Investigations of Varietal Differences in Farmers' Indigenous and Improved Faba Bean (*Vicia faba* L.) for Growth, Yield, P-Uptake and N_2 Fixation in Acid Soils at Sito, Dedo District, Southwest Ethiopia

MSc Thesis

Addisu Dulacha Gobana

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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 Agronomy

Major Advisor: Amsalu Nebiyu (Ph.D.)

Co-Advisor: Zeleke Wondimu (Ph.D. Scholar)

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

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DEDICATION

I dedicate this thesis to my beloved parents; my dad Dulacha Gobana Dhera and my mom Huxule Racha Irkako.

STATEMENT OF AUTHOR

I, Addisu Dulacha Gobana, declare that this thesis is a result of my own work and all sources of materials and information used in this thesis have been accordingly acknowledged. To the best of my knowledge, the findings have never been presented to Jimma University or elsewhere to any other institution for the award of any academic qualification.

Addisu Dulacha Gobana

Date: _____/______/______

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BIOGRAPHICAL SKETCH

The author, Addisu Dulacha Gobana, was born on March 09, 1993 at Hartume Lema, Bule Hora, West Guji Zone in Oromia Regional National State, Ethiopia. He attended public elementary school at Hartume Lema primary school and Kilenso Resa primary school, and public secondary school at Bule Hora High school and Preparatory School. After finishing preparatory school in June 2012, he joined EARTH University in Costa Rica, Central America, in January 2013, and graduated with Degree of Agronomic Engineer, Academic degree of Licenciatura in Agricultural Sciences (Honor BSc in Agricultural science) on December 02, 2016. Right after his graduation, he was employed by EXPORTADORA ENLASA S.A. from Guatemala, Central America, as a Coordinator of Research, Validation and Technical Assistance, for the company's fertilizers commercialization in Ethiopia. He joined Jimma University in November 2017 to study the Degree of Master of Science in Agronomy.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ATA	Ethiopian Agricultural Transformation Agency
BNF	Biological Nitrogen Fixation
CSA	Central Statistical of Ethiopia
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agricultural Organization of United Nations
HARC	Holetta Agricultural Research Center
IFPRI	International Food Policy Research Institute
KARC	Kulumsa Agricultural Research Center
MoANR	Ministry of Agriculture and Natural Resources
Ndfa	Nitrogen derived from atmosphere
NUpE	Nutrient Uptake Efficiency
NUtE	Nutrient Utilization Efficiency
TSP	Triple Super Phosphate

TABLE OF CONTENTS

Contents **Pages**

LIST OF TABLES

LIST OF FIGURES

LIST OF TABLES IN THE APPENDIX

INVESTIGATIONS OF VARIETAL DIFFERENCES IN FARMERS' INDIGENOUS AND IMPROVED FABA BEAN (*VICIA FABA* L.) FOR GROWTH, YIELD, P-UPTAKE AND N_2 FIXATION IN ACID SOILS AT SITO, DEDO DISTRICT, SOUTHWEST ETHIOPIA

ABSTRACT

In the Ethiopian highlands, low soil fertility which is resulting from soil acidity has been a major problem and maintaining sufficient available P and N for crop growth is a major challenge. Therefore, use of legumes with efficient P uptake and N fixation capacity under such conditions can increase yield of legumes and soil fertility that contribute for sustainable crop production. This study was carried out on farmer field in the highland of southwestern Ethiopia to evaluate faba bean varietal difference in growth, yield, P-uptake and N_2 fixation with and without P application in acid soils. Eight faba bean varieties consisting of improved varieties (Dagaga, Gebelcho, Gora, Dosha and Tumsa) and farmers' varieties (Arabe, Kambata and Orome) were grown with two levels of P application (0 and 23 kg P ha^{-1}) with factorial arrangement in a Randomized Complete Block Design with three replications. Collected data were subjected to ANOVA using SAS statistical package version 9.3. The result showed that variety and P application significantly affected growth, yield components, P and N accumulation, biological nitrogen fixation (BNF) and %Ndfa of faba beans. Significant interaction of variety by P was observed for root dry weight and yield. Variety Gebelcho had the highest total P accumulation (20.7 kg P ha^{-1}), total N accumulation (130.5 kg N ha^{-1}) and N_2 fixed (94.0 kg N ha^{-1}), while variety Orome had the lowest value of 10.0 kg P ha^{-1}, 65.4 kg N ha^{-1} and 29 kg ha^{-1} for the respective parameters. Variety Tumsa had the highest %Ndfa (68.1%) and Orome had the lowest value (36.2%). P application significantly influenced N fixation as 48.9 kg N ha^{-1} was fixed by the plants without P application and plants with P application fixed 86.4 kg N $ha^{-1}$and, thus, p application increased nitrogen fixed by 77%. Variety Gebelcho with P application had the highest grain yield (5.6 t ha^{-1}), haulm weight (4.88 t ha^{-1}) and total above ground biomass yield (10.49 t ha^{-1}), while variety Orome had the lowest grain yield (2.1 t ha^{-1}) and total above ground biomass yield (4t ha^{-1}) with no P application, and haulm weight with P application (1.89 t ha^{-1}). Variety Gebelcho showed the highest P uptake, N_2 fixing and yield capacity. Among the farmer's varieties, Kambata showed statistically similar capacity to that of Gebelcho except having lower yield with P application. Application of P with improved varieties like Gebelcho could be ideal for acid soils with low P and N in the Ethiopia highlands cropping systems. However, under condition in which farmers cannot afford for agricultural input package the variety Kambata could give farmers an option to increase soil fertility, contributing to sustainable agricultural intensification to enhance resilience of resource poor farmers.

Keywords: Faba bean, Biological N fixation, P uptake, P harvest index

1 INTRODUCTION

Faba bean (*Vicia faba* L.), also called broad bean, horse bean, is grown globally for food and feed (Multari *et al*., 2015), medicine (Lim, 2013) and contribution to the sustainable cropping system (Jensen *et al*., 2010). This has led to significant advances in global faba bean production.

Faba bean is among the most important legume crops in the highlands of Ethiopia. The country is considered as the second largest center of diversity after Afghanistan (Nigussie *et al*., 2019). Nine million smallholders' farmers in Ethiopia depend on grain legumes production (ATA, 2015). Faba bean takes the first rank in terms of total area coverage (27.36%) and production (30.94 %) of total pulse production, with average grain yield of 2.1 t ha^{-1} on farm and 2.5- 4 t ha^{-1} on research field (CSA, 2018).

In Ethiopia, faba bean is mostly grown by smallholder farmers for human consumption, fodder and forage for animals, and income generator for the households. For the past two decades (1997 to 2017), change of 32% in harvested area, 95% in yield and 158% in production of faba bean has been reported in Ethiopia (FAOSTAT, 2019). Of the produced, 18% of faba bean is marketed and the rest is consumed (IFPRI, 2010). It occupies 24% in volumes of exported grain legumes (ATA, 2015).

Faba bean is also used in cropping system for its ability to improve soil fertility through BNF in symbiosis with Rhizobium (nitrogen fixing bacteria), on average it fixes 120 kg N ha^{-1} per cropping season (Hauggaard-Nielsen *et al*., 2011) and the value of which can vary between 50 to 250 kg N ha^{-1} (Power, 1987; Carranca *et al*., 1999; Amanuel *et al*., 2000). In acid soils, where N and P availability is limiting, faba bean has mechanisms to improve the availability through association with mycorrzia, mobilizing by releasing enzymes and exuding organic anions and protons (Rose *et al*., 2010).

Despite of its importance to the economy, food security and sustainable soil fertility management, faba bean productivity is lower than the potential. Being a cool climate crop, faba bean is grown at high altitudes ranging from 1200 to 3000 m.a.s.l (EIAR, 2018), where soil acidity is a critical problem due to repeated cultivations and high rainfall intensity. Of the total arable land in Ethiopia, 43% is affected by soil acidity and found in the highlands of the country (Mosissa, 2018). Under such condition, N deficiency occurs from slow mineralization, and P is unavailable because phosphate is retained by Al and Fe (Desta, 2015; Kubure *et al*., 2016).

The use of chemical fertilizers can improve low soil fertility problems (Antoniadis *et al*., 2015). However, large proportion of applied chemical fertilizers is lost due to various factors including low nutrient uptake efficiency by crop. Efficiency of fertilizers has been reported to be less than 50% for N, 10% for P and 40% for K (Baligar and Bennett, 1986). Fertilizers are too expensive that resource-poor farmers cannot afford (Nebiyu *et al*., 2014). Consequently, farmers use nitrogen fixing legumes as an option to resolve the problem of low soil fertility (Jensen *et al*., 2010; Nebiyu *et al*., 2014; Bano and Iqbal, 2016).

Studies have been done in Ethiopia assessing improved faba bean varieties that are productive under low levels of available N and P, introduction of those varieties could improve low soil fertility problem (Nebiyu *et al*., 2016; Kubure *et al*., 2016). However, improved varieties have several constraints as they have been developed under condition that may not represent farmer's environment (Fess *et al*., 2011), and may displace farmers' varieties, reducing crop diversity, heavily depend on the climatic condition, need external agricultural inputs package (Pingali, 2012) and farmers cannot easily access these inputs.

Not only improved variety but farmer's varieties could also have such trait of being productive under low levels of available N and P. Study done in Southwestern Ethiopia revealed that farmers believe that their varieties of faba bean are effective in improving soil fertility under acidic soil condition compared to the improved/released ones (Asmamawu, 2017). However, there is no scientifically supported evidence about how these varieties are increasing soil fertility and perform better under acid conditions. Phosphorus uptake and N_2 fixation efficiency can be the reason and identifying farmers' varieties with such traits can increase soil fertility, contributing to sustainable agricultural intensification to enhance the resilience of resource-poor farmers.

1.1 Objectives

1.1.1 General objective

To assess the variation between farmers' indigenous and improved varieties of faba bean with respect to growth, yield, P-uptake and N_2 fixation capacities with and without P application in acid soils

1.1.2 Specific objectives

- ✓ To evaluate faba bean varieties for growth, phenology and grain yield performance in acid soils with and without P application
- ✓ To assess and quantify the variation among faba bean varieties in P uptake, N accumulation, N_2-fixation and %Ndfa in acid soils with and without P application
- ✓ To assess the influence of variety, P application and their interaction on yield, P uptake and N-fixation parameters of faba bean in Dedo area

2 LITERATURE REVIEW

2.1 Importance and role of faba bean in Ethiopian highlands

Faba bean is the oldest grain legume crop, it's farming in old times was well known by Egyptians, Greeks and romans most of the times as food, but sometimes it represented religious value in Egyptian and Roman cultures (Hauggaard-Nielsen *et al*., 2011). Faba bean is grown worldwide with large range of latitudes for many uses such as food and forage (Ruisi *et al*., 2011), green manure crop to improve yields of subsequent cereal crops (Hauggaard-Nielsen *et al*., 2011), offers ecosystem service by fixing atmospheric nitrogen, enhancing wild fauna diversity like bee pollinators and other beneficial microorganisms (Veloso *et al*., 2016), medicine to treat various disease such us Parkinson's disease for its source of levodopa (Singh *et al*., 2013) and also used as raw material to produce ethanol and biogas (Petersson *et al.*, 2007).

Ethiopia is the second faba bean growing country after china (IFPRI, 2010) and considered as secondary center of diversity along with Afghanistan (Muehlbauer and Tullu, 1997). Pulse production in Ethiopia accounts for about 12.61% in total area and 9.73% in total production of which faba bean takes 27.36 % in area and 30.94% in production being at the first rank (CSA, 2018). In the country pulses are economically very important being at the third rank for export earnings and faba bean is one of them, as of produced 18% is marketed and the rest are consumed on farm (IFPRI, 2010). Though the marketed amount is small, faba bean has a potential to increase incomes for small holders more than cereals giving up to 77% more profit than wheat and up to six times more profit than barley (ATA, 2015).

