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Residual Effect of Lime Rate after Five Years and P Fertilizer Rates on 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 particular. This study aimed 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. The experiment was laid out in a randomized complete block design 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 from 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. 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 seeds per plant (21.54), plant height (64.50 cm) and spike length (5.24 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 t ha^{-1} of lime application plot the grain yield and biomass yield of wheat were increased by (151.1%) and (123.3%) related to the 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 boosting wheat production in the study area and similar areas with possible re-liming of the soils in every five years.*

KEYWORDS: Acidic soil, Lime, Phosphorus, P Fertilizer, North Western Ethiopia

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INTRODUCTION

Soil acidity is a widespread limitation to crop production in many parts of the world. It is a major constraint to agricultural productivity throughout Africa where high rainfall is common due to the deficiencies of nitrogen (N) by leaching, phosphorus (P) by fixation, and low soil organic matter (OM) (Kisinyo, 2011). As indicated by Wassie and Shiferaw (2009), soil acidity has become a serious threat to crop production in most highlands of Ethiopia in general. Currently, it is estimated that about 43% of the total arable land of Ethiopia is affected by soil acidity (ATA, 2014). Specifically, because of the severity of soil acidity problems, many crops give very low productivity in the study district. Based on the problem that soil acidity causes a larger area in Ethiopia, it needs due attention to be addressed by different coping mechanisms (Mesfin, 2007). The productivity of crops in acid soils with Al toxicity and low soil availability of P may be improved by the use of lime, fertilizers with liming effects, and/or organic materials (Osundwa *et al*., 2013). Liming is a dominant and effective practice to overcome these constraints and improve crop production on acidic soils (Achalu *et al*., 2012).

Also, inadequate information is available about the duration effect of residual lime rate and phosphorus fertilizer under the area of acidic soil 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. Moreover, there is a need for additional information about the effect on this approach on soil chemical characteristics, plant mineral nutrition, and crop production. 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.

MATERIALS AND METHODS

Description of study area

The study was conducted for three consecutive years from 2015 to 2017 main cropping seasons at Banja District, Awi Zone, Amhara National Regional State, Ethiopia. The sub-station is located at the latitude of 10° 56.2753' north and longitude of 36° 52.2755' east, an altitude of 2489 m.a.s.l. According to the 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 the main wet season from June to September usually continued with a less pronounced wet period up to November. The parent material is made up of volcanic rock and quaternary basalts. The major soil types include Andosols, Nitisols, and Cambisols. Generally, the soil types of the study area are characterized by shallow, moderate to deep, and very deep in-depth and sandy clay to clay texture types (Bireda, 2015).

Description of the experimental materials

High yielding bread wheat (*Triticum aestivum* L.) variety named Danda'a was used as a test crop. Urea and triple superphosphate (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.

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.

Field management

The field layout was maintained as a path of 2 m between each block and 1m pathway 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 a gross plot area of 5 m x 4 m (20 m^2) and the net plot size 18 m^2 was harvested. All recommended cultural practices of wheat production were adopted for the management of the experiment. The blanket recommended rate of 69 kg ha^{-1}N was applied uniformly to all treatments in two split, which half was applied in the band at planting in all plots and the remaining half was applied by banding after one month. The whole dose phosphorus was applied in all representative plots at sowing. Lime was applied in a broadcast by hand to all representative plots before five years or into the 2010 year.

Soil sampling and analysis

Before treatment application surface (0-20) 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. The sampled soils were taken to the laboratory for analysis of selected soil chemical properties (pH, Exchangeable acidity, Organic matter, CEC, Total nitrogen, Available phosphorus, Exchangeable bases (K and Na).

The collected soil samples were air-dried, ground, and sieved with 2 mm sieve size. 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 the 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 by Bray I methods. The Bray I P extract was carried out by shaking the soil samples with an extracting solution of 0.03 M NH_3F in 0.1 M HCl for1 minute (Bray and Kurtz, 1945). Exchangeable bases (Na and K) were measured by atomic absorption spectrophotometer after extraction by ammonium acetate (Blake, 1965). Selected soil physicochemical properties of the study site determined before the establishment of the experiment are presented in Table 1.

