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Original Research Article

Effect of Lime rates and Incubation Periods on the amelioration of Acidic Nitisols of Bedi area in Ethiopia

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Abstract

A study was conducted to determine the optimum lime/$CaCO_3$ rate and incubation period and exchangeable acidity equivalence for the amelioration of acidic nitisols collected from the central highlands of Ethiopia. A pot experiment was conducted at Holeta Agricultural Research Centre (HARC) in lath house using acidic soil samples collected from a depth of 0-20 cm from Bedi area, central high lands of Ethiopia. The treatments consisted of factorial combination of lime rates (0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5 mg kg soil) and different incubation periods (7, 14, 21, 28, 35, 42 days). The treatments were arranged in RCBD with two replications. The result of the study showed that the soil pH consistently increased with the increase in lime application rates. There is no clear trend of incubation period effect on soil pH but higher pH was recorded after four weeks of incubation following lime application indicating that lime incubation period for optimization of soil pH would be one month before planting, if soil moisture level is kept optimum. The results showed that incubation method of calibrating soil pH using lime/ calcite completely changes soil pH from extremely acidic (3.85) to near optimum pH of 6 or 6.5 suitable for crop production. Incubation method ends up in higher rates of lime application compared to the exchangeable acidity based method. Results of the current incubation method study revealed that 12.6 and 16.8 t ha^{-1} needs to be applied to raise the soil pH from 3.85 to 6 or 6.5 which has to be applied four weeks before planning.

Keywords: Incubation, lime requirement, acidic nitisol, exchangeable acidity, pH

INTRODUCTION

Nutrient deficiency, in part, is aggravated by soil acidity (Tolera Abera *et al*., 2006) which is the most wide spread problem in the Central Highlands of Ethiopia. In Ethiopia, large areas of highlands with altitude >1500 meter above sea level located in almost all regional states of the country are affected by soil acidity. According to EthioSIS (2014) and Behailu (2015) about 43% of the Ethiopian arable land is affected by soil acidity.

In very acidic soils, all the major plant nutrients (nitrogen, phosphorus, potassium, sulphur, calcium, magnesium and also the trace element molybdenum) may be unavailable, or only available in insufficient quantities. As soils become more acidic, plants that are intolerant to acidic conditions would be negatively affected leading to productivity decline. Thus any attempt to adjust soil acidity primarily focuses on neutralizing the soil acidity though raising the pH so that toxicity of Al and Mn will be avoided and yet most macro nutrients become available for plant uptake (Fageria and Baligar, 2008). This can be achieved by adding lime to the soil and farmers can improve the quality of acidic soils through liming to adjust the pH to the levels needed by the crop to be grown and for most nutrients to be available (Mahesh, 2006).

At the moment, liming is the most common management practice used to neutralize and overcome problems associated with soil acidification. A study conducted on barley at Bedi, West Shoa Zone, in Ethiopia showed that the application of lime at the rate of 12 t ha^{-1} raised the soil pH from 4.8 to 5.8, whereas further raising the lime rate by 3–4 t ha^{-1} raised the pH of the same soil to 6.3 (Beyene, 1987). Application of lime to acidic soils resulted in increase in grain yields by 50% to over 100% in wheat, barley, tef, soybean and maize in Ethiopia (Abewa et al., 2014; Asrat et al., 2014; Ayalew, 2007; Chimidi et al., 2013; Kidanemariam et al., 2013).

A green house based incubation of acidic soils treated with lime showed that the application of 10 t ha^{-1} calcium carbonate incubated for 90 days significantly reduced the strength of soil acidity levels and severity of exchangeable acidity and Al saturation in the soils (Achalu et al., 2012). The magnitude of the alteration of the soil pH value due to liming, however, considerably varied with lime rates tested. Effiong and Okon, (2009) reported that incubation of acidic soils with various liming materials just only for 30 days was sufficient to reduce exchangeable acidity. The authors found $CaCO_3$ as the most efficient liming material as it resulted in 68% reduction of the exchangeable acidity of the soil.