Faba bean plays a significant role in maintaining farmer's food security as an affordable source of protein to improve human nutrition. In Ethiopia it is mainly used as *shiro* flour to make *shirowot* which is a stew commonly in Ethiopian daily dishes, *Baqellanifro* (boiled faba bean eaten for snack) and *boq'ullit* (boiled embryo of faba bean with salt) traditionally used as snack during religious holidays at evening (Buraka *et al*., 2016). Green hauls and straw are used to feed animals and dry straw are traditional used for brick making and as fuel (Muehlbauer and Tullu, 1997).

Apart from its nutritional and economical values faba bean plays important role in sustainable intensification of cropping system. It improves cereal crop productivity planted intercropping or crop rotation farming system through improvement in physical, chemical and biological soil properties (Saxena, 1991). Faba bean has ability to maintain growth depending on N_2 fixation, fix more N than other grain legumes under the same soil N supply and in average it fixes 120 kg N $ha^{-1}year^{-1}$, which is about the same quantity that soybean fixes while the rest legumes fix less than this value (Hauggaard-Nielsen *et al*., 2011). The amount of N fixed varies according to the variety, management and environment where crop is grown (Argawu and Malku, 2017). In three different agro-ecologies, amount of N_2 fixed ranged from 169 to 210 kg N ha^{-1}, 139 to 184 kg N ha^{-1} and 147 to 174 kg N ha^{-1} (Amanuel *et al*., 2000).

Faba bean has a key role in sustaining the production of farming system in Ethiopia highlands. Due to exponential growth of country population lands become to a small piece that farmers has no option to make cultivation land expansion. The problem of low soil fertility has becoming common especially in highlands. To maintain soil fertility and crop production use of legume crops as intercropping or crop rotation has become norm (Degago, 2000). Currently farmers use faba bean as one of the legume crops for its contribution to sustainable cropping system by improving soil fertility in low agricultural input by fixing N_2 and mobilizing fixed P (Rose *et al*., 2010), break crop for pest control (Agegnehu, 2018), reduce cost for synthesized fertilizers (Jensen *et al*., 2010).

2.2 Factors affecting faba bean production in Ethiopian highlands

Despite of its importance as source of protein, income, environmental services and health benefits faba bean production is constrained by various factors. Both biotic and abiotic constraints limit to get potential yield causing instability in the yield, but the impact varies depending on the geographical location and agro-ecological conditions where faba bean is cultivated (Saxena, 1991). Commonly appearing constraints are salinity, acidity, low soil nutrients, toxicity of heavy metals, insufficient or excess moisture, inadequate photosynthesis, disease and insect pests (Zahran, 1999; Saxena, 1991).

In Ethiopia, ATA (2015) has listed pulses of importance to be prioritized on its strategy. The prioritization is in order their importance based on area coverage and economic importance that faba bean is on the first rank to be focused on. Regardless of focus and expectation of increase faba bean production to improve farmer's income and food security, its production and productivity still remained low being 2.1 t ha^{-1} (CSA, 2018), while the average potential yield reported to be between 2.5 to 4 t ha^{-1} (IFPRI, 2010; Gereziher *et al*., 2017). Low productivity in the country is related to soil acidity, low fertility, low agricultural inputs, limited utilization of modern agronomical management practices (Kabata *et al*., 2017) and less priority have been given from government policy (ATA, 2015)

One of the major problems that cause low productivity of faba bean in Ethiopia highland is soil acidity associated nutrients deficiency and unavailability (Fekadu *et al*., 2018). Under acidic soil condition nutrients imbalance occur due to toxicity of aluminum (Al) and Manganese (Mn) with deficiency of available N, P and other nutrients limiting crop productivity (Fageira, 2002). Most critical problems in the acidic soils of Ethiopian highlands are phosphorus unavailability due to fixation by Al and Mg along with N deficiency are of the (Kubure *et al*., 2016). Faba bean for being legumes need more P than other crops for improved root and nodule development (Fageria *et al*., 2013).

2.3 Effect of P on N fixation of faba bean

Phosphorus plays a crucial role in plant growth, development and functions. Legumes even need more P than other crops for root development and process that it is important for nitrogen fixation (Sultenfuss *et al*., 1999). It is used as energy source for *Rhizobium* bacteria to convert N_2 (atmospheric nitrogen) to NH_3 (Sultenfuss *et al*., 1999; Weisany *et al*., 2013). The process of fixation need more P for energy transfer that happen in nodule function, for mitochondrial and symbiosome membrane synthesis for nodule development, even demanding more as N_2 fixation increases (Rotaru and Sinclair, 2009).

Nitrogen fixation is strongly controlled by P that low soil P content restricts rhizobia population (Yakubu *et al*., 2010), inhibits root growth and development, sugar translocation, photosynthesis and other processes, directly or indirectly negatively influencing N fixation by legume plants (Sultenfuss *et al*., 1999). Yahiya (2008), reported that nodulation and N fixation of chickpea varieties were increased on P application, from improved development of plant morphology making more photosynthates for transport to nodules. Application of P significantly increased N fixed by cowpea, groundnut and Bambara groundnut by 378, 169 and 138% respectively compared to control (Yakubu *et al*., 2010).

However, other studies reported that P application had no any significant effect on N_2 fixation when soil is rich in P from previous fertilizer application but it was fixed and unavailable due to soil acidity (Amanuel *et al*., 2000). Phosphorus could be unavailable in soils while the total soil P is still high (Vance *et al*., 2003), plants have developed different mechanism to uptake adequate P under P limiting condition (Balemi and Negisho, 2012). In phosphorus sufficient soils N_2 fixation was controlled by N availability, but both plant growth and fixation were constrained in P poor soils even when inoculated with extracellular phosphatases and mycorrhiza symbionts (Batterman *et al*., 2013).

2.4 Effect of variety on P uptake and utilization of faba bean

Phosphorus unavailability occurs in soils of tropics and subtropics (Antoniadis *et al*., 2015), has been considered as the most limiting plant nutrients in this regions (Yang *et al*., 2014). Studies showed that P is available mostly at the range of pH 6 and 7 that the availability is controlled by its solubility and fixation in the soil (Ch'ng *et al*., 2014). When soil pH is between a range of 4.5 to 6 P found to be fixed with Al and Fe (Adnan *et al*., 2003). The problem could be addressed by liming or application of P fertilizers (Antoniadis *et al*., 2015), but this has impact on environment and it is economically not viable that resources poor farmers may not have access and could not afford it (Ch'ng *et al*., 2014). Identifying cultivars with efficient P acquisition from soil and incorporating in farming system is important for sustainable agricultural production and food security (Rose *et al*., 2010).

Plants have several mechanisms to improve P acquisition through production of higher root-shoot ratio (larger root system), longer root hair by associating with mycorrhiza, modification of root architecture, mobilization by exuding organic anions and protons, mineralization of organic P by releasing acid phosphatase, phytases and RNase thereby increasing P availability making possible to produce high yield in low soil P condition (Rose *et al*., 2010; Balemi and Negisho, 2012). Due to their ability to improve soil fertility grain legumes are recommended to be incorporated as crop rotation in the area like sub-Saharan Africa, where traditional cropping system is major for crop production (Nebiyu *et al*., 2016).

Plant P-efficiency mechanisms under P limiting conditions include both improved uptake efficiency and improved utilization (Balemi and Negisho, 2012). Studies on P efficiency have been done on varieties of crop species like wheat (McDonald *et al*., 2015), soybean (Vandamme *et al*., 2012), common bean (Jorge-Mustonen *et al*., 2013), rice (Rose *et al*., 2012), cotton (Marcante *et al*., 2016), cowpea (Krasilnikoff *et al*., 2003), corn (Fageria and Baligar, 1997) and faba bean (Stelling *et al*., 1996; Nebiyu *et al*., 2016).

Crop species and varieties differ in their ability to take up and utilize P. Five cow pea varieties were significantly varied in P uptake from different source which are soil P and phosphate rock (Ankomah *et al*., 1995). Study in tropical highland of Ethiopia reported that for total PAE, variety effect was not observed, while P application showed variation, but the reverse was true for PUE that variety affected and P application did not affect (Nebiyu, 2016). In common bean varieties appeared to be efficient in P uptake but not in utilization (Jorge-Mustonen *et al*., 2013). It seemed that P efficiency also depend on plant characteristics and environment. Rose *et al.* (2010) reported that screening of 50 faba bean genotypes from different geographical origins found that P uptake efficiency is strongly correlated to root growth trait in acid soils, but not in alkaline soils. The positive correlation observed between root biomass and P uptake in common bean varieties (Jorge-Mustonen *et al*., 2013).

2.5 Effect of variety on growth and yield of faba bean

A variety with a high agronomic efficiency may result in higher yields. Response to applied nutrients at recommended rate and large yield response with further additions of nutrients may also depend on genetic makeup of the variety. The goal is to use appropriate variety to improve yield, while reducing inputs of fertilizers (Bovil *et al*., 2013). Farmers demand better yielding varieties to increase their production, and get better the livelihood of their families. Specifically to reduce vulnerability of small holder farmers, growing of high yielding varieties of faba bean is key to guarantee the sustainability of the crop and food security (Gereziher *et al*., 2017).

Faba bean genotypes have different capacity of growth under various conditions. The ability of accumulating total dry matter is important as in most cases it positively and strongly influence grain yield, similar pattern can be observed for total nutrient accumulation nitrogen fixation (Silim and Saxena, 1992). Though genetic is a key factor that affects growth, yield and yield components, but faba bean is also extremely sensitive to environment and management (Hossain et al. 2017).

Regardless of environmental and management factors the effect of faba bean variety have been reported by various scholars. Mitiku and Wolde (2015), have reported variation between faba bean varieties for pods plant^{-1}, 100 grain weight, harvesting index and grain yield at two location in the highlands of southeastern Ethiopia. Dobocha et al. (2019) also have reported grain yield, total biomass yield and test weight of seed were significantly affected by faba bean varieties. Dahmardeh *et al.* (2010), have reported similar results that faba bean varieties significantly differed in total biomass yield and grain yield.

2.6 Effect of P on growth, yield and yield components of faba bean

Phosphorous nutrition plays a prime role in growth and development, dry matter production and protein synthesis of leguminous crops is vital. Hence a balanced availability of P for legumes gains significance to reap better yields, particularly under rain fed cropping conditions, where rain fall quantum and its distribution controls the crop production system (Kubure et al., 2016). For better expression of their genetic potential in terms of growth, development and productivity faba bean genotypes need P (Bovil *et al*., 2013).

Phosphorus application rates per crop vary and depend on a range of factors including target yield, paddock fertilizer history and soil test results, soil type, and farm financial constraints. Management of P in cropping systems generally goes through several phases. In the majority of soils where the levels of soil P are low, soil P reserves are built up to levels that will not limit crop yields (Bovil *et al*., 2013). The formation of seeds and fruits is especially depressed in plants suffering from P deficiency. Thus, not only yields but also poor quality seeds and fruits are obtained from P-deficient soils (Kubure et al., 2016).

Grain legumes show a range in responsiveness to P. Fekadu *et al*. (2018), have reported that application of 30 kg P ha^{-1} had significantly increased plant height, number of leaves and branches per plant, pod length, haulm yield, grain per pod, grain yield and thousand grain weight of faba bean. Nebiyu *et al.* (2016), have also reported that application of 30 kg P ha^{-1} resulted in a highly significant response to grain yield and total biomass yield of faba bean. Similar result was reported by Amanuel *et al*. (2000) that application of 20 kg P ha^{-1} in acid soils of southeastern Ethiopia significantly influenced grain yield, haulm yield, harvest index and total biomass at three different location.

