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Response of barley to liming of acid soils collected from different land use systems of Western Oromia, Ethiopia

Achalu Chimdi[1*], Heluf Gebrekidan[2], Kibebew Kibret[2], Abi Tadesse[3]

[1]Wollega University, P. O. Box 395, Nakemte, Ethiopia

[2]Haramaya University, School of Natural Resources Management and Environmental Sciences, P. O .Box 138, Dire Dawa, Ethiopia

[3]Haramaya University, College of Computational and Natural Sciences, P. O .Box 138, Dire Dawa, Ethiopia

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Abstract

Barley (*Hordeum vulgare* L.) is one of the acid soil sensitive but genetically diverse cereal crop in Ethiopia. A green house pot experiment was conducted to assess the response of barley variety (HB-1307) to application rates and particle sizes of lime. The study employed a randomized complete block design of three-way factorial arrangement of three land use types, six rates of lime (0, 2, 4, 6, 8 and 10 tons ha^{-1}) and two particle sizes(50 and 100 mesh) of lime in three replications. Plant height, fresh biomass (FB), dry biomass (DB), grain yield (GY), harvest index and plant phosphorus uptake were measured and subjected to analysis of variance using SAS software to evaluate the treatment effects. Maximum mean barley yield components for both 50 and 100 mesh lime particle sizes (LPS) were obtained at 6 t ha^{-1} on forest land followed by 8 and 10 t ha^{-1}, respectively, on grazing and cultivated lands. The highest GY obtained from different lime rates for both 50 and 100 mesh LPS were not significantly ($P > 0.05$) different from each other but significantly ($P < 0.05$) different from the yields of other treatments. The mean square estimate responded insignificant ($P > 0.05$) interaction effects between lime rates and LPS; highly significant ($P < 0.001$) between lime rates and land uses; land uses and LPS on barley height, FB, DB, GY and plant phosphorus uptake. The study showed, plant height, FB, DB and GY increased due to liming of the soils under different land uses. However, response pattern of these traits to varying lime application rates varied from one land use to other.

***Corresponding Author:** Achalu Chimdi ✉ achalucc@yahoo.com

Introduction

Some 10,000 years ago, ancient farmers started selecting wild plant species for their own use leading to the domestication of several agricultural crops, some of which including barley are important food and feed crops today. Modern plant breeders continued on the process of developing improved varieties from landraces and sometimes wild species that meets our needs. Recently the use of conventional and molecular breeding techniques and robust statistical procedures helped plant breeders tremendously to increase crop yield or improve quality under different environments (Martin *et al.,* 2006). However, barley yield in Ethiopia is low due to several constraints of both biotic and abiotic natures. Soil acidity and the associated excessive aluminum (Al) accumulation leading to toxicity of various severities is one of major challenge across the barley growing regions of Ethiopia.

Barley is one of the most important cereal crops in the world. Canada, Spain, Turkey, USA, Germany, France, Algeria, Ethiopia and Tunisia are the major barley producing countries. It is believed to have been cultivated in Ethiopia as early as 300 BC. This long history of cultivation and large agro-ecological and cultural diversity in the country has resulted in large number of landraces and rich traditional practices (Zemede, 2002; Martin *et al.,* 2006). In Ethiopia, among cereals, barley is the fifth most important cereal crop next to teff *(Eragrostis tef),* maize *(Zea mays L) sorghum* (*Sorghum bicolor L.*) and wheat (*Triticum aestivum L.*) Central Statistical Authority, 2008/2009). It is the staple food grain for Ethiopian highlanders, who manage the crop with indigenous technologies and utilize different parts of the plant for preparing various types of traditional food such as *Kita, Kolo, Beso, Enjera,* local beverage called *tela* and as an important raw material for many industries. The world has now "re-discovered" barley as a food grain with desirable nutritional composition including some medicinal properties, which is as a chemical agent known to lower serum cholesterol levels (Anderson *et al.* 1991). Its grain contains carbohydrate, starch, protein and small amount of fat (Martin *et al.,* 2006).

Barley can be cultivated and gives better yields in a large number of environmental conditions, except in extreme high rainfall areas which limit the yields (Zemede, 2002; Getaneh, 2007). Barley is cultivated and grown for many purposes throughout the year in the main rainy, residual moisture and small rainy season production systems in the highlands of Ethiopia, However the problem of soil acidity and diseases, decreases the productivity and the national average yields of the crop and becomes as low as 1 t ha^{-1}under farmers' condition in Ethiopia (Berhane *et al.***,** 1996; Central Statistical Authority, 2001/2002). The major production of barley still largely depends on the traditional varieties and farming practices, this is also assumed to be one of the constraints accounting for its low yield. In addition, cultivation of barley in marginal areas with low soil fertility, drought in the lowlands and soil acidity in the highland, diseases and pests are assumed to contribute to the low yield of the crop (Baghizadeh *et al.*, 2007; Ofosu and Leitch , 2009).

