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Response of faba bean (*Viciafaba* L.) varieties to lime application in wolaita zone, Southern Ethiopia

Resposta das variedades de feijão-fava (Viciafaba L.) à aplicação de cal na zona Wolaita, sul da Etiópia

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ABSTRACT

Soil acidity and scarcity of faba bean varieties adapted to lower pH soils are major factors that limit faba bean production in Ethiopia. The dominant soil type in the study area is Eutric Nitisols. Therefore, greenhouse experiment was conducted in 2019 toevaluate the response of faba bean varieties to different rates of lime application.Four rates of lime (0, 2, 4, and 6 t ha^{-1}) and five-faba bean varieties (local, Dosha, Gebelecho, Tumsa, and Bobicho) were used as treatments, which laid out as CRD with six replications. The main and interaction effects of lime rates and varieties significantly ($P < 0.05$) influenced all growth, yield components, and yield parameters. The root morphological parameters were significantly ($P < 0.05$) affected by the main effects of the lime rate. Accordingly, the most significant high aboveground biomass of 47.92 g pot^{-1}, and seed yields of (19.16 g pot^{-1}) were obtained in response to the interaction of Tumsa variety with 3 g pot^{-1}lime rate (2 t ha^{-1}). The lowest aboveground biomass of (32.08 g pot^{-1}) and seed yield of (12.84 g pot^{-1}) were obtained in local variety planted without lime application. Overall, in terms of seed yield, Gebelcho and Tumsa varieties performed best by attaining their maximum seed yields in response to the application of 3 g lime pot^{-1} (2 t ha^{-1}). Thus, 3 g pot^{-1} (2.0 t ha^{-1}) liming rate with the Gebelcho and Tumsa varieties was found to be the best-combined treatment to improve the yield of the crop in the study area.

KEYWORDS: growth; phenology; root morphology; soil acidity; yield; yield components.

RESUMO

A acidez do solo e a escassez de variedades de fava adaptadas a solos com pH mais baixo são fatores importantes que limitam a produção de feijão-fava na Etiópia. O tipo de solo dominante na área de estudo é o Nitissolo. Portanto, em 2019, realizou-se um experimento em estufa para avaliar a resposta das variedades de feijão-fava a diferentes taxas de aplicação de calcário. Utilizaram-se quatro doses de calcário como tratamentos (0, 2, 4 e 6 Mg.ha–1) e cinco variedades de feijão-fava (Local, Dosha, Gebelecho, Tumsa e Bobicho), dispostas em um delineamento em blocos casualizados com seis repetições. Os efeitos principais e de interação das doses de calcário e das variedades influenciaram significativamente ($p < 0,05$) todos os componentes de crescimento e rendimento, assim como os parâmetros de rendimento. Os parâmetros morfológicos da raiz foram significativamente ($p < 0,05$) afetados pelos efeitos principais da taxa de calcário. Como resultado, a maior biomassa aérea de 47,92 g por vaso e os rendimentos de sementes de 19,16 g por vaso foram obtidos em resposta à interação da variedade Tumsa com 3 g de calcário por vaso (2 Mg ha–1). A menor biomassa aérea de 32,08 g por vaso e o rendimento de sementes de 12,84 g por vaso foram obtidos na variedade local sem aplicação de cal. Em geral, em termos de rendimento de sementes, as variedades Gebelcho e Tumsa se destacaram ao atingir seu máximo rendimento de sementes em resposta à aplicação de 3 g de cal por vaso (2 Mg ha–1). Assim, verificou-se que a taxa de calagem de 3 g por vaso (2,0 Mg ha–1) com as variedades Gebelcho e Tumsa foi a melhor combinação para melhorar o desempenho da cultura na área de estudo.

PALAVRAS-CHAVE: crescimento; fenologia; morfologia da raiz; acidez do solo; rendimento; componentes de rendimento.

INTRODUCTION

Faba bean (Viciafaba L.) has a significant nutritional role in Ethiopia. The stalk of the faba bean is also used as livestock feed as well as for improving soil fertility (WONDAFRASH et al. 2019). FAO (2016) reported that Ethiopia is the fourth largest fababean exporting country in the world. However, the average national yield of the crop is only about 2.12 t ha^{-1} (CSA 2019), which is very low compared to the average yield of 2.9 t ha^{-1} in other major faba-bean-producing countries in the world (FAOSTAT 2019, CSA 2019). Particularly in Wolaita Zone, the faba bean occupies 96.4% of the area of land cultivated for pulses (1,074.91 hectares) (CSA 2018). However, farmers harvest a lower average yield (1.2 t ha^{-1}) than the national average yield obtained in the country (CSA 2018).

The yield of faba bean is low in Ethiopia due to climatic (WONDAFRASH et al. 2019), genetic (KIFLEMARIAM et al. 2019), edaphic (ENDALKACHEW et al. 2019), and biotic (diseases, pests, and weeds) factors (DEGIFE & KIYA 2016). Soil acidity associated poor soil fertility is a serious problem constraining faba bean production in Ethiopia (GETACHEW 2018, GETAHUN & ABERE 2019). In most cases, the soils with a pH value less than 5.5 are deficient in Macronutrients like N, P, K, Ca, and Mg (FAGERIA et al. 2011).

Soil acidity has become a major threat to crop production in most highland areas of Ethiopia (HIRPA et al. 2013). This is because it limits the availability of nutrients like phosphorus (P), calcium (Ca), magnesium (Mg), and molybdenum (Mo). Furthermore, the levels of soil nitrogen (N) and potassium (K) are highly depleted in acidic soils (FAGERIA et al. 2011). Contents of organic matter (OM) and nutrients in the soil are being depleted due to soil acidity-associated problems (CROWFORD et al. 2008). In Ethiopia, about 40% of highland soils are extremely low in OC (ATA 2019). The soils of the studied area at the KokateMarachere sub-district are strong to moderately acidic (MESFIN et al. 2020). The pH of the study area is as low as 4.4 (SHANKA et al. 2018). Thus, according to the rating of LANDON (1991) and MURPHY (1968), the pH of the soil of the study area is categorized as very strongly acidic. Also, faba bean grows best in soils with a pH ranging from 6.5 to 9.0 (JENSEN et al. 2010). However, growing faba beans at a pH value of 5 or less resulted in poor growth and yield (FRENCH & WHITE 2005). Therefore, soil acidity is likely to significantly reduce the yield of faba bean in the study area, due to its effect on the complex association of the legume host interaction (GRAHAM 2016). Particularly, soil acidity has a dramatic impact on the chemical and biological processes of faba beans. Besides the low pH, soil acidity is associated with the high availability of Al3+, which is stressful or toxic to faba beans (KIFLEMARIAM & FREDERICK 2017). Thus, soil acidity is among the most common problems that limit the production of faba beans in Ethiopia (ASEFA et al. 2010, MULISSA & FASIL 2014, ENDALKACHEW et al. 2019). Particularly, the seed yield of faba bean is very low in Wolaita Zone due to the soil acidity-related problem (TADELE et al. 2016). This is because the acidic condition of the soil affects the survival, nutrient use efficiency, growth, and seed yield of a crop (MULISSA & FASIL 2014).

