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Response of barley to liming of acid soils collected from different land use systems of Western Oromia, 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) grown on acid soils 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 (forest, grazing and cultivated lands), 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 and dry biomass, grain yield, harvest index and plant P 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} of lime rate on the forest land followed by 8 and 10 t ha^{-1}, respectively, on grazing and cultivated lands. The mean square estimate revealed highly significant ($P < 0.001$) between lime rates and land uses on barley height, fresh and dry biomass, harvest index and P uptake whilst it showed an insignificant ($P > 0.05$) interaction effects between lime rates and lime particle sizes. There was significant ($P< 0.05$) interactions between lime rates, lime particle sizes and land use types on barley height, dry biomass and harvest index while insignificant ($P > 0.05$) on fresh biomass, grain yields and harvest index. The study showed, plant height, fresh and dry biomass increased due to liming of acidic soils of the three different land uses. However, response pattern of these traits to varying lime application rates varied from one land use to the other.

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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 yields 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 the major challenges 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 the cereals, barley is the fifth most important crop next to teff *(Eragrostis tef),* maize *(Zea mays* L.), *sorghum* (*Sorghum bicolor* L.) and wheat (*Triticum aestivum* L.) (CSA, 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 serves 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). It is cultivated for many purposes throughout the year in the main rainy season, using residual soil moisture at the end of the main rainy season and during the small rainy season in the highlands of Ethiopia, However, the problems of soil acidity and diseases decreases its productivity and national average yields to as low as 1 t ha^{-1} under farmers' condition in Ethiopia (Berhane *et al***.,** 1996; CSA, 2009). The major production of barley still largely depends on the traditional varieties and farming practices, which 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 semi arid and subhumid lowlands, soil acidity in the highlands and diseases and pests throughout the country contribute to the low yield levels 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, environmental 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 the high rainfall areas of western Oromia Region. Aluminum toxicity to plants is the main concern farmers have with acid soils in western Oromia (Fite *et al.,* 2007). Thus, the present study was mainly focused on the acidic soils of different land use types of the highlands in western Oromia.

Acidic soil solutions especially when the pH drops below 4.5 are dominated by aluminum (Al) ion which is highly soluble under such soil reaction and phytotoxic metal. As a result, the concentration and supply of most basic plant nutrients become limited (Eduardo *et al.*, 2005). In acidic soils, plant growth is often limited by Al toxicity 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).

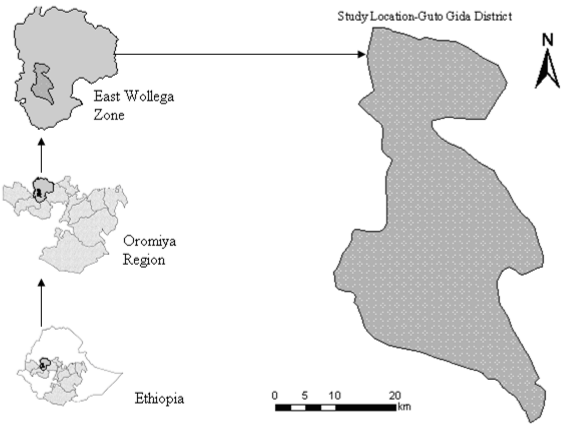

Fig. 1. Location map of study area.

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 on 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 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 areas of western Oromia Region, particularly in East Wollega Zone. Therefore, the present study explored the effects of different lime rates and its particle size applied to acid soils from differing land use types on barley yield and selected yield components under green house conditions.

Materials and methods

Study sites

The study was conducted in the Guto Gida District (East Wollega Zone) of Oromia Regional State, western highlands of Ethiopia (Figure 1). The District is situated at a road distance of 310 km from the capital, Addis Ababa, within 08° 59'and 09° 06` north latitude and 37° 09` and 37° 51`east longitude. 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 1300 mm and the monthly mean minimum and maximum temperatures between 11.25 to 14.50 and 25.00 to 29.00 °C, (Fig. 2). The ten years (1996-2007) weather information of the study area shows a unimodal rainfall pattern with annual mean maximum rainfall received in the month of August.