2.7 Effect of faba bean variety on N fixation, uptake and utilization

Use of high N_2 fixing legumes has been emerging to improve soil fertility in low input cropping system as an option to replace or reduce application of mineral fertilizers for sustainable agricultural intensification (Jensen *et al*., 2010; Nebiyu *et al*., 2014). Legumes N_2 fixation ability vary depending on different factors like soil N availability, the legume species, N demand, ability to accumulate N and environment where crop is grown (Ruisi *et al*., 2017; Hossain *et al*., 2017).

Large difference exists in N_2 fixation among legumes and varieties within single species. Studies have reported values of N_2 fixation in chickpea, dry bean, faba bean, field pea and lentil was 103.59, 11.87, 107.69, 68.5 and 86.76 kg ha^{-1}, respectively (Hossain *et al*., 2017). In the same study, amount of N_2 fixed by chickpea varieties differed as variety CDC Frontier had 65.33 $kgha^{-1}$ and CDC Anna had 39.02 kg ha^{-1}. Legume N_2 fixation does not only determined by species varieties, but it is also affected by the interaction between plant-available soil N and plant growth (Ruisi *et al*., 2017). Faba bean is the top performer among legumes for nitrogen fixation that used to improve low input cropping system (Hossain *et al*., 2017). The N_2 fixation of faba bean after 25 years' assessment reported to be ranging from 75 – 229 Kg N ha^{-1} (Ruisi *et al*., 2017).

Nitrogen is among the most limiting plant nutrients special in low input cropping system use of high N efficient crop varieties would help for sustainable agricultural intensification (Akter *et al*., 2017). Kostadinova *et al*. (2016) defined nitrogen use efficiency (NUE) in two main concepts as N uptake efficiency (NUpE; ability of the crop to absorb available N) and N utilization efficiency (NUtE; ability of crop to convert N taken up in to grain), both are affected by plant characteristics. Root biomass and surface area were highly correlated with N uptake efficiency, while grain yield was highly correlated to N uptake efficiency and N use efficiency (Akter *et al*., 2017)

Genetic differences in plants affect NUE (Akter *et al*., 2017). Studies have been done on common bean (Fageira *et al*., 2015; Akter *et al*., 2017), barley (Kostadinova *et al*., 2016), maize (Worku *et al*., 2007) and oilseed rape (He *et al*., 2017) and have shown that N uptake and use efficiencies significantly differ among crop varieties. Akter *et al*. (2017) mentioned that most of NUE studies are done in cereals than legumes and this is due to legumes obtain their N from N_2 fixation. Positive correlation exists between N_2 fixation and N uptake (Hossain *et al*., 2017). Nitrogen use efficiency differences among common bean varieties observed due to phenotypic traits like root architecture including root volume, number of root hairs, root mass and root-shoot ratio (Dorcinvil *et al*., 2010).

2.8 Effect of faba bean variety by P interaction on growth, yield, P uptake and N fixation

Phosphorus (P) is one of the important element required for crop growth and development and is often applied in the form of fertilizers for obtaining high productivity. Legume crops including faba bean, without adequate P supply, can have only limited success to growth, yield, nutrient uptake and BNF due to the high P requirement. Legumes demand more P than other crops (Sultenfuss *et al*., 1999) because P is used as energy source for rhizobia to fix N in faba bean (Weisany *et al*., 2013). Low P availability in the soil restricts microorganism's population growth, root growth and development, nodulation, sugar translocation and Photosynthesis (Sultenfuss *et al*., 1999). The variation of P uptake and use among crop varieties is regarded as efficient strategy to mitigate the problem of phosphorus limitation. Release of P-efficient genotypes for both high and low input farming systems would reduce the production cost of P fertilizer application especially in acidic soils, minimize environmental pollution and contribute to the maintenance of P reserve globally (Daoui *et al*., 2012).

Phosphorus (P) deficiency is particularly widespread in rain-fed upland farming systems throughout the tropics and remains a major plant nutrient constraint. In this respect, the Ethiopian soils are similar to the other agricultural soils of the tropics being generally low in P and hence P is one of the limiting elements in crop production in the highlands of Ethiopia (Kubure *et al*., 2016). Utilization of P-efficient crops has been proved as an effective way to improve P use efficiency (Fageria *et al*., 1997). The effect of P on plant growth and performance in nutrient accumulation depends on the capacity of the crop variety. Studies have reported that in low P stress, the P uptake efficiency and performance of physiological characteristics of crops depend on the genetic ability of crop and amount of available phosphorus in the soil.

Various studies have shown the interaction effect of P by variety on faba bean. Kubure *et al*. (2016) have reported interaction effect of variety by 46 kg P ha^{-1} on seed pod^{-1}, pod length, on biological yield, seed yield of faba bean. Kubure *et al*. (2015) have reported interaction effect of 46 kg P ha^{-1} by variety on seed yield, P uptake and N accumulation of faba bean varieties Hachalu, Walki and local in central highland of Ethiopia. Mouri *et al*. (2018) also have reported that application of 60 kg P ha^{-1} by variety shown significant effect on dry matter accumulation, number of primary branches $plant^{-1}$, number of total pods $plant^{-1}$, weight of 100-seeds, seed yield, pod yield, haulm yield and P harvest on groundnut in Bangladesh. Nebiyu et al. (2016) have also reported interaction effect of variety and P application on P-harvest index (PHI %) of six faba bean varieties at two P application levels in a field experiment in the Ethiopian highlands. The interaction effect of variety by P application may help increase the efficiency of the plant's use of applied P fertilizer (Nuruzzaman *et al*., 2005).

3 MATERIALS AND METHODS

3.1 Description of study area

A field experiment was conducted under rain-fed conditions on farmer's field at Sito, Dedo District in southwestern Ethiopia (Figure 1) in the 2018-2019 cropping season. The site is located at 7° 30' 00.5"N latitude and 36°51'13"E longitude at an elevation of 2327 m.a.s.l. The annual mean temperature of the study area is 20 ± 0.2 °C and average yearly total rainfall is 1,874 ± 77 mm, where most of the rain (73 %) falls in the months of April–September (Nebiyu *et al.*, 2014). Soils of the experimental site are redish-brown clay classified as Nitisol according to the FAO/WRB system. The soil has a pH value of 5.2 and is strongly acidic (Table 3). The major cropping system in the area involves cereal based (wheat, teff, barley, maize and sorghum), legumes (faba bean, lentil and field pea) and potato.

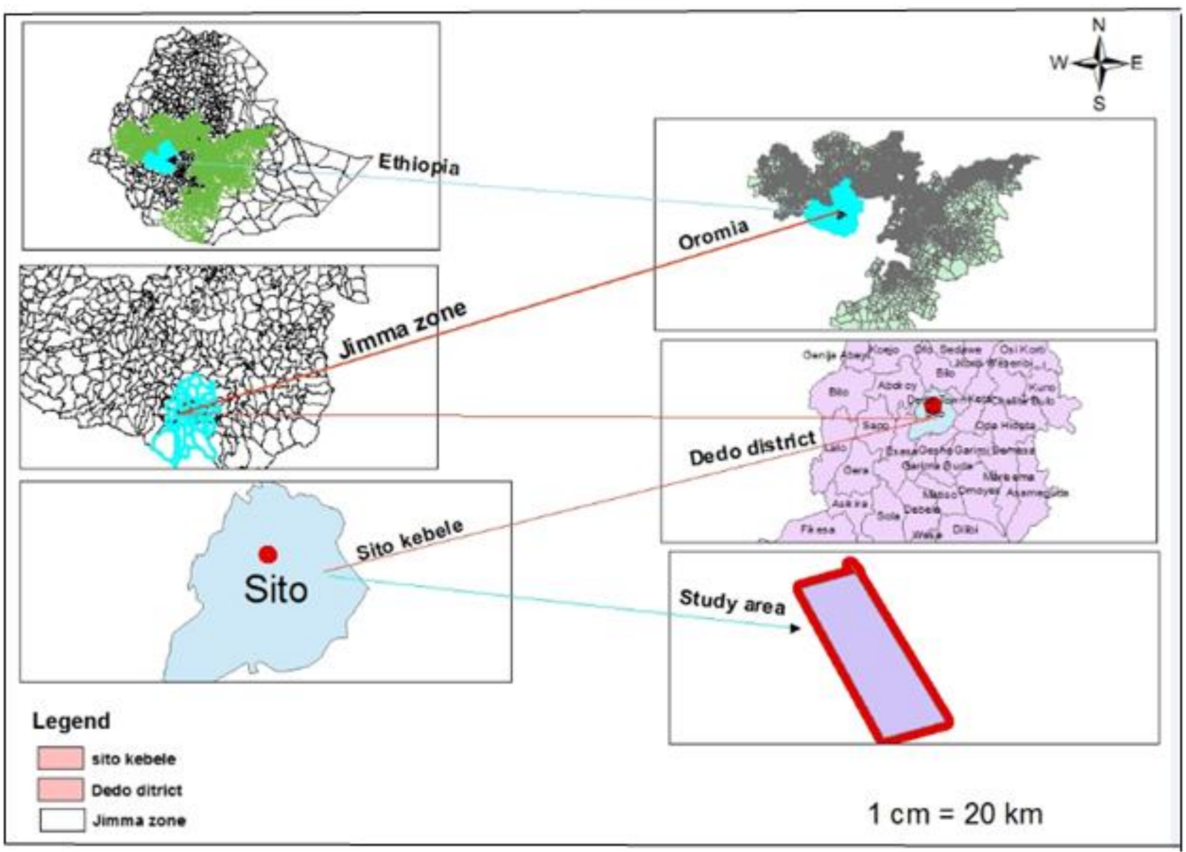


Figure 1. Map of study area (Sito, Dedo District, Jimma Zone, Ethiopia)

3.2 Experimental materials

A total of eight faba bean varieties (five improved and three farmers as listed in the Table 1) were selected and used based on their adaptation potential to the study area. TSP fertilizer (46% P_2SO_5) was applied as a source of P. Seeds of improved varieties were obtained from Holetta Agricultural Research Center of the Ethiopian Institute of Agricultural Research. The farmers' varieties, Arabe and Orome, were collected from Omo Nada area and Kamabata was from Bonga area.

Table 1. Description of the Faba Bean varieties used for the experiment

Variety name	Pedigree name	Source	Year of release	DF	DM	GYP (t ha^{-1})	Adaptation altitude (m)
Arabe	N/A	Farmer	N/A	56	117	1.9-3.0	1800-3000
Dagaga	R-878-3	HARC	2002	61	125	2.0-5.0	1800-3000
Dosha	COLL 155/00-3	HARC	2009	60	144	2.3-6.2	1800-3000
Gebelcho	EH 96009-1	HARC	2006	46	160	2.5.6.1	1900-3000
Gora	EK 01024-1-2	KARC	2013	47	147	2.2-5.7	1900-2800
Kambata	N/A	Farmer	N/A	60	136	1.8-4.0	1800-3000
Orome	N/A	Farmer	N/A	48	105	1.7-3.0	1800-3000
Tumsa	EH99051-3	HARC	2010	61	148	2.0-4.0	1800-3000

N/A=not applicable, DF= Days to Flowering, DM=Days to Maturity, GYP=Grain Yield Potential

Source: MoANR, 2016; Nigussie *et al*., 2019, Table 4 and Table 9

3.3 Treatments and experimental design

The treatments consisted of eight faba bean varieties (Dagaga, Dosha, Gebelcho, Gora, Tumsa, Arabe, Kambata and Orome) and two P levels (0 and 23 kg P ha^{-1}) (Table 2). The eight varieties were grown with two level of P application given as TSP during the main cropping season (July - November) of 2018/2019. The experiment was arranged factorial and laid out in Randomized Complete Block Design with three replications. The amount of P application was based on the blanket recommendation of fertilizers for faba bean production (EIAR, 2018).