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

Soil properties	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

Agronomic data collection
Important plant data collected from crop emergence to harvest were treated as growth parameters. The growth parameters were plant height and spike length. However, the number of seeds per plant, biomass yield, and grain yield were considered as yield parameters. Plant height, spike length, and the number of seeds per plant were measured from ten randomly sampled plants at physiological maturity. Plant height was measured from the ground level to the tip of spike excluding awns. Similarly, spike length was measured from the base to the tip of a spike by excluding the awns. Grain yield was estimated by adjusting moisture content to 12.5%.

Statistical analysis
Analysis of variance (ANOVA) was performed using the SAS statistical software 9.3 version (SAS, 2014). Whenever the ANOVA detected significant differences between treatments, mean separation was conducted using the least significant difference (LSD).

RESULTS AND DISCUSSION

Number of seeds per plant
The number of seeds per plant was affected statistically ($p < 0.01$) by the application of lime rates. The application of 4.6 t ha^{-1} lime rate recorded the highest average (21.54) number of seeds per plant and there is no statistically significant difference with 3.45 and 4.6 t ha^{-1} lime rate, while the lowest (16.86) was recorded from control (no lime) treatment (Table 2). Hence, increases the application of lime rates significantly increased the number of seeds per plant of bread wheat.

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Sultana et al. (2009) reported that the maximum number of seeds per plant was found in treatment received higher lime rate. Similarly, the number of seeds per plant significantly increased by increases the rate of lime application (Kamaruzzaman *et al*., 2013). Similarly, the application of phosphorus rates significantly ($p < 0.05$) increased the number of seeds per plant. The highest number of seeds per plant was recorded from addition rates of P treatments, while the lowest was recorded in the control (no P addition) of treatment. Similarly, the number of seeds per plant of wheat had significantly increased into increases the rate of P application (Tadesse *et al*., 2018).

Plant height

The main effects of lime and phosphorus rates were significantly ($p < 0.01$) affected plant height (Table 2). The plant height of wheat progressively increased with an increase in lime rates. The plant height ranged from 52.02 cm in (control) treatment to 64.5 cm in the lime rate of 4.6 t ha^{-1} treatment. The highest plant height recorded in the application of 4.6 t ha^{-1} lime rate was significantly comparable to those obtained in 3.45 lime rate whereas statistically superior to the other treatments. Sultana *et al*. (2009) and Kamaruzzaman *et al*. (2013) reported that the plant height of wheat progressively increased with an increase in lime rates. Similarly, the application of 4.6 t ha^{-1} lime rate increased plant height by 24% against the control treatment. According to Asmare *et al*. (2015) soils treated with lime, rates increased plant height by 22 to 41% over the non-amended soils. Abreha *et al*. (2013) also reported a wheat plant height increment of 26 and 27% over control on soils that received Wukro and Sheba limes rates. Similarly, the application of phosphorus rates increased the plant height progressively giving maximum and the lowest values were obtained from control. Similarly, plant heights increased with increasing the addition of P rates (Peter, 2017). Plant height of wheat had significantly increased into increases in the rate of P application (Tadesse *et al*., 2018).

Table 2. The residual effect of lime and p levels on the number of spikes per plant and plant height of bread wheat on acidic soils combined over three years.

Lime rates	Number of Seeds Per Plant				Plant Height (cm)			
(t ha^{-1})	2015	2016	2017	CA	2015	2016	2017	CA
0	13c	19.78b	17.78b	16.86c	52.71b	50.8b	52.6b	52.02c
1.15	15b	21.96ba	20.16ba	19.02b	55.33b	51.2b	56.3b	54.30c
2.30	16.8ba	22.26a	21.82a	20.28ba	64.23a	55.7ba	62.7a	60.90b
3.45	18.2a	23.46a	22.14a	21.26a	65.78a	60.6a	63.3a	63.23ba
4.60	17.8a	23.12a	23.62a	21.54a	66.65a	59.7a	67.1a	64.50a
LSD (0.05)	1.809	2.4464	3.7394	1.4196	6.0156	6.317	6.323	3.115
Significance	***	*	*	***	***	**	**	***
Phosphorus (kg ha^{-1})								
0	14.86	20.38	18.94	18.06b	58.847	50.5b	54.44b	54.60b
10	16.42	22.56	20.94	19.98a	59.800	57.8a	60.87a	59.50a
20	16.6	22.7	22.84	20.40a	62.760	56.0ba	63.44a	60.75a
30	16.74	22.78	21.7	20.72a	62.353	58.1a	62.88a	61.11a
LSD (0.05)	ns	ns	ns	1.2702	ns	5.651	5.66	2.78
Significance	ns	ns	ns	**	ns	*	**	***
CV %	13.57	13.4	21.5	15.4	11.96	13.8	12.7	11.3

Note: *** Significant at $P < 0.001$, ** significant at $P < 0.01$, * significant at $P < 0.05$, ns – no significant difference, CA = Combined Analysis. Means along the column with the same letter are not significantly different.

