ORIGINAL ARTICLE

Screening of Barley Cultivars (*Hordeum vulgare* ssp.*vulgare* L.) for Acid Soil Tolerance Under Greenhouse Condition

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ABSTRACT

Soil acidity has become a serious threat to crop production in most Ethiopian highlands in general and in the western part of the country in particular. A greenhouse experiment was conducted using 16 barley (*Hordeum vulgare* ssp. *vulgare* L.) cultivars grown under lime treated and untreated conditions to evaluate for tolerance to soil acidity and responsiveness to lime. Treatments were arranged in a randomized complete block design with three replications. Results showed that all growth parameters of the test cultivars grown under lime untreated condition were significantly reduced ($P<0.05$) compared to those grown under lime treated soil. Significant differences were observed among the barley cultivars for plant height, leaf number, tiller number, shoot and root weights, root volume, relative yield, phosphorus concentration in plant tissue and total phosphorus uptake under both lime treated and untreated soil conditions. Cultivars such as "Dedero", "Beka", "Shege", "Sabini", "Eh 1847", "HB-42", "Misrach", "Dimtu" and "M-21" had higher relative shoot yield while cultivars such as "Ardu 1260 B", "Ibon 174/03", "HB 1307", "Bekoji-1", "Cross 41/98" and "Holker" had lower relative shoot yield relative to the average. Cultivars "Ibon 174/03" and "Eh 1847" showed higher shoot biomass yield compared to cultivar "Bekoji-1 under lime untreated soil condition. Under lime treated soil condition, the highest shoot biomass yield was obtained for cultivar "Ibon 174/03" and the lowest for cultivar "Holker". Cultivar "Ardu 1260 B" had higher root biomass yield compared to cultivar "Bekoji-1" under lime untreated soil condition, whereas cultivar "Cross 41/98" showed higher root biomass yield compared to cultivar "Sabini" under lime treated soil condition. Cultivars "HB 1307" and "Eh 1847" had higher total P uptake under lime untreated soil condition compared to cultivars "Cross 41/98", "Bahati" and "Bekoji-1". Under lime treated soil condition, cultivars "Cross 41/98" and "Ibon 174/03" had higher total P uptake when compared to cultivar "Beka".

Key words: acid soil tolerance, barley cultivars, lime, relative yield,

INTRODUCTION

Barley (*Hordeum vulgare* L.) , a crop believed to have been cultivated in Ethiopia as early as 300 BC (Zemede, 2002; Martin *et al*., 2006) is the fifth most important cereal crop next to teff, maize, sorghum and wheat (CSA, 2009). Barley is the predominant cereal in the high altitudes areas (>2000 m.a.s.l.). In Ethiopia, low soil fertility and problems of soil acidity in the highlands and diseases and pests pressure throughout the country contributed to the low national average yield of the crop (Paulos, 2001).

It is estimated that about 40.9% of the total arable land of Ethiopia is affected by soil acidity (Abdenna*et al*., 2007; Taye, 2007), which covers 95% of the cropped area. Soil acidity and the associated aluminum (Al) and manganese (Mn) toxicity is one of major challenges across the barley growing regions of Ethiopia (Fite *et al*., 2007). This problem is further aggravated by the continuous use of acid-forming chemical fertilizers like urea and diammonium phosphate (Abebe, 2007). Applications of lime, manure, compost, and other organic fertilizer sources were recommended to cope with the problem of soil acidity (Pandey *et al*., 2007). However, utilization of lime, manure and other organic fertilizer sources had their own technical and or socio economic constraints (Rao *et al*., 1993). When surface soils are amended with lime, it fails to increase the pH of the sub-soil, resulting in restricted root growth and poor plant growth (Rao *et al*., 1993; Abebe, 2007). Limited root growth also increases the vulnerability of plants to drought of even short duration (Foy, 1992). More importantly, resource poor farmers are constrained by unavailability, transport and high cost of these bulky materials (Rao *et al*., 1993). In addition, lime has low mobility and its mechanical incorporation into the subsoil is often difficult for small-scale farmers without tractors and subsoil rippers.

The use of organic matter in the form of manure and compost may make a significant contribution to reduce soil acidity (Wong and Swift, 2003). In countries like Ethiopia, however, animal manure and crop residues have competitive use as fuel and animal feed, respectively, and large-scale use of this option is not common (IFPRI, 2010).

Worldwide, the development of varieties tolerant to soil acidity has been used as a sound alternative to liming, and other management options in crops such as wheat, rice, maize, barley, sorghum and rye (Hede *et al*., 2001; Paterniani and Furlani, 2002; Kochian *et al*., 2005; Portaluppi *et al*., 2010).

Alternative low-cost options of coping with the problem of soil acidity need to be developed in Ethiopia, if farmers in acidic soil areas have to improve yields of barley crop and remain in production. Among these options is the use of cultivars tolerant to soil acidity. Genotypic difference for acid soil tolerance have been reported in many studies such as Garvin and Carver (2003) in barley; Ezeh*et al*., (2007), in cow pea; Foy (1996); Wang *et al*., (2006) and Yang *et al*., (2011) in wheat; Brown and Devine (1980) in soybean; Ligeyo (2007) in maize. Thus, the existence of such genetic variability among crop cultivars in acid soil tolerance is an important opportunity to develop varieties that are suitable for cultivation in acid soils. Therefore, the use of acid soil tolerant cultivars is a better option for resource poor farmers to enhance barley production and productivity on acidic soils. Hence, the present study was conducted with the objective of evaluating barley cultivars for acidic soil tolerance and responsiveness to lime application.

MATERIALS AND METHODS

Location of the study

This study was conducted in the greenhouse of Ambo University. Ambo University is located approximately on latitude 8° 9' North and longitude 37° 8' East. Rainfall pattern at Ambo is bimodal with a mean annual total of 1169.24 mm. The lowest mean monthly temperature of 13°C is usually recorded in August and the highest mean monthly temperature of 25.4°C is recorded in February (Ambo University Meteorological Station).

Experimental treatments and design

The treatments consisted of two lime treatments (with and without lime) and 16 barley cultivars making up a total of 32 treatments laid out in Randomized Complete Block Design with three replications.

Soil Sampling, pH Calibration and Soil Analysis

Soil samples (0-20 cm) were collected from Cheliya district, specifically from acid soil affected kebeles. The collected soil was immediately air-dried and sieved through 2 mm sieve to separate roots from the soil and homogenized. Before treating the experimental soil with lime, the amount of lime required to raise the soil pH to a level suitable for the growth of barley was determined in a separate pre-experiment. Soil pH was measured potentiometrically with a digital pH meter in the supernatant suspension of 1:2.5 soils to water ratio. The electrical conductivity was also measured for the same supernatant suspension using conductivity meter.

Available P in the soil samples was determined following the procedure of Olsen's $NaHCO_3$ extraction method (Olsen *et al*., 1954). Soil organic carbon was determined following the wet digestion method as described by Walkley and Black (1934). Organic matter content was determined from the organic carbon content by multiplying the latter by 1.724. Cation Exchange Capacity (CEC) and exchangeable bases (Ca, Mg, K and Na) were determined by extracting with 1.0 M ammonium acetate (NH_4OAc) solution at pH 7 (Chapman, 1965). The extracts of Ca and Mg ions were determined using Atomic absorption spectrophotometer (AAS) while K and Na were determined by flame photometer. Exchangeable aluminum was determined by Volumetric-KCl Extraction method. Percent Al saturation was calculated from the ratio of exchangeable Al to the CEC. The soil percent base saturation (PBS) was calculated from sum of the basic exchangeable cations (Ca, Mg, K and Na) as the percentage of CEC.

Experimental materials

A pot experiment was conducted to evaluate 16 barley cultivars under both lime treated and untreated soil conditions.

a. Plant material

A total of sixteen different barley cultivars (Table 1) collected from Holleta Agricultural Research Center (Bekoji-1, Ardu 1260B, Beka, Shege, HB-42, Dimtu, Bahati, Misrach, Miscal-21, Cross 41/98, Ibon 174/03, Dedero, Holker, Sabini, HB-1307 and Eh-1847) were used for the study. All cultivars were developed and released by the National Barley Improvement programme of Holleta Agricultural Research Center, Ethiopian Institute of Agricultural Research (EIAR) and are being cultivated throughout barley growing areas of the country.