Faba bean has been neglected in some agricultural regions in Ethiopia due to the problem linked with soil acidity (GENANEW et al. 2012). The inheritable sensitivity of the crop to acidic soils and the low-yield local faba bean variety is a major yield-limiting factors (TAMENE & TADESE 2019). The productivity of crops in the Wolaita Zone is affected also by the lack of improved varieties that tolerate soil acidity (FEKADU 2018).

The research findings from different countries indicated that the application of lime improved the nutrient availability and yield of faba beans (LUKAS et al. 2015, QIAN et al. 2018). Particularly in different parts of Ethiopia, improvement in growth and yield attributes of faba bean due to the lime application has been reported (MEKONNEN et al. 2014, MEKONNEN et al. 2020). Also, the lime application has been recognized as an effective means of improving soil pH and increasing crop yields (ENDALKACHEW et al. 2019). This is because the application of lime raises the soil pH by displacement of H+, Fe2+, Al3+, and Mn4+ ions from the soil adsorption site, and subsequent neutralization of H+ and precipitation of Fe, Al, Mn as hydroxides (CROWFORD et al. 2008). In the meantime, it improves the plant availability of P, Mo, and B. Also, liming creates more favorable conditions for microbial-mediated reactions such as N2 fixation and nitrification, and in some cases improved soil structurethrough enhancement of availability of essential nutrient (KOPKE & NEMECEK 2010).

Managing acidic soil by applying lime may be difficult for economically poor farmers and is less effective when cultivars are sensitive (SUN et al. 2008). On the other hand, the applied lime may not reach up to the sub-soil to address the soil acidity problem (ZHENG 2010). However, some faba bean varieties may remain productive when the surface soil pH is as low as 4.5 (SINGH et al. 2012). Therefore, screening of soil acidity-tolerant, nutrient-efficient, and high-yielding crop varieties could be a means to alleviate the problem (GEMECHU et al. 2016). ICARDA (2010) reported that in acidic soil replacing local varieties with improved ones led to a gain of 42% more seed yield in Ethiopia. However, the finding of the preliminary survey in this study showed that over 65% of faba bean farmers in the studied districts grow local faba bean varieties. Research conducted so far to screen soil acidity-tolerant faba bean varieties revealed significant faba bean growth and yield improvements (KIFLEMARIAM & FREDERICK 2017, MESFIN 2020). However, in the study area, the effects of integrating lime rate and soil acidity tolerant faba bean varieties on the growth and yield of the crop have not been investigated.

In this study, it was hypothesized that integrating liming with the planting of different faba bean varieties results in increased growth, yield components, and yield of the crop. Therefore, this research was conducted to determine the optimum lime rate and suitable varieties for improved faba bean production in the SodoZuria district in Wolaita Zone.

MATERIAL AND METHODS

Description of the Growing Condition

A pot experiment was conducted in a greenhouse at Hawassa University in 2019 to screen best performing faba bean varieties under soil acidity with varying liming rates. According to FAO (2013), the majority of plants grown in greenhouses are adapted to average temperatures in the range of 17–27 °C, with approximate lower and upper limits of 10 and 35 °C. Also, the relative humidity within the range of 60–90% has little effect on plants (FAO 2013). In agreement with this, the temperature and relative humidity of the greenhouse used for this study were adjusted by taking the average of the recommended range, which is 22 ^{0}C and 60%, respectively. Also, SERHAT et al. (2007) recommended a 22–23 °C temperature adjustment for faba bean production in the greenhouse. The study site is located at the 7°25’21” E latitude, 37°46’52” N longitude, and at the elevation of 2873 meters above sea level. The soil media was obtained by following (EIAR 2018) protocol through digging from the depth of 30 cm from the experimental site in the KokateMarachere sub-district of SodoZuria district in southern Ethiopia.The dominant soil type in the study area is Nitisols (SHANKA et al. 2018).

Preparation of Soil for Planting

Approximately 480 kg of sub-soil was dug out from a depth of 30cm from the field experiment site. All soil clumps were removed from the collected soil to make it ready for filling in pots. The soil was air-dried and homogenized. The bulked soil was air-dried and passed through a 5 mm wire mesh sieve.

Description of Experimental Materials

Four improved faba bean varieties that were obtained from Arbaminch, Hawassa, Areka, and Worabe agricultural research centers were used (Table 1). The varieties are well adapted to the study area and have high yield potential and other agronomic traits (YASIN & ESRAEL 2017). In addition, a local faba bean cultivar was used as a control for the study.

Table 1. Description of faba bean cultivars.

Name of Variety	Year of release	Suitable agro ecology		Days to maturity	Seed color
		Altitiude (ma.s.l.)	Annual rainfall(mm)		
Dosha	2009	1900–2800	700–1000	120–130	Light brown
Gebelecho	2006	1900–3000	700–1000	108–165	Light brown
Tumsa	2010	900–2800	700–1293	120–130	Light brown
Bobicho	2002	1800–3000	800–1100	116–135	Light brown
Local	Unknown	Unknown	Unknown	Unknown	Light brown

m.a.s.l = meter above sea level, Polythene pots with 14.5 and 19.5 cm bottom and top diameters, respectively, and 16.5 cm height were used to grow the plants. The pots were filled with 4 kg soil. Triple super phosphate (TSP) [Ca (H2PO4)2] (20% P) and Urea [CO (NH2)2] (46% N) were used as sources of P and N, respectively. The liming materials used for pH calibration and the pot experiment were $CaCO_3$ with a purity of 89%.

Experimental Procedure

Soil sampling, sample preparation and analysis

Soil sampling and analysis were done before planting the crop. Samples were randomly collected using an auger to the soil depth of 0–30 cm in a zigzag pattern from the experimental field before planting on the pot.

The samples were mixed thoroughly in a bucket to form a one-kilogram composite sample. The soil samples were analyzed at Hawassa soil laboratory for pH, CEC, OC, total N, available P, exchangeable cations, and soil texture. Soil pH (1: 2.5 soils to water ratio) was measured using a glass electrode pH meter as described by MYLAVARAPU (2009). CEC of the soil was determined from NH4OAc saturated samples, which were measured through distillation using the micro Kjeldahl procedure. Soil organic carbon (OC) was determined by the chromate acid oxidation method (WALKLEY & BLACK 1934). Total nitrogen was analyzed using the macro-Kjeldahl digestion method, followed by the ammonium distillation and titration method (BREMNER 1965). Soil available P was analyzed using the Olsen method (OLSEN et al. 1954). Exchangeable K was extracted by the ammonium acetate (1M NH OAc at pH 7) extraction method as described by ROWELL (1994) and determined by flame photometry. The particle size distribution was done following the Bouyoucos hydrometer method (BOUYOUCOS 1951) and the textural class was determined based on the soil textural triangle using the International Soil Science Society (ISSS) system (ROWELL 1994).

