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Response of Barley (*Hordeum Vulgare* L.) Genotypes to Soil Acidity, at Hula District, Sidama Region, Ethiopia

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Abstract: Barley (Hordeum vulgare L.) was domesticated at about 8000 B.C. It is one of the most important cereal crops in Ethiopia, accounting for over 60% of the food of the peoples living in the highlands of Ethiopia. Soil acidity is expanding in its scope, about 43 % out of the total cultivated land in Ethiopia, is dominated with acidic soil, as a sensitive highland crop, barley productivity is decreasing due to soil acidity and in areas where the problem is severe the crop is going out of production. A greenhouse pot experiment was conducted with the objective of performance comparison and screening of soil acidity-tolerant barley genotypes. The treatments consisted of two lime levels (with and without lime) and ten barley genotypes making up a total of 20 treatments laid out in a completely randomized design with six replications. Crop phenology, growth parameters, yield and yield components were evaluated. Primary root length, lateral root length, lateral root number, and root dry weight were significantly ($P < 0.05$) affected by the application of lime. Stand count at harvest, above-ground biomass, plant height, total seed number per pot, and seed number per plant were significantly ($P < 0.05$) affected by the application of lime. Accession 215454a, has shown a greater value of relative root length measurement with 73.76 centimeter. The study revealed the impact of soil acidity could be so severe it can result to the extent of having no yield as compared to lime-treated soils. This necessitates the use of lime in areas that are prone to acidic soils. Overall, the accession that showed relative tolerance from early stage screening can be candidate for further breeding program to develop barley variety that is tolerant to acidic soils.

Keywords: Accessions, barley genotypes, screening, soil acidity, tolerant.

Research Paper

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1. INTRODUCTION

Barley (*Hordeum vulgare* L.) was domesticated at about 8000 B.C, in the Fertile Crescent area of the near and middle east (Badr *et al*., 2000). It is one of the most important cereal crop in the world; European Union, Russia, Australia, Turkey, and Canada are the major barley-producing countries (Espinosa *et al*., 2023). On the African continent, Morocco, Algeria, Ethiopia, Tunisia and South Africa are the top five largest barley producers (Espinosa *et al*., 2023). It's believed to have been cultivated in Ethiopia as early as 3000 B.C (Kebede and Tadesse, 2015). In Ethiopia, among cereals, barley is the fifth most important crop next to tef (*Eragrostis tef* L.), maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), and sorghum (*Sorghum bicolor* L.) with a total area of 926,107 hectares (CSA, 2020). Barley is the major staple food in the highlands of Ethiopia, accounts for over 60% of the food of the peoples living in the highland areas (Kifle, 2016). It is used to prepare different kinds of traditional foods (Grando and Macpherson, 2005). It is also an important raw material for many industries, such as the malt and beer production industries (Kaso and Guben, 2015).

Despite its long history and importance, the national average yield of barley is 2.45 ton per hectare which is still less than the world average 2.96 ton per hectare (Espinosa *et al*., 2023). This low yield of barley in Ethiopia is due to several constraints of both biotic and abiotic natures (Chimdi *et al*., 2012). The biotic stresses include diseases and pests, diseases like scald, net blotch, spot blotch, rusts, as well as insect pests like aphids and barley shoot fly, while the abiotic stresses are associated with poor soil drainage, drought, poor agronomic practices, low levels of fertilizer application, soil acidity ($pH < 5.5$), and deficiency of nutrients (Haile, 2018). From abiotic stress, soil acidity is one of the major constraints for barley production that limits and prevents profitable and sustained agricultural productivity in many parts of the country (Ayenew *et al*., 2018). The major causes for soil acidity are leaching due to heavy

rainfall, acidic parent material, decomposition of organic matter, removal of major cations through crop harvest, and Nitrification of Ammonium (Gillespie, 2020).

The process of acidification happens, because of the replacement of basic cations such as Ca, Mg and K in the soil exchange sites with Al, Mn and Fe and this increases the concentration of H^+ in the soil solution and due to this the availability of nutrients needed for the growth of the crop is reduced (Matiyas *et al*., 2021). Soil acidity leads to reduced yield, poor plant growth, poor nodulation of legumes, stunted root growth, persistence of acid-tolerant weeds, and increased incidence of diseases and development of abnormal leaf color (Dinkecha *et al*., 2019). Soil acidity results in Al and Mn toxicity plus deficiency in N, P, K, Mg, Ca and Mo, and this in turn leads to a lack or reduced response to the applied fertilizers due to high P fixation by oxides of Al and nutrient deficiency which can result in 50% and above yield reduction (Zeleke *et al*., 2010).

At Hula, Sidama Regional State, Ethiopia, soils are acid–affected (pH below 5), characterized by having high rainfall associated with inherently acidic soils (Kiflu *et al*., 2017). In previous studies by the Ethiopian Geological Survey Institute in 1989, 40% of the total cultivated land was dominated by acidic soil, but in recent years (2021) it reached 43 % (ATA, 2021), out of which 28% of it is strongly acidic which implies that out of the total cultivated land 3.7 million hectares is acidic soil. Soil acidity is increasing in Ethiopia from time to time as a result of it the yields of barley, wheat, and faba bean is decreasing and furthermore in areas where the problem is severe the crops are going out of production (ATA, 2021). Adding liming materials help to reduce soil acidity by neutralizing acid reactions in the soil. The carbonate component reacts with hydrogen ions present in the soil solution and raises the soil pH (Mahmud and Chong, 2022).

The practice of liming acid soils to mitigate soil acidity has been used for optimal crop production in acid soils. However, these methods have limited practical applicability for resource-poor farmers (Legesse and Teshale, 2020). Hence, the utilization of crops that are tolerant to acidic soils is an important complementary strategy to lime application for cropping on acidic soils (Moroni *et al*., 2018). Worldwide, the development of varieties tolerant to soil acidity has been used as an alternative option 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). Alternative low-cost options for coping with the problem of soil acidity need to be developed in Ethiopia, in order to enable farmers to improve yields of barley and remain in production in acidic soil prone areas of Ethiopia. However, there is no released tolerant cultivar of barley for production in acidic soil environments in Ethiopia.