Spike length

The main effect of application lime levels significantly ($p< 0.01$) influenced the spike length of wheat. Spike lengths ranged between 5.24 and 4.28cm with a mean of 4.76 cm (Table 3). Hence, combined overall cropping season, spike length obtained by applications of 2.3, 3.45 and 4.6 t ha^{-1} lime were statistically similar and significantly superior to contro1plot (no lime) and 1.5 t ha^{-1} lime rate. Application of 4.6 t ha^{-1} lime rate increased spike length by 22.4% against the control treatment. This result is agreed with Sultana et al. (2009) and Kamaruzzaman *et al*. (2013) who reported that spike length of wheat had significantly increased by the application of lime. Similarly, the application of different rates of phosphorus significantly increased the spike length than the control (no P addition) plot. Spike length of wheat had significantly increased into increases rates of P application (Tadesse *et al*., 2018).

Biomass yield

Moreover, over years combined analysis results show, the highest biomass yield (3591.2 kg ha^{-1}) was obtained from the application of 4.6 t ha^{-1} lime rate whereas the lowest biomass yield (1608.2 kg ha^{-1}) was in the control treatment (Table 3). Application of 4.6 t ha^{-1} lime rate increased the biomass yield by 123% over the control. Moreover, increasing the rates of application lime had significantly increased biomass yield of wheat. With that regard, the applications of combined NP fertilizers along with Wukro and Sheba limes revealed significant augmentation over control by about 174 and 172% in total biomass yield, respectively (Abreha *et al*., 2013). The application 3.5 t ha^{-1}lime rate recorded a 33.3% yield increase compared to lime control treatment (Sultana *et al*., 2009).

Similarly, successive applications of phosphorus fertilizer also resulted in increased biomass yield of wheat. Hence, the highest significant ($p < 0.001$) mean values of 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}. Over the years of combined analysis, the highest biomass yields (2826.7 and 2877.6 kg ha^{-1}) were recorded by application of 30 and 20 P kg ha^{-1}, respectively. In line with this result, Bereket *et al*. (2014) reported the highest total biomass 3.91t ha^{-1} recorded from the highest level 30 kg P ha^{-1} though not significantly different from 3.2 t ha^{-1} obtained at 20 kg P ha^{-1}. Similarly, biomass yield increased with increasing the addition of P rates (Peter, 2017).

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

Lime rates (t ha^{-1})	Spike length (cm)				Biomass Yield (kg ha^{-1})			
	2015	2016	2017	Combine	2015	2016	2017	CA
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
2.30	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
4.60	4.51a	5.8a	5.39a	5.24a	5018.5a	2638.9a	3116.3a	3591.2a
LSD (0.05)	0.394	0.60	0.654	0.294	1029.5	515.93	734.84	416.81
Significance	***	*	*	***	**	***	***	***
Phosphorus rates (kg ha^{-1})								
0	3.880	5.2	4.40b	4.51b	4159.3	1291.7c	1340.3b	2263.7b
10	4.227	5.7	4.93ba	4.93a	3577.8	1826.4ba	1784.7ba	2396.3b
20	4.187	5.7	5.29a	5.06a	4570.4	1757.0b	2305.6a	2877.6a
30	4.247	5.6	5.06a	4.95a	4125.9	2222.2a	2132.0a	2826.7a
LSD (0.05)	ns	ns	0.584	0.272	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

Note: *** Significant at $P < 0.001$, ** significant at $P < 0.01$, * significant at $P < 0.05$, ns – no significant difference, CA = Combined Analysis. Means along the column with the same letter are not significantly different.