Although a considerable amount of research work has been conducted on several LR methods and correlated with the incubation method, there is scarcity of information on optimization of soil pH using incubation method. Thus, there was a need to investigate the effect of lime rate and incubation period and their interaction effect on attaining the predetermined target pH levels; and to compare both incubation and exchangeable acidity methods based on the amount of lime required to reclaim a specific area of land.

MATERIALS AND METHODS

Description of the Study Environment

The study was conducted at Holeta Agricultural Research Centre (HARC) in lath house. HARC is situated at a distance of 30 km from the capital, Addis Ababa along Ambo road. Soil samples were collected at a depth of 0-20 cm from Bedi area within 9°05.551' to 9°06.039' latitude and 38°36.091' to 38°36.210' longitude and with the altitude range of 2565-2702 m.a.s.l. in the central highlands of Ethiopia.

Treatments, Experimental Design and Procedures

The treatments consisted of factorial combination of different lime ($CaCO_3$) rates (0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5 g kg^{-1} soil) and incubation period (7, 14, 21, 28, 35, 42 days). The treatments were arranged in RCBD with two replications. The lime rates that correspond to the desired target pH were determined as described by (Dechassa, 2001). Consequently, the amount of lime that was sufficient to raise the pH of the soil to target pH levels were selected for liming the experimental soils. The soil was air dried and sieved through 2 mm diameter sieve to remove big sized clods and other debris. After homogenizing the sieved soil, each pot was filled with 1.0 kg of soil. The initial pH of the soil for all pots prior to liming was 3.85. The pots were kept in the lath house for six weeks watering them at every 7 days intervals.

The pH of the soil at the end of each incubation period was determined with 1:2 (soil: water) ratio. For six consecutive weeks, soil samples were taken periodically and analyzed for pH, to determine wether the equilibrium pH_w was reached. The lime level that resulted in the pre determined pH_w values (i.e. pH = 5, 5.5, 6 and 6.5) were selected and used as lime rates adjustment for pH target values. The amount of lime determined with incubation method was compared with the corresponding amount determined through exchangeable acidity method. The latter was calculated on the basis of the mass of soil per 0.2 m hectare-furrow-slice, soil sample density and exchangeable Al^{+3} and H^{+1} by the following formula, assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$ (Kamprath, 1984):

$$LR, CaCO_3\ (kg/ha) = \frac{cmolEA/kg\ of\ soil * 0.20\,m * 10^4\ m^2 * B.D.(Mg/m^3) * 1000}{2000}$$

Where, LR= lime rate; EA= exchangeable acidity, B.D. = bulk density of soil.

Soil sample analysis

The different soil parameters were determined using appropriate procedures. Soil particles size distribution (texture) was analyzed by using the Bouyoucos hydrometer method following the procedure described by Day (1965). Soil textural class was assigned based on the relative contents of the percent sand, silt and clay separates using the soil textural triangle described by Rowell (1994). The pH of the soil was measured potentiometrically using a pH meter with combined glass electrode in soil water ratio of 1:2.5 as described by Brady and Weil (1996). Organic carbon was determined using the wet oxidation method (Walkley and Black, 1934). The total N content of the soil was determined using the Kjeldahl method (Jackson 1967). Available phosphorus was determined using Bray II method Bray and Kurtz (1945), while exchangeable potassium was determined using flame photometer after extracting with 1 M ammonium acetate solution.