Lime requirement determination (pH calibration)

To determine the lime requirement for the pot experiment, duplicate dry soil samples each weighing 0.5 kg were thoroughly mixed with 0, 167, 334, 501, 668, 835, 1,002, and 1,169 mg of calcium carbonate (CaCO3). Based on the soil bulk density of 1.5 g cm–3 and depth of 20 cm, this liming rate corresponded to 0, 1, 2, 3, 4, 5, 6, and 7 tons per hectare. The middle rates of the lime was fixed based on the recommendation given by SHANKA et al. (2018) neighboring district for the study area. Then, the soils were added into each polythene pot with a capacity of containing 1 kg of soil. The 250 ml distilled water was added to the samples approximately to field capacity. The soil was then incubated at room temperature for two weeks (SHANKA et al. 2018). Then, the soils were ground and sieved through a 2-mm sieve to determine their pH and available phosphorus.

Greenhouse experiment

After completion of soil preparation four rates of lime in the form of $CaCO_3$ were separately mixed by shoveling with the respective bulk soil before filling the soil into each pot. Accordingly, 0, 2,667, 5,334, and 8,001 mg pot^{-1} $CaCO_3$ were applied to each pot containing 4 kg soil representing 0, 2, 4, and 6 t ha^{-1} lime rate, respectively. The phosphorous and nitrogen fertilizers were applied according to the blanket recommendations given by the Ethiopian Institute of Agricultural Research (EIAR 2018), which is 100 kg DAP ha^{-1} (18-46-0) and 50 kg urea ha^{-1} (46-0-0) for all legumes crops. Phosphorus was applied to each pot at the rate of 46 kg P2O5 in the form of 100 kg ha^{-1} Triple Super Phosphate (TSP) (Ca (H2PO4)2). Thus, all soil batches (480 kg) were piled together and 16,000 mg of TSP was added, in which each pot received 133 mg pot^{-1} and thoroughly mixed before the soil was filled into the pots. Nitrogen was applied at the equivalent rate of 23 kg N ha^{-1} in the form of 100 kg ha^{-1} Urea [CO (NH2)2] (46% N) in which each pot received 66.5 mg urea at the active vegetative stage each pot by dissolving it in water. Then, six replicate soil samples each of which weighing four kg were filled into the plastic pots for each treatment. The soil was filled into each plastic container to the natural bulk density of 1.5 g cm–3. On 02 December 2019, four faba bean seeds were sown per pot and later thinned into two plants after germination. Each pot was watered equally by using a water can twice a day before flowering, once a day after flowering, and at two-day intervals after the pod set. Root samples were also taken at the active vegetative growth stage (just after flowering) from the pots prepared for destructive sampling. The two plants remaining in each pot were used to collect the required data. The plants in the remaining pots were harvested above the soil by using a sickle on 2 April 2019.

Treatments and Experimental Design

The treatments consisted of four liming rates (0, 2, 4, and 6 tons per hectare as CaCO3) and four faba bean varieties (Dosha, Gebelcho, Tumsa, and Bobicho), and one local cultivar as a control treatment. The 0, 2, 4, and 6 tons per hectare as of lime corresponded to rates amounting to amounted to 0, 3, 5, and 8 g pot^{-1}, respectively, based on the soil bulk density of 15 g cm–3 and soil depth of 20 cm. Each pot contained 4 kg of soil. The experiment was laid out as a Completely Randomized Design (CRD) in four lime rates by five varieties factorial arrangement and replicated with six replications per treatment. A total of 120 pots were used. Plants in some of the six replicates were used for destructive sampling.

Data Collection and Measurement

Phenological data

Data on the number of days to emergence and flowering were recorded starting from the date of planting until 50% of the plant population in the pot emerged and 50% of exhibited visible flowers, respectively. However, the number of days to physiological maturity was recorded from the date of planting to when 90% of pods of the plant stands in a pot changed to dark color.

Plant height was measured from the base to the tip of the plant by using a measuring tape. Leaf area (mm^2) was recorded by using a digital leaf area meter.

The number of branches was determined by counting all branches originating from the main stem and secondary growth was excluded.

Root morphological data

Data on the root morphology was recorded at the flowering stage. Prior to measuring the root length, number of roots per plant and the number of nodules per root, root samples of pots in balls of earth were carefully soaked in a bucket filled with water. The soil was removed and washed carefully through a 2 mm sieve and rinsed in water (SHANKA et al*.* 2018). The root length of longest root per plant was measured from the base to the tip of the root by using a measuring tape. The number of roots per plant and the number of nodules per root were counted after the soil clods were carefully removed.

Yield components and yield data

All seeds per pod of a plant were determined by counting the numbers at harvest. Aboveground dry biomass yield per pot was taken by cutting the aboveground plant part of a plant at the ground level at maturity and sun drying. Then biomass yield (gram per pot) was measured using a sensitive balance and recorded.

The seed yield (gram per pot) was determined after threshing the sun-dried plants harvested and the yield was adjusted at 10% moisture content (BIRRU 1979) by using Dicky Johns' hand moisture tester and then weighed by using a sensitive balance. The stover yield (gram per pot) was calculated as the difference between total aboveground biomass and seed yield.

Data Analysis

All crop, plant tissue, and soil data will be subjected to analysis of variance using the statistical analysis system (SAS) version 8.4 (SAS 2004). Significant treatment means were separated using the least significant difference (LSD) test at a0.05 probability level.

RESULTS AND DISCUSSION

Physical and Chemical Properties of the Experimental Soil

The soil used for the pot experiment was strongly acidic in reaction, according to MURPHY (1968) (Table 2). The value is far below the range suitable for most crops which is optimum for the availability of nutrients i.e. 6.5 to 7.5 (FAO 2008). Moreover, faba bean grows best in soils with pH values ranging from 6.5 to 9.0 (JENSEN et al. 2010). This shows that soil acidity is a limitation for faba bean productivity in the study area. Thus, reclaiming the soil using lime and planting soil acidity tolerant varieties is required. This is because lime application increases soil pH in which Ca reacts with H^+ in the exchange site and neutralizes the soil acidity, thereby increasing the pH of the soil (ANDERSON 2013). The CEC value of the soil is moderate according to the rating of HAZELTON & MURPHY (2007), which indicates its retention of adequate cations. The soil has medium organic carbon and total N contents according to the rating of BerhanuDebele as cited by TADESE (1991). Thus, it indicates the ability of the soil to supply organic carbon and mineralizable nitrogen for the proliferation of soil biota, which are important for soil biochemical processes that increase the mobility of nutrients and others for plant uptake (MURAGE et al. 2000). The available P content of the soil is low according to the rating of COTTENIE (1980). Thus, the application of P fertilizer is required for improving faba bean yield in the study area (FAO 2008). The exchangeable K in the soil is low according to the rating of FAO (2006), which indicates the level is not sufficient for high crop yields. Since critical values for K that begin to limit plant growth are around 0.2–0.5 c mol (+) kg ha^{-1} according to GOURLEY (1999), the content of exchangeable K was low and the soil requires external application of the nutrient.

Table 2. Soil physical and chemical properties of the study site in SodoZuria district, Southern Ethiopia in 2019 cropping season.

