres *et al*., 2006; Madani *et al*., 2008). It can be used as a vegetable, either green or dried, fresh or canned.

Faba bean has been considered as a meat extender or substitute and as a skim-milk substitute. Sometimes grown for green manure, but more generally for stock feed. Large-seeded cultivars are used as a vegetable. Roasted seeds are eaten like peanuts in India" (Duke, 1981). Straw from faba bean harvest fetches a premium in Egypt and Sudan and is considered as a cash crop (Bond *et al*., 1985). The straw can also be used for brick making and as a fuel in parts of Sudan and Ethiopia.

2.5.1. Human consumption

The most profitable use for pulses is the human consumption market. It is generally consumed whole, canned, split and/or milled into flour. The main uses are: Cooked or baked whole beans are used in soups, purées, baked goods, snack foods, and breakfast foods, or can be cooked into a thick gruel. Ground – uncooked beans ground with other ingredients make falafel or tameya. Sprouts – sprouted for use in salads and stir-fries. Fresh sold fresh in the pod or frozen. Faba bean is also a valuable source of amino acids, being particularly rich in the essential amino acids' arginine, lysine, and leucine, at up to 67 g kg^{-1} dry matter, the crude protein content of faba bean ranges from 24–31% (Koivunen *et al*., 2016). Faba bean is a good source of carbohydrate and protein and is low in fat. Carbohydrate is mainly starch. They are also high in fiber. (Robinson and Raynes, 2013). Faba bean meet all adult human requirements for essential amino acids except methionine and tryptophan. They also provide the recommended daily allowance of all essential minerals except calcium (Lines *et al*., 2013; McMurray, and Jeisman, 2013).

2.5.2. Animal feed

Pulses are a valuable stock feed due to their high protein levels and palatability and can be used as part of intensive livestock rations or as supplements for paddock reared stock.
Faba bean is used in the aquaculture, pig, poultry and horse industries as a source of protein as an alternative to field pea, fishmeal, lupin, soybean meal, and other protein supplements (Brand *et al*., 2016). Faba bean is highly digestible and the metabolizable energy for pigs, poultry, and ruminants is similar to lupin, field pea and soybean meal. They can correct the deficiencies in cereal stubbles or dry feed better than cereal grains. However, they are not as low in starch or as high in fiber as lupin, so they must be introduced gradually and fed regularly to avoid grain poisoning. Faba bean produces excellent weight gain in sheep and cattle. Cattle are unable to pick up spilled seed from smaller pulses, / but can manage faba bean pulse Australia (2016).

2.6. Agronomic Potential of faba bean

2.6.1. Role in ecosystem sustainability

The increasing use of fertilizers has affected the nitrogen (N) cycle, resulting in a high concentration of reactive N in the biosphere, with negative consequences on the climate, ecosystems, and health (Galloway *et al*., 2003).

Cropping systems with legumes reduce nitrous oxide emissions and have positive phytosanitary effects, with higher environmental benefits, than cropping systems without legumes (Reckling*et al*., 2016).

Systems involving faba bean such as, for example, crop rotation or intercropping, which have the capacity to capture atmospheric N_2 are cheaper and a more sustainable alternative than conventional agriculture (Köpke and Nemecek, 2010; Carranca, 2013). Consequently, the N benefit from faba bean to subsequent crops is often high.

2.6.2. Role in Crop rotation

Crop rotation is planned succession of crops of different genus or species. The rotation may vary from two or three years, aiming to balance nutrient demands, soil structure improvement and reduction of pest populations, diseases, and weeds (Carranca, 2013). In rotation, faba bean can be used between the seasons of cereal (wheat, winter barley and silage maize) or other cash crops (Carranca*et al*., 1999; Amanuel *et al*., 2000; Paull *et al*., 2011).

Faba bean should not be used in successive years in order to avoid yield losses mainly due to fungal infections. The minimum number of break years required to reduce the risk of fungal infections is considered to be 4 years (Stoddart*et al*., 2010). Faba bean acts as a break crop in intensive cereal dominated crop rotations and so, it is a key species for enhancing the sustainability of the agro ecosystems (Jensen *et al*., 2010; Köpke and Nemecek, 2010).

Growers also need to consider the beneficial impact of faba bean on subsequent cereal yields and weed control options even if the faba bean crop performs poorly (Lamb, 2004). It plays an essential role in crop rotation due to the ability to fix N, and also able to provide a significant level of N from the soil air using a symbiotic relationship with Rhizobium bacteria.

2.6.3. Intercropping

Intercropping is the practice of growing simultaneously two or more compatible crops in close proximity to promote interaction between them and increase productivity per unit of land (Carranca, 2013). It is a widely distributed practice due to its high and more stable productivity in a wide range of crop combinations (Pelzer *et al*., 2012; Carranca, 2013). Intercropping may minimize crop failure due to adverse effects of biotic and abiotic factors (Jensen *et al*., 2010; Fernández-Aparicio *et al*., 2011), protect soil against erosion, provide a good weed control (Wolfe *et al*., 2013), improve the use of limited resources, increase the stability of yield and provide higher returns (Tilman*et al*., 2006; Agegnehu *et al*., 2008). Intercropping is common in the tropics (Agegnehu *et al*., 2008; Lithourgidis*et al*., 2011) and China (Fan *et al*., 2006), but is less common in temperate climates, because high input monocropping with precise applications of fertilizers and pesticides has higher revenues (Köpke and Nemecek, 2010; Schroder and Köpke, 2012). However, intercropping is becoming more used for low input and organic agriculture systems (Köpke and Nemecek, 2010). The most significant advantage of grain legumes in intercropping is that nitrogen fixed by the legume may be transferred to a non-legume intercropping partner (Jamont*et al*., 2013). Faba bean has been intercropped with oil crops, as for example oilseed rape (Jamont*et al*., 2013). Intercropping faba bean with rapeseed resulted in complimentary use of N resources and the complementary root architecture between the two crops reduces plant competition for the N-soil at the beginning of their development (Jamont*et al*., 2013). On the other hand, it was found that maize promotes N_2 fixation in the intercropping system with faba bean and recently, Li *et al*. (2016) explained the reason for that. It was demonstrated the facilitative root-root interactions that constitute a mechanism for a positive relationship between productivity and plant diversity in ecosystems.

2.7. Soil Fertilization

Nitrogen fertilization is not generally required, but the application of "starter" nitrogen fertilization at a rate of 20 kg ha^{-1} seems to enhance the nodulation process in faba bean plants (Mohamed and Babiker, 2012). Furthermore, legume biological nitrogen fixation (BNF) is energy intensive process that requires large amounts of phosphorus (P). Thus, P fertilization at a rate of 40 kg ha^{-1} can often enhance the nodulation process and N_2 fixation, and increase yield (Bolland *et al.*, 2000; Adak and Kibritci, 2016). Several studies show that faba bean responds to S and K fertilization (Sangakkara *et al*., 1996; Niewiadomska *et al*., 2015). Nevertheless, S or K fertilizers are rarely applied, because faba bean is cultivated as a low-input crop. Furthermore, micronutrient (e.g., zinc and boron) deficiencies are rare and can easily be corrected through foliar sprays.

2.7.1. Phosphorus

Phosphorus (P) is the second most important macro-nutrient after N that plays a significant role in physiological and biochemical reactions such as photosynthesis and transfer characteristics (Mehrvarz *et al*., 2008). It is also a part of the structure of DNA, RNA, ATP, and phospholipids in membranes. The chemical weathering of inorganic P results in the release of plant- available orthophosphate (HPO_4^{2-} and $H_2PO_4^-$).

This reaction is slow and very little plant-available P derived from this source is present in the soil solution at any time (Sims and Sharpley, 2005). Phosphorus is also a non-renewable natural resource and, Phosphorus utilization in crop production is inefficient due to low P solubility and mobility in the soil (Fixen and Bruulsema, 2014). Phosphorus is an important plant nutrient for pulse crops. It promotes the development of extensive root systems and vigorous seedlings. Encouraging vigorous root growth is an important step in promoting good nodule development. It also plays an important role in the N fixing process and in promoting earlier, more uniform maturity. Phosphorus is the first major limiting nutrient in legume crops production because an adequate amount of P nutrition enhances the physiological activities of legume crops including stimulation of early root formation, growth, nodulation, photosynthesis, and flowering (Giller *et al.*, 1994).

From the essential plant nutrients, nitrogen and phosphorus are often deficient in many soils of tropical Africa as well as in many Ethiopian soils (Ngugi, 1982). In the tropics, the amount of available P in soils is largely insufficient to meet the demand of legumes and thus phosphorus deficiency is widespread in pulse crops (Rao *et al.*, 1998).

Phosphorus deficiency leads to a general reduction in most metabolic processes, including cell division, cell expansion, respiration and photosynthesis (Marschner, 1995). This low P fertility may contribute to reduced stand vigor, poor nodulation and growth, and ultimately lower yield. It is known that P nutrition plays a prime role in growth and development of roots and its role in nodulation, dry matter production, N fixation, and protein synthesis of leguminous crops is vital (Tekle *et al*., 2015), though the nutrition for N is met through rhizobia fixation of atmospheric nitrogen.

Totally, one of the most important effects of P on the yield of faba bean is its low efficiency in soil due to low solubility and absorption. Phosphorus is considered the second essential nutrient element for both the plants and microorganisms. In spite of the considerable addition of phosphorus to soil, the amount available for the plant is usually low. Phosphate dissolving bacteria and soil microorganisms can play an important role in improving plant growth and phosphate uptake efficiency by releasing P from rock or tri-calcium phosphate. Microorganisms can play an important role in the availability of phosphorus in calorific and nutritive value especially in the diet of low soils. Egyptian Government is pressing hard to plant in the presence of phosphate dissolving increase the yield and quality of faba bean plant through microorganisms (Salem and EL-Nakhlawy, 1987).

2.7.2. Effects of phosphorus application on yield and yield components of faba bean

Al- Farhan and Al-Rawi (2002) reported that improving agricultural practices such as fertilization with phosphate dissolving bacteria enhance crop growth, phosphorus, seed inoculation with phosphate dissolving improve seed and straw yields, and increase nutrient bacteria and foliar application with zinc uptake. In a field experiment on the faba bean, (Abou-Salama and Dawood, 1994) found that increases in P up to 90 kg ha^{-1} could increase yield production. The studies of Selim and El-Seessy, (1991) on faba bean showed that the effect of 240 kg ha^{-1} calcium superphosphate using was less than controls on yield, whilst 360 kg ha^{-1} from this fertilizer reduced the yield. For the improvement of solubility and absorption, the best P-resource should be identified and apply to faba bean (Ahmed, and El-Abagy 2007). It is believed that the reason for the nonsignificant effect of P on the yield is the antagonistic interaction between P and microelements (Towshih and Sadri, 2003).

