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Review paper

Impacts of Soil Acidity on Growth Performance of Faba bean (*Vicia faba* L.*)* and Management Options

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Soil acidity is a major production constraint of crops in general and faba bean in particular in the highlands of Ethiopia. It has a proven impact on the growth performance of leguminous crops. It aggravates disease susceptibility and reduces plant vigour which leads to yield reduction in faba bean. Thus, this paper is reviewed with the objective to assess the impacts of soil acidity on growth and performance of faba bean and its management options. As crop production is decreasing improving the productivity of marginal areas like soil acidity is a major priority as a demand of food and raw materials are increasing rapidly. This can be achieved by using different soil acidity management options: lime application, use of soil acidity tolerant crops and breeding for soil acidity stress tolerance. Liming is a potential option for sustainable soil managements than other options for restoring soil health and fertility despite the amount required and unaffordable cost for low income farmers. Since, cultivated crops vary in their tolerance to soil acidity, choice of crops with better yield potential under stress environments is very important for economic reasons because use of tolerant varieties remains the first option and low cost. As wide diversity exists among faba bean landraces for different stresses like, chocolate spot, orobanche and water logging tolerant/resistance, the chance of getting soil acidity stress tolerance genotypes through breeding is not scanty. Therefore, selecting and developing acid-tolerant cultivars might be a sustainable approach for better growth and productivity of faba bean on acid soils which is eco-friendly and economically feasible alternative as a management option.

Keywords: Acid-tolerant, Faba bean, Lime and Soil acidity

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INTRODUCTION

Faba bean (*Vicia faba* L.) is among the oldest crops in the world (Singh *et al.,* 2013) and one of the earliest domesticated food legumes in the world, probably in the late Neolithic period (Torres *et al.,* 2006). In Ethiopia faba bean is mainly cultivated in the mid to high altitude areas, characterized with elevations of 1800-3000 m.a.s.l. (Mussa and Gemechu, 2006). Its production is totally rain-fed on nitosols and cambisol type of soils (Gemechu and Mussa, 2002) and currently on vertisol (Tadele, 2019). The crop has a potential to substitute meat in many parts of the world where there is demand for non-animal protein sources (Crépona *et al.*, 2010). So, it is an important source of protein for subsistence farmers in the developing countries like Ethiopia (Asnakech *et al.,* 2016). Furthermore, it is a source of cash to the farmers and foreign currency to the country and serves as "break" crop to pests and restores soil fertility when grown in rotation with cereals and other crops (Tewodros *et al.,* 2015; Asnakech *et al.,* 2016; Gemechu *et al*., 2016; Tadele, 2019). Despite its diverse benefits and availability of more than 30 high yielding improved varieties (Tadele, 2019), in Ethiopia the national average yield of faba bean 2.11 t ha^{-1} (CSA, 2017/18) has remained very low compared to Egypt and United Kingdom 3.47 and 3.83 t ha^{-1}, respectively (FAOSTAT, 2018). The average yield of faba bean becomes decreasing due to its susceptibility to biotic and abiotic stresses (soil acidity and others) (Gemechu *et al*., 2016).

Soil acidity is a significant problem in tropical and subtropical regions (Bordeleau and Prevost, 1994). It is a serious threat to crop production in Ethiopia that strong soil acidity affects 28% of the entire country and 43% of the agricultural land mostly in the highlands of Oromiya, Amhara and Southern Nation Nationalities and Peoples region (Tegbaru, 2015). Soil acidity limits the productivity of legumes (Fageria *et al*., 2012). Currently, it is among the major production limiting factors of faba bean in Ethiopia (Endalkachew *et al*., 2018; Mesfin *et al.,* 2019).

The soils of western highlands of Ethiopia are categorized as moderate to strongly acidic and reduces yield of faba bean (Abebe and Tolera, 2014). Improving the productivity of acid soil is major priority as a demand of food and raw materials are increasing rapidly. This can be achieved by adding limestone to the soil (Maheshwari, 2006). The use of lime is a potential option for sustainable management soils than other options for restoring soil health and fertility. It is an effective and widespread practice to improve crop yields on acid soils and it make the soil environment better for leguminous plants and associated microorganisms as well as increase concentration of essential nutrients by raising its pH and precipitating exchangeable aluminum (Kisinyo *et al*., 2012).