Property	Values	Rating	Reference
pH (1: 2.5 H_2O**)**	4.9	Very strongly acidic	MURPHY (1968)
CEC ($cmol_{(+)}\ kg^{-1}$)	23.1	Medium	HAZELTON & MURPHY (2007)
OC (%)	2.7	Medium	BERHANU (1980) as cited by TADESE et al (1991)
Total N (%)	0.12	Medium	BERHANU (1980) as cited by TADESE et al (1991)

Available P(mg kg^{-1})	5.94	Low	COTTENIE (1980)
Exchangeable K (cmo$_{(+)}$kg soil^{-1})	0.4	Low	FAO (2006)

CEC= Cation Exchange Capacity; OC= Organic Carbon; Total N = Total Nitrogen; Av.P= Available phosphorous.

Overall, the pH of the soil of the experimental site was too low (strongly acidic) for faba bean growth. Hence, before liming the soil, the amount of lime that required raising the soil pH to a level suitable for faba bean growth wasdetermined. Accordingly, the relationships between the amounts of $CaCO_3$ applied and the pH values obtained were plotted and the level of $CaCO_3$ was sufficient to raise the pH of the soil to the desired level *i.e.,* 6.5 was found to be 334 mg $CaCO_3$per 0.5 kg^{-1} (Figure 1).

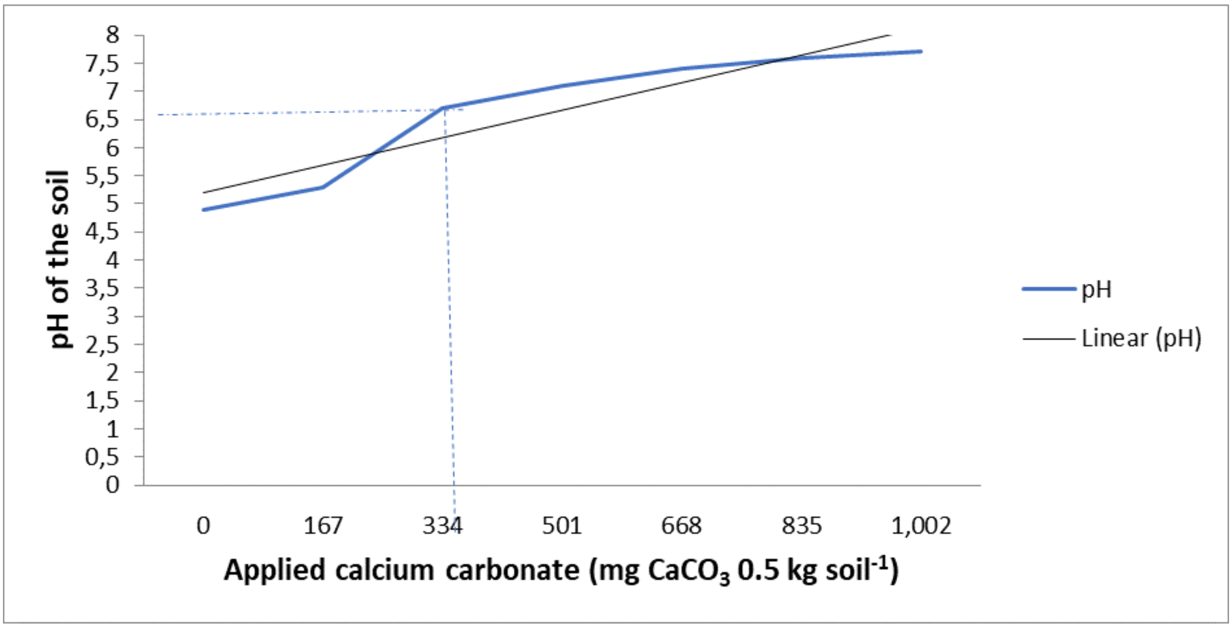

Figure 1: Influence of liming on soil pH (the broken line indicates the selected level of liming for the target pH of the experimental soil).

The relationships between the amounts of $CaCO_3$ applied and the level of extracted available phosphorus were plotted and the best level of $CaCO_3$ to raise the available phosphorus was determined (Figure.3.2).

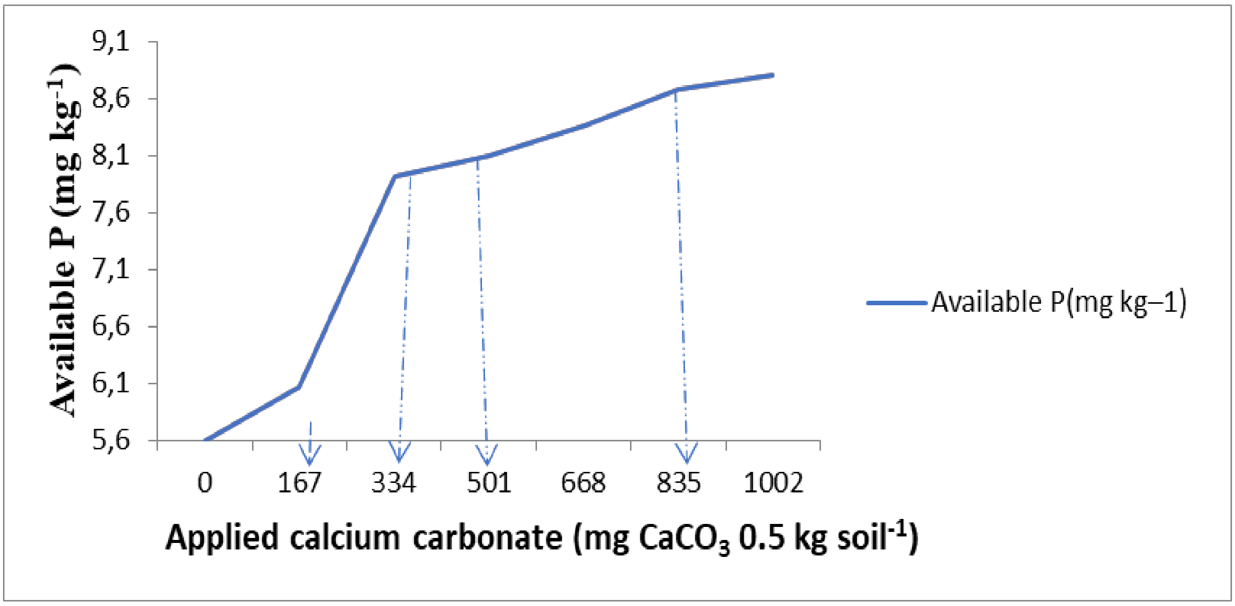

Figure 2: Influence of liming on available P level (broken lines indicate amounts o f P chosen for treatment ofthe experimental soil).

According to OLSEN et al. (1954), the level of $CaCO_3$ was sufficient to raise the available phosphorus from low to mediumwas found to be 334 mg $CaCO_3$ 0.5 kg^{-1} (Figure 2). Therefore, the amount of calcium carbonate that was sufficient to raise the pH of the soil to 6.5 was selected for liming the experimental soil. The rate is equivalent to 2 tonne ha^{-1} is assuming 89% purity of lime, 20 cm plough depth, and 1.15 g cm^{-3} soil bulk density.