Grain yield

Moreover, over year combined mean the highest grain yield (1115.9 kg ha^{-1}) was recorded under 4.6 t ha^{-1} of lime application of plot (Table 4). The lowest grain yield was recorded in control plots. According to Achalu *et al*. (2012), the increase in crop yield through the application of lime may be attributed to the neutralization of Al^{3+}, the supply of Ca^{2+} and increasing availability of some plant nutrients like P. Similarly, the highest application of 4.6 t ha-1 lime rate increased grain yield of wheat by 151.1% related to control plot. This is in agreement with (Osundwa *et al*., 2013) who stated that the application of lime significantly increased grain yield. Similarly, the application of

3.5 t ha^{-1} lime recorded a 37.9% yield increase compared to lime control treatment (Sultana *et al*., 2009). Surface liming caused increases by up to 140% in the grain yield of wheat (Caires *et al*., 2006). In line with the report of Mekonnen *et al*. (2014) the grain yield 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). Lime application (4ton/ha) gave the highest grain yield of malt barley.

Similarly, successive applications of phosphorus fertilizer also resulted in increased grain yield of wheat. Hence, the highest significant ($p < 0.001$) of grain yield was 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, the highest grain yields (881.3 and 898.1 kg ha^{-1}) were recorded by applications of 30 and 20 P kg ha^{-1}, respectively whereas the lowest grain yield was recorded in control plots. Hence, the addition of 30 and 20 kg P ha^{-1} recorded 53 and 50% yield increases compared to control treatment. In line with this, Mekonen *et al*. (2014) also reported more than 100% yield increment due to the application of phosphorus. Temesgen *et al*. (2016) reported additions of 10, 20, and 30 kg P ha^{-1} have also increased grain yield by about 29, 55, and 66% than the control without P additions. Similarly, by addition of 20, 30 and 40kg P/ha, the grain yield increased by about 52.53, 69.31 and 70.74%, respectively, as compared to control (Tadesse *et al*., 2018).

Table 4. The residual effect of lime and p levels on grain yield of bread wheat on acidic soils combined over three years (2015, 2016 and 2017).

	Grain Yield (kg ha^{-1})			
Lime rates (t ha^{-1})	2015	2016	2017	Combined Analysis
0	715.6b	239.6b	377.9c	444.4c
1.15	897.7b	318.4b	369.5c	528.4c
2.30	1362.4a	403.5b	753.6b	839.8b
3.45	1341.8a	640.9a	783.2b	921.9b
4.60	1391.7a	768.6a	1187.3a	1115.9a
LSD (0.05)	387.35	215.49	261.46	159.34
Significance	**	***	***	***
Phosphorus rates (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)	ns	192.74	233.85	140.54
Significance	ns	**	**	***
CV %	10	35.1	25.6	33.8

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

Relationships between wheat grain yield and yield components

The correlation between grain yield and yield components are presented in Table 5. Grain yield was positively correlated with biomass yield, seeds per plant, plant height, spikes length, and the correlation was significant at (p< 0.001). Moreover, grain yield was most strongly correlated with biomass yield (r =0.995), followed by plant height (r = 0.984), spikes length (r = 0.954) and seeds per plant (r = 0.937). Similarly, biomass yield had positive and significant correlation (p< 0.001) with plant height (r = 0.974), spikes length (r = 0.966) and seeds per plant (r = 0.949). Similar results obtained by numerous authors (Ortiz *et al.*, 2002; Abeledo *et al.*, 2003; Temesgen *et al.*, 2016) indicated that significant associations of barley grain yield with its yield components.

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Table 5. Correlation matrix among grain yield and yield components of wheat grown on acid soils amended with lime and phosphorus

Parameters	GY	BMY	SPP	PH	SL
GY	1.00000	0.99490***	0.93714**	0.98419**	0.95351**
BMY		1.00000	0.94860**	0.97402**	0.96552**
SPP			1.00000	0.96420**	0.99399***
PH				1.00000	0.97236**
SL					1.00000

Note: GY= grain yield; BMY= biomass yield; PH= plant height; SPP= seeds per plant; SL= spikes length, *** Significant at $p < 0.001$, ** significant at $p < 0.01$

CONCLUSION

Poor wheat production in the 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 and yield components were increased by higher through improved soil chemical properties over five years. This yield reduction after five years of liming may indicate re-acidification of the soil which necessitates re-liming of the soil. Hence, lime application at the rate of 3.45 t ha^{-1} coupled with 20 kg ha^{-1} P fertilizer could serve as a reference to boosting wheat production in the study area.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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