Study on soil acidity problems and response to lime application have been done in some part of the country. It is proved that soil acidity has a great impact on the growth and performance of leguminous crops. Impact assessment of soil acidity on performance of faba bean is very important to design remedial measures. To organize information on soil acidity stress tolerance of faba bean and soil management options is very important. Therefore, this revirew was done with the objective to assess the impacts of soil acidity on growth and performance of faba bean and its management options.

Genetic Resources of Faba Bean

Knowledge of genetic diversity is valuable for germplasms conservation, individual, population, variety or breed identification. Since International Center for Agricultural Research in the Dry Areas (ICARDA) has global mandate on faba bean, it houses 9320 germplasm accessions of faba bean in its Gene Bank (Maalouf, 2011), China Institute of Crop Science 5229 and Ethiopia Biodiversity Conservation and Research Institute (EBCRI) has 1208 germplasm accessions (Anonymous, 2009).

Genetic diversity can be introduced at different levels in different ways which might encompass inter-varietal, intra-varietal, inter-parental and inter-specific diversities (Gemechu *et al*., 2012). Selection and improvement of crops through breeding to ensure the food security needs the genetic resource as a basic material. The genetic variation among genotypes of various legume crops is being vastly eroded as the modern cultivars are replacing the traditional cultivars over large areas across the world (Duc *et al*., 2010). On the other hand, the genetic diversity is threatened for breeding the crops for future generations due to the destruction of wild relatives of the cultivated crop species (Wang *et al*., 2012). Therefore, to reduce genetic vulnerability, breeding for specific adaptation instead of wide adaptation, systematic spatial and temporal gene arrangement, use of inter-specific varietal mixtures and integration of horizontal and vertical resistances have been suggested as best solutions (Gemechu *et al*., 2012).

Agro-biodiversity is the most important component of plant genetic resources, which exists in the primitive forms of cultivated plant species and landraces, obsolete and modern cultivars, weedy types, wild species, genetic stocks and breeding lines (Kumar *et al.,* 2011). The existence of genetic diversity of faba bean is reported from morphological characterization of faba bean accessions collected from different regions of Ethiopia (Gemechu *et al.,* 2005). Likewise, molecular study using SSR markers of Ethiopian faba bean germplasms collections showed the presence of high genetic diversity (Asnakech, 2014). This information implies the existence of genetic diversity in Ethiopian faba bean genotypes.

Importance and Production Potential of Faba Bean

Faba bean is used as a source of protein in human diets, as fodder and a forage crop for animals (Maalouf, 2011). It plays a significant role in soil fertility restoration as suitable rotation crop by fixing atmospheric nitrogen; thereby result in savings for smallholder farmers from less fertilizer use (IFPRI, 2010). Therefore, it is a very valuable legume crop that contributes to the sustainability and diversification of cropping systems through improving soil health, decreasing disease, insect pest and weed buildup (Jensen *et al*., 2010). It is also grown for green manure production or as a rotation crop with cereals (McVicar *et al.,* 2013). Ethiopian farmers are also aware of the role of faba bean and widely use in rotation with cereals (Gemechu *et al*., 2016). From the economic perspective, it is a source of cash to the farmers and foreign currency to the country (Tewodros *et al.,* 2015; Asnakech *et al.,* 2016; Gemechu *et al*., 2016).

Generally, faba bean seed recognized to have good nutritional value and has long history of uses in human foods or animal feeds (Duc *et al.,* 2010; Jensen *et al*., 2010). This is the result of its valuable and digestible major seed components, starch and proteins. Faba bean genotypes display a large genetic variability for starch, protein and fiber contents (Duc *et al.,* 2011). It is confirmed that faba bean is rich in protein and other nutritional contents (Crépona *et al*., 2010; Fekadu *et al*., 2012). In Ethiopia, faba bean is the main source of protein for the poor high land inhabitants those who cannot afford to purchase animal products (Mesfin *et al.,* 2019).