Currently, the main strategies promoted by the government extension service to counter the problem of soil acidity are the promotion of mineral fertilizers, compost and lime use, along with water conservation practices (Bekana *et al*., 2022). Thus, screening of barley genotypes adapted to soil acidity is a promising alternative to enhance barley production more from a combined application of mitigation measures. Therefore, the present study was conducted to evaluate barley genotypes for acidic soil tolerance and responsiveness under limed and non-limed soil conditions.

2. METHODOLOGY

2.1. Description of Experimental Site

The soil was collected from Wirama Kebele, Hula district. It is located in Sidama Region, Ethiopia, at a coordinate between 38^0 27’ 4’’ E Longitude and 06^0 26’ 59’’ N Latitude. It has an elevation of 2648 meter above sea level. The climate of the site is sub humid type with a bimodal rainfall pattern. The main rainy season is June to September and the mean annual precipitation of the site range from 1000-to-1300 mm, and has a clay loam Dystric Luvisols soil.

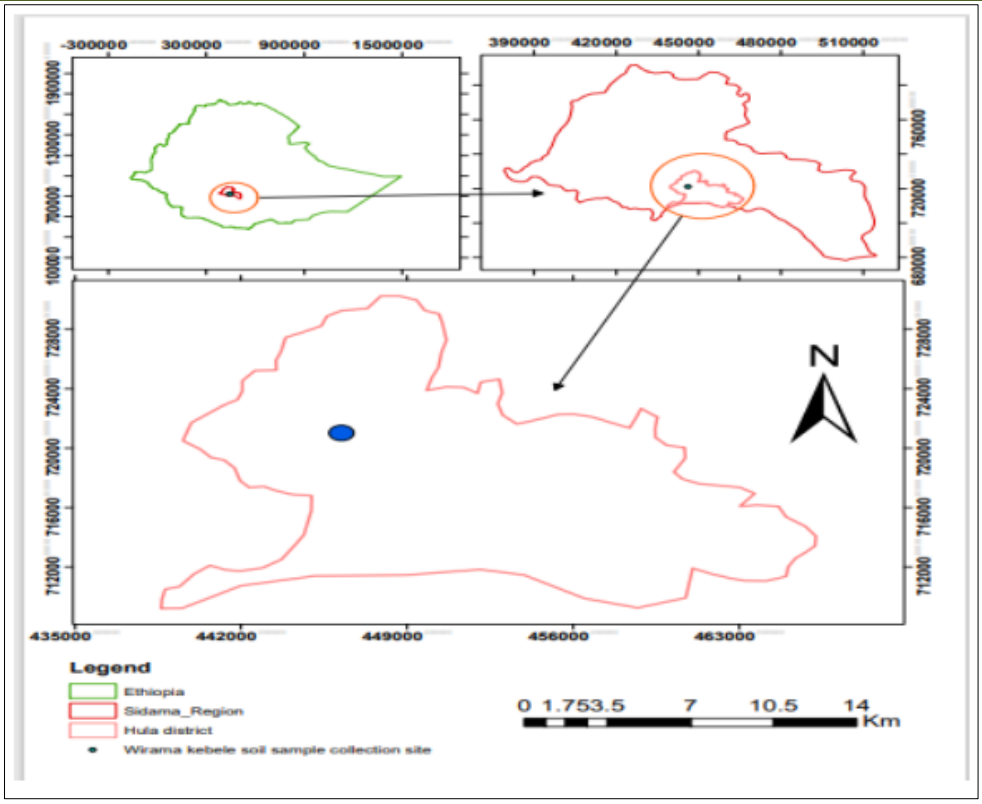

Figure 1: Map of soil sample collection site/ Wirama Kebele

The study was done at Hawassa university college of Agriculture research site, which is located 275 km south of Addis Ababa, at a coordinate between 7° 3′ N longitude and 38° 28′ E latitude with an altitude of 1708 m.a.s.l., receiving an annual rainfall of 1076 mm and the mean annual temperature is 26°C.