Soil acidity and its problem are common in all regions where precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil surface. Although acidification is a natural process in many soil environments, agricultural practices and pollution, mining, and other human activities have accelerated the process (Oguntoyinbo *et.al.*, 1996; Curtin and Syers, 2001). Soil acidity is a common problem that has major ramifications for plant growth and cause significant losses in production, especially in high rainfall areas of Western Oromia Region. Aluminum toxicity to plants is the main concern farmers have with acid soils in the Western Oromia (Fite *et al.,* 2007). Thus, the present study was mainly focused on the acidic soils of different land use types of the western Oromia highland.

In acidic soil areas especially, when the pH drops below 4.5 is dominated by the highly soluble toxic metal like aluminum (Al) in a soil solution. As a result, the concentration and supply of most basic plant nutrients become limited (Eduardo *et al.*, 2005). In acidic soil plant growth is often limited by Al toxicity in acid soil and this is characterized by marked reduction in shoot and particularly roots growth by preventing the plants from using available soil phosphorus (P) effectively. These problems are particularly acute in soils of humid tropical regions that have been highly weathered. According to Sanchez and Logan (1992), one third of the tropics, or 1.7 billion hectares (ha), is acid enough for soluble Al to be toxic for most crop plants. The more acidic the soil, the greater Al, Fe and Mn will be dissolved into soils solutions (Curtin and Syers, 2001).

Currently, there is increasing awareness that soil nutrient depletion from the agro-ecosystem is a very wide spread problem and is an immediate crop production constraint in the country. It is important that soil acidity be understood in terms of its fundamental chemistry so that appropriate soil management and remediation schemes are based on sound principles rather than empirical knowledge that may only be locally relevant. One method in alleviating acid soil constraints to crop production is to modify or supplement soils to remove deficiencies through lime application (Adugna, 1984; Paulos, 2001; Taye, 2001). Liming acid soil may often increases plant P uptake by reducing the amounts of soluble Al rather than any direct effects up on P availability (Curtin and Syers, 2001).

Although barely crop is the major staple food in the highlands, used as source for many nutritional values and industrial applications, there was no much research work done on liming to improve its productivity in acidic soils of different land use systems in the particular site of the present study. Due to the lack of sufficient and detailed scientific research work in the area, barley production and productivity have been decreasing from year to year and the crop is forced to go out of production leading to shortage of barley food sources in most of Western Oromia Region, particularly East Wollega Zone. Therefore, the present study explored the effects of different lime rates and its particle size applied to acid soils on barley yield and yield components under green house conditions.

Materials and methods

study sites

Geographically, the study site is located in the Guto Gida District (East Wollega Zone) of Oromia Regional State, Western highlands of Ethiopia (Fig. 1). The District is situated at a road distance of 310 km from the capital, Addis Ababa within 08^{0} 59'and 09^{0} 06` N latitude and 37$^{0}$ 51`and 37^{0} 09` E longitude.

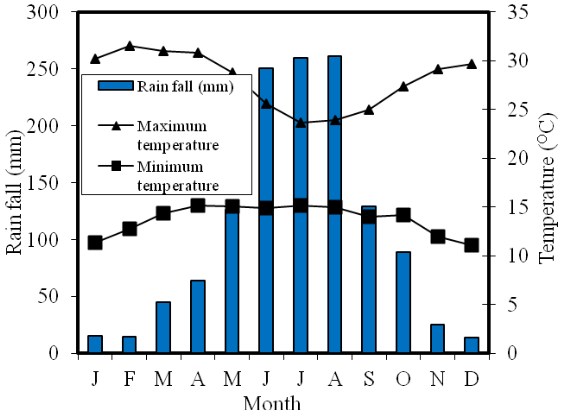


Fig. 2. Mean monthly rainfall and mean maximum and minimum temperatures of the study area based on records at the Nekemte Meteorological Station.

As per the local and traditional practice, the study area is agro-climatically classified as highland (*Baddaa*) and mid-altitude *(Badda Darree).* According to the weather data recorded at the Nekemte Meteorological Station, the average annual rainfall of the study site is 1,780 mm and mean annual minimum and maximum monthly temperatures between 13.75 to 14.50 and 25 to 29 ^{0}C (Fig. 2). The ten years weather information (1996-2007) of the study area shows a unimodal rainfall pattern with annual mean maximum rainfall received in August.

The topography of the study site is mountainous and has a gentle sloping landscape. According to FAO (1990) classification, the soil class of most of the East Wollega areas is Nitosols. Similar to most parts of the country, the economic activities of the local society of the study area are primarily mixed farming system that involves animal husbandry and crop production. The major crops are coffee (*Coffee arabica L.)*, teff *(Eragrostis tef),* barley *(Hordeum vulgare L)*, maize (*Zea mays L.*) and potato *(Solanum tubersoum L.*). These major crops are produced usually once in a year. An exponential increase of the population of the study site resulted in substantial change in land use system. Food crops production took precedence over grazing lands, while most natural forest has been cleared for crop production. This un-environmental farm practices exposed soil to erosion resulting in nutrient loss, land and natural resource degradation.