The increased plant node number, plant length and the yield due to more TSP application. Since the flowers of faba bean produced on the nodes, thus the presence of more nodes and length in plants results in more yield. The seed dry matter and the grain protein was not affected by amounts and type of P fertilizers, but plant dry matter in TSP treatment was better. Work published by Jensen *et al*. (2010) found that phosphorus uptake rate follows (or regulates) dry matter production of the crop. They also found that faba bean plants are more responsive to phosphorus at maturity than at the seedling stage.

This is thought to be due to the high levels of phosphorus reserves in the faba bean seed. According to Shubhashree, (2007) applications of different rates of phosphorus fertilizer influence the number of pods per plant. Veeresh (2003) observed a significant number of pods per plant of faba bean at the application rate of 75 kg P_2O_5 ha^{-1}. Also, Singh *et al*.

(2000) reported a significant increase in the number of pods per plant, due to increased P fertilization.

Thus, the increment of the number of pods per plant due to the application of P fertilizer confirms with P fertilizer promotes the formation of nodes and pods in legumes (Buttery, 1969). According to Angaw and Asnakew, (1994) application of P at the rates of 13, 26, 39 and 52 kg P_2O_5 ha^{-1} was significantly and linearly increased seed yield with advantages of 23, 32, 38 and 48%, respectively compared to the control treatment. It was also reported that the highest yield was obtained at the rate of 52 kg P_2O_5 ha^{-1} compared to other rates. Grain yield was significantly affected by the application of P fertilizer and have got a significant effect on faba bean yield and agronomic parameters at the rate of 90 kg P_2O_5 ha^{-1} as compared to control treatment Asgelil, (2000). Majumdar *et al*. (1985) found that increasing of sulfur, P, and zinc caused the significant increase in seed yield, nitrogen concentration, sulfur, and phosphorus in seeds, stem, and leaves of faba bean. The application of NP significantly increased seed yields of faba bean (Angaw and Asnake, 1994; Amare *et al*., 1999).

2.8. Importance of Spacing and Optimum Population

Singh and Singh (2002) explained that the establishment of an optimum population per unit area in the field is essential to get maximum yield. Population density is also dependant on the moisture availability and nutrient status of the soil. Under conditions of sufficient soil moisture and nutrients, the higher population is necessary to utilize all the growth factors efficiently.

The level of plant population 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. Yield per plant decreases gradually as the plant population per unit area increases. However, the yield per unit area is increased due to the efficient utilization of growth factors. High plant density brings out certain modifications in the growth of plants example, increase in plant height, reduction in leaf thickness, alteration in leaf orientation, and leaves become erect, narrow and are arranged at longer vertical intervals to intercept more sun light (Singh and Singh, 2002). According to Reddy (2000), both too narrow and too wide spacing do affect grain yields through competition and due to the effect of shading.

In the case of 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 certain level, it declines (Azam-Ali and Squire, 2002).The spacing between stands per hectare in turn determines the number of stands per hectare (Onwueme and Sinha, 1991). The number of stands per hectare, and the number of plants per stand together determine the number of plants per hectare, or the plant density. A number of factors also influence spacing: fertility status of the soil, growth pattern of the crop and cultural practices (Martin *et al*., 1976).

Crop plants should cover the soil as early as possible to intercept maximum sunlight to produce higher dry matter as the intercepted solar radiation and dry matter production are directly related. Closely spaced and quick growing crops like faba bean 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, the optimum plant population is necessary (Singh and Singh, 2002). As plant density increases, the amount of dry matter in vegetative parts also increases. Both the biological and economic yields increase with increasing plant population up to a certain point and subsequently no addition in biological yield can be obtained and economic yield decreases. Therefore, the optimum plant population of the individual crops should be worked out under suitable environmental conditions (Singh and Singh, 2002).

2.9. Plant Population in Pulse Crops

Plant population/ density of faba bean is an important factor in the newly reclaimed lands which depends on stand establishment. However, plant competition for environmental resources is affected by the spatial of the crop, the arrangement of those plants, this may be affected by the plant density (number of plants per unit area) distance between rows.

The spatial distribution in a crop community is an important determinant of yield. Different experiments have been conducted on the plant population of different pulse crops to determine the optimum population that would be resulted in the optimum population density of such crops. Martin *et al*. (2006) indicated that the objective of the population 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 have resulted in difficulty in harvesting activities, greater harvest loss, disrupts the leaf canopy and often limits grain development and yield. If the 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 faba bean will produce fewer pods per plant and fewer seeds per pod.

2.10. Effects of Plant Population on Yield Component and Yield of Faba Bean

Plant density is defined as the number of main stems within a unit area, which determines the size of the area available to the individual plant. 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. The low yield of faba bean was attributed to several factors, in which the poor cultural practices were the most critical (Tawaha and Turk, 2001). One of the most important cultural practices is planting density.

In general, the effect of plant population depends largely on the available soil moisture. When soil moisture is adequate and irrigation is provided, increasing row spacing resulted in a significant yield increase, on the other hand, a lower density was found to result in a greater yield of faba bean when grown under rainfed conditions (Salih, 1985).

The effect plant population on grain yield, however, seems to result from the production of heavier seeds at the higher plant population. This is rather expected since pod initiation usually starts early in the growing season before any moisture stress. Therefore, moisture stress which resulted from low rainfall or moisture depletion due to high plant competition, / will be more pronounced at the end of the growing season, which coincides with the seed filling stage, thus affect seed weight.

Also, the advantage resulted from the extended period of vegetative growth, which resulted in the improvement of several agronomical characters contributing to yield such as plant height, the number of pods produced and the number of nodules, nodule dry weight, and root dry weight.

Turk *et al*. (2003) who worked on lentil, reported that high plant density promotes phenological development; with flowering occurring 14 days earlier in the high plant density. Ahmad *et al*. (2002) also reported that row spacing had a significant effect on the number of days to flower maximum days (56) were taken to flower at 60 cm row spacing, while crop sown at 30 cm rows took minimum days (52) to flower.

Similar findings were reported by (Khalil *et al.*, 2010) and Singh *et al*. (2013), indicated that the denser plant population increased the plant height of faba bean due to competition among plants.

Gezahegn *et al*. (2016) found that the highest seed yield of faba bean at Vertisols in 30 cm inter and 8 cm intra-row spacing compare to 40 cm inter and 10 cm intra-row spacing.

Dry matter yield was higher in high plant densities compared to low plant densities. Moosavi *et al*. (2012) reported that a positive effect of increasing plant density on dry biomass. Al-Rifaee *et al*. (2004) also reported that the dry matter yield of faba bean increased with increasing plant population due to the increase in the number of plants per unit area and the associated increase in plant height.

The highest harvest index in low plant density might be better utilization of available nutrients by faba bean plants. Imran *et al*. (2015) found that a maximum harvest index at lower plant density as compared to high plant density.

Increasing plant population from 10 to 50 plants m^{-2} increased seed yield from 4.59 to 5.23 tons ha^{-1} (Bianchi, 1979; Al-Rifaee, 1999). The optimum faba bean yield was obtained at a plant population of 25 plants m^{-2} whereas, the highest yields were obtained at 40 and 85 plants m^{-2} (Christensen, 1974; Bonari and Macchia *et al*., 1975).

According to Turk and Tawaha (2002), the reduction in pod length was associated with increasing plant density. Inter and intra-row spacing had a significant effect on the number of seeds per pod. Khalil *et al*. (2010) found that the highest number of seeds per pod in low plant density.

Seed yield in faba bean is the product of several components which include number of pods per plant, a number of seed per pod and 100 seed weight (Pendleton and Hartwing, 1973) Higher number of pods per plant, seeds per pod and seed yield per plant were obtained in the wider spacing the seed yield per hectare was significantly lower in wider inter and intra-row spacing (Almaz Gezahegn and Kindie Tesfaye *et al*., 2017). However, As plant density increases (i.e. narrow spacing) intensity of interplant competition increases and reduce many parameters (i.e. number of pods/plant, number of seeds/pod, 100 seed weight and seed yield /plant) in the individual plants of faba bean, although seed yield per unit area, total dry matter and harvest index of lentils, chickpeas, peas, and faba beans increased as the plant populations increased (Ayaz *et al*., 2001).

In Ethiopia yield of 3074, 3815 and 2388 kg ha^{-1} at 50, 44 and 33 plants m^{-2}, respectively the 22 plants m^{-2} (222,222 plants per ha) gave higher yield (more than 110 kg ha^{-1}) than the recommended 25 plants m^{-2} (250,000 plants per ha) (Tekle *et al*., 2015). According to Christensen (1974), Bonari and Macchia *et al*, (1975) and Turk and Tawaha (2002), reported that high yields for faba bean at high plant density.

3. MATERIALS AND METHODS

3.1. Description of the Experimental Sites

The study was conducted at the Haramaya University Research site in 2019 main production season. Haramaya University is located at 525 km the capital city, Addis Ababa, and about 20 km Northwest of Harar town. The site is located at an altitude of 2026 meters above sea level, 9.0ºN, latitude, and 42.0º E longitudes. The site has a bimodal rainfall pattern and is representative of a sub-humid, mid-altitude agro-climatic zone. The short rainy season extends from April to July whereas the long rainy season extends from July to October. With minimum and maximum mean annual temperatures of 9.59ºC and 24.15ºC, respectively (Haramaya University Weather Station, 2019). It is situated in semi-arid tropical belt of Eastern Ethiopia, characterized by sandy clay loam soil with pH value of 5.4- 6.2 and sub humid type of climate with an average annual rain fall of about 550-790 mm (Berecha, 2015). The total annual rainfall in 2019 was 728 mm.