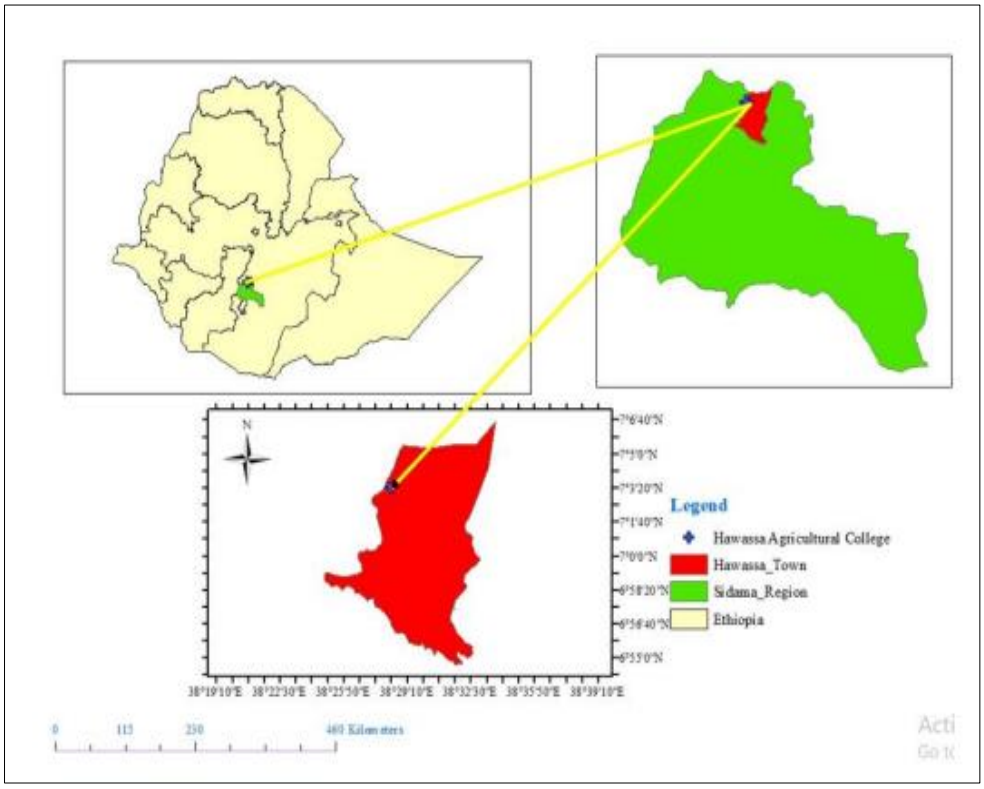

Figure 2: Map of the study area at which the greenhouse experiment was conducted

2.2. Description of Experimental Materials

Two different pot sizes were used to plant barley genotypes Vis 10 and 2 kg sized pots were used. The 10 kg sized pots were used to collect second harvest data which was done at physiological maturity, whereas the 2 kg sized pots were used to collect first harvest data which was done fourteen days after sowing. Ten Barley genotypes were used for the experiment (8 of them were accessions, one land race and one released variety) and the seeds were obtained from Hawassa University, College of Agriculture. Barley genotypes used in this experiment were Accession 217176b, Accession 23491, Accession 240478a, Accession 240478b, HB 1307, Accession 208855b, Accession 278965a, Accession 215453b, Accession 215454a, and Juma Tikur. HB-1307, which is a released variety that was used as a standard check. It was released in 2006 by Holleta Agricultural research Center, whereas Juma Tikur was used as a local check and was obtained from Gumer, Gurage Zone and all the rest were landraces.

2.3. Treatments and Experimental Design

The treatments consisted of two lime levels (with and without lime) and ten barley genotypes making up a total of twenty treatments laid out in a completely randomized design with six replications.

2.4. Experimental Procedures and Management

A tone of top soil (0-20 cm depth) was collected. The collected soil was then air-dried and sieved through 2 mm sieve to separate roots and stones from the soil and homogenized. A composite sample of the soil was sent Horticoop Ethiopia, plc. Soil and water Analysis Laboratory based at Bishoftu. Before treating the experimental soil with lime, the amount of lime required to raise the soil pH to 6.5, that is suitable for the growth of barley was determined.

Table 1: Analytical methods used in soil physico-chemical analysis

Analytical methods		
Parameter		Examination standards
Acidity	PH - H_2O	ES ISO 10390-2014-1:2:5
Soil texture		Bouyouocos hydrometer method
Organic carbon	OC	Walkey and black
Total nitrogen	TN	ES ISO 11261:2015 (Kjeldahl method)
Ava. phosphorus	P	ES ISO 11263:2015 (Olsens method)
Cation exchange capacity	CEC	Ammonium acetate method
Calcium (Ca), Potassium (K), Magnesium (Mg), Sulfur (S), Silicon (Si), Molybdenum (Mo), and Boron (B)		Mehlich-3

Lime required to ameliorate the soil was computed using the formula suggested by Agegnehu *et al*., 2019, i. e `
Lime Rate (LR) = (Target pH – initial pH of the soil sample) * BC (Buffering Capacity)
BC = 0.1079 per 100 gram soil
Here, the target pH was 6.5 because; barley grows best at this pH (Legesse, and Teshale, 2020).

The pH of the site where the soil sample is collected was 4.58, according to the soil analysis result done at Hoorticoop Ethiopia PLC, based at Bishoftu, Ethiopia. The limes Ca Co3 was found to be with 89.5 % purity by the test done at Hawassa university soil and plant analysis laboratory using the manual prepared by FAO, (2020).

Accordingly, The Lime Rate was calculated as Follows:
LR = (6.5 - 4.58) * 0.1079 = 0.207168 per 100 gram soils
Amount of lime added per pot that was filled with 8 kg of soil was calculated as follows:

LR = $\frac{8000 * 0.207168}{100}$ = 16.57 gram

Hence,

LR = $\frac{100 * 16.57}{89.5}$ = 18.5 gram of lime was added per pot

Amount of lime added per two liter pot that was filled with 1.4 kg of soil was calculated as follows:

LR = $\frac{1400 * 0.207168}{100}$ = 2.9 gram

Hence,

LR = $\frac{100 * 2.9}{89.5}$ = 3.24 gram of lime was added per plastic water bottle

After treating it with lime, it was kept for a month (30 days) to let the lime well interacted with the soil (Effiong and Ekon, 2009). This was done because lime slowly improves soil acidity, where early application of lime starting 30 days before planting is important to allow a lime to have enough time for reaction. This would allow release of essential nutrients to ameliorate acid soil and also raising of the pH of acidic soils and thereby improves the availability of essential nutrients for growth of plants (Ketema and Tefera, 2022). During the incubation period pots were watered to field capacity as required. After an incubation period N fertilizer was applied at the rate of 50 mg N per a kilogram of soil as it was suggested by Sosena and Sheleme (2020).

The Rates were computed as Follows:
For ten kg pot that was filled with 8 kg soil
50 mg = 0.05 gram…….. = 0.05 * 8 = 0.4 gram, and
100 kg = 100000 gram

N = $\frac{0.4 * 100000}{46000}$ = 0.87 gram of urea was applied per each pot

For two kg pot that was filled with 1.4 kg soil

= 0.05 * 1.4 = 0.07

N = $\frac{0.07 * 100000}{46000}$ = 0.152 gram of urea was applied per each pot

Urea was applied on split, first at the time of planting and secondly after thinning. Phosphorus was not applied in order to make the acidity stress strong enough, so that the experiment will have stronger screening power. Seeds of the barley genotypes were planted after an incubation period of a month. Eight barley seeds were planted in each ten kg pot, while six seeds were planted on each two kg pot and the stands were later thinned to four per each pot. Throughout the growth period, the pots were watered to field capacity as required. Three replications were harvested at the 1st harvest and the remaining 3 replications were harvested at the 2nd harvest. The 1st harvest was done at 14 days after sowing for the earliest, whereas, the 2nd harvest was carried out at harvest maturity.