Faba bean is produced throughout the world in different agro-ecological regions in which China followed by Ethiopia, Australia, United Kingdom, France and Egypt are the leading producers (FAOSTAT, 2018). Ethiopia is the leading producer of faba bean in Africa and the crop is the leading pulse category of the country in area coverage and production and grown on about 437,106.04 ha of land (27.34%) of the total area covered by pulse and about 0.92 million ton (30.95%) of the total pulse production. It is produced in different regions of the country, Oromia, Amahara, Tigray, Southern Nation Nationalities and Peoples Region, and Benishangul-Gumuz regional states. Oromia region is the largest producer in the country (0.48 million ton) followed by Amhara region (0.28 million ton). The two regions together share about 83.20% of the country's faba bean production (CSA, 2017/18).

Production Constraints of Faba Bean

In spite of its diverse benefits and high production, the productivity of faba bean has remained very low in Ethiopia 2.11 t ha^{-1} (CSA, 2017/18) compared to Egypt and United Kingdom 3.47 and 3.83 t ha^{-1}, respectively (FAOSTAT, 2018). The major production constraints of faba bean that attributed to lower productivity in Ethiopia associated with stresses from the adverse conditions for crop growth attributed by biotic and abiotic stresses, coupled with poor crop management practices (Gemechu *et al.,* 2016) and inherent biological limitations of the crop which leads to flower abortion (Mussa and Gemechu, 2006).

The biotic factors include diseases, like chocolate spot (*Botrytis fabae*), rust (*Uromyces Vicia fabae*), black root rot (*Fusarium solani*), foot rot (*Fusarium avenaceum*) and "faba bean gall'' (*Olpidium viciae*), insects, African bollworm (*Helicoverpa armigera*), bean bruchids (*Callosobruchus chinensis*) and broad-leaved weed, grass weeds, and parasitic weed (*Orobanche crenata*). Whereas, abiotic factors comprise waterlogging, moisture stress, soil acidity and poor cultural practices (Gemechu *et al.,* 2016). Presently, soil acidity associated with low nutrient availability is one of the major production constraints of faba bean in the highlands of Ethiopia (Endalkachew *et al*., 2018, Mesfin *et al*., 2019). Soil acidity has a dramatic impact on most chemical and biological processes of a crop (Jensen *et al*., 2010).

Soil Acidity as Production Constraint of Faba Bean

Soil acidity is a worldwide problem and it associated with high availability of Al^{3+} besides the simple matter of low pH (Atemkeng *et al.,* 2011). It is one of the major soil chemical constraints which limit agricultural productivity in the mid and highlands of Ethiopia (Workneh, 2013). It becomes a serious threat to crop production in most highlands of Ethiopia in general and in the western part of the country in particular (Hirpa *et al*., 2013). It affected 28.1% of the entire country and 43% of the agricultural land (Tegbaru, 2015). Thus, soil acidity is one of the environmental factors that limit plant production as it associates with increased Aluminium and Manganese toxicity and limit calcium and Phosphorus up take by plants (Hungria and Vargas, 2000).

Soil acidity is a natural process with major difficulties on plant growth. Soil with pH value between 6.6 and 7.3 are considered as neutral, 5.6 to 6.5 moderately acid and below 5.5 strongly acid (Alemu *et al*., 2016). As soils become more acidic, particularly when the pH drops below 4.5, it becomes increasingly difficult to produce food crops; because the supply of most plant nutrients decreases while aluminum and a few micronutrients become more soluble and toxic to plants (Harter, 2007). It has a dramatic impact on most chemical and biological processes of crops (Jensen *et al*., 2010). Moreover, it hinders legume production more than any other crops as it affects the complex nitrogen fixation process (Graham, 1992). As faba bean is acknowledged sensitive to soil acidity and its sensitivity to acid soils limits the usage of faba bean in some cropping systems.