3.2. Experimental Materials, Treatments and Design

The experiment was conducted using four levels of phosphorus (P_2O_5: 0, 23, 46, and 69 kg/ha) and six levels of plant population (133,333; 166,667; 200,000; 222,222; 250,000 and 300,000 plants per ha^{-1}) arranged in factorial combination. The treatments were laid out in randomized complete block design (RCBD) with three replications. A gross plot size of 3.0 × 2.1 m (6.3 m^2) and a net harvest plot size of 3 × 1.5 m (4.5 m^2) was used for all treatments. The number of rows per plot for the 30, 40, and 50 cm inter-row spacing were 7, 5, and 4, respectively. The plant population in each treatment combination is presented in Table 1. The experimental material used in this study was faba bean variety *Gachena*. The variety was released by the Highland Pulses Research Program at Haramaya University in

2007. The variety has indeterminate growth habit and grows well in the Hararghe highlands with annual rainfall of 700–1,000 mm (Ministry of Agriculture and Rural Development, 2008).

Table 1: Details of treatment combination and plant population

Treatments	Inter- row x Intra-row spacing (cm)	Plant population per hectares	Phosphorus (kg P_2O_5 ha^{-1})
T1	50 x 15	133,333	0
T2	"	"	23
T3	"	"	46
T4	"	"	69
T5	50 x 10	200,000	0
T6	"	"	23
T7	"	"	46
T8	"	"	69
T9	40 x 15	166,667	0
T10	"	"	23
T11	"	"	46
T12	"	"	69
T13	40 x 10	250,000	0
T14	"	"	23
T15	"	"	46
T16	"	"	69
T17	30 x 15	222,222	0
T18	"	"	23
T19	"	"	46
T20	"	"	69
T21	30 x 10	300,000	0
T22	"	"	23
T23	"	"	46
T24	"	"	69

3.3. Agronomic Practices

The experimental field was plowed and harrowed to a fine tilth using a tractor. The seeds were planted manually by placing two seed per hill based on intra-row spacing for each treatment on 13 July 2019. The plants were thinned to one plant per hill 10 days after emergence. Initially, plant density was precisely maintained after thinning to attain the required densities under different treatments. Plots were regularly monitored and kept free of weeds and pests by manual weeding and pesticide application, respectively. Harvesting was done manually on December 15 and 16, 2019.

3.4. Soil Sampling and Analysis

Soil samples 0–30 cm depth were taken from five random places of the experimental site before planting. The collected samples were air-dried at room temperature under shade and ground to pass through a 2 mm sieve. Samples were analyzed for organic carbon (OC) and nitrogen (N) determination and for selected physicochemical properties, mainly (percent sand, silt, and clay), soil pH, total nitrogen, organic matter content, available phosphorus, exchangeable potassium and cation exchange capacity (CEC) following standard laboratory procedures for each parameter.

Soil organic matter content was determined by Walkely and Black procedure (Walkley and Black, 1954) and total nitrogen by Kjeldahl method (Jackson, 1958). The pH of soil samples was measured in water at soil to water ratio of 1:2.5 (Van Reewijk, 1992), and cation exchange capacity was measured by ammonium acetate method after saturating the soil with 1 N NH4OAC and displacing it with 1 N NaOAC (Chapman, 1965). Exchangeable K was extracted with 1 N NH4OAC at pH 7 and the extract was read using a flame photometer. Available phosphorous was determined by the Olsen method (*et al*., 1954) and soil texture analysis was performed by Bouyoucous hydrometer method (Bouyoucos, 1951).

3.5. Data Collection

3.5.1. Phenological parameters

Number of days to 50% flowering: Was recorded as the number of days from planting to when 50% of the plants produced flowers through visual observation.

Days to 90% physiological maturity: Was recorded as the number of days from planting to when the plants attained 90% physiological maturity i.e. when the plants and the pods turned pale yellow in color based on visual observation.

3.5.2. Growth related parameters

Total leaf area (cm^2): Just before flowering five plants from the destructive sampling rows of each plot were taken randomly. Leaf area was measured using a leaf area meter. The average leaf area was obtained as the leaf area of five leaves which was obtained from the top, middle and bottom parts per plant. Total leaf area per plant was calculated based on average leaf area multiplied by the total number of leaves per plant.

Leaf area index (LAI): Leaf area index (LAI) is a measure of leafiness per unit ground area and denotes the extent of photosynthesis. Leaf area index of five plants was calculated as the ratio of total leaf area per five plants (cm^2) to the area of land occupied by the plants.

Total number of nodules per plant: Was determined by counting from randomly taken five plants from destructive sampling row of each plot at 50% flowering stage. Roots were carefully from the soil and nodules were separated from the soil by washing and the total number of nodules was counted. The nodules was separated from the soil washed and the total number of nodules were determined by counting. Then, the mean value of the five plants was recorded as the number of nodules per plant.

Number of effective nodules: Twenty five representative nodules were taken from five uprooted plants from each plot and dissected with blade to observe their color in the center. The color score was made using 1-4 scale as: 1 = white, 2 = pink, 3 = slightly dark red and 4 = deep dark red as adopted by Tekalign and Asgelil (1994).

Plant height (cm): Height of five randomly tagged plants from the net plot area was measured from ground to the tip (apical bud) at physiological maturity stage and the averages were recorded as plant height.

Number of primary tillers per plant: Was taken by counting the number of primary tillers from the main stem for randomly taken five plants at physiological maturity.

3.5.3. Yield components and yield

Stand count: Stand count was recorded after establishment and at harvest per net plot area when the plants attained maturity. Percentage of survival was calculated to determine the difference in stand count due to the competition effect.

Number of pods per plant: Was recorded by counting the number of pods from randomly tagged five plants and their average was taken.

Number of seeds per pod: Five random pods from each of the five random plants were used to determine the number of seeds per pods from five plants and their average was taken.

Above ground dry biomass yield (kg ha^{-1}): At maturity, plants from the net plot area of each plot were manually harvested close to the ground surface using a sickle. The harvested plants were sundried in the open air until constant weight after the grain was removed and weighed to determine the above-ground dry biomass yield.

Grain yield (kg ha^{-1}): It was measured for all plants harvested from the net area of each plot. Grain was cleaned following harvesting and threshing, weighted using an electronic balance and adjusted to 12.5% moisture content according to Kindie (2004). Finally, yield per plot was converted to per hectare basis.

Seed moisture content: This was determined as the percent water content of the seed. It was measured using moisture tester.

Hundred Seed weight (g): This parameter was determined based on the weight of 100 seeds randomly sampled from each treatment by counting manually and weighing by an electronic balance.

Harvest Index (HI): Was calculated as the ratio of grain yield to the total above ground dry biomass yield and multiplied by a hundred.

$$\text{Harvest Index (HI)} = \frac{\text{Seed yield (g)}}{\text{Biological yield (g)}} x100$$

3.6. Data Analysis

Analysis of variance for treatment means was carried out using Model (GLM) of Gen-Stat 18th edition (Gen-Stat, 2012) for RCBD and the interpretations were made following the procedure described by Gomez and Gomez (1984). Least significant difference (LSD) test at a 5% probability level was used for mean comparison when the ANOVA showed significant differences.

3.7. Economic Analysis

Economic analysis was performed using partial budget analysis following the procedure described by CIMMYT (1988) in which prevailing market prices for inputs at planting and for outputs at harvesting were used. All costs and benefits were calculated in Ethiopian Birr on a ha basis. The concepts used in the partial budget analysis were the mean grain yield of each treatment, the field price of faba bean grain, and the gross field benefit (GFB) ha.

Gross average seed yield (kgha^{-1}) (Av. SY): Was an average yield of each treatment.

Adjusted yield (Aj. SY): Was the average yield that was adjusted downward by a 10% to reflect the difference between the experimental yields and yield of farmers (CIMMYT, 1988).

$$\text{Aj. Y} = \text{Av. SY} - (\text{Av. Y} * 0.1)$$

Gross field benefit (GFB): Was computed by multiplying field/farm gate price that farmers receive for the crop when they sale it as adjusted yield.

Total cost: The cost of P_2O_5, urea and others used for the experiment. Their price was based on the 2019 market price during planting. The cost of production practices such as labor cost for land preparation, planting, weeding, crop protection and harvesting was to be remain the same or the difference was insignificant/constant among treatments.

Net benefits (NB): was calculated by subtracting the total costs from gross field benefits for each treatment.

$$\textbf{NB= GFB - Total Cost}$$

Marginal rate of return (MRR %): Which is the measure of increasing in return by increasing input, was calculated by dividing change in net benefit by change in cost.

Marginal rate of return (MRR %) = $\frac{Change\ in\ net\ benefit}{change\ in\ total\ cost}$ x 100

4. RESULTS AND DISCUSSION

4.1. Some Soil Physico-chemical Properties of the Experimental Site

The soil texture of the experimental site was sandy clay loam (Table 2). Results of Pre-planting soil analysis indicated that it has a pH value of 6.36, which was slightly acidic and, thus, suitable for faba bean production. As the experimental plot was not covered with native, it contained low amounts of organic C (0.836%) and total N (0.06%) (Tekalign, 1991). The available phosphorus level was 12.9 ppm (Table 2) which is found in very low range (Cottenie, 1980). This indicates that P fertilizer application is crucial for the study area in order to maximize faba bean production. The low available P could be due to P fixation in such acidic soils and removal of basic cations such as Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} from the top soil because of high rain fall of the area. In addition, experimental soil exhibited high Cation Exchange Capacity (35.8 meq/100 g soil). It can be concluded that, as with the report of Tairo and Ndakidemi (2013), in legumes phosphorus supplements are effective in improving growth, yield and economic benefits, as well as photosynthesis and plant nutrition. Besided, due to the positive effect phosphorus fertilizer has on the root development of plants, its adoption is also strongly recommended.

Table 2: Soil characteristics of the experimental site.

	Soil properties	Value
1	pH	6.36
2	Total N (%)	0.06
3	Available P (ppm)	12.9
4	CEC (meq/100 g soil)	35.8
5	OM (%)	1.441
6	OC (%)	0.836

7	Soil texture	
7.1	Clay (%)	31
7.2	Sand (%)	63
7.3	Silt (%)	4
7.4	Class	Sandy clay loam

4.2. Phenological Parameters

4.2.1. Days to 50% flowering

The main effects of P and plant population were highly significant ($P<0.01$) for number of days to 50% flowering, whereas, their interaction was non-significant ($P\leq0.05$) (Appendix Table 1). Application of 69 kg P_2O_5 ha^{-1} significantly reduced the number of days to 50% flowering as compared to 0 and 23 kg P_2O_5 ha^{-1} (Table 3). This might be due to the fact that phosphorus fertilizer enhances flowering. Photosynthesis and assimilate partitioning of crops from source to sink (Iqbal *et al*., 2003).