2.5. Soil Sampling and Analysis

Soil samples were collected before planting and after harvesting and was subjected to soil physico-chemical analysis. The 1st Composite soil sample was collected from soil collection site before lime application and it was subjected to analysis of acidity attribute and other soil physico-chemical properties, and the 2nd done after harvesting to detect the effect of lime application on soil pH, exchangeable acidity and exchangeable Aluminum. The soil pH was measured potentiometrically with a digital pH meter in the supernatant suspension of 1:2:5 soils to water ratio (Huluka, 2005). Soil organic carbon content was determined by the dichromate oxidation and organic matter was estimated from the organic carbon content by multiplying the latter by 1.724. Total N was determined using the micro-Kjeldahl digestion, distillation and titration procedure as described by Bremner and Mulvaney, 1982.

Soils available P was extracted by using the Bray-II method and was quantified using spectrophotometer (wave length of 880 m) calorimetrically using the mixture of ammonium, molybdate, sulphuric acid and potassium antimony tartrate as an indicator. Exchangeable basic (Ca, Mg, K and Na) ions were extracted using 1 M ammonium acetate (NH4OAc) solution at pH 7. The extracts of Ca and Mg ions were determined using AAS while K and Na were determined by flame photometer. To determine the cation exchange capacity (CEC), the soil samples were first leached with M NH4OAC, washed with ethanol and the adsorbed ammonium was replaced by sodium (Solomon, 2008). The CEC was then measured titrimetrically by distillation of ammonia that is displaced by Na following the micro- Kjeldahl procedure. Total exchangeable acidity was determined by saturating the soil samples with 1M KCl solution and titrating with 0.02M HCl as described by Tesfaye *et al*., 2020. From the same extract, exchangeable Al in the soil is titrated with a standard solution of 0.02M HCl.

2.6. Data Collection

2. 6. 1. Crop Phenology and Plant Growth

Data for first harvest: To compensate for differences in growth duration, the following correction factor was used to determine the harvest duration for first sampling as follows.

Harvest duration = $(\frac{PMx}{PMs} * HD)$

Where, PMx and PMs are days to physiological maturity of genotype X and the earliest genotype, respectively and HD, planned harvest duration.

Table 2: Harvest duration for the first sampling

No	Genotypes	Mean maturity * date	Harvest date for a 14 day sampling	Harvest duration (rounded)
1	Acce, 217176b	118.5	14.76	15
2	Acce, 234911	122.6	15.27	15
3	Acce, 240478a (white)	115.9	14.43	14
4	Acce, 240478b (black)	112.4	14.00	14
5	HB-1307	140.0	17.53	18
6	Acce, 208855b	122.5	15.27	15
7	Acce, 278965a	117.3	14.59	15
8	Acce, 215453b	121.6	15.14	15
9	Acce, 215454a	115.5	14.38	14
10	Juma Tikur	139.7	17.40	17

The Following Data were collected from first Harvest

Stalk Length (SL)

The pots were cut and the soils were removed from the roots and then the roots were washed with clean water. Seedlings were then is cut off at the main root to a point of the longest leaf to measure stalk and root length.

Primary Root Length (PRL)

It was obtained after cutting the pots and removing the roots carefully to avoid root damage and washing the roots then measuring the length of the root of a plant that develops first and originates from the radicle that has grown vertically.

Lateral Root Length (LRL): It was obtained by measuring the length of the roots from the cutting point to the tip of the longest lateral root.

Lateral Root Number (LRN): It was obtained by counting the number of lateral roots.

Shoot Dry Weight: It was obtained by weighing the shoot after it was dried in an oven at 70ºC for 48 hours.

Root Dry Weight: It was obtained by weighing the root after it was dried in an oven at 70^0C for 48 hours.

Relative Root Length (%): It was obtained by computing the root length of the non-limed over the root length of limed.

Relative Root Weight (%): It was obtained by computing the root weight of non-limed over the root weight of limed.

Relative Shoot Length (%): It was obtained by computing the shoot length of non-limed over the shoot length of limed.

Relative Shoot Weight (%): It was obtained by computing the shoot weight of non-limed over the shoot weight of limed.

Data for the Second Harvest

Second harvest was done at ripening maturity:

Data on a plant and on-pot basis was recorded from each pot

A. Pot basis: The following plant parameters were determined:

Biomass: It was obtained by weighing the total above-ground biological yield in grams obtained from each pot at harvest.

Grain Yield: It was obtained by weighing the kernel yield of each pot at harvest.

B. Plant basis: The following plant parameters were determined:

Plant Height

It was obtained by measuring the height of plants from all plants in each pot that were measured in centimeters from the ground surface to the top of the main stem at maturity.

Stand Count at Harvest: It was obtained by counting the number of plants in each pot after harvesting.

Total Seed Number per Pot: It was obtained by counting the number of seeds obtained in each pot after threshing.

Grain Yield (Yield): It was determined by weighing the amount of harvested grains in grams.

Biomass: It was determined by the dry weight of the biomass in grams after drying the samples in an oven at 70ºC for 48 hours.

2.7. Data Analysis

2.7.1. Analysis of Variance on Collected Data

All collected data were subjected to analysis of variance using the general linear model of SAS software (version 9.0) to assess the difference among treatments. Mean separation was done using the least significant difference (LSD) test whenever the F-test showed significant difference.

2.7.2. Correlation Analysis

Correlation analysis was carried out to generate information about the association of yield and other parameters by using Pearson's correlation coefficients for the intended parameters.

3. RESULTS AND DISCUSSION

3.1. Effect of Lime Application on Selected Soil Chemical Properties

The physical properties of soil or textural class of the soil were 30% sand, 30% clay, and 40% silt with clay loam texture (Table 3), which is ideal for barley production (Pratt *et al*., 2023). The soil pH was 4.58 and according to Landon, 2014 this was rated as strongly acidic and this was due to high precipitation of the area which causes large leaching of bases down the soil profile. In such soils wide ranges of plants could be affected by aluminum toxicity (Taye *et al*., 2020). With application of lime the pH was raised to 5.05, Alemu *et al*., 2017, stated that treating the acid soils with lime increased the soil pH, which is mainly due to the neutralization of Al ion in the soil solution. The total N of the soil in the study area was 0.33 % which is medium according to Landon, 2014, who classified soils as having very high N, high N, medium N, low N, and very low N in total nitrogen content having the total N percentage of greater than 1.0%, 0.5-1.0%, 0.2-0.5%, 0.1-0.2%, and less than 0.1%, respectively.