Impacts of Soil Acidity on Faba Bean Production

Soil acidity is a major constraint for agricultural producers in tropical and subtropical regions and limit legume productivity (Bordeleau and Prevost, 1994). Acid soil infertility is a result of severe chemical imbalance caused by toxic levels of exchangeable aluminum, manganese and hydrogen ions. This resulted in parallel critical deficiency of available nitrogen, phosphorus, potassium, calcium, magnesium, zinc and molybdenum which limits the growth and production of legumes (Fageria, 2002). Phosphorus plays an important role in legumes symbiotic N_2 fixation and formation of seeds and fruits. Its deficiency results not only low yields but also poor quality seeds and fruits (Fageria, 2009). It has been reported that faba bean requires high P for energy expenditure for nodule formation (Kopke and Nemecek, 2010). However, P fixation takes place in acid soils thereby its availability becomes too low.

Soil acidity is the major constraints of faba bean production in the highlands of Ethiopia (Endalkachew *et al.,* 2018). Most legumes prefer pH > 5.0 at least in a depth of 20cm and layers below 5cm adversely affect root growth, nodulation, plant vigour and N-fixation potential of acid-sensitive pulses (Burns *et al.,* 2017). Faba bean grows best in soils with pH ranging from 6.5 to 9.0 (Jensen *et al.,* 2010) and poorly perform at a pH values of 5 or less (French & White, 2005). Soils with pH < 5.5 result retardation of plant growth and low yields of faba bean due to low P availability and deficiency of Ca and Mg or toxicity of Al, Fe and Mn (Dodd and Mallarino, 2005). However, some accessions remain productive in soil with pH values as low as 4.5 (Singh *et al.,* 2012). Poor soil fertility associate with low soil pH which adversely affects the growth and yield of faba bean (Endalkachew *et al.,* 2018). Toxicities of Al and Mn provide a hostile environment to root growth (Ouertatani *et al*., 2011). In Ethiopia, lower yield of faba bean (0.68 to 1.03 t ha^{-1}) than national average (1.52 t ha^{-1}) were reported at pH 5.1 on different varieties (Degife and Kiya, 2016). Due to soil acidity a mean yield reductions of 32.34% were recorded on faba bean genotypes at soil pH of 4.49 - 4.96 in the central highlands of Ethiopia (Mesfin, 2019).

Acid soil expose faba bean to greater chocolate spot infection (increase disease susceptibility) and reduce plant vigour thereby reduce yield (Getachew *et al*., 2005; Elliot and Whittington, 2009). Response of faba bean genotypes to soil acidity at early stage was diverse; some genotypes showed less than 3% reduction in root length, whereas other genotypes showed significant reductions 30-40% hindrance in root growth. Specifically, Dosha, NC 58 and Kassa were tolerant to acidity showing less than 3% reduction in taproot length (Kiflemariam *et al.,* 2017). Likewise, acid soil affects root growth, agronomic and yield traits and also increased soil acidity have a deleterious effect on the overall growth of soybean (Michael *et al*., 2011). Faba bean is generally acknowledged as being sensitive to soil acidity and it successfully grows on slightly acidic soils (Chris and Stephen, 2009; Burns *et al.,* 2017). Therefore, soil acidity needs to be ameliorated to create a better growing environment for crop production in general for faba bean in particular.

Management Strategies of Soil Acidity

In order to feed the increasing population from existing natural resources, significant advances are required in the field of agricultural production. Increasing agricultural productivity from the existing arable land in an environmentally friendly manner; however, it's a big challenge for the global agricultural system (Robertson and Swinton, 2005). More specifically, increased efforts are needed to raise crop productivity on marginal lands like acid affected soils by combining crop production, management practices and genetic improvement of crops that are environmental friendly, sustainable and socially acceptable.

To improve production and productivity of faba bean in soil acidity problem areas, different strategies needs to be implemented: use of soil acidity tolerant genotypes (fitting genotypes to environments) for sustainable production, using soil management practices (fitting environments to genotypes), use of integrated biological (tolerant genotypes) and appropriate soil management practices such as liming. Therefore, in soil acidity problem areas, faba bean production can be increased by growing adapted genotypes to acid soil condition in circumstances where other soil amendment strategies are not readily practical. However, this is not possible until tolerant genotypes are developed.