The topography of the study site is mountainous and has a gentle sloping landscape. According to the FAO classification legend, the main soil group of most of the East Wollega areas is Nitosols. Similar to most parts of the country, the economic activities of the local community of the study area are primarily mixed farming system that involves crop production and animal husbandry. The major crops grown in the area are coffee (*Coffee arabica L.)*, teff *(Eragrostis tef)*, barley *(Hordeum vulgare L)*, maize (*Zea mays L.*) and potato *(Solanum tubersoum L) and* are usually produced once in a year. An exponential increase of the human and livestock populations at the study site has resulted in a substantial change in land use system whereby Food crops production took precedence over grazing lands, while most natural forest has been cleared for crop production. This environmental unfriendly farm practices and the high rain fall amounts have exposed the soils to sever erosion resulting in nutrient loss, soil acidity and overall land and natural resource degradation.

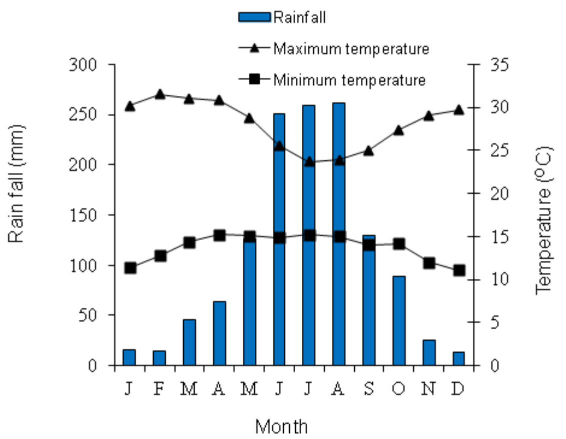

Fig. 2. Mean monthly rainfall and mean maximum and minimum temperatures of the study area based on records at the Nekemte Meteorological Station.

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 (Table 1) from the Guto Gida District of East Wollega Zone were identified based on their history and occurrence at different landscape positions. Composite surface (0-20 cm) soil samples were collected from representative site of each land use system and air dried ground and passed through a 2 mm sieve and analyzed for laboratory analysis of selected soil chemical properties (Chimdi *et al.*, 2012). Analysis of soil samples were carried out at the Ambo Crop Protection Research Center and the Holetta Agricultural Research Centers Soil Laboratory based on their standard laboratory procedure (Table 2).

Table 1. Description of the land use types considered in the study.

Land use type	Description
Forest land	Areas covered with long and dense trees forming closed canopy with dense indigenous natural forest.
Grazing land	Areas comprising of communal and private lands with little and no vegetations used for livestock grazing and brewing purpose.
Cultivated land	Areas cultivated for annual crop production conditions. These areas contain very few scattered trees deliberately left as traditional agroforestery trees and are often bounded with strips of trees and scattered settlements.

Soil sample collection and preparation for pot experiment

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

Table 2. Selected chemical properties of the experimental soils.

	Land use types		
Soil properties	Forest land	Grazing land	Cultivated land
pH (H_2O)	5.25	5.15	4.56
Total phosphorus (Olsen) (mg kg^{-1})	975.60	908.00	553.40
Exchangeable Ca (cmol(+) kg^{-1})	7.43	5.13	2.94
Exchangeable Mg (cmol(+) kg^{-1})	1.25	1.14	0.43
Exchangeable K (cmol(+) kg^{-1})	0.51	0.46	0.39
Exchangeable Na (cmol(+) kg^{-1})	0.47	0.41	0.38
CEC (cmol(+) kg^{-1})	28.20	22.20	19.2
Base saturation (%)	34.22	32.61	21.5
Acid saturation (%)	22.59	34.19	71.7

Potting experimental crop and design

To evaluate the responses of barley to lime rates and lime particle sizes of acidic soils from three different land use types, a green house pot experiment involving 2 kg of surface (0-20 cm) was conducted. Accordingly, the respective lime rates of the specific lime particle sizes were mixed thoroughly on a dry and clean tray, potted and the pots were placed in a green house and incubated for 30 days. After one month of incubation with regular watering as required, all the pots were planted.

The study employed three-way factorial combination of three land use types (forest, grazing and cultivated lands), six rates (0, 2, 4, 6, 8 and 10 tons ha^{-1}) of agricultural limestone ($CaCO_3$) and two particle sizes (50 and 100 mesh sizes) of lime as treatments. The experiment was then laid down in a randomized complete block design with three replications. The test crop used was a six raw barley (variety HB-1307) which is a dominant food barley crop variety cultivated in East Wollega Zone of Oromia Region. Twelve (12) seeds of the test crop per pot were planted in a green house at the Ambo Crop Protection Research Center and thinned to 6 seedlings per pot at 14 days after seedling emergence. The soil moisture level was maintained at approximately the field capacity.