Table 1: Description of barley cultivars investigated in the experiment

Code of cultivars	Variety name	Origin/Description	Source of seed	Year of release	Row type
1	Bekoji-1				
2	Ardu 1260 B	Landrace selection from Arsi	HARC	1986	Six row
3	Beka	Introduction from France	HARC	1973	Two row
4	Shege	Landrace selection from Arsi	HARC	1996	Six row
5	HB-42	A cross of IAR/H/81/ Comp29 // omp14/20/Cost	HARC	1985	Six row
6	Dimtu	landrace selection from Arsi	HARC	2001	Irregular
7	Bahati		HARC		
8	Misrach	Landrace selection from Arsi	HARC	1998	Six row
9	Miscal-21	Introduction from I CARDA/ CIMMYT and developed at Holetta	HARC	2006	Two row
10	Cross 41/98		HARC		
11	Ibon 174/03		HARC	2003	Two row
12	Dedero	Dominant farmers' variety	HARC		
13	Holker	A cross made at Holetta from Hol. mixed and Kenya Research	HARC	1979	Two row
14	Sabini		HARC		
15	HB 1307	A cross made from Awura gebs-1	HARC	2006	Six row
16	Eh 1847		HARC		

*HARC- Holetta Agricultural Research Center

b. Liming Material

c. Fertilizer material

Nitrogen and phosphorus fertilizers were applied at the rate of 0.24 g N per 3 kg soil and 0.54 g P per 3 kg soil) in the form of urea and TSP, respectively. N fertilizer was applied ½ at planting and ½ at three weeks after planting, while the whole of the phosphorus fertilizer was applied at sowing time.

Sowing

Air-dried, sievedand homogenized soil samples was divided in to two half part was treated with lime at the rate of 10 g/kg soil to bring the soil pH from 5.2 to 6.8 and the rest was left untreated. Three kg of each of these two (lime treated and untreated) soils were filled into plastic pots of 5 kg capacity. Seeds of the barley cultivars were sown into the pots and a uniform amount of nitrogen (N) (0.24 g per 3 kg soil) and phosphorus (P) fertilizer (0.54 g per 3 kg soil) in the form of urea and triple superphosphate (TSP), were applied respectively. Ten barley seeds were sown in each pot and the stands were later on thinned to 5 plants after the seedlings were well established. Throughout the growth period, the pots were watered at field capacity. The plants in each pot were harvested for biomass estimation at 65 days after sowing.

Data Collection

Plant parameters such as plant height, number of leaves per plant, tiller numbers, shoot weights, root weights were measured at 65 days after planting from three randomly selected plants per pot and the average value of three plants was used for statistical analysis. Pconcentration in plant tissue was determined using vando-molybdate yellow-method according to Gericke and Kurmies (1952).Plant total P uptake was calculated as a product of plant dry matter and P concentration in plant tissue.

Statistical Analysis

Data were subjected to analysis of variance using the GLM procedure of SAS software version 9.2 (SAS Institute INC., Cary, USA). Treatment means were compared using tukey test at $\alpha=5\%$ significance level.

RESULTS AND DISCUSSION

Effect of lime application on selected Soil Chemical Properties

Results of the present investigation showed that liming affected soil pH, electrical conductivity, cation exchange capacity, exchangeable bases (Ca, Mg, Na and K), available P, organic carbon and exchangeable Al contents. The pH of lime untreated soil was 5.2 whereas that of lime treated soil was 6.8 (Table 2). This observation is in agreement with the result of Hossner and Juo (1989), who also reported that reclaiming acid soils by agricultural liming material increased the soil pH mainly due to the neutralization of Al ion in the soil solution by the hydroxyl (OH) ion provide by the hydrolysis reaction of the agricultural liming material added to the soils. Soil exchangeable bases such as Ca, Mg, K and Na of lime treated soil increased by 572, 111, 50, and 153 percent over that of lime untreated soil. The CEC of lime treated soil also increased by 39 percent over that of lime untreated soil (Table 2). Effiong*et al.*, (2006) also reported an increase in the exchangeable bases as a result of lime application to soils, which agrees with our observation. The exchangeable Al and its percent saturation were however, highly depressed following lime treatment. The reductions in exchangeable Al and percent Al saturation of the soils following lime application were related to the increased exchangeable bases and soil pH (Table 2). The results clearly indicated that lime application could be used to treat acid soil making it more suitable for crop production.

Table 2: Selected chemical properties of the experimental soil

Soil properties	Lime untreated soil	Lime treated soil
pH	5.2	6.8
Available phosphorus (mg/ kg soil)	11.5	11.8
EC (ds/m)	0.21	0.28
CEC (cmol(+)/kg)	20.3	28.3
Exchangeable Ca (cmol(+)/kg)	3.37	22.63
Exchangeable Mg (cmol(+)/kg)	2.62	5.52
Exchangeable K (cmol(+)/kg)	0.20	0.30
Exchangeable Na (cmol(+)/kg)	0.36	0.91
Al saturation (%)	1.48	ND
Exchangeable Al (meq/100g soil)	0.3	ND

ND – results with less than the method's detection limit

Effect of acid soil stress and lime application on plant height

Plant height significantly differed ($P<0.001$) among the barley cultivars under both lime treated and untreated soil condition. Plant height of the barley cultivars was higher under lime treated than untreated soil condition (Figure 2). Plant height varied from 40.9 cm for cultivar "Dedero" to 20.6 cm for cultivar "M 21" under lime treated, and from 38.9 cm for cultivar "Sabini" to 15.8 for cultivar "Ardu 1260B" under lime untreated condition. Cultivars "Sabini" and "Ibon 174/03" showed significantly longer plant height compared to cultivars "HB-42" and "Ardu 1260B" while all the other cultivars ("Ibon 174/03", "Dedero", "Eh 1847", "Dimtu", "Shege", "Misrach", "HB 1307", "M-21", "Bekoji-1", "Holker", "Cross 41/98", "Bahati", "Beka" and "HB-42") didn't significantly differ from each other in terms of plant height under lime untreated condition (Figure 2A). On the other hand, cultivars "Dedero" and "Sabini" had significantly longer plantheight compared to cultivars "Ardu 1260B", "Shege", "HB 42", "Beka", "Bahati", "Bekoji-1" and "M-21" while the other cultivars ("Sabini", "Misrach", "Cross 41/98", "Ibon 174/03", "Dimtu", "Holker", "Eh 1847"and "HB 1307") didn't significantly differ in terms of plant height under lime treated condition (Figure 2B). The increased plant height of the cultivars underlime treated condition could be ascribed to the ability of lime to neutralize the aciditywith concomitant increase in nutrient availability through better solublization that ultimately brought about better nutrient acquisition and enhanced plant growth. The result in the current study is in agreement with that of Oluwatoyinbo*et al*., (2005) and Achalu (2012), who also reported increased plant height in okra and barley, respectively with the application of lime to acid soils. The relatively shorter plants in the case of lime untreated soil may be attributed to the toxic effect of excess Al and Mn, which might have affected root growth leading to stuntedoverall plant growth.

Effect of acid soil stress and lime application on number of tillers per plant

The number of tillers plant^{-1}significantly ($P<0.05$) differed between cultivars as well as lime treatments. The number of tillers plant^{-1} were higher for plants grown in lime treated soil than for lime untreated soil (Figure 3A and B). Under lime untreated soil condition, the lowest tiller number per plant (3) was obtained for the cultivar "Cross 41/98" whereas the highest tiller number per plant (8) was obtained for the cultivar "Eh-1847" (Figure 3A).For the lime treated soil, the highest tiller numbers per plant (10 and 11) were recorded for cultivars "Ibon174/03" and "HB 1307", respectively whereas the lowest tiller numbers per plant (4 for both) were observed for cultivars "Misrach" and 'Dedero" (Figure 3B). Cultivars "Eh 1847", "Ibon 174/03" and "Dedero", had significantly more tiller numbers plant^{-1} as compared to cultivars "HB-42", "Misrach", "Sabini" "Bekoji-1" and "Cross 41/98" while all the other cultivars (“M-21”, “Holker”, “HB1307”, “Bahati”, “Ardu 1260 B”, “Beka”, “Shege” and “Dimtu”) didn’t significantly differ in terms of tiller number plant^{-1} under lime untreated soil condition (Figure 3 A). On the other hand, cultivars “Ibon 174/03” and “HB 1307” showed significantly higher number of tiller plant^{-1} compared to cultivars “Dedero”, “Misrach” and “Ardu 1260 B” while all the other cultivars (“Bekoji-1”, “M-21”, “Shege”, “Eh 1847”, “Holker”, “Dimtu”, “Cross 41/98”, “Sabini”, “Beka”, “HB-42” and “Bahati”) didn’t differ in terms of number of tillers plant^{-1} under lime treated soil condition (Figure 3B). Generally, lime application increased the number of tillers plant^{-1} and significant difference among cultivars was noticed both under lime treated and untreated soil conditions. In acid soils, the high aluminum concentration might have an inhibitory effect on tillering capacity (Guo et al., 2004) in barley.