Table 2. Treatment combinations of faba bean varieties and P levels

Treatment number	Faba bean variety	Status	P application (kg ha^{-1})
1	Arabe	Farmers' traditional	0
2	Arabe	Farmers' traditional	23
3	Dagaga	Released	0
4	Dagaga	Released	23
5	Dosha	Released	0
6	Dosha	Released	23
7	Gebelcho	Released	0
8	Gebelcho	Released	23
9	Gora	Released	0
10	Gora	Released	23
11	Kambata	Farmers' traditional	0
12	Kambata	Farmers' traditional	23
13	Orome	Farmers' traditional	0
14	Orome	Farmers' traditional	23
15	Tumsa	Released	0
16	Tumsa	Released	23

3.4 Experimental procedure

The experiment was conducted in farmer field with 48 experimental units (8 Varieties x 2 P levels = 16 treatments x 3 replication) arranged based on randomization and tagged for identification. The plot size used was 3 m ×1.6 m, consisting four rows in each plot, 40 cm between rows and 10 cm within rows was maintained (i.e. 30 plants row^{-1} and 120 plants $plot^{-1}$). The TSP fertilizer was used as source of P and the applied amount was calculated based on the area of plot in relation with the area of a hectare and applied to the plots per the level for each treatment and incorporated into the soil just before sowing. All the necessary agronomic practices were applied as recommended (EIAR, 2018). Wheat was used as a reference crop to quantify the N_2 fixed by faba bean and incorporated in the experimental treatment combination as one unit.

Nitrogen fixed by faba beans was determined using the N difference method (Unkovich *et al*., 2008). N difference method is simple, cheap and provides more information on the amount of nitrogen fixed (Hardson and Danso, 1993; Unkovichet al., 2008). A comparative study of ^{15}N

isotope dilution and N difference method for selected legumes revealed that there were no significant differences between the two methods and under low N availability in the field, estimation of N_2 fixation obtained by N difference method are more reliable than those obtained with the ^{15}N isotope dilution method (Müller and Thorup-Kristensen, 2002).

Therefore, taking in mind financial resources, energy and man power N difference method was used. The legume and reference crop are assumed to take up the same amount of N from soil in a given growing season (Hardson and Danso, 1993). N fixing plant and reference plant can be of the same species, but in practice it is difficult to prevent contamination and infection of rhizobia in the soils for the same species plants and wheat can be used as appropriate reference crop for faba bean (Unkovich *et al*., 2008).

3.5 Soil sampling and analysis

Soil samples were collected from experimental site at depth of 0-30 cm from three different points within the replication prior to planting and fertilizing. Samples were mixed to a representative composite sample of 500 g. After air-drying, soil was ground, sieved (2 mm) and analyzed for pH by pH meter, texture was determined by the Boycouos hydrometric method (Van Reeuwijk, 1992). Soil organic carbon (OC) was determined by using Walkley and Black method. Soil organic matter was oxidized under standard conditions with potassium dichromate in sulfuric acid solution. A measured amount of $K_2Cr_2O_7$ was used in excess of that needed to destroy the organic matter and the excess was determined by titration with ferrous sulfate solution, using diphenylamine indicator to detect the first appearance of unoxidized ferrous iron (Walkley and Black, 1934). Soil organic matter (OM) and total nitrogen (TN) were calculated by using conversion factor of % OC to %OM and %TN (i.e. % OM = 1.724 * % OC = %TN*20). Available phosphorus was determined by the Bray II method (Bray and Kurtz, 1945). Ammonium fluoride in acid solution was used to extract acid and remove phosphate ions and also dissolve calcium phosphate. The increase of acidity from 0.025 M (as with P-Bray I) to 0.10 M in Bray II dissolves more calcium phosphate. With the ammonium fluoride concentration of 0.03 M and an acidity of 0.10 M HCl Phosphate in the extract was determined photometrically. This method has been most successful on acid soils.

3.6 Data collection

3.6.1 Phenological parameters

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

Days to physiological maturity: were recorded as the number of days from planting to the time when 90% of the plants in a plot had mature pods and was taken by visual observation.

3.6.2 Growth parameters

Plant height: At late flowering, length of the central axis of the stem was measured from the soil surface to the tip of the stem for twenty randomly selected plants from the central rows of each plot.

Number of tillers plant^{-1}: At late flowering, number of tillers plant^{-1} was counted for twenty randomly selected plants from the two central rows of each plot.

Root and shoot dry weight (t ha^{-1}): At late flowering, five faba bean plants were randomly selected and uprooted from the two central rows. Plant parts were separated into root and shoot components. Roots were gently washed over a fine sieve to remove soil particles and nodules were removed to assess nodule parameters. The shoot and root samples were dried in an oven at 70°C to a constant weight and then the dry weight was measured using sensitive balance.

3.6.3 Nodule parameters

Nodule number: during late flowering, the nodules from each plant root were removed after roots were washed. The number of nodules on each root of five plants plot^{-1} was determined and expressed as mean nodule number per plant.

Nodule dry weight (mg plant^{-1}): After recording their numbers nodules were oven dried at 70°C to a constant weight and then the dry weight was measured using sensitive balance.

3.6.4 Yield and yield components

Number of pods plant^{-1}: was determined as the average number of pods plant^{-1} and recorded at harvesting time for twenty randomly selected plants of the two middle rows of each plots.

Number of seeds pod^{-1}: was determined as the average of seeds pod^{-1} and recorded at harvesting time for twenty randomly selected plants of the two middle rows of each plots.

100 seeds weight (g): 100 seeds were randomly sampled from the composited seeds of each plot, weighed before and after drying to estimate and adjust moisture content.

Haulm yield, grain yield and total above ground yield (t ha^{-1}): At harvesting, the haulm and seed yield of two middle rows from each plot were determined and later converted to yield ha^{-1}. Total above ground biomass was obtained by adding haulm and seed yield at 10% moisture content.

3.6.5 Determination of P uptake, N accumulation and N_2-fixation

P accumulation in plant parts and P harvest index (PHI): P concentration (%) in the shoot (at late flowering stage), haulm and grain was determined through wet digestion method. Milled plant tissues were decomposed by using combination of HNO_3, H_2SO_4 and $HClO_4$, and was treated on a hot plate with concentrated acid and addition of H_2O_2. Pipetted 5 ml of sample of solution was added to a 50ml volumetric flask and to develop color 10 ml of the molybdate and vanadate were added to the solution. After waiting 10 minutes for the color to develop and P in the solution was determined colorimetrically by reading on the spectrophotometer at a wavelength of 460 nm. Then the following P responses were calculated: P uptake (P accumulated in plant parts, kg P ha^{-1}) in shoots (Shoot P = % shoot P * shoot dry yield t ha^{-1} 10^{-3}), haulm (Haulm P = % haulm P * haulm dry yield t ha^{-1}10^{-3}), grains (Grain P = % grains P * grains dry yield t ha^{-1}10^{-3}), total above ground biomass (total P = Haulm P + Grain P) and P harvest index in % (PHI = Grain P/total P *100).

N accumulation in plant parts, N2- fixed and %Ndfa calculation: Total nitrogen content (TN) in plant samples was analyzed following Kjeldahl procedure as described by Bremner and Mulvaney (1982). After determination of TN (%) in plant samples, the following N responses were calculated: TN accumulation (kg N ha^{-1}) in shoots (Shoot N = % shoot TN * shoot dry yield t ha^{-1}10^{-3}), haulm (Haulm N = % haulm TN * haulm dry yield t ha^{-1}10^{-3}), grains (Grain N = % grains TN * grains dry yield t ha^{-1}10^{-3}) and total N in above ground biomass (total N = Haulm N + Grain N). N_2-fixed was calculated using N difference method that compares total N accumulated by the N_2 fixing plants with neighboring non N_2 fixing (reference) plants, with the difference assumed to be due to N_2 fixed (Unkovich*et al*., 2008). The amount of N_2 fixed and %Ndfa were calculated as follows: N_2- fixed = total N yield in faba bean – total N yield in wheat; %Ndfa = $\frac{\text{N fixed by faba bean}}{\text{Total N yield in faba bean}} * 100$.

3.7 Statistical data analysis

A two-way ANOVA for variety and P application was carried out using the general linear model (GLM) procedure of Statistical Analysis System (SAS) software version 9.3 (SAS, 2013) for all parameters. All the data were first checked for meeting the basic ANOVA assumptions such as normality using the proc univariate, option normal procedure of SAS. Accordingly, it was observed that data of nodule number, nodule dry weight, % shoot P, Haulm P and total P violated the ANOVA assumptions. Hence, according to Gomez and Gomez (1984), logarithmic transformation was applied to those data and back transformed to original data after analysis. Whenever the F-test denotes significant variations due to the main effect or interactions, least significance difference (LSD) was used to compare the mean values of treatments at 5% probability level.

4 RESULTS AND DISCUSSIONS

4.1 Soil physicochemical characteristics

Selected physicochemical characteristics of the soil at the experimental site are presented in Table 2. The texture of the soil was classified as clay with pH 5.2, which is classified as strongly acid and such soils are generally have a low availability of phosphorus (USDA, 1998). Organic carbon in the soil was about 2.9%, considered as optimum. Soil organic carbon threshold for sustaining soil quality is widely suggested to be about 2% or more (Moshir *et al*., 2017). Soil organic matter was found to be at optimum range (5%), as most arable land organic matter ranges between 2 to 10% that the ideal average optimum is thought to be around 5% (FAO, 2005). Total nitrogen (TN) in the soil of the experimental site was 0.26% and considered as medium, since on the surface layer of cultivated soils it can vary between 0.06 to 0.5% depending on the land use and management system (Bremner and Mulvaney, 1982). The available P (6.0 ppm) was at very low range (Ravikumar and Somashekar, 2013). P in strongly acid characteristics of soils is generally found to be unavailable because phosphate is fixed by Al and Fe (Kubure *et al*., 2016).

Table 3. Selected physicochemical characteristics of the soil at the experimental site at Sito in Dedo District during the year 2018/2019 cropping season

Parameters	Values	Rating	Reference
pH	5.2	Strongly acid	USDA, 1998
Organic Carbon (%)	2.9	Optimum	Moshir*et al*., 2017
Organic Matter (%)	5.0	Optimum	FAO, 2005
Total Nitrogen (%)	0.26	Medium	Bremner and Mulvaney, 1982
Available P (ppm)	6.0	Very low	Ravikumar and Somashekar, 2013
Soil Texture (%)			
Clay	43.4		
Silt	35.3		
Sand	21.3		
Class	Clay		

4.2 Crop phenology

Statistically significant difference was observed between varieties for days to 50% flowering and days to physiological maturity ($p<0.0001$), but P application and interaction of variety by P application had no significant effect ($p>0.05$) (Appendix Table 1). Variety Orome was the earliest to flower (48.3 days) and reach physiological maturity (105 days), which was significantly different from the rest varieties, while variety Tumsa took longer (62.3 days) to flower and was statistically similar to Gebelcho and Kambata. Variety Gebelcho took longer (136.3 days) to physiological maturity being statistically similar with variety Dagaga and Kambata (Table 4).