Growth Parameters

Leaf area, plant height, and number of branches per plant

Application of lime, varieties, and their interactions significantly ($P \leq 0.001$) affected the leaf area, plant height, and number of branches per plant of faba bean plants. Varieties such as local, Dosha, Gebelcho, and Bobicho required the highest rate of lime (8 g pot^{-1}) to attain the widest leaf area and tallest plant height. This could be associated with the phenomenon that the application of lime considerably increases the pH of the soil, in which the beneficial *Rhizobium* bacteria proliferates to fix an adequate amount of nitrogen for crop growth (MESFIN 2007). On the other hand, for all the above four varieties, the lowest values of leaf area, plant height, and the number of branches per plant were obtained in response to nil application of lime per hectare, followed by the application of 3 g pot^{-1}.

The leaf area of the local, Dosha, Gebelcho, and Bobicho varieties obtained at 6 t ha^{-1} lime applications exceeded the leaf areas of the same varieties produced at nil rate of lime application by 118%, 63%, 32%, 11%, and 48%, respectively. The values of plant height obtained at 8 g pot^{-1}lime application exceeded the plant height obtained at the nil rate of lime application for the local, Dosha, Gebelcho, and Bobicho varieties by 17%, 11%, 10%, 11%, 19%, and 19%, respectively. The number of branches per plant obtained at 8 g pot^{-1}lime application exceeded the number of branches per plant obtained at nil rate of lime application for the local, Bosha, Gebelcho, and Bobicho varieties by an equal amount of about 100% (Table 3).

Table 3. Interaction effect of variety and lime rates on growth of faba bean in SodoZuria district, Southern Ethiopia in 2019 cropping season.

Faba bean variety	Lime rate ($gpot^{-1}$)	Plant height (cm)	Leaf area (mm^2)	Number of branches per plant
Local	0	69.50dc	4.95de	1.00b
	3	75.50b	6.42c	1.83a
	5	68.83d	7.81b	1.90a
	8	81.50	10.81a	1.96a
Dosha	0	74.50bc	5.44d	1.17b
	3	74.95bc	6.42c	1.10b
	5	81.50a	8.37b	1.83a
	8	82.50a	8.86ab	1.94a
Gebelecho	0	74.48c	5.22d	1.00b
	3	75.71b	7.25bc	1.99a
	5	78.50ab	5.79cd	1.70b
	8	82.53a	6.91bc	1.83a
Tumsa	0	69.50dc	5.22d	1.19b
	3	81.70a	9.17a	2.00a
	5	75.50b	7.60bc	2.00a
	8	83.00a	5.79cd	1.17b
Bobicho	0	69.83dc	5.23d	1.00b
	3	74.83bc	9.73a	2.00a
	5	81.94a	7.73b	1.67a
	8	82.49a	1.00b	2.00a
LSD (5%)		5.53	2.08	0.47
CV (5%)		3.46	12.79	13.98

Means of each variable in a column and row followed by the same letter are not significantly different at P = 0.05 according to Fishers Protected LSD tes.

However, the response of the Tumsa variety to the lime application was quite different from the responses of the other four aforementioned varieties such that this variety required as low as 3 g lime pot^{-1} to produce the widest leaves, the tallest plants, and the most numerous branches per plant (Table 3). This result signifies that liming alone may not be the only factor contributing to increased plant height in faba beans. In addition, the result clearly indicates that the local, Dosha, Gebelcho, and Bobicho varieties required much more lime than the Tumsa variety to produce plants with the widest leaves, the tallest plant heights, and plants with the most numerous branches. Thus, the Tumsa variety is relatively tolerant to soil acidity than the other four varieties in terms of the abovementioned growth variables.

The low values of leaf area, plant height, and the number of branches per plant obtained at nil rate of lime applications testify to the problem of soil acidity, which results in critical deficiencies of N, P, K, Ca, Mg, Zn, and Mo, thereby limiting the overall growth and production of legumes (FAGERIA 2002). It is known that soil acidity causes severe chemical imbalances due to toxic levels of exchangeable Al, Mn, and hydrogen (H) (MESFIN 2007). In line with this suggestion, ENDALKACHEW et al. (2019) indicated that faba bean plants treated with 7.2 t lime ha−1 had 56.8% more branches than plants that were not treated with lime. Furthermore, KIFLEMARIAM & FREDERICK (2017) showed a significant variation in leaf area among faba bean varieties in response to the lime rates.

Root Morphology

Root number and length

The application of lime significantly (P<0.001) affected the root number and length per plant. However, the main effects of variety, as well as the interaction of lime with variety, did not affect the number of roots per plant.

The absence of varietal effects on root growth may be attributed to the similarity of the test varieties in root morphological traits. However, the application of lime significantly affected root growth Increasing the rate of lime application from nil to 3 g pot^{-1} increased the number of roots produced per plant by about 33%, while it increased root length by about 35%. Beyond this rate of lime, no significant change occurred in root growth. This indicates that the non-treated soil is too acidic for roots to proliferate and grow in length possibly. Because of aluminum toxicity and applying this rate of lime may have increased the soil pH to the level that was already tolerable for the faba bean plants to grow by proliferating their roots. Particularly, the availability of P and K, in turn, might have led to more partition of assimilates to root growth which enables exploration of wider soil volumes by the plant to absorb nutrients (FAGERIA et al. 2011). This postulation is consistent with the suggestion of FEKADU (2018) that the application of lime reduced soil acidity and increased the availability of nutrients (MEKONNEN et al. 2014). Consistent with this postulation, ENDALKACHEW et al. (2019) suggested that the availability of P increased and hastened the root growth of faba bean. In line with this result, ABEBE & TOLERA (2014) reported that the application of lime increased the average root length of faba bean plants by about 44% over plants not treated with lime.

Number of root nodule per root

The application of lime significantly (P<0.01) affected the number of root nodules produced per plant. However, the main effect of variety did not influence this parameter. Also lime and variety did not interact to influence this root growth parameter.

Similar to the effect it had on root number and length, increasing the rate of lime from zero to 3 g pot^{-1} increased the number of root nodules produced per plant by about 38%. Above this rate of lime application, there was no significant increment in the number of root nodules produced per plant. The increase in the number of root nodules in response to the increasing rate of lime application upto 8 g pot^{-1} signifies that the acidity of the original soil was already ameliorated at this rate of lime application, which resulted in enhanced growth of root nodules (Table 4). The increased number of root nodules per plant may be associated with enhanced availability of phosphorus in particular, which becomes drastically deficient in such soils. This suggestion is corroborated by FEKADU (2018) and MEKONNEN et al. (2014) who reported that application of lime reduced soil acidity and increased the availability of nutrients.

Yield and Yield Components Parameters

Aboveground biomass

The variety, lime rate, and their interaction significantly (P<0.01) affected the production of aboveground dry biomass.

Increasing the rate of lime application did not significantly increase the aboveground biomass of all faba bean varieties tested except the Tumsa and Bobicho varieties. Thus, increasing the rate of lime from nil to 3 g pot^{-1} increased the aboveground biomass yield of the Tumsa variety by about 34%. However, beyond this rate of lime, the variety did not respond in terms of aboveground biomass yield. This indicates Tumsa variety attained its maximum aboveground biomass yields already at 3 pot^{-1} lime application. While the Bobicho variety responded for 5 g pot^{-1} then 3 g pot^{-1} lime application rate (Table 4). These results indicate that these two varieties are in fact limited to growing sufficient biomass yield by the strong soil acidity, which needs amendment by liming to enhance growth. On the other hand, the biomass yield of local, Dosha, and Gebelecho varieties was not affected by the lime application. At nil rate of lime application, these varieties produced the aboveground biomass yield that was in statistical parity with the aboveground biomass yields obtained from its response to the application of all rates of lime ranging from 3 to 8 g pot^{-1} (Table 4). This indicates that aboveground biomass production of local, Dosha, and Gebelecho varieties was unaffected by soil acidity; and relatively tolerant to strong soil acidity.