In line with this result, Turk and Tawaha (2002) reported that P application increased development rate of crops and resulted in reduction of the number of days to 50% flowering of faba bean as compared to the control plots. Number of days to flowering significantly decreased as the pant population increased from 133,333 to 300,000 plants ha^{-1} (Table 3). This might be due to the fact that, as competition for light, nutrients and moisture increased the crop revealed hastened to flower as plant spacing increased**.** Contrary to the present result, Farag and EI-Shamma (2004) have reported that wider plant spacing of 50 cm reduced the number of days to flowering in broad bean as compared to 40 cm plant spacing. Similarly, Turk *et al*. (2003) have found that the highest plant population hastened days to flowering in lentil.

4.2.2. Days to 90% physiological maturity

The number of days to 90% physiological maturity (DPM) was highly significantly ($P<0.01$) affected by the main effects of P and plant population. However, their interaction did not affect the attribute (Appendix Table 1). Treatments maintained without P application (0 kg P_2O_5 ha^{-1}) significantly delayed DPM as compared to other levels of P_2O_5. This could be due to the fact that P fertilization enhances physiological maturity of plants. In agreement with the present results, hastening crop maturity due to increased P supply has been reported by Brady and Weil (2002). Furthermore, Halvin *et al*. (1999) have also indicated that ample P nutrition could reduce the time required for grain ripening.

Plants in the highest population density, 300,000 plants ha^{-1} (10 x 30 cm) took 133.5 days to attain physiological maturity, which was significantly earlier than the lowest plant population (133,333 plants ha^{-1}) (15 x 50 cm) that took 137.9 days (Table 3). The hastened days to maturity with narrower plant spacing might be due to high competition for the available resource such as light and moisture that hastened maturity. Contrary to this result, Hodgson and Blackman (2005) have reported that narrower row and plant spacings prolonged maturity days of faba bean compared to wider spaced crops. Similarly, Oad *et al*. (2002) have reported that closer row and plant spacing delayed maturity days of sunflower as compared to wider spacing.

Table 3: Effects of phosphorus rate and plant population on number of days to 50 % flowering (DTF) and 90% maturity (DTM) of faba bean.

Treatments	Days to 50% flowering	Days to 90% maturity
Phosphorus (kg P_2O_5 ha^{-1})		
0	58.33^{a}	140.1^{a}
23	56.78^{b}	136.0^{b}
46	55.94^{bc}	134.6^{bc}
69	54.83^{c}	133.8^{c}
LSD (0.05) =	1.365	1.832
Populations (plants ha^{-1})		
133,333	58.33^{a}	137.9^{a}
166,667	57.08^{ab}	137.8^{a}

200,000	57;00[ab]	137.2[ab]
222,222	56.08[bc]	135.3[bc]
250,000	55.92[bc]	135;0[bc]
300,000	54.42[c]	133.5[c]
LSD (0.05) =	1.672	2.243
CV (%) =	3.6	2.0

Mean values followed by same letter(s) within a column for a given treatment and parameter are not significantly different at 0.05 P level., LSD = least significant difference at 5% level; CV= coefficient of variation.

4.2.3.Total number of nodules per plant

The analysis of variance revealed that total number of nodules per plant was significantly ($P<0.01$) affected by application of phosphorus fertilizer, plant population and their interaction (Appendix Table 1). It was observed that total number of nodules per plant increased in response to increasing rate of phosphorus application. The highest number of nodules per plant of faba bean (155.2) was recorded for 46 kg P_2O_5 ha^{-1} while the lowest value (144.4) was for 0 kg P_2O_5 ha^{-1}. In agreement with the present result, Demissie and Deresa (2018) have reported that increasing the rate of application of phosphorus fertilizer from 20 kg of P ha^{-1} to 30 and 40 kg of P ha^{-1} increased the total number of nodules per plant by about 16.1 and 19.5%, respectively.

These results were also in line with the findings of Getachew and Angaw (2006),Yirga and Kiros (2012), and Yohannes *et al*. (2014), indicating that application of mineral phosphorus fertilization significantly increased nodule number per plant in faba bean. Moreover, Ganeshamurthy (2000) has reported that nodule number and weight of various legumes increased due to P and FYM applications. As plant population increased from 133,333 to 300,000 total number of nodules per plant also increase from 146.5 to 153.4. Total number of nodules was influenced by plant density due to competition for water and mineral nutrition; as plant densities have statistically significant effect on faba bean nodulation (Al-Abduselamand and Abdai, 1995). The interaction effects of P and plant population, the highest number of nodules per plant of faba bean (162.67) was recorded for 46 kg P_2O_5 ha^{-1}

and 300,000 plants ha^{-1} while the lowest value (133.13) was for 0 kg P_2O_5 ha^{-1} and 133,333 plants ha^{-1} interaction (Table 5). Taj *et al*. (2002) who worked experiment on mungbean reported that more competition for light in narrow spacing that resulted in taller plants while at wider spacing light distribution was normal.

4.2.4. Number of Effective nodules (ENN) per plant

The analysis of variance showed that P rate and plant population, significantly ($P<0.01$) affected the number of effective nodules (NEN), but their interaction was non significant (Appendix Table 1). The lowest (14.26) and the highest (16.42) NEN were recorded for 0 and 46 kg of P_2O_5 per ha. respectively (Table 4).

There was a linear increase in total number of nodules per plant, number of effective nodules with increasing rate of P up to 46 kg P_2O_5 per ha. Increases in these parameters due to application of phosphorus may be due to the fact that there is a positive correlation between phosphorus and the parameters. As plant population increased from 133,333 to 300,000 plants ha^{-1} number of effective nodules also increased from 14.53 to 15.98. Number of effective nodules was influenced by plant population due to competition for water and mineral nutrition. In both cases, increasing P rate and plant population increased the number of effective nodules.

Table 4: Effect of phosphorus rate and plant population on total number of nodules (TNN) and number of effective nodules (ENN) per plant of faba bean.

Treatments	Total number of nodules	Number of effective nodules
Phosphorus (kg P_2O_5 ha^{-1})		
0	144.4^{c}	14.26^{c}
23	152.1^{b}	15.07^{b}
46	155.2^{a}	16.42^{a}
69	154.1^{ab}	16.1^{a}
LSD (0.05) =	2.357	0.5627
Population (plants ha-1)		
133,333	146.5^{c}	14.53^{d}
200,000	148.1^{c}	14.97^{cd}
166,667	151.9^{b}	15.03^{cd}

250,000	155.9[a]	16.67[a]
222,222	152.9[ab]	15.58[bc]
300,000	153.4[ab]	15.98[ab]
LSD (0.05) =	2.887	0.6892
CV (%) =	2.3	5.4

Mean values followed by same letter (s) within a column for a given treatment level and parameter are not significantly different at 0.05 P level., LSD = least significant difference at 5% P level; CV= coefficient of variation.

Table 5: Interaction effect of phosphorus and plant population on total number of nodules of faba bean.

Total number of nodules per plant						
Treatments	Population (plants ha^{-1})					
Phosphorus (kg P_2O_5 ha$^{-1)}$	133333	166667	200000	222222	250000	300000
0	133.13	157.87	135.55	141.6	150.33	147.67
23	154.13	148.2	144.67	164.4	153.2	148.07
46	150.07	152.13	156	153.13	162.67	157.2
69	148.67	149.4	156	152.47	157.47	160.67
LSD (0.05) =						5.774
CV (%) =						2.3

4.2.5. Stand count at emergence and harvest

As compared to initial value (100%), the final stand count decreased, probably due to interplant competition as well as environmental conditions prevailing during the season. As phosphorus application rates increase initial stand count also increased from 96.56% to 97.5% (Table 6). Whereas the interaction between phosphorus fertilizer rates and plant population was not significant for stand count at harvest **(**Appendix Table 2). The lowest plant population, 133,333 plants ha^{-1} (15 x 50 cm), had the maximum (90.25%) final stand count as compared to higher plant populations (250,000 plants ha^{-1} (10 x 40 cm) with 89.5% and 300,000 plants ha^{-1} (10 x 30 cm) with 88.33%) (Table 6). At lower plant population availability of more space might have resulted in less competition for resources (nutrients, moisture, and light) whereas at higher plant population due to more intra-specific competition the weaker plants disappeared by the time the crop approached maturity. Similar results were reported by Abdel (2008) who found lower stand count at harvest at higher plant population due to the reduced plant competition and plant mortality.

4.2.6. Plant height

Results of the analysis of variance showed highly significant ($P<0.01$) variation due to phosphorus rate and plant population, whereas the interaction between the two factors was not significant for plant height (Appendix Table 2).

The tollest plants (189.7 cm) were recorded for the highest rate of P (69 kg of P_2O_5 ha^{-1}), while 0 kg P_2O_5 ha^{-1} resulted in the shortest plants (174.8 cm) (Table 6). The increase in plant height in response to application of higher P rate indicates higher vegetative growth of the plants under higher P availability. In line with this, Hussain~~,~~ *et al*. (2006) have reported that, promotion effect of P level on plant height was probably due to better development of root system and nutrient absorption. Likewise, Yirga Weldu, *et al*. (2012) have reported increase in plant height of faba bean both at 50% flowering and maturity stages in response to increased P application. In agreement with this result, Getachew and Rezene (2006) have reported that plant height of faba bean was significantly influenced by P application compared to control plots in Holeta area, central Ethiopia.

The highest plant population (300,000 plants per hectares) resulted in the tallest plants (191.4 cm), while the minimum plant height (175.8 cm) (175.8 cm) was recorded for the lowest plant population (133,333 plants per hectares) (Table 6). The increase in plant height at higher plant densities was probably due to increased competition of plants in higher densities for light, resulting in taller plants. Similar findings have been reported by Khalil *et al*. (2010) and Singh *et al*. (2013), who indicated that denser plant populations increased plant height of faba bean due to competition among plants. Furthermore, Taj *et al*. (2002) have reported that more competition for light in narrow spacing (high plant population) of mung bean resulted in taller plants, while at wider spacing (low plant population) light distribution was normal. Likewise, Parvez *et al*. (1989) have also indicated that with increasing plant density, there was increases in plant height. This is because in narrow spacing (high plant population) plants compete more for available resources especially for light and, thus, result in more height than widely spaced plants (Singh, 2002). In agreement with this, Ogunlella *et al*. (2005) and Amanullah *et al*. (2010) have indicated that plants were taller with increased plant density in reaction to an enhanced competition among plants for light. Generally, plant height tended to increase with increasing plant densities.