Effect of acid soil stress and lime application on number of leaves

The number of leaves plant^{-1} was significantly ($P<0.001$) higher for lime treated soil than for lime untreated soil. The barley cultivars significantly differed in number of leaves plant^{-1} (Figure 4A and B), with cultivar “Holker” and “Dedero" producing the lowest (4) and the highest (7) number of leaves per plant, respectively under lime treated soil condition. On the other hand, cultivars “Sabini” and “Bahati” had the highest leaf number per plant (6 each) whereas “Ardu 1260 B” had the lowest leaf number (4) under lime untreated soil condition Cultivars “Sabini” and “Bahati”, recorded significantly more number of leaves as compared to cultivar “Ardu 1260B”, whereas cultivars “Ibon 174/03”, “Dedero”, “Dimtu”, “HB 1307”, “Cross 41/98”, “Eh 1847”, “Misrach”, “Beka”, “Holker”, “M-21”, “Bekoji-1”, Shege” and “HB-42” didn’t significantly differ in number of leaves per plant under lime untreated soil condition (Figure 4 A). Under lime treated soil condition, cultivar “Dedero”, recorded significantly more number of leaves as compared to cultivar “Holker” while cultivars “Misrach”, “Cross 41/98”, “Sabini”, “Ibon 174/03”, “Bahati”, “HB-42” “HB 1307”, “Beka”, “M-21”, “Ardu 1260B”, “Dimtu”, Shege”, “Eh 1847” and “Bekoji-1” didn’t significantly differ from each other (Figure 4 B). This difference in number of leaves plant^{-1} of cultivars in response to liming was in agreement with the results of Oluwatoyinbo *et al*., (2005), who also reported that the number of leaves of okra increased with lime application. This idea is also in close conformity with the results of Zhang *et al*., (2007), who also reported that soil acidity led to Alinduced leaf necrosis resulting in reduced healthy leaf number. This result is also consistent with the report of Foy (1984), who also observed leaf yellowing and dropping in response to low soil pH and also with that of Wang *et al*., (2006), who stated that soil acidity led to inhibition of leaf growth in barley thus resulting in reduced number of leaves per plant.

Effect of acid soil stress and lime application on shoot growth

Shoot fresh weight significantly ($P<0.05$) differed between lime treated and untreated soils and between cultivars. These parameters were higher for lime treated soil than for untreated soil (Figure 5). The shoot fresh weight significantly differed among the barley cultivars both under lime treated and lime untreated soil condition (Figure 5A and B). The highest shoot fresh weight of 13.5 and 13.3 g $plant^{-1}$ was obtained for the cultivars “Ibon 174/03” and “Eh 1847”, respectively; whereas the lowest shoot fresh weight of 7.3 and 7.8 g $plant^{-1}$ was obtained for the cultivars “Holker” and “Bekoji-1”, respectively. Cultivars “HB 1307”, “Misrach” “Beka”, “Dedero”, “M-21”, “Shege”, “Dimtu”, “HB-42”, “Sabini”, “Ardu 1260 B”, “Bahati” and “Cross 41/98” did not significantly differ in shoot fresh weight under lime untreated soil condition (Figure 5 A). For the lime treated soil, the highest shoot fresh weight of 19.5 g $plant^{-1}$ was recorded for cultivar “Ibon 174/03” whereas the lowest shoot fresh weight of 11.5 and 11.5 g $plant^{-1}$ was observed for cultivars “Sabini” and “Holker”. Cultivars “HB 1307”, “Cross 41/98” “Eh 1847” “Misrach” “Ardu 1260 B”, “Beka”, “M-21”, “Dimtu”, “Bekoji-1”, “Dedero”, “Shege”, “Bahati” and “HB-42” did not significantly differ in shoot fresh weight under lime treated soil condition (Figure 5B).

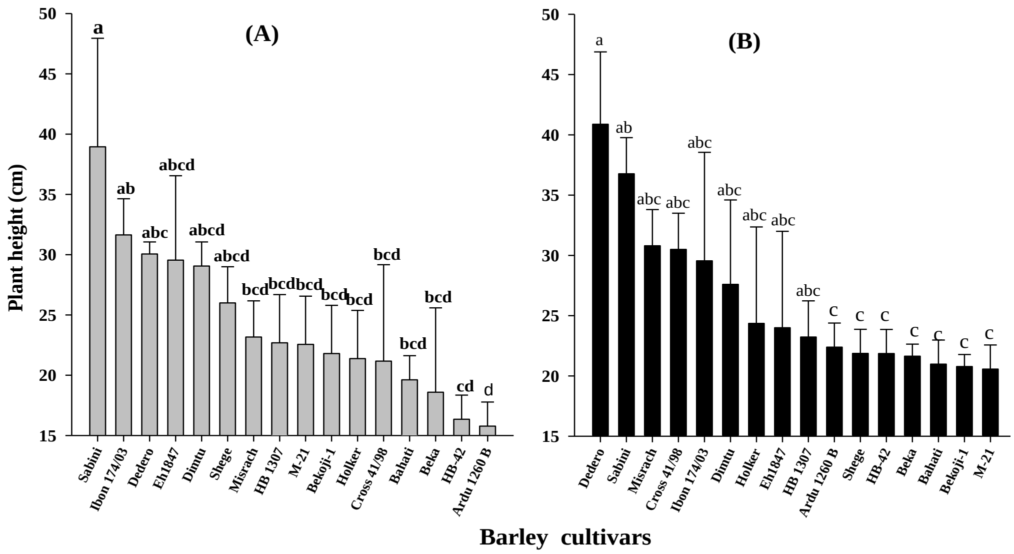

Figure 2: Plant height of barley cultivars under lime untreated (A) and lime treated (B) soil condition

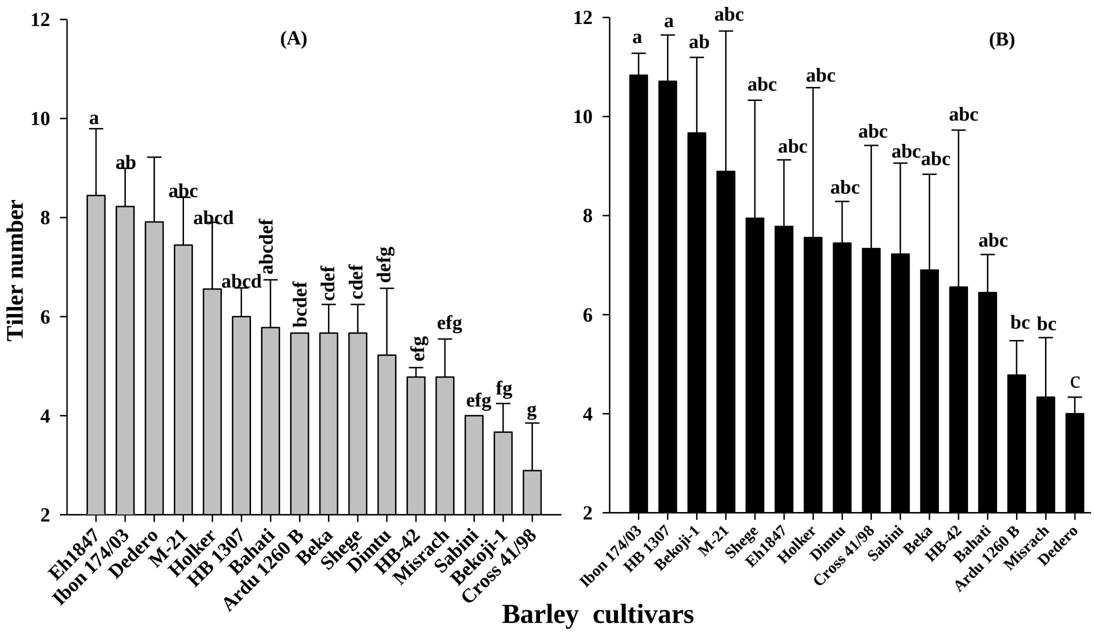

Figure 3: Number of tillers plant^{-1} in barley cultivars under lime untreated (A) and lime treated (B) soil condition

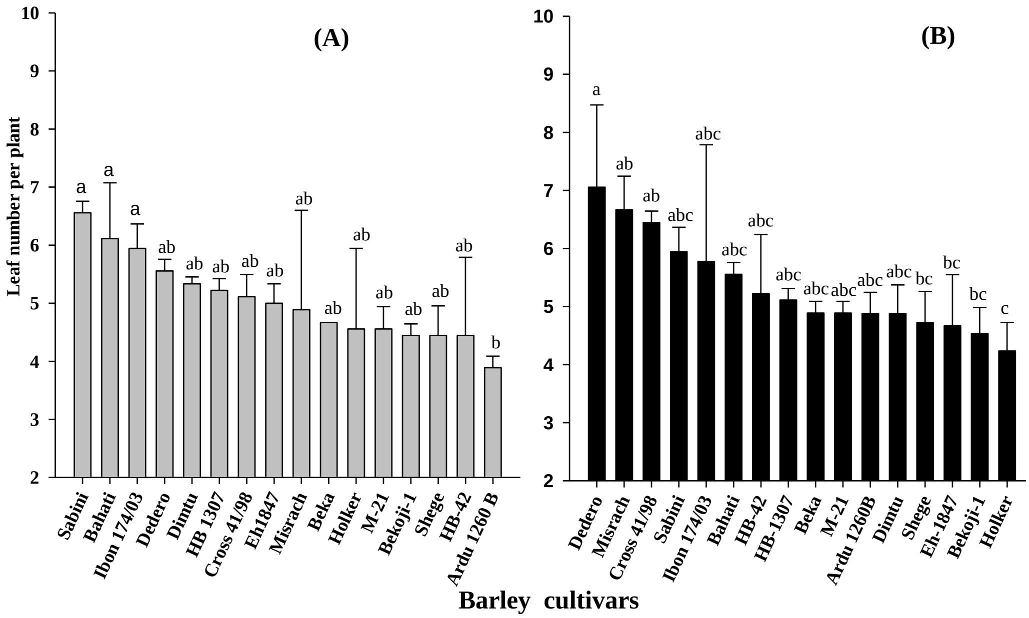

Figure 4: Leaf number of barley cultivars under lime untreated (A) and lime treated (B) soil condition