Data recording and statistical analysis

Data on plant height and some yield components and yield growth were recorded as required over 130 days of experimental period. The plant heights of all plants in a pot were measured using a ruler from the base to the tip of the owns at the late heading stage. The fresh weight of the plants per pot was determined using a digital balance after cutting the plants just at the ground level and considered as total fresh above ground biomass. Similarly, the dry biomass was weighed after air drying all the harvested above ground plant parts of the plants of each pot for 15 days and/or attained constant weight at the Ambo Crop Protection Research Center. Grain yield per pot was determined after carefully separating the grain from the straw and cleaned and adjusted to 12.5% seed moisture content using a hand seed moisture tester instrument. Harvest index was obtained as the ratio of the grain yield per pot to the total dry above ground biomass including the grain yield.

Plant P uptake was analyzed from an extract obtained through calcinations (wet digestion) of the tissue samples which were dried and ground to pass a standard mesh size. Finally, it was quantified using spectrophotometer at 460 ηm wavelength after adding molybdate and metavandate for color development as described by Woldeyesus *et al.* (2004) and based on standard laboratory procedures at the Holetta Agricultural Research Center. Data recorded were subjected to analysis of variance (GLM procedure) using SAS software version (SAS Institute, 2004). Duncan's Multiple Range Test was employed to test significant differences between means of treatment combinations.

Results and discussions

The output of the statistical analysis of the data demonstrated that applied lime rates, interaction between soils from various land use types and between lime rates, lime particle sizes and soils from different land use types affected plant height very highly significantly ($P < 0.001$) (Table 3). The mean square estimate show that, the main effects between lime rates, between land use types were very highly significant ($P < 0.001$) on the fresh biomass and dry biomass of barley variety HB-1307 and the interaction effects between lime rates, lime particle sizes and land use types were significant ($P < 0.05$) on the barley height, dry biomass, and harvest index but insignificant ($P > 0.05$) on the fresh biomass, grain yield and P up take (Table 3). Similarly, the main effects of the applied lime, between land use types and the interaction effects between lime rates and land use types (Table 7) responded very highly significant ($P < 0.001$) on the yield parameters of barley. Except the barley P up take and grain yields, the interaction effect of lime rates and lime particle sizes is not significant ($p > 0.05$) on the other yield parameters of barley.

Table 3. Mean square estimates for plant height, fresh and dry biomass, grain yield and P uptake as analyzed complete block design on different land use types.

Yield Parameters	Mean squares for sources of variations								
	LR (5)	LPS (1)	LU (2)	LR*LPS(5)	LR*LU(10)	LPS*LU(2)	LR*LPS*LU(10)	Error (70)	CV (%)
Plant height (cm)	254.6^{***}	3.12^{**}	2027^{***}	0.5^{ns}	13.3^{***}	4.7^{***}	0.6^{*}	0.3	1.1
FB (kg ha^{-1})	797606.3^{***}	77602.1^{**}	11128749.0^{***}	12072.1^{ns}	59332.4^{***}	33168.7^{*}	9854.7^{ns}	8825.4	2.6
DB (kg ha^{-1})	479643.1^{***}	21112.0^{***}	6836366.6^{***}	842.4^{ns}	26135.7^{***}	4206.5^{***}	1071.1^{*}	438.4	0.8
GY (kg ha^{-1})	342168.3^{***}	2770.5^{**}	1023784.1^{***}	703.6^{*}	9637.0^{***}	373.5^{ns}	596.5^{ns}	268.1	1.7
Harvest Index (%)	92.1***	0.003ns	7.6***	0.3ns	7.6***	0.4ns	0.3*	0.2	1.5
P uptake (mg kg^{-1})	1.9^{***}	0.2^{***}	28.1^{***}	0.03^{*}	0.08^{***}	0.07^{***}	0.02^{ns}	0.2	2.1

Number in parentheses = Degrees of freedom; LR = Lime rate; LU = Land use; LPS = Lime particle size; CV = Coefficient of variation; FB = Fresh biomass; DB = Dry biomass; GY = Grain yield; *, **and *** = Significant at $P \leq 0.05$; $P \leq 0.01$ and at $P \leq 0.001$, respectively; ns = Non-significant

