GROWTH AND YIELD OF COMMON BEAN (*Phaseolus vulgaris* L.) CULTIVARS AS INFLUENCED BY RATES OF PHOSPHORUS AT JIMMA, SOUTHWEST ETHIOPIA

MSc THESIS

AMANUEL ALEMU HAILE

JUNE, 2017

JIMMA, ETHIOPIA

Growth and Yield of Common Bean (*Phaseolus vulgaris* L.) Cultivars as influenced by Rates of Phosphorus at Jimma, Southwest Ethiopia

Amanuel Alemu Haile

MSc Thesis

Submitted to the School of Graduate Studies, Jimma University College of Agriculture and Veterinary Medicine in Partial Fulfillment of the Requirements for the Degree of Master of Science in Agriculture (Agronomy)

June, 2017

Jimma, Ethiopia

Approval sheet

Jimma University College of Agriculture and Veterinary Medicine

Thesis submission Request form (F= 05)

Name of students: Amanuel Alemu ID No. RM9457/08

Program of study: MSc. In Agronomy

Title: Growth and Yield of Common Bean (*Phaseolus vulgaris* L.) Cultivars as Influenced by Phosphorus Rates at Jimma, South Western Ethiopia.

I have completed my thesis research work as per the approved proposal and it has been evaluated and accepted by my advisers. Hence, I hereby kindly request the department to allow me to present the finding of my work and submit thesis.

Amanuel Alemu __________ _________

Name of the student signature Date

We, the thesis advisors have evaluate the contents thesis and found to be satisfactory, executed according to approved proposal, written according to the standards and formats of the university and is ready to be submitted. Hence, we recommend the thesis to be submitted.

Amsalu Nebiyu (PhD) _____________ ____________

Major advisor Signature Date

Merkeb Getachew (Msc, Ass. Prof) _____________ ______________

Co-advisor Signature Date

Internal Examiner (it depends on the verdict)

Name Gezahegn Berecha (PhD _____________ _________

Signature Date

Decision / suggestion of Department Graduate Council (DGC)

____

_______________________ _____________ _____________

Chair person, DGC Signature Date

_________________________ ______________ ______________

Chair person, CGS Signature Date

DEDICATION

I dedicated this thesis to my family.

STATEMENT OF AUTHOR

First, I declare that this thesis is my original work and that all sources of material used for this thesis have been appropriately acknowledged. This thesis has been submitted in partial fulfillment of the requirements of M.Sc. degree at Jimma University, College of Agriculture and Veterinary Medicine and is deposited at the University Library to be made available to users under rules of the Library. I seriously declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate. Brief references from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended reference from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the School of Graduate Studies when in his or her judgment the proposed use of the material is for scholarly interest. In all other instances, however, permission must be obtained from the author.

Name: Amanuel Alemu Haile Signature: ……………………

Place: Jimma University

Date of Submission:

BIOGRAPHICAL SKETCH

The author, Amanuel Alemu Haile, was born in Saylem District of Kaffa Zone in SNNPR, on October 12, 1986 G.C. He attended his Elementary and Secondary school at Saylem Elementary and Masha Senior Secondary Schools (1999 – 2002 G.C), respectively. After completion of his high school education, he joined Wolayita Sodo Agricultural Technique and Vocational Education Training College in 2003 and graduated with a diploma in Plant Sciences in 2006 G.C. After graduation, he was employed by the Ministry of Agriculture in Saylem District of Kaffa Zone as agronomist and served the organization for more than 3 years. Then after, he got an opportunity to join Mizan Teppi University for his BSc degree in Plant Science in 2010 and graduated with a BSc. degree in Plant Sciences in 2014. After graduation he was re-employed by Saylem woreda Ministry of Agriculture and served the organization as agronomist for 1 year. In 2015, he joined the school of graduate studies, Jimma University College of Agriculture and Veterinary Medicine to pursue his MSc study in Agronomy.

ACKNOWLEDGEMENTS

I would like to express my heartfelt thanks to my major advisor Dr. Amsalu Nebiyu and co-adviser Mr. Merkeb Getachew for their valuable advice, insight and guidance starting from proposal development to the completion of the research work and thesis write up. I would like to extend my sincere gratitude to Saylem woreda administrative office for giving me the chance to pursue my post graduate study, and Jimma University, College of Agriculture and Veterinary Medicine for providing me with research fund and other facilities. I am also grateful to thank Alemseged Amanuel and the whole staff of Eladale research site of Jimma University college of Agriculture and Veterinary Medicine for their valuable support during the field work, allowing me to use experimental fields, and for providing me with the required inputs and labour needed to establish and manage the field experiment. I am also indebted to Hawassa Agricultural Research Center and Mr. Teshome Mamo for providing me with the experimental inputs (improved cultivars and fertilizer).

I would like to express my sincere gratitude to my wife Kidist Abebe, for her dedication and strong support throughout my study and moral and financial support. I express my heartfelt gratitude to my family for their encouragement during the study period. I am grateful to my mother Aster Ambo, my father Alemu Haile, Mr. Melaku Haile, Abebe G/Mariam; and I keep expressing my thanks to my glad brothers Tsegaye Alemu and Habtamu Alemu for their unreserved and continuous encouragement, considerate and financial support. Moreover, I thank my colleagues and JUCAVM MSc students Girma Abebe, Belachew Beyene and Tamirat Belayneh for their unreserved support by idea for the successes of my study. At last but not least, I would like to thank Mr. Bayu Dume and Abiyot Hunde for their particular help in soil and plant analyses in their respective laboratories.

Above all, I would like to thank my heavenly Father Lord God for giving me the health, peace and directing me with his true spirit all the time with success.

TABLE OF CONTENTS

Contents **Page**

LIST OF TABLES

LIST OF FIGURE

LIST OF APENDIXS

LIST OF ACRONYMSAND ABBREVIATIONS

BNF	Biological Nitrogen Fixation
BPEDORS	Bureau of Planning and Economic Development of Oromia region State
CIAT	Centro Internationalized Agricultural Tropical
CSA	Central Statistical Agency
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
NSL	National Soil Laboratory
PABRA	Pan-Africa Bean Research Alliance
SNNPR	Southern Nations and Nationalities and Peoples Regional State

Growth and Yield of Common Bean (*Phaseolus vulgaris* L.) Cultivars as Influenced By Rates of Phosphorus at Jimma, Southwest Ethiopia

ABSTRACT

Common bean (Phaseolus vulgaris L.) is an important food and cash crop in southwest Ethiopia with multiple uses. Productivity of the crop is, however, low at national as well as regional levels, mainly due to low soil fertility. Phosphorus (P) deficiency is particularly important in acid soils of southwest Ethiopia affecting growth and yield of seed legumes in general and that of common beans in particular. Cultivar differences are known to exist in response to performance under low P and acidity conditions. Therefore, a field experiment was conducted to assess the response of common bean cultivars to P application on Nitisols of Jimma in 2016 main cropping season. The treatments consisted of three common bean cultivars (Ibbado, Tatu, and Remeda) and four P fertilizer rates (0, 23, 46, and 69 kg P_2O_5 ha^{-1}). The experiment was laid out in a Randomized Complete Block Design in a factorial arrangement replicated three times. Growth parameters, Phenological parameters and Yield parameters were collected and statistically analyzed using SAS version 9.2 software. P use efficiency of the cultivars under the different P application rates was also assessed. Results indicated that the main effect of P significantly ($P < 0.01$) influenced number of primary branches and harvest index. Highest number of primary branches (3.25) and harvest index (48.63%) were recorded at application of 69 kg P_2O_5 ha^{-1}. The main effect of cultivars significantly ($P < 0.01$) influenced plant height, hence Remeda was the tallest plant (53.24 cm). The interaction effects of cultivars and P rates also significantly ($P < 0.01$) influenced days to 50% flowering, days to 90% physiological maturity, root length, number of nodules, nodule dry weight, number of pods per plant, number of seeds per pod, pod length, hundred seed weight, dry biomass yield and seed yield. The highest dry biomass yield (5874 kg ha^{-1}) and seed yield (2821 kg ha^{-1}) were obtained from the treatment combination of cultivar Tatu and 69 kg P_2O_5 ha^{-1}. The P use efficiency parameters (recovery efficiency, agronomic efficiency) were also significantly affected by the interaction effect of cultivar and P application rate. Cultivar Tatu was found to be more P efficient at P rate of 23 kg P_2O_5 ha^{-1}. In conclusion, the study pointed out that common bean cultivars responded differently to the various P application rates suggesting the possibility of exploiting cultivar differences to combat P deficiency under acidic conditions. Phosphorus at rate of 23 kg ha^{-1} will be recommendable for P-efficient cultivar based on phosphorus use efficiency parameters. Accordingly, Farmer who have no capacity to buy fertilizer cultivar Tatu was recommended to specific soil of study area. However, since the data is only for one season and location repeating the experiment across location may be helpful to validate the results.

Keywords: Common Bean, Phosphorus use Efficiency, Seed Yield, Soil Acidity

1. INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) belongs to the family *Fabacea* and originated from Central and South America. It is now widely cultivated as a major food crop in many tropical and subtropical areas of America, Europe, Africa and Asia (Wortmann, 2006). It is highly polymorphic warm-season, herbaceous annual crop and which has two growth habit: erect herbaceous bushes (determinate), up to 20-60 cm high; and twining, climbing vines (indeterminate) up to 2-5 m long (Ecocrop, 2013).

Common bean is a major grain legume consumed worldwide for its edible seeds and pods. In Ethiopia, it is one of the most important cash crops and source of protein in many lowlands and mid land area areas. It is high in starch, dietary fiber and is an excellent source of potassium, selenium, molybdenum, thiamine, vitamin B6, and folic acid (Maiti, and Singh, 2007). It is used as food in different form the green unripe pods are cooked or conserved as vegetable and the ripe seeds cooked for "*nifro*" or boiled with mixed with sorghum or maize and can be consumed as "*woti*" using powder form (MOARD, 2009). Common bean is highly preferred by Ethiopian farmers because of its fast maturing characteristics that enable households to get cash income required to purchase food and other household needs when other crops have not yet matured (Legese *et al*., 2006). Its ability to fix nitrogen makes it important in cropping systems as it can enhance soil fertility. The versatility of common beans and its contribution to a household's food income, diet, health and even environmental security is remarkable. The country's export earnings is estimated to be over 85% of export earnings from pulses, exceeding that of other pulses such as lentils, faba bean and chickpea. Common bean ranks third as an export commodity in Ethiopia, and contributing about 9.5% of total export value from agricultural income of the country (FAOSTAT, 2015). The amount of export per annum from common bean is about $70.187million (Boere *et al.*, 2015).

World production of common bean exceed more than 25 million MT, out of which about 6 million MT is produced in Africa (FAOSTAT, 2015). In Ethiopia it is widely grown as traditional pulse crop with area of about 0.37 million hectares and total annual production of 0.51million MT at main season only (FAOSTAT, 2015). Among pulses it takes the largest share of in terms of area coverage, with an increasing trend for the last ten years (CSA, 2015). However, the national average yields (1.59t ha^{-1}) (CSA, 2015) is far lower than the average yield reported at research sites (2.5 to 3t ha^{-1}) (Frehiwot, 2010). In terms of geographical distribution of production, Oromia took the lion share (51%) of common bean production in the country, followed by SNNPR (27%), Amhara (20%) and, Benishangul-Gumuz (1%) and the other regions contributing 1% of the country total production (CSA, 2015). Production obtained from common bean at Jimma zone is about 4906.3 ha with the total production of 4,428.6 t and productivity of 0.9 t ha^{-1} (CSA, 2015). Low yield of the crop in the country is attributed to declining soil fertility, drought and rainfall variability, pest attack, and poor agronomic practices (Katungi *et al.,* 2010). Furthermore, poor availability of essential plant nutrients especially P is one of yield limiting factor in grain legumes (Kochian *et al.,* 2004).

Common bean has high nitrogen and P requirement for expressing its genetic potential. However, as bean has the ability to fix and use atmospheric nitrogen with regards to soil fertility and mineral nutrition requirement, P is considered as the first and nitrogen as the second limiting plant nutrient for bean yield in the tropical zone (Tesfaye *et al.,* 2007). According to Amare (1987); cited in Gifole *et al*., 2011, the yield of common bean increases with P application and its nodulation and atmospheric nitrogen fixation can also be improved with P application. Legumes, including common bean, have high P requirement due to the production of protein containing compounds, in which P are important constituents. High seed production of legumes primarily depends on the amount of P absorbed (Khan *et al*., 2003).

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

Improved common bean production encompasses proper use of different agronomic practices which include improved cultivars, seed rate, spacing, fertilizer rate and pesticide application as per recommendations (Alemitu, 2011). Different common bean cultivars consist of different morphological growth habits specially root architecture. Cultivars differ in their P nutrient uptake and utilization efficiency largely influenced by the environmental conditions. P-efficient common bean cultivars which increase below-ground biomass are able to acquire P in P-deficiency conditions (Namayanja, 2014). Blair *et al*. (2009) reported that greater production of adventitious roots in common beans helps in P acquisition by improving plant foraging in most P rich soil environment. Thus, the difference in root traits indicates the differences among common bean cultivars in P acquisition efficiency.

Application of phosphate fertilizers has been suggested to enhance availability of soil P and crop yields (Vance *et al.,* 2003). One of the strategies to improve bean yield on P deficient soils is application of adequate levels of P (Fageria, 2012). Furthermore, various research findings indicated that bean respond differently to different rates of P at various locations. Gifole *et al*. (2011) reported that application of 23 kg P_2O_5 ha^{-1} significantly improved seed and biomass yield of common bean on Ultisols of Areka. Dereje *et al.* (2016) found that application of P at the rate of 69 kg P_2O_5 ha^{-1} at Areka and 23 kg P_2O_5 ha^{-1} at Kokate resulted in highest seed yield of the crop on Haplic Alisol. Mesfin *et al*. (2014) showed the highest seed yield and yield components at 69 kg P_2O_5 ha^{-1} on Nitisols at Boloso Sore and Damot Woreda of Wolayita Zone. However, Amare *et al*. (2014) reported that application of 20 kg P_2O_5 ha^{-1} gave the maximum seed yield and related yield parameters of common bean at Arbaminch. Tesfaye *et al*. (2015) also pointed out that application of 2.7 t lime ha^{-1} and 30 kg P_2O_5 ha^{-1} had resulted in higher seed yield and economic return on acidic soil of Areka.

These studies have suggested that response of common bean to P application is site specific and agro-ecology dependent. This calls for further studies in southwest Ethiopia where information on the response of common bean cultivars to P fertilizer on Nitisols is scares. Therefore, this study was conducted with an overall objective of examining the influence of P rates on growth and yield of common bean cultivars at Jimma.

Specific objectives of this study were;

- To determine the interaction effect of phosphorus and common bean cultivars on yield and yield components under Nitisol of Jimma, southwest Ethiopia.
- To examine phosphorus use efficiency of common bean cultivars to various levels of applied P under Nitisol of Jimma, southwest Ethiopia.

2. LITERATURE REVIEW

2.1. Origin, Botany and Ecological Requirement of Common Beans

Common bean (*Phaseolus vulgaris* L.) was originated in Tropical America (Mexico, Guatemala, and Peru). There are also evidences for its multiple domestication within Central America (Kay, 1979). It was most likely introduced to Ethiopia by the Portuguese in the 16th century (Wortmann, 1997). It is also known as by different names such as haricot bean, string bean, field bean, flageolet bean, French bean, garden bean, pop bean, or snap bean (USDA, 2010).