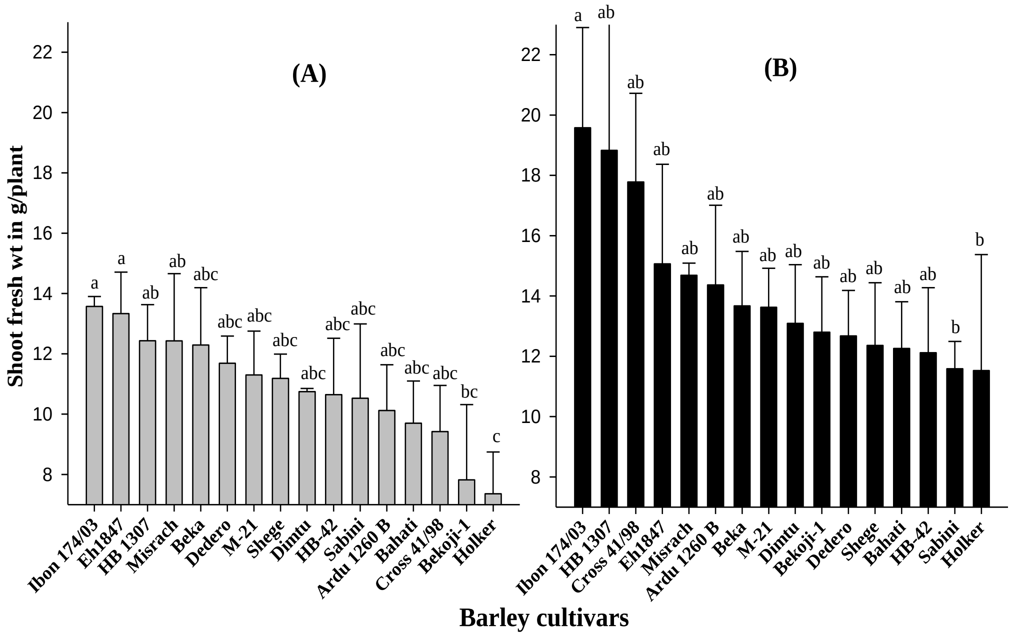

Figure 5: Shoot fresh weights of barley cultivars under lime untreated (A) and lime treated (B) soil condition

The lower shoot fresh weight under lime untreated soil condition compared to lime treated soil condition could be attributed to toxicity and deficiency of some nutrients which are fundamental to plant growth. According to Kochian*et al*., (2004); Foy (1992) and Akinrinde*et al*., (2005), the limiting factors for plant growth in acid soils include the toxic levels of aluminum (Al), manganese (Mn) and iron (Fe), as well as deficiencies of some essential elements, such as phosphorus (P), nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg) and some micronutrients (Mo) which are needed by plants for their proper growth and development. Oguntoyinbo*et al*., (1996) and Curtin and Syers (2001) described that the increment in biomass yield of plants due to liming of acidic soils may be attributed to the reduction in acidity (H and Al) ions and reduction in nutrient deficiency especially of Ca and P. A study by Oluwatoyinbo*et al*., (2005) also indicated the possibility of increasing shoot biomass yield by improving soil acidity through the application of lime. According to the author, the increase in shoot biomass yield as a result of lime application may be attributed to the neutralization of Al, supply of Ca and increasing availability of some plant nutrients like P. Effect of acid soil stress and lime application on root growth Root fresh weight significantly differed between lime treated and untreated soils and it was higher for lime treated soil than for untreated soil ($p<0.001$). The root fresh weight also significantly differed among the barley cultivars both under lime treated and untreated soil conditions (Figure 6). The root fresh weight varied from 10.2 g/plant for cultivar "Ardu 1260B" to 4.1 g/plant for cultivar "Holker" under lime untreated soil condition, and from 13.6 g/plant for cultivar "Cross 41/98" to 6.3 g/plant for cultivar "Sabini" under lime treated soil condition. Cultivar "Ardu 1260B" showed significantly higher root fresh weight compared to cultivars "Bekoji-1", "Sabini" and "Holker", while the other cultivars ("Beka", "Dedero", 'Ibon 174/03", "Eh 1847", "Bahati", "M-21", "HB-42", "Cross 41/98", "Misrach" and "Dimtu") didn't significantly differ in root fresh weight under lime untreated soil condition (Figure 6A).

On the other hand, cultivar "Cross 41/98" had significantly higher root fresh weight compared to cultivar "Sabini", while all the other cultivars ("HB 1307B", "Ardu 1260B", "Bahati", "HB 42", "Ibon 174/03", "Eh 1847", "Shege", "Holker", "Misrach", "Dedero", "M-21" "Beka", "Bekoji-1" and "Dimtu") didn't significantly differ from each other in root fresh weight under lime treated soil condition (Figure 6B). Munns and Fox (1977) also reported that the root growth of soybean cultivars responded differently to acid soil, which supports the present finding. In acid soils, aluminum and manganese concentrations are high and have an inhibitory effect on the root growth (Jayasundra*et al*., 1998). This result is in agreement with reports of Fageria (1985), who also observed differential responses in root growth among rice cultivars to different levels of aluminum toxicity. Al toxicity inhibits root cell division and elongation, thus reducing water and nutrient uptake, consequently resulting in poor plant growth and reduced yield (Ciamporova 2002).The primary effect of Al-toxicity is inhibition of root growth, which eventually results in hampered absorption of water and nutrients (Deborah and Tesfaye, 2003; Kochian*et al*., 2004) and ultimately resulting hampered growth. In this study, difference among the barley cultivars in terms of root growth (root fresh and dry weight and root volume) was observed under lime untreated soil condition compared to lime treated soil. This was in agreement with report of Delhaize *et al*., (1991), who also observed significant inhibitory effect of Al^{3+} on root growth in wheat cultivars. In line with this, Conyers *et al*., (2003) also reported that, amendment of acid soils with lime increased pH and reduced the adverse effects of Al on root growth. Root volume was significantly affected by lime treatment ($P<0.01$). Root volume of the barley cultivars was generally higher under lime treated soil condition than under untreated condition (Figure 7). Root volume also significantly differed among the barley cultivars both under lime treated and untreated conditions ($P<0.001$). Cultivar "Eh1847" and "Dedero" had the highest root volume under lime untreated condition compared to cultivar "Bekoji-1" and "Holker". However, all the other cultivars ("Ardu 1260B", "Beka", "Bahati", "HB 1307B", "HB-42", "Misrach", "M-21", "Ibon 174/03", "Shege", "Cross 41/98", "Sabini" and "Dimtu") didn't significantly differ in root volume under lime untreated condition (Figure 7A). Under lime treated condition, cultivar "Cross 41/98" had the highest root volume (18.3 ml) when compared to cultivars "Bekoji-1", "Sabini" and "Beka", which had root volumes of 8.7 ml, 8.7 ml and 8 ml, respectively. Cultivars "HB 1307B", "HB-42", "Dedero", "Bahati", "Eh1847", "M-21", "Ibon 174/03", "Shege", "Misrach", "Ardu 1260B", "Dimtu" and "Holker" didn't significantly differ in root volume under lime treated condition (Figure 7B).

The variation in root volume among the barley cultivars under lime treated and lime untreated soil conditions indicates that there was a genetic variation among the cultivars in response to lime application in resuming root growth. Since root is the plant organ most affected by Al toxicity, and more specifically the root tip is considered to be the root part most affected by Al toxicity as described by Archambault*et al*., (1997), in acid soil intolerant cultivars such as Bekoji-1 and Holker the root elongation is inhibited thus resulting in reduced root growth and thus, in root volume. Similar to the current investigation, the variability in Al tolerance in crop genotypes in relation to difference in root growth has previously been noted in sorghum (Magalhaes*et al*., 2007), barley (Tamas*et al*., 2006) and maize (Ligeyo, 2007).