The soils cation exchange capacity (CEC) was 32.44 (Meq/100 gram soil) which is rated as high according to the Landon, 2014, who rated soils having CEC greater than 40 cmol (+) /kg soil as very high and 25-40 cmol (+)/kg as high, 15-25, 5-15 and < 5 cmol (+) kg of soil as medium, low and very low respectively in CEC. According to this classification the soil has high CEC to retain cations. The available phosphorus content of the soil was 9.84 (mg/kg(ppm)), which was rated as low according to Landon, 2014, the low availability of phosphorus was due to the soil's pH level, because when the soils are too acidic, phosphorus reacts with iron and aluminum that makes it unavailable to plants and also becomes inaccessible. The organic carbon content of the experimental soil was 4.33 %, which was rated as high, Organic carbon content of the soil is the measure of the total amount of organic matter that is present in the soil,

which needs to be decomposed to release the nutrients for the uptake of the plant.

Table 3: Physico-chemical properties of the experimental soil

Parameter		Analytical result	Unit	Optimum range	Rating
Acidity	pH-H_2O	4.58	-	5.50 -7.00	Low
Ava. Phosphorus	P	9.84	mg/kg (ppm)	20 – 30	Low
Potassium	K+	382.12	mg/kg (ppm)	90 – 190	High
Calcium	Ca2+	2054.62	mg/kg (ppm)	1000 – 2000	High
Magnesium	Mg2+	198.16	mg/kg (ppm)	120 – 360	Moderate
Sulphate	S	15.02	mg/kg (ppm)	20 – 80	Low
Iron	Fe	163.26	mg/kg (ppm)	2.10 - 5.00	High
Manganese	Mn	101.88	mg/kg (ppm)	1.00-20.00	High
Zinc	Zn	7.40	mg/kg (ppm)	0.50 -1.00	High
Boron	B	0.18	mg/kg (ppm)	0.80-2.00	Low
Copper	Cu	3.49	mg/kg (ppm)	2.60-5.00	Moderate
Molybdenum	Mo	0.49	mg/kg (ppm)	2.60-5.00	Moderate
Sodium	Na^+	21.45	mg/kg (ppm)	69-161	Low enough
Organic carbon	OC	4.33	%	1.00-3.00	High
Total nitrogen	N	0.33	%	0.12 - 0.25	High
C:N	C/N	13.12	-	-	-
Cation exchange capacity	CEC	32.44	meq/100g soil	15 – 25	High
Sand	30		%		
Silt	30		%		
Clay	40		%		
Textural class				Clay loam	
Exch. acidity	0.64				
Exch. H^+	< 0.01				
Exch. $Al3^+$ < 0.01					

3.2. Effect of Soil Acidity on Crop Phenology and Plant Growth Parameters

3.2.1. Stalk Length (SL)

The analysis of variance revealed that stalk length was not significantly ($P > 0.05$) affected both by lime and lime with genotype interaction. In contrast, it was significantly ($P < 0.01$) affected by the genotypes. The mean length of the genotypes treated with lime was 23.11 centimeters, and that of non-limed was 21.99 centimeters (Table 4). The maximum mean stalk length was 30.08 centimeters recorded from Accession 240478b, which is statistically similar to Accession 240478a. The minimum stalk length was 17.08 centimeters recorded from Accession 208855b. Statistically similar and shorter stalks were also produced from Accession 217176b, HB-1307, and Juma Tikur. The lime application failed to enhance stalk length probably due to the shortness of the 2-week growth duration to make the lime to have a significant influence. This is because liming significantly influences plants at physiological maturity.

3.2.2. Primary Root Length (PRL)

The analysis of variance revealed that primary root length was significantly ($P < 0.05$) affected both by genotype and lime with genotype interaction. The maximum PRL was recorded from HB-1307 which was 18.58 centimeter, whereas the minimum PRL was recorded from Accession 208855b which was 13.33 centimeter, which is statistically similar to Accession 240478b and Accession 24044478a (Table 4). The variation in PRL was due to the sensitivity of barley to acidic soils because soil acidity had an effect on root growth which resulted in stunted and shortened root growth. The results indicated that soil acidity exerted a stronger impact on root growth. This finding is in agreement with Alam, (1981) and Clarkson, (1966), who also reported that acidity affects root growth.

3.2.3. Lateral Root Length (LRL)

The analysis of variance revealed that lateral root length was significantly ($P < 0.01$) affected both by lime and genotypes. The maximum LRL was 6.46 centimeters which was recorded from Accession 217176b. The minimum mean LRL was 4.85 centimeters which was recorded from the local landrace Juma Tikur (Table 4). The application of lime has promoted root growth by reducing the toxic effects of aluminium which might hinder the rooting ability of the barley genotypes that were used in this study. This finding is in agreement with Haling *et al*., 2010, who also stated that the application of lime on acid soil facilitates root growth compared to untreated soil.

3.2.4. Lateral Root Number (LRN)

The analysis of variance revealed that lateral root number was significantly ($P < 0.01$) affected both by lime and genotype. The maximum LRN was recorded from Accession 215454a, whereas the minimum LRN was recorded from Accession 208855b, which was 5.73 and 3.88 respectively. The influence of lime in root growth was very high due to the role of lime in minimizing the impact of soil acidity in root growth and development; as a result of it the genotypes have shown better root growth. This finding is in agreement with Getahun *et al.*, 2021, who also reported that liming with optimum rate could increase the soil pH and improves soil structure, hence rooting could be improved.

3.2.5. Shoot Dry Weight (SDW)

The analysis of variance revealed that shoot dry weight was not significantly ($P > 0.05$) affected by the application of lime. But, it was significantly ($P < 0.05$) affected by the genotypes. The maximum shoot dry weight was recorded from Accession 240478a, which was 46.6 milligrams, whereas the minimum was recorded from Accession 208855b which was 28.8 milligrams (Table 4). Shoot dry weight varied among the genotypes used in this study and this may be associated with the influence of genetic variability that could have existed among the genotypes used in this study. This finding is in agreement with Fageria *et al.*, 2012, who also stated that genetic variability has influenced shoot dry weight.