Common bean (2n=2x=22) belongs to the order Rosales, family Fabaceae, subfamily Papilionoideae, tribe Phaseoleae (CIAT, 1986). Cultivated forms of common beans are herbaceous annuals, which are determinate or indeterminate in growth habit. On germination, the plant is initially tap-rooted, but adventitious roots emerge soon thereafter, and dominate the tap root which remains 10-15 cm in length (Duke, 1981). Papilionaceous flowers are borne in auxiliary and terminal racemes. Racemes may be one or many flowered. Flowers are zygomorphic with a bi-petalled keel, two lateral wing petals and a large outwardly displayed standard petal. Flower color is genetically independent of seed color, but association between particular flower and seed colors is common. Flowers may be white, pink or purple. The flower contains ten stamens and a single multi ovuled ovary which is predominantly self-fertilized, and develops into a straight or slightly curved fruit or pod. Seeds may be round, elliptical, somewhat flattened or rounded elongate in shape, and a rich assortment of coat colors and patterns exists (Graham, 1997). In developmental terms, there are two types of common beans: determinate and indeterminate (Singh, 1982). The determinate type is short, self-supporting or bushy in which the main axis terminated in an inflorescence, no vegetative nodes after flowering and short growth duration. Indeterminate genotypes showed a wide range of node number on the main stem, climbing tendency and long growth duration (Laing *et al.,* 2010). Most beans cultivated in East Africa are determinate, with bushy growth habit but indeterminate non-climbing, semi-bush types, and indeterminate climbing types are also adopted (Laing *et al.,* 2010).

Common bean is widely grown in low land and mid high altitude areas. It has a wide range of adaptations and grows well between 1400 to 2000 meters above sea level (Fikru, 2007). It grows best in warm climate at temperature of 18 to 24 ^{o}C (Teshale *et al.*, 2005) and to the areas with annual average rainfall 500-1500 mm (Amare, 1989). However, rainfall towards the end of growing periods is undesirable. It can be grown successfully on most soil types, from light sands to heavy clays, but friable, deep and well-drained soils are best preferred having pH of 5.0 to 6.5 (Onwueme and Sinha, 1991). They are grown throughout the cooler tropics, but not in hot semi-arid or humid regions. Common bean requires a minimum frost free period of 105-120 days, as they are killed by frost. In general, high temperature (20-30 ^{0}C) during flowering causes the dropping of buds and flowers, which reduces yield (Amare, 1989). Full maturity for common bean seed type was attained from 45 to 150 days after emergence, depending on growth habit type and location (Singh, 1982). The late maturing beans were more often indeterminate while those of the early ones were determinate (Kelly *et al.*, 1987). Maturity of bean increased with the altitude. Low temperature prolongs the maturity period of beans and it was more pronounced in indeterminate than determinate types (Amare, 1987).

2.2. Importance of Common Beans in Ethiopia

Common bean is one of the most important cash crops and source of protein in many lowlands and mid altitude. Among legumes, common bean constitute a significant part of human diet in Ethiopia (Ali *et al.*, 2003). Their role in reducing blood cholesterol level and combating chronic heart diseases, cancers and diabetics is also gaining recognition from human health point of view (Singh, 1999). It is also high in starch, dietary fiber contents and is an excellent source of potassium, selenium, molybdenum, thiamine, vitamin B6, and folic acid (Maiti and Singh, 2007). It is used as food stuff and the green unripe pods are cooked or conserved as vegetable. The ripe seeds are cooked for soups and broth in the world (Brucher, 2011), and in Ethiopia it is mostly prepared as nifro (boiled seed), mixed with sorghum or maize and woti (MoARD, 2009). Seeds of common beans are rich source of 22% proteins, 46% carbohydrate and very small amount of fat (PABRA, 2005; Sandhyarani, 2010).

CIAT (2001) reported that common bean supplies 25 to 30% of the recommended levels of iron and meets about 25% of the daily requirement of magnesium (Mg) and copper (Cu). In addition, it is a good source of Fe and Zn (Broughton *et al,* 2003; PABRA, 2005). Hence, nutritionists characterize the common bean as a nearly perfect food because of its high protein content and generous amounts of fiber, complex carbohydrates, and other dietary necessities (CIAT, 2001). It is also highly preferred by Ethiopian farmers because of its fast maturing characteristics that enable households to get cash income required to purchase food and other household needs when other crops have not yet matured (Legese *et al*., 2006).

In addition to source of dietary protein, the common bean plays a vital role in the endowment of food security and as cash income (Ferris and Kaganzi, 2008). As an export commodity, common bean ranks third in Ethiopia contributing for about 9.5% of total export value of agriculture (FAOSTAT, 2015). For instance, in 2014 the total national production was estimated about 0.514 million MT, with export earnings of US$ 132.9 million (FAOSTAT, 2015). Moreover, the crop is also a basic component of cropping system of small farmers (CIAT, 2003). In south west, the crop is intercropped with other crops particularly with maize, sorghum and in garden coffee plantation (Tilahun *et al.,* 2001). Hence, it contributes to soil fertility improvement through biological nitrogen fixation. In general, common bean has high nutrient contents, commercial potential and atmospheric N-fixing ability. Thus, it holds a great promise for increasing income, improving soil fertility as well as ensuring food security in Sub Saharan Africa (Katungi *et al.,* 2010; Margaret *et al.,* 2014).

In Africa, common bean is a popular crop among small-scale farmers, given its short growth cycle (about 70 days) which permits production when rainfall is erratic. It is often grown by women farmers mainly for subsistence and markets (Katungi *et al*., 2010). Within East Africa, the areas bordering the Great Lakes have particularly high per capita common bean consumption rates (above 40 kg year^{-1}). The region is intensively farmed due to the high populations with common bean as one of the major crops of each country (Matthew *et al*., 2010).

2.3. Role of Phosphorus on Common Bean Growth and Nodule Formation

2.3.1. Importance of Phosphorus on common bean growth

Phosphorus is an important element for plant growth among 17 essential nutrients and its function cannot be performed by any other nutrient (Uchida, 2000). Phosphorus deficiency is one of the most important fertility problems in tropical agriculture. Insufficient levels of P may hinder plant growth; lower the chlorophyll accumulation which limits photosynthesis in turn decrease in shoot growth, and limits the transport of photosynthates to nodules (Lambers *et al*., 2006). Commonly, inadequate P slows the processes of carbohydrate utilization, development of a dark green leaf color or plant leaves developing a purple color (Samavat *et al*., 2012). Generally, P is vital to plant growth and is found in every living plant cell. Phosphorus is the second most critical plant nutrient over all, but for legumes it assumes primary importance (Sinclair and Vadez, 2002). Plants need P for growth throughout their life cycle, especially during the early stages of growth and development. P is involved in several key plant functions, including energy transfer, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics from one generation to the next (Uchida, 2000).

Legumes including common bean have high P requirement due to the production of protein containing compounds, in which P are important constituents. Gangasuresh *et al*. (2010) noted that P is a crucial element in legume crop production which plays an important role for many characteristics such as sugar and starch utilization, photosynthesis, cell division and organization. Moreover, the importance of P in BNF is well known, as it is an energy driven process. Sufficient P is also required to enhance plant growth, promote nodulation, early maturity and seed formation in legumes (Kamara *et al*., 2010). On the other hand, Lambers *et al*. (2006) pointed out that, P is required in large quantities in young cells particularly in shoot tips where metabolism is high and cell division is rapid. Tesfaye *et al*. (2015) has also indicated that plant height and number of primary branches per plant on common beans was increased through applied P. Therefore, extra application of P fertilizers to soil improves the root growth, and then enhancing the shoot growth subsequently increases the yield component of the crop (Samia *et al*., 2012).

2.3.2. Response of Nodulation and N_2-Fixation to P Nutrition

Legumes have a high P requirement for growth and also for nodulation and N_2 fixation (Israel, 1987). Phosphorus influences nodule development through its basic functions in plants as an energy source. Fageria (2012) reported that P plays a vital function in increasing plant tip and root growth, decreasing the time needed for developing nodules to become active and of benefit to the host legume. Besides, P increases the number and size of nodules and the amount of nitrogen assimilated per unit weight of nodules, increasing the percent and total amount of nitrogen in the harvested portion of the host legume and improving the density of Rhizobium bacteria in the soil surrounding root (Bashir *et al*., 2011). Mulongoy (1992) reported that P is needed for plant growth, nodule formation and development, and ATP synthesis, each process being vital for N_2 fixation. This is mainly due to the fact that symbiotic nitrogen fixation is a high P demanding process, therefore nodule formation and N_2 fixation are generally limited by low P availability through adversely affecting nodule number and mass, as well as nitrogenase activity (Schulze *et al*., 2006). Phosphorus brings about the ability of catalyzing stress in the symbiotic relation between root bacteria and legume plants (Tsvetkova *et al*., 2003). Tesfaye *et al*. (2015) reported that P application had highly significant effect on number of effective nodules per plant on common bean. Furthermore, Tesfaye *et al.* (2015) indicated that total number of nodules and nodules volume per plant were significantly affected by P rates on soybean. Positive response of both nodule number and volume to P application in high P sorption soil might be due to the ability of Rhizobia to mobilize inorganic P from insoluble P sources as suggested by Alikhani *et al*. (2006) who demonstrated that when Rhizobia were cultured in liquid medium supplied with $Ca_3 (PO_4)_2$ as P source, soluble P concentration increased in the medium.

It is usually accepted that N_2 fixing systems require more phosphorus than non-N_2 fixing systems. Amare *et al.* (2014) have shown that the benefit of P fertilizer application and cultivars consideration common bean for nodulation potential and better nutrient use efficiency. It has been suggested that the high energy costs of supporting the rhizobial symbiosis require the uptake of large amounts of P to meet the need for adenosine triphosphate (ATP) (Tang *et al*., 2001). N_2 fixation is also very sensitive to P deficiency because it reduces nodule mass where shortage of P will severely limit the formation of nodules and N_2 fixation.

2.4. Role of Phosphorus in Yield and Yield Components of Common Bean

Common bean need P for growth, utilization of sugar and starch, photosynthesis, nucleus formation and cell division, fat and albumen formation, transfer and storage of energy within plants. Energy from photosynthesis and the metabolism of carbohydrates is stored in phosphate compounds for later use in growth and reproduction (Georgina *et al*., 2007; Sixbert and George, 2012). Adequate P results in rapid growth, earlier maturity and increased root growth which means plant can explore soil for nutrients and moisture and its deficiency slow overall plant growth, (McKenzie and Middleton, 1997; Sixbert and George, 2012). Tesfaye *et al.* (2015) noted that number of pod per plant, number of seed per pod, biomass yield, hundred seed weight and seed yield of common bean significantly increased with application of P fertilizers.

Research results by different workers under Ethiopian condition and elsewhere in Africa also revealed significant crop yield increments in response to the application of P fertilizers (Ochwoh *et al.,* 2015; Fisseha and Yayis, 2015). This indicates the inevitability of application of inorganic nutrient sources to improve yield. Significant variations in the number of pods per plant among common bean cultivars when grown at different P levels have been reported (Mourice and Tryphone, 2012). Application of P produced 20 and 36% higher number of pods plant^{-1}. Similarly, averaged across cultivars, about 7 and 8% higher number of seeds per pod was produced at medium and higher P rates (Dereje *et al*., 2016). Improvement in number of pods per plant and seeds per pod can be attributed to higher photosynthetic activities such as photophosphorylation and energy transfer (Malik *et al.,* 2002; Vance *et al.,* 2003), which might have contributed for better biomass accumulation and partitioning into yield attributing traits such as number of pods per plant and number of seeds per pod.

Common bean cultivars produced significantly varying seed yields across the soil applied P. There are also immense research findings that confirm the varying response of seed yield of common bean cultivars at different rates of soil applied P (Boutraa, 2009; Fageria *et al.*, 2010). This indicates that common bean cultivars differ in P fertilizer requirement. Generally, the efficient cultivars produced higher seed yield at all nutrient levels compared to the inefficient ones.

2.5. Root Architecture and P Uptake

Roots are important plant organs. They absorb water and nutrients from the soil and translocate them to plant tops (Merrill *et al*., 2002). Roots also give mechanical support to plants and supply hormones that affect many physiological and biochemical processes associated with growth and development. Roots exert control over whole-plant growth and development by controlling the uptake of mineral nutrients (Zobel, 1986). Vigorous root systems are needed for the development of healthy plants and consequently, higher yields. Roots that are left in the soil after crop harvest improve soil organic matter (OM) content and contribute to the nitrogen cycle and microbial activity (Sainju *et al*., 2005).

Genetic differences exist in the root architecture traits of different bean genotypes that are key adaptations to P stress in low-input agro-ecosystems (Lynch and Brown, 2008). Root traits that enhance topsoil foraging are advantageous in low P soil since P bio-availability is typically greatest in surface horizons (Lynch and Brown, 2001). Genotypes with shallow root architecture have greater growth and yield in low-P soil than related genotypes with deep architectures (Rubio *et al*., 2003). Adventitious roots may improve crop 10 adaptation to low-P soils by enhancing topsoil foraging (Rubio *et al*., 2003). In a tropical field study, P stress stimulated adventitious rooting in P-efficient genotypes of common bean but not in P-inefficient genotypes. Choosing adventitious rooting is a useful adaptation to low P availability, because adventitious roots explore topsoil horizons more efficiently than other root types (Miller *et al*., 2003). Root architectural plasticity traits of common bean that increase topsoil foraging are advantageous for P acquisition but may incur tradeoffs for the acquisition of deep soil resources such as moisture (Lynch and Brown, 2001). In a combined moisture and P stress the genotype that have a dimorphic root system that permit vigorous rooting throughout the soil profile are more advantageous for multiple resource acquisition particularly when resources are differentially localized in the soils (Ho *et al*., 2005). The roots of plant genotypes that are efficient in mobilizing nutrients from surrounding soil are better able to penetrate and make use of the moisture and minerals contained in subsoil (Susan and George, 2010). These qualities are also associated with greater seedling vigor resulting in increased crop yields (Rengel and Graham, 1995).

2.6. Phosphorus Use Efficiency

Common bean plants respond to low P availability through efficient use of absorbed P to produce biomass (Boutraa, 2009; Liao *et al*., 2004). This is related to the capacity of the plant to accumulate dry matter despite the inadequacy of soil P for plant growth. Distribution of more biomass to roots than shoots is related to P use efficiency of common bean plants. Crops develop an excellent ability to change the acquired P into plant biomass and yield, which is related to reduce P requirement in plant tissues (Blair *et al*., 2009). In separate studies, Boutraa (2009) and Namayanja *et al*. (2014) observed that more P-efficient common bean genotypes had greater root biomass and higher root: shoot ratio than the less efficient genotypes. Furthermore, low P-tolerant genotypes are able to produce more pods and seeds than non-P-tolerant genotypes (Boutraa, 2009, Atemkeng *et al*., 2011).

The amount of seed produced per unit of applied P is determined by the amount of P accumulated in plant biomass per unit P applied in fertilizer (recovery efficiency) and the seed yield per unit P accumulated (physiological efficiency). Physiological efficiency (PE) is also known as neutralized efficiency or internal efficiency. It can be a characteristic of the cultivars or a characteristic of environmental conditions (Haefele *et al*., 2003). To enhance P use efficiency of applied P fertilizer, time and method of its application are critically important because different P application methods differ in Phosphorus Utilization Efficiency (PUtE). Applying P fertilizer by band methods without contact with seed increases PUE (Shah *et al*., 2006). Significant variations in P use efficiency observed among the common bean cultivars with the findings of other workers (Akhtar *et al.*, 2008; Fageria *et al.*, 2010;

Dereje *et al*., 2016). Fageria *et al.* (2010) reported similar findings for efficient and inefficient common bean cultivars under P adequate and in adequate conditions. The high P use efficiency of the efficient common bean cultivars might be linked to re-translocation of P from vegetative part and better utilization of the trans-located P for seed formation (Vesterager *et al.,* 2006; Shen *et al.,* 2011). The differences in P efficiency of common bean genotypes may be related to differences in their P uptake ability (Lynch, 1995), which is mainly dependent on root morphological characteristics (Raghothama, 1999; Ortiz-Monasterio *et al.,* 2001). Greater P acquisition enables crops to accumulate more P in their tissue than inefficient crops when grown under P deficient soils (White *et al.,* 2005). Higher P efficiency is associated with higher P uptake efficiency of plants (Nigussie *et al*., 2004). Nutrient efficiency is mainly considered as dry matter produced per unit nutrient element concentration in dry matter (Godwin and Blair, 1991), which can also be termed as the internal nutrient requirement. However, there is much controversy concerning the concept of nutrient use efficiency, as it can be defined in different ways. Considering yield parameters, efficiency with regard to a specific mineral nutrient, is the capability of any species or cultivar of producing dry matter, in a soil limiting in that particular nutrient element (Buso and Bliss, 1988). Agronomic efficiency (AE) is defined as the total harvestable amount per unit of growth limiting nutrient element applied in the soil (Caradus and Woodsfield, 1990). External efficiency is the sum of nutrient content in soil primarily taken up by plants to produce a certain fraction of whole dry matter produced (Fohse *et al*., 1991). Some researchers have used the term nutrient efficiency ratio, which is calculated as the reciprocal of the nutrient concentration in the whole plant (Gourley *et al*., 1994). Other workers have used the term nutrient uptake efficiency (Buso and Bliss, 1988). Uptake efficiency is defined in terms of total uptake per plant or specific uptake per unit root length (Marschner, 1995).