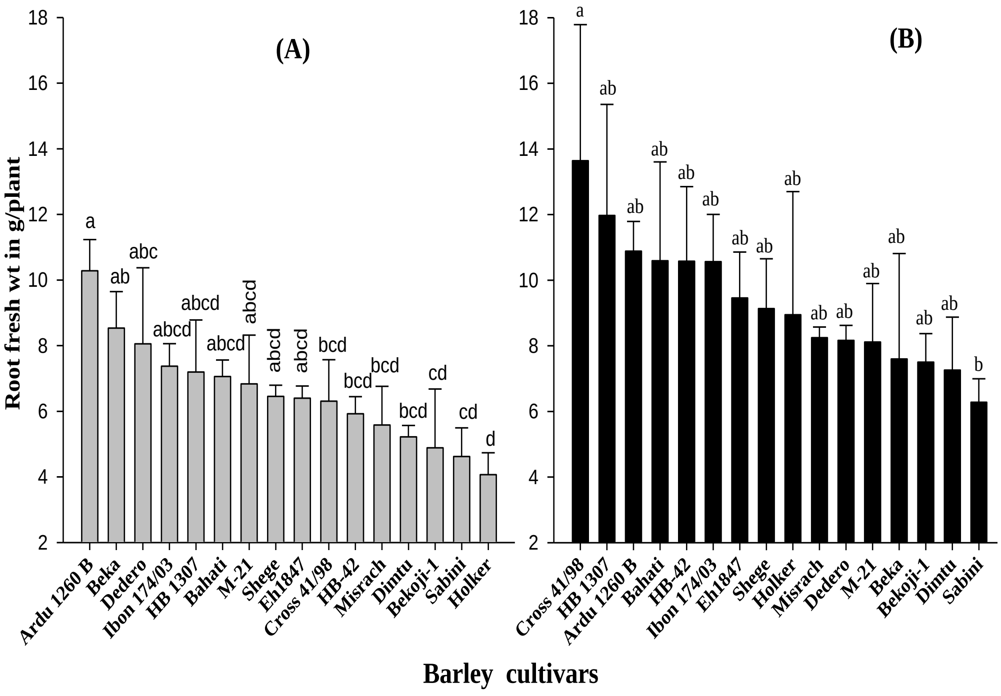

Figure 6: Root fresh weight of barley cultivars under lime untreated (A) and lime treated (B) soil condition

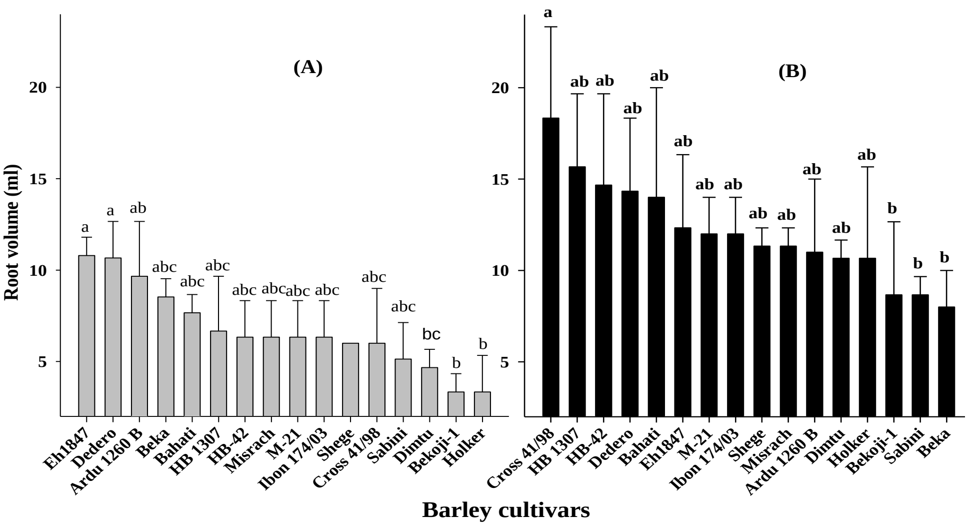

Figure 7: Root volume of barley cultivars under lime untreated (A) and lime treated (B) soil condition

Effect of acid soil stress and lime application on phosphorus concentration in plant tissue

The concentration of phosphorus (P) in plant tissue of the barley cultivars was generally higher under lime treated soil condition than under lime untreated soil condition (Figure 10A and B). P concentration in plant tissue ranged from 1.7 mg/g d.m for cultivar “Bahati” to 2.2 mg/g d.m for cultivar “Shege” for lime untreated soil, and from 1.6 mg/g d.m for cultivar “Beka” to 2.5 mg/g d.m for cultivar “Sabini” under lime treated soil condition.

Cultivar “Shege” and “Dimtu” had higher P concentration of 2.2 and 2.1 mg/gd.m under lime untreated condition when compared with cultivars “Ibon 174/03”, “Misrach” and “Bahati” 1.8, 1.7 and 1.7 mg/g d.m, respectively. All the other cultivars (“HB-42”, “HB 1307B”, “Holker”, “Bekoji-1”, “Sabini” “M-21”, “Ardu 1260B”, “Cross 41/98”, “Beka”, “Eh 1847”, “Beka” and “Dedero”) didn’t significantly differ in P concentration under lime untreated condition (Figure 8A). Under lime treated condition, cultivar “Sabini” and “Holker” had higher P concentration of 2.5 and 2.5 mg/g d.m compared to cultivars “Dedero”, “Ibon 174/03” and “Beka” ,which had the P concentration of 1.7, 1.7 and 1.6 mg/g d.m, respectively. Cultivars “Shege”, “Bekoji-1”, “HB-42”, “Misrach”, "Dimtu", "Ardu 1260B", "Cross 41/98", "HB 1307B", "Bahati", "Eh1847" and "M-21", didn't significantly differ in P concentration under lime treated condition (Figure 8B). In this study, liming increased P concentration in plant tissue due to amendment of soil acidity and a concomitant increase in P availability in the soil. The increase in the P concentration of barley due to liming may be attributed to the increases in soil pH, ultimately improving P availability for plant P acquisition. The P concentration in the plant tissue both under lime treated and untreated conditions were however, quite lowcompared to the optimum P concentration in barley given by Bergmann (1992).

Effect of acid soil stress and lime application on total phosphorus uptake

The total P uptake was generally higher for lime treated soil than for untreated soil (Figure 11A and B). In the present study, total P uptake ranged from 5.1 mg plant^{-1} for cultivar "HB 1307" to 3.2 mg plant^{-1} for cultivar "Bekoji-1" under lime untreated condition; and from 8.1 mg plant^{-1} for cultivar "Cross 41/98" to 4.6 mg plant^{-1} cultivar "Beka" under lime treated condition (Figure 9A and B). Cultivar "HB 1307", "Eh 1847", "Ibon 174/03" and "Dedero", had higher total P uptake of (5.1, 5.0, 4.8 and 4.8 mg plant^{-1}) under lime untreated condition compared with cultivars "Cross 41/98", "Bahati" and "Bekoji-1" which had a total P uptake of 3.6, 3.5 and 3.2 mg plant^{-1}, respectively. All the other cultivars ("M-21", "Shege", "Dimtu", "Beka", "Sabini", "Misrach", "HB-42", "Ardu 1260B" and "Holker") didn't significantly differ in P uptake under lime untreated condition (Figure 9A). Under lime treated condition cultivar "Cross 41/98" and "Ibon 174/03" had higher P uptake (8.1 and 7.6 mg plant^{-1}) compared to cultivar "Beka" , which had the least P uptake of 4.5 mg plant^{-1}, whereas cultivars "Sabini", "Misrach", "HB 1307B", "Ardu 1260B", "Bekoji-1", "Eh1847", "Dimtu", "Holker", "Bahati", "Dedero", "HB-42", "M-21" and "Shege" didn't significantly differ in P uptake under lime treated condition (Figure 9B). The low total P uptake in acid soil untreated with lime is due the strong binding of phosphate ion with Al and Fe oxides, resulting in reduction of P availability and uptake by plants. In this study, liming increased P uptake by improving soil acidity and improving P availability. This result is in line with that of Achalu*et al.*, (2013), who reported increased P up take of barley cultivars due to liming of acid soils.

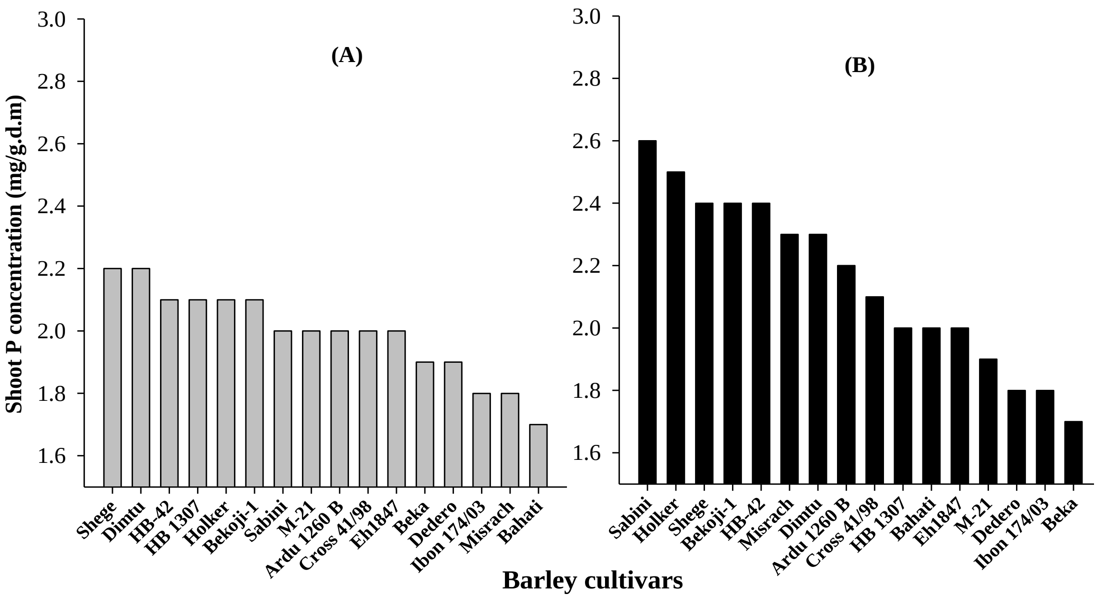

Figure 8: Phosphorus concentration in plant tissue of barley cultivars under lime untreated (A) and lime treated (B) soil condition

