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Residual Effect of Lime and P Fertilizer Levels on Selected Soil Chemical Properties and Bread Wheat (*Triticum Aestivum* L.) Yield on Acidic Soil in Banja District, North-Western Ethiopia.

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Abstract

Soil acidity problem is one of the bottlenecks to improve crop production in high rainfall regions of Ethiopia in general and in Banja District of Amhara region in particular. The aim of this study were to determine residual effect of lime and P fertilizer on the acid properties of soils and to develop models where by the change in acidity indicators of soils can be predicted as a result of lime application. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Five levels of lime (0, 1.15, 2.3, 3.45, 4.6 t ha^{-1}) and four levels of Phosphorous (0, 10, 20, and 30 kg ha^{-1}) were combined in a complete factorial arrangement. The study was conducted for three consecutive years during 2015 to 2017 main cropping seasons at Banja District. Mean grain yield and yield components as affected by different levels of lime and phosphorus fertilizer. Since the interaction effects of lime and P were not significant for grain yield and yield components. Analysis of variance showed that all limed treatments were higher mean values of grain yield and yield components relative to control plot (no lime and P) in all over combined cropping years. Moreover, over year combined mean the highest grain yields (1115.9 kg ha^{-1}), biomass yields (3591.2 kg ha^{-1}), number of spike per plant (10.77), plant height (64.50 cm) and panicle length (5018.5 cm) were recorded under 4.6 t ha^{-1} of lime application of plot. The lowest grain and biomass yields were recorded in control plots. However, over year mean 4.6 ton /ha^{-1} of lime application plot the grain yield and biomass yield of wheat were increased by (151.1%) and (123.3%) related to control plot, respectively. Hence, lime application at the rate of 3.45 t ha^{-1} (150% of the lime requirement of the soils based on its exchangeable acidity) coupled with 20 kg ha^{-1} P fertilizer could serve as a reference to boost wheat production in the study area and in similar areas with possible re-liming of the soils in every five years.

Keywords: Soil acidity; Lime; Exchangeable Acidity

1. Introduction

Soil acidity is one of the main factors that limit and prevent sustainable agricultural productivity and production in many parts of the world (Sumner and Noble, 2003). It is estimated that approximately 50% of the worlds' arable soils are acidic and may be subjected to the effect of aluminum (Al) toxicity of which the tropics and subtropics account for 60% of the acid soils in the world (Sumner and Noble, 2003). It is mostly distributed in developing countries, where population growth is fast and demands for food and fiber are increasing.

Currently, it is estimated that about 40% of the total arable land of Ethiopia is affected by soil acidity (Taye, 2008). Of this land area, about 27.7% is moderately acidic (pH in KCl) 4.5 - 5.5) and about 13.2% is strongly (pH in KCl) < 4.5) acidic. Thus, the most strongly acidic soils are found in western, southwestern, central highlands, and high rainfall areas of northwestern parts of Ethiopia (Mesfin, 2007). The highlands of Ethiopia (areas >1500 meters above sea level) are particularly the most affected region by the problem due to the removal of ample amount of nutrients by leaching, crop mining, and runoff as compared with grazing and forest lands (Temesgen *et al.*, 2014).

Moreover, the cause of soil acidity is the high amount of precipitation that exceeds evapotranspiration, which leaches appreciable amounts of exchangeable bases from the soil surface and continuous application of acid-forming chemical fertilizers on highly weathered tropical soils increase soil acidity problems (Temesgen *et al.*, 2014) and (Nekesa, 2007), respectively. Hence, one of the major factors limiting agricultural production in the highlands of Ethiopia is mainly related to the presence of exchangeable acidity in highly weathered acid soils (IFPRI, 2010; Paulos, 2001).

Soil acidity affects the growth of crops because acidic soil contains toxic levels of aluminum and manganese and is characterized by the deficiency of essential plant nutrients such as P, N, K, Ca, Mg, and Mo when the soil pH falls below 5.5; and the plant root system is affected by high Al concentrations because of Al interferes with the uptake, transport, and utilization of essential plant nutrients such as P, K, Ca, Mg, and water, as well as enzyme activity in the roots (Lofton *et al.*, 2010; M Abdulaha-Al Baquy *et al.*, 2016) and (Wang *et al.*, 2006), respectively. The degree of toxicity depends upon how high the concentration of soluble or exchangeable Al3+ is and how low the pH is (Crawford *et al.*, 2008).