Soil Amendment (Liming)

Liming acid soil make the soil environment better for leguminous plants and associated microorganisms as well as increase concentration of essential nutrients by raising its pH and precipitating exchangeable aluminum (Kisinyo *et al.,* 2012). The amount of lime needed to achieve a certain pH depends on the pH and the buffering capacity of the soil. The buffering capacity is related to the cation exchange capacity. Soils with a high buffering capacity require larger amounts of lime to increase the pH than soils with a lower buffering capacity (Derib, 2014).

Lime requirement refers to the amount of lime required to neutralize all or part of the acidity in soil from an initial level to a desired or targeted less acid condition. The target level of soil acidity depends both on the soil and crop type. Thus, neutralization of soil acidity involves not only neutralization of H^+ in soil solution but also all or part of the soil's reserve acidity (Eshetu, 2011). A lime requirement test is necessary to determine the correct amount of lime as over-applications may decrease soil productivity. Consequently, on soils having less than pH 5.5 performing a lime requirement tests is necessary for legumes (Mahler and McDole 1987).

A report on faba bean evaluated with and without lime application on acid soil showed that liming significantly influenced all the growth parameters; particularly pronounced for plant height and pod number. Applied lime enhances nutrient use efficiency of both P and K which is reflected by increase in pod per plant. Thus, application of lime and mineral fertilizers together further increase grain yield (Ouertatani *et al*., 2011). Similar studies indicated that significant grain yield increment resulted from neutralization of excess acidity over time with lime (Fuentes *et al*., 2006). Likewise, the effect of Al^{3+} toxicity can be ameliorated by applying P-containing fertilizers (Atemkeng *et al.,* 2011).

Lime is slow acting of long duration and a significant increment in yield is expected in the next planting season (Adane, 2014). Amelioration of acid soils by surface application of lime and other materials is the main commercially available option. However, lime application on surface soil generally does not have a rapid effect in reducing subsoil acidity and mixing lime with subsoil generally not economically feasible (Hynes and Mokolobate, 2001). Some of these options are less effective if cultivars are sensitive to acid soil and either not available to farmers or farmers are poor to purchase the materials (Sun *et al*., 2008). Acid tolerant crop varieties reduce the amounts of lime required (Adane, 2014). The utilization of soil acidity tolerant genotypes is an important strategy in improving bean yields and reducing cost of production (Fageria *et al*., 2012). Therefore, selecting and growing acid-tolerant cultivars might be a sustainable approach for the better growth and productivity of pulse crops on acid soils.

Use of Soil Acidity Tolerant Crops

The use of acid tolerant crops and pasture is a low cost input that is easily adopted and can often change the cost portion to value more favorable for initiating lime use. The choice of crops with better yield potential is obviously important for economic reasons. However, the choice of variety is also an important management strategy to offset acidification and plants that tolerate soil acidity use water through a better root growth (Coventry *et al*., 1997). In Ethiopian, Triticale, Oat and Potato grow on acid problematic areas and considered as acid tolerant crops.

Cultivated crops vary in their tolerance to soil acidity. Therefore, selecting and growing species and variety adaptable to acidic soils is one solution (Scott *et al., 1997*). Study on soil acidity stress tolerance on faba bean is scanty. Nevertheless, wide diversity exists among faba bean landraces for agro-ecological adaptation (French & White, 2005), for biotic and abiotic stress resistance (Khazaei *et al.,* 2013). So far in Ethiopia lime based managements of acid soil were conducted in different location with different crops soybean (Workneh, 2013), haricot bean (Adane, 2014), faba bean (Endalkachew *et al.,* 2018). These authors reported that, the limitation of lime application with its wider utility is that the amount of lime needed per hectare is in tons and the cost also is not affordable by small scale farmers (Workneh, 2013; Adane, 2014; Endalkachew *et al.,* 2018). The use of acid tolerant varieties remains the first option and low cost if the use of lime is beyond the reach of smallholder farmers. Therefore, use of soil acidity tolerant crops in acid prone areas is eco-friendly and economically feasible alternative when considered as a management option.