Table 4. Effect of variety on days to 50% flowering and 90% physiological maturity of faba bean at Sito, Dedo in 2018/19 cropping season

Variety	Days to 50% flowering	Days to 90%physiological maturity
Arabe	55.8d	117.0c
Dagaga	57.3cd	136.2a
Dosha	58.5cd	131.0b
Gebelcho	61.5ab	136.3a
Gora	59.2bc	131.0b
Kambata	60.0abc	136.2a
Orome	48.3e	105.0d
Tumsa	62.3a	131.5b
$LSD_{0.05}$	2.7	2.0
P application (kg ha^{-1})		
0	57.3	127.9
23	58.4	128.1
$LSD_{0.05}$	ns	ns
CV (%)	4	1.3

Means followed by different letters in a column are significantly different at $p\leq0.05$; ns = not significant

The time to flowering and physiological maturity of crop may depend on genetic makeup of the varieties, environment and management. Plants flower or mature depending on available nutrients, temperature and genotypes of crop (Gonzaléz *et al*., 2016). Mitiku and Wolde (2015), and Tadele *et al*. (2019) reported that in the acid soils of southern and southeastern highlands of Ethiopia, days to flowering and maturity of faba bean varieties were affected by the crop genetic makeup. Alemayehu and Shumi (2018) have also reported that five levels of phosphorus application (0, 10, 20, 30 and 40kg P ha^{-1}) did not affect crop phenology on faba bean variety Gebelcho. In another way, P being one of the major nutrients needed by plants, it affects growth and reproduction of crops that P fertilizer application initiates flowering and maturity (Sultenfuss et al., 1999). As shown on Table 3, soil at the experimental site was strongly acid with very low available P that the amount of applied P could have not been enough to have an effect on days to flowering and days to physiological maturity.

4.3 Crop growth

4.3.1 Plant height and number of tillers $plant^{-1}$

Both variety and P application had a highly significant ($p<0.01$) effect on plant height and tiller number $plant^{-1}$. Interaction of variety by P application did not show significant difference for both plant height and tillers $plant^{-1}$ (Appendix Table 2). Variety Gora had the tallest, which was statistically similar to the rest varieties except varieties Orome and Arabe that had the shortest plant height. The most tiller number $plant^{-1}$ was recorded for variety Kambata that is statistically similar to variety Gebelcho, while variety Orome had the least (Table 6). Similarly P application significantly increased both plant height and number of tillers $plant^{-1}$. This result was in agreement with the findings of Mitiku and Wolde (2015), and Kubure *et al*. (2016) who reported significant effect of variety and P application on plant height and tiller number $plant^{-1}$ of faba bean. Similarly, Tadele *et al*. (2019) also reported significant effect of P application on faba bean plant height and tiller number $plant^{-1}$.

4.3.2 Shoot and root dry weight

Result of the ANOVA showed that variety had highly significant ($p<0.0001$) effect on shoot and root dry weight. P application had no significant effect ($p>0.05$) on both shoot and root dry weight of faba bean varieties. However, variety by P application interaction had significant ($P<0.05$) effect on root dry weight (Appendix Table 2). Variety Gebelcho had the highest shoot dry weight (4.92 t ha^{-1}), while the lowest value was recorded for Arabe (2.38 t ha^{-1}) with statistically similar value to that of Orome (Table 5). The difference could be due to the genetic makeup of varieties to produce dry weight. In line with this Mitiku and wolde (2015) have reported significant effect of faba bean varieties on shoot dry biomass. Manning (2017) and Etemadi *et al*. (2018) have also reported the same result indicating that production of shoot dry biomass varied significantly among faba bean varieties.

Table 5. Effect of variety and P application on plant height, number of tillers plant^{-1} and shoot dry weight at late flowering stage of faba bean at Sito, Dedo in 2018/19 cropping season.

Variety	Height (cm)	Tillers plant^{-1}	Shoot dry weight (t ha^{-1})
Arabe	79.1bc	0.73c	2.38e
Dagaga	87.6a	0.68c	3.57cd
Dosha	89.4a	0.83c	4.47ab
Gebelcho	83.4ab	1.12ab	4.92a
Gora	91.0a	0.92bc	4.07bc
Kambata	88.8a	1.20a	4.52ab
Orome	75.6c	0.22d	2.45e
Tumsa	85.9ab	0.72c	3.23d
$LSD_{0.05}$	8.0	0.28	0.72
P application (kg ha^{-1})			
0	82.0 b	0.65b	3.59
23	88.2 a	0.96a	3.80
$LSD_{0.05}$	4.1	0.14	ns
CV (%)	8.0	29.1	16.5

Means followed by different letters in a column are significantly different at $p \leq 0.05$; ns=not significant

Variety Kambata had the highest root dry weight both with and without P application, while the lowest value was recorded for variety Orome without P application (Table 6). The difference could be due to complimentary effect of P with variety for better nutrient uptake from soil through promotion of root growth and development. This result was in agreement with the findings of Weldua *et al*. (2012) who reported that P application significantly affected root dry weight of faba bean at 50% flowering stage. Negasa *et al*. (2019) also reported the significant influence of P application on dry biomass yield of Dosha, Tumsa and

Gebelcho varieties of faba bean. Similarly, Basawa and Yussif (2016) have reported significant interaction between for cowpea cultivars and p application for root dry weight.

Table 6. Interaction effect of variety by P application on root dry biomass at late flowering stage of faba bean at Sito, Dedo in 2018/19 cropping season

Variety	P application (kg ha^{-1})	
	0	23
Arabe	1.30gh	1.91efg
Dagaga	2.65bcd	1.80efg
Dosha	2.43cde	3.19ab
Gebelcho	3.19ab	2.98abc
Gora	2.35cde	2.91abcd
Kambata	3.34a	3.46a
Orome	1.10h	1.70fgh
Tumsa	1.94efg	2.31def
$LSD_{0.05}$	0.65	
CV (%)	16.19	

Means followed by different letters in a column are significantly different at $p \leq 0.05$

4.4 Nodule number and nodule dry weight

The result of ANOVA showed highly significant effects ($p<0.01$) of the variety on number and dry weight of nodules, but P application and interaction of variety by P application had no significant effect ($P>0.05$) on both parameters (Appendix Table 5).

Dosha had the highest nodule number and nodule dry weight, which was statistically similar with that of Kambata, Gora and Gebelcho, while the lowest values was recorded for variety Tumsa (Figure 2, Figure 3, Appendix Table 9). In agreement with these results Kubure *et al*. (2016) reported that nodule number and nodule dry weight significantly varied between varieties of faba bean and P application did not show any significant influence. Farid and Navabi (2015) have also reported highly significant effect of genotypes on nodule number and nodule dry weight. Similarly, Amanuel *et al*. (2000) observed no variation in nodule number and nodule dry weight due to P fertilization.

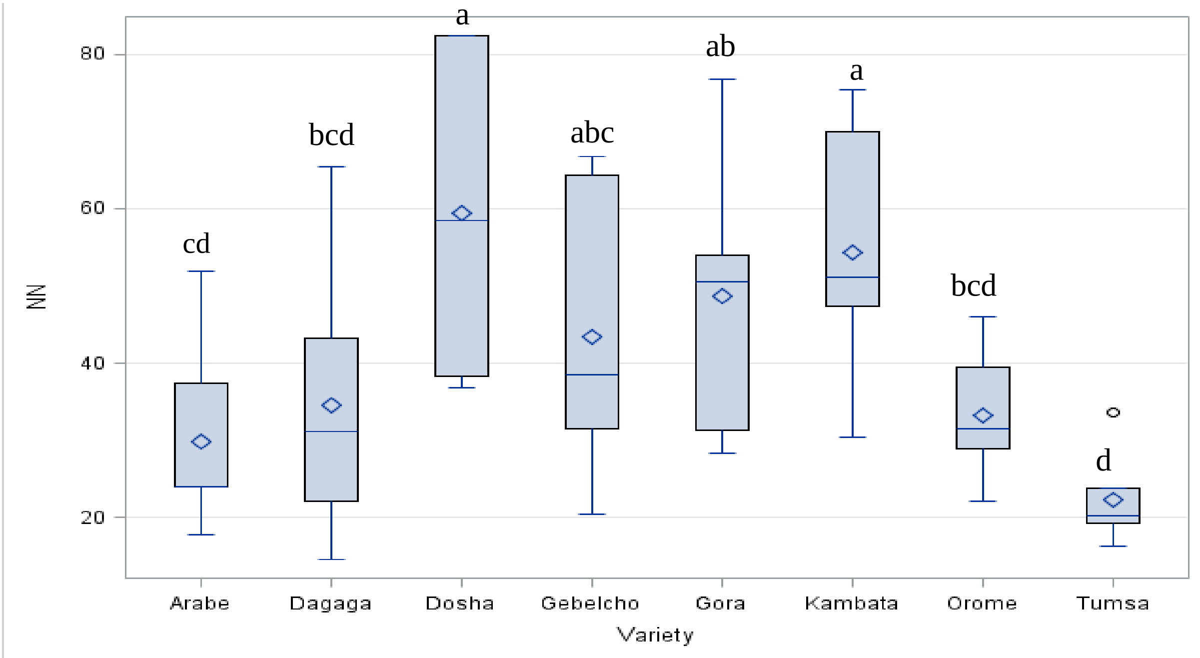


Figure 2. Effect of variety on nodule number plant^{-1} (NN) of faba bean at Sito, Dedo District in 2018/19 cropping season. Bars capped with the same later are not significantly different at 0.05 p level.

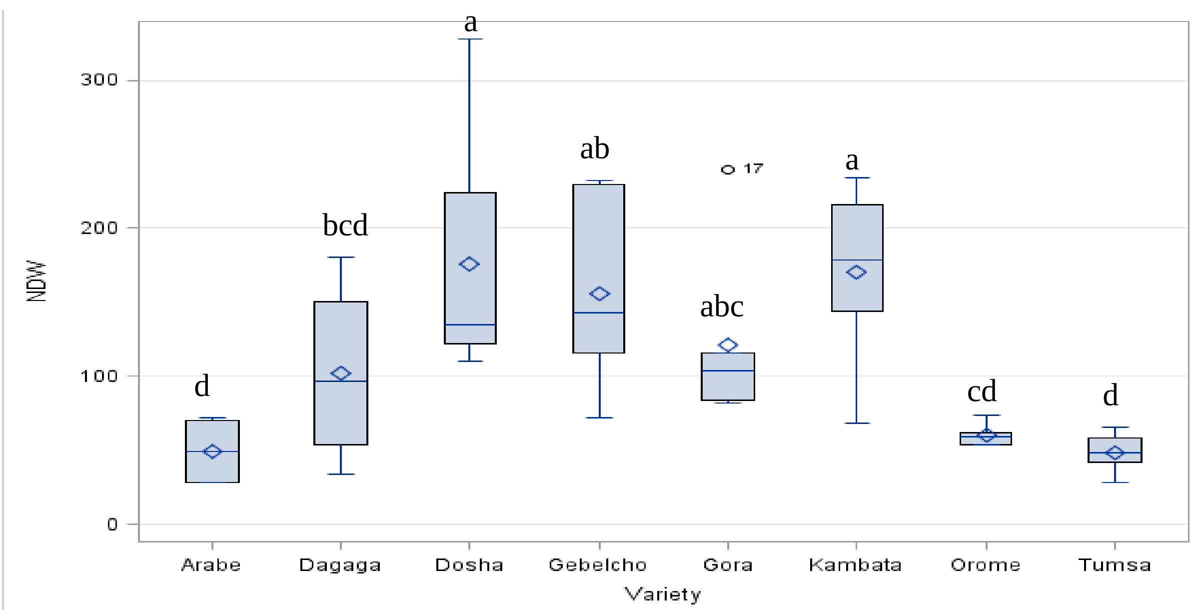


Figure 3. Effect of variety on nodule dry weight (NDW, mg plant^{-1}) of faba bean at Sito, Dedo District in 2018/19 cropping season. Bars capped with the same later are not significantly different at 0.05 p level.