Soil acidity can also reduce the availability of phosphorous by forming insoluble compounds when combined with Fe and Al oxide at pH < 5.0. Thus, due to the increased acidity of the soil, inorganic phosphorous applied to the soil becomes fixed or immobilized (Chude *et al.,* 2004; Kim, 2010; Tinker and Nye, 2000). Therefore, acid soils possess toxic concentrations of Al^{3+} and Mn^{2+}, deficient concentrations of P, and low availability of bases, which together cause a reduction in crop yield (Schroder *et al.*, 2010). The presence of Al in plant tissues interferes with Ca and Mg uptake from the soil, as well as damages the chloroplast and mitochondrial membrane (Meriño-Gergichevich *et al.*, 2010).

About 24% of the Amhara National Regional State of Ethiopia is affected by acidity while 23% of the Amhara region has been severely eroded (Amhara National Regional State's Investment office, 2006), Banja District is one of the areas highly affected by soil acidity in Amhara National Regional State of Ethiopia. As a result, farmers were forced to grow acid-tolerant crops at the expense of economically important crops or to allocate their cultivated lands to eucalyptus plantations for the last seven and more decades.

Wheat is one of the most common staple food and economically important crop in the Amhara region. However, wheat productivity has been declining from year to year in northwestern Ethiopian highlands, in general, and in the study area in particular mainly due to intensive soil degradation and depletion of plant nutrients (Mekonnen *et al.*, 2014). Moreover, wheat productivity in northwestern Ethiopian highlands is 1.38 t ha-1 (very low) as compared with 1.58 t ha-1of Ethiopian highlands and 2.5 t ha-1 of the global productivity (Ashenafi, 2007; Warku, 2008).

To make soils less acid, it is a common practice to apply a material that contains calcium and/or magnesium oxides or carbonates. Amelioration of acidic soils is beneficial to plant growth because it improves soil pH and replenishes nutrients (Moon *et al*., 2014). Moreover, lime applied to acidic soils raises the pH of soils, resulting in enhanced availability of nutrients, such as P, N, Ca, Mg, Mo, etc. and improved crop yields though it reduces exchangeable acidity (Caires *et al*., 2005; Kisinyo *et al.*, 2009; Nekesa, 2007). Lime has been known as an effective ameliorant to reduce soil acidity, decrease exchangeable Al as well as Al saturation (Caires *et al*., 2008; Chimdi *et al*., 2012; Sadiq and Babagana, 2012).

Moreover, the fixed P would be released for plant uptake after liming, the amount of additional P needed has to be determined experimentally (Waigwa *et al*., 2003). However, Crop yield is significantly increased by the integrated use of lime and fertilizer (International Food Policy Research Institute, 2010). Hence, on acidic soils, the applications of both lime and phosphorus fertilizer are frequently required for successful crop production (Temesgen *et al*., 2014). Under these situations, an appropriate combination of lime and P is an important strategy for improving crops grown in highly weathered acid soil.

Also, inadequate information is available about the integrated use of lime and Inorganic fertilizer under the area of acidic soils condition and also the effects on crop yield which limits the adoption of integrated fertility management in the Amhara region in general and Banja District in particular. Therefore, generating information on the management effect on wheat yield may help to design strategies for future research and development interventions. Hence, the objectives of this study were to determine the residual effect of lime and P fertilizer on the acid properties of soils and to develop models whereby the change in acidity indicators of soils can be predicted as a result of lime application.

2. Materials and Methods

2.1. Description of Study Area

2.1.1. Geographical Location

The study was conducted for three consecutive years of main cropping seasons at Banja District, Awi Zone, Amhara National Regional State, Ethiopia. The sub-station is located at latitude of 10° 56.2753' north and longitude of 36° 52.2755' east, an altitude of 2489 m.a.s.l and 130 km far from the regional city Bahir Dar to south and 460 km north to Addis Ababa (Figure 1). The district 80% of the area is highland, 20% is middle highland.