3.2.6. Root Dry Weight (RDW)

The analysis of variance revealed that root dry weight was significantly ($P < 0.01$) affected both by lime and genotypes. The maximum RDW was recorded from Accession 217676b which was 31.25 milligrams, whereas the minimum RDW was recorded from Accession 240478a which was 20 milligrams (Table 4). The increment gained in root dry weight was due to the inhibitory effect of lime on the toxic effect of soil acidity. This finding is in agreement with Sisay and Balemi, 2014, who have also stated that liming has an increment effect on root dry weight.

Table 4: Mean values for crop growth and phenological parameters

Treatment	SL (cm)	PRL (cm)	LRL (cm)	LRN (Nº)	SDW (mg)	RDW (mg)
Liming						
Limed	23.11^{a}	21.9^{a}	3.28^{a}	2.13^{a}	38.7^{a}	22.25^{a}
Unlimed	21.99^{a}	9.09^{b}	1.21^{d}	1.62^{d}	34.36^{a}	8.00^{e}
LSD (5%)	NS	2.24	0.13	0.19	NS	2.48
Genotypes						
Accession, 217176b	18.26^{d}	17.75^{ba}	6.46^{a}	5.10^{b}	27.5^{d}	31.25^{a}
Accession, 234911	25.50^{b}	15.18^{ba}	6.03^{b}	4.81^{cb}	38.3^{b}	29.16^{bac}
Accession, 240478a	29.25^{a}	13.51^{b}	5.98^{b}	4.76^{cb}	46.6^{a}	20.00^{e}
Accession, 240478b	30.08^{a}	13.50^{b}	5.48^{dc}	5.11^{b}	43.3^{ba}	29.71^{ba}
HB – 1307	18.26^{d}	18.58^{a}	5.58^{c}	4.71^{cb}	30.7^{dc}	29.86^{ba}
Accession, 208855b	17.08^{d}	13.33^{b}	5.08^{fe}	3.88^{d}	28.8^{d}	21.66^{ed}
Accession, 278965a	26.58^{ba}	15.41^{ba}	5.31^{dce}	4.30^{cd}	37.8^{bc}	23.08^{ed}
Accession, 215453b	19.83^{dc}	16.08^{ba}	5.15^{dfe}	4.46^{c}	38.6^{b}	25.56^{bdc}
Accession, 215454a	23.40^{bc}	15.73^{ba}	5.15^{dfe}	5.73^{a}	36.6^{bc}	22.96^{ed}
Juma Tikur	17.08^{d}	16.26^{ba}	4.85^{f}	4.30^{cd}	27.5^{d}	24.08^{edc}
LSD (5%)	3.61	5.02	0.37	0.57	7.43	5.48
CV (%)	13.7	27.7	5.83	10.41	17.99	18.36

Means that share the same letter are not significantly different, LSD = least significantly different at 5 %, CV = coefficient of variation (%), SL = Shoot length, PRL = primary root length, LRL = lateral root length, LRN = latera root number, SDW = shoot dry weight, RDW = root dry weight.

3.2.7. Relative Shoot Length

The analysis of variance revealed that relative shoot length was not significantly ($P > 0.05$) affected by the genotypes. The longest average relative shoot length was recorded from Accession 217176b which was 111.53 centimeters, and the shortest average relative shoot length was recorded from Accession 240478a which was 75.2 centimeters (Table 5).

3.2.8. Relative Root Length

The analysis of variance revealed that relative root length was significantly ($P < 0.05$) affected by the genotypes. The longest average relative root length was recorded from Accession 215454a which was 73.76 centimeters. The shortest average relative root length was recorded from Accession 217176b and Accession 278965a which was 28.40 and 28.33 centimeters respectively (Table 5). Soil acidity has adversely affected root growth, because it decreases the availability of plant nutrients, such as phosphorus and molybdenum, and increases the availability of some elements to toxic levels, particularly aluminum and manganese. In this study, differences were observed with regard to root length. The difference in root length has resulted from

the variation of the genotypes with regard to soil acidity tolerance; this finding is in agreement with Fekadu *et al*., 2022, who also stated the existence of genetic variation with respect to resistance to soil acidity. According to Gallardo *et al*., 1999, and Wang *et al*., 2006, relative root length could serve as a criterion to evaluate Al tolerance, this is because, in acidic soils excessive H^+ affects the root membrane permeability, by competing with other cations for absorption sites and interfering with ion transport, losing K or reducing Ca acquisition and translocation (Foy and Peterson, 1994), as a result, the roots of plants damaged by a low pH becomes short, thick, having a brown color (Islam *et al*., 1980). In general, the best-performing genotype that is identified in this study is accession 215454a, having a length of 73.76 (cm).

3.2.9. Relative Shoot Weight

The analysis of variance revealed that relative shoot weight was not significantly ($P > 0.05$) affected by the genotypes. The largest relative shoot weight was recorded from HB-1307 which was 116.43 grams, while the smallest relative shoot weight was recorded from Accession 234911 and Accession 2135453b which was 82.17 and 84.70 grams respectively (Table 5). The variation in relative shoot weight might have been related to the partitioning of photosynthates which could be influenced by the exposure of plant canopies to C_O2 concentrations, as C_O2 favors the growth of shoots. This finding is in agreement with Rogers *et al*., 1995, who also stated shoot weight varies depending upon the partitioning of photosynthates.

3.2.10. Relative Root Weight

The analysis of variance revealed that relative root weight was not significantly ($P > 0.05$) affected by the genotypes. The largest average relative root weight was recorded from Accession 215454a which was 105.06 milligrams, while the smallest average relative root weight was recorded from HB-1307 which was 66.13 milligrams (Table 5). The possible causes of variation in root weight might be associated with the size of the seed, sowing depth, time taken for seedling emergence, and length of cotyledons at emergence.