4.5 Yield and yield components

4.5.1 Number of pods plant^{-1} and seeds pod^{-1}, and 100 seeds weight

At physiological maturity, faba bean pods plant^{-1}, seeds pod^{-1} and 100 seed weight were determined. Results of the ANOVA revealed highly significant effects of variety ($p<0.01$) for number of pods plant^{-1}, seeds pod^{-1} and 100 seeds weight of faba beans. For number of pods plant^{-1} and 100 seeds weight significant effect of P application ($p<0.05$) was observed. No interaction of variety and P application was observed for all three parameters (Appendix Table 3).

Variety Orome had highest number of pods plant^{-1}, and Gora had the lowest value that was similar to varieties Tumsa, Kambata and Gebelcho. Variety Kambata had the highest number of seeds pod^{-1} that was statistically similar to that of varieties Gora, Dosha and Arabe, and Gebelcho had the lowest value. Variety Gora had the highest and Orome had the lowest 100 seed weight with statistical similarity to Kambata and Arabe (Table 7). This could be due to the difference of seed size and density according to the variety genetic character. Similar result was reported by Kubure et al. (2016) that evaluation of Hachalu, Walki and local faba bean varieties resulted in significant different in pods plant^{-1}, seeds plant^{-1}, seeds pod^{-1} and 100 seeds weight. Dobocha *et al*. (2019) on varieties Dagaga, Gora and Moti and Negasa *et al*. (2019) on varieties Gebelcho, Tumsa and Dosha have also reported similar results. P application did significantly affect pods plant^{-1} and 100 seeds weight. These results are in agreement with the findings of Tadele *et al*. (2019) that P application resulted in significant large number of pods plant^{-1} and 100 seeds weight compared to plants with no P application. Malik *et al*. (2006) have also reported similar result in soybean crop.

Table 7. Main effect of variety and P application on number of pods plant^{-1}, number of seeds pod^{-1} and 100 seeds weight of faba bean at Sito, Dedo in 2018/19 cropping season.

Variety	Pods plant^{-1}	Seeds pod^{-1}	100 seeds weight (g)
Arabe	10.4b	2.6abcd	64.5cd
Dagaga	9.7b	2.5bcd	73.4c
Dosha	10.0b	2.6abc	87.6b
Gebelcho	9.1bc	2.3d	87.1b
Gora	7.4c	2.7ab	108.2a
Kambata	8.5bc	2.8a	56.6d
Orome	13.1a	2.4cd	55.7d
Tumsa	8.4bc	2.5cd	97.7ab
$LSD_{0.05}$	2.1	0.22	10.9
P application (kgha^{-1})			
0	8.6b	2.5	76.1b
23	10.5a	2.6	81.7a
$LSD_{0.05}$	1.1	ns	5.5
CV (%)	19	7.3	11.7

Means followed by different letters whithin a column are significantly different at p≤0.05; ns= not significant

4.5.2 Grain, haulm and total biomass yield

The result of ANOVA revealed highly significant effect of variety ($p<0.0001$) and P application ($p<0.0001$) on grain, haulm and total biomass yield. Variety and P application had significant interaction ($p<0.05$) for grain and haulm yield, and highly significant interaction ($p<0.01$) for total biomass yield (Appendix table 4).

Variety Gebelcho with P application produced the highest grain yield (5.6 t ha^{-1}), haulm yield (4.88 t ha^{-1}) and total above ground biomass yield (10.49 t ha^{-1}), while variety Orome with no P application produced the lowest value for grain (2.1 t ha^{-1}) and total above ground biomass yield (4t ha^{-1}), and haulm yield with P application (1.89 t ha^{-1}) (Table 8). The above ground biomass yield was higher at P application since P in the plant promotes root growth and development directly influencing the whole plant performance depending on crop genetic character.

Table 8. Interaction effect of variety and P application on grain, haulm and total biomass yields of faba bean at Sito, Dedo in 2018/19 cropping season.

Treatments		Grain	Haulm	Total biomass
Varieties	P application (kgha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})
Arabe	0	2.46gh	2.51fgh	4.97fg
	23	2.74fgh	2.84ef	5.58ef
Dagaga	0	2.80efgh	2.61fgh	5.41f
	23	3.65cdef	3.25cdef	6.91cde
Dosha	0	2.87efgh	2.70fg	5.55f
	23	4.46bc	3.70bcd	8.14bc
Gebelcho	0	3.10defg	3.10def	6.15def
	23	5.61a	4.88a	10.49a
Gora	0	3.13defg	2.53fgh	5.70ef
	23	4.74ab	3.94bc	8.70b
Kambata	0	2.27gh	2.92def	5.18fg
	23	3.57cdef	4.15ab	7.73bc
Orome	0	2.10h	2.07gh	4.00g
	23	2.95efgh	1.89h	5.02fg
Tumsa	0	3.67cde	3.47bcde	7.15cd
	23	3.96bcd	3.53bcde	7.48bcd
$LSD_{0.05}$		0.91	0.77	1.34
CV (%)		16.26	14.81	12.38

Means followed by different letters within a column are significantly different at $p \leq 0.05$

The result of the present study was in line with the work of Agegnehu and Missa (2011) who reported that Gebelcho had highest grain yield compared to Selale and Dagaga varieties with P fertilizer application at Holetta. Kubure *et al*. (2016) have also reported that the interaction of 46 kg P ha^{-1} by variety had significant effect on seed yield faba bean varieties Hachalu, Walki and local in central highland of Ethiopia. Similarly, Negasa *et al*. (2019) that faba bean varieties Tumsa, Gebelcho and Dosha by P application produced superior biomass, while lowest biomass yield was from no P application in southeastern highland of Ethiopia. Zike *et* *al*. (2017) reported interaction effect of phosphorus application by variety on haulm yield of lentil in central highland of Ethiopia. Basawa and Yussif (2016) reported significant interaction effect on shoot and total dry weight of four cowpea varieties by P application. Without P application, there was no statistically significant difference in grain yield among farmers and improved varieties. With P application, improved varieties grain yield was increased significantly, while farmer's varieties did not increased grain yield significantly except for variety Kambata. Similar situation was observed for dry total above ground biomass. This result confirms that improved varieties need external agricultural inputs package to give improved yield compared to farmers' verities (Pingali, 2012).

4.6 Total P accumulation and P harvest index (PHI)

4.6.1 P accumulation

Total P accumulation (P, kg P ha^{-1}) in shoot was determined at late flowering stage (Shoot P), and for haulm (Haulm P) and grain (Grain P) at physiological maturity. ANOVA showed that varieties had highly significant difference ($p<0.01$) for P at late flowering stage and total P accumulation in above ground biomass at physiological maturity, and significant effect ($P<0.05$) on seed P. P application had significant effect ($P<0.05$) on haulm P and total P at physiological maturity. The variety by P application interaction did not result in significant difference ($P>0.05$) of P accumulation in any part of the plant at any stage or total P plant yield (Appendix Table 6).

At late flowering stage the average of 5.72 kg P ha^{-1} was accumulated by faba bean varieties ranging from 3.6 to 7.6 kg P ha^{-1}, with highly significant difference ($p<0.0001$) between varieties. Gebelcho had the highest value (7.6 kg P ha^{-1}) that was statistically similar to Dosha, Gora and Kambata. Variety Orome had the lowest value (3.6 kg ha^{-1}) and was statistically similar to Arabe. P application did not show significant effect on shoot P (Table 9). The difference could be due to the significant difference in shoot dry weight by effect of faba bean varieties. Rose et al. (2010) reported similar result that faba bean varieties genotype significantly effect on P acquisition in acid soils at flowering.

At physiological maturity the average accumulation of P in haulm, grain and total biomass was determined. Average P accumulation in haulm was recorded as 5.5 kg P ha^{-1} and varied between 4.08 kg P ha^{-1} to 7.65kg P ha^{-1}, with non-significant differences ($p>0.05$) among varieties. Grain P accumulation had an average of 8.9 kg P ha^{-1}, variety Gebelcho had the highest accumulation of P accumulation in grain that statistically similar with varieties Kambata and Tumsa, and lowest value were recorded from variety Orome that was statistically similar to varieties Dosha, Dagaga, Arabe and Gora. According to Bovil *et al*. (2013) the average P acquisition in grain of faba bean is about 7.59 kg ha^{-1}, and the result of current study was comparable to this number. Early maturity in some varieties may have contributed to difference in grain P accumulation. Nebiyu et al. (2016) reported similar result as six faba bean varieties had significantly different grain P accumulation. Total P accumulation in above ground biomass had the average of 14.5 kg P $ha^{-1,}$ ranging from 10 to 20.7 kg P ha^{-1} with highly significant difference between varieties ($p<0.01$). Variety Gebelcho had the highest and Orome had the lowest. P application had significant effect ($P<0.05$) on P accumulation in haulm and total plant. Plants with P application had higher P accumulation in haulm (6.4 kg P ha^{-1}) and in total above ground biomass (16.4 kg P ha^{-1}). Similarly, Nebiyu *et al*. (2014, 2016) have reported that at an application rate of 30 kg P ha^{-1}, faba bean varieties accumulated significantly higher P in haulm and total plant. There was no statistical significant difference between farmers and improved varieties for P accumulation.

4.6.2 P harvest index (PHI)

The P harvest index (PHI, proportion of P exported via grains) was determined for the faba bean varieties and P application to assess the amount to which P was removed from the system. ANOVA showed that there was non-significant effect ($p>0.05$) between varieties, P application and interaction of variety by P application (Table 9 and Appendix Table 6). The average percentage of 60 was recorded and the values ranged from 58.3% (Dagaga and Dosha) to 65.7% (Kambata) with non-significance difference between varieties.

Table 9. Effect of variety and P application on P accumulation in plant at late flowering stage (Shoot P) and physiological maturity stage (Haulm P, Grain P, Total P and PHI) of faba bean at Sito, Dedo in 2018/19 cropping season.

Variety	Shoot P (kg ha^{-1})	Haulm P (kg ha^{-1})	Grain P (kg ha^{-1})	Total P (kg ha^{-1})	PHI (%)
Arabe	4.0cd	5.83	8.3bc	14.20b	59.7
Dagaga	5.5b	4.70	7.9bc	12.6b	58.3
Dosha	7.1a	4.92	6.9c	11.8b	58.3
Gebelcho	7.6a	7.43	13.3a	20.7a	59.3
Gora	6.2ab	4.85	8.5bc	13.4b	62.7
Kambata	6.5ab	7.65	11.9ab	19.5a	65.7
Orome	3.6d	4.08	5.9c	10.0b	58.7
Tumsa	5.3bc	5.03	8.8abc	13.9b	62
$LSD_{0.05}$	1.5	ns	4.7	5.2	ns
P application (kgha^{-1})					
0	5.5	4.7b	10.1	12.6b	60
23	6	6.4a	7.8	16.48a	61.2
$LSD_{0.05}$	ns	1.6	ns	2.6	ns
CV (%)	22.6	25.2	44.57	11.7	22.1

NS= not significant. Means followed by different letters within a column for a given variables are significantly different at p≤0.05

4.7 N accumulation, N_2 fixed and %Ndfa

4.7.1 N accumulation

N accumulated ha^{-1} in shoot at late flowering stage (Shoot N), and haulm (Haulm N), grain (Grain N) and total N (Total N) at physiological maturity were determined. The ANOVA showed that shoot N, grain N and total N were significantly ($p<0.05$) affected by faba bean variety. P application resulted in significant difference ($P<0.05$) for haulm N, grain N and total N accumulation, but it didn’t affect shoot N (Table 10). Variety by P interaction did not result in significant difference ($p>0.05$) of N accumulation in any part at any stage or total N yield (Appendix Table 7).

At late flowering stage an average of 91.4 kg N ha^{-1} was obtained. Gebelcho had the highest N accumulation (126 kg N ha^{-1}) that was statistically similar with varieties Dosha and Kambata, lowest value was recorded for variety Arabe (59.7 kg N ha^{-1}) that was statistically similar with variety Orome (Table 12). P application did not show significant effect (P>0.05) on shoot N accumulation (Appendix Table 7). The result is similar to that of Nebiyu *et al*. (2014) who reported significant difference of total N in four faba bean varieties and non-significant effect of four level of P (0, 10, 20 and 30 kg P ha^{-1}).