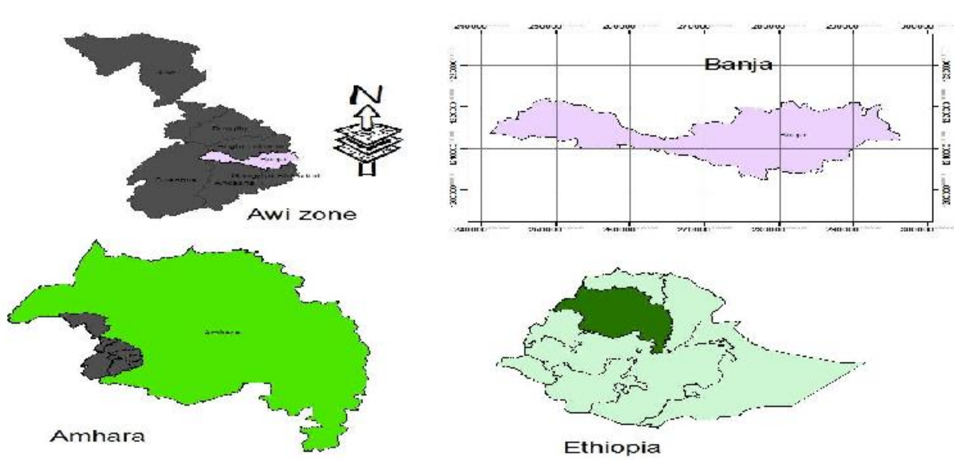

Figure 1. Location Map of the study area, Banja district, Northwestern Ethiopia.

3.1.2. Climate

According to National Meteorology Agency weather data from 1984–2015, the mean minimum and maximum temperature of the study area 9.4°C and 26°C, respectively. The mean annual rainfall was 1215.3 mm with main wet season from June to September usually continued with a less pronounced wet period up to November.

3.1.3. Geology and Soil

The parent material is made up of the volcanic rock and quaternary basalts. The major soil types include Andosols, Nitisols, and Cambisols. Generally, the soil types of the study area are characterized with shallow, moderate to deep and very deep in depth and sandy clay to clay texture types (Bireda, 2015).

2.2. Description of the Experimental Materials

High yielding bread wheat (*Triticum aestivum* L) variety named Danda'a was used as test crop a seed rate of 120 kg ha^{-1}. Urea and triple super phosphate (TSP) fertilizers were used as the source of N and P, respectively. A high quality limestone (98 % $CaCO_3$, 99.5 % <250 µm in diameter) was used.

2.3. Treatment and Experimental Design

The experiment was laid out in a randomized complete block design (RCBD) with three replications. Five levels of lime (0, 1.15, 2.3, 3.45, 4.6 t ha^{-1}) and four levels of Phosphorous (0, 10, 20, and 30 kg ha^{-1}) were combined in a complete factorial arrangement. Lime requirement of the soil was calculated based on its exchangeable acidity (Al^{3+} plus H^+) adapted from (Kamprath, 1984).

2.4. Experimental Procedure

2.4.1. Land Preparation and Field Management

Land preparation was uniformly performed across all plots by tractor mounted moldboard plough to 30 cm soil depth. Subsequent tilling operations were done by harrowing to about 10 cm depth by conventional tillage. The field layout was maintained as a path of 2m between each block and 1m path way between each plot. Bread wheat was sown at 120 kg ha^{-1} seed rate in 20 cm inter-row spacing and hand drilling was used for sowing. Bread wheat was planted on gross plot area of 4 m x 4 m (16 m^2) and the net plot size 14.4 m^2 was harvested. All recommended cultural practices of wheat production were adopted for the management of the experiment. All plots will be hand weeded at 30, 45 and 60 days after sowing.

2.4.2. Methods and Time of Lime and Fertilizer Application

Lime was applied to plots at once through broadcasting uniformly by hand and incorporated into the soil by using hoe at least a month before planting. The amount of lime applied was calculated on the basis of exchangeable acidity concentration of the site (Kamprath, 1984), assuming that one equivalent of exchangeable acidity would be neutralized by an equivalent of $CaCO_3$. The amount of lime that was applied at each level was calculated on the basis of the mass of soil per 15 cm hectare-furrow-slice, soil sample density and exchangeable Al^{3+} and H^+ as described in Eq. 1.

$$LR, CaCO_3 (kg/ha) = \frac{cmol\,EA/kg\,of\,soil * 0.15\,m * 10^4\,m^2 * B.D.(Mg/m^3) * 100}{2000}$$

where, LR = Lime Requirement; EA= Exchangeable Acidity; B.D. = Bulk Density

Triple super phosphate (TSP) and urea were used as inorganic fertilizer sources. The blanket recommended rate of 69 kg ha^{-1}N was applied uniformly to all treatments in two split, which half was applied in band at planting in all plots at the depth of 3-5 cm below and around the wheat seed, and the remain half after one month was applied by slightly opening the soil at each row, with 5 cm far and covering with banding of fertilizer with soil to prevent ammonia effect on root and loss by volatilization. The whole doses phosphorus was applied in band at planting in all representative plots at the depth of 3-5 cm below and around the wheat seed at the time of sowing.