Table 1. The physicochemical property of the test soil before liming

Parameters	Ec (µs/cm)	pH (1:2) (H_2O)	pH (1:2) (KCL)	AP (ppm)	EA ($cmol_{(+)}$/ kgsoil)	K (Meq/100g)	TN (%)	OC (%)	Percent composition Clay	Percent composition Silt	Percent composition Sand
Value	263.51	3.85	3.79	10.45	2.13	0.97	0.2	2.82	40.5	38	21.9

AP= avil. Phosphorus, *EA= Exchangeable acidity*

Table 2. Mean square, F and P value of main factors and their interaction

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Lime_rate	13	67.21000298	5.17000023	1113.11	<.0001
Incubation_period	5	1.28773155	0.25754631	55.45	<.0001
Lime_rate*Incubation	65	1.15314345	0.01774067	3.82	<.0001

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Statistical analysis

Analysis of variance for soil pH data recorded weekly from a soil incubated with different lime rates was subjected to SAS statistical package (SAS, 2004) and ANOVA was generated using PROC GLM procedure, and mean separation was done at 5% probability level using tuckey test.

RESULTS AND DISCUSSION

Soil Physicochemical Characteristics

The results of the laboratory analysis of the experimental soils taken at 0-20 cm depth showed that the soil is clay in textural class with 40%, 22% and 38% of clay, sand and silt contents, respectively. The exchangeable acidity of the soil was 2.13 cmol kg^{-1} of soil. The electrical conductivity of the soil showed that the soil was salt free and extremely acidic (Jones, 2003), has medium organic carbon (Tekalign, 1991), high total nitrogen (Tekalign, 1991) and low available phosphorus (Landon, 1991; Jones, 2003) and very high exchangeable potassium (Jones, 2003) (Table 1).

Effects of Lime Rates and Incubation period on pH Optimization

In this study, the intention was to determine the optimum lime requirement of acidic soils collected from Bedi area through incubation method to raise the pH from the initial level of 3.85 to the ideal pH for crop production. The ideal soil pH for crop production described in FAO (2008) was 6.5-7.5. However, since the lime required to reach that pH level is considerably high, a pH above 6 is regarded as good under farmer's condition. The analysis of variance showed that there was significant main factors (lime rate and incubation period) effect as well as interaction effects the main factors ($P<0.05$) on soil pH readings (Table 2).

Main effect of Lime Rates on soil pH

The pH of the incubated acidic soils were significantly influenced by the main effect of Lime rate ($P<0.05$). The soil pH progressively increased with increasing lime rate (from zero to 6 g kg soil) but tended to decline when the lime rate exceeds 6 g kg^{-1} soil) (Figure 2). The target pH