Table 6: Effects of phosphorus rate and plant population on stand count at emergence (SCE), stand count at harvest (SCH) and plant height (PH) of faba bean.

Treatments	PH (cm)	SCE%	SCH%
Phosphorus (kg P_2O_5 ha^{-1})			
0	174.80^{c}	96.56^{b}	89.28^{a}
23	183.90^{b}	96.72^{b}	89.56^{a}
46	186.90^{ab}	96.72^{b}	89.56^{a}
69	189.70^{a}	97.50^{a}	89.72^{a}
LSD (0.05) =	3.724	0.694	1.011
Population (plants ha^{-1})			
133,333	175.8^{c}	97.25^{a}	90.25^{ab}
200,000	181.5^{b}	97.25^{a}	91.17^{a}
166,667	182.2^{b}	97.08^{a}	89.17^{bc}

250,000	183.3[b]	96.50[a]	89.50[bc]
222,222	188.6[a]	96.67[a]	88.75[c]
300,000	191.4[a]	96.50[a]	88.33[c]
LSD (0.05) =	4.561	0.85	1.238
CV (%) =	3.0	1.1	1.7

Mean values followed by same letter (s) within a column for a given treatment level and parameter are not significantly different at 0.05 P level., LSD = least significant difference at 5% P level; CV= coefficient of variation.

4.2.7. Total leaf area

The main effects of P and plant population were highly significant ($P<0.01$) for leaf area, but their interaction was non significant (Appendix Table 2). Total leaf area per plant increased as P rate increased. The highest leaf area (58.42 cm^2) was recorded for the highest rate of P (69 kg P_2O_5 ha^{-1}) and other rates were significantly lower than the highest rate (Table 7). In line with this, it has been reported that the highest physiological growth indices are achieved under high plant nutrition because photosynthesis is enhanced by the growth and development of leaf areas (Bennett, 1993). In agreement with results of the present study, Tairo and Ndakidemi (2013) have reported that phosphorus application has significantly increased the leaf area of soybean. On the other hand, total leaf area per plant significantly decreased from 60.15 cm^2 to 52.6 cm^2 as plant population increased from 133,333 to 300,000 plants ha^{-1} (Table 7). The rate of increase in leaf area determines the rate of increase in photosynthetic capacity of the plant.

4.2.8. Leaf area index

The main effects of P, and plant population as well as their interaction were highly significant ($P<0.01$) for leaf area index (Appendix Table 2). The highest leaf area index (2.923) was recorded for the highest rate of P (69 kg of P_2O_5 ha^{-1}) which was statistically similar with leaf area index (LAI) obtained due to 46 kg of P_2O_5 ha^{-1} whereas the lowest value (2.832) was recorded for the control plots (Table 7). It has been reported that the highest physiological growth indices are achieved under high plant nutrition because photosynthesis enhanced by the growth and development of leaf areas (Bennett, 1993). In agreement with this result, Tairo and Ndakidemi (2013) also reported that phosphorus application has significantly increased the leaf area and leaf area index of soybean.

Leaf area index significantly decreased from 3.376 to 2.336 as plant population increased from 133,333 to 300,000 plants ha^{-1} (Table 7). This was probably due to increased total leaf area per plant when plant population decreased. With regard to the interaction effect of P and plant population, significantly highest leaf area index (3.7) was obtained with 69 kg ha^{-1} and 133,333 plants ha^{-1} however, the lowest (2.151) was recorded due to 46 kg ha^{-1} and 300,000 plants ha^{-1} interaction (Table 8). The present result was in line with the findings of Gezahegn *et al*. (2016) who indicated that LAI was negatively related with plant population. In contrast with this result, Caliskan *et al*. (2007) and Solomon (2010) both worked on haricot bean reported that leaf area index increased as both inter and intra-row spacing decreased. Similarly, Worku and Demisie (2012) have also reported that a high LAI at high plant density may attribute to improved light interception thus, ensuring high biomass and yield than at low plant density.

4.2.9. Number of primary tillers per plant

The effects of phosphorus rate and plant population and their interaction were highly significant ($P<0.01$) for number of primary tillers per plant (Appendix Table 3). The highest and lowest number of primary tillers per plant were recorded for the highest (69 kg P_2O_5 ha^{-1}) and lowest rate of phosphorus (0 kg P_2O_5 ha^{-1}), respectively. As P is responsible for good root growth which directly affects the overall plant performance, application of P at the rate of 0 kg ha^{-1} resulted in the lowest number of effective tillers $plant^{-1}$.

The increment in the number of primary tillers per plant in response to increased phosphorus application rate indicates higher vegetative growth of the plants under higher P availability. In line with this result, Shubhashree (2007) has reported significantly higher number of primary tillers per plant of common bean with 75 kg of P_2O_5 ha^{-1} over the control. Number of primary tillers per plant increased with decreasing plant population, as the highest value (3.383) was recorded for the lowest plant population (133,333 plants ha^{-1}) and the highest plant population (300,000 plants ha^{-1}) gave the lowes number of primary tillers (2.7) (Table 7). This could probably be due to the fact that, as space among plants increases resources become more available for each plant, enhancing lateral vegetative growth of the crop. In agreement with this result, Mehmet (2008) has reported an increased number of primary tillers due to wider plant spacing for soybean.

Table 7: Effect of phosphorus rates and plant population on total leaf area (TLA), leaf area index (LAI) and number of primary tillers (NPB) per plant of faba bean.

Treatments	LA (cm^2)	LAI	NPB
Phosphorus (kg P_2O_5 ha^{-1})			
0	51.65^{c}	2.631^{b}	2.900^{c}
23	56.05^{b}	2.820^{a}	3.100^{b}
46	56.24^{b}	2.832^{a}	3.211^{ab}
69	59.42^{a}	2.923^{a}	3.278^{a}
LSD (0.05) =	2.526	0.0979	0.1389
Population (plants ha^{-1})			
133,333	60.15^{a}	3.376^{a}	3.383^{a}
200,000	58.19^{ab}	2.577^{d}	3.183^{b}
166,667	55.24^{bc}	3.202^{b}	3.233^{ab}
250,000	54.53^{c}	2.492^{d}	3.183^{b}
222,222	54.33^{c}	2.826^{c}	3.050^{b}
300,000	52.60^{c}	2.336^{e}	2.700^{c}
LSD (0.05) =	3.094	0.12	0.1702
CV (%) =	6.7	5.2	6.6

Mean values followed by same letter (s) within a column for a given treatment level and parameter are not significantly different at 0.05 P level., LSD = least significant difference at 5% P level; CV= coefficient of variation

Regarding the interaction effects of P and plant population, number of primary branches per plant (NPB) was decreased with increasing plant population. Significantly highest number of primary branches per plant value (4) was achieved for the interaction of 69 kg ha^{-1} and 133,333 plants ha^{-1} and the lowest (2.2) was due to 0 kg ha^{-1} and 300,000 plants ha^{-1} interaction (Table 8). Similarly, Khalil *et al*. (2010) and Yucel (2013) have reported that the number of primary tillers showed increasing trend as the space among plants increased compared to plants at narrow spacing. In contrast, Yalemtesfa (2017) has reported that increased intra-row spacing decreased the number of branches per plant. This could be due to more nutrient, moisture and space become available for the growth of other vegetative parts than for branches.

Table 8: Interaction effect of phosphorus and plant population on leaf area index and number of primary tillers per plant of faba bean.

Leaf area index						
Treatments	Population (plants ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	133333	166667	200000	222222	250000	300000
0	2.617	3.15	2.467	2.417	2.373	2.763
23	3.713	3.141	2.57	2.989	2.366	2.138
46	3.473	3.263	2.566	2.767	2.773	2.151
69	3.7	3.253	2.707	3.129	2.457	2.29
LSD (0.05) =						0.2399
CV (%) =						5.2

Number of primary tillers per plant						
Treatments	Population (plants $ha^{-1)}$					
Phosphorus (kg P2O5 ha^{-1})	133333	166667	200000	222222	250000	300000
0	2.8	3.467	2.6	3.333	3	2.2
23	3.267	3.333	3.2	3	3	2.8
46	3.467	3.133	3.333	2.933	3.533	2.867
69	4	3	3.6	2.933	3.2	2.933
LSD (0.05) =						0.3403
CV (%) =						6.6

4.3. Yield Components and Yield

4.3.1. Number of pods per plant

The analysis of variance indicated that plant population and P rate had a highly significant ($P<0.01$) effect on the number of pods per plant (PPP), whereas their interaction was not significant (Appendix Table 3). The highest number of pods per plant (26.34) was obtained at the highest rate of phosphorus (69 kg of P_2O_5 ha^{-1}) application, while the lowest value (23.15) was recorded for the control treatment (Table 9). This result was in line with the findings of Aminpanah (2015) who reported that, number of pods per plant was significantly influenced by application of P.

Similarly, Meseret and Amin (2014) have indicated that all applied P fertilizer rates significantly increased number of PPP of common bean over the control. It was observed that number of PPP decreased as plant population increased. The lowest plant population (133,333 plants ha^{-1}) gave the highest (26.9) number of pods per plant and the lowest value (23.75) was recorded for the highest plant population 300,000 plants ha^{-1} (Table 9). The increment in the number of PPP at the lower population density might be due to an increase in net assimilation rate and reduction of competition among individual plants for growth factors in wider spacing, favoring the development of more number of flowers and pods per plant. This result was in line with the findings of Abdel (2008) and Shad *et al*. (2010) who reported decrease in the number of PPP in faba bean due to a reduction in the number of stems per plant at higher plant densities. Similarly, Melak (2014) has reported that significantly the highest number of pods $plant^{-1}$ (34.7) of chickpea was recorded at 50 cm x 15 cm spacing as compared to 20 cm x 5 cm spacing (16.7). Moreover, Derogar and Mojaddam (2014) and Almaz *et al*. (2016) have shown that increasing plant densities may lead to a decrease in the number of pods per plant in faba bean due to a reduction in the number of pod bearing branches per plant.