2.5. Soil and Plant Sampling and Analysis

Prior to treatment application surface (0-15) cm depth soil samples were randomly taken using a soil auger from several points at the experimental sites and thoroughly mixed together to make a composite sample to determine selected physiochemical properties. Prior to the experiment set up, soil samples were collected from 0-15 cm depth for initial determination of soil fertility parameters. One month after limed at planting and during harvesting composite samples were again taken from each treatment at the depth of 0-15 cm to determine all selected chemical properties and to monitor changes in soil available P, pH and exchangeable acidity, respectively. The sampled soils were taken to the laboratory for analysis of selected physical (texture and bulk density) and chemical (pH, Exchangeable acidity, Organic carbon, CEC, Total nitrogen, Available phosphorus, Exchangeable bases (K, Na, Ca and Mg). From each treatment one composite wheat grain and straw samples were collected after harvesting using standard procedure to evaluate the treatment effect on P uptake. The collected samples were dried in an oven at 65 C^o to constant weight. The dried material of each plant part were ground and sieved with 0.5 mm mesh, for analysis of P concentrations.

The collected soil samples were air-dried, ground and sieved with 2 mm sieve size. Separate soil core samples were collected with a sharp-edged steel cylinder forced manually into the soil for bulk density determination. Soil texture analysis was performed using hydrometric method (Bouyoucos, 1962). The USDA particle size classes viz. sand (2.0-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm), were used when classifying textural classes. Soil pH was determined by potentiometric methods at a 1:2.5 soil to water ratio. Soil organic carbon was determined by the Walkley-Black oxidation method (Walkley and Black, 1934). Total nitrogen (TN) was determined by Kjeldahl digestion method (Bremner and Mulvaney, 1982).

Exchangeable acidity was determined by saturating the soil samples with 1M KCl solution and titrating with 0.01 M NaOH as described in Rowell (1994). Exchangeable Al was determined from aqueous solutions extracted by 1M KCl and NaF and titrated with 0.01M HCl. The cation exchange capacity (CEC) was determined by extraction with ammonium acetate (Chapman, 1965). Available P was determined both by the Olsen and Bray I methods. The analysis of P by the Olsen method was carried out by shaking the soil samples with 0.5 M NaHCO at nearly constant pH of 8.5 in 1:20 of soil to solution ratio for half an hour (Olsen *et al.*, 1954). The Bray I P extract was carried out by shaking the soil samples with an extracting solution of 0.03 M NH_3 F in 0.1 M HCl for1 minute (Bray and Kurtz, 1945). Exchangeable bases (Na, K, Ca, and Mg) were measured by atomic absorption spectrophotometer after extraction by ammonium acetate (Black *et al.*, 1965). Selected soil physicochemical properties of the study site determined before establishment of the experiment are presented in Table 3.

Table 1 . Selected soil chemical properties before establishment of the experiment.

Soil properties	Unit	Value
pH 1:2.5 (H_2O)		4.69
pH 1:2.5 (KCl solution)		3.81
Organic matter	%	4.38
Total N	%	0.23
Available P	mg kg^{-1}	11.07
Exchangeable acid	$cmol_{(+)}$ kg^{-1}	3.056
Exchangeable Al	$cmol_{(+)}$ kg^{-1}	2.565
Exchangeable K	$cmol_{(+)}$ kg^{-1}	0.436
Exchangeable Na	$cmol_{(+)}$ kg^{-1}	0.12
Cation exchange capacity (CEC)	$cmol_{(+)}$ kg^{-1}	23.19

Statistical Analysis

Analysis of variance was performed using SAS statistical software 9.3 version (SAS, 2014). General linear model (GLM) was constructed to compare the measured agronomic parameters. Significance differences were set at p<0.05. When the effects were found significant, further mean separation was made using Tukey multiple comparison test.