Hammond *et al*. (2004) describes plant P use efficiency as being composed of four areas; early signaling events, morphological, metabolic, and physiological responses. Early signaling events include ribo-regulators which regulate gene expression under various conditions. Morphological responses include increasing root-shoot ratio or increasing growth of lateral roots. Plants can alter metabolism by alternative photosynthetic and respiratory pathways.

Physiological responses to P stress focus on modifying rhizosphere conditions in order to increase P uptake; this includes the exudation of organic acids and phosphatase enzymes. Determination of plant P efficiency is achieved by quantifying the plant tissue P concentration per mass of plant yield (Batten, 1992). Phosphorus efficiency index can also be determined using this method by taking the biomass production per unit of P concentration within the plant. Plant yield can be either seed yield or biomass yield. Plants that have high biomass yields with low P concentrations in low P soils are considered P-use efficient because of their low internal P requirement. Plants with high biomass and high P concentrations in low P soils are considered P-uptake efficient, utilizing various strategies in order to increase uptake in low P environments (Fohse *et al*., 1991).

Dereje *et al*. (2016) pointed that common bean cultivars acquired different tissue P concentration when grown at nil, medium and high P levels. The overall improvement in tissue P concentration at medium and highest P levels might be attributed to improved soil P level due to the soil applied P. However, low P concentration in the leaf of some of the efficient cultivars was observed at high or medium P levels, which might be attributed to the dilution of the absorbed nutrient throughout the plant tissues as a result of higher growth of the cultivars at medium or higher P levels (Hammond *et al.,* 2009). According (Tesfaye *et al*., 2015) agronomic efficiency and P recovery efficiency decreased with increasing P rates, the highest AE and PR were obtained at 23 kg P_2O_5 ha^{-1} P rates of application on soybean. More than 80% of added P gets fixed and only a part of it goes to soil solution which may be either taken up by crops or precipitates (Leytem and Mikkelsen, 2005). With time, adsorbed P becomes difficult to release into soil solution and consequently efficiency of P fertilizer in Nitisol remains low (Delgado *et al*., 2002). P fixation is of great importance in the interpretation of oil tests and fertilizer recommendations. Therefore, site and crop specific P recommendations on scientific basis are needed (Nisar *et al*., 1992).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted at Eladale research site of the College of Agriculture and Veterinary Medicine, Jimma University, Ethiopia in 2016 main cropping season (June to September). The study area is located at 7^0 42' N latitude and 36^o48' E longitudes at Oromiya Regional State, Jimma Zone, 356 km southwest of Addis Ababa 7 km far from Jimma town. The altitude of the experimental site was 1710 m.a.s.l.

Table 1. Monthly maximum and minimum temperature, Monthly Rainfall and Relative humidity weather condition of experimental site at growing season of the crop.

Month	Weather Element			
	Average Temperature (^{o}C)		Total Rainfall (mm)	Average Relative Humidity
	Max	Min		
June	26.42	13.8	149.9	64.96
July	24.99	14.61	185.7	72.29
August	25.74	14.06	334.2	67.548
September	26.37	13.98	153.1	65.1

Source: weather station and Jimma Meteorology Station (2016)

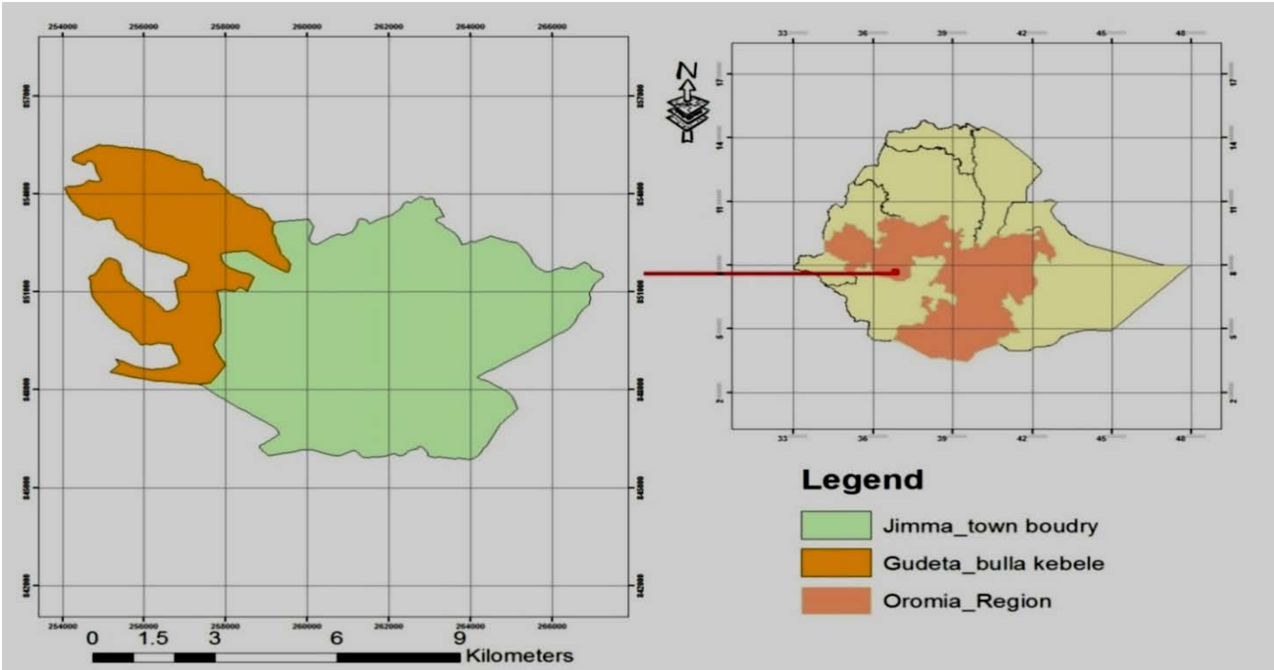

Figure 1. Map of study site Gudeta Bulla Kebele Source: Jimma Town Administration Office (2015)

3.2. Experimental Materials

The common bean cultivars Ibbado, Tatu and Remeda were used for the study. The cultivars were released by Hawassa Agricultural Research Centre in 2003, 2014 and 2014, respectively (MoA, 2014). Ibbado cultivar has large sized, round and mottled seed and white flower colour with a maturity period of 90-120 days and yield on farmer field and research field was 2102 and 2400kg ha^{-1} respectively. Tatu cultivar has large sized, round and red mottled seed and white flower colour with a maturity period of 85-90 days and yield on farmer field and research field was 2108 and 2400 kg ha^{-1} respectively. Whereas, Remeda cultivar has large sized, kidney shape red seed and white flower colour with a maturity period of 90-95days and yield on farmer field and research field was 2012 and 2316 kg ha^{-1} respectively. All the cultivars are bush type with determinate growth habit (MoA, 2014). The cultivars are adapted to an altitude range of 1400-1800 meter above sea level with rainfall of more than 1200-1500 mm in growing season and high yielder, resistance to disease; hence they are selected for the study.

3.3. Treatments and Experimental Design

The treatments consisted of three common bean cultivars (Ibbado, Tatu and Remeda) and four level of phosphorus (0, 23, 46 and 69 kg P_2O_5 ha^{-1}). The source of P was Triple Superphosphate (TSP; **46% P_2O_5** P). Phosphorus rates were calculated on the basis of blanket recommendation of P for common beans on Nitisol which is 100 kg ha^{-1}. Treatments were arranged in a factorial combination using randomized complete block design (RCBD) with three replications. The gross plot size was 2m x 2.4m (4.8m^2) and the plot had five rows and 23 seeds were sown per row. The net plot size was 3 rows x 0.4 m x 2.2 m= 2.64 m^2. The spacing between blocks and plots was 1m and 0.5 m, respectively.

Table 2. Experimental Treatment

Treatment combinations	Description
IR_0	0 kg P_2O_5 ha^{-1} and Ibbado cultivar
IR_1	23 kg P_2O_5 ha^{-1} and Ibbado cultivar
IR_2	46 kg P_2O_5 ha^{-1} and Ibbado cultivar
IR_3	69 kg P_2O_5 ha^{-1} and Ibbado cultivar
TR_0	0 kg P_2O_5 ha^{-1} and Tatu cultivar
TR_1	23 kg P_2O_5 ha^{-1} and Tatu cultivar
TR_2	46 kg P_2O_5 ha^{-1} and Tatu cultivar
TR_3	69 kg P_2O_5 ha^{-1} and Tatu cultivar
RR_0	0 kg P_2O_5 ha^{-1} and Remeda cultivar
RR_1	23 kg P_2O_5 ha^{-1} and Remeda cultivar
RR_2	46 kg P_2O_5 ha^{-1} and Remeda cultivar
RR_3	69 kg P_2O_5 ha^{-1} and Remeda cultivar

Where, I: Ibbado; T: Tatu; R: Remeda; R_0: no fertilizer application; R_1: Rate 1; R_2: Rate 2; R_3: Rate 3

3.4. Experimental Procedures

The experimental field was ploughed by oxen, disked and harrowed before sowing. The sowing was done on June, 10, 2016 at Eladale research site of JUCAVM. TSP was used as P fertilizer which was applied in band at sowing time based on the specific rates required. The common bean cultivars were sown in inter-row spacing of 40 and intra row spacing of 10 cm. Nitrogen was applied at the rate of 23 kg N ha^{-1} in the form of Urea (46% N) to be used as a starter material at sowing time (MoARD, 2009). Weeding and other crop management practices such as pest and disease control was done for all experimental plots as required. The outer most rows on each side of a plot was left as a boarder row. The middle three rows were used for data collection and yield measurement.

3.5 **Soil and Plant Tissue Sampling and Analysis**

3.5.1. Soil Sampling and Analysis

A composited soil sample taken at (10cm) depth using an auger from the experimental site by zigzag sampling techniques. The soil sample was air dried and ground to pass through a 2 mm sieve and subjected to physical and chemical properties before sowing. Whereas after harvesting, soil samples were collected from each of the experimental plots, air dried and ground similarly as above. Soil samples taken before sowing was analyzed for organic carbon, total N, soil pH, available P, cation exchange capacity (CEC) and texture. While the sample taken after harvest was analyzed for available P by using standard laboratory procedures at JUCAVM soil laboratory.

Texture particle was determined by hydrometer method (Van Reeuwijk, 1992) after destroying OM using hydrogen peroxide (H_2O_4), sodium carbonate (Na_2co_3) was used as soil dispersing agent. Two drops of amyl alcohol was used for foam reduction. The soil texture classes were determined using the international soil science society system (Yong and Warkentin, 1966), triangular guideline. Organic carbon content was determined by the Walkley and Black method using potassium dichromate ($K_2Cr_2O_7$) in sulfuric acid solution and titrated with 0.5 N ferrous sulfate solution (Walkley and Black, 1934). Total nitrogen was analyzed by Micro-Kjeldhal digestion method with sulphuric acid (Jackson, 1962).

The pH of the soil was determined according to FAO (2008) using 1:2.5 soil water ratio methods. For the soil-water ratio methods, 25 ml of distilled water was added to 10 g of soil. The solution was stirred for one minuets and left for 1 hour to rest. Then, the soil suspension was stirred and measured by using glass electrode pH meter. The CEC was measured after saturating the soil with 1N ammonium acetate (NH4OAc) and displacing it with 1N NaOAc (Chapman, 1965). Available P was determined by Bray II extraction method (Bray and Kurtz, 1945). Thus; 2 g of soil was mixed with 14 ml extracting solution Bray, containing 0.03 MNH_4F and 0.025 MHCL. The solutions was shaken for 1 minute and filtrated through Whitman filter paper. The 2 ml of the sample was pipetted into a test tube and 8 ml boric acid as well as 2 ml mixed reagent was added. The Solution was left for about 1 hour to develop the blue color. Absorbance was measured at 882 nm with UV/VIS Spectrophotometer.

The pre-sowing soil analysis showed that the experimental soil had a pH $_{(H2O)}$ of 5.43 (moderately acidic). FAO (2008) reported that the preferable pH ranges for most seed crops are in between 4 and 8. Thus, the pH of the experimental soil was within this range and suitable for common bean cultivation. Texture of the soil have compositions of 33% clay, 38% silt and 29% sand, which is in the textural class of clay loam in which it is also suitable for common bean as well as for other agricultural crops (Tekalign,1991). Total nitrogen and organic carbon content of the experimental site was 0.21% and 4.08%, respectively (Table 2). As the research site was previously covered by other cereal crops and continuously fertilized, the nitrogen and organic carbon contents of the soil was found to be in medium range Hazelton and Murphy (2007). Available P of the soils was 4.57 ppm (Table 2) and according to Hazelton and Murphy (2007), the experimental soil is found to be very low and deficient in P. As the area receives heavy rainfall, P is probably fixed by high concentrations of iron and aluminum because of leaching of the basic cations. In general, the experimental soil was found to be conducive for common beans cultivation with external P application.

Table 3. Initial physico-chemical properties of the soil

Parameter	Value	Rating	Reference
Texture class	Clay loam		
pH	5.43	Moderately acid	Landon (1991)

OC (%)	4.08	Medium	Hazelton and Murphy (2007)
TN (%)	0.21	Medium	Bruce and Rayment (1982)
Av.p (ppm)	4.57	Low	Hazelton and Murphy (2007)
CEC (Cmol)	16	Medium	Landon (1991)
Sand (%)	29		
Clay (%)	33		
Silt (%)	38		

Where, Cmol = Cent mole; pH=hydrogen power; %OC= percent of organic carbon; %TN = Percent of Total nitrogen; Av.p.ppm = available P in parts per million; EC (ds) m = Electrical conductivity in dessicemen; CEC= Cation exchange capacity; % = percent; Txr class = Texture class; Nd = not determined.

3.5.2. Plant tissue sampling and analysis

At physiological maturity, five randomly selected plants were harvested from three central rows and partitioned into seed and straw. The seed and straw samples were separately oven dried at 70 ºC for 48 hours, ground to pass 1 mm sieve and used for tissue analysis of seed and straw**.**

Phosphorus in seed and straw sub-samples were determined by using Metvanadate method (NSL, 1994). Samples were accustomed in the furnace for 24 hours at 450 ºC and the ash was dissolved in 20% nitric acid (HNO_3) to liberate organic phosphorus. The P in solution was determined colorimetrically by using Molybdate and Metavanadate for color development.

The reading of P was made at 460nm in spectrophotometer. P-uptake by seed and straw was determined from the P content of the respective parts after multiplying with the seed and straw yield, respectively. Then total P uptake was calculated as the summation of seed and straw P uptake as described by Godwin and Blair (1991) where;

P uptake = P concentration (%) x dry matter

Total P uptake = Seed P uptake + Straw P uptake

3.6. Data Collection

The data on plant growth and related traits were recorded from 5 randomly selected plants from three middle rows in each plot. Yield was recorded from all sample plants in the middle rows excluding the boarder rows of each side.

Growth parameters

Plant height: was measured as the height of five randomly selected plants from the ground level to the apex of each plant at the time of physiological maturity from the net plot area.

Number of primary branches per plant: was determined as the total number of branches and were recorded from 5 randomly selected plants in net plot area at physiological maturity.

Average root length (cm): was measured from randomly selected five plants of each plot at pod setting time.

Total number of nodules: was determined by counting randomly taken five plants from boarder rows of each plot at pod setting time.

Nodule dry weight was measured from five sample plants after oven dry at 70 ^{o}C for 24 hours.