4.3.2. Number of seeds per pod

Number of seeds per pod was highly significantly ($P < 0.01$) affected by both phosphorus rate and plant population as well as by their interaction (Appendix Table 3). The highest number of seeds per pod (3.378) was obtained at the highest rate of phosphorus (69 kg P_2O_5 ha^{-1}) application, while the lowest value (3.011) was recorded for the control treatment (Table 9). The highest number of seeds per pod at the highest rate of phosphorus may be due to the positive role of phosphorus in photosynthetic materials production and their allocation to reproductive organs of the crop. The result was in line with the findings of Kubure *et al*. (2016) who have found that phosphorus application tended to improve seeds pod^{-1} when compared with no phosphorus. The current result was also in agreement with the findings of Meseret and Amin (2014) who reported that significantly the highest number of seeds per pod (5.85) was obtained at the highest rate of P (40 kg P_2O_5 ha^{-1}) and the lowest value (3.14) was recorded for the untreated plot.

On the other hand, the highest (3.517) and lowest (3.000) number of seeds per pod were recorded for 133,333 and 300,000 plants ha^{-1}, respectively (Table 9). This may be due to decreased inter-plant competition for resources at lower plant populations that leads to increased plant capacity for utilizing the environmental inputs in building a great amount of metabolites to be used in developing new tissues and increasing its yield components. This was in agreement with some previous reports on faba bean (Abdel, 2008; Hodgson and Blackman, 2005).

4.3.3. Above ground dry biomass yield (DBY)

The analysis of variance showed that both factors (P rate and plant population) and their interaction highly significantly ($P<0.01$) affected above ground dry biomass yield (Appendix Table 3). The result showed that there was significant increase in biomass yield when phosphorus application increased from the lowest to the highest rate. The highest total dry biomass at the highest level of phosphorous might be due to the more application of phosphorus fertilizer which might have led to efficient use of phosphorus fertilizer improvement in fodder and grain yields ha^{-1}. The increase in above ground dry biomass at the highest rate of phosphorus might be attributed to the enhanced availability of P for vegetative growth of the crops. Since phosphorus is responsible for good root growth and development, it directly affects the overall plant performance, as a result, a good and optimum supply of P is important for crops to explore more soil nutrients and moisture Tadele Buraka *et al*. (2016). In line with this, Tesfaye (2015) has reported that the highest (8135 kg ha^{-1}) and the lowest (4399 kg ha-^{1}) dry biomass yields of common bean were recorded for 30 kg P_2O_5 ha^{-1} and 0 kg P_2O_5 ha^{-1} rates of P, respectively.

The highest above ground dry biomass yield (15676 kg ha^{-1}) was recorded for 300,000 plants ha^{-1} and the lowest (13941 kg ha^{-1}) was obtained from the lowest plant population (133,333 plants ha^{-1}) (Table 9). This result was in line with the findings of Moosavi *et al*. (2012) who reported a positive effect of increased plant population on dry biomass yield of crops. Similarly, Derogar (2014) has reported that increasing plant density resulted in increased biological yield of faba bean due to an increase in the number of plants in a unit's area (Dahmardeh *et al*., 2010). Al-Rifaee *et al*. (2004) have also observed that at the final harvest of faba bean, the dry matter yield of above ground parts increased with increasing plant population due to the increase in the number of plants per unit area and the associated increase in plant height.

Table 9: Effects of phosphorus rate and plant population on number of pods per plant (PPP), number of seeds per pod (SPP) and above ground dry biomass yield (DBM) of faba bean.

Treatments	PPP	SPP	DBY_kg_ha^{-1}
Phosphorus (kg P_2O_5 ha^{-1})			
0	23.15^{b}	3.011^{b}	13150^{c}
23	26.00^{a}	3.256^{a}	14853^{b}
46	26.06^{a}	3.289^{a}	14940^{b}
69	26.34^{a}	3.378^{a}	15978^{a}
LSD (0.05) =	0.916	0.1235	404.6
Population (plants ha^{-1})			
133,333	26.90^{a}	3.517^{a}	13941^{b}
200,000	25.80^{ab}	3.317^{b}	14028^{b}
166,667	25.50^{b}	3.200^{b}	14122^{b}
250,000	25.20^{b}	3.183^{b}	15201^{a}
222,222	25.17^{b}	3.167^{b}	15416^{a}
300,000	23.75^{c}	3.000^{c}	15676^{a}
LSD (0.05) =	1.122	0.1246	495.5
CV (%) =	5.4	5.7	4.1

Mean values followed by same letter (s) within a column for a given treatment level and parameter are not significantly different at 0.05 P level., LSD = least significant difference at 5% P level; CV= coefficient of variation.

With regard to the interaction effects of P and plant population, the highest and lowest number of seeds per pod was recorded at 69 kg ha^{-1} and 133,333 plants ha^{-1} and 0 kg ha^{-1} and 250,000 plants ha^{-1} interaction respectively (Table 10). The present result was also in agreement with that of Mahmoud (2014) who reported that the number of seeds per pod of faba bean decreased with close planting. Similarly, Bakry *et al*. (2011) on their work on effect of row spacing on yield and its components of some faba bean varieties under newly reclaimed sand soil conditions reported that the highest number of seeds per pod was obtained from the wider spaced plants compared to close spaced plants.

Table 10: Interaction effect of phosphorus and plant population on seed per pod and Dry biomass yield (kg ha^{-1}) of faba bean.

Seeds per pod						
Treatments		Population (plants ha^{-1})				
Phosphorus (kg P_2O_5 ha^{-1})	133333	166667	200000	222222	250000	300000
0	3.133	2.867	3.2	3.067	2.8	3
23	3.4	3.333	3.4	3.067	3.133	3.2
46	3.533	3.333	3.4	3.2	3.2	3
69	4	3.267	3.267	3.333	3.6	2.8
LSD (0.05) =						0.3051
CV (%) =						5.7

Dry biomass yield (kg ha^{-1})						
Treatments		Population (plants ha^{-1})				
Phosphorus (kg P_2O_5 ha^{-1})	133333	166667	200000	222222	250000	300000
0	11207	13472	13389	13107	13441	14285
23	13667	13444	14556	15444	16528	15482
46	14167	14028	14556	15667	14028	17194
69	16722	15542	13611	17444	16806	15741
LSD (0.05) =						348.1
CV (%) =						4.1

Concerning the interaction effect of effects of P and plant population, significantly highest above ground dry biomass yield (17194 kg ha-^{1}) was recorded at 46 kg ha^{-1} and 300,000 plants ha^{-1} and the lowest (11207 kg ha^{-1}) was obtained with 0 kg ha^{-1} and 133,333 plants interaction (Table 10). In line with this result, Solomon (2003) reported that above ground dry biomass yield per ha was significantly increased with decreasing plant spacing on soybean due to increased dry matter accumulation in densely populated crops.

4.3.4. Hundred seed weight

The effects of P, rate and plant population and their interaction were highly significant ($P<0.01$) for hundred seed weight (Appendix Table 4). The highest and lowest hundred seed weights were recorded for application of 69 kg of P_2O_5 ha^{-1} and 0 kg of P_2O_5 ha^{-1} respectively. The increment in hundred seed weieght with increasing rate of P application might be due to increased photosynthetic area and more dry matter portioning from source to sink and economic part, which demonstrates a strong correlation with the size of the seed. The current result was in line with that of Girma (2009) who reported that hundred seed weight and dry matter accumulation were increased with application of phosphorus fertilizer compared to the control plots. Similarly, Yamane and Skjelvåg (2003), in their experiment on field pea, indicated that increasing P application increased hundred seed weight. On the other hand, the highest hundred seed weights (73.88 g) was recorded for the widest plant spacing (50 x 15 cm) (133,333 plants ha^{-1}), while the lowest was due to the narrowest plant spacing (30 x 10 cm) (300,000 plants ha^{-1}) (Table 11). The variation in hundred seed weight might be due to in wider spaced plants, the supply of assimilates to be stored in the seed improved and the weight of hundred seeds increased.

4.3.5. Seed moisture content (%)

The analysis of variance indicated that there was a significant ($P<0.05$) effect of P on seed moisture content, while the difference due to population density and its interaction with P rate was highly significant ($P<0.01$) (Appendix Table 4). The highest and lowest seed moisture contents were recorded for application of 0 kg of P_2O_5 ha^{-1} (17.31%) and 69 kg of P_2O_5 ha^{-1} (16.31%), respectively (Table 11). The decreases in seeds moisture content as phosphorus rate increase might be due to use of phosphorus has been an effective means for improving growth such as early maturity, soil fertility, and improving the moisture-holding capacity of soils, increasing the soil cation exchange capacity and increasing crop yields. Similarly, the highest plant population (300,000 plants ha^{-1}) resulted in the lowest seed moisture content (16.22%), while the highest value (17.70%) was recorded for the lowest plant population (133,333 plants ha^{-1}) (Table 11). This might be due to increasing plant density (population) intensifies competition for solar radiation, soil nutrients and soil moisture**.**

Table 11: Effect of phosphorus rate and plant population on hundred seed weight (100SW) and seed moisture content percent.

Treatments	100SW	Moist%
Phosphorus (kg P_2O_5 ha^{-1})		
0	69.29^{b}	17.31^{a}

23	70.46b	16.63b
46	71.29b	16.59b
69	74.22a	16.31b
LSD (0.05) =	2.216	0.4829
Population (plants ha^{-1})		
133,333	73.88a	17.70a
200,000	72.27ab	16.67b
166,667	72.68a	16.82b
250,000	69.66bc	16.30b
222,222	71.52ab	16.56b
300,000	67.91c	16.22b
LSD (0.05) =	2.714	0.5914
CV (%) =	4.6	4.3

Mean values followed by same letter (s) within a column for a given treatment level and parameter are not significantly different at 0.05 P level., LSD = least significant difference at 5% P level; CV= coefficient of variation.