Breeding Faba Bean Tolerance to Soil Acidity

Faba bean breeding strategy in Ethiopia targets specific adaptation for exploiting genetic potential of cultivars that are responsive to optimum environments and for widely adapting (stable) varieties that consistently perform better under various environments. In addition, breeding for specific adaptation of crop cultivars that can adapt under resource poor environments like soil acidity prone areas is very important (Gemechu *et al.,* 2016). Due to production cost and environmental concerns particularly to the resource-poor farmers do not justify the economics to apply external inputs in faba bean production (Mussa *et al.,* 2008). Thus, the ultimate goal of cultivar development under resource poor environment is to select resistant/tolerant cultivars that have better performance with modest resources demand (Gemechu *et al.,* 2016).

Sources of tolerance to abiotic production constraints of faba bean in Ethiopia such as soil acidity or low soil pH, poor soil fertility and frost have not yet been identified although genetic variability for most of the stresses is expected to exist (Mussa *et al.,* 2008). Breeding success for different biotic and abiotic stresses have been reported in faba bean for chocolate spot disease (Tamene *et al*., 2015; Asnakech *et al*., 2016) and for high moisture stress (water logging) (Mussa *et al.,* 2008) by identifying different materials for sources of tolerance introduced from ICARDA and collected from areas with water logging problem as source of resistance for hybridization. As a strategy of last alternative, where soil pH has fallen to values less than 6.0, plant breeding or biotechnology to improve resistance of plants to acidity is necessary (Conyers *et al.,* 2005). Genetic manipulation of crops is better than continual manipulation of growing environments to improve productivity because of unaffordable production costs by resource-poor farmers to purchase inputs and varietal selection needs to be on target production environment (Gemechu, 2007). Therefore, breeding acid soil tolerant genotypes has to be done in acid prone environments and selection of parents having genes for efficient use under low soil fertility and tolerance to soil acidity stress needs to be identified for use in hybridization for better genetic manipulation.

Previous efforts to identify soil acidity tolerant faba bean genotypes showed that, there were great variation among genotypes with acidity tolerance level ranging from 3% to 40% hindrance in taproot growth at pH 4.5 (Kiflemariam *et al.,* 2017). This information indicates the need to evaluate faba bean genotypes for soil acidity stress tolerance and the chance of getting tolerant genotypes from existing genetic resources.

CONCLUSION

Nowadays soil acidity is a worldwide problem in general and the highlands of Ethiopia in particular. It becomes a major production constraint of crops in general and faba bean in particular. However, the current word population is 7.8 billion and that of Ethiopia is greater than 114 million as of May 2020 based on *worldometer* elaboration of the latest United Nations data. The world population is increasing while arable land is shrinking due to urbanization and low soil fertility. Thus, to feed the increasing population it needs transformation in the field of agriculture either in using modern technologies or using marginal areas like soil acidity prone areas of the world. Thus, improving the productivity of acid soil is a major priority as a demand of food and raw materials are increasing rapidly. This can be achieved by using different soil acidity management options: lime application, use of soil acidity tolerant crops and breeding for soil acidity stress tolerance.

Soil acidity has a proven impact on the growth performance of leguminous crops. It aggravates disease susceptibility of faba bean and reduces plant vigour which leads to yield reduction. Hence, soil acidity management options are very important to create a better growing environment for crop production in general for faba bean in particular. Lime application is a potential option for sustainable soil managements than other options for restoring soil health and fertility despite the high amount of lime required and unaffordable cost for low income farmers. As cultivated crops vary in their tolerance to soil acidity and use of acidity tolerant crops (triticale, oat and potato) are low cost inputs which is easily adopted by farmers and can often change the cost portion incurred for lime use. Thus, choice of crops with better yield potential under stress environments is very important for economic reasons because use of tolerant varieties remains the first option and low cost if the use of lime is beyond the reach of smallholder farmers. As wide diversity exists among faba bean landraces, the chance of getting soil acidity stress tolerance genotypes through breeding is not scanty. Therefore, breeding (selecting and developing) acid-tolerant cultivars might be a sustainable approach for better growth and productivity of pulse crops on acid soils. Generally, use of soil acidity tolerant crops in acid prone areas is eco-friendly and economically feasible alternative when considered as a management option.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interest.

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