Phenological parameters

Days to 50% flowering was recorded as the number of days from sowing to 50% of the plants produced flowers.

Days to 90% physiological maturity was recorded as the number of days from sowing to 90% of the pods become yellow.

Yield and yield components

Number of pods per plant: was determined as the total number of pods from randomly selected five plants of net plot area at physiological maturity.

Pod length (cm): was measured from five randomly selected plants from net plot area at physiological maturity.

Number of seeds per pod: was determined as the total number of seeds per pod from randomly selected five plants at maturity from net plot area.

Dry biomass yield (kg): was determined by taking the total weight of the harvest including the seeds from each net plot area at physiological maturity after oven drying at 70 ^{o}C for 48 hours to a constant weight.

Hundred seed weight (g): was determined by taking 100 seeds from randomly taken plants that have been grown in the net plot area at 12% moisture content.

Harvest index (%): was expressed as the ratio of seed yield per total dry biomass of sampled plants multiplied by 100.

Seed yield (kg) was taken from whole plants harvested from the net plot area, excluding plants grown in border rows at harvest and it was determined by weighing the beans using a sensitive balance and adjusted to 12% moisture level.

Phosphorus use efficiency

Based on the laboratory results of plant tissue analysis, recovery efficiency, utilization efficiency agronomic efficiency and physiological efficiency were computed according to the formulae described by Fageria and Barbosa Filho (2007).

P recovery (PR): is defined as the quantity of nutrient uptake per unit of nutrient applied.

$\mathrm{PR}\ (\%) = \frac{(PUf - PUu)}{Pa} x\ 100$ (Fageria and Barbosa Filho, 2007)

Where, PUf is the total P uptake (seed plus straw) of the fertilized plot (kg), PUu is the total P uptake (seed plus straw) of the unfertilized plot (kg) and Pa is the quantity of P applied (kg)

Agronomic efficiency (AE): is defined as the quantity of seed yield per unit of nutrient applied.

$\mathrm{AE}(\mathrm{Kg\ kg}^{-1}) = \frac{(\mathrm{SYf} - \mathrm{SYu})}{Pa}$ (Fageria and Barbosa Filho, 2007)

Where, SYf is the seed yield of the fertilized plot (kg); SYU is the seed yield of the unfertilized plot (kg) and Pa is the quantity of P applied (kg).

Physiological Efficiency (PE): Physiological efficiency is defined as the biological yield obtained per unit of nutrient uptake.

$\mathrm{PE}(\mathrm{Kg\ kg^{-1}}) = \frac{(\mathrm{BYf-BYu})}{(PUf-PUu)}$ (Fageria and Barbosa Filho, 2007)

Where, BYf is the biological yield (seed plus straw) of the fertilized plot (kg), BYu is the biological yield of the unfertilized plot (kg), PUf is the total P uptake (seed plus straw) of the fertilized plot (kg), PUu is the total P uptake (seed plus straw) of the unfertilized plot (kg).

Phosphorus Utilization efficiency (PUtE): is defined as the product of physiological efficiency and P recovery.

$\mathrm{PUtE}(\mathrm{Kg\ kg^{-1}}) = PR\ X\ PE$ (Fageria and Barbosa Filho, 2007)

Where, PR is P recovery and PE is physiological efficiency

3.7. Statistical Data Analysis

After the data were checked for normality, the data was subjected to Analysis of Variance using SAS software (SAS, 2009 version 9.2). When ANOVA showed significant difference, mean separations were carried out using LSD test at 5% probability level. Pearson’s correlation analysis was done to observe the relationship between different parameters.

4. RESULTS AND DISCUSSION

4.1. Growth and Phenological Parameters of Common bean

4.1.1. Plant height

Main effects of cultivars had showed significant ($P < 0.01$) effect on plant height at maturity. However, main effect of P and interaction did not show significant effect on plant height (Appendix Table 2). Regarding cultivars effect, the highest value for plant height was recorded with Remeda cultivar whereas the lowest value of plant height was recorded with Ibbado cultivar (Table 4). This might be attributed to the fact that plant height is generally governed by genetic constitute of cultivars rather than phosphors application. This finding is in agreement with Amare *et al.* (2014) who reported that significant plant height was recorded by common bean cultivars. However, the response of plant height to the different rates of P and interaction effect was not significant (Table 4). These results are similar to that of Birhan (2006) who described that a non-significant response of plant height to P application on common bean cultivars.

4.1.2. Number of primary branches per plant

Analysis of variance showed significant ($P < 0.01$) effect of P rates on number of primary branch while main effect of cultivars and interaction did not show significant effect on number of primary branch (Appendix Table 2). The highest number of primary branch was observed at the highest rate of P application (69 kg P_2O_5 ha^{-1}) while the lowest number of primary branch was recorded in the control plot (Table 4). Application of P showed (46.4%) increments on number of primary branch from the rate of 69 kg P_2O_5 ha^{-1} as compared to control plot. The increment in number of primary branch in response to the increased P application rate might be related to the effect of P in young cells particularly shoot tips where metabolism is high and adequate supply increases initiation of buds and cell division is rapid (Lambers *et al.*, 2006). This result is in agreement with, Tesfaye *et al.* (2015) who indicated that number of primary branch increased in acid soil as application of P increased. This positive growth response of common bean for application of P in soil may be related to a better availability of P as the rates of P application increased.

On other hand the observed lowest primary branches per plant might be due to low nutrients availability and high acidity of the soils. This result is in agreement with Steiner *et al*. (2008) who reported that in acidic soil aluminum reduce root growth while manganese disrupts photosynthesis and other functions of growth and agriculture is limited by low P availability.

Table 4. Mean plant height and number of primary branch of common bean cultivars as influenced by the main effect cultivars and P application rate at Jimma, 2016.

Cultivars	PH (cm)	NPB
Ibbado	38.14^{c}	2.64^{a}
Tatu	41.53^{b}	2.76^{a}
Remeda	53.24^{a}	2.70^{a}
LSD $_{(0.05)}$	1.54	ns
P_2O_5 rates kg ha^{-1}		
0	43.49^{a}	2.22^{c}
23	43.96^{a}	2.56^{bc}
46	44.54^{a}	2.78^{b}
69	45.23^{a}	3.25^{a}
CV (%)	12.9	4.11
LSD $_{(0.05)}$	ns	0.34

Where, PH: Plant height; NPB: Number of primary branches; CV: Coefficient of variation; LSD: Least significant difference; ns: non-significant; Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

4.1.3. Average root length

Average root length was significantly ($P < 0.01$) influenced by the interaction effect of cultivars and P rate (Appendix Table 2). The mean comparison showed that highest average root length was recorded from Tatu cultivar at 69 kg P_2O_5 ha^{-1}, whereas the lowest value of average root length was observed in Remeda cultivar with no P application (0 kg P_2O_5 ha^{-1}) (Table 5). The increment in root length might be due to root morphological traits of common bean cultivars with increase in P levels. This result is in conformity with Dereje *et al*. (2016) who reported that significant effect on root length of common bean cultivars at high level of phosphorus.

4.1.4. Nodule Number per plant

Nodule number was significantly ($P < 0.01$) influenced due to the main effects of common bean cultivars and P application. Common bean cultivars produced significantly different nodule number across the P levels (Appendix Table 2). The maximum nodule number per plant was recorded from Tatu when grown on soil that received 69 kg P_2O_5 ha^{-1}, while the minimum nodule number per plant was recorded from Remeda at 0 kg P_2O_5 ha^{-1} (Table 5). The higher number of nodules at the highest rate of P indicated the influences of P in nodule development through its basic functions in plants as an energy source. P plays a vital function in increasing plant tip and root growth, decreasing the time needed for developing nodules to become active and of benefit to the host legume and P increases the number and size of nodules (Bashir *et al*., 2011). Different authors reported that significant effects of P on common bean nodule number (Yoseph and Worku, 2014; Amare *et al*., 2014). The present result was also consistent with Tesfaye *et al*. (2015) on soybean that had showed nodule initiation increased as P nutrition increases.

Moreover, the improvement in nodule number due to P fertilizer could be associated with its stimulating effect on growth as described by Tang *et al.* (2001). The variation in cultivars in nodule number under fertilizer treatment could be related to inherent symbiotic characteristics of common bean cultivars.

4.1.5. Nodule dry weight

Nodule dry weight was significantly ($P < 0.01$) affected by interaction effect of cultivars and P rates (Appendix 2). The highest nodule dry weight per plant was recorded by Tatu cultivar that was grown at 69 kg P_2O_5 ha^{-1}, while lowest nodule dry weight per plant was recorded by Remeda and Ibbado with no P application (Table 5). This might be due to the fact that P increases the number and size of nodules and the amount of nitrogen assimilated per unit weight of nodules (Bashir *et al*., 2011).

Table 5. Mean root length, number of nodules per plant and nodule dry weight of common bean as influenced by interaction effect of P rate and cultivars at Jimma, 2016.

P rates P_2O_5 kg ha^{-1}	ARL (cm)			NNPP			NDW (g)		
	Cultivars								
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	15.07^{e}	15.47^{e}	13.33^{f}	30.07^{fg}	37.73^{ef}	21.80^{g}	0.74^{fg}	1.33^{de}	0.67^{g}
23	17.20^{d}	17.80^{d}	17.07^{d}	41.93^{cde}	52.93^{c}	39.80^{def}	1.42^{de}	2.51^{b}	1.16^{ef}
46	19.11^{c}	19.47^{c}	19.12^{c}	53.20^{c}	91.73^{b}	51.00^{cd}	1.99^{c}	2. 91^{b}	1.57^{cde}
69	20.93^{b}	23.57^{a}	21.23^{b}	47.00^{cde}	114.8^{a}	40.60^{def}	2.93^{b}	3.98^{a}	1.70^{cd}
CV (%)	3.85			12.92			13.62		
LSD $_{(0.05)}$	1.18			11.29			0.43		

Where, ARL: Average root length; NNPP: Number of nodule per plants; NDW: Nodule dry weight; CV: Coefficient of variation; LSD: Least significant difference; Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

4.1.6. Days to 50% flowering

The interaction of cultivars and P rates had significant ($P < 0.01$) effect on days to 50% flowering (Appendix Table 3). Cultivar Tatu was earlier to flower when 69 kg P_2O_5 ha^{-1} was applied. While cultivar Remeda took the longest days to flower at 0 kg P_2O_5 ha^{-1} (Table 6). Early flowering probably due to P increased cytokinins synthesis and enhanced of photosynthates and flower formation in common bean (Tesfaye and Alemayehu, 2015). Moreover, significant variations among different levels of P application might be due to the fact that P fertilizer fastens flowering, Photosynthesis and assimilate partitioning of crop from source to sink which is mainly determined by the ability of crop to utilize P (Iqbal *et al*., 2003). Adequate P enhances many aspects of plant physiology like fundamental process of photosynthesis, flowering, seed formation and maturation (Brady and Weil, 2002).

On other hand, longest days to flower might be due to the fact that cultivars produce additional nodes after initial flowering and cultivars have different genetic characteristics.

Present finding is in agreement with Beruktawit *et al*. (2012) who reported that significant differences were detected among cultivars of common bean on days to flowering.

4.1.7. Days to 90% physiological maturity

The interaction effect of cultivars and P rates had significant ($P < 0.01$) effect on days to 90% physiological maturity (Appendix Table 3). Shorter number of days was recorded for cultivar Tatu when it was fertilized with a P rate of 69 kg P_2O_5 ha^{-1} while Remeda cultivar that received 0 kg P_2O_5 ha^{-1} took longer number of days to physiological maturity (Table 6). The days to maturity in the present study was within the range of 45 to 150 days as reported by Singh (1982) for common bean seed depending on the type of growth habit and location (Kelly *et al.,* 1987). This could be due to the fact that P fertilizer enhanced the physiological maturity of plants and cultivars also exhibited different days to physiological maturity genetically. This result is in agreement with, Tesfaye *et al*. (2015) who reported that significant variations were found among the different levels of P application for physiological maturity period in common bean. Havlin *et al.* (1999) also indicated that ample P nutrition could reduce the time required for seed ripening. Likewise, Marshier (2002) also reported that P could reduce days to physiological maturity by controlling some key enzyme reactions that involve in hastening crop maturity.

Table 6. Mean days to 50% flowering and days to 90% physiological maturity of three common bean cultivars as influenced by interaction effect of P rate and cultivars at Jimma, 2016.

	DF				DPHM			
	P rate P_2O_5 kg ha^{-1}							
Cultivars	0	23	46	69	0	23	46	69
Ibbado	48.33^{ab}	47.33^{bc}	47.33^{bc}	46.00^{de}	88.67^{b}	87.00^{c}	86.00^{c}	82.67^{e}
Tatu	45.67^{de}	45.00^{ef}	44.33^{f}	40.00^{g}	84.00^{d}	82.33^{e}	81.00^{f}	78.00^{g}
Remeda	49.00^{a}	48.33^{ab}	47.67^{bc}	46.67^{dc}	92.00^{a}	91.60^{a}	89.33^{b}	89.00^{b}
CV (%)	1.35				0.86			
$LSD_{(0.05)}$	1.05				1.25			

Where, DF: Days to 50% flower; DPHM: Days to 90% physiological maturity; CV: Coefficient of variation; LSD: Least significant difference; Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

4.2. Yield Parameters

4.2.1. Number of pods per plant

The productive potential of common bean is ultimately determined by number of pods per plant which is the main yield component. Number of pods per plant was significantly ($P < 0.01$) influenced by the interaction effect of cultivar and P fertilizer rate (Appendix Table 3). The results showed that Tatu cultivar produced the highest number of pods per plant when 69 kg P_2O_5 ha^{-1} was applied whereas, the lowest number of pods per plant was recorded from Ibbado cultivar that received 0 kg P_2O_5 ha^{-1} (Table 7). The variation on the number of pods per plant might be primarily related to the genotypic variation of the common bean cultivars. In general, the number of pods per plant significantly increased in response to increasing the rate of P up-to 69 kg P_2O_5 ha^{-1}. The increment in number of pods per plant might be due the metabolic role that P plays in promoting the reproductive growth of the crop (Rafat and Sharifi, 2015).Besides, the improvement in the number of pods due to P could be resulted from availability of plant nutrient which stimulated the plants to produce more pods per plant as compared to control treatment. Although P strongly encourages flowering and pod setting in common beans (Zafal *et al*., 2003). This result was in line with different authors, who reported that significant variations in the number of pods per plant on different crops including common bean due to P applications (Mesfin, 2014; Tesfaye *et al*., 2015; Dereje *et al.*, 2016).

4.2.2. Pod length

Analysis of variance showed significant ($P < 0.05$) variation in pod length due to the interaction effect of cultivar and P fertilizer rate (Appendix Table 3). The results showed that Tatu cultivar produced the longest pod length at 69 kg P_2O_5 ha^{-1}. The smallest pod length was recorded from Ibbado cultivar with no P application (Table 7). Longer pod formation due to application of P might be attributed to improvement in growth attributes owing to improved availability of P that could play an important role in cell division (Zafar *et al.,* 2013). There is better photo-assimilate translocation to other plant parts that would contribute to increments in yield attributing traits such as pod length. This result is inconformity with Dereje *et al.* (2016) who reported that significant effect of P application on pod length of common bean cultivars at Areka, south west Ethiopia.

4.2.3. Number of seeds per pod

Number of seeds per pod is perceived as a significant constituent that directly imparts in exploiting potential yield recovery in leguminous crops (Devi *et al*., 2012). Number of seeds per pod was significantly ($P < 0.05$) influenced by the interaction of cultivars and P fertilizer rate (Appendix Table 3). The results showed that Tatu produced the highest seeds per pod when 69 kg P_2O_5 ha^{-1} was applied. The lowest number of seeds per pod was recorded from Ibbado without P application (Table 7). The result may be attributed to the fact that applying P fertilizer increases crop growth and yield on soils which are naturally low in available P and in soils that have been sorbed (Mullins, 2001). This result was agreed with Mesfin *et al.* (2014) who reported that number of seeds per pod was significantly affected by interaction effects of common bean cultivars and P on Nitisols at Boloso sore and Damot Woreda of Wolayita Zone.