Plant height

In the present study, the interaction effects of lime rates, lime particle sizes and land use types was significant ($P < 0.05$) on plant height (Table 3). The plants in the control plots were 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 at lime rate of 6 t ha^{-1} with 100 mesh lime particle size which was not significantly different from the one on 50 mesh lime particle size. The highest plant height recorded on soils of grazing land for 50 mesh at lime particle size 8.0 t ha^{-1} lime rate was not significantly different from the one for 100 mesh lime particle size but at 10.0 t ha^{-1} lime rate. On the soils of cultivated land however, the highest plant height was recorded on 10.0 t ha^{-1} lime rate and not significantly different from each other (Table 5). Depending on the land use types and lime particle sizes, plant height increased continuously and significantly in response to the increase in applied lime rate. The soils of forest land required less lime (6 t ha^{-1}) to attain highest plant height. The soils of grazing land required almost 8 t ha^{-1} lime while the cultivated land 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).

Table 4. Effects of lime rates on Plant height, fresh biomass, dry biomass, grain yields, harvest index and P-uptake of barley variety HB-1307.

Lime rate (t ha-1)	Plant height	Fresh biomass	Dry biomass	Grain yield	Harvest index	P uptake
0	46.8f	3273.4c	2452.7e	675.2e	21.3c	4.8d
2	47.5e	3331.3c	2499.6d	917.8d	26.6b	4.9c
4	48.9d	3437.1b	2565.6c	934.5c	26.8ab	5.1b
6	52.8c	3711.8a	2773.6b	1018.6b	26.91ab	5.55a
8	54.5b	3721.8a	2802.5a	1035.2a	26.92ab	5.56a
10	55.6a	3724.6a	2811.4a	1036.1a	26.93ab	5.59a

Means with same letters in same column of each yield parameter are not significantly different at P> 0.001

Table 5. Interaction effect of lime rate, lime particle sizes (LPS) and land use types on plant height (cm) of barley variety HB-1307.

Lime rate (t ha-1)	Land use type					
	Forest land		Grazing land		Cultivated land	
	50 LPS	100 LPS	50 LPS	100 LPS	50 LPS	100 LPS
0	50.79f	56.06e	44.39lm	44.56lm	40.00p	41.33o
2	56.39e	57dc	44.78lm	43.89m	41.10o	42.00no
4	57.44d	59.61c	44.78lm	42.89n	42.83n	44.66lm
6	61.67ab	62.25a	51.67hi	52.00h	46.00k	45.06l
8	61.05b	62.22a	54.53fg	53.89g	48.00j	47.50j
10	61.48ab	62.17a	54.13fg	54.14fg	50.72i	51.01i

Interaction means across all columns and rows followed by the same letter are not significantly different at P >0. 001

Table 6. Interaction effect of lime rate, lime particle size (LPS) and land use types on barley dry biomass weight (kg ha-1)

Lime rate(t ha-1)	Land use type					
	Forest land		Grazing land		Cultivated land	
	50 LPS	100 LPS	50 LPS	100LPS	50 LPS	100 LPS
0	2912g	2916g	2351o	2368o	2080q	2078q
2	3000f	3051e	2362o	2404n	2093q	2098q
4	3072e	3155d	2423mn	2471l	2111q	2161q
6	3270ab	3287a	2587j	2634hi	2426mn	2442lm
8	3239bc	3283a	2589j	2637hi	2526k	2538k
10	3229c	3273ab	2604ij	2642h	2541k	2579j

Interaction means across all treatment combinations (columns and rows) followed by same letter are not significantly different at P >0.001

Table 7. Interaction effects of lime rates and land use types on Plant height, fresh biomass, dry biomass, harvest index and P-uptake of barley.

Lime rate(t ha^{-1})	Land use type		
	Forest land	Grazing land	Cultivated land
	Plant height		
0	55.42^{d}	44.34^{j}	40.67^{m}
2	56.69^{c}	44.33^{j}	41.56^{l}
4	58.52^{b}	45.53^{i}	42.86^{k}
6	61.96^{a}	51.83^{f}	44.72^{j}
8	61.64^{a}	54.10^{e}	47.75^{h}
10	61.81^{a}	54.13^{a}	50.86^{g}
	Fresh biomass		
0	8207de	3318^{hi}	2680^{k}
2	3907^{d}	3404^{h}	2684^{k}
4	4064^{c}	3527^{g}	2720^{k}
6	4266^{c}	3760^{e}	3148^{j}
8	4244^{ab}	3045^{f}	3277^{i}
10	4141^{bc}	3725^{ef}	3269^{i}
	Dry biomass		
0	2914^{e}	2365^{j}	2079^{l}
2	3026^{d}	2377^{j}	2096^{l}
4	3114^{c}	2447^{i}	2136^{k}
6	3277^{a}	2610^{f}	2434^{i}
8	3263^{ab}	2613^{f}	2532^{h}
10	3251b	2623^{f}	2560^{g}
	Harvest index		
0	23.08^{c}	22.65^{c}	18.20^{c}
2	26.80^{a}	26.70^{a}	26.89^{a}
4	26.95^{a}	26.15^{a}	26.92^{a}
6	27.04^{a}	27.09^{a}	26.59^{a}
8	26.92^{a}	26.94^{a}	26.94^{a}
10	26.91^{a}	26.96^{a}	26.88^{a}
	P-uptake		
0	5.80^{d}	4.63^{i}	4.16^{j}
2	6.05^{c}	4.75^{hi}	4.18^{j}
4	6.22^{b}	4.91^{g}	4.26j
6	6.55^{a}	5.20^{ef}	4.86^{gh}
8	6.52^{a}	5.25^{e}	4.93^{g}
10	6.50^{a}	5.22^{e}	5.09^{f}

Fresh biomass

The fresh biomass increased on soils from all land use systems in response to the increasing lime rate of both 50 and 100 mesh lime particle sizes but its interactions between lime rate, lime particle sizes and land use types have no significant ($P > 0.05$) effects on fresh biomass (Table 3). However, for all land use types, the lime rates have highly significant ($P < 0.001$) effect on fresh biomass (Table 4). The fresh biomass increased consistently up to the lime rate of 6 t/ ha of both forest land 50 and 100 mesh lime particle sizes on forest and grazing land. However, it 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 cultivated land. Similar trend in maximum plant height was observed under forest land and cultivated land for both 50 and 100 mesh lime particle sizes. However, maximum fresh biomass was recorded at 6 t/ ha lime rate for both 50 and 100 mesh lime particle size of soils of grazing land.

Dry biomass

The interaction effects of lime rates, lime particle sizes and land use types have significant ($P < 0.05$) effects on the barley dry biomass (Table 3). The lowest dry biomass was recorded in the control treatment. The highest total dry biomass (3286 kg ha^{-1}) was recorded on forest land with 8 t ha^{-1} lime but almost similar to 3283 kg ha^{-1} dry biomass recorded with 6 t ha^{-1} limes of 100 mesh lime particle size. Lime application above 6 and 8 t ha^{-1}, respectively, for 50 and 100 mesh lime particle size lime particle size did not result in a significant increase of dry biomass on forest land. Followed by the highest 2642 kg ha^{-1} dry biomass for trial on grazing Land and 2579 kg ha^{-1} for cultivated land at 10 t ha^{-1} lime of 100 mesh lime particle size is substantially lower than the one recorded on forest land. On soils of grazing and cultivated lands, the dry biomass increased up to 10 t ha^{-1} lime rates for both 50 and 100 mesh lime particle sizes (Table 6). The maximum dry biomass obtained on forest land has a yield advantage over the control by 375 kg ha^{-1}. A 274 and 501 kg ha^{-1} dry biomass advantage, respectively, on soils of grazing and cultivated lands 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 acidity (H and Al) ions 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.

Grain yield

In this study, the interaction between lime rate and land use types have highly significant ($p < 0.001$) effect the grain yield, however, insignificant ($P > 0.05$) on the interaction effects of lime rates, lime particle sizes and land use types (Table 3). An increase in liming rate did not result in statistically significant increase in grain yield on soils of forest land. However, the highest mean grain yield (1211 kg ha^{-1}) was obtained from forest land with the application of 6 t ha^{-1} lime of 100 mesh lime particle size. However, the grain yield of 974 and 955 kg ha^{-1} were the highest, respectively, on soils of grazing and cultivated land both at the lime rate of 10 t ha^{-1} of 100 mesh lime particle size. 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 338 kg ha^{-1} was recorded on soils forest land; the mean grain yield advantage was 287 and 487 kg ha^{-1} respectively, on soils of grazing and cultivated lands.