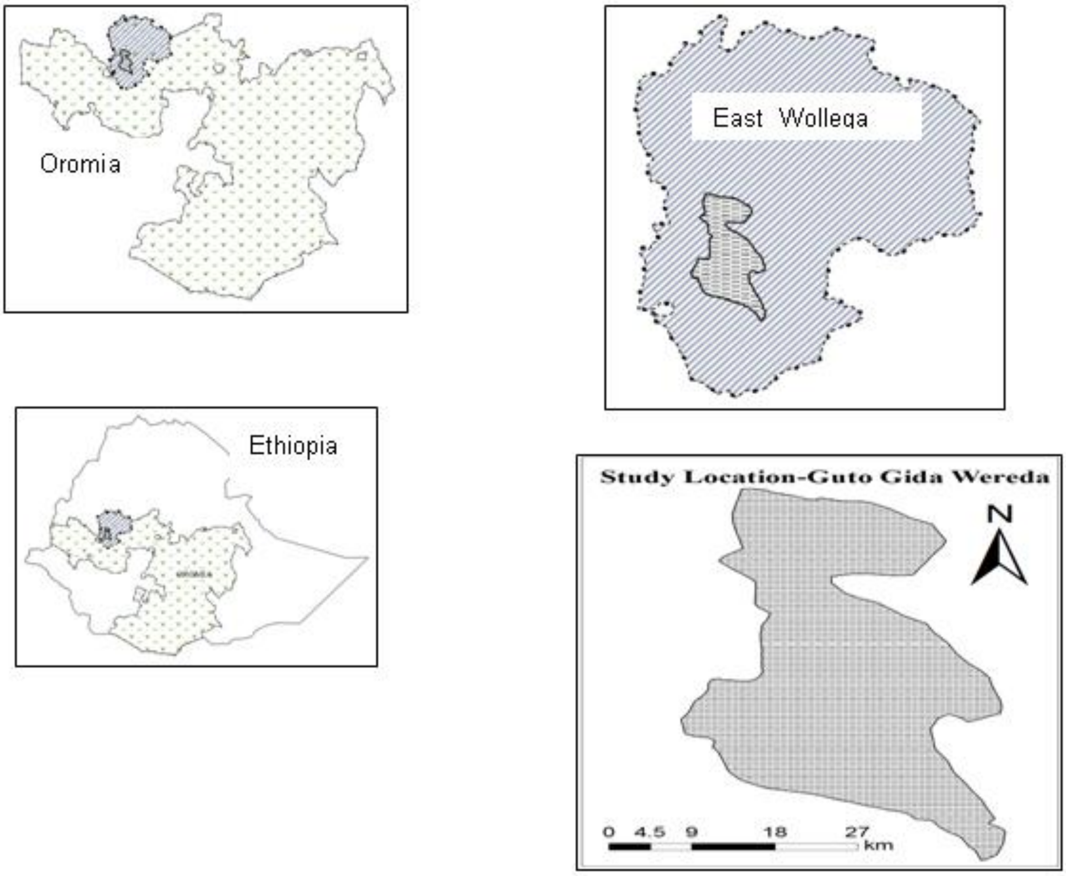


Fig. 1. Study site map.

Site selection and soil sampling

A preliminary survey and field observation was carried out using topographic map (1:50,000) in order to have general information about the land forms, land uses, topography and vegetation cover of the study site. Accordingly, three major representative land use types (natural forest, grazing and cultivated) lands from the Guto Gida District of East Wollega Zone were identified based on their history and occurrence at different landscape positions. This is supported by (Table 1). The composite top soil (0-20 cm) samples from representative site of each land use system were collected, air dried, ground and passed through a 2 mm sieve for analysis. Finally, analysis of soil samples were carried out at Ambo Crop Protection Research Center and Holetta Soil Research

Laboratory Center based on their standard laboratory procedure.

Table 1. Characteristic features of the land use systems of the study site.

Land use systems	Description of the nature of land use type
Forest land	Areas that are covered with dense indigenous natural forest and closed canopies
Grazing land	This includes communal, private grazing lands with little and no vegetations.
Cultivated land	Cultivated with rain fed crops and bounded with scattered settlements.

Soil sample collection and preparation for pot experiment

Two kilograms of composite soil samples were collected from top soil (0-20 cm) depth of natural forest, grazing and cultivated lands of the study site. The soil bulk density was determined from the mass of the soil in 1 ha of land having a depth of 20 cm. The soils were air dried, grounded and sieved through a 2 mm for green house pot experiment establishment. Agricultural lime was collected from Awash Cement Factory located in Zone Three of the Afar Regional State (ARS) of Ethiopia. Its calcium carbonate equivalent (CCE) was determined by acid neutralization method at the Chemistry Laboratory of Ambo University, Ethiopia and found to be 93.7%. The lime was sieved first through 50 mesh and then 100 mesh size lime to be used for pot experiments.

Potting preparation

To evaluate the responses of barley to liming of acidic soils of various land use systems, a green house pot experiment was conducted using potting experiment. The potting was prepared by mixing different proportions of liming rates and 2 kg of soil samples collected from each land use system. The soil and lime were mixed thoroughly and separately on a dry and clean tray, and put in to a green house and incubated for 30 days. After one month of incubation with regular watering as required, all the potting was planted with the crop, barley (*Hordeum vulgare* L.).