Table 7. Mean number of pod per plant, pod length and number of seeds per pod on common bean cultivars as influenced by interaction effect of P rate and cultivars at Jimma, 2016.

P rates P_2O_5 kg ha^{-1}	NPPP			PDL (cm)			NSPP		
	Cultivars								
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	2.80^{h}	4.93^{fg}	4.57^{g}	9.46^{e}	9.75^{de}	9.83^{cde}	2.61^{f}	3.11^{cd}	2.65^{ef}
23	5.47^{fg}	6.53^{de}	5.83^{ef}	9.77^{cde}	10.10^{bcd}	10.01^{cde}	2.83^{def}	3.52^{bc}	2.77^{def}
46	7.07^{cd}	9.03^{b}	7.97^{c}	9.87^{cde}	10.33^{bc}	10.07^{bcd}	3.11^{cd}	3.83^{b}	3.36^{c}
69	9.17^{b}	11.83^{a}	9.50^{b}	10.14^{bcd}	11.44^{a}	10.59^{b}	3.51^{bc}	4.62^{a}	3.59^{bc}
CV (%)	7.91			3.6			7.7		
$LSD_{(0.05)}$	0.94			0.57			0.43		

Where, NPPP: Number of pod per plant; PDL: Pod length; NSPP: Number of seeds per pod; CV: Coefficient of variation; LSD: Least significant difference; Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

4.2.4. Dry Biomass Yield

Interaction effect of cultivars and P rate had highly significantly affect ($P < 0.01$) on dry biomass yield (Appendix Table 4). Mean dry biomass yield of common bean cultivars varied across different rates of P. The maximum dry biomass yield was produced by Tatu from plots that received 69 kg P_2O_5 ha^{-1} while the minimum biomass was produced by Ibbado without P application. But the dry biomass produced by Ibbado and Remeda that grown at both highest and lowest P (control) was statistically similar (Table 8). The variation in dry biomass yield of the cultivars across P levels might be attributed to enhanced availability of P for root growth and number of nodules by which increases nutrient absorption that contribute for full development of above ground parts of the plants and genotypic variations of the cultivars in leaf area index and number of branch, which may affect photosynthesis and photo-assimilate synthesis (Fujita *et al.,* 1999). Furthermore, the significant increment in total dry mater might be ascribed to improvement in yield and yield components as demonstrated by Malik *et al*. (2006). Regarding cultivars, the response to applied P could be attributed to genotypic characteristics. Consistent with these results, Dereje *et al*. (2016) reported significant increases in biomass yield in response to P application. In a similar study, Mourice and Tryphone (2012) reported that common bean cultivars produced different dry matter at different P level. In other words, the cultivars have different fertilizer requirements. In contrast Tesfaye *et al*. (2015) reported that application of P fertilizer on soybean did not significantly affect the above ground dry biomass yield.

4.2.5. Hundred seed weight (g)

Hundred seed weight is also an important yield component which reflects the magnitude of seed development which ultimately reflects on the final yield of a crop. The results of analysis of variance showed that the interaction effect of P rates and cultivars significantly ($P < 0.05$) influenced hundred seeds weight (Appendix Table 4). Hundred seed weight was the highest for Tatu cultivar at 69 kg P_2O_5 ha^{-1} whereas it was lowest for Ibbado cultivar without P application (Table 8). The increase in hundred seed weight as a result of increased P application might be attributed to important roles that P played in regenerative growth of the crop (Zafar *et al.,* 2013), leading to increased seed size which in turn may improve hundred seed weight. In a similar study, Amare *et al.* (2014) and Dereje *et al*. (2016) observed significant variations in hundred seed weights of common bean cultivars as a result of P application. Thus, application of P might improve the seed quality of beans.

4.2.6. Seed yield (kg ha^{-1})

Seed yield was significantly ($P < 0.01$) affected by the interaction effect of cultivar and P rates (Appendix 4). The results showed that Tatu cultivar produced the highest seed yield at 69 kg P_2O_5 ha^{-1}. The lowest seed yield was recorded from Ibbado cultivar without P application. But seed yield obtained from Ibbado and Remeda at control was statistically similar (Table 7). Moreover, application of P showed (69.25%) seed yield increment on Tatu cultivars treated with 69 kg P_2O_5 ha^{-1} as compared to control plot. Whereas, inter varietal variation showed (31.12 and 20.57 %) seed yield increment by Tatu as compared to Ibbado and Remeda from the rate of 69 kg P_2O_5 ha^{-1} respectively. Differences in seed yield among the common bean cultivars might be related to the genotypic variations for P use efficiency (Fageria *et al.,* 2010; Dereje *et al*., 2016), which may arise from variation in P acquisition (Lynch, 1995) and translocation and use of absorbed P for seed formation (Shen *et al.,* 2011). Hence, the cultivars which gave higher seed yield might have either better ability to absorb the applied P from the soil solution or translocate and use the absorbed P into plant biomass and seed yield, which is related to reduce P requirement in plant tissues than the low yielding cultivar (Blair *et al.,* 2009).

Similarly, increase in seed yield might be attributed to overall improvement in growth attributes such as number of primary branch and aboveground dry biomass yield, thereby increasing yield attributing traits such as number of pods per plant, number of seed per pod and hundred seed weight upon partitioning, which also showed an increasing trend as a result of P application. Moreover, seed yield had significantly and positively correlated with number of pods per plant, number of seeds per pod and hundred seed weight (Table 13). Findings of this study is in agreement with other authors (Gobeze and Legese, 2015; Dereje *et al*., 2016) who observed that significant variations in seed yield for different crops including common bean.

Different authors also reported association of increase in these yield attributing traits with increase in seed yield (Sofi *et al.,* 2011; Amare *et al.,* 2014). This result is consistent with, Gifole *et al.* (2011) and Gobeze and Legese (2015) who reported that significant increases in the seed yields of common bean in response to P application under field and greenhouse conditions. In contrast, Tolera *et al.* (2005) who reported that a non-significant effect of P application on seed yield of climbing bean intercropped with maize at Bako, Western Oromia region of Ethiopia on acid soil.

The lowest seed yield at the control plots could be explained by the fact that essential plant nutrients are deficient that can limit plant growth, flower number, pod setting and development. The present result is in line with Amare *et al.* (2014) who described that seed yield decreased without application of p fertilizer.

Table 8. Mean dry biomass yield, hundred seed weight and seed yield on common bean cultivars as influenced by interaction effect of P rate and cultivars at Jimma, 2016.

P rates P_2O_5 kg ha^{-1}	DBY (kg ha^{-1})			HSW (g)			SY (kg ha^{-1})		
	Cultivars								
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	3080.3^{g}	3697.7^{ef}	3291.7^{fg}	25.43^{i}	28.37^{fgh}	27.63^{gh}	1402.3^{h}	1666.7^{fg}	1494.0^{gh}
23	3701.3^{ef}	4699.7^{bc}	3942.7^{de}	26.64^{hi}	31.91^{bcd}	29.82^{def}	1704.7^{fg}	2162.0^{c}	1835.7^{ef}
46	3944.7^{de}	5137.7^{b}	4374.0^{cd}	28.90^{efg}	33.24^{b}	30.97^{cde}	1896.3^{def}	2496.0^{b}	2093.3^{cde}
69	4426.0^{c}	5874.0^{a}	4815.7^{bc}	30.73^{de}	37.75^{a}	32.96^{bc}	2148.7^{cd}	2821.0^{a}	2349.7^{bc}
CV (%)	6.69			4.24			7.66		
$LSD_{(0.05)}$	479.55			2.17			258.92		

Where, DBY: dry biomass yield; HSW: Hundred seed weight; SY: Seed yield; CV: Coefficient of variation; LSD: Least significant difference; Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

4.2.7. Harvest index (%)

Harvest index is very useful in measuring nutrient partitioning in crop plants, which provides an indication of how efficiently the plant utilized acquired nutrients for seed production. Main effects of P had significant ($P < 0.01$) effect on harvest index. However, cultivars and their interaction with P rates had no significant effect on harvest index (Appendix Table 4). The mean comparison showed that highest harvest index was recorded at application of 69 kg P_2O_5 ha^{-1}, which was not statistically different from 46 kg P_2O_5 ha^{-1}. Whereas the lowest value of harvest index was observed from no P application (Table 9). The highest mean of harvest index indicates biological success in partitioning assimilated photosynthate to the harvestable product (Li *et al.*, 2003). This finding is in agreement with Wasonga *et al.* (2008) who reported that significant increase in harvest index of soybean due to P fertilizer application.

Table 9. Mean harvest index on common bean cultivars as influenced by P application at Jimma, 2016

Cultivars	HI (%)
Ibbado	47.02^{a}
Tatu	46.91^{a}
Remeda	47.13^{a}
LSD $_{(0.05)}$	ns
P_2O_5 rates (kg ha^{-1})	
0	45.32^{d}
23	46.19^{c}
46	48.32^{ab}
69	48.63^{a}
CV (%)	0.95

LSD $_{(0.05)}$	0.43

Where, HI: Harvest index; CV: Coefficient of variation; LSD: Least significant difference; ns: non-significant; Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

4.3. Phosphorus uptake and use Efficiency

4.3.1. Seed, straw and total P uptake

Interaction effect of cultivars and P rates showed significant ($P < 0.01$) variation on seed, straw and total P uptake (Appendix Table 5). In general, the highest mean seed, straw and total P uptake was observed from Tatu when 69 kg P_2O_5 ha^{-1} was applied. However, the lowest of seed, straw and total P uptake was recorded from Ibbado at control (0 kg P_2O_5 ha^{-1}) respectively (Table 10). The seed P uptake accounted for 62.89% of the maximum total P uptake, whereas straw P accounted for 37.1%. Therefore, the variation in seed, straw and total P uptake might be due to plant root architecture regulates the capacity of soil explored by roots, thereby playing a central role in P acquisition. Since P content and availability are more in top than in subsoil, root architectural traits that allow the exploration and use of P from surface layers govern P acquisition (Beebe *et al*., 2010). Cichy *et al*. (2009) observed that the shallower the basal root angle, and the greater total root length and root length of basal roots in the top 3 cm area, will help for the greater P uptake. Thus, the difference in these root traits elucidates the differences among common bean genotypes in P acquisition efficiency Furthermore, total P uptake had highly significantly and positively correlated with average root length (Table 13). Results are in conformity with Gifole *et al*. (2011) who reported that application of P fertilizer highly significantly influenced the concentration of P in seed. Similarly, Dereje *et al*. (2016) observed that leaf P concentration was varied by interaction effect of common bean cultivars and P. Tesfaye *et al*. (2015) reported that total P uptake by soybean was significantly affected by P application.

Table 10. Mean P uptake by seed, straw and total P uptake of common bean as influenced by interaction effect of cultivars and P rate at Jimma, 2016.

P rates P_2O_5 kg ha^{-1}	PUS (kg ha^{-1})			PUSt (kg ha^{-1})			TPU (kg ha^{-1})		
	Cultivars								
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	11.33^{g}	11.65^{f}	11.45^{fg}	5.91^{f}	6.43^{e}	6.20^{ef}	17.24^{j}	18.08^{i}	17.66^{ij}
23	12.36^{e}	12.61^{e}	12.46^{e}	6.50^{e}	7.47^{d}	6.47^{e}	18.86^{h}	20.08^{ef}	18.93^{gh}
46	12.97^{d}	13.51^{c}	13.15^{d}	6.61^{e}	8.06^{bc}	7.48^{d}	19.57^{fg}	21.57^{c}	20.63^{de}
69	13.24^{cd}	14.68^{a}	14.01^{b}	7.78^{cd}	8.66^{a}	8.01^{b}	21.02^{cd}	23.34^{a}	22.31^{b}
CV (%)	1.31			3.9			1.92		
LSD $_{(0.05)}$	0.28			0.47			0.64		

Where, PUS: P uptake by seed; PUSt: P uptake by straw; TPU: Total P uptake; CV: Coefficient of variation; LSD: Least significant difference; Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

4.3.2. Phosphorus Use Efficiency

4.3.2.1. Phosphorus recovery (PR)

Analysis of variance showed that the interaction effect of cultivars and P rates significantly ($P < 0.01$) influenced P recovery (Appendix Table 5). The results showed that Tatu recorded the highest P recovery when 23 kg P_2O_5 ha^{-1} was applied. The lowest P recovery was recorded from Ibbado with 69 kg P_2O_5 ha^{-1}. However, the differences in P recovery between (46 kg P_2O_5 ha^{-1}) and (69 kg P_2O_5 ha^{-1}) were observed to be statistically similar (Table 11). The low recovery efficiency in the present study may be associated with high rate of P fixation in this soil due to presence of Al and Fe compounds and clay minerals (Chaudhary *et al*., 2003). The differences in P recovery efficiency of common bean genotypes might be related to differences in their P uptake ability (Lynch, 1995), Similar result was also reported by

Tesfaye *et al*. (2015) the highest and lowest PR (12.52 - 7.98%) was also recorded with P rates ranging from 23 to 46 kg P_2O_5 ha^{-1}on soybean respectively.

4.3.2.2. Agronomic efficiency

Agronomic efficiency (AE) was significantly ($P < 0.01$) affected by the interaction effect of cultivar and P rates (Appendix Table 6). The highest AE was obtained by Tatu when it was grown at application of 23 kg P_2O_5 ha^{-1}. The lowest agronomic efficiency was recorded from Ibbado at 46 kg P_2O_5 ha^{-1}. But the agronomic efficiency recorded at 46 kg P_2O_5 ha^{-1} and 69 kg P_2O_5 ha^{-1} was not statistically different (Table 11). Agronomic efficiency indicated that the increased grain yield for a unit of fertilizer P applied. As to the present experiment, the decrease in agronomic efficiency with the increase in P supply was reported for common bean (Girma *et al*., 2014) and soybean (Devi *et al*., 2012). This could be due to the limiting effect of other nutrients with increasing level of P (Mengel and Kirby, 2001), or because the rate of increase in seed yield was less than the rate of increase in P supply. Similarly, Dereje *et al*. (2016) reported higher AE by the interaction effect of P and common bean cultivars was recorded at low P rate. The decreasing trend in AE with increasing P rates was also reported by Gifole *et al*. (2011) who found a declining trend of agronomic efficiency (AE) from 69.8 to 9.3 kg kg^{-1} at the rates of P ranging from 23 to 137.4 kg P_2O_5 ha^{-1}.

Table 11. Mean Phosphorus recovery and P utilization efficiency of common bean as influenced by interaction effect of cultivars and P rate at Jimma, 2016

P rates P2O5 kg ha-1	PR %			AE (kg kg^{-1})		
	Cultivars					
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	-	-	-	-	-	-
23	7.0^{b}	8.7^{a}	7.0^{b}	15.9^{bc}	21.5^{a}	17.3^{b}
46	5.5^{cd}	7.2^{b}	6.5^{bc}	10.7^{d}	17.4^{b}	13.0^{cd}
69	5.1^{d}	7.3^{b}	6.7^{bc}	10.8^{d}	16.7^{b}	12.4^{cd}
CV (%)		15.4			19.3	
LSD $_{(0.05)}$		1.3			3.9	

Where, PR: P recovery; AE: Agronomic Efficiency; CV: Coefficient of variation LSD: Least significant difference; Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

4.3.2.3. Physiological efficiency (PE)

Interaction effect of cultivars and P rates showed significant ($P < 0.01$) variation on physiological efficiency (Appendix Table 6). The highest physiological efficiency (PE) was obtained by Tatu cultivars at 46 kg P_2O_5 ha^{-1} and the lowest value of physiological efficiency (PE) was recorded by Ibbado when 23 kg P_2O_5 ha^{-1} was applied. Furthermore, PE value recorded from application of 69 kg P_2O_5 ha^{-1} was not statistically different from that recorded from 46 kg P_2O_5 ha^{-1} (Table 12). The highest physiological efficiency of common bean cultivars might be the yield increases in relation to the increasing in crop uptake of the nutrient in the above ground part of the plants; relatively the highest portion was used in seed formation at the rate of 46 kg P_2O_5 ha^{-1}, whereas the lowest was used at 23 kg P_2O_5 ha^{-1}. The percent result is in agreement with Tesfaye *et al*. (2015) who reported that, application of 69 kg P_2O_5 ha^{-1} is optimum to obtain the highest physiological efficiencies on soybean.