Comparing the lime particle sizes, the 100 mesh increased the grain yield significantly, while an increase of grain yield due to increased lime rate of 50 mesh lime particle size 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, fresh biomass, dry biomass and grain yield almost continued to increase up to 10 t ha^{-1}. Although, there is an increase in the plant P uptake with increasing lime rate above 6 and 8 t ha^{-1} of 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} of lime may attributed to the deficiency of some micronutrients, the solubility and availability of which decreases with the increase of soil pH values.

Table 8. Interaction effect of lime rate, lime particle size and land use types on the harvest index (%) of barley variety HB-1307.

Lime rate(t ha^{-1})	Land use type					
	Forest land		Grazing land		Cultivated land	
	50 LPS	100 LPS	50 LPS	100 LPS	50 LPS	100 LPS
0	23.03^{d}	23.10^{d}	22.41^{d}	22.89^{d}	18.16^{e}	18.24^{e}
2	26.66^{ab}	26.95^{ab}	26.62^{ab}	26.79^{ab}	26.87^{ab}	26.93^{ab}
4	26.96^{ab}	26.93^{ab}	26.92^{ab}	25.37^{c}	26.80^{ab}	27.02^{ab}
6	27.13^{a}	26.94^{ab}	27.21 ^{a}	26.98^{ab}	26.24^{b}	25.95^{ab}
8	26.95^{ab}	26.96^{ab}	26.95^{ab}	26.93^{ab}	26.93^{ab}	26.95^{ab}
10	26.92^{ab}	26.92^{ab}	27.03^{ab}	26.93^{ab}	26.74^{ab}	27.03^{ab}

Interaction means across all treatment combinations (columns and rows) followed by same the letter are not significantly different at $P > 0.001$

Similarly, the increase in the yield of barley 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. Results of Studies 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 rates 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.

Harvest index

In this study, non amended soil produced the lowest harvest index on soils from all land use systems. The increased percent harvest index obtained on soils from all land use types treated with different lime rate as compared to respective 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 27.13 and 27.21% of the barley variety HB-1307 were obtained respectively from soils of forest land and grazing land with the application of 6 t ha^{-1} lime; however, it was 27.03% on soils of cultivated land with the application of 10 t ha^{-1}. In soils of each land use type, the *p*ercent harvest index obtained under the 50 and 100 mesh lime particle sizes did not result in statistically significant variation (Table 8). The maximum leaf area and final grain yield 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 10 t ha^{-1} for cultivated land. *However, the pattern of increment in percent harvest index with the applied lime rates and* lime particle size *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 grain yield.

Plant P uptake

In this study, soil of forest land had higher mean plant P uptake and is more responsive to liming than the response of soils of grazing land and cultivated land. Liming increased plant P uptake as demonstrated by the highest 6.55 mg kg^{-1} from barley variety harvested from 8 t ha^{-1} lime application of 100 mesh lime particle size. Un-amended soil of grazing land had higher plant P uptake than that of cultivated land. The highest plant P uptake of 5.27 mg kg^{-1} and 5.09 mg kg^{-1} were recorded, respectively, with barley straw harvested from soil of grazing and cultivated lands with the application of 8 t ha^{-1} and 10 t ha^{-1} (Table 7). The maximum plant P uptake obtained from the application of 6 t ha^{-1} of lime to soils of forest land increased by about 11.5 % 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 grazing and cultivated lands were, respectively, 12% and 19 %. The plant P uptake recorded with 100 mesh lime particle sizes was higher than that with 50 mesh lime particle sizes. 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 lime particle sizes on soils of forest and grazing lands.

An increased liming beyond these rates with lime particle sizes 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 forest and grazing lands. 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 of 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, Pup take which is making up about 0.2- 0.23% of plants dry weight suggested by (Daniel *et al*., (1998). 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). 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 soils of the study site.

Conclusions

The Results from the green house pot experiments demonstrated the application of agricultural lime improved barley grain yield and its yield components, although the responses observed with different lime particle sizes and lime rates and the yield advantages gained varied from one land use type to the other. It was highest in the forest land and lowest in the soils of the cultivated land. Use of lime, organic fertilizer sources and rotating crop production in the cultivated lands may alleviate the problem of low productivity of the soils. However, it is difficult to make definite and concrete conclusion based on findings of a green house pot experiment. To generate optimum lime rate recommendations for economically sound barley production, field trials on different soil type and different crop species as well as varies across locations are crucial to validate the findings from the trials of green house pot experiments on soils of the study areas and on locations of similar agro-ecology.

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