3. Results and Discussion

Mean grain yield and yield components as affected by different levels of lime and phosphorus fertilizer are presented in Table 2, 3 and 4. Since the interaction effects of lime and P were not significant for grain yield and yield components, their individual effects are presented. Analysis of variance showed that all limed treatments were higher mean values of grain yield and yield components relative to control plot (no lime and P) in all cropping years.

Table 2. Residual effect of lime and p levels on number of spike per plant and plant height of bread wheat on acidic soils combined over three years.

Lime	Number of Spike Per Plant				Plant Height (cm)			
(t ha^{-1})	2015	2016	2017	combine	2015	2016	2017	combine
0	6.5c	9.89b	8.89b	8.43c	52.71b	50.8b	52.6b	52.02c
1.15	7.5b	10.98ba	10.08ba	9.51b	55.33b	51.2b	56.3b	54.30c
2.3	8.4ba	11.13a	10.91a	10.14ba	64.23a	55.7ba	62.7a	60.90b
3.45	9.1a	11.73a	11.07a	10.63a	65.78a	60.6a	63.3a	63.23ba
4.6	8.9a	11.56a	11.81a	10.77a	66.65a	59.7a	67.1a	64.50a
LSD (0.05)	0.9045	1.2232	1.8697	0.7098	6.0156	6.3174	6.3226	3.115
Significance	***	*	*	***	***	**	**	***
P (kg ha^{-1})								
0	7.43	10.19	9.47	9.03b	58.847	50.5b	54.44b	54.60b
10	8.21	11.28	10.47	9.99a	59.800	57.8a	60.87a	59.50a
20	8.30	11.35	11.42	10.20a	62.760	56.0ba	63.44a	60.75a
30	8.37	11.39	10.85	10.36a	62.353	58.1a	62.88a	61.11a
LSD (0.05)	ns	ns	ns	0.6351	ns	5.6504	5.6551	2.7798
Significance	ns	ns	ns	**	ns	*	**	***
CV %	13.57	13.4	21.5	15.4	11.96	13.8	12.7	11.3

*** Significant at $P < 0.001$, ** significant at $P < 0.01$, * significant at $P < 0.05$, ns – no significant difference. Means with the same letter are not significantly different.

Among the liming treatments, the highest rate (4.6 t ha^{-1}) of lime recorded the highest mean values grain yield, biomass yield, number of spike per plant, plant height and panicle length of bread wheat on combined over three years. However, among the mean number of spike per plant, plant height and panicle length an application of 4.6 t ha^{-1} lime was not statistically different from lime rate of 2.3 and 3.45 t ha^{-1} applications. Hence, combined over all cropping season, number of spike per plant, plant height and panicle length obtained by applications of 2.3, 3.45 and 4.6 t ha^{-1} lime was statistically similarly, and significantly superior to contro1plot (no lime) and 1.5 t ha^{-1}lime rate.

Table 3. Residual effect of lime and p levels on panicle length and biomass yield of bread wheat on acidic soils combined over three years.

Lime (t ha^{-1})	Panicle length (cm)				Biomass Yield (kg ha^{-1})			
	2015	2016	2017	Combine	2015	2016	2017	combine
0	3.5c	5.0b	4.33c	4.28c	2680.6c	1067.7c	1076.4c	1608.2d
1.15	3.95b	5.4ba	4.71bc	4.68b	3657.4bc	1258.7cb	1171.9c	2029.3c
2.3	4.32ba	5.6ba	5.15ba	5.02a	4685.2ba	1614.6b	2057.3b	2785.7b
3.45	4.40a	5.9a	5.02ba	5.11a	4500.0ba	2291.7a	2031.3b	2941.0b
4.6	4.51a	5.8a	5.39a	5.24a	5018.5a	2638.9a	3116.3a	3591.2a
LSD (0.05)	0.3935	0.602	0.6534	0.2941	1029.5	515.93	734.84	416.81
Significance	***	*	*	***	**	***	***	***
P (kg ha^{-1})								
0	3.8800	5.2	4.40b	4.51b	4159.3	1291.7c	1340.3b	2263.7b
10	4.2267	5.7	4.93ba	4.93a	3577.8	1826.4ba	1784.7ba	2396.3b
20	4.1867	5.7	5.29a	5.06a	4570.4	1757.0b	2305.6a	2877.6a
30	4.2467	5.6	5.06a	4.95a	4125.9	2222.2a	2132.0a	2826.7a
LSD (0.05)	ns	ns	0.5844	0.2721	ns	461.46	657.26	369.65
Significance	ns	ns	*	**	ns	**	*	**
CV %	11.5	13.2	16.1	13.4	30.37	35.2	47.1	34.3

*** Significant at $P < 0.001$, ** significant at $P < 0.01$, * significant at $P < 0.05$, ns – no significant difference. Means with the same letter are not significantly different.