Table 4. Effect of variety and lime application on root morphology of faba bean bean in SodoZuria district, Southern Ethiopia in 2019 cropping season.

Variety	Number of root per plant	Root length (cm) per plant	Number of nodule per root
Local	8.57	11.43	34.88
Dosha	8.36	11.15	34.42
Gebelcho	8.29	11.23	34.08
Tumsa	8.49	11.32	34.63
Bobicho	8.65	11.63	36.13
LSD (5%)	NS	NS	NS
CV (5%)	15.33	15.01	12.31
Lime rate (g pot^{-1})			
0	6.82b	9.10b	26.30b
3	9.06a	12.28a	36.17a
5	9.20a	12.27a	38.30a
8	8.81a	11.75a	38.53a
LSD (5%)	0.88	1.15	5.24
CV (%)	15.33	15.01	12.31

Means of each variable in a column of the same letter are not significantly different at P = 0.05 according to Fishers Protected LSD test.

Overall, the Tumsa variety responds to the lime application and shows improved biomass production, whereas the other varieties do not respond well to this method of treating soil acidity. This may be attributed to differences in the genetic constitution of the varieties. The results also indicate that the biomass productivity of faba bean crop on acidic soil is variety-dependent This suggestion is consistent with the results of KIFLEMARIAM & FREDERICK (2017) who reported that lime application enhanced the biomass yield of faba bean depending on the genetic constitution of the genotypes planted. Consistent with this result, for example, ABEBE & TOLERA (2014) also reported that improved faba bean variety Dagagaresponded to the lime application and produced 23% more aboveground biomass yield than the control treatment only when the lime rate reached as high as 6 t ha^{-1}lime.

Number of seeds per pod

The number of seeds per pod of faba bean significantly ($P < 0.05$) responded to the main effect of lime rates and the interaction of lime rate by varieties. However, it was not significantly influenced by the main effect of varieties.

The results showed that increasing the rate of lime application increased the number of seeds produced per pod across the tested varieties except that of the Bobicho variety. However, the varieties differed in the vigor at which they responded to the increasing rate of lime. Thus, Tumsa and Gebelcho varieties attained their maximum number of seeds per pod already at the lime application rate of 3 g pot^{-1}. However, Dosha and Gebelcho varieties required the application of an 8 g lime pot^{-1} to attain their maximum numbers of seeds per pod (Table 5). However, the number of seeds per pod produced by the Bobicho variety at a nil rate of lime was high and statistically parity with the number of seeds per pod produced by the variety at all rates of the increased lime application (Table 5). This shows that this variety is relatively more tolerant to soil acidity than the other varieties.

The increases in the number of seeds per pod in response to lime application indicate that liming ameliorates soil acidity and improves the availability of nutrients in the soil for uptake by plant roots and improved growth and productivity. The differences observed among the faba bean varieties in the magnitude of production of seeds per pod in response to the lime application may be attributed to differences in the genetic constitution of the varieties as suggested by KIFLEMARIAM & FREDERICK (2017). Similar to the response of the crop in biomass yield, this result indicates that the response of the crop to lime in terms of the number of seeds produced per pod is also variety-sensitive.

Table 5. Interaction effect of varieties and the rate of lime application on yield and yield components of faba bean in SodoZuria district, Southern Ethiopia in 2019 cropping season.

Faba bean variety	Lime rate (gpot^{-1})	AGM (g pot^{-1})	NSPP	GY (g pot^{-1})	SY (g pot^{-1})
Local	0	32.08bc	3.33bc	12.84bc	19.24bc
	3	39.16b	4.00b	15.66b	23.5b
	5	40.92ab	4.17ab	17.66ab	23.26ab
	8	32.08bc	4.33ab	16.84ab	15.24a
Dosha	0	35.42b	3.66b	14.16b	21.26b
	3	38.34b	4.00b	15.34b	23b
	5	42.92ab	4.33ab	17.16ab	25.76ab
	8	42.5ab	4.81a	17.00ab	25.50ab
Gebelecho	0	37.92b	4.00b	15.16b	22.76b
	3	41.84ab	4.33ab	17.16ab	24.63ab
	5	40.00b	4.17ab	16.00b	24.00b
	8	42.92ab	4.50ab	17.16ab	25.76ab
Tumsa	0	35.84b	4.00b	14.34b	21.50b
	3	47.92a	4.83a	19.16a	28.76a
	5	45.00ab	4.67ab	18.00ab	27.00ab
	8	40.42ab	4.33ab	20.50a	19.92ab
Bobicho	0	39.58b	4.17ab	15.84b	23.74b
	3	35.74b	3.67b	14.66b	21.08b
	5	49.16a	5.00a	19.66a	29.50a
	8	44.16ab	4.50ab	17.66ab	26.50a
LSD (5%)		11.08	2.6	4.40	6.70
CV (5%)		15.22	14.51	16.15	15.10

Means of each variable in a column and row followed by the same letter are not significantly different at P = 0.05 according to Fishers Protected LSD test, AGBM= Above Ground Biomass, NSPP =Number of seed per pod, the mean result share the same latter not significantly varied.

Seed yield per plant

Seed yield per faba bean plant was significantly (P <0.01) affected by the main effects of variety, lime application as well as their interaction. Increasing the rate of lime application significantly increased the seed yields of all five varieties tested. However, the vigor of the response of the varieties to lime application in terms of seed yield varied significantly. Thus, the local variety, Dosha variety, and Bobicho variety did not respond to increasing the rate of lime application from nil to 3 g pot^{-1}. However, when the rate of lime was increased further from nil to 5 g pot^{-1} and above, the seed yields of all these three varieties increased significantly. However, the grain yields of Tumsa and Gebelcho varieties increased significantly already at the lime rate of 3 g pot^{-1}, indicating that increasing the lime rate above this rate was not necessary for improving grain yields obtained from these two faba bean varieties. Thus, the two varieties attained their highest grain yields already at a lime rate that was half the rate required by the other varieties to attain their optimum grain yields. Increasing the rate of lime from nil to 3 g pot^{-1} increased the grain yield of the Tumsa variety by about 34% and that of the Gebelcho variety by 13% (Table 5).

The results indicate that the Tumsa variety and Gebelecho variety were relatively tolerant to the strongly acidic condition of the soil in the pots compared to the other three varieties. This is because the two faba bean varieties attained their highest grain yields in response to the application of only 3 g pot^{-1} lime ha^{-1}. This means that the application rate of lime-increased faba bean yields is dependent on varietal differences, which may be attributable to the genetic constitution of plants. The relatively lower response of the other three varieties to the application of lime in seed yield may indicate that these varieties may require lime rates equal to or higher than 5 g pot^{-1} to increase the pH to higher threshold values for better growth and yield. This result may also indicate that the three varieties are less responsive to lime application and may not be economical for cultivation in acidic soils in the study area compared to the Tumsa and Gebelcho varieties.