Experimental crop and establishment of the experimental design

A six raw dominant food barley variety named as (HB-1307) in East Wollega, 12 seeds per pot were planted in a green house located at Ambo Crop Protection Research Center and thinned to 6 seedlings per pot at 12 days after planting. The soil moisture level was maintained to approximately field capacity**.** Under each land use system, a randomized complete block design with three replications was used for this study. Six levels (0, 2, 4, 6, 8 and 10 ton ha^{-1}) of agricultural lime stone ($CaCO_3$) for each of 50 and 100 mesh particle sizes was mixed with soils collected from the study site.

Data recording and statistical analysis

Data on plant growth and developmental were recorded as required over 130 days experimental period. Plant height was measured for all plants per pot at the late of flowering stage. Fresh Biomass (FB) of all above ground parts for all pots was weighed using a digital balance. Dry biomass (DB) was weighed after air drying all the harvested above ground plant parts for 15 days and attained constant weight at Ambo Crop Protection Research Center of Ethiopia. Plant P uptake of the straw was analyzed as described by Woldeyesus *et al.* (2004) and based on standard laboratory procedures at Holetta Agricultural Research Center of Ethiopia. Data recorded were subjected to analysis of variance (GLM procedure) using SAS software version (SAS Institute, 2004). Duncan's Multiple Range Test (DMRT) was employed to test significance differences of means of treatments.

Results and discussion

Plant height

In the present study, as expected, control plants (with 0 t ha^{-1} lime) were remarkably shorter than the treated ones on soils from all land use systems. A maximum of 62.25 cm mean plant height was recorded on soils of forest land (FL) at lime rate of 6 t ha^{-1} with 100 mesh lime particle size (LPS), which was not significantly different from the one on 50 mesh LPS (Table 2). The highest plant height recorded on soils of grazing land (GL) for 50 mesh LPS at 8.0 t ha^{-1} lime rate was not significantly different from the one for 100 mesh LPS but at 10.0 t ha^{-1} lime rate. On the soils of cultivated land (CL), however, the highest plant height was recorded on 10.0 t ha^{-1} lime rate and not significantly different from each other (Table 2). Depending on the land use type and LPS, plant height increased continuously and significantly in response to the increase in applied lime rate. The soils of FL required less lime (6 t ha^{-1}) to attain highest plant height. The soils of GL required almost 8 t ha^{-1} lime while the CL required the highest lime rate (10 t ha^{-1}) for this study to attain highest plant height.

The increase in plant height with increasing lime rates on acidic soils is highly likely related to the increase in soil fertility and reduction of the toxic concentration of acidic cations. Liming might have reduced the detrimental effect of soil acidity on plant growth due to high concentration of H^+ and Al^{3+} ions in the acid soils. Activities of exchangeable basic (Ca^{2+}, Mg^{2+} and K^+) cations; orthophosphate ($H_2PO_4^-$), nitrate (NO_3^-) and sulfate (SO_4^{2-}) anions with soil organic matter content and their availability to plant roots might be hampered by acidifying ions (Thomas and Hargrove, 1984). With the neutralization of part of the soil acidity by lime application, negative charges of the soil exchange complex are released, and then occupied by basic cations (Oates and Kamprath, 1983; Haynes and Mokolobate, 2001). This improves soil fertility and gives favorable condition for agricultural production such as; increased plant height observed in this study.

Although this study demonstrates an increase in plant height due to the increase in lime rate on soils from all land use systems, it should be noted that highest plant height does not mean that highest grain yield is achieved. An increase in plant height to more than 100 cm makes the plant vulnerable to lodging. Susceptibility to lodging depends on the straw strength, which is mainly governed by the genetic constitution of a variety under consideration; which of course is beyond the scope of the current study. The requirement of various lime rates to attain highest plant height on soils from different land use systems demonstrates that land use has substantial effect on contributing to the decrease in soil fertility. In mitigating soil acidity by liming, highest lime rate is required for CL unlike the FL. This study demonstrates that annual crop production contributes to soil acidification. The increasing trend in changing land use systems such as clearing forest and changing grazing lands to crop cultivation is a series treat to natural resources sustainability and food security.

Table 2. Interaction effect of lime rate, lime particle sizes (LPS) and land use types on plant height (cm) of barley variety HB-1307 with soils from forest, grazing and cultivated lands.

Lime rate (t ha^{-1})	Land use type					
	Forest land		Grazing land		Cultivated land	
	LPS (Mesh)		LPS (Mesh)		LPS (Mesh)	
	50	100	50	100	50	100
2	56.39^{e}	57.00^{de}	44.78^{l}	43.89^{n}	41.11^{o}	42.00^{o}
4	57.44^{d}	57.61^{c}	46.00^{kl}	45.06^{l}	42.88^{o}	42.83^{o}
6	61.67^{ab}	62.25^{a}	51.67^{ij}	52.0^{j}	44.77^{m}	44.66^{m}
8	61.06^{b}	62.22^{a}	54.53^{gh}	53.67^{fgh}	48.00^{k}	47.5^{k}
10	61.48^{ab}	61.17^{a}	54.14^{gh}	54.13^{gh}	50.72^{k}	51.01^{kl}
No lime	54.79^{fg}	54.82^{fg}	44.39^{n}	44.39^{n}	40.00^{o}	40.09^{o}
Mean	58.81	59.20	49.25	48.86	44.58	44.76

Interaction means across treatment combination in same column with same letter are not significantly different at ($P < 0.001$).