The interaction effects of P and plant population, the highest hundred seed weight of faba bean (74.77) was recorded for 0 kg P_2O_5 ha^{-1} and 133,333 plants ha^{-1} while the lowest value (64.73) was for 46 kg P_2O_5 ha^{-1} and 300,000 plants ha^{-1} (Table 12). In agreement with this result, Mahmoud (2014) has reported that seed weight of faba bean significantly increased with increasing intra-rows spacing from 10 to 25 cm and the highest value (49 g) was obtained at 25 cm plant spacing compared to the narrowest spacing. Regarding the interaction effects of P and plant population, the lowest seed moisture content percent of faba bean (14.417) was recorded at 23 kg P_2O_5 ha^{-1} and 250,000 plants ha^{-1} while the highest value (18.7) was for 0 kg P_2O_5 ha^{-1} and 133,333 plants ha^{-1} interaction respectively (Table 12).

Table 12: Interaction effect of phosphorus and plant population on hundred seed weight and seed moisture content of faba bean.

100 Seed weight						
Treatments	Population (plants ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	133333	166667	200000	222222	250000	300000

0	74.77	73.65	72.27	59.07	69.77	66.23
23	73.27	69.5	72.07	71.63	68.7	67.6
46	74.03	74.47	70.87	73.83	69.83	64.73
69	73.43	73.1	73.87	81.53	70.33	73.07
LSD (0.05) =						5.428
CV (%) =						4.6

Seed moisture%

Treatments	Population (plants ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	133333	166667	200000	222222	250000	300000
0	18.7	17.367	17.867	17.8	17.2	14.933
23	18	17.15	15.933	16.917	14.417	17.367
46	17.6	16.967	16.567	16.067	17.267	15.1
69	16.5	15.8	16.3	15.467	16.333	17.467
LSD (0.05) =						1.1829
CV (%) =						4.3

4.3.6. Grain yield per hectares (kg ha^{-1})

The analysis of variance indicated that there was a highly significant ($P<0.01$) effect of P_2O_5 and significant ($P<0.05$) effect of population and interaction between the two factors on grain yield of faba bean (Appendix Table 4). The highest grain yield was obtained from application of P fertilizer at a rate of 46 kg of P_2O_5 ha^{-1} (2983 kg ha^{-1}) while the lowest (2374 kg ha^{-1}) was obtained from the control plot (Table 13). All P fertilizer rates significantly increased grain yield of faba bean over the control. The increase in grain yield with application of phosphorus might be attributed to the fact that phosphorus increases crop growth and yield on soils which are naturally low in phosphorus and in soils that have been depleted (Mullins, 2001).

The current result was in agreement with those of Tekle *et al*. (2015) who; reported that significantly higher grain yield (3814.8 kg ha^{-1}) was recorded for application of 46 kg of P_2O_5 ha^{-1} due to enhanced translocation of photo assimilates from vegetative biomass to grains. On the other hand, the highest grain yield (2893 kg ha^{-1}) was recorded for plant spacing of 30 x 10 cm (300,000 plants ha^{-1}) (Table 13). Balanced growth and development of plants need an optimum plant density, enable efficient utilization of available nutrients, soil water and better light interception by the plants. Moreover, high plant density can cause lodging, less light penetration in the crop canopy leading reduced photosynthetic efficiency of the plants resulting in drastic yield reduction (Lemerle *et al*., 2006; and Shad *et al*., 2010). On the other hand, plant density lower than the optimum exhibited lower grain yield per unit area which might be attributed to a lower number of plants per unit area and under utilization of the available resources. Similarly, Hashemi- Dezfouli and Herbert (1992) and Echarte *et al*. (2000) have that plant density below the optimum led to decreased use efficiency of available resources. Shad *et al*. (2010) have also observed a linear increase in grain yield with an increase in plant density and reached the highest value at a density of 450,000 plants ha^{-1}.

The present result was in line with that of Kissi Wakweya *et al*. (2016) who reported that seed yield per hectare significantly increased with densities up to certain plant population m^{-2}. Al-Suhaibani *et al*. (2013) have also stated that the highest and lowest seed yields were obtained with the highest and lowest plant density, respectively. These findings were similar to that of Dahmardeh *et al.* (2010) who stated biological, and seed yields were significantly increased with increasing plant density from 22 to 44 plant m^{-2}. Similarly, Badawy (2011) has reported higher biological yield in sandy loam soil for higher plant density due to an increase in the number of plants in a unit’~~s~~ area. With regard to the interaction effect of P and plant population, significantly highest grain yield (3362 kg ha^{-1}) was obtained with 46 kg ha^{-1} and 300,000, the lowest (2148 kg ha^{-1}) was recorded due to 0 and 133,333 interaction (Table 14). In agreement with the present result, Melaka (2014) who, reported that the highest (1219 kg ha^{-1}) and the lowest (733 kg ha^{-1}) grain yields were recorded at 30 cm x 10 cm and 20 cm x 5 cm spacing combination, respectively of common bean.

4.3.7. Harvest index (HI%)

The analysis of variance showed that both main effects (P rate and plant population) and their interaction were highly significant ($P<0.01$) for harvest index (Appendix Table 4). The highest harvest index (HI) was obtained with the application of 69 kg of P_2O_5 ha^{-1} and the lowest was recorded for the control treatment (Table 13). The increment in harvest index with application of P fertilizer might be due to the fact that an increase in grain yield due to adequate supply of phosphorous and, thus, translocation of more amount of photo-assimilates to grains. In line with this, Amanuel *et al*. (2000) have reported that harvest index of faba bean increased with application of a 20 kg of P_2O_5 ha^{-1} due to enhanced grain yield production compared to the control treatment. Similarly, Rakesh *et al*. (2012) and Murat *et al*. (2009) have also reported a significant increase in harvest index of mung bean and field pea due to phosphorus application.

Unlike the case with P rate, harvest index significantly decreased with increasing plant population, with the highest value (22.07%) recorded for 133,333 plants ha^{-1} (50 x 15 cm) and the lowest (16.6%) for 300,000 plants ha^{-1} (30 cm x 10 cm spacing) (Table 13). Lower harvest index at higher plant populations, was associated with lower rate of increase in grain yield than the corresponding increase in total dry matter yield which might be due to intense competition between densely populated plants for nutrients, moisture and light, resulting in increased flower abortion, subsequently reduced harvest index. In line with this, AL-Rifaee *et al*. (2004) and Tekle *et al*. (2015) have indicated that low plant density results in higher HI as compared to higher plant densities. Mahmoud (2014) has also reported that harvest index was significantly affected by inter-and intra-row spacing and higher value (34.5%) was recorded for the wider spacing (50 cm x 25 cm) as compared to the narrower (40 cm by 15 cm) inter and intra-row spacing (21.6%). Regarding the interaction effects of P and plant population, harvest index was decreased with increasing plant population. Significantly highest harvest index (HI) value (21.47%) was achieved for the interaction of 69 kg ha^{-1} and 133,333 plants ha^{-1} and the lowest (14.04%) was due to 0 kg ha^{-1} and 222,222 plants ha^{-1} (Table 14). Similarly, Yucel (2013) has reported increased harvest index of local bean as plant populations decreased.

Table 13: Effect of phosphorus rate and plant population on yield kilogram per hectare (Y kg ha-1) and harvest index (HI) of faba bean.

Treatments	Y-kg ha^{-1}	HI%
Phosphorus (kg P_2O_5 ha^{-1})		
0	2374^{c}	18.00^{c}
23	2693^{b}	18.63^{c}
46	2983^{a}	19.58^{b}
69	2889^{a}	20.32^{a}
LSD (0.05) =	151.9	0.677
Population (plants ha^{-1})		
133,333	2570^{b}	22.07^{a}
200,000	2616^{b}	20.84^{b}
166,667	2723^{ab}	20.55^{b}
250,000	2890^{a}	18.32^{c}
222,222	2717^{ab}	16.42^{d}
300,000	2893^{a}	16.60^{d}
LSD (0.05) =	186	0.829
CV (%) =	8.3	5.3

Mean values followed by same letter (s) within a column for a given treatment level and parameter are not significantly different at 0.05 P level., LSD = least significant difference at 5% P level; CV= coefficient of variation.

Table 14: Interaction effect of phosphorus and plant population on Grain yield per hectares (kg ha^{-1}) and harvest index (%) of faba bean.

Grain yield per hectares (kg ha^{-1})						
Treatments	Population (plants ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	133333	166667	200000	222222	250000	300000
0	2148	2326	2241	2558	2563	2406
23	2460	2770	2809	2489	2708	2921
46	2970	3160	2551	2658	3190	3362
69	2701	2635	2863	3164	3110	2865
LSD (0.05) =						372
CV (%) =						8.3

Harvest index%						
Treatments	Population (plants ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	133333	166667	200000	222222	250000	300000
0	21.38	19.7	18.14	14.04	19.76	14.99
23	21.02	19.23	20.44	16.79	17.91	16.36
46	24.4	22.2	21.06	17.18	16.46	16.18
69	21.47	21.05	23.73	17.65	19.18	18.85
LSD (0.05) =						1.658
CV (%) =						5.3

4.4. Partial Budget Analysis

The economic analysis revealed that the highest net benefit (75831.318 Birr ha^{-1}) was obtained from the application of 46 kg of P_2O_5 ha^{-1} x 300,000 plants ha^{-1}, while the lowest net benefit (48403.953 Birr ha^{-1}) was obtained from the lowest phosphorus application rate (23 kg of P_2O_5 ha^{-1}) and 133,333 plants ha^{-1} (Table 15). Therefore, production of faba bean variety Gachena with 300,000 plants ha^{-1} and 46 kg of P_2O_5 ha^{-1} was found to be most productive and economical and, thus, could be recommended for the study area.

Table 15: Partial budget analysis for phosphorus application rate and plant population per hectare of faba bean at HU.