Stover yield per plant

Variety, lime rate, and their interaction significantly (P<0.01) affected stover yield per plant.

Increasing the rate of lime application increased the stover yield per plant across four of the tested varieties. Thus, increasing the rate of lime from nil to 3 g pot^{-1} increased stover yields of the local, Dosha, Gebelcho, and Tumsa varieties by about 22%, 8%, 10%, and 34%, respectively. Increasing the rate of lime beyond 3 g pot^{-1} decreases stover yields of the four faba bean varieties (Table 5). However, the higher stover yield for the Bobicho variety was obtained by increasing the rate of lime beyond 3 g pot^{-1} (Table 4). This shows that this variety is relatively more intolerant to soil acidity than the other varieties.

The increase in seed in stover yields in response to the increased lime application may be attributed to possible mitigation of the soil acidity and enhanced availability of nutrients in the soil for enhanced growth and uptake by plants and increased biomass production. The differences observed between the local, Dosha, Gebelcho, and Tumsa varieties on one hand and the Bobicho variety on the other hand in stover yield may be attributed to genetic differences. Consistent with this postulation, GOBENA et al. (2019) reported a higher stover yield for the Local faba bean variety than improved ones as a result of genetic differences in the Bilbilo District.

CONCLUSION

The results of this study have demonstrated that the response of faba bean to the lime application was variety-dependent. It was found that the varieties varied in the vigour of response they showed to lime application. Bobicho variety attained its maximum biomass yield without any lime application whereas the other three varieties and the local cultivar required the application of 3 g lime pot^{-1} (2 t ha^{-1}) to attain their maximum aboveground biomass yield. However, in terms of seed yield, it was the improved Gebelcho and Tumsa varieties that performed best by attaining their maximum seed yields in response to the application of 3 g lime pot^{-1} (2 t ha^{-1}). All the other varieties attained their maximum seed yields in response to the application of 5 g lime per pot^{-1} (4 t ha^{-1}). Therefore, cultivating Tumsa variety and Gebelcho varieties were found to respond vigorously to a lime application already at the lowest rate, indicating by applying lime rates that are more economical than the rates required for cultivating the other varieties. This implies that there is potential to select faba bean varieties that can tolerate soil acidity for the comical production of the crop in the strongly acidic soil of the study area.

REFERENCES

ABEBE Z. & TOLERA A. 2014. Yield Response of Faba bean to Fertilizer Rate, Rhizobium Inoculation and Lime Rate at Gedo Highland, Western Ethiopia. Global Journal of Crop, Soil Science and Plant Breeding 2: 134-139.

ATA. 2019. Agriculture Transformation Agency. Status of soil resources in Ethiopia and priorities for sustainable management. GSP for Eastern and Southern Africa, ATA, Addis Abeba, Ethiopia.

ANDERSON W. 2013. Increasing seed yield and water use of wheat in a rainfed Mediterranean type environment. Australia Journal Agricultural Research 43: 1-17.

ASEFA K et al. 2010. Characterization of acid and salt tolerant rhizobial strains isolated from faba bean fields of Wollo, Northern Ethiopia. Journal of Agricultural Science and Technology 12: 365-376.

BERHANU D. 1980. The physical criteria and their rating proposed for land evaluation in the highland region of Ethiopia. Land Use Planning and Regulatory Department, Ministry of Agriculture, Addis Ababa, Ethiopia.

BIRRU A. 1979. Agricultural Experiment Management Manual, Part III. Institute of Agricultural Research. Addis Abeba.

BOUYOUCOS G. 1951. A Recalibration of the Hydrometer for Making Mechanical Analysis of Soils. Agronomy Journal 43: 434-438.

BREMNER J. 1965.Total Nitrogen. In: BLACK CA. (eds.) Method of soil analysis. Part 2. Madison: American Society of Agronomy. p. 119-178.

CSA. 2018. Centeral Stastical Agency. Area and production of major crops: the federal democratic republic of Ethiopia central statistical agency agricultural sample survey: volume I. Addis Abeba, Ethiopia.

CSA. 2019. Centeral Stastical Agency. Area and production of major crops: the federal democratic republic of Ethiopia central statistical agency agricultural sample survey: volume I. Addis Abeba, Ethiopia.

COTTENIE A. 1980. Soil and plant testing as a basis of fertilizer recommendations. FAO soil bulletin 38/2. Rome: Food and Agriculture Organization of the United Nations.

CROWFORD T et al. 2008. Solving Agricultural problems related to Soil Acidity in Central Africa's Great Lakes Region: CATALIST Project Report. Albama: IFDC.

DEGIFE A. & KIYA A. 2016. Evaluation of Faba Bean (*Vicia faba* L.) Varieties foryield at Gircha Research Center, Gamo

Gofa Zone, Southern Ethiopia. Scholarly Journal of Agricultural Science 6:169-176.

ENDALKACHEW F et al. 2019. Yield of faba bean (Vicia faba L.) as affected by lime, mineral P, farmyard manure, compost and rhizobium in acid soil of lay gayint district, northwestern highlands of Ethiopia. Agriculture and Food Security 7: 1-11.

EIAR. 2018. Ethiopian Institute of Agricultural Research. Faba bean production manual. Addis Ababa: Ethiopia.

FAGERIA N. 2002. Nutrient management for sustainable dry bean production in the tropics. Commun Soil Sci Plant Anal 33: 1537–75.

FAGERIA N et al. 2011.Growth and mineral nutrition of field crops.3ed. USA: CRC Press.

FEKADU M. 2018. Progress of Soil Acidity Management Research in Ethiopia. Adv Crop Sci Tech 6: 377.

FAO. 2006. Food and Agriculture Organization. Plant nutrition for food security: A guide for integrated nutrient management. Rome: FAO, Fertilizer and Plant Nutrition. Bulletin 16.

FAO. 2008. Food and Agriculture Organization of the United Nations. FAO fertilizer and plant nutrition bulletin: Guide to laboratory establishment for plant nutrient analysis. Rome: FAO. 203 p.

FAO. 2013. Food and Agriculture Organization. Plant Production and Protection Division. Good Agricultural Practices for greenhouse vegetable crops. Rome: FAO. 63p.

FAO. 2016. Food and Agriculture Organization. Food and Agriculture Organization of the United Nations. FAOSTAT homepage. Available at http://faostat3.fao.org/home. Date accessed: 21 January 2020.

FAOSTAT. 2019. Food and Agriculture Organization Corporate Statistical Database. Available at http://www.fao.org/faostat/en/#data/QC. Date accessed: 31 January 2022.

FRENCH B & WHITE P. 2005. Soil and environmental factors affecting pulse adaptation in Western Australia. Australia Journal of Agricultural Research 50: 375-387.

GEMECHU K et al. 2016. Reflections on Highland Pulses Improvement Research in Ethiopia. Ethiopian journal of agricultural sciences 9: 17-5

GENANEW T et al. 2012. Farmers soil management practices and their perceptions to soil acidity, at Ankesha District of Awi Zone, Northwestern Ethiopia. Libyan Agriculture Research Center Journal International 3: 64-72.