Table 5: Mean values for ratios RSL, RRL, RSW, and RRW

Treatment	RSL	RRL	RSW	RRW
Ratios (limed/unlimed	111.53^{a}	73.76^{a}	116.43^{a}	105.06^{a}
Genotypes				
Accession 217176b	111.53^{a}	28.40^{d}	122.23^{a}	71.86^{bd}
Accession 234911	93.03ba	37.13^{cd}	82.17^{d}	81.43^{b}
Accession 240478a	75.20^{b}	44.80^{cb}	85.70^{dc}	79.70^{cb}
Accession 240478b	100.37^{ba}	36.86^{cd}	106.67^{bac}	78.33^{cbd}
HB – 1307	96.53^{ba}	32.76^{cd}	116.43^{a}	66.13^{d}
Accession 208855b	100.83^{ba}	29.93^{cd}	115.97^{ba}	75.53^{cbd}
Accession 278965a	108.37^{ba}	28.33^{d}	113.10^{ba}	68.70^{cd}
Accession 215453b	105.70^{ba}	44.56^{cb}	84.70^{d}	75.23^{cbd}
Accession 215454a	101.70^{ba}	73.76^{a}	94.43^{bdc}	105.06^{a}
Juma Tikur	84.97^{ba}	53.46^{b}	88.33^{dc}	71.56^{cbd}
LSD (5%)	33.37	14.91	21.61	12.64
CV (%)	20.02	21.20	12.47	9.52

Means that share the same letter are not significantly different, LSD = least significantly different at 5 %, CV = coefficient of variation (%), RSL = Relative Shoot length, RRL = Relative root length, RSW = Relative shoot weight, RRW = Relative root weight.

3.3 Effect of Soil Acidity on Yield and Yield Components of Barley

3.3.1. Stand Count at Harvest

The analysis of variance revealed that stand count at harvest was significantly affected ($P < 0.01$) both by lime and genotype. The genotypes with the minimum number of stand count at harvest was that of Accession 208855b (Table 6), and all the remaining genotypes showed statistically similar greater stand counts without significant difference among them. Thus, almost all genotypes maintained similar number of stand count at harvest, which could be attributed to the use of the same seed lot that has been harvested in the previous season.

3.3.2. Biomass

The analysis of variance revealed that biomass was significantly ($P < 0.01$) affected both by lime and genotype. The highest above-ground biomass was recorded from the local land race Juma Tikur which had 49 % more biomass than that obtained from the lowest accession (Table 6). However, Acce, 234911, Acce, 217176b, and Acce, 215454a have produced statistically similar lowest above-ground biomass among the genotypes used in this study.

3.3.3. Plant Height

The analysis of variance revealed that plant height was significantly ($P < 0.01$) affected both by lime and genotype. Almost all genotypes except HB- 1307 have produced statistically similar highest plant height

(Table 6). Plant height had increased significantly by application of lime. The lowest plant height was recorded from HB-1307 which was 19.03 centimeter. The increase in plant height could be attributed to the effect of lime in neutralizing acidic soil toxicity effect and increase soil nutrient availability. This finding is in line with Abdeta, 2021, who also stated that the application of lime has resulted in plant height.

3.3.4. Total Seed Number per Pot

The analysis of variance revealed that the total seed number per pot was significantly ($P < 0.05$) affected both by lime and genotype. The maximum number of total seed number per pot was recorded from Accession, 208855b which had 54.8 % more total seed number per pot than that obtained from the lowest Accession (Table 6). All genotypes that were planted in non-limed soil conditions did not give a yield; this was because barley is considered to be more sensitive to acidic soils. The initial toxic effects of acid soil are stunted and shortened root growth then delay barley germination and initiation. This finding is in agreement with Dolling *et al*., 1991, who also reported that barley is very sensitive to Al toxicity.

3.3.5. Seed Number per Plant

The analysis of variance revealed that seed number per plant was significantly ($P < 0.01$) affected both by lime and genotype. The highest number of seed numbers per plant was recorded from Accession 217176b that was 7.66 which had 23.8 % more seed number per plant than that obtained from the lowest Accession (Table 6). The variation in the number of seeds obtained per plant was due to the sensitivity of barley to soil acidity. Barley is considered to be the most sensitive to Al toxicity among cereal species. It is considered to be more sensitive to acidic soils than rye, oat, rice, and wheat (Bona *et al*., 1993; Ishikawa *et al*., 2000).

3.3.6. Yield

The analysis of variance revealed that yield was not significantly ($P > 0.05$) affected by lime, whereas it was significantly ($P < 0.1$) affected by the genotype. The application of lime failed to have a significant influence on yield. This was probably due to the reason that, lime works very slowly to release nutrients from fixation. As a result, the genotypes were unable to utilize the required amount of nutrients in the critical yield forming period. Moreover, a decrease in pH has resulted in an increase in soluble aluminium and so, aluminium has retarded root growth, and restricted access to water and nutrients. This has resulted in poor crop growth and reduction in yield as a result of inadequate water and nutrition to support the growth of the crop. The reaction time of lime in soils has to be increased for lime to effectively neutralize the exchangeable acid and hence more yields could be obtained. This finding is in agreement with Ameyu, 2019, and Ejigu *et al*., 2023, who also stated that the lime efficiency was greater in the succeeding years than in the first year of its application.

Table 6: Mean values for yield and yield components

Treatments	Stand Co. (Nº)	Biomass (mg/pot)	Plant ht. (cm)	Tot. Seed (Nº)	Seed /Plant (Nº)	Yield (mg/pot)
Genotypes						
Accession 217176b	4.00^{a}	1206.7^{e}	40.13^{a}	15.66^{ba}	7.66^{a}	160.0^{bac}
Accession 234911	4.00^{a}	1333.3^{e}	39.60^{a}	14.00^{bac}	5.16^{b}	136.6^{bc}
Accession 240478a	4.00^{a}	1390.3^{de}	39.76^{a}	12.00^{dc}	3.60^{cbd}	116.6^{c}
Accession 240478b	4.00^{a}	1763.3^{dc}	34.06^{a}	12.66^{bdc}	2.50^{cd}	205.0^{a}
HB – 1307	4.00^{a}	2266.7^{b}	19.03^{b}	14.33^{bac}	3.43^{cbd}	148.3^{bac}
Accession 208855b	2.66^{b}	2110.0^{bc}	32.46^{a}	17.00^{a}	4.33^{cb}	158.8^{bac}
Accession 278965a	4.00^{a}	1380.0^{de}	34.40^{a}	13.00^{bc}	8.33^{a}	180.0^{ba}
Accession 215453b	3.66^{a}	2336.7^{ba}	30.73^{a}	9.33^{d}	2.26^{cd}	147.3^{bac}
Accession 215454a	4.00^{a}	1073.3^{e}	31.06^{a}	14.33^{bac}	1.83^{d}	136.6^{bac}
Juma Tikur	4.00^{a}	2716.7^{a}	32.26^{a}	14.33^{bac}	2.66^{cd}	133.3^{bc}
LSD (5%)	0.41	422.11	10.03	3.47	2.12	23.8
CV (%)	6.35	13.9	17.5	14.8	29.6	22.3

Means that share the same letter are not significantly different, LSD = least significant different at 5 %, CV = coefficient of variation, NS = non-significant, Stand co. = stand count at harvest, Biomass = above ground biomass, Plant ht. = plant height, Tot. Seed = total seed number per pot, Seed/plant = seed number per plant, yield = yield obtained after harvest.