Fresh biomass

The fresh biomass (FB) increased ($P < 0.001$) on soils from all land use systems forest land (FL), grazing land (GL) and cultivated land (CL) in response to the increasing lime rate of both 50 and 100 mesh lime particle sizes (LPS) (Table 3). The FB increased consistently up to the lime rate of 6 t/ ha of both FL

50 and FL 100 mesh LPS on FL and GL. However, the FB was almost similar for the 0 to 4 t/ha lime rate and then increased slightly from 6 to10 t/ha lime rate applied to CL. Similar trend in maximum plant height was observed under FL and CL for both 50 and 100 mesh LPS. However, maximum FB was recorded at 6 t/ ha lime rate for both 50 and 100 mesh LPS of soils of GL.

Dry biomass

The lowest DB was recorded in the control treatment without applied lime. The highest total DB (3286 kg ha^{-1}) was recorded on FL with 8 t ha^{-1} lime but almost similar to 3283 kg ha^{-1} DB recorded with 6 t ha^{-1} limes of 100 mesh LPS. Lime application above 6 and 8 t ha^{-1}, respectively, for 50 and 100 mesh LPS did not result in a significant increase of DB on FL. Followed by the highest 2642 kg ha^{-1} DB for trial on GL and 2579 kg ha^{-1} for CL at 10 t ha^{-1} lime of 100 mesh LPS is substantially lower than the one recorded on FL. On soils of GL and CL, the DB increased up to 10 t ha^{-1} lime rate for both 50 and 100 mesh LPS (Table 4). The maximum DB obtained on FL has a yield advantage over the control by 371 kg ha^{-1}. A 377 and 496 kg ha^{-1} DB advantage, respectively, on soils of GL and CL was achieved when the maximum records and the control were compared in each case. The increase in the agronomic yield of barley due to liming of acidic soils of different land use systems may be attributed to the reduction in ion toxicity (H, Al, or Mn) and reduction in nutrient deficiency of Ca and P (Oguntoyinbo *et.al.*, 1996; Curtin and Syers, 2001). A study by Oluwatoyinbo (2005) also indicated the possibility of increasing the crop yield by improving soil acidity through the application of lime, N and P fertilizers. According to this author the increase in crop yield through the application of lime may be attributed to the neutralization of Al, supply of Ca and increasing availability of some plant nutrients like P. These findings may corroborate that liming may positively significant and but improved differently the yield components of all agronomic traits on soils from different land use systems.

Table 3. Interaction effect of lime rate, lime particle size and land use types on barley fresh biomass (kg ha-1) of barley HB-1307 with soils from forest, grazing and cultivated lands.

Lime rate (t/ha)	Land use type					
	Forest land		Grazing land		Cultivated land	
	LPS (Mesh)		LPS(Mesh)		LPS (Mesh)	
	50	100	50	100	50	100
2	3870^{cd}	3441^{c}	3365^{ijkl}	3442^{hij}	2704^{o}	2663^{o}
4	3975^{c}	4153^{ab}	3470^{hi}	3584^{gh}	2779^{o}	2662^{o}
6	4257^{a}	4273^{a}	3751^{f}	3769^{d}	3158^{mn}	3138^{n}
8	4213^{a}	4274^{a}	3682^{fg}	3582^{gh}	3223^{klmn}	3306^{jklm}
10	4024^{bc}	4259^{a}	3693^{fg}	3756^{d}	3253^{lmn}	3316^{ijkl}
No lime	3319^{cd}	3316^{cd}	3248^{klmn}	3248^{ijk}	2678^{o}	2680^{o}
Mean	3945.5	3952.7	3534.8	3563.5	2965.8	2962.5

Interaction means across treatment combination in same column with same letter are not significantly different at (P < 0.001).

Table 4. Interaction effect of lime rate, lime particle size and land use types on barley dry biomass weight (kg ha-1) of barley HB-1307 with soils from forest, grazing and cultivated lands.

Lime rate (t/ha)	Land use type					
	Forest land		Grazing land		Cultivated land	
	LPS (Mesh)		LPS (Mesh)		LPS(Mesh)	
	50	100	50	100	50	100
2	3000^{g}	3051^{ef}	2350^{p}	2404^{no}	2103^{s}	2098^{s}
4	3072^{e}	3155^{d}	2423^{m}	2471^{m}	2161^{q}	2111^{r}
6	3270^{ab}	3283^{a}	2587^{j}	2634^{i}	2426^{n}	2442^{mn}
8	3239^{bc}	3286^{a}	2587^{j}	2637^{i}	2526^{l}	2538^{l}
10	3229^{c}	3273^{ab}	2604^{ij}	2642^{i}	2541^{kl}	2579^{jk}
No lime	2915^{h}	2918^{fg}	2366^{op}	2369^{op}	2085^{s}	2083^{s}
Mean	3120.8	3163.5	2469.7	2528.8	2308	2308.5

Interaction means across treatment combination in same column with same letter are not significantly different at (P < 0.001).