GETACHEW A. 2018. Soil Fertility and Crop Management Research on Cool-season Food Legumes in the Central Highlands of Ethiopia Ethiop. J. Agric. Sci. 28: 95-109.

GETAHUN M & ABERE M. 2019. Faba Bean (Vicia faba L.) Yield and Yield Components as Influenced by Inoculation with Indigenous Rhizobial Isolates under Acidic Soil Condition of the Central Highlands of Ethiopia. Ethiop. J. Agric. Sci. 29: 49-61.

GOURLEY C. 1999. Potassium. in "Soil analysis: an interpretation manual". Melbourne: CSIRO Publishing. p. 229-246.

GOBENA N et al. 2019. Influence of Phosphorus Fertilizer Rates on Yield and Yield Components of Faba Bean (*Viciafaba* L.) Varieties in Lemu Bilbilo District, Southeastern Ethiopia. International Journal of Plant & Soil Science 28: 1-11.

GRAHAM P. 2016. Stress tolerance in Rhizobium and Bradyrhizobium and nodulation under adverse soil conditions. Canadian Journal of Micro 38: 475-484.

HAZELTON P & MURPHY B. 2007. Interpreting soil test results: What do all thenumbers mean? 2.Ed. CSIRO Publishing. 152p.

HIRPA L et al. 2013. Response to Soil Acidity of Common Bean Genotypes (Phaseolus vulgaris L.) Under Field Conditions at Nedjo, Western Ethiopia. Sci. Technol. Arts Res. J 2: 03-15.

ICARDA. 2010. International Center for Agricultural Research in the Dryland Areas. Ethiopia and ICARDA Ties that Bind. No. 29. Aleppo: ICARDA.

JENSEN E et al. 2010. Faba bean in cropping systems. Field Crops Research 115: 203-216.

KIFLEMARIAM Y & FREDERICK L. 2017. Screening of faba bean (*Vicia faba* L.) accessions to acidity and aluminium stresses. Peer J. 5: 224-240.

KIFLEMARIAM Y et al. 2019. Association of Shoot and Root Responses to Water Deficit in Young Faba Bean (*Vicia faba* L.). Front. Plant Sci. 10: 1063.

KOPKE U & NEMECEK T. 2010. Ecological services of faba bean. Field Crops Res 115: 217–33.

LANDON J. 1991. Booker Tropical Soil Manual: A hand book for soil survey and agricultural land evaluation in the Tropics and Subtropics. Essex: Longman Scientific and Technical.

LUKAS V et al. 2015. Enhanced biological N_2 fixation and yield of faba bean (Vicia faba L.) in an acid soil following biochar addition: dissection of causal mechanisms. Plant Soil 395: 7–20.

MEKONNEN A et al. 2014. Effect of integrated use of lime, manure and mineral P fertilizer on bread wheat (Triticum aestivum) yield, uptake and status of residual soil P on acidic soils of Gozamin District, north-western Ethiopia. Agriculture, Forestry and Fisheries 3: 76-85.

MEKONNEN A et al. 2020. Effects of Lime, Manure and Kitchen Ash Application on Yield and Yield Components of Faba Bean (*Vicia faba*L.) on Acidic Soils of Gozamin District. Journal of Plant Sciences 8: 17-28

MESFIN A. 2007. Nature and Management of Acid Soils in Ethiopia. Addis Abeba, Ethiopa.MoARD (Minstry of Agriculture and Rural Development). Addis Ababa: Crop Development. Issue No.3.

MESFIN K et al. 2020.Fertility Status of Acid Soils under Different Land Use Types in Wolaita Zone, Southern Ethiopia**.** Applied and Environmental Soil Scienc 4: 335-356.

MESFIN T. 2020. Impacts of Soil Acidity on Growth Performance of Faba bean (Viciafaba L.) and Management Options. Academic research journal 8: 2360-7874.

MULISSA J & FASIL A. 2014. Effects of Acidity on Growth and Symbiotic Performance of Rhizobium leguminos arumbv. viciae Strains Isolated from Faba Bean Producing Areas of Ethiopia. Sci. Technol. Arts Res. J. 3: 26-33.

MURAGE EW et al. 2000. Diagnostic indicators of soil quality in productive and non-productive smallholders' fields of Kenya's Central Highlands. Agriculture. Ecosystems and Environment 79: 1–8

MURPHY H. 1968. A report on fertility status and other data on some soils of Ethiopia. Experimental Station Bulletin No. 44. Stillwater: Collage of Agriculture, Oklahoma State University. 551p.

MYLAVARAPU, R. 2009. UF/IFAS extension soil testing laboratory (ESTL) analytical procedures and training manual. Circular 1248, Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida

OLSEN S et al. 1954. Estimation of available P in soils by extraction with NaHCO3.USDA Cir. 939.US. Washington: Government printing office.

QIAN Z et al. 2018. Cinnamic Acid Inhibited Growth of Faba Bean and Promoted the Incidence of Fusarium Wilt. Plants 23: 26-33

ROWELL D. 1994. Soil Science; Methods and Application, Longman Scientific and Technical. Essex: Longman Group UK Ltd. 350p.

SERHAT O et al. 2007. The Quantitative Effect of Temperature and Light on Growth, Development and Yield of Faba Bean (Vicia Faba L.). International Journal of Agricultural Research 2: 765-775.

SHANKA D et al. 2018. Phosphorus Use Efficiency of Common Bean Cultivars in Ethiopia. Communications in Soil Science and Plant Analysis.

SINGH A et al. 2012. Improvement of faba bean (Viciafaba L.) yield and quality through biotechnological approach: a review. African Journal of Biotechnology 11: 15264-15271.

SAS. 2004. Statistical Analysis System Institute. SAS/STAT user's guide. Proprietary software version 9.00. Cary: SAS Institute.

SUN Q et al. 2008. Phosphorus enhances Al resistance in Al-resistant Lespedeza bicolor but not in Al-sensitive L. cuneataunder relatively high Al stress. Annals of Botany 102:795-804.

TADELE B et al. 2016. Response of Faba Bean (Vicia Faba L.) to Phosphorus Fertiliizer and Farm Yard Manure on Acidic Soils in Boloso Sore Woreda, Wolaita Zone, Southern Ethiopia. Food Science and Quality Management 53: 2224-6088.

TAMENE T & TADESE S. 2019. Registration of a Faba Bean variety named *Gora.* East African Journal of Sciences 7: 133-136.

TADESE T et al. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. Addis Ababa: ILCA.

WALKLEY, A. and Black, C. 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.

WONDAFRASH M et al. 2019. Quantifying Yield Potential and Yield Gaps of Faba Bean in Ethiopia Ethiop. J. Agric. Sci. 29: 105-120.

YASIN G & ESRAEL K. 2017. Participatory on Farm Evaluations and Selection of Improved Faba Bean (Vicia faba L.) Varieties in Four Districts of South Ethiopia. Adv Crop Sci Tech 5: 2329-8863.

ZHENG S. 2010. Crop production on acid soils: overcoming aluminum toxicity and phosphorus deficiency. Annals of Botany 106:183–84.