4.3.2.4. *Phosphorus utilization efficiency (PUtE)*

Analysis of variance showed that the interaction effect of cultivars and P rates significantly ($P < 0.01$) influenced P utilization efficiency (Appendix Table 6). Highest result of PUtE was obtained by Tatu when it have been grown on 46 kg P_2O_5 ha^{-1}. While lowest PUtE was obtained by Ibbado that have been grown on 23 kg P_2O_5 ha^{-1}. But value obtained from P rate of 46 and 69 kg P_2O_5 ha^{-1} was statistically similar (Table 12). The highest P utilization efficiency of the efficient common bean cultivars might be linked to re-translocation of P from vegetative part and better utilization of the trans-located P for seed formation (Shen *et al.,* 2011). Differences in PUtE of common bean cultivars might be related to differences in their P uptake ability (Lynch, 1995), which is mainly dependent on root morphological characteristics (Ortiz-Monasterio *et al.*, 2001). This implies that P efficient cultivars are more productive than P inefficient cultivars both under P deficient and P-sufficient conditions. Fageria *et al.* (2010) reported similar findings for efficient and inefficient common bean cultivars under P adequate and inadequate conditions. Greater P acquisition enables crops to accumulate more P in their tissue than inefficient crops when grown under P deficient soils (White *et al.,* 2005). Higher P efficiency is associated with higher P uptake efficiency of plants (Nigussie *et al*., 2004). Present finding is in line with, Dereje *et al*. (2016) who confirmed that the varying response of PUtE of common bean cultivars at different rates of soil applied P.

Table 12. Mean of physiological efficiency and phosphorus utilization efficiency on common bean cultivars as influenced by interaction effect of cultivars and P rate at Jimma, 2016.

P rates P_2O_5 kg ha^{-1}	PE (kg kg^{-1})			PUtE (kg kg^{-1})		
	Cultivars					
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	-	-	-	-	-	-
23	149.7^{f}	211.7^{cde}	190.7^{de}	10.00^{d}	17.07^{ab}	12.28^{cd}
46	200.7^{cd}	281.3^{a}	225.3^{bcd}	11.01^{cd}	20.53^{a}	13.66^{bc}
69	190.7^{de}	244.7^{ab}	179.0^{ef}	11.53^{cd}	17.86^{ab}	14.03^{bc}
CV (%)	18.17			13.45		

LSD $_{(0.05)}$	37.5	3.51

Where, PE: Physiological efficiency; PUtE: P utilization efficiency; CV: Coefficient of variation; LSD: Least significant difference; Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

The soil analysis result after harvest of the crop showed a 26.03% soil available P increment from the rate of 69 kg P_2O_5 ha^{-1} on the plot that Ibbado cultivar had grown compared to the initial available P (Appendix Table 1). The increase in available P concentration in soil might be due to corresponding application of phosphate fertilizer that enhanced the availability of P in the soil solution and low P uptake efficiency of Ibbado cultivar from the applied P fertilizer. The low available P in the control plot might be due to further fixation of P by soil colloids and other losses through cultural practices and due to utilization of residual P by P efficient plant especially Tatu cultivar and further adsorption by Al (Alley and Zelazeny, 1997).

4.4. Correlation Analysis

Person's correlation analysis was done to show the association between yield and yield components as well as P uptake and use efficiency parameters (Table 13). A positive and highly significant correlation was obtained between root length and seed yield and Root length was also highly significantly and positively correlated with number of nodules ($r = 0.71^{**}$), nodule dry weight ($r = 0.76^{**}$) and seed yield ($r = 0.86^{**}$). Number of pod per plant was highly and positively associated with seed yield ($r= 0.93^{**}$) (Table 13). Similarly, number of seed per pod showed that positive and highly significant correlated with seed yield ($r = 0.8^{**}$) and dry biomass yield ($r = 0.82^{**}$) (Table 13). This implies the higher number of pod per plants contributed to increased yield through increasing the number of seed. This result is in agreement with Beruktawit *et al*. (2012) who reported that seed yield was highly correlated with number of pods per plant, seeds per pod, dry biomass yield and hundred seed weight. Correlation analysis showed that number of nodules had significantly and positively correlated with Seed yield ($r = 0.82^{**}$), total P uptake ($r = 0.74^{**}$) and P utilization efficiency ($r = 0.66^{**}$) (Table 13). Nodule number was significantly and positively associated phosphorus recovery ($r = 0.54^{*}$) and agronomic efficiency ($r = 0.55^{*}$). Likewise, hundred seed weight ($r = 0.93^{**}$), harvest index ($r = 0.75^{**}$), and seed yield was positive and highly significant correlated total P uptake ($r = 0.94^{**}$) (Table 13). Moreover, P recovery ($r = 0.65^{**}$), agronomic ($r = 0.67^{**}$) and utilization efficiency was positive and highly significantly correlated with ($r = 0.97^{**}$) seed yield and total P uptake ($r = 0.84^{**}$) (Table 13). Harvest index also showed a positive and highly significant correlation with number of pod per plant (r = 0.69**), hundred seed weight (r = 0.79**) (Table 13). But, the correlation between dry biomass yield and harvest index was highly significant and negative correlated (r = -0.68**) indicating that as the above ground dry biomass decreased the harvest index increase due to more proportion of seed yield. This implies that applied phosphorus had more contribution to seed yield production. Interestingly, the increase in HI almost fully accounted for the progressive increase in the grain yield potential of common bean.

Table 13. Pearson correlation

	ARL	NNPP	NDW	NPPP	NSPP	DBY	HSW	HI	SY	TPU	PRE	AE	PUtE
ARL	1	0.71**	0.76**	0.91**	0.73**	0.83**	0.76**	0.81**	0.86**	0.91**	0.67**	0.60**	0.76**
NNPP		1	0.88**	0.75**	0.83**	0.83**	0.77**	0.52**	0.82**	0.74**	0.54*	0.55*	0.66**
NDW			1	0.83**	0.85**	0.89**	0.83**	0.6**	0.88**	0.81**	0.62**	0.63**	0.86**
NPPP				1	0.81**	0.9**	0.89**	0.81**	0.93**	0.96**	0.63**	0.57*	0.84**
NSPPD					1	0.82**	0.83**	0.49**	0.8**	0.83**	0.57*	0.48*	0.72**
DBY						1	0.94**	-0.68**	0.99**	0.93**	0.66**	0.68**	0.97**
HSW							1	0.62**	0.93**	0.9**	0.59**	0.58**	0.89**
HI								1	0.75**	0.77**	0.50*	0.49*	0.7**
SY									1	0.94**	0.65**	0.69**	0.97**
TPU										1	0.70**	0.61**	0.84**
PRE											1	0.91**	0.90**
AE												1	0.93**
PUtE													1

Where, ARL: Average root length; NNPP: Number of nodule per plant; NDW: Nodule dry weight; NPPP: Number of pod per plants; NSPP: Number of seed per pod; DBY: Dry Biomass yield; HSW: Hundred seed weight; HI: Harvest index; SY: Seed yield; TPU: Total P uptake; PRE: Phosphorus recovery efficiency; AE:

Agronomic efficiency; PUtE: P utilization efficiency; NS= non-significant; * = Correlation is significant at the 0.05 level. ** = significant at the 0.01 level.

5. SUMMARY AND CONCLUSION

Field experiment was conducted on common bean cultivars against various rates of phosphorus at JUCAVM research site in 2016. The treatments were laid out using randomized complete block design. The results of this study showed that growth and yield parameters of common bean such as total root length, number of nodule per plant, nodule dry weight, days to 50% flowers, days to 90% maturity, number of pods per plant, pod length, seed per pod, dry biomass yield and hundred seed weight of the crop increased as a result of interaction effect of cultivars and P rates. However, maximum seed yield per hectare were obtained from Tatu cultivar at 69 kg P_2O_5 ha^{-1}. Dry biomass yield (5874 kg ha^{-1}) and seed yield (2821 kg ha^{-1}) were obtained from the treatment combination of cultivar Tatu and 69 kg P_2O_5 ha^{-1}. Compared to Ibbado and Remeda, Tatu cultivar gave a yield advantage of 31.12% and 20.57% when grown at 69 kg P_2O_5 ha^{-1}. Likewise, interaction effect of cultivars and P significantly influenced P uptake in seed, straw, and total P. In general, the highest mean seed, straw and total P uptake was observed by Tatu (14.68, 8.66 and 23.34 kg ha^{-1}) when 69 kg P_2O_5 ha^{-1} was applied respectively.

The P use efficiency parameters (recovery efficiency and agronomic efficiency) were significantly affected by the combined effect of cultivar and P application rate. Cultivar Tatu was found to be more P efficient at P rate of 23 kg P_2O_5 ha^{-1}. Whereas, P utilization efficiency and physiological efficiency increased when P rate increases, highest P utilization efficiency (20.53kg kg^{-1}) and physiological efficiency (281.3 kg kg^{-1}) were obtained by Tatu cultivars that received 46 kg P_2O_5 ha^{-1}, respectively.

Correlation analysis indicates that number of nodules was significantly and positively correlated with seed yield, total P uptake and P utilization efficiency. More importantly, seed yield was significantly and positively correlated with total P uptake and P utilization efficiency. The correlation between dry biomass yield and harvest index was significant but negative. This implies that applied phosphorus had more contribution to seed yield.

In conclusion, the study pointed out that common bean cultivars responded differently to the various P application rates suggesting the possibility of exploiting cultivar differences to combat P deficiency under acidic soil. Phosphorus at rate of 23 kg ha^{-1} will be recommendable for P-efficient cultivar based on phosphorus use efficiency parameters. Accordingly, Farmer who have no capacity to buy fertilizer cultivar Tatu was recommended to specific soil of study area. However, since the data is only for one season and location repeating the experiment across location may be helpful to validate the results.

REFERENCES

Akhtar, M.S., Y. Oki and T. Adach., 2008. Genetic variability in P acquisition and utilization efficiency from sparingly soluble P-sources by Brassica cultivars under P-stress environment. *Journal of Agronomy and Crop Science,* **194**: 380–392.

Alemitu, M. 2011. Factors affecting adoption of improved common bean cultivars and associated agronomic practices in Dale woreda, SNNPRS M.Sc. Thesis, Hawassa University, Hawassa, Ethiopia PP: 59.

Ali, K., G. Keneni., S. Ahmed., R. Melhotra., S. Beniwal., K. Makkout and M. H. Halila., 2003. "Food and forage legumes of Ethiopia: Progress and Prospects. Proceedings of the Workshop on Food and Forage Legumes 22-26 September 2003, Addis Ababa, Ethiopia. Sponsors: EIAR and ICARDA." International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. PP: 351.

Alikhani, H.A., N. Saleh-Rastin and H. Antoun., 2006. Phosphate solubilization activity of rhizobia native to Iranian soils. *Plant Soil*, **287**:35 – 41.

Alley,M.M. and L.W. Zelazeny.,1997. Soil Acidity: Soil pH and Lime needs. *Journal of Soil Science Society of America,* **86**:45-50.

Amare, A. 1987. Common bean (*Phaseolus vulgaris* L.) cultivars performance and recommended method of production. In: proceedings of the 19th National Crop Improvement Conference, 22-26 April, IAR, Addis Ababa, Ethiopia.

Amare, G., Assaye. D. and Tuma A. 2014. The response of common bean cultivars to different rates of phosphorus at Arbaminch, southern Ethiopia. *ARPN Journal of Agricultural and Biological Science.* vol**. 9**(10), 346p.

Atemkeng, F., R. Remans., J. Michiels., A. Tagne and M. Ngonkeu, 2011. Inoculation with *Rhizobium eti*enhances organic acid exudation in common bean (*Phaseolus vulgaris* L.) subjected to P deficiency. *African Journal of Agricultural Research, **6***(10), 2235-2243.

Bashir, K., Ali, S. and Umair, A. 2011. Effect of different P levels on xylem sap components and their correlation with growth variables of mash bean. *Sarhad Journal of Agriculture*, **27**(4).

Batten, G.D. 1992. A review of P efficiency in wheat. Plant and Soil **146**(1-2): 163–168.

Beebe, S.J., C. Rubyogo and R. Buruchara., 2010. Improving common bean productivity: An Analysis of socioeconomic factors in Ethiopia and Eastern Kenya. Baseline Report Tropical legumes II. CIAT. Cali, Colombia. 139 PP.

Beruktawit, M., Tamada, T. and Nigussie, D. 2012. Response of Common Bean (*Phaseolus Vulgaris* L.) Cultivars with Different Growth Habits to Plant Density at Haramaya, Eastern Ethiopia.

Birhan, A. 2006. "Response of haricot bean (*Phaseolus vulgaris L.*) To nitrogen, Pand inoculation of *Rhizobium Leguminosarum*on yield and yield components at Melkassa", M.Sc. Thesis, University of Hawassa, Awassa College of Agriculture, Ethiopia, PP 97.

Blair, W. M., H. Mendoza, S. Snapp and D. J. Kelly., 2009. QTL Analysis of root architecture triats and low P tolerance in an Andean bean population. *Crop Science, **49***, 59-68.

Boutraa, T. 2009. Growth and carbon partitioning of two genotypes of bean (Phaseolus vulgaris) grown with low P availability. *Eur Asian Journal of Bio Sciences*, **3**, 17-24.

BPEDORS., 2000. Physical and socio economical profile of 180 District of Oromia Region. Bureau of Planning and Economic Development of Oromia Regional state, Physical planning Development. Finfinne, Ethiopia. PP.248-251.

Brady, N.C. and R.R. Weil., 2002. The nature and properties of soils (13th ed). Prentice Hall, Upper Saddle River, New Jersey, USA.

Bray, R.H. and L.T.Kurtz., 1945. Determination of total organic and available P in soils. *Soil Science Journal*, **59**: 39-45.

Boere, A., R., Thijs, W., Daphne, K., Dawit, D., Wannes. 2015. Business Opportunities Report Oilseeds and pulses #5 in the series written for the "Ethiopian Netherlands business event 5-6 November 2015, Rijswijk, The Netherlands" Pp 9.

Broughton, W.J., G. Hern´andez, M. Blair., S. Beebe., P. GeptsandJ. Vanderleyden., 2003. Beans (*Phaseolus* spp.) – model food legumes, *Plant and Soil*, **252**: 55–128.

Bruce, R. C. and Rayment, G. E., 1982. Analytical methods and interpretations used by Agricultural Chemistry Branch for Soil and Land Use Surveys. Queensland, USA.

Brucher, H. 2011. Yield and Use of Common Bean. Available at: http://www2. mpiz. koeln. mpg. de/pr/ garten/schau/phaseolus vulgaris/common bean.ntml).

Buso, G.S. and F.A., Bliss., 1998. Variability among lettuce cultivars grown at two levels of available P, *Plant Soil*, **111**, 67-73.

Caradus, J.R. and D.R. Woodfield., 1990. Estimates of heritability for, and relationships between, root and shoot characters of white clover, I. Replicated clonal material, *Euphytica*, **46**, 203-209.

Chapman, H.D. 1965. Cation exchange capacity by ammonium saturation. pp. 891-901. *In*: C.A. Black (ed.). *Methods of soil Analysis*. Agron. Part II, No. 9, Am. SoSc. Agron. Madison, Wisconsin, USA.

Chaudhary, E.H., A.M. Ranjha., M.A. Gill and S.M. Mehd., 2003. P requirement of maize in relation to soil characteristics. *International Journal of Agriculture and Biology*, **4**, 625 – 629.

CIAT (Centro Internationalized Agricultural Tropical), 1986. The cultivated species of *Phaseolus*: Study guide to be used as a supplement to the audio tutorial unit on the same topic. pp. 52-58. In: R. Hidalgo, L. Song, P. Gepts (eds.). Scientific Content: Production. Colombia, California.

CIAT (Centro Internationalized Agricultural Tropical), 2001. Bean project annual report.

CIAT (International Center for Tropical Agriculture), 2003. Highlights of CIAT in Africa, No. 3: New bean cultivars for Ethiopian farmers.