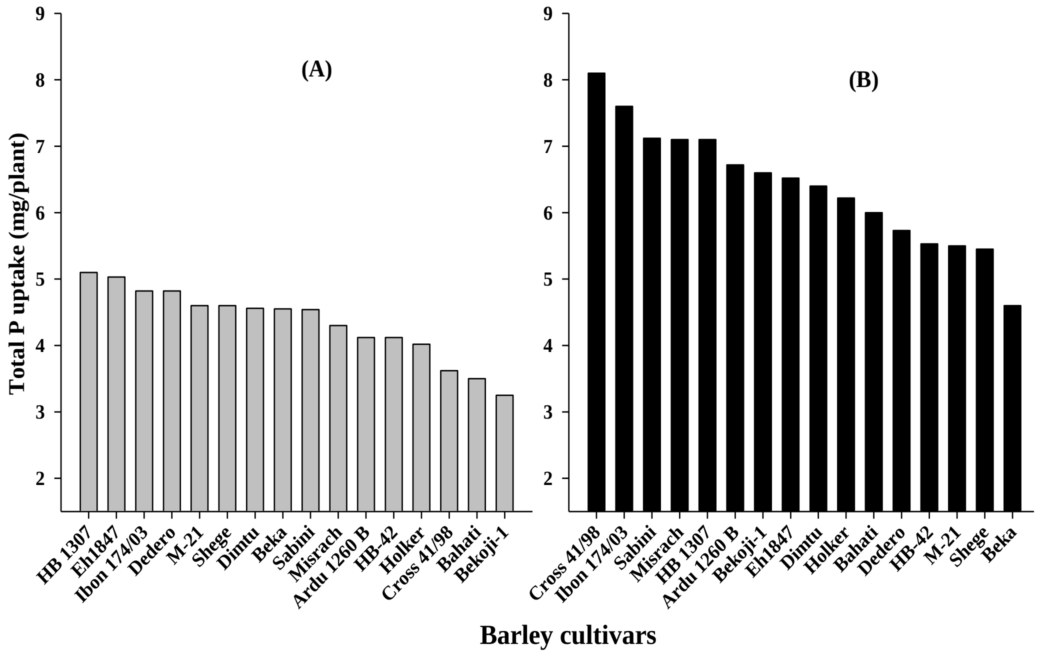

Figure 9: Total phosphorus uptake of barley cultivars under lime untreated (A) and lime treated (B) soil condition

Effect of acid soil stress and lime application on Relative shoot Yield

Relative shoot yield was calculated as the shoot yields, without lime treatment expressed as a percentage of shoot yields for similar treatment under limed condition. In this study, relative shoot yield varied considerably among the barley cultivars ranging between 55% for cultivar "Holker" to 94% for cultivar "Dedero". Cultivars such as "Beka", "Shege", "Sabini", "Eh 1847" and "HB-42" had a relative shoot yield of 92%, 91%, 90%, 90% and 89%, which was higher when compared to cultivars such as "Cross 41/98" and "Bekoji-1" in which a lower relative shoot yield of 55% and 61% were recorded, respectively (Figure 10). Those cultivars which had a relative yield above the average (Dedero, Beka, Shege, Sabini, Eh 1847 and HB-42, Misrach, Dimtu and M-21) can be classified as acid soil tolerant whereas the rest cultivars can be classified as acid soil intolerant.

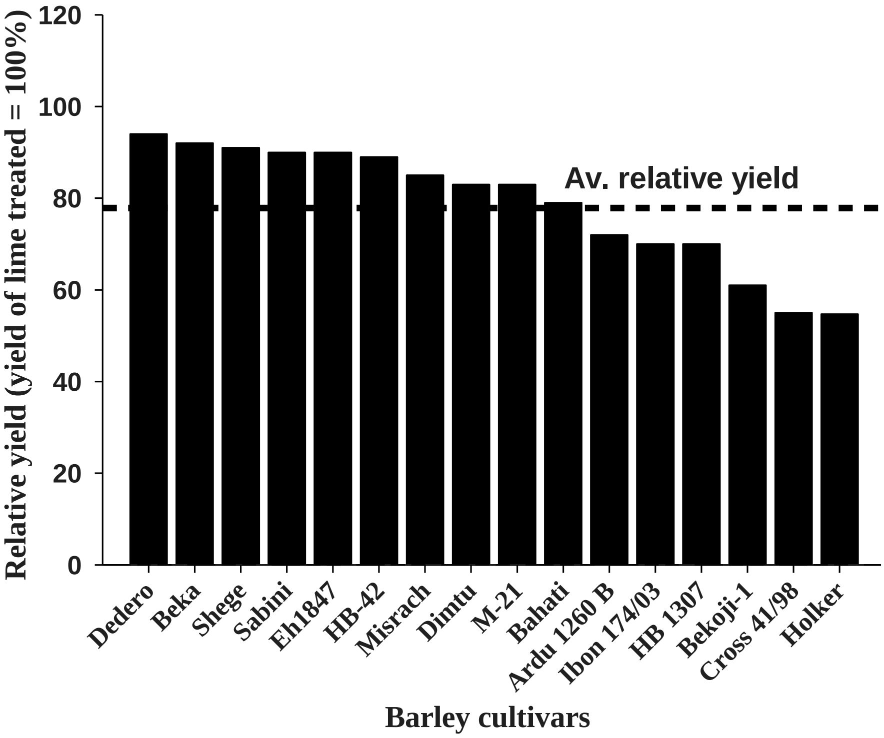

Figure 10: Relative shoot yields of barley cultivars (broken line indicates average relative yields of all the cultivars)

Categorization of barley cultivars into acid soil tolerance and responsiveness to lime application

Root and shoot growth were successfully explored for evaluation of environmental stresses such as soil acidity, salinity, drought, and cold (Malatrasi*et al*., 2002; Tajbakhsh*et al*., 2006). In the present study, significant ($p < 0.001$) genotypic differences existed in terms of root growth and shoot biomass under lime treated and untreated conditions among the 16 barley cultivars investigated. Ma *et al*., (2004) used root and shoot biomass yield as important parameters to rank cultivars for acid soil tolerance at early growth stage. Other parameters such as relative shoot yield have also been used to assess cultivars for acid soil tolerance (Foy, 1996). In the present investigation shoot weight, root weight, root volume, relative yield and total p uptake were considered as reliable parameters for screening the barley cultivars for acid soil tolerance. However, only figures showing categorization was presented only for shoot fresh weight (Figure 13), while for other parameters only summary was presented in Table 5.

Categorization based on shoot and root growth

Based on shoot fresh weight results, cultivars 8, 11, 15 and 16 were acid soil tolerant and responsive to lime application. On the other hand, cultivars 3, 9, 12 and 4 were acid soil tolerant but were not responsive to lime application. Cultivar 10 and 12 were responsive to lime application but were not acid soil tolerant. Cultivars 13, 1, 7, 5, 6 and 14 were both non responsive to lime application and acid soil intolerant (Figure 13). Shoot growth parameters of seedlings were commonly used to evaluate genetic variability and to screen cultivars for acid/ Al tolerance in many crops and forage species (Foy and Murray, 1998; Hede*et al*., 2001 and Dai *et al*., 2011). Thus, in the present study, the same parameters were considered to evaluate the barley cultivars for acid soil tolerance.