Grain yield

In this study, non amended soil produced the lowest grain yield (GY) on soils from all land use systems. An increase in liming rate did not result in statistically significant increase in grain yield on soils of FL (Table 5). However, the highest mean grain yield (1211 kg ha^{-1}) was obtained from FL with the application of 6 t ha^{-1} lime of 100 mesh LPS. However, on soils of GL and CL, increase in liming rate improved grain yield significantly. The grain yield of 974 and 955 kg ha^{-1} were the highest, respectively, on soils of GL and CL both at the lime rate of 10 t ha^{-1} of 100 mesh LPS (Table 5). When the maximum yield and the yield components on respective controls of all land use types were compared separately, the advantage gained varied from one land use to the other. A yield advantage of 337 kg ha^{-1} was recorded on soils FL; the mean grain yield advantage was 298 and 497 kg ha^{-1} respectively, on soils of GL and CL.

Comparing the lime particle sizes, the 100 mesh LPS increased the grain yield significantly, while an increase of grain yield due to increased lime rate of 50 mesh LPS was not statistically significant. This is probably due to the fact that, the finer the lime the more quickly it will react with the soil solution. A lime with fine particle sizes has more surface area exposed to acid soil. As a result more particles distributed through the soil than an equal weight of lime with coarse material. In general, the grain yield continues to increase per unit of lime applied until 6 t ha^{-1} and 8 t ha $^{-1}$ for both 50 and 100 mesh sizes lime on soils of forest and grazing lands after which, do not result in an increase in the gain yield of barley, instead relatively, it decreases. However, in the cultivated land, for both 50 and 100 mesh sizes lime, all the yield traits such as plant height, FB, DB and GY continued to increase up to 10 t ha^{-1}. Even though there is an increase in the plant P uptake with increasing lime rate above 6 and 8 t ha^{-1} for both 50and 100mesh sizes lime in soils of natural forest and grazing lands, absence of further increase in grain yield with increasing lime rate above 6 and 8 t ha^{-1} for 50 and 100 mesh sizes lime may attributed to the deficiency of some micronutrients, the solubility and availability of which decreases with the increase of soil pH values.

Table 5. Interaction effect of lime rate, lime particle size and land use types on the grain yield (kg ha^{-1}) of barley variety HB-1307 with soils from forest, grazing and cultivated lands.

Lime rate (t ha^{-1})	Land use type					
	Forest land		Grazing land		Cultivated land	
	LPS (Mesh)		LPS (Mesh)		LPS(Mesh)	
	50	100	50	100	50	100
2	1105^{abcd}	1126^{abc}	867^{efgh}	880^{efgh}	775^{hi}	774^{hi}
4	1132^{ab}	1164^{a}	892^{efgh}	840^{efghi}	797^{fghi}	782^{ghi}
6	1209^{a}	1211^{a}	967^{cde}	973^{bcde}	864^{efgh}	901^{efgh}
8	1195^{a}	1209^{a}	955^{def}	971^{bcde}	931^{efg}	949^{def}
10	1188^{a}	1206^{a}	965^{cde}	974^{bcde}	927^{efgh}	955^{def}
No lime	873^{efgh}	875^{efgh}	689^{i}	687^{i}	460^{j}	458^{j}
Mean	1117	1133.5	891.5	887.5	794	803.2

Interaction means across treatment combination in same column with same letter are not significantly different at (P < 0.001).

Table 6. Mean square estimates for plant height, biomass and grain yield as analyzed for two and three factors randomized complete block design on different land use types

Yield Parameters	Mean squares for sources of variations								
	LR(5)	LPS(1)	LU(2)	LR*LU(10)	LPS*LU(2)	LR*LPS(5)	LR*LU*LPS(10)	Error (70)	CV (%)
FB (kg ha^{-1})	797606.34***	77602.08**	11128749.01***	59332.41***	33168.69*	12072.06^{ns}	9854.67^{ns}	8825.38	2.65
DB (kg ha^{-1})	473774.90***	39866.90***	7011251.68***	22967.03***	8820.84***	1105.70^{ns}	1206.31*	561.31	0.89
GY (kg ha^{-1})	323293.09***	19066.89^{ns}	842754.34***	19273.51^{ns}	13282.23^{ns}	11508.47^{ns}	80.36.17^{ns}	9867.87	10.71
Plant height (cm)	264.61***	1.21^{ns}	2033.07***	13.27***	4.14***	0.11^{ns}	0.65*	0.30	1.08
P uptake(mg kg^{-1})	1.92***	0.18***	28.06***	0.08***	0.08***	0.03*	0.02^{ns}	0.01	2.13

LR*LU = Interactions between lime rates and land uses, LPS*LU = Interactions between lime particle sizes and land uses, LR* LPS*LU = Interactions between lime rates, lime particle sizes and land uses, CV = Coefficient of variation; *, **and ***, respectively = Significant at P ≤ 0.05; P ≤ 0.01and at P ≤ 0.001; number in parentheses = Degrees of freedom, ns = Non significant.