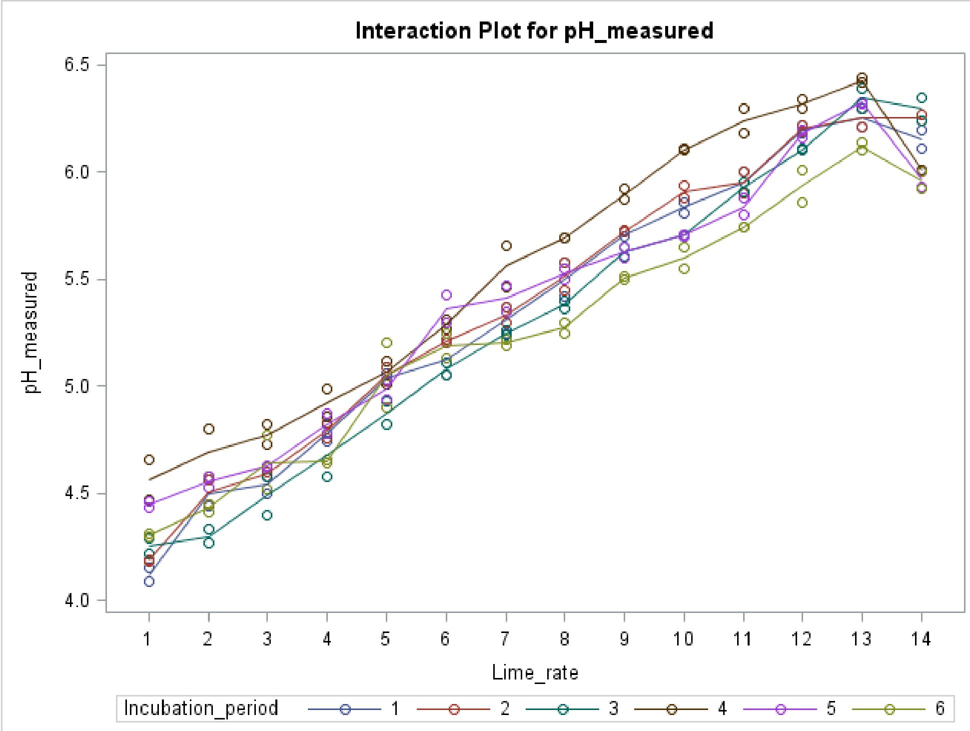

Figure 1. Graph represnetation of the interction effects of lime rates and incubation period

Table 3. Interaction effect of Lime application rate and incubation period on soil pH reading

$CaCO_3$ (g kg $^{-1}$ soil)	LSD	Incubation period 1 weeks	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks
0	0.25	4.12C	4.19C	4.26BC	4.57A	4.45AB	4.31BC
0.5	0.33	4.50AB	4.51AB	4.30B	4.69A	4.56AB	4.43AB
1	0.38	4.54A	4.59A	4.49A	4.78A	4.63A	4.65A
1.5	0.32	4.78A	4.79A	4.68A	4.93A	4.83A	4.65A
2	0.41	4.04A	5.06A	4.88A	5.07A	4.99A	5.05A
2.5	0.28	5.13AB	5.21AB	5.08B	5.29AB	5.37A	5.19AB
3	0.31	5.31AB	5.36AB	5.25AB	5.56A	5.41AB	5.21B
3.5	0.25	5.5AB	5.51AB	5.38B	5.69A	5.53AB	5.28B
4	0.1	5.71BC	5.73B	5.63BC	5.89A	5.63C	5.51D
4.5	0.15	5.84BC	5.91B	5.71CD	6.10A	5.71CD	5.60D
5	0.24	5.95B	5.95B	5.93B	6.24A	5.84B	5.74B
5.5	0.19	6.20AB	6.21AB	6.11BC	6.32A	6.18AB	5.93C
6	0.19	6.26AB	6.26AB	6.35A	6.43A	6.33A	6.12B
6.5	0.21	6.16AB	6.26A	6.30A	6.00B	5.96B	5.96B

Means within a row followed by same letter are not significantly different from each other

value (pH≥6) of the incubated soil was attained with the application of nearly 5 g kg^{-1} soil or more (Figure 2).

Main effect of incubation period on soil pH

The pH of the incubated acidic soils were significantly influenced by the main effect of incubation period ($P<0.05$). Incubation period did not show any clear trend although the highest pH was observed after four weeks of incubation implying that pH optimization period for calcite at any rate would be one month before planting. Further incubating the soils beyond four weeks, tended to result in decline of the pH values. Incubation period had little effect on change in soil pH compared to lime rates.