P_2O_5 x Pop. (kg ha^{-1})	AV. SY (kg ha^{-1})	Adj. SY (kg ha^{-1})	TVC (Birr)	GFB (Birr)	NB (Birr)	MRR	MRR%
23 x 133,333	2459.63	2213.67	29074.497	77478.45	48403.953	392.2455157	39224.55157
46 x 133,333	2969.96	2672.964	29091.713	93553.74	64462.027	932.7412872	93274.12872
23 x 200,000	2809.4	2528.46	29120.802	88496.1	59375.298	1900.53216	190053.216
69 x 200,000	2863.2	2576.88	29600.514	90190.8	60590.286	1690.265475	169026.5475
23 x 166,667	2769.67	2492.7	29627.196	87244.5	57617.304	2010.239919	201023.9919
46 x 166,667	3159.967	2843.97	29632.308	99538.95	69906.642	2404.017606	240401.7606
23 x 250,000	2708.4867	2437.638	30113.202	85317.33	55204.128	1468.566832	146856.6832
46 x 250,000	3179.53	2861.58	30120.922	100155.3	70034.378	1921.016839	192101.6839
46 x 222,222	2657.767	2391.99	30605.518	83719.65	53114.132	10.39854799	1039.854799
69 x 222,222	3163.7	2847.33	30607.526	99656.55	69049.024	7935.703187	793570.3187
23 x 300,000	2920.943	2628.849	30635.312	92009.715	61374.403	6684.649752	668464.9752
46 x 300,000	3380.23	3042.21	30646.032	106477.35	75831.318	1348.592817	134859.2817

P_2O_5 x Pop**.** (Kg ha^{-1})= phosphorus fertilizer rates with plant population per hectares combination; AV. SY (kg ha^{-1}) = average seed yield; Adj. SY = adjusted faba bean seed yield in kg ha^{-1}; TVC= total variable cost; Birr = Ethiopian birr; GFB= gross field benefit; NB= net benefit; MRR and MRR (%) = marginal rate of return as ratio of change in net benefit to change total variable cost and as percentage of marginal rate of return, respectively.

5. SUMMARY AND CONCLUSION

An ever-increasing world population requires producing more food in land which is gradually shrinking and losing its fertility each year due to over misappropriation and poor soil fertility managements. Faba bean is the most important food and export crop especially in the highlands of Ethiopia and it is the source of protein and cash for poor farmers. In view of this, an experiment was conducted to determine the effect of plant population (density) and phosphorous levels on yield components and yield of faba bean. The experiment consisted of six plant populations (133,333; 200,000; 166,667; 250,000; 222,222 and 300,000 plants ha^{-1}) and four phosphorous application rates (0, 23, 46 and 69 kg ha^{-1}). A factorial experiment was conducted in RCBD with three replications.

Phosphorus application significantly influenced some phenological growth parameters and yield components of faba bean. The results showed that phosphorus rates had significant effect on number of days to 50% flowering and 90% physiological maturity, total number of nodules and number of effective nodules per plant, total leaf area per plant, leaf area index, plant height, number of primary tillers per plant, number of seeds per pod, hundred seed weight, above ground dry biomass yield, seed moisture content, grain yield per ha and harvest index. The highest rate of P (69 kg P_2O_5 ha^{-1}) resulted in the lowest number of days to flowering (54.3 days) and physiological maturity (133.9 days). Similarly, the highest leaf area index (2.923), plant height (189.7 cm), number of primary branches per plant (3.278), number of seeds per pod (3.378), hundred seed weight (74.22 g), above ground dry biomass yield (15978 kg ha^{-1}), and harvest index (20.32%) were recorded for the highest rate of P (69 kg of P_2O_5 ha^{-1}, but the highest grain yield (2633 kg ha^{-1}) was obtained from 46 kg of P_2O_5 ha^{-1}. In general, faba bean showed significant response to the application of phosphorus.

The results also indicated that almost all plant parameters were significantly affected by plant population density. Accordingly, plant population of 300,000 plants ha^{-1} (30 cm x 10 cm) showed earlier flowering (54.42 days) 90% physiological maturity (133.5 days) as compared to 133,333 plants ha^{-1}. On the other hand, lower plant population (133,333 plants ha^{-1}) (50 cm x 15 cm) showed significantly higher values of leaf area, leaf area index, number of primary branches per plant, hundred seed weight and harvest index as compared with high plant population (300,000 plants ha^{-1}) (30 cm x10 cm) highest grain yield per hectare was recorded for 300,000 plants ha^{-1} (30 cm x 10 cm). The interaction of phosphorus and plant population was significant ($P \leq 0.05$) for leaf area index, total number of nodules, number of primary branches per plant, number of seeds per pod, above ground dry biomass yield, hundred seed weight, seed moisture percentage, grain yield per hectares and harvest index.

Recommendations

The highest grain yield per hectare and maximum economic return were recorded due to application of 46 kg of P_2O_5 ha^{-1} with 300,000 plants ha^{-1} (30 cm x 10 cm). Therefore, application of 46 kg of P_2O_5 ha^{-1} with 300,000 plants ha^{-1} (30 cm x 10 cm plant spacing) could be fiseable recommendation for faba bean production in the study area and in areas with similar soils and agro-ecologies. However, as this study was done for one season at one location, a similar experiment has to be further carried out in different seasons and over locations to come up with a more comprehensive recommendation.

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7. APPENDIXS

Appendix Table 1: Analysis of variance table showing mean square values for the effect of phosphorus rate and plant population on number of days to 50% flowering (DTF), number of days to 90% maturity (DTM), total number of nodules per plant (TNN), number of effective nodules per plant (ENN) and stand count at emergence (SCE) of faba bean.

Source of Variation	df	Days to 50% Flowering	Days to 90% maturity	Total number of nodules	Effective number of nodules	Stand count at emergence
Replication	2	1.764	23.597	5.82	0.0089	8.375
P_2O_5	3	39.13**	139.593**	431.28**	17.6452**	3.236 ns
Population (P)	5	21.122**	37.722**	149.04**	7.2702**	1.558ns
P_2O_5 X Pop	15	2.33ns	4.248ns	129.62**	1.0021ns	0.425ns
Error	46	4.141	7.452	12.34	0.7034	1.071
CV (%)		3.6	2.0	2.3	5.4	1.1

Pop = population density, CV= Coefficient of Variation and **, *, and ns represent significant variation at $P < 0.01$, and $P \leq 0.05$ levels and non-significant variation, respectively.

Appendix Table 2: Analysis of variance table showing mean square values for the effect of phosphorus rate and plant population on stand count at harvest, total leaf area per plant (LA), leaf area index (LAI) and plant height (PH (cm)) of faba bean.

Source of Variation	df	Stand count at harvest	Leaf area(cm^2)	Leaf area index	Plant height (cm)
Replication	2	2.431	51.75	0.00662	3.29
P_2O_5	3	0.611ns	183.68**	0.26985**	754.25**
Population (P)	5	12.89**	93.36**	2.04816**	364.63**
P_2O_5 X Pop	15	1.356ns	28.15ns	0.24697**	15.74ns
Error	46	2.271	14.18	0.02131	30.83
CV (%)		1.7	6.7	5.2	3.0

Pop = population density, CV= Coefficient of Variation and **, *, and ns represent significant variation at $P < 0.01$, and $P \leq 0.05$ levels and non-significant variation, respectively.

Appendix Table 3: Analysis of variance table showing mean square values for the effect of phosphorus rate and plant population on number of primary branches per plant (NPB), number of pods per plant (PPP) and seeds per pod (SPP) and above ground dry biomass yield of faba bean.

Source of Variation	df	Number of primary branches	Pods per plant	Seeds per pod	Dry biomass yield kilogram per hectares
Replication	2	0.05389	0.348	0.07389	577810
P_2O_5	3	0.49185^{**}	40.551^{**}	0.43611^{**}	24667925^{**}
Population (P)	5	0.65156^{**}	12.573^{**}	0.35922^{**}	7372586^{**}
P_2O_5 X Pop	15	0.31141^{**}	3.852^{ns}	0.11833^{**}	3462271^{**}
Error	46	0.04287	1.863	0.03447	363588
CV (%)		6.6	5.4	5.7	4.1

Pop = population density, CV= Coefficient of Variation and **, *, and ns represent significant variation at $P < 0.01$, and $P \leq 0.05$ levels and non-significant variation, respectively.

Appendix Table 4: Analysis of variance table showing mean square values for the effect of phosphorus rate and plant population on hundred seed weight (100SW), seed moisture content grain yield kilogram per hectare and harvest index (HI) of faba bean.

Source of Variation	df	Hundred seed weight (100SW)	Seed moisture%	Yield kilogram per hectares (kg ha)	Harvest index (%)
Replication	2	4.49	0.4555	93562	2.221
P_2O_5	3	79.65^{**}	3.2406^{*}	1305342^{**}	18.900^{**}
Population (P)	5	56.91^{**}	3.4178^{**}	218653^{*}	67.199^{**}
P_2O_5 X Pop	15	48.49^{**}	3.4132^{**}	138257^{*}	6.393^{**}
Error	46	10.91	0.518	51236	1.018
CV (%)		4.6	4.3	8.3	5.3

Pop = population density, CV= Coefficient of Variation and **, *, and ns represent significant variation at $P < 0.01$, and $P \leq 0.05$ levels and non-significant variation, respectively.

Appendix Table 5: Total costs for each treatment per hectare in Ethiopian birr (ETB) for faba bean.

		Fertilizer cost				
P_2O_5kg ha^{-1}	UREA kg ha^{-1}	For P_2O_5	For UREA	FA	For seed and labour	TVC (Birr)
0	20	0	300	50	28699.521	29049.521
0	20	0	300	50	28724.497	29074.497
0	20	0	300	50	28731.713	29091.713
0	20	0	300	50	28742.873	29102.873
0	20	0	300	50	28760.914	29110.914
0	20	0	300	50	28770.802	29120.802
23	20	391	300	100	28803.698	29594.698
23	20	391	300	100	28809.514	29600.514
23	20	391	300	100	28829.252	29620.252
23	20	391	300	100	28836.196	29627.196
23	20	391	300	100	28841.308	29632.308
23	20	391	300	100	28843.316	29634.316
46	20	782	300	150	28878.778	30110.778
46	20	782	300	150	28881.202	30113.202
46	20	782	300	150	28888.922	30120.922
46	20	782	300	150	28893.666	30125.666
46	20	782	300	150	28900.462	30132.462
46	20	782	300	150	28907.406	30139.406
69	20	1173	300	200	28932.518	30605.518
69	20	1173	300	200	28934.526	30607.526
69	20	1173	300	200	28959.888	30632.888
69	20	1173	300	200	28962.312	30635.312
69	20	1173	300	200	28973.032	30646.032
69	20	1173	300	200	28976.776	30649.776

P_2O_5 = 1700 birr / quintal; UREA = 1500 birr/quintal; FA for fertilizer application cost; TC for Total costs of fertilizers and others; ETB for Ethiopian birr; fertilizer application cost 50 birr/ day/person; transportation cost for fertilizer from Union to field 80 birr/ quintal; transportation cost for Seed yield 70 birr/ half quintal.