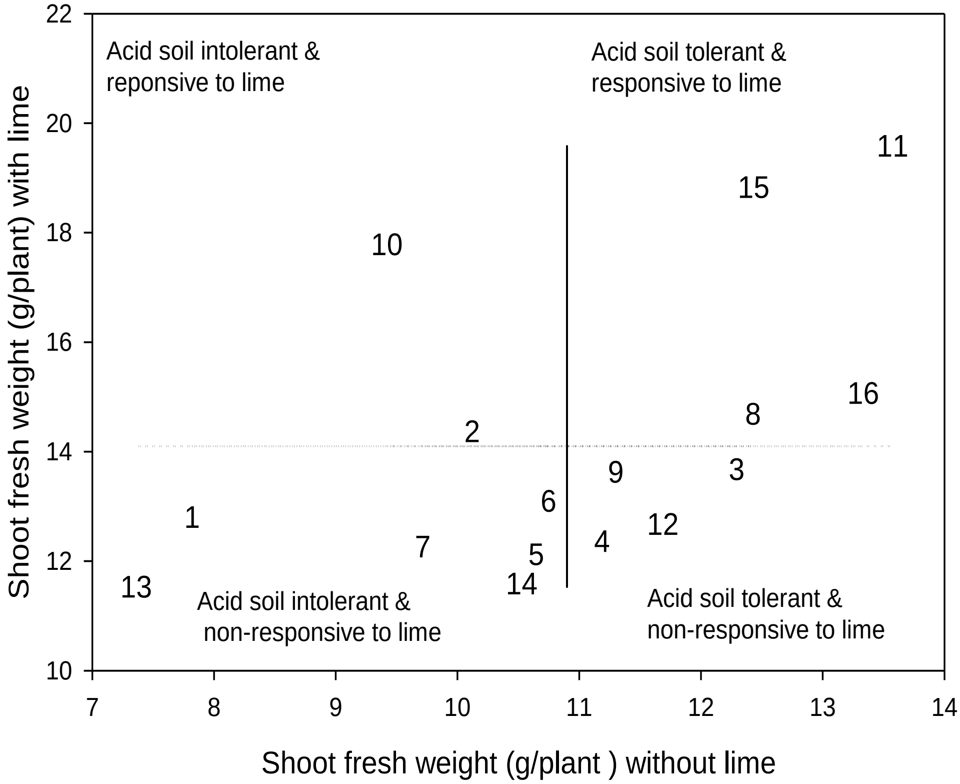

Figure 11: Categorization of barley cultivars for acid soil tolerance and responsiveness to lime application based on shoot fresh weight (*broken lines indicate average shoot fresh weight and under limed and unlimed condition*)

Root growth parameters of crops were also commonly used to evaluate genetic variability and to screen cultivars for acid soil or Al-tolerance in many crops and forage species (Hede*et al.*, 2001 and Dai *et al.*, 2011). Thus, in the present study similar parameters were also additionally used to evaluate the barley cultivars for acid soil tolerance. Cultivars showed difference in root growth (root weight and root volume) under both lime untreated and lime treated soil condition indicating the existence of genetic variation in acid soil tolerance among the barley cultivars. The primary effect of Al stress on plants occurs in roots, such as inhibiting cell division and elongation, followed by distortion and swelling of cells, discoloration and death of root and leaf tips (Hossain*et al.*, 2005). Rengel (1999) reported existence of great variation among wheat cultivars in terms of root growth under acidic soil condition. Under acidic soil condition, active, phytotoxic forms of Al are released to the soil solution to levels that can inhibit root growth and damage roots (Delhaize *et al.*, 1993) which may lead to reduced crop growth and hence yield. Study by Holford (1997) indicated that due to adsorption, and /or precipitation and domination of the organic form of phosphorus in the soil, more than 80% of phosphorus become immobile and unavailable for plant uptake. Especially, as soils become increasingly acidic, important nutrients like phosphorus becomes less available to plants.

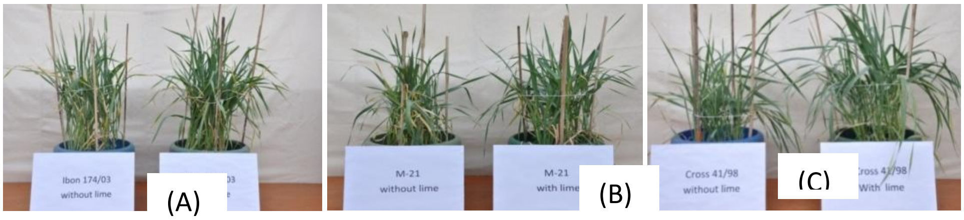

Figure 12: Acid tolerant cultivars (A and B) and a cultivar responsive to lime application (C)

CONCLUSION

Since no any single criteria for screening cultivars for acid tolerance can be used, parameters such as shoot weight, root weight and volume, relative yield and P acquisition capacity were used to screen the barley cultivars altogether in the present study. Cultivars, which met at least three of the criteria were selected as acid soil tolerant or responsive to lime application. Accordingly, as summarized in Table 5, cultivars 3, 4, 11, 12, 14, 15 and 16 were identified as consistently acid soil tolerant while cultivars 10, 11, 15 and 16 were identified as consistently responsive barley cultivars to lime application, as they fulfilled at least three of the screening criteria. In conclusion, those selected acid tolerant barley cultivars can be recommended to be grown directly by farmers who have no or less access for liming materials, whereas the barley cultivars that was responsive to lime application can be recommended to farmers having access to use lime.

Table 5: Summary of barley cultivars categorization for acid soil tolerance and responsiveness to lime application

Plant parameters	Acid soil tolerant barley cultivars	Cultivars responsive to lime application
Shoot biomass yield	3, 8, 9, 11, 15 and 16	8, 10, 11, 15 and 16
Root biomass (root weight and root volume)	2, 3, 7, 12 and 16	5, 7, 10, 15 and 16
Relative yield	3, 4, 5, 12, 14 and 16	1, 2, 10, 11, 13 and 15
Total p uptake	3, 4, 6, 9, 11, 12, 14, 15 and 16	1, 2, 8, 10, 11, 14, 15 and 16
Cultivars meeting most requirement	3, 4, 9, 11, 12, 14, 15 and 16	10, 11, 15 and 16

REFERENCES

Abdenna, D., Negassa, C. and Tilahun, G. 2007. Inventory of Soil Acidity Status in Crop Lands of Central and Western Ethiopia, Utilization of Diversity in Land Use Systems: Sustainable and Organic Approaches to Meet Human Needs, Witzenhausen, 9-11 October.

Abebe, M. 2007. Nature and Management of Acid Soils in Ethiopia. Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia

Achalu, C., Heluf, G., Kibebew, K. and Abi, T. 2012. Response of barley to liming of acid soils collected from different land use systems of Western Oromia, Ethiopia, *Journal of Biodiversity and Environmental science.* 2(3): 57-71.

Achalu, C., Heluf, G., Kibebew, K. and Abi, T. 2013. Changes in Soil Chemical Properties as Influenced by Liming and its Effects on Barely Grain Yield on Soils of Different Land Use Systems of East Wellega, Ethiopia, *World Applied Sciences Journal* 24 (11): 1435-1441.

Akinrinde, E., Iroh, L., Obigbesan, G., Hilger, T., Romheld, V. and Neuman, G. 2004.Tolerance to soil acidity in cowpea genotypes as differentially affected by phosphorus nutritional status.Paper presented at Annual Conference of DeutsheGesellschaftfuerPflanzenernahrung , Goettigen, 1-3 Sept. 2004 and International congress Rhisosphere 2004-Perspectives and challenges-A tribute to Lorenz Hiltner, Munich, Germany, Sept. pp 12-17.

Archambault, D., Zhang, G. and Taylor, G. 1997. Spatial variation in the kinetics of aluminium (Al) uptake in roots of wheat (Triticumaestivum L.) exhibiting differential resistance to Al - Evidence for metabolism-dependent exclusion of Al. *Journal of Plant Physiology* 151: 668 - 674.

Bergmann, W. 1992. Nutritional Disorder of Plants: Development, Visual and Analytical Diagnosis. Gustav Fischer Verlag, Jena, Germany.6

Brown, J. and Devine, T. 1980. Inheritance of tolerance or resistance to manganese toxicity in soybeans.*Agron. J.* 72:898–904.

Central Statistical Authority, 2009. Report on area and production for major crops (Private peasant holdings), Meher season.

Chapman, H. 1965. Cation Exchange Capacity.*In:* Black, C.A. et al., (ed.), Methods of Soil Analysis, Part 2 – Chemical and Microbiological Properties. Am. Soc. Agron., Inc., Madison Wisconsin, pp: 891-901.

Ciamporova, M. 2002. Morphological and structural responses of plant roots to aluminium at organ, tissue and cellular levels.*BiologiaPlantarum*. 45: 161-171.

Conyers, M., Mullen, C., Scott, B., Poile, G. and Braysher, B. 2003. Long-term benefits of limestone applications to soil properties and to cereal crop yields in southern and central New South Wales. *Australian Journal of Experimental Agriculture*. 43: 71-78.

Curtin, D. and Syres, J. 2001. Lime-induced changes in indices of soil phosphate availability, *Soil Science Society of American Journal*. 65: 147-152.

Dai, H., Shan, W., Zhao, J., Zhang, G., Li, C. and Wu, F. 2011. Difference in response to aluminum stress among Tibetan wild barley genotypes. *J Plant Nutr Soil Sc*.174: 952-960.

Deborah, A. and Tesfaye, M. 2003. Plant improvement for tolerance to aluminum in acid soils .A review.*Plant Cell Tiss Org*. 75: 189-207.

Delhaize, E., Higgins, T. and Randall, P. 1991. Aluminum tolerance in wheat: analysis of polypeptides in the root apices of tolerant and sensitive genotypes. Pp 1071-1079

Delhaize, E., Ryan, P. and Randall, P. 1993. Aluminium tolerance in wheat (Triticumaestivum L.) II. Aluminium-stimulated excretion of malic acid from root apices. *Plant Physiol*, 103: 695-702.

Effiong, G., Isirimah, N. and Eshiet, E. 2006. Influence of liming on extractable phosphorus. Growth and Yield of Okra (*Abelmoschus esculentus* (L.) Moench).*Nigerian J. Agric., Food and Environ*.3: 131-134.

