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LIME AND NPK EFFECT ON SOIL ACIDITY AND YIELD OF BARLEY IN DIFFERENT ACID SOILS OF SOUTHERN REGION, ETHIOPIA

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ABSTRACT

In southern region acid soils cover appreciable areas of arable land and reduce or cause total failure of some sensitive crop yield. Barley is the most sensitive crop to soil acidity. A field experiment was carried out for three years (2007 to 2009) on loam Haplic Alisols of Chencha and clay loam Dystric luvisols of Hagerselam, Southern Region of Ethiopia, to evaluate the response of food barley and change in soil acidity to applied lime and NPK fertilizers. The study comprises three levels of calcitic lime (no lime, half and full doses of the recommend lime rate) and five different combinations of N-P-K fertilizers at the rate of 46-40-50 kg ha-1 (no fertilizer, NP, NK, PK, and NPK). The experimental design was factorial randomized complete block with three replications. Results obtained showed that application of lime and all combinations of fertilizers, either alone or combined, significantly ($p < 0.05$) increased barley yield over untreated control. The highest barley grain yield (2792 and 3279.3 kg ha^{-1}) was recorded from combined application of NPK and half the recommended lime rate (3.84 and 0.85 t/ha at Chencha and Hagerselam, respectively) in 2007 when lime is freshly applied. In 2008 and 2009, when lime is used as residual effect, highest barley grain and biomass yields were obtained from applications of full lime rate + NPK. NPK application either alone or with lime gave better barley yield, which might suggest the importance of balanced (NPK) fertilizer application. The efficiency of fertilizers increased in the order of NP<NK<PK<NPK for Alisols of Chencha and NK<PK<NP<NPK for Luvisols of Hagereselam, with the effects accentuated more in the limed than in the un limed treatments. Liming 1.75 to 7.68 Mg ha^{-1} decreased the concentration of surface (0-30 cm) soil exchangeable aluminum by 50 to 80 per cent and increased pHw by 0.5 to 1.3 units after one month of application. Half and full recommended lime rates had statistically similar direct and residual effect on barley yield in both investigated soils; hence, applying half the recommended lime rate can be used without significant yield loss.

Keywords: Alisols, Luvisols, Barley, Lime, NPK fertilizers.

1. INTRODUCTION

In all humid climates, acidification of soil is a natural process and one that has major ramifications for plant growth and these problems are particularly acute in humid tropical regions that have been highly weathered [1]. As soils become more acid, particularly when the pH drops below 4.5, it becomes increasingly difficult to produce food crops. In acid mineral soils of tropical climate regions, the high aluminum (Al) content, associated to high acidity and low fertility, is one of the main constraints for agricultural production [2], since toxic concentrations of Al are often concerned as having detrimental effects on plants. Sanchez and Logan [3] reported that one third of the tropics, or 1.7 billion hectares, is acid enough for soluble aluminum to be toxic for most crop plants.

Though many surface soils of Ethiopia are already acidic in their natural state, current systems of agricultural land use aggravated the acidification. Barley thrives well in pH range of 5.5-7.0 [4] and relatively lower Al-toxicity and exchangeable Al^{3+} solubility above pH value of 5.0. The increasing trend of soil acidity and exchangeable Al in arable and abandoned lands are attributed to intensive cultivation and continuous use of acid forming inorganic fertilizers. If it is not corrected, acidification can continue until irreparable damage takes place in the soil

Also the status and magnitude of acidity in Ethiopia are not well known some 40% of arable lands were reported as acidic [5]. Large areas of acidic soils occur in southern and south western regions of Ethiopia.

In southern region Alisols, Nitisols and Fluvisols (FAO classification) are among dominant acidic soils. Hossana, Soddo, Chencha, and Hagereselam are some of the reported areas that are severely affected by soil acidity in the region. Critical acidity problems in eastern and western Oromia were also reported [6]. A number of adverse effects such as loss of crop diversity, decline in the yield of existing crops, lack of response to ammonium phosphate and urea fertilizers, and complete failure of crop yield were reported by [7]. Research results showed that on Alisols of Chencha, barley, wheat and other crops yields are too low or zero even in application of optimum rate of NP fertilizers [8].