Cichy, A. K., S. S. Snapp, and W. M. Blair., 2009. Plant growth habit, root architecture traits and tolerance to low soil P in an Andean bean population. *Euphytica*, ***165***, 257-268.http://dx.doi.org/10.1007/s10681-008-9778-2

CSA (Central Statistical Agency), 2015. Report on area and production of major crops. CSA, Addis Ababa, Ethiopia.

Delgado, A., I. Uceda, L. Andreu and S. Kassem., 2002. Fertilizer P recovery from gypsum amended reclaimed calcareous marsh soils. *Arid land Res. Manage*., **16**: 319-334.

Dereje, Sh., Nigussie, D., Setegn, G. and Eyasu E. 2016. P Use Efficiency of Common Bean (*Phaseolus Vulgaris* L.) And Response of the Crop to the Application of P, Lime, and Compost in Boloso Sore and Sodo Zuria Districts, Southern Ethiopia. *East African Journal of Sciences*.**9** (1): 57

Devi, N.K., N.K. Singh, S.T. Devi, N.H. Devi, B.T. Singh, K.K. Singhand, M.W. Singh., 2012. Response of Soybean [*Glycine max* (L.) Merrill] to Sources and Levels of P. *Journal of Agricultural Science*, **4**(6):44-53.

Duke, J.A. 1981. Handbook of Legumes of World Economic Importance. Plenum Press, New York. 345p.

Ecocrop., 2013. Ecocrop database. FAO, Rome, Italy. http:// Ecocrop.fao.org/Ecocrop/srv/en/

Fageria, N. K. and M. P. Barbosa Filho., 2007. Dry matter and seed yield, nutrient uptake, and P use efficiency of lowland rice as influenced by P fertilization. *Commun. Soil Sci. Plant Anal.* **38**:1289–1297.

Fageria, N. K., A. Moreira and A. M. Coelho., 2012. Nutrient Uptake in Common bean Genotypes. *Communications in Soil Science and Plant Analysis,* **43** (17): 2289 - 2302.

Fageria, N.K., Baligar, V.C., A. Moreira, and T.A. Portes., 2010. Dry Bean Genotypes Evaluation for Growth, Yield Components and P use Efficiency. *Journal of Plant Nutrition,* **33(14)**: 2167 – 2181.

FAO (Food and Agriculture Organization of the United Nations). 2008. FAO fertilizer and plant nutrition bulletin: Guide to laboratory establishment for plant nutrient analysis. FAO

FAO. 2015. *Analysis of price incentives for common beans in Ethiopia.* Technical notes series, MAFAP, by Workao T. K., MasAparisi A., Lanos B. and Rome.

FAOSTAT. 2015. Food and Agriculture Organization at www.fao.org.

Ferris, S. and E. Kaganzi., 2008. *Evaluating marketing opportunities for common beans in Ethiopia*. **2**: PP 59-78

Fikru, M., 2007. Common ban (*Phaseolus Vulgaris* L.) cultivars development in the lowland areas of Wollo. Proceedings of the 2nd Annual Regional Conference on Completed Crops Research Activities 18 - 21 September 2007, Bahir Dar, Ethiopia, pp. 86-93.

Fisseha, N. and Yayis, R. 2015. Nitrogen and P Fertilizers Rate as Affecting Common Bean Production at Areka, Ethiopia. *Journal of Agriculture and Crops,* **1**(3):33-37.

Fohse, D., N., Claassen and A., Jungk. 1991. P efficiency of plants. I. External and internal P requirement and P uptake efficiency of different plant species, *Plantand Soil*, **110**, 101-109.

Frehiwot, M. 2010. Profile of Common bean production, supply, demand and marketing issues In Ethiopia Addis Ababa. Pp. 11-16

Fujita, K., M. I. Chaudhary, A. Y. Fujita, M. Kai, H.E. Takayanagi and J.J. Adu-Gyamfi., 1999. Photosynthesized carbon translocation and distribution of crops adapted to low-nutrient environments. *In*: Adu-Gyamfi, J.J. (ed.). *Food security in nutrient-stressed environments, exploiting plants' genetic capabilities: summary and recommendations of an International Workshop,* 27-30 September 1999, ICRISAT, Patancheru, India (in En). Japan International Research Center for Agricultural Sciences (JIRCAS) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Gangasuresh, P., V. Muthuselvi, E. Muthulakshmi, S. Muthumari and G. Maniammal., 2010. Synergistic Efficiency of Phosphate Solubilizer Associated with Nitrogen Fixer on the Growth of Soybean (*Glycine max*). *International Journal of Biological Technology,* **1**(2): 124-130.

Georgina, H. R., V. L. Oswaldo, Mesfin, T., Michelle, A. G., Tomas, C., S. Armin., W. Maren., E. Alexander, C. Foo, C. W. Hank, L. Miguel, D. T. Christopher, K .Joachim, K. U. Michael and P. V. Carroll., 2007. P Stress in Common Bean: Root Transcript and Metabolic Responses. *Plant Physiology,* **144:**751-757.

Gifole, G., Sheleme, B., Walelign W. 2011. The Response of Haricot Bean (*Phaseolus vulgaris* L.) to P Application on Ultisols at Areka, Southern Ethiopia. *Journal of Biology, Agriculture and Healthcare,* **1** (3-49): 45.

Girma, A., Demelash A. and Ayele T. 2014. The response of haricot bean cultivars to different rates of P at Arba Minch, Southern Ethiopia. ARPN J. Agric. Biol. Sci., **9**: 344-350.

Gobeze, L. and Legese, H. 2015. Evaluation of common bean cultivars at Pdeficient and sufficient condition in southern Ethiopia. *Ash Ese Journal of agricultural science,* **1**(4):020-027.

Godwin, D.C. and G.J., Blair., 1991. P efficiency in pasture species: A comparison of white clover accessions, *Australian Journal of Agricultural Research*, **42**, 531-540.

Gourley, C.J., D.L. Allan and M.P. Russsele., 1994. Plant nutrient efficiency: A comparison of definitions and suggested improvement, *Plant and Soil,* **158**, 29-37.

Graham, P. and O. Ranalli., 1997. Common bean (*Phaseolus vulgaris* L.). *Field Crops Res*., **53**: 131-146.

Haefele, S.M., M.C. Wopereis, M.K. Ndaiye, S.E. Barro and M. OuldIsselmou., 2003. Internal nutrient efficiencies, fertilizer recover rates, and indigenous nutrient supply of irrigated lowland rice in Sahelian West Africa. *Field Crops Research*, **80**: 19-32.

Hamdi, H. Z., 1999. *Rhizobium*-legume symbiosis and nitrogen fixation under severe conditions and in an arid climate. *Microbiology and molecular biology reviews.* **63**(4):968–989.

Hammond, J.P., M.R. Broadley and P.J. White., 2004. Genetic responses to P deficiency. Annals of botany **94**(3): 323–32.

Hammond, J.P., M.R. Broadley, P.J. White, G.J .King, H.C. Bowen, R. M. Hayden, A. Mead, T. Overs, W.P. Spracklen and D.J. Greenwood., 2009. Shoot yield drives P use efficiency in *Brassica oleracea* and correlates with root architecture traits. *Journal of Experimental Botany,* **60** (7):1953–1968.

Havlin, L., L. Beaton., L. Tisdale and L. Nelson., 1999. Soil fertility and fertilizers; an introduction to nutrient management. 6th ed. Pearson education Inc. New Delhi, India. PP. 90 405.

Hawtin G. C., K. B. Singh and M. C. Saxena., 1980. Some recent development in the understanding and improvement of Cicer and Lens. pp. 613-623. In: R. J.

Hazelton, PA. & BW. Murphy., 2007. *Interpreting Soil Test Results*: What do all the Numbers mean CSIRO Publishing, Collingwood, Victoria, xiþ152 pp.160 paperback ISBN 978-0-643092-25-9.

Ho, M.D., J.C. Rosas, Brown, K.M. and Lynch, J.P. 2005. Root architectural tradeoffs for water and P acquisition. *Functional Plant Biology* **32**:737–748.

Iqbal, R.M., H.Q. Iqbal Chauhan., 2003. Relationship between different growth and yield parameters in maize under varying levels of P. *Journal of Biological Science*, **3**: 921 – 925.

Israel, D.W. 1987. Investigations of the role of P in symbiotic di nitrogen fixation. *Plant Physiol*., **84**: 835-840.

Jackson, M. L. 1962. *Soil chemical analysis.* New Delhi, Prentice Hall of India Pvt. Ltd. 498p.

Kamara, A.Y., J. Kwari, F. Ekeleme, L. Omoigui and R. Abaidoo., 2010. Effect of P Application and Soybean Cultivar on Seed and Dry Matter Yield of Subsequent Maize in the Tropical Savannas of North-Eastern Nigeria. *African Journal of Biotechnology*, **7**(15): 2593-2599.

Katungi, E., A. Farrow, T. Mutuoki, Gebeyehu S., D. Karanja, Alamayehu, F., L. Sperling, S. Beebe and J. C. Rubyogo., 2010. "Improving common bean productivity: Analysis of socioeconomic factors in Ethiopia and Eastern Kenya. Baseline Report Tropical legumes II." Centro International de Agricultural Tropical - CIAT. Cali, Colombia.

Kay, D.E., 1979. Food Legumes. Gray's Inn Road London WCIX8LU, London. 124-146p.

Kelly, J.D., M.W. Adams and G.W. Varner., 1987. Yield stability of determinate and indeterminate common bean cultivars. *Theoretical and Applied Genetics,* **20** (74): 516-521.

Khan, B.M., M. Asif, N. Hussain and M. Aziz., 2003. Impact of different levels of P on growth and yield of mung bean genotypes, *Asian Journal of Plant Sciences.* **2**(9): 677 -679.

Kochian, L.V., Hoekenga, O.A. and M.A. Pineros., 2004. How do Crop Plants Tolerate Acid Soils? Mechanisms of Aluminum Tolerance and Phosphorous Efficiency. *Annual Review of Plant Biology,* **55**:459–93.

Laing, D.R., P.G. Jones and J.H. Devines., 2010. Common bean (*Phaseolus vulgaris* L.). pp. 304-310. in: P.R. Golds Worthy, N.M. Fisher (eds.). Physiology of Tropical Field Crops, 2nd Edition. London.

Lambers, H., M.W. Shane, M.D. Cramer, S.J. Pearse and E.J. Veneklaas., 2006. Root Structure and Functioning for Efficient Acquisition of P: *Matching Morphological and Physiological Traits. Annual Botanica.***98**: 693-713.

Landon, J.R. 1991 *Booker Tropical Soil Manual*: A Hand Book for Soil Survey and Agricultural Land Evaluation with Tropics and Subtropics. Longman Scientific and Technical, Essex, New York. PP 474.

Legese, D., Gure, K. and Teshale A. 2006. Production and marketing of white pea Beans in rift valley Ethiopia. A sub sector analysis CRS-Ethiopia program, Addis Ababa.

Leytem, A.B. and R.L. Mikkelsen., 2005. The nature of P in calcareous soils. *Better Crops*, **89**: 11-13.

Liao, H., X. Yan, G. Rubio, E. S. Beebe, W. M. Blair, and P. J. Lynch., 2004. Genetic mapping of basal root gravitropism and P acquisition efficiency in common bean. *Functional Plant Biology*, **31**, 959-970.

Li P., LH. Zhu and YG. Zhu., 2003. Characterization of QTLs for Harvest Index and Source-sink Characters in a DH Population of Rice (Oryza sativa L.) Acta Genetica Sinica. **30** (12):1118–1126.

Lynch, J. 1995. Root Architecture and Plant Productivity. *Plant Physiology*, **109**: 7-1 3.

Lynch, J. P. and K.M. Brown, 2001. Topsoil foraging - an architectural adaptation of plants to low P availability. *Plant Soil* **237**: 225–237

Lynch, J.P, K.M. Brown, 2008. Root strategies for P acquisition. In: White P.J. and Hammond, J.P. (Eds.), The Eco physiology of Plant–P Interactions. Springer.

Maiti, R.K. and V.P. Singh., 2007. Advances in Common Bean and Related Species, 1st edit. Publisher: Agro bios (International).PP 1-2. *Plant Physiology*. **84**: 835-840.

Malik, M. A., M. A. Cheema, H. Z. Khan and M.A. Wahid., 2006. Growth and yield response of soybean (*Glycine max* L.) to seed inoculation and varying P levels. J. Agric. Res. **44**(1).

Malik, M.A., S.H. Sham, M.F. Saleem, and M.S. Jami., 2002. Determining Suitable Stand Density and P Level for Improving Productivity of Rice Bean (Vigna umbellata). *International Journal of Agriculture and Biology*, **4** (1): 120- 122.

Margaret, N., J. S. Tenywa, E. Otabbong, D.N. Mubiru and T.A. Basamba., 2014. Development of common bean (*Phaseolus vulgaris* L.) production under low soil P and drought in Sub-Saharan Africa: A Review. *Journal of Sustainable Development*, **7**(5): 128-139.

Marschner, H. 1995. *Mineral Nutrition of Higher Plants*, Ed 2. Academic Press, London McMillan, New York, USA.

Matthew, W. B., L. F. Gonzalez, P. M. Kimani and L. Butare., 2010. Genetic diversity and common bean productionand consumption correlates with root architecture traits. *Journal of Experimental Botany,* **6** (7):1953–1968.

McKenzie, R.H. and A. Middleton., 1997.P Fertilizer Application in Crop Production. *Agriculture and Rural development* 542: 3

Mengel, K. and E.A. Kirkby., 2001. Principles of Plant Nutrition. 5th Edn. Kluwer Academic Publishers, Dordrecht/Boston/London and ISBN-13: 9781402000089, Pages: 849.

Mesfin, K., Belay, Y., Abera, H. 2014. The Response of Haricot Bean (*Phaseolus vulgaris* L.) Cultivars to P Levels on Nitisols at Wolaita Zone, Ethiopia. *Greener Journal of Plant Breeding and Crop Science*. **2** (4): 162.

Merrill, S. D., Tanaka, D. L., and Hanson, J. D. (2002). Root length growth of eight crop species in haplustoll soils. Soil Sci. Soc. Am. J. 66, 913–923.

MOA (Ministry of Agriculture), (2014) Plant Cultivars Release, protection and Seed Quality control directorate Addis Ababa, Ethiopia.

MoARD (Ministry of Agriculture and Rural Development), 2009. *Crop Development. Issue No.3.* Addis Ababa, Ethiopia.

Mourice, S.K. and G.M. Tryphone., 2012. Evaluation of Common Bean (*Phaseolus vulgaris* L.) Genotypes for Adaptation to Low P. International Scholarly Research Network Agronomy. *Research Article.*

Mullins, G. 2001. Phosphorus, agriculture & the environment. Virginia Cooperative Extension, Virginia state university. No: 424-029.

Mulongoy, K. 1992. Technical paper 2: Biological nitrogen fixation. pp. 150-156. *In*: Tripathl, R.B. and Psychas, J.P. (eds.) *the AFNETA Alley Farming Training Manual.* Vol, **2**. Source Book for Alley Farming Research. International Livestock Centre for Africa, Addis Ababa.

Namayanja, A., J. Semoka, R. Buruchara, S. Nchimbi and M. Waswa., 2014. Genotypic variation for tolerance to low soil phosphorous in common bean under controlled screen house conditions. *Agricultural Sciences*, **5**, 270-285.

Nigussie, D. and M.K. Schenk., 2004. Exudation of Organic Anions by Roots of Cabbage, Carrot, and Potato as Influenced by Environmental Factors and Plant Age. *Journal of Plant Nutrition and Soil Science,* **167**: 623-629.

Nisar, A., M.T. Saleem and I.T. Twyford., 1992. P research in Pakistan: A review. PP. 59-92. *In*: A. Nisar (eds.), *Proceeding Symposium on the Role of Pin Crop Production*. 15-17 July 1990. NFDC, Islamabad, Pakistan.

NSL (National Soil Laboratory), 1994. Manual for plant analysis and interpretation. Food and Agriculture Organization of the United Nations, Addis Ababa.