Ezeh, K., Omogoye, A. and Akinrinde, E. 2007.Aluminum influence on performance of some cowpea (Vignaunguiculata) varieties on Nigeria Alfisols.*World Journal of Agricultural Sciences*. 3(4): 517-522.

Fageria, N. 1985. Influence of aluminum in nutrient solution on chemical composition in two rice cultivars of different growth stages. *Plant and Soil*.85: 423-429.

Fite, G., Abdenna, D. and Wakene, N. 2007. Utilization of diversity in land use systems: Sustainable and organic approaches to meet human needs. Trope tag, October 9-11, Witzenhausen, Germany.

Foy, C. 1992. Soil chemical factors limiting plant root growth. *In:* Advances in Soil Sciences: Limitations to Plant Root Growth, Vol. 19. Hatfield JL and Stewart BA (Eds), Springer Verlag, New York. 97-149,

Foy, C. 1996. Tolerance of barley cultivars to an acid, aluminum toxic subsoil related to mineral element concentrations in their shoots. *Journal of Plant Nutrition*.19: 1361–1380.

Foy, C. and Murray, J. 1998.Developing aluminium-tolerant strains of tall fescue for acid soils.*J Plant Nutr*.21: 1301 1325

Garvin, D. and Carver, B. 2003.The Role of the Genotype in Tolerance to Acidity and Aluminum Toxicity. In: Rengel Z, editor. *Handbook of Soil Acidity*. New York: Marcel Dekker; pp. 387–406.

Gericke,V.S., and Kurmies, B. 1952. Die KolorimetrischePhosphorsäurebe stimmungmit Ammonium-Vanadat-molybdat und ihreAnwendung in der Pflanzenanalyse. *ZeitschriftfürPflanzenernährung und Bodenkunde*. 59: 235-245.

Guo, T., Zhang, G., Zhou, M., Wu, F. and Chen, J. 2004.Effect of Aluminum and Cadmium toxicity on growth and antioxidant enzyme activities of

Policy Research Institute (IFPRI). Working paper, Washington, USA.Available at www.ifpri.org.Accessed on: 12 April 2011.

Jayasundara, H., Thomson, B. and Tang, C. 1998. Response of cool season grain legumes to soil abiotic stresses. *Advances in Agronomy,* 63: 77-151.

Kochian, L., Hoekenga, O. and Pineros, M. 2004. How do crop plants tolerate acid soils? Mechanisms of

two barley genotypes with different Al resistance.*Plant and Soil,* 258: 241-248.

Hede, A., Skovmand, B. and López, J. 2001. Acid soils and aluminum toxicity. In: Reynolds MP, Ortiz-Monasterio JI, McNab A (eds) Application of Physiology in Wheat Breeding. CIMMYT, Mexico, pp 172-182.

Holford, I. 1997. Soil phosphorus: its measurement and its uptake by plants. *Australian Journal of Soil Research,*35: 227-239.

Hossain, M., Zhou, M. and Mendham, N. 2005.A reliable screening system for aluminium tolerance in barley cultivars. *Aust. J. Agric. Res.* 56(5):475–482.

Hossner, L. and Juo, A. 1989.Mineralogical and chemical properties of acid soils. In: BernhandHintze and C.R. Ellot (eds.). First training Workshop on acid Tropical Soils Management and Land Development practice. 28 August-11 September, 1988. IBSRAM Technical Notes, 2: 59-78.

International Food Policy Research Institute. 2010. Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system, International Food

aluminium tolerance and phosphorous efficiency.*AnnualReview of Plant Biology*, 55: 459-493.

Kochian, L., Piñeros, M. and Hoekenga, O. 2005.The physiology, genetics and molecular biology of plant aluminum resistance and toxicity.*Plant and Soil*, 274: 175-195.

Ligeyo, D. 2007. Genetic analysis of maize (*Zea mays* L.) tolerance to aluminium toxicity and low phosphorus stress and development of synthetics for use in acid soils of Western Kenya. PhD thesis submitted in Department of Biological Science, Moi University, 2007.

Ma, J., Nagao, S., Sato, K., Ito, H., Furukawa, J. and Tekeda, K. 2004.Molecular mapping of a gene responsible for Al-activated secretion of citrate in barley.*J. Exp. Bot.* 55: 1335–1341.

Magalhaes, J., Caniato, F., Guimaraes, C., Schaffer, R., Alves, V., Borem, A., Klein, P. and Kochian, L. 2007.Genetic diversity for Aluminium tolerance in sorghum.*Theoretical and Applied Genetics,*114: 863-876.

Malatrasi, M., Close, T. and Marmiroli, N. 2002. Identification and mapping of putative stress response

Oluwatoyinbo, F., Akande, M. and Adediran, J. 2005.Response of Okra (*Abelmoschusesculentus*) to Lime and Phosphorus Fertilization in an Acid Soil.*World Journal of Agricultural Science,* 1(2): 178-183.

Pandey, S., Narro, L., Friesen, D. and Waddington, S. 2007. Breeding maize for tolerance to soil acidity.*Plant Breed Rev*. 28:59-100.

Paterniani, M. and Furlani, P. 2002. Aluminum toxicity tolerance of maize inbred lines and hybrids evaluated in nutrient solution.*Bragantia*. 61: 11-16.

Paulos, D. 2001. Soil and water resources and degradation factors affecting productivity in Ethiopian highland agro-ecosystems. Northeast African Studies, (ISSN 0740-9133) Vol.8, No.1 (New Series), pp.8: 27-51.

Portaluppi, R., Brammer, S., Magalhaes, J., Costa, C., Caierao, E., Nascimento, A. and Silva, J.

regulator gene in barley. *Plant Mol. Biol*. 50: 143–152.

Martin, J., Walden, R. and Stamp, D. 2006. Principle of field crop production. Pearson Education, Inc. USA.

Munns, D. and Fox, R. 1977. Comparative lime requirements of tropical and temperate legumes.*J.Plant and Soil* 46, 533- 548.

Oguntoyinbo, F., Aduayi, E. and Sobulo, R. 1996.Effectiveness of some local liming materials in Nigeria as ameliorant of soil.*Journal of Plant Nutrition,* 19: 999-1016.

Olsen, S., Cole, C., Watanabe, F. and Dean, L. 1954.Estimation of available phosphorus in soil by extracting with sodium bicarbonate.In J.R. Okalebo, K. W. Gathua and P. L. J. Woomer (1993).A working manual. TSBF, SSSEA, KARI. Nairobi Kenya.

2010.Tolerance of small grain cereal genotypes to aluminum in hydroponic and field cultivation.Pesqui.*Agropecu Bras*. 45: 178-185.

Rao, I., Zeigler, R., Vera, R. and Sarkarung, S. 1993. Selection and breeding for acid-soil tolerance in crops. *Bio Sci.* 43:454-465.

Rengel, Z. 1999. Physiological mechanisms underlying differential nutrient efficiency of crop genotypes. In Mineral Nutrition of Crops: Fundamental Mechanisms and Implications. Ed. Z Rengel, pp. 227–265, Haworth Press, New York.

Tajbakhsh, M., Zhou, M., Chen, Z. and Mendham, N. 2006.Physiological and cytological response of salt-tolerant and non tolerant barley to salinity during germination and early growth.*Aust. J. Agric. Res*. 46: 555–562.

Tamas, L., Budikova, S., Simonovicova, M., Huttova, J., Siroka, B. and Mistrik, I. 2006. Rapid and Simple method for Al toxicity analysis in emerging barley roots during germination.*BiologiaPlantarum*. 50(1):87- 93.

Taye, B. 2007. An Overview of Acid Soils Their Management in Ethiopia, The 3 International Workshops on Water Management (Waterman) Project, Haramaya, pp: 19-21.

Walkley, A. and Black, IA. 1934. An Examination of Degtjareff Method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method. Soil Sci. 37:29-37.

Wang, J., Raman, H., Zhang, G., Mendham, N. and Zou, M. 2006. Aluminium tolerance in barley (*Hordeum vulgaris* L.): Physiological mechanisms, genetic and screening methods. *Journal of Zhejiang University Science*, 7: 769-787.

Wong, M. and Swift, R. 2003.Role of organic matter in alleviating soil acidity. *In:* Rengel Z (ed) Handbook of Soil Acidity. Marcel Dekker, New York, pp 33-358.

Yang, Y., Wang, Q., Geng, M., Guo, Z. and Zhao, Z. 2011.Rhizosphere pH difference regulated by plasma membrane H+-ATPase is related to differential Al-tolerance of two wheat cultivars. *Plant and Soil Environment,* 57(5): 201-2016.

Zemede, A. 2002.The barley of Ethiopia.pp 77-108.*In:* Stephen BB. (Ed). Genes in the Field: On-Farm Conservation of Crop Diversity. IDRC/IPGRI., Lewis, Publishers, Boca Raton.

Zhang, X., Peng, L., Yang, Y. and Gen, D. 2007.Effect of Al in soil on photosynthesis and related morphological and physiological characteristics of two soybean genotypes.*Botanical Studies,* 48: 435-444.