Rutugna and Neel [9] and Verma and Singh [10] reported that crops responded to combined application of lime and fertilizers in acid soils. Disappointing results from liming trials due to miss management of lime and not complimenting by appropriate fertilizer use to correct other critical factors were also reported elsewhere. It is generally agreed that liming is essential to overcome soil acidity but should be combined with inorganic or organic fertilizer in order to get adequate production. Adequate information on the effect of lime and NPK alone or in combination on the yield of barley in southern region is lacking. So, the present investigation was under taken to study the effect of lime and NPK fertilizers on yield and yield components of barley.

2. MATERIALS AND METHODS

2.1. Description of Study Sites

A field experiment was carried out from 2007 to 2009 to see the effects of lime and NPK fertilizers applied alone or combined on the yield and yield components of barley. The test soils were loam Haplic Alisols of Chencha ($38^{0}4'$ E and $5^{0}55'$ N, alt. 2900 m a s l) and clay loam Dystric Luvisols of Hagereselam ($38^{0}27'44''$ and $06^{0}26'59''$, alt. 2650 m a s l). The climate of both sites is sub humid type with bi-modal rainfall pattern. The main rainy season is June to September and means annual precipitation of both sites range from 1000-to- 1300 mm.

2.2. Soil Sampling and Lime Requirement Determination

Initially on composite soil sample from each site was collected from all experimental sites before lime application and subjected to analyses of acidity attribute and other soil physic-chemical properties. The analysis results are depicted in Table 1. Lime Requirement (LR) of each site and each crop was determined based on exchangeable acidity (Ex. Ac) after Kamprath [11] using the following formula:

$$\text{LR, } CaCO_3 \text{ cmolc kg}^{-1} \text{ soil} = 2.0 * \text{Ex. Ac. Cmolc} \quad (1)$$

$$\text{LR, } CaCO_3 \text{ (Mg ha}^{-1}) = (2.0 * \text{Ex. Ac}^{+} * 10^{6} * 2) / (2 * 1000) \quad (2)$$

Where Ex Ac = exchangeable acidity ($Al^{+3} + H^{+}$) cmolc that is to be neutralized.

2.3. Experimental Design

A factorial experiment was laid down in randomized complete block design (RCBD) in three replications. The treatments comprise 3 levels of lime (No lime, half and full doses of the recommended lime rate) and five combinations of N-P-K fertilizers (untreated control, NP, NK, PK, and NPK) at the rate of 46-40-50 kg ha^{-1}, respectively. The half and full doses of lime used were 0.85 and 1.75 Mg ha^{-1} at Hagerselam site, whereas 3.84 and 7.68 Mg ha^{-1} at Chencha site. Gross plot size was 4 meter by 4 meter. In 2007 calcitic lime (CaCO3) was hand broadcasted and thoroughly mixed with soils one month before planting of the test crop. In 2008 and 2009 lime was used as residual effect. Whole dose of P and K fertilizers and half dose of N fertilizer were basally applied at planting after one month of lime application. Permanent plot were used in 2008 and 2009. The rest half of N fertilizer was top dressed at full tillering. Local barley varieties at each site were planted in main cropping season. All agronomic operations were done when necessary. Data on yield and yield contributing parameters were collected and ANOVA was computed using SAS computer software [12].

Soil samples also were collected before planting and after harvesting of the test crops and dried crushed with mortar, passed 2 mm sieve and subject to soil physic-chemical analysis. The results are depicted in (Table 2).

Particle size distribution (soil texture) was analyzed by modified Bouyoucos hydrometer method [13]. Soil pH was measured using a glass combination pH meter in the supernatant of 1:2.5 soil to solution ratio of H_2O and 1 N KCl. Soil organic carbon was determined by the wet oxidation method as described by Walkley and Black [14]. Determination of total nitrogen was performed by the Kjeldahl method [15]. Exchangeable cations were extracted with 1 M ammonium acetate at pH 7.0 following standard methods for each parameter and CEC was determined using ammonium saturated soil using distillation and back titration with 0.1 N H_2SO_4. Exchangeable acidity (Al^{3+} + H^+) was determined by saturating the soil samples with potassium chloride solution, filtering and titrating with sodium hydroxide as described by McLEAN [2] whereas effective cation exchange capacity (ECEC) was determined by the summation of exchangeable bases and exchangeable acidity. Al- saturation per cent were computed from ECEC. Available P content was measured after Bray II [16].