Table 10. Effect of variety and P application on N accumulation in plant parts at late flowering stage (Shoot N) and at physiological maturity stage (Haulm N, Grain N and Total N) of faba bean at Sito, Dedo in 2018/19 cropping season.

Variety	Shoot N ($kg\ ha^{-1}$)	Haulm N ($kg\ ha^{-1}$)	Grain N ($kg\ ha^{-1}$)	Total N ($kg\ ha^{-1}$)
Arabe	59.7e	36.5	43.4b	80.2bc
Dagaga	85.3cd	43.4	69.0ab	112.2ab
Dosha	111.1ab	41.5	71.0a	112.5ab
Gebelcho	126.2a	46.8	83.6a	130.5a
Gora	99.9bc	35.9	74.6a	111.0ab
Kambata	108.6ab	36.3	61.8ab	98.1abc
Orome	60.2e	21.0	44.4b	65.4c
Tumsa	79.9d	43.7	79.8a	123.8a
$LSD_{0.05}$	18.9	ns	26.5	33.9
P application ($kgha^{-1}$)				
0	89.2	31.6b	54.2b	86.1b
23	93.5	44.7a	77.7a	122.4a
$LSD_{0.05}$	ns	7.7	13.2	17
CV (%)	17.6	34.1	34.0	27.6

ns= not significant. Means followed by different letters within a column for a given variables and treatment are significantly different at $p \leq 0.05$

At physiological maturity the averages of haulm, grain and total N accumulation were 38.2, 65.9 and 104.2 kg N ha^{-1}, respectively. Accumulation of N in haulm varied between 21.0 to 46.8 kg N ha^{-1} with no significant difference between faba bean varieties. Grain N accumulation was significantly affected by variety, Gebelcho had the highest N accumulation in seed (83.7 kg N ha^{-1}) that was statistical similar to varieties Tumsa, Gora, Dosha Dagaga and Kambata, while lowest was from Arabe (43.4 kg N ha^{-1}) that was statistical similar to variety Orome. Total N yield in plants was affected by variety that Gebelcho had the highest (130.5 kg N ha^{-1}), while lowest value was recorded for Orome (65.4 kg N ha^{-1}), which was statistical similar to result for variety Arabe. P application had significant effect on N accumulation in haulm, grain and total plant (Table 10). The range of total N accumulated in plant parts was comparable to the range reported by Anglade *et al*. (2015). The findings of the present study were in line with work of Nebiyu *et al*. (2014) who reported significant difference among four faba bean varieties for N yield in grain and total plant. Significant difference among faba bean varieties for total N in above ground biomass in Morocco (Silim and Saxena, 1992) and in Poland (Ksiezak, 2007). Significant influence of P application on N accumulation in plant parts has also been reported in various legume crops. Furthermore, Walley *et al*. (2004) and Yakubu *et al.* (2010) have reported significant influence of P application (20 and 40 kg P ha^{-1}) on accumulation of N in total plant of chickpea plant shoot in Canada and legumes (groundnut, cowpea and Bambara groundnut) in Nigeria, respectively. Improved varieties numerical had higher total N accumulation in above ground biomass, but there was not statistically significant difference compared to farmer's varieties except for variety Orome that had significantly lower N accumulation.

4.7.2 N_2 fixed and %Ndfa

N_2 fixed and %Ndfa significantly varied ($P<0.05$) with faba beans varieties (Appendix table 8). Variety Gebelcho showed the highest N fixation (94.0 kg N ha^{-1}) capacity, which was statistically similar to that of varieties Tumsa, Dosha, Dagaga, Gora and Kambata, while the lowest value was recorded for variety Orome (29 kg ha^{-1}) (Figure 4, Appendix table 10). Different amount of N fixed by faba bean has been reported in the past as 118 kg ha^{-1} (Peoples *et al*., 2009) and 135 kg ha^{-1}(Jensen *et al*., 2010). Although the amount of N fixed by Orome was relatively low in the present study, the trend was somewhat in line with the finding of Hossain *et al*. (2017), who have reported the range of 49 to 107 kg N ha^{-1}. Variety had a significant effect ($p<0.05$) on %Ndfa. Variety Tumsa had the highest %Ndfa (68.1%), while Orome showed the lowest value (36.2%) (Figure 5, Appendix Table 10). In line with this, Silim and Saxena (1992) and Hossain *et al.* (2017) have reported the range of %Ndfa from 62 to 88% and 54.34% -79.72%, respectively. The result of the present study was in this range except for the variety Orome which had the lowest fixation rate. Lowest dry matter accumulation may have contributed lower N_2 fixed and %Ndfa in Orome, and also it could be the impact of environment. In line with this it has been reported that genetic characteristic is a key factor that affects BNF and %Ndfa in legumes, but they are also extremely sensitive to environment and management practices (Hossain *et al*. 2017). Peoples *et al*. (2009) have also reported that the amount of N fixed is generally controlled by faba bean growth rather than by %Ndfa implying that BNF in faba beans is largely controlled by variety. As that of total N accumulation in above ground biomass, improved varieties had higher fixed N, but there was not statistically significant difference compared to farmer's varieties except for variety Orome that had significantly lower fixed N.

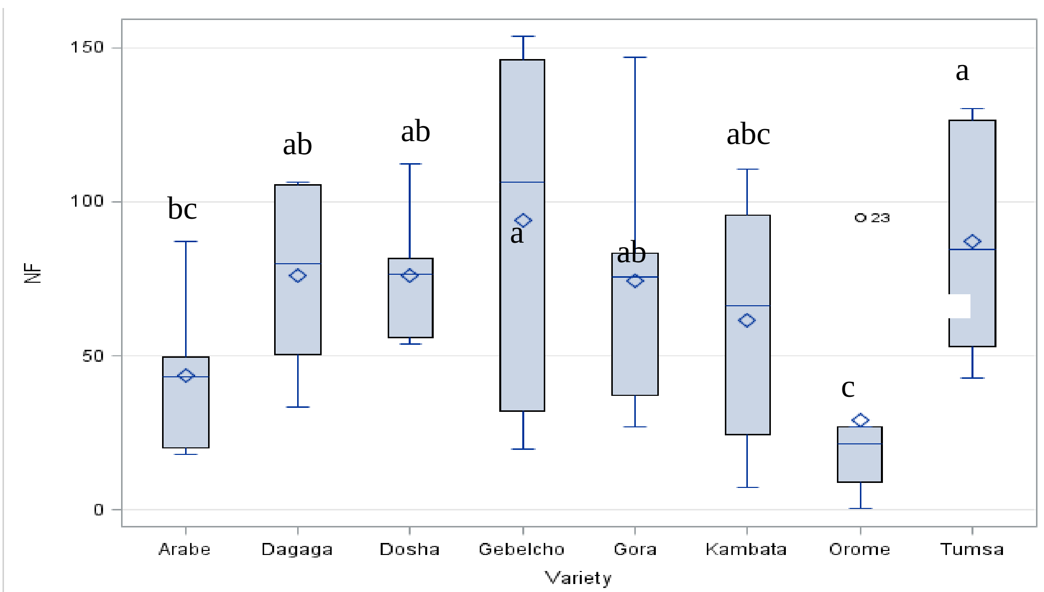


Figure 4. Effect of variety on nitrogen fixation rate (NF, kg N ha^{-1}) by faba bean at Sito, Dedo District in 2018/19 cropping season. Bars capped with the same later are not significantly different at 0.05 p level.

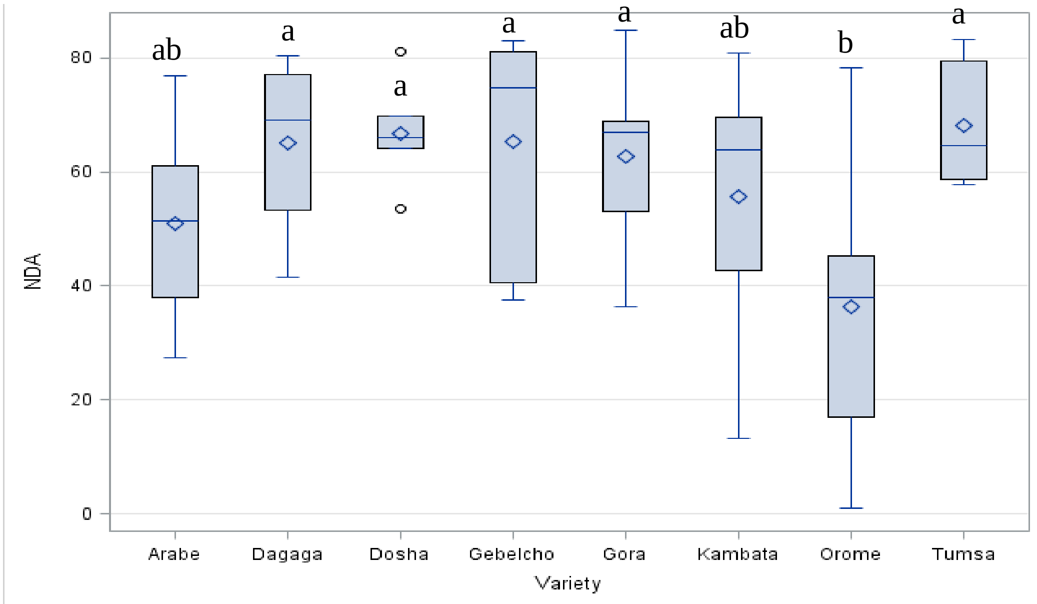
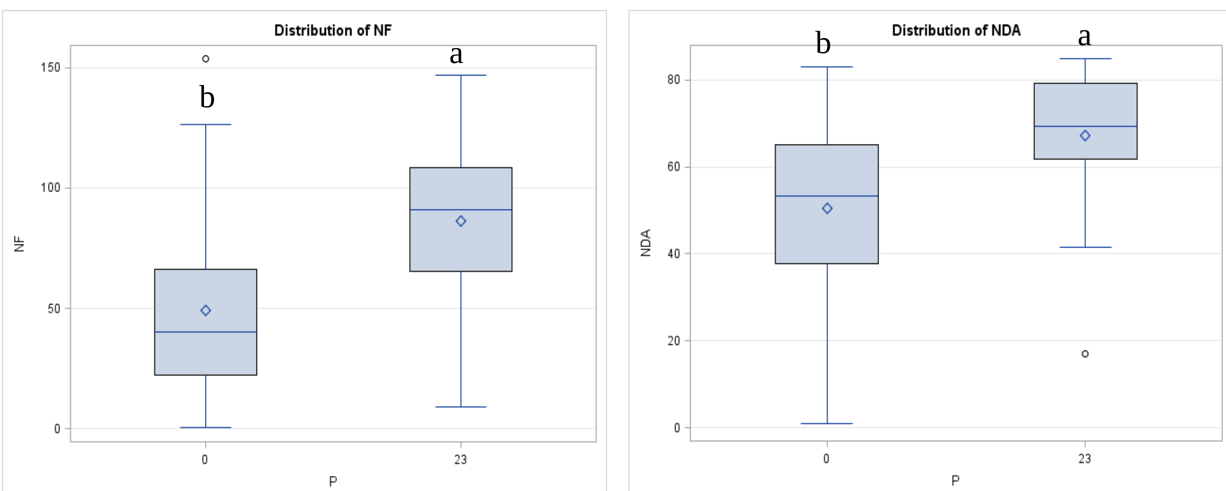


Figure 5. Effect of variety on percentage of nitrogen derived from atmosphere (Ndfa, %) by faba bean at Sito, Dedo District in 2018/19 cropping season. Bars capped with the same later are not significantly different at 0.05 p level.