Ochwoh, V.A., E, Nankya, P, Abulo, P. Obuo., 2015. Influence of nitrogen and P fertilizer application on seed yield of upland rice in Eastern Uganda. *African Journal of Crop Science*, **3** (9): 230-233.

Onwueme, I.C. and T.D. Sinha., 1991. "Field crop production in tropical Africa", Technical Center for Agriculture and Rural Co-operation.

Ortiz-Monasterio, J.I., G.G. Manske and M. Van Ginke., 2001. Nitrogen and P use Efficiency. *In*: Reynolds, M.P., Ortiz-Monasterio, J.I. and McNab, A. (eds.), Application of Physiology in Wheat Breeding. Mexico, D.F.: CIMMYT.

PABRA (The Pan-Africa Bean Research Alliance). 2005. PABRA outlook: A network to nourish the future. Issue 1. PABRA, Kampala, Uganda. Plant Breeding. Kluwer Academic Publishers, Dordrecht, Boston, London

Rafat, M. and P. Sharifi., 2015. The Effect of P on Yield and Yield Components of Green Bean. *Journal of Soil and Nature*, **8**(1): 9-13.

Raghothama, K.G. 1999. Phosphate Acquisition. *Annual Review of Plant Physiology and Plant Molecular Biology,* **50**:665- 693.

Rengel, Z. and R. D. Graham, 1995. Importance of seed Zn content for wheat growth on Zn-deficient soil. *Plant Soil* **173**: 259-265.

Rubio, G., H. Liao, *X*. Yan and J.P. Lynch, 2003. Topsoil foraging and its role in plant competitiveness for P in common bean. *Crop Science* **43**: 598–607**.**

Sahlemedhin, S. and Taye, B. 2000. Procedures for Soil and Plant Analysis. National Soil Research Center, EARO, Technical Paper No. 74, Addis Ababa, Ethiopia *Sciences and Biotechnology (special issue-1), 45-49.*

Sainju, U. M., Singh, B. P., and Whitehead, W. F. (2005). Tillage, cover crops, and nitrogen fertilization effects on cotton and sorghum root biomass, carbon, and nitrogen. Agron. J. 97, 1279–1290.

Samavat, S., S. Mafakheri and M. J. Shakouri., 2012. Promoting Common Bean Growth and Nitrogen Fixation by the Co-Inoculation of *Rhizobium* and *Pseudomonas fluorescens* Isolates. *Bulgarian Journal of Agricultural Sciences*, **18** (3): 387-395.

Samia, Y.O., W.M. Ahmed and A. A. Mariod., 2012. Effect of Urea, NPK and Compost on Growth and Yield of Soybean (*Glycine max* L.), in Semi-Arid Region of Sudan ISRN Agronomy.

Sandhyarani, N. 2010. Fava Beans Nutrition Facts <www.buzzle.com/articles/fava-beans-nutrition-facts.html accessed on 12/18/2010.

SAS (Statistical Analysis System) Institute, Inc, 2009. JMP .Version 3.1. Cary, North Carolina.

Schulze, J., G. Temple., S.J. Temple., H. Beschow and C.P. Vance., 2006. *Nitrogen fixation by white lupin under P deficiency*. *Ann. Bot.* **98**: 731-740.

Shah, P., K. M. Kakar and K. Zada., 2006. P use efficiency of soybean as affected by P application and inoculation. *Plant Nutrition-Food Security and Sustainability of Agro-ecosystems 670-671.*

Shamim M. and A. Naimat., 1987. Effect of seed inoculation with rhyzobium and NP fertilizers on the yield of gram. Pakistan Journal. Agric Res. **8**: 383-385.

Shen, J., L. Yuan., J. Zhang., H. Li., Z. Bai., X. Chen., W. ZhangandF. Zhang., 2011. Phosphorus Dynamics: From Soil to Plant. *Plant Physiology,* **156**: 997–1005.

Sinclair, T.R. and V. Vadez, 2002. Physiological traits for crop yield improvement in low N and P environments. *Plant and Soil*, **245**: 1-15.

Singh, S.P. 1982. A key for identification of different growth habits of *Phaseolus vulagris*L. *New York Ann. Rep. Bean Improv. Coop, Program,* **25**: 92-95

Singh, S.P. 1999. *Common Bean Breeding in the developments* inon the growth, yield, energy content and P utilization efficiency at Pakistan. *Journal of Plant Nutrition*, **3**:119–134.

Sixbert, M. and M.T. George., 2012. Evaluation of Common Bean (*Phaseolus vulgaris* L.) Genotypes for Adaptation to Low P. *International Scholarly Research Network* 9: 10.

Sofi, P.A., M.Y. Zargar, D. Debouck and A. Graner., 2011. Evaluation of Common Bean (*Phaseolus vulgaris* L.) Germplasm under Temperate Conditions of Kashmir Valley, *Journal of Phytology,* **3**(8): 47-52.*Soil Science Society of America,* 86:45-50.

Steiner, C., B. Glaser, W. Teixeira, J. Lehmann Blum and W. Zech., 2008. Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. Journal of Plant Nutrition and Soil Science-Zeitschrift Fur Pflanzenernahrung Und Bodenkunde**, 171**: 893-899.

Susan, N. M. and M. T. George, 2010. The Effects of the Environment on Iron and Zinc Concentrations and Performance of Common Bean (Phaseolus vulgaris L) genotypes. *Asian Journal of Plant* Sciences **9**: 455-462.

Tang C., P.J. Hinsiger, J. Drevonn and B. Jailard., 2001. P deficiency impairs early nodule functioning and enhance proton release in roots of Medicagotruncatula L. Ann. Bot. **88**:131-138.

Tekalign, T. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa,

Tesfaye, D., Tamado T. and Elias U. 2015. Response of common bean (*Phaseolus vulgaris* l.*)* to application of lime and P on acidic soil of Areka, southern Ethiopia. MSc Thesis, *Haramaya University*. Pp 19-35.

Tesfaye, F., Tamada T. and Anteneh A. 2015. Effect of *Bradyrhizobium* Inoculation and P Rate on Nodulation, Yield and Yield Related Traits of Soybean Intercropped With Sugarcane In Metahara Sugar Estate, Central Rift Valley of Ethiopia.

Tesfaye, M.J., D.L. Liu and C.P. Vance., 2007.Genomic and genetic control of phosphate stress in legumes. *Plant Physiol.,* **144***,* 594- 603.

Teshale, A., Girma, A., Chemeda, F., Bulti, T. and Abdelrahman M. 2005. Participatory Bean Breeding with Women and Small Holder Farmers in Eastern Ethiopia. *World Journal of Agricultural Sciences,* **1**: 28-35.

Tessema T. and Alemayehu B. 2015. Effect of P application and cultivars on seed yield and yield components of common bean (*Phaseolus vulgaris* l.). *American Journal of Plant Nutrition and Fertilization Technology. ISSN 1793-9445/DOI: 10.3923/ajpnft.2015.79.84.* **5** (3)*: 79-84.*

Tilahun A., Takele B. and Endrias A. 2001. Managing Africa's Soils No.23 Reversing the degradation of arable land in the Ethiopian Highlands AHI: Areka Research Centre.

Tolera A., Tamado T. and L. M. Pant., 2005. Seed yield and Land Equivalent Ratio of Maize\climbing Bean Intercropping as affected by Inorganic, Organic fertilizers and Population Density in Western Oromia, Ethiopia. *Asian Journal of Plant Sciences*, **4**(5): 458-46.

Tsvetkova, G. and G. Georgiev., 2003. Effects of P nutrition on the nodulation, nitrogen fixation and nutrient use efficiency of Brady rhizobium japonicum- Soybean (*Glycine max* L. Merr.) Symbiosis. Bulgarian *Journal of Plant Physiology*. Special Issue 2003, 331-335.

Uchida, R. 2000. Essential nutrients for plant growth: Nutrient functions and deficiency symptoms. Plant nutrient management in Hawaii's soils. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa: 31-55 pp.

USDA. 2010. United State Department of Agriculture. *Phaseolus vulgaris* L. Agricultural research service, August 19, 2010.

Vance, C. P., C. Uhde-Stone and D. L. Allan., 2003. P acquisition and use: critical adaptations by plants for securing a nonrenewable resource. *New Phytologist*, **157**: 423 - 447.

Van Reeuwijk, L.P. 1992. Procedures for Soil Analysis. 3rd Edn. International Soil Reference and Information Centre (ISRIC), Wageningen, the Netherlands, ISBN: 9789066720442.

Vesterager, J.M., N.E. Nielsen and H. Hogh-Jensen., 2006. Variation in P uptake and use Efficiencies between Pigeon pea Genotypes and Cowpea. *Journal of Plant Nutrition*, **29** (10): 1869 -1888.

Walkley, A and C.A. Black, 1934. An experimentation of Degtjareff method for determining soil organic matter and the proposed modification of the chromic acid titration method. *Soil Science*, **37**: 29-38.

Wasonga, C.J., D.O. Sigunga and A.O. Musandu., 2008. P Requirements by Maize cultivars in different soil types of Western Kenya. *African Crop Science Journal*, **16** (2):161 - 173.

White, P.J., M.R. Broadley, D.J. Greenwood and J.P. Hammond., 2005. Genetic modifications to improve phosphorus acquisition by roots. *Proceedings of 568th the International Fertilizer Society*, the International Fertilizer Society, Cambridge, United Kingdom.

Win, M., S. Nakasathien and E. Sarobol., 2010. Effects of P on Seed Oil and Protein Contents and P Use Efficiency in Some Soybean Cultivars. *Kasetsart J. (Nat.Sci.)*, 44: 1–9.

Wortmann, C.S. and C. A. Eledu., 1997. Distribution of bean types in Eastern Africa. *Annual Report of the Bean Improvement Cooperative,* 40: 30-31.

Wortmann, C.S. 2006. *Phaseolus vulgaris* L. (common bean). Record from PROTA4U. M.Brink& G. Belay, (Editors). PROTA (Plant Resources of Tropical Africa / Resources vegetables de l'Afrique tropicale), Wageningen, Netherlands

Wortmann, C.S., L. Lunze., V.A. Ochwoh and J. Lynch., 1995. Bean improvement for low fertility soils in Africa. *African crop science journal,* **3**: 469 – 477.

Yong, R.N.and Warkentin B.P.1966.Soil properties and behavior. Amestradam etc., Elsevier Scientific Publishing Comp., 1975.449pp. Bibliography: PP431-439.

Yoseph, T. and Worku, W. 2014. Effect of NP Fertilizer Rate and *Bradyrhizobium* Inoculation on Nodulaton, N-Uptake and Crude Protein Content of Soybean [*Glycine Max* (L.) Merrill], At Jinka, Southern Ethiopia. *Journal of Biology, Agriculture and Healthcare,* **4**(6): 49-54.

Zafal. M., M. Maqsood, M. R. Anser and Z. Ali., 2003. Growth and Yield of Lentil as Affected by Phosphorus. Department of Agronomy, University of Agriculture, Faiselabad-38040, Pakistan.

Zafar, M., M.K. Abbasi and A. Khaliq., 2013. Effect of different P sources on the growth, yield, energy content and P utilization efficiency in maize at Rawalako Azad Jammu and Kashmir, Pakistan. *Journal of Plant Nutrition,* **36**:1915–1934.

Zobel, R. W. (1986). Rhizogenetics (root genetics) *of vegetable crops. HortScience* **21**, 956–959.

APPENDIX

Appendix Table 1. Main effect of cultivars and Phosphorus rate on available P after common bean harvest

Treatment	P_2O_5 kg ha^{-1}	cultivars	Av. P. (ppm)
1	0	Ibbado	4.10
2	0	Tatu	3.61
3	0	Remeda	3.85
4	23	Ibbado	4.70
5	23	Tatu	4.10
6	23	Remeda	4.57
7	46	Ibbado	5.25
8	46	Tatu	4.44
9	46	Remeda	4.93
10	69	Ibbado	5.76
11	69	Tatu	4.82
12	69	Remeda	5.28

Appendix Table 2. Mean squares of ANOVA for Plant height, Number of primary branch, Number of pod per plant, total root length, nodules number per plant and nodule dry weight of common bean cultivars with phosphorus

		Mean square				
source of variation	df	Plant height	Number of primary branch	Total root length	Number of nodules	Nodule dry weight
Rep	2	4.91^{ns}	0.70^{**}	0.64^{ns}	47.39^{ns}	0.28^{**}
P	3	5.09^{ns}	1.70^{**}	84.99^{**}	18.03^{**}	4.89^{**}
C	2	753.34^{**}	0.04^{ns}	6.15^{**}	2870.40^{**}	6.46^{**}
P*C	6	0.35^{ns}	0.13^{ns}	1.51^{*}	4590.25^{**}	0.24^{**}
Error	22	3.31	0.12	10.60	798.47	0.05

Where, ns, * and **: Non significant, Significant at 5 and 1% respectively, df: degree freedom, Rep: Replication, P: Phosphorus, and C: Cultivars.

Appendix Table 3. Mean squares of ANOVA for day to 50% flower, days to 90% physiological maturity, number of pod per plants, Pod length and Number of seed per pod of common bean cultivars with phosphorus

source of variation	df	Mean square				
		50% Days to flower	90% Days to Physiological maturity	Number of pod per plant	Pod length	Number of seed per pod
Rep	2	0.44^{ns}	0.11^{ns}	1.37**	0.24^{ns}	0.28**
P	3	19.66**	41.88**	61.75**	1.63**	2.08**
C	2	60.11**	252.19**	11.58**	1.06**	2.87**
P*C	6	2.85**	1.94**	0.81**	0.26*	0.11*
Error	22	0.38	0.60	0.22	0.10	0.05

Where, ns, * and **: Non significant, Significant at 5 and 1% respectively, df: degree freedom, Rep: Replication, P: Phosphorus, and C: Cultivars.

Appendix Table 4. Mean squares of ANOVA for Biomass, Hundred seed weight, Seed yield, and Harvest index of common bean cultivars with phosphorus

source of variation	df	Mean square			
		Biomass yield kg^{-1}	Hundred seed weight gm	seed yield kg^{-1}	Harvest index %
Rep	2	770815.86**	9.29**	237044.53**	3.01**
P	3	4481508.44**	70.70**	1376283.44**	20.49**
C	2	3580821.53**	71.79**	780632.86**	0.15^{ns}
P*C	6	102715.31**	3.02*	25794.82**	0.41^{ns}
Error	22	18269.01	0.97	4203.74	0.20

Where, ns, * and **: Non significant, Significant at 5 and 1% respectively, df: degree freedom, Rep: Replication, P: Phosphorus, and C: Cultivars.

Appendix Table 5. Mean squares of ANOVA for Seed P up take, Straw P up take, total P up take and P recovery efficiency of common bean cultivars with phosphorus

		Mean square			
source of variation	df	Seed P up take	Straw P up take	total P up take	P recovery efficiency
Rep	2	0.05^{ns}	0.37^{**}	0.68^{**}	3.06^{**}
P	3	10.20^{**}	6.96^{**}	33.79^{**}	108.09^{**}
C	2	1.22^{**}	2.76^{**}	7.65^{**}	7.63^{**}
P*C	6	0.23^{**}	0.20^{**}	0.44^{**}	1.18^{*}
Error	22	0.03	0.05	0.10	0.41

Where, ns, * and **: Non significant, Significant at 5 and 1% respectively, df: degree freedom, Rep: Replication, P: Phosphorus, and C: Cultivars.

Appendix Table 6. Mean squares of ANOVA for P utilization efficiency, Agronomic efficiency and physiological efficiency of common bean cultivars with phosphorus

		Mean square		
source of variation	df	P utilization efficiency	Agronomic efficiency	Physiological efficiency
Rep	2	30.91^{**}	26.09^{**}	14024.1^{**}
P	3	432.93^{**}	554.53^{**}	99166.7^{**}
C	2	72.06^{**}	73.54^{**}	1957.4^{**}
P*C	6	9.72^{**}	8.46^{*}	29850.4^{**}
Error	22	1.94	2.88	780.62

Where, ns, * and **: Non significant, Significant at 5 and 1% respectively, df: degree freedom, Rep: Replication, P: Phosphorus, and C: Cultivars.