3. RESULTS AND DISCUSSION

Results of soil analysis were depicted in Tables 2 and 3. Soils of study sites were strongly acidic with low available P and available K. Soil organic C was low and TN was low to medium. Base saturation per cent of the soil is low but relatively higher Al- saturation was recorded in Alisols of Chencha (28%) which might be the cause for lower barley production Chencha. Soil results after one month of lime application showed that full rate lime application increased the soil pH value above 6.0 at both locations and reduced the concentration of exchangeable acidity and exchangeable Al^{3+} (Table 2). This higher *p*H value (for example from *p*H 4.8 to 6.1) increments should be seen cautiously because this might not be due to neutralization of acidity but also might be due to undesolved CaCO3 taken with soil. This result is in agreement with many workers [10, 17-19] who reported the ameliorating effect of lime in reducing soil acidity by increasing soil pH and reducing activity of aluminum ion in soil solution by chelating organic molecules.

However, results of soil collected at harvesting of barley in 2008 from study areas and indicated decreasing trend of soil *p*H and increasing trends of exchangeable Al^{3+} (Table 3); this trend may continue with time if no other lime applied to the soil. The observed decrease in pH value and increase in exchangeable acidity and Al^{3+} in time were due in part to plant uptake of Ca^{2+} and in part to mixing up with soil to lower depth through tillage ploughing and losses through leaching. From their lime research on Alisols of Mata, Ruwanda, Rutugna and Neel [9] reported that the soil pH was higher in few days after 8 Mg lime application and progressively decreased with time. These results revealed that re-acidification of the soil may take place and needs careful monitoring through regular soil sampling to now time-span of residual effect after initial liming before critical acidity exists.

Results of grain yield of barley are depicted in (Table 4). All treatments significantly ($p < 0.05$) influenced the production of barley in soils investigated. Results obtained showed that application of lime alone or combined with fertilizers significantly increased barley yield over untreated control at both locations. As to chemical fertilizers alone, PK and NPK application in Alisols of Chencha and all fertilizer combination alone in Luvisols of Hagerselam increased grain and biomass yield of barley (Table 4 and 5). NP and NK alone did not affect the yield in Alisos of Chencha but their combined application significant affect barley yield. This increased yield might in part be due to increased pH and reduced exchangeable aluminum and in part might be due to improved nutrients recovery as a result of lime application.

In 2007, in the year of lime application, the highest mean barley grain yield (2792 kg at Chencha and 3279 kg ha^{-1} at Hagerselam) was obtained from treatments received half dose of lime and 46:40:50 kg NPK ha^{-1}. Lime as residual effect (in 2008 and 2009), however, the highest yields were obtained from full dose applied treatments at both sites (Table 4). This would indicate that applied lime had residual effect but full dose lime had more efficient residual effect in the second year. (ADD)

Although statistically similar barley yield was obtained in Hagerselam Luvisols in 2007, the relative barley yield increased due to application of 0.85 and 1.75 Mg lime alone or with different combinations of NPK was promisingly high. Application of 0.85 and 1.75 Mg ha^{-1} lime gave 64 and 100% higher yield, respectively, over control. whereas 7 and 64%, 52 and 37%, 116 and 100% and 24 and 22% higher yields were observed by combining half and full recommended rates of lime with NP, NK, PK and NPK, respectively as compared to application of respective fertilizers alone. In 2008 and 2009, when lime is used as residual effect, highest barley grain and biomass yields were obtained from applications of full lime rate + NPK. NPK application either alone or with lime gave better barley yield, which might suggest the importance of balanced (NPK) fertilizer application. The efficiency of fertilizers increased in the order of NP<NK<PK<NPK for Alisols of Chencha and NK<PK<NP<NPK for Luvisols of Hagereselam, with the effects accentuated more in the limed than in the un limed treatments.

At the time of crop harvest biomass weight (ton ha^{-1}) also was influenced by different treatment in both soils and both sites (Fig. 1). Plant height and spike length did follow similar trends (data not shown).