3.4. Correlation between Yield and Yield Related Traits

The correlation analysis of the present study (Table 7) showed that grain yield was strongly and positively correlated with all parameters tested except stand count at harvest and biomass. Moreover, the correlation of grain yield was strong and highly significant ($P < 0.001$) with total seed number per plant ($r = 0.79^{***}$), and seed number per plant($r = 0.77^{***}$). The result of these relations showed that grain yield is the function of positively and significantly related parameters (Table 7). Similarly, seed number per plant was significantly associated and positively correlated with all parameters tested. The relations were strong with total seed number per plant ($r = 0.96^{***}$), and plant height ($r = 0.36^{*}$), biomass ($r = 0.23$) and stand count at harvest ($r = 0.10$). This result implies that seed number per plant is the function of positively and significantly related parameters. The increase in plant height and

Biomass resulted in improved vegetative growth and better light use efficiency of the genotypes which might have contributed to increase in photo assimilates production and partitioning to different plant parts.

Table 7: Correlation between yield and yield related traits

Parameters	Stand count at harvest	Above ground biomass	Plant height	Total seed number per pot	Seed number per plant	Yield
Stand count at harvest	1					
Above ground biomass	-0.26518**	1				
Plant height	0.02245^{ns}	0.17644^{ns}	1			
Total seed number per pot	0.22694^{ns}	0.08208^{ns}	0.34022^{ns}	1		
Seed number per plant	0.10149*	0.23364*	0.36699*	0.96640***	1	
Yield	0.07038^{ns}	0.13565^{ns}	0.54466***	0.79766***	0.77109***	1

ns, *, **, *** = Correlation is non-significant at 0.05 %, Correlation is significant at 0.05 %, Correlation is significant at 0.1 %, Correlation is significant at 0.01 % levels of significance respectively.

3.5 Performance of Barley Genotypes

The average grain yield of each genotype was 0.54, 0.16, 0.51,0.67, 0.02, 0.2,0.08, 0.24, 0.3, 0.36(gram per pot) for Accession 217176b, Accession 234911, Accession 240478a, Accession 240478b, HB-1307, Accession 208855b, Accession 27895a, Accession 215453b, Accession 215454a, and Juma Tikur respectively in non-stress soil conditions. The mean grain yield of all 10 (ten) genotypes was 0.324 mg/pot (0.000324 gram/pot) in non-stress soil conditions. The poor fertility of acidic soils is due to a combination of mineral toxicities (Al, Mn, and Fe) and nutrient deficits caused by the leaching or decreased availability of phosphorus (P), calcium (Ca), magnesium (Mg), sodium (Na), and micronutrients such as molybdenum (Mo), zinc (Zn), and boron (B) (Gupta *et al*., 2013). A decrease in pH has resulted in an increase in soluble aluminium and so, aluminium retards root growth, restricts access to water and nutrients. This results in Poor crop growth and reduction in yield as a result of inadequate water and nutrition to support the growth of the crop. In acid soils, excess Al primarily injures the root apex and inhibits root elongation (Sivaguru and Horst, 1998). The poor root growth leads to reduced water and nutrient uptake, and as a result crops grown on acid soils are impaired with poor nutrients and water availability. The net effect of which is reduced growth and yield of crops.

Figure showing early performance differences of barley plants 44 days after sowing under unlimed (left) and limed (right) soli.

Figure showing late performance differences of barley genotypes 79 after sowing under limed (left) and unlimed (right) soil.

4. SUMMARY, CONCLUSIONS AND RECOMMENDATION

Soil Acidity is one of the major threats to crop production and productivity in the highlands of Ethiopia. Soil acidity is expanding in its scope, about 43% out of the total cultivated land is dominated with acidic soil, as a sensitive highland crop, barley productivity is decreasing due to soil acidity and in areas where the problem is severe the crop is going out of production. A Greenhouse pot experiment was conducted to assess the effect of lime application on soil acidity and to identify barley genotypes that are tolerant to soil acidity. The treatment consisted of liming and ten barley genotypes making up of a total twenty treatments laid out in completely randomized design with six replications. Crop phenology, growth parameters, yield and yield components were evaluated. Primary root length, lateral root length, lateral root number, and root dry weight were significantly ($P < 0.05$) affected by the application of lime. Stand count at harvest, above-ground biomass, plant height, total seed number per pot, and seed number per plant were significantly ($P < 0.05$) affected by the application of lime. The results of this experiment have revealed the presence of variability among the genotypes. The study has revealed the impact of soil acidity which can result in the extent of having no yield, which necessitates the use of lime in areas that are prone to acidic soils. Based on the results of this study Accession 215454a, has shown a greater value of relative root length with 73.76 centimeter, which is considered the most suitable approach for early screening of the barley genotypes that are tolerant to soil acidity. Therefore, this Accession that was identified as having the largest root length among the ten genotypes used in this study shall be used for further breeding programs to develop soil acidity tolerant lines.

Based On the Findings of This Study, the Following Key Recommendations Are Forwarded

- The Accession 215454a that showed relative tolerance from early-stage screening can be candidates for further breeding programs to develop barley varieties that are tolerant to acidic soils.
- The Accession 215454a that was identified in this study as soil acidity tolerant line shall be subjected to genomic screening using known primers/markers for this purpose.
- The farmers in the study area shall be provided with the required amount of lime. Unless the crops are going out of production.

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