Similarly, the increase in the yield of the barley variety HB-1307 due to liming may partially be attributed to the reduction in the toxicity of Al and increase soil pH in these acidic soils. The result of this study corroborates by Oliveira and Pavan (1996) who reported that an increase in grain yield with surface application of lime for four consecutive crop harvests of soybean. A study by Scott *et al.* (2000) and Eduardo *et al.* (2005) suggested that Al toxicity at low pH level seemed to be the major limiting factor in growth of plants in highly weathered acid soil of the tropics. They indicated that favorable crop response to liming appeared to be primarily due to Al deactivation. Ito *et al.* (2009) also reported the positive responses of barley root growth and yield improvements thereby increasing the bio-availability of P and Ca ions on acidic Andosols. They suggested that the Al^{3+} ion toxicity in the soil solution would be deactivated through the amelioration of acidic soil with allophonic materials. In this study, the increased grain yield obtained on soils from all land use types treated with different lime rate as compared to respective controls is highly likely associated with reduction of concentration of exchangeable acidity and enhancement of exchangeable bases, CEC and plant P uptake.

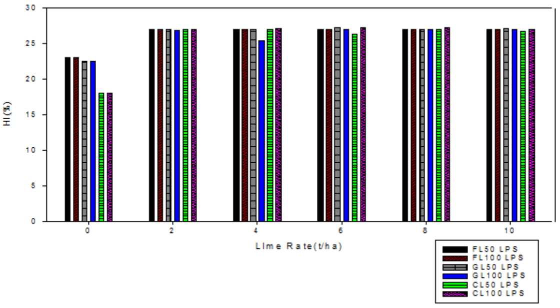
Statistical analysis of the data demonstrated that applied lime rates, interaction between soils from various land use types and between lime rates, LPS and soils from different land use types affected plant height very highly significantly ($P<0.001$) (Table 6). The mean square estimate (Table 6) show that, the main effects between lime rates, between land use types were very highly significant ($P<0.001$) on the FB and DB of barley variety HB-1307 and the interaction effects between lime rates, lime particle sizes and land use types on the FB and DB were significant ($P<0.05$) on barley height DB and insignificant ($P>0.05$) on the FB and GY. Similarly, the mean square estimate (Table 6) of this study show that, the main effects of the applied lime, between land use types and the interaction effects between lime rates and land use types; lime particle sizes and land use types responded very highly significant ($P<0.001$) on the barley variety HB-1307 P uptake. However, the interaction effect of lime rate and lime particle sizes on barely grain yield is not significant ($p>0.05$). The highest plant P uptake obtained from different rates of lime particle sizes are not significantly different from each other but are significantly ($p<0.05$) different from the rest of most other treatments.

Harvest index

In this study, non amended soil produced the lowest harvest index (HI) on soils from all land use systems. The increased percent HI obtained on soils from all land use types treated with different lime rate as compared to respective controls (non amended) ones is highly likely associated with reduction of concentration of exchangeable acidity and enhancement of exchangeable bases, CEC and available P of the soils. The maximum percent harvest indices 26.99 and 27.21% of the barley variety HB-1307 were obtained respectively from soils of FL and GL with the application of 6 t ha^{-1} lime; however, it was 27.22% on soils of CL with the application of 8 t ha^{-1}. In soils of each land use type, the percent HI obtained under the 50 and 100 mesh LPS did not result in statistically significant variation (Fig. 3). The maximum leaf area and final GY obtained under each land use type of the applied lime rate might be an important contributing factor for high barley variety harvest index at 6 t ha^{-1} lime rates for forest and grazing lands. It was 8 t $ha^{-1}$for cultivated land. However, the pattern of increment in percent HI with the applied lime rates and LPS were not uniform and varies from one land use type to the other. The variation may be due to difference in crop spike number and weight of the barley GY.

Plant phosphorus uptake

In this study, soil of FL had higher mean plant P uptake and is more responsive to liming than the response of soils of GL and CL even when un-amended with lime. Liming increased plant P uptake as demonstrated by the highest 6.57 mg kg^{-1} mean P uptake obtained from barley straw harvested from 8 t ha^{-1} lime application of 100 mesh LPS (Table 7). Un-amended soil of GL had higher plant P uptake than that of CL. Increased liming rate improved plant P uptake on both GL and CL. The highest plant P uptake of 5.27 mg kg^{-1} and 5.16 mg kg^{-1} were recorded, respectively, with straw harvested from soil of GL and CL with the application of 8 t ha^{-1} and 10 t ha^{-1} both with 100 mesh LPS (Table 7). The maximum plant P uptake obtained from the application of 6 t ha^{-1} of lime with 100 mesh sizes to soils of FL increased by about 17.8 % plant P uptake over the control. The percentage increment of plant P uptake increment when the maximum plant P uptake due to liming was compared with the one recorded with control on soils of GL and CL were, respectively, 14.04% and 19.19%. The plant P uptake recorded with 100 mesh LPS was higher than that with 50 mesh LPS. The plant P uptake increased continuously with the increased application of lime till 6 t ha^{-1} and 8 t ha^{-1} for both 50 and 100 mesh LPS on soils of FL and GL.