Yield component (plant height, biomass weight, and spike length and hectoliters weight) results indicated that combined application of lime significantly influenced biomass weight of barley (data not shown). Strong linear relationships also were observed between biomass weight and barley grain yields both at Chencha (R^2 = 0.748***) and Hagerselam (R^2 = 0.703) soils. Biomass yield of barley was significantly improved by application of lime and fertilizers alone.
Partial budget analysis was made to ec0nomic visibility of applied lime and fertilizers. Higher marginal rate of return was obtained by applying half the recommended lime rate followed by full rate but the yields of barley recorded from these treatments were marginal low (Table 6).

4. CONCLUSION AND RECOMMENDATIONS

Crop development and potential yield depend on different environmental and soil factors. If one of the factors is limiting crop yields declined. Low or no barley yield obtained from un-limed but treated with NP and NK mineral fertilizers was common in Chencha Alisols. The current experiment confirmed that and suggested that lime is essential but must be complimented with balanced plant nutrients in order to get adequate barley yield in the study areas. In Chencha condition, 7 68 Mg ha^{-1} lime remains significant for two seasons and can be recommend for the area but further research should be required in time of application length of residual effect. As soil data of second year revealed that re-acidification of the soil may take place and needs careful monitoring through regular soil sampling to now length of residual effect after initial liming before critical acidity exists. From soil and barley yield data lime could be considered in improving barley yield in Hagereselam Luvisols too. Half and full recommended lime rates had statistically similar direct and residual effect on barley yield in both investigated soils; hence, this results demonstrated that applying half the recommended lime rate can be used without significant yield loss for 2 to 3 seasons.

Table-1. Some soil chemical properties of initial soils of testing sites

Parameter	Chencha	Hagerselam
pH_W	4.8	5.1
*p*HKCl	3.9	4.3
OC %	3.26	3.82
TN %	0.308	0.334
AVP mg kg-1	2.48	3.36
CEC Cmolc	32.28	29.4
Ca cmol+	4.29	4.42
Mg cmol+	1.12	0.75
K cmol+	2.33	0.70
Na cmol+	0.10	0.45
Ex. Ac cmolc	3.56	0.52
Ex. Al^{+3} cmolc	3.21	0.29
BS%	24	21
Al^{+3}	28	4

OC = organic carbon, TN =Total Nitrogen, AvP =available phosphorus, Ca = calcium, Mg = magnesium, K = potassium, Na = sodium, Ex. Ac = exchangeable acidity, Ex. Al^3 = Exchangeable aluminum, BS = Base saturation, Al^3 = Aluminum

Table-2. Effect of lime application on soil pH, exchangeable acidity and exchangeable Aluminum after one month of lime application (at planting of test crops)

	Chencha				Hagerselam			
Lime	pH 1:2.5		Exchangeable		pH 1:2.5		Exchangeable	
Mg ha^{-1}	H2O	KCl	Acidity	Al^{3+}	H2O	KCl	Acidity	Al^{3+}
L1	4.8	3.9	3.58	3.05	5.2	4.3	0.40	0.31
L2	5.5	4.7	0.46	0.19	5.7	5.2	0.12	0.02
L3	6.1	5.2	0.09	0.00	6.3	5.9	0.04	0.00

**L1 = 0 L2 = 0.85 Mg for Hagereselam and 3.82 Mg for chencha, L3 = 1.75 Mg for Hagerselam, and 7.64Mg for Chencha*

Table-3. Some chemical properties of Chencha Alisols soils as influenced by Lime and NPK management in 2008 cropping season (at barley harvesting)