Table 4. Residual effect of lime and p levels on grain yield of bread wheat on acidic soils combined over three years.

Lime (t ha^{-1})	Grain Yield (kg ha^{-1})			
	2015	2016	2017	combine
0	715.6b	239.6b	377.9c	444.4c
1.15	897.7b	318.4b	369.5c	528.4c
2.3	1362.4a	403.5b	753.6b	839.8b
3.45	1341.8a	640.9a	783.2b	921.94b
4.6	1391.7a	768.6a	1187.3a	1115.9a
LSD (0.05)	387.35	215.49	261.46	159.34
Significance	**	***	***	***
P (kg ha^{-1})				
0	1017.9	285.8b	457.3b	587.0b
10	987.9	509.1a	645.1ba	714.0b
20	1310.3	479.1a	854.5a	881.3a

30	1251.3	622.8a	820.3a	898.1a
LSD (0.05)	1017.9	192.74	233.85	140.54
Significance	ns	**	**	***
CV %	41	55.1	45.6	43.8

*** Significant at $P < 0.001$, ** significant at $P < 0.01$, * significant at $P < 0.05$, ns – no significant difference. Means with the same letter are not significantly different.

Moreover, over year combined mean the highest grain yields (1115.9 kg ha^{-1}), biomass yields (3591.2 kg ha^{-1}), number of spike per plant (10.77), plant height (64.50 cm) and panicle length (5018.5 cm) were recorded under 4.6 t ha^{-1} of lime application of plot. The lowest grain and biomass yields were recorded in control plots. However, over year mean 4.6 ton /ha^{-1} of lime application plot the grain yield and biomass yield of wheat were increased by (151.1%) and (123.3%) related to control plot, respectively. In line with the report of Mekonen A., et al., 2014 the yield parameters in this experiment showed more than 200% and 100% yield increment due to the application of lime and phosphorus respectively. Progressive increases in grain yields were recorded with incremental levels of lime and P fertilizer application (Getachew *et al*., 2017).

Similarly, successive applications of phosphorus fertilizer also resulted in increased grain yield and biomass yields wheat. Hence, the highest significant ($p < 0.001$) mean values of grain and biomass yield were recorded by application of 20 and 30 P kg ha^{-1} were also comparable, and significantly higher than the control plot and applications of 10 P kg ha^{-1}. The lowest grain yield was recorded in control plots (with no lime, no P) addition. Over year combined mean, grain yield (898.1 kg ha^{-1}) and biomass yield (2877.6 kg ha^{-1}) the highest were recorded by application of 30 and 20 P kg ha^{-1}, respectively. The lowest grain biomass yields were recorded in control plots.

4. Conclusions

Poor wheat production in Banja area has been associated with soil acidity viz. Al-toxicity and/or P deficiency. Application of lime and P fertilizer had significantly improved grain yield of wheat and soil chemical properties. Wheat grain yield increased progressively with higher lime and P application rates. The highest yield was 4.6 t ha^{-1} lime and 30 kg ha^{-1} P fertilizer application, but at par with 3.45 t ha^{-1} lime and 20 kg ha^{-1} P application. During the initial five years completed activity of lime application, wheat grain yield was increased by higher. This yield reduction after five years of liming may indicate re- acidification of the soil which necessitates re-liming of the soil.

Though there were no significant differences between 3.45 and 4.6 t ha^{-1} lime applications, both rates raised soil pH close to the optimum pH requirement of wheat, but drastically decreased the exchangeable Al^{3+} to a minimum level of 0.1 cmol/kg, which enhanced available P as a result of increased pH and decreased acidity level.

Hence, lime application at the rate of 3.45 t ha^{-1} (150% of the lime requirement of the soils based on its exchangeable acidity) coupled with 20 kg ha^{-1} P fertilizer could serve as a reference to boost wheat production in the study area and in similar areas with possible re-liming of the soils in every five years.

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