FL= forest land, GL= grazing land, CL= cultivated land, LPS= lime particle sizes at 50 and 100 mesh sizes.

Fig. 3. Harvest Indices of barley crop variety HB-1307from soils of different land use systems.

An increased liming beyond these rates with LPS did not result in an increased plant P uptake. However, in the cultivated land, for 100 mesh sizes lime, the plant P uptake and all other barley yield components relatively increases up to 10 t ha^{-1}. Even though the P uptake of the crop in a cultivated land increases for the application of different lime rates, its amounts of P taken up by the crop is lower than soils of FL and GL. This lower plant P uptake in cultivated land may be attributed to its higher acidity and soil compaction which reduces aeration and pore space in the barley root zone, further reduces plant growth and its P uptake. As soils become increasingly acidic, important nutrients like P become less available to plants. In addition, study by Holford (1997), indicated that due to adsorption, and /or precipitation and domination of the organic form of P in the soil to, more than 80% of P become immobile and unavailable for plant uptake. In the present study, across each the land use system of different lime rate, P uptake was in the range 0.19-0.22% of its dry biomass yields. This is relatively consistent with, P which is making up about 0.2-0.23% of plants dry weight suggested by (Daniel *et al*., (1998). In this study, barley grain yield and its yield components increased differently with the increase of liming rates on soils from different land use types. The increase in the agronomic yields and P up take of barley due to liming may be attributed to the increases in soil pH reduction in the ion toxicity of H^+, Al^{3+} or Mn^{2+} and reduction in nutrient deficiency (Ca, P, or Mo) as well as due to indirect effect of better physical condition of the soil (Haynes, 1984; Kettering *et al*., 2005).

Table 7. Interaction effect of lime rate, lime particle size and land use types on the plant P uptake (mg kg^{-1}) of barley variety HB-1307 with soils from forest, grazing and cultivated lands.

Lime rate (t ha^{-1})	Land Use Type					
	Forest land		Grazing land		Cultivated land	
	LPS (Mesh)		LPS (Mesh)		LPS (Mesh)	
	50	100	50	100	50	100
2	6.01^{d}	6.1^{d}	4.69^{mn}	4.81^{lmn}	4.17^{op}	4.2^{p}
4	6.14^{d}	6.31^{b}	4.84^{klmn}	4.98^{ijkl}	4.31^{o}	4.22^{p}
6	6.54^{a}	6.56^{a}	5.24^{fg}	5.26^{ef}	4.85^{klmn}	4.88^{jklm}
8	6.48^{ab}	6.57^{a}	5.18^{fgh}	5.27^{e}	5.06^{ghij}	4.81^{lmn}
10	6.46^{ab}	6.55^{a}	5.16^{fgh}	5.25^{ef}	5.02^{fghi}	5.16^{fgh}
No lime	5.57^{d}	5.59^{d}	4.55^{no}	4.53^{no}	4.17^{p}	4.18^{p}
Mean	6.20	6.30	4.96	5.02	4.59	4.58

Interaction means across treatment combination in same column with same letter are not significantly different at (P < 0.001).

For different lime rates of both 50 and 100 mesh LPS, the plant P uptake increased across all soils from various land use types with the increase of the soil pH (data not shown). This may be attributed to the fact that, raising the pH of acid soil through liming generally provide more favorable environments for microbial activities and possibly resulted in net mineralization of soil organic P. In line with this, Conyers *et al.* (2003) also reported that, amendment of acid soils with lime to increase pH and reduce the adverse effects of Al on root growth is necessary to prevent soil degradation and the decline in crop productivity. In this study, liming increased P concentration in plant straw and improved soil acidity. Therefore, it is beneficial to apply lime in order to improve barley yield on acid soil area of the study site.

Conclusions

Results from the green house pot experiments demonstrated the effectiveness of the application of agricultural lime improved barley grain yield and its yield components. Although better responses of barley yield components were observed with different lime particle sizes and lime rates, the yield advantage gained varied from one land use type to the other. It was highest in forest land and lowest in soils of cultivated land. The increasing trend in changing land use systems such as clearing forest and changing grazing lands to crop cultivation is a series treat to natural resources sustainability and food security. Use of organic manure and rotating crop production in soil of cultivated land may alleviate the problem of low productivity of soils of cultivated land. However, there was a difficulty of making definite and concrete conclusion from the data of green house pot experiment of soils of different land use systems of same horizon. To generate optimum lime rate recommendations for economically sound barley production, field trials is crucial to validate the findings from green house pot experiment on soils of the studied area and on locations of similar agro-ecology.

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