Treatment	*p*Hw 1:2.5	*p*H KCl	Exchangeable Cmolc acidity	Exchangeable Cmolc Al^3	OC %	TN %	Bray II -P mg kg^{-1}	Av-K mg kg^{-1}
L1	4.8	4.0	4.14	3.26	3.43	0.315	2.71	34.6
L2	5.3	4.4	0.69	0.59	3.22	0.335	2.99	32.6
L3	5.6	4.7	0.19	0.14	3.18	0.336	3.25	32.6
L1+NP	4.7	3.9	4.22	3.37	3.03	0.346	5.21	34.0
L2+NP	5.1	4.4	0.88	0.67	3.01	0.351	4.96	33.6
L3+NP	5.4	4.6	0.28	0.20	2.97	0.353	5.17	34.2
L1+NK	5.0	4.3	3.94	3.06	3.18	0.344	3.64	54.9
L2+NK	5.4	4.5	0.74	0.58	3.11	0.344	3.89	52.0
L3+NK	5.7	4.6	0.24	0.09	3.02	0.349	3.92	53.4
L1+PK	5.1	4.5	3.03	2.84	3.50	0.320	5.34	55.6
L2+PK	5.5	4.9	0.41	0.29	3.14	0.333	5.28	53.2
L3+PK	5.8	4.9	0.15	0.07	3.05	0.336	5.56	52.7
L1+NPK	5.0	4.3	3.18	2.91	3.19	0.349	5.39	51.6
L2+NPK	5.4	4.6	0.47	0.33	3.10	0.352	5.12	50.4
L3+NPK	5.6	4.9	0.22	0.13	2.99	0.355	5.80	49.6

Table-4. Chemical properties of Hagerselam Luvisols soils as influenced by Lime and NPK management in 2008 cropping season (at barley harvesting)

Treatment	*p*Hw 1:2.5	*p*H KCl	Exchangeable Cmolc acidity	Exchangeable Cmolc Al^3	OC %	TN %	Bray II -P mg kg^{-1}	Av-K mg kg^{-1}
L1	5.2	4.4	0.47	0.36	3.82	0.381	3.06	74.4
L2	5.5	4.8	0.17	0.11	3.69	0.394	3.09	72.6
L3	5.7	5.0	0.08	0.05	3.68	0.391	3.25	62.1
L1+NP	5.1	4.3	0.51	0.44	3.75	0.403	4.41	54.0
L2+NP	5.3	4.6	0.21	0.13	3.70	0.411	5.96	53.6
L3+NP	5.7	4.7	0.10	0.05	3.72	0.409	6.17	54.2
L1+NK	5.2	4.4	0.42	0.26	3.80	0.423	3.24	94.9
L2+NK	5.6	4.7	0.16	0.10	3.77	0.450	5.89	92.0
L3+NK	5.6	4.7	0.08	0.05	3.78	0.447	4.72	83.4
L1+PK	5.3	4.5	0.39	0.27	3.64	0.386	6.34	105.6
L2+PK	5.8	4.9	0.14	0.08	3.70	0.390	6.28	105.2
L3+PK	5.9	5.0	0.07	0.04	3.68	0.393	6.56	72.7
L1+NPK	5.2	4.4	0.41	0.27	3.60	0.408	5.39	81.6
L2+NPK	5.6	4.7	0.16	0.09	3.66	0.419	5.42	80.4
L3+NPK	5.8	4.9	0.09	0.06	3.58	0.422	5.95	79.6

Table- 5. The effect of lime and NPK fertilizer application on the grain yield of Barely (kg ha^{-1}) in acidic soils of Chencha and Hagereselam

	Chencha			Hagereselam	
Treatment	2007	2008	2009	2007	2008
Lime					
L1	1036.83b	1008.3	662.5	1369.4	1159.0b
L2	1558.33a	1454.2	954.2	1978.4	1576.0ab
L3	1618.75a	1643.8	1045.9	2109.1	1925.0
LSD (0.05)	382.4	373.7	214.3	NS	582.2
Fertilizers					
Control (no fertilizer	585.3c	822.9c	482.6b	1171.2b	617.9d
NP	1343.75b	1045.1b	729.2b	1988.0ab	1985.0b
NK	1262.78b	1267.4b	684.0b	1447.4b	1081.5cd
PK	1479.06b	1809.0a	1222.3a	1669.7b	1468.4bc
NPK	2333a	1899.4a	1319.4a	2816.8a	2614.3a
LSD(0.05)	493.6	437.2	276.7	1170	582.2
Lime*Fertilizers	NS	NS	NS	NS	NS
CV%	36.6	29.9	23.2	40.2	28.9