A B

Figure 6. Effect of P on (A) nitrogen fixated (NF, kg N ha^{-1}) and (B) percentage of nitrogen derived from atmosphere (Ndfa, %) by faba bean at Sito, Dedo District in 2018/19 cropping season. Bars capped with the same later are not significantly different at 0.05 p level.

P application had highly significant effect ($p<0.01$) on both N_2 fixed and %Ndfa (Figure 6, Appendix table 8). The amount fixed N_2 by the plants without P application was 48.9 kg N ha^{-1}, while plants with P application fixed 86.4 kg N ha^{-1}. P application increased N fixation by 76.7 %. In line with this higher %Ndfa with P application has been reported by Amanuel *et al*. (2000) at Asasa, eastern highland of Ethiopia. Similarly, it has been reported that application of 40 kg P ha^{-1} increased N fixation in cowpea, groundnut and bambara groundnut by 378, 169 and 138% respectively, over the control (Yakubu *et al*., 2010).The interaction of variety by P application had no significant effect on both BNF and %Ndfa (Appendix Table 8).

5 SUMMARY AND CONCLUSIONS

The present study evaluated the difference between eight faba bean varieties; five improved (Dagaga, Dosha, Gebelcho, Gora and Tumsa) and three farmers' traditional (Arabe, Kambata and Orome), for yield, P-uptake and N fixation rate in acid soils of Ethiopia highlands. Varieties and P application showed considerable difference for plant growth, P and N accumulation, BNF and %Ndfa. Interaction of variety by P application had effect on root dry weight, grain yield, haulm yield and total above ground biomass. Non-significant effect of variety, P application and interaction of variety by P application was observed for PHI. Variety Gebelcho had the highest total P accumulation (20.7 kg P ha^{-1}), total N accumulation (130.5 kg N ha^{-1}) and N2 fixed (94.0 kg N ha^{-1}), while variety Orome had the lowest value of 10.0 kg P ha^{-1}, 65.4 kg N ha^{-1} and 29 kg ha^{-1} for the respective parameters. Variety Tumsa had the highest %Ndfa (68.1%), while Orome had the lowest value (36.2%). Plants without P application had lower P accumulation (12.6 kg P ha^{-1}) and N fixed (48.9 kg N ha^{-1}), while plants with P application had higher, 16.48 kg P ha^{-1} and 86.4 kg N ha^{-1} for the respective parameters. Variety Gebelcho with P application had the highest grain yield (5.6 t ha^{-1}), while variety Orome with no P application had the lowest grain yield (2.1 t ha^{-1}). Farmers' and improved varieties showed no significant difference for grain yield without P application, but improved varieties significantly higher grain yield with application of P, while farmer's varieties did not, except for variety Kambata. This confirms that, to obtain better yield from improved varieties, external agricultural input package is needed. No significant difference was observed for N fixed except for variety Orome, which had significant lowest value. Variety Gebelcho showed highest P uptake, N fixation and grain yield capacity. Among the farmer's varieties, Kambata showed statistically similar capacity to that of Gebelcho except for grain yield. Application of P with the two varieties could be ideal for acid soils with low P and N in the Ethiopia highlands cropping systems. However, under condition which farmers cannot afford for agricultural input package do not have access, Kambata could give farmers an option to increase soil fertility contributing to sustainable agricultural intensification by enhancing resilience of resource poor farmers.

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7 APPENDICES

Appendix Table 1. ANOVA for days to flowering and physiological maturity

Source of variation	Degree of freedom	Mean square	
		Days to 50% flowering	Days to 90% physiological maturity
Variety (Var)	7	115.79***	754.57***
P application (P)	1	14.08^{ns}	0.75 ^{ns}
Var*P	7	13.13 ^{ns}	2.75 ^{ns}
Replication	2	16.18 ^{ns}	1.31 ^{ns}
Error	30	5.41	2.78
CV (%)		4.02	1.3

Var*P=interaction between variety and P application; ***=Significant at P<0.0001; **=Significant at p<0.01; *=Significant at p<0.05; NS=Not significant

Appendix Table 2. ANOVA for plant height, shoot and root dry weight and tiller number plant^{-1}

Source of variation	Degree of freedom	Mean square			
		Height (cm)	Tiller plant^{-1}	Shoot dry biomass (t ha^{-1})	Root dry biomass (t ha^{-1})
Variety (Var)	7	173.26**	0.55***	5.49***	0.19***
P application (P)	1	463.76**	1.17***	0.56 ^{ns}	0.039 ^{ns}
Var*P	7	37.18 ^{ns}	0.070 ^{ns}	0.73 ^{ns}	0.027*
Replication	2	18.55 ^{ns}	0.11 ^{ns}	0.038 ^{ns}	0.0056 ^{ns}
Error	30	46.49	0.055	0.38	0.0099
CV (%)		8.01	29.1	16.57	16.44

Var*P=interaction between variety and P application; ***=Significant at P<0.0001; **=Significant at p<0.01; *=Significance at p<0.05; ns=Not significant

Appendix Table 3. ANOVA for Pod number plant^{-1}, Seed number pod^{-1} and 100 seed weight

Source of variation	Degree of freedom	Mean square		
		Pod plant^{-1}	Seed pod^{-1}	100 seed weight (g)
Variety (Var)	7	17.89**	0.13**	2252.10***
P application (P)	1	43.51**	0.12 ^{ns}	390.05*
Var*P	7	0.75 ^{ns}	0.036 ^{ns}	81.34 ^{ns}
Replication	2	0.35 ^{ns}	0.045 ^{ns}	105.40 ^{ns}
Error	30	3.32	0.034	85.89
CV (%)		19.01	7.3	11.75

Var*P=interaction between variety and P application; ***=Significant at P<0.0001; **=Significant at p<0.01; *=Significance at p<0.05; ns=Not significant

Appendix Table 4. ANOVA for seed, haulm and total above ground biomass yield

Source of variation	Degree of freedom	Mean square		
		Seed yield (t ha^{-1})	Haulm yield (t ha^{-1})	Total biomass yield (t ha^{-1})
Variety (Var)	7	2.61***	2.24***	8.70***
P application (P)	1	16.22***	8.27***	47.7***
Var*P	7	0.87*	0.58*	2.80**
Replication	2	0.10 ^{ns}	0.027 ^{ns}	0.20 ^{ns}
Error	30	0.31	0.22	0.68
CV (%)		16.6	15.24	12.66

Var*P=interaction between variety and P application; ***=Significant at P<0.0001; **=Significant at p<0.01; *=Significance at p<0.05; ns=Not significant

Appendix Table 5. ANOVA for nodule number and nodule dry weight

Source of variation	Degree of freedom	Mean square	
		Nodule number $plant^{-1}$	Nodule dry weight (Mg $plant^{-1}$)
Variety (Var)	7	989.1**	17294.4**
P application (P)	1	244.3^{ns}	901.3^{ns}
Var*P	7	280.9^{ns}	2839.6^{ns}
Replication	2	409.8^{ns}	2577.5^{ns}
Error	30	222.6	2818.8
CV (%)		36.6	48.1

Var*P=interaction between variety and P application; ***=Significant at P<0.0001; **=Significant at p<0.01; *=Significance at p<0.05; ns=Not significant

Appendix Table 6. ANOVA for Shoot P, Haulm P, Grain P, Total P and PHI

Source of variation	Degree of freedom	Mean square				
		Shoot P (Kg ha^{-1})	Haulm P (Kg ha^{-1})	Grain P (Kg ha^{-1})	Total P (Kg ha^{-1})	PHI (%)
Variety (Var)	7	12.10***	10.34^{ns}	36.78*	84.02**	42.73 ^{ns}
P application (P)	1	3.05 ^{ns}	34.34*	61.88 ^{ns}	188.02**	17.57 ^{ns}
Var*P	7	2.05 ^{ns}	14.91^{ns}	22.86 ^{ns}	50.54^{ns}	267.74 ^{ns}
Replication	2	0.44 ^{ns}	0.48^{ns}	31.70 ^{ns}	36.57^{ns}	265.14 ^{ns}
Error	30	1.68	7.98	15.87	19.43	179.47
CV (%)		22.64	25.2	44.57	11.7	22.11

Var*P=interaction between variety and P application; ***=Significant at P<0.0001; **=Significant at p<0.01; *=Significance at p<0.05; ns=Not significant

Appendix Table 7. ANOVA for Shoot N, Haulm N, Seed N and Total N

Source of variation	Degree of freedom	Mean square			
		Shoot N (Kg ha^{-1})	Haulm N (Kg ha^{-1})	Seed N (Kg ha^{-1})	Total N (Kg ha^{-1})
Variety (Var)	7	3526.47***	385.66 ^{ns}	1370.29*	2885.66**
P application (P)	1	222.3 ^{ns}	2042.32**	6601.17**	15837.7***
Var*P	7	457.78 ^{ns}	282.48 ^{ns}	541.22 ^{ns}	655.70 ^{ns}
Replication	2	35.25 ^{ns}	200.70 ^{ns}	567.6 ^{ns}	1095.12 ^{ns}
Error	30	257.93	169.3	504.32	828.9
CV (%)		17.57	34.08	34.05	27.6

Var*P=interaction between variety and P application; ***=Significant at P<0.0001; **=Significant at p<0.01; *=Significance at p<0.05; ns=Not significant

Appendix Table 8. ANOVA for BNF and %Ndfa

Source of variation	Degree of freedom	Mean square	
		Fixed N (Kg ha^{-1})	%Ndfa
Variety (Var)	7	2883.9*	709.1*
P application (P)	1	16818.8**	3373.4**
Var*P	7	656.3 ^{ns}	147.3 ^{ns}
Replication	2	789.4 ^{ns}	47.4 ^{ns}
Error	30	1124.7	304.2
CV (%)		49.5	29.6

Var*P=interaction between variety and P application; ***=Significant at P<0.0001; **=Significant at p<0.01; *=Significance at p<0.05; ns=Not significant

Appendix Table 9. Effect of variety on nodule number and nodule dry weight $plant^{-1}$ of faba bean at Sito, Dedo District in 2018/19 cropping season.

Variety	Nodule number $plant^{-1}$	Nodule dry weight (mg $plant^{-1}$)
Arabe	29.9cd	49.3d
Dagaga	34.7bcd	102.0bcd
Dosha	59.5a	175.7a
Gebelcho	48.4abc	15.0ab
Gora	48.6ab	121.7abc
Kambata	54.3a	170.0a
Orome	33.3bcd	60.3cd
Tumsa	22.3d	48.3d
$LSD_{0.05}$	17.9	62.6
P application (kg ha^{-1})		
0	42.9	114.7
23	38.5	106.1
$LSD_{0.05}$	ns	ns
CV (%)	37.4	48.1

Means followed by different letters in a column are significantly different at $p \leq 0.05$; ns= not significant

Appendix Table 10. Effects of variety and P application on nitrogen fixation and %Ndfa by faba bean at Sito, Dedo District in 2018/19 cropping season.

Variety	Fixed nitrogen (kg ha^{-1})	Ndfa (%)
Arabe	43.5bc	51.1ab
Dagaga	75.9ab	65.1a
Dosha	76.1ab	66.8a
Gebelcho	94.0a	65.3a
Gora	74.2ab	62.9a
Kambata	61.7abc	55.8ab
Orome	29.0c	36.2b
Tumsa	87.0a	68.1a
$LSD_{0.05}$	39.5	20.5
P application (kgha^{-1})		
0	48.9b	50.5b
23	86.4a	67.3a
$LSD_{0.05}$	19.7	10.3
CV (%)	49.5	29.6

NS= not significant. Means followed by different letters in a column are significantly different at $p \leq 0.05$