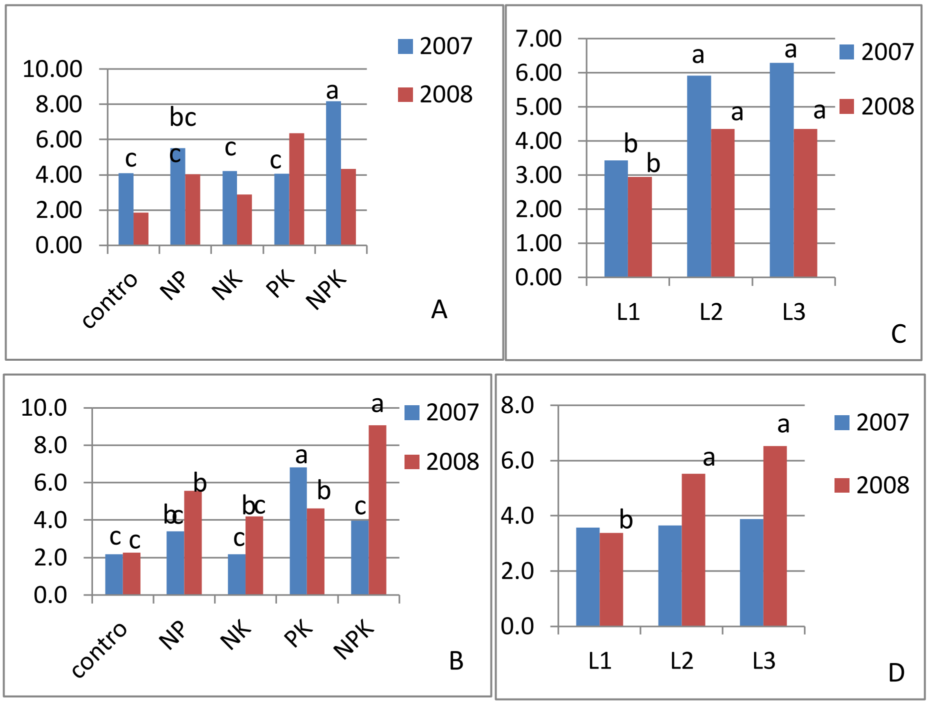
Table-6. Partial budget analysis for the mean grain yield of barley

	Partial Budget									
Treatments	mean grain yield	Adj. yield kg/ha (10%)	Gross benefit birr/ha	Lime	N	P	K	TVC	Net benefit	MRR %
Control	333	300	1498	0	0	0	0	0	1498	
Half lime	659	594	2968	192	0	0	0	192	2776	665
Full lime	877	789	3946	384	0	0	0	384	3562	205
NP	808	727	3636	0	706	800	0	1506	2130	D*
NP + half lime	1281	1153	5765	192	706	800	0	1698	4067	114
NP + full lime	1915	1724	8618	384	706	800	0	1890	6728	141
NK	744	670	3349	0	706	0	600	1306	2043	D
NK + half lime	1246	1121	5607	192	706	0	600	1498	4109	138
NK + full lime	1273	1145	5727	384	706	0	600	1690	4037	D
PK	1212	1091	5455	0	0	800	600	1400	4055	D
PK + half lime	1488	1339	6696	192	0	800	600	1592	5104	66
PK + full lime	1624	1461	7307	384	0	800	600	1784	5523	24
NPK	1953	1758	8788	0	706	800	600	2106	6682	55
NPK + half lime	2465	2218	11091	192	706	800	600	2298	8793	92
NPK+ full lime	2076	1869	9344	384	706	800	600	2490	6854	D

Price of inputs: Lime = 50 birr/ton, Urea = 7.06 birr/kg, DAP = 8.00 birr/kg, KCl = 6.00 birr/kg,

Farm get price of Barley = 5.00 birr/kg

Figure-1. The effect of lime and fertilizers on the biomass yield of barley (A) effect of fertilizers on biomass yield of barley at Chencha Alisols (B) effect of fertilizers on biomass yield of barley at Hagerselam (C) effect of lime at Chencha Alisols and (D) effect of lime at Hagerselam Luvisols.



**Bars followed by the same letter are not statistically different from each other*

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