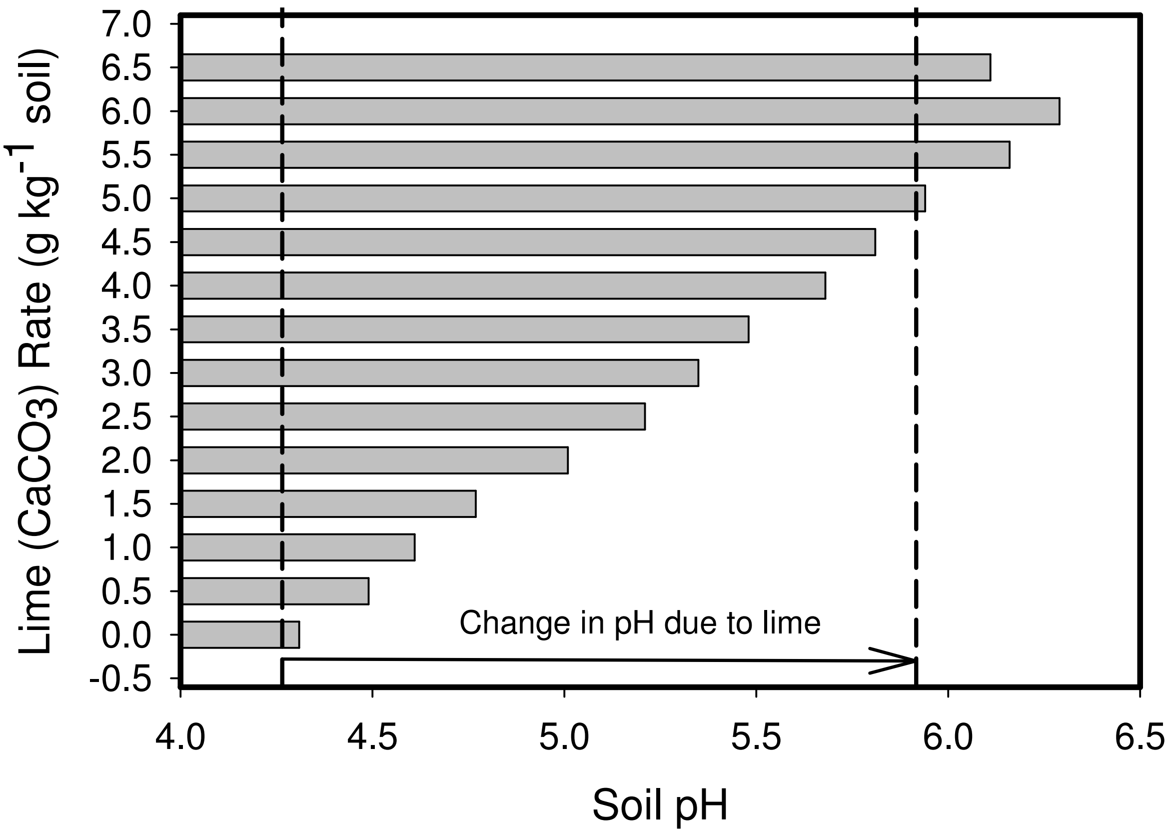

Figure 2. Main effect of Lime rate on soil pH reading

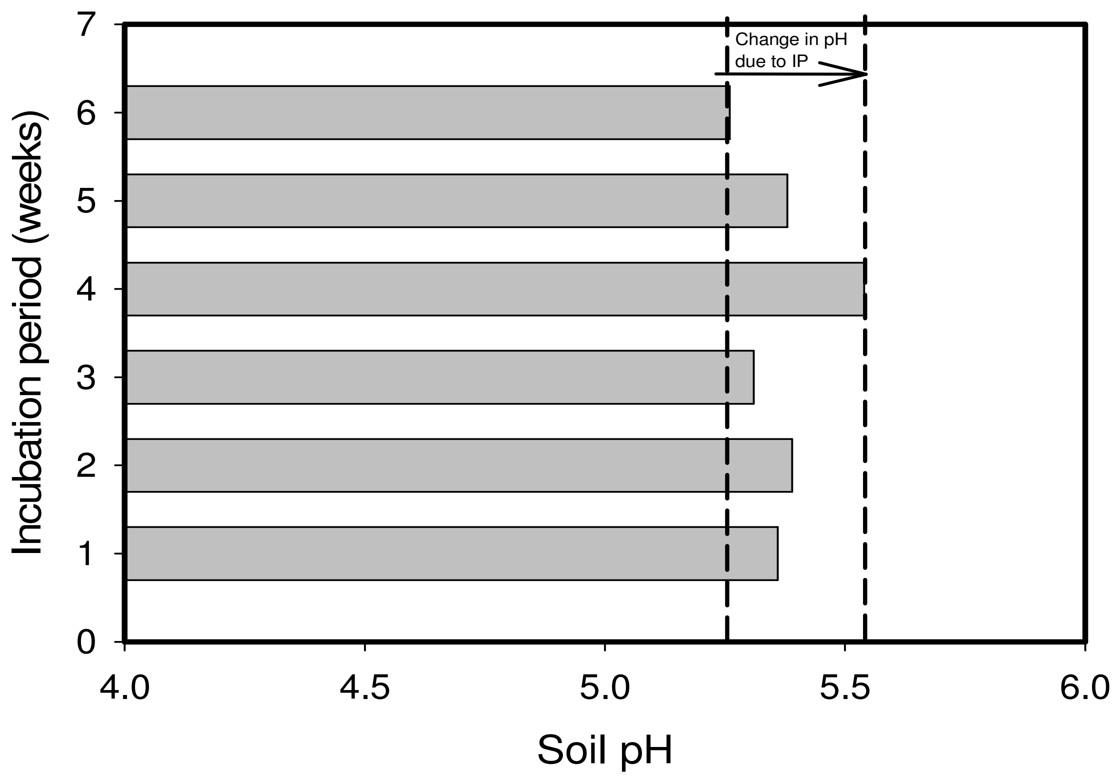

Figure 3. Main effect of incubation period on soil pH reading

Interaction effect of Lime application rate and incubation period

Generally, the application of lime at the rate of zero to 1.5 g kg^{-1} soil did not raise the soil pH above 5 for any of the incubation periods. However, further increasing lime application rate from 1.5 to 2.0 g kg^{-1} soil increased pH to 5 for all the incubation periods except for the first and third incubation periods. Increasing the lime rate from 2 to 4 g kg^{-1} soil increased soil pH from 4 to 5.7, 5 to 5.7, 4.9 to 5.6, 5 to 5.9, 5 to 5.6 and 5 to 5.5, respectively for the 1, 2, 3, 4, 5 and 6 weeks incubation periods. Further increasing the lime rate from 4 to 6.5 g kg^{-1} soil increased the soil pH from 5.7 to 6.2, 5.7 to 6.3, 5.6 to 6.3, 5.9 to 6.0, 5.6 to 6 and 5.5 to 6, respectively for the 1st, 2nd, 3rd 4th 5th and 6th incubation periods. There was a significant interaction effect of lime application rate and incubation period. At the lower lime application rate of 0.5 g kg^{-1} soil, the 4th week incubation period produced significantly higher soil pH compared to other incubation periods. However, soil pH did not significantly differ between incubation periods for the lime rates of 1, 1.5 and 2 g kg^{-1} soil. At the lime application rates ranging from 3 to 6 g kg^{-1} soil, the 4th incubation period produced significantly higher soil pH than the other incubation periods. However, for the lime rate of 6.5, the 2nd and 3rd incubation period produced significantly higher soil pH (6.3). Figure 1, Table 3

Relating Incubation Method for Practical Field level Lime Rate Determination

From the current incubation study, the lime rates that best matches the target pH levels (6 and 6.5) were 4.5, 6.0 (g $CaCO_3$ kg soil $^{-1}$). By considering the pot area 358 cm^2, to raise a pH of soil from 3.85 to 6 and 6.5 the calcite lime estimated to reclaim a hectare of acidic soil was 12.6 t ha^{-1}, and 16.8 t ha^{-1}, respectively. Figure 2 and 3

Determination of Lime Rate using Exchangeable Acidity Method

The average exchangeable acidity of Bedi soil used for this incubation study was 2.13 coml kg $soil^{-1}$. With this exchangeable acidity value at 20 cm soil depth and assumed bulk density of 1, the calculated LR, $CaCO_3$ (kg ha^{-1}) is 3.2 t ha $^{-1}$. For cereal production, when multiplied with a correction factor of 1.5 the LR needed is 4.8 t ha $^{-1}$.

Lime estimates with incubation method that changes a soil pH from 3.85 to 6 and 6.5 was 12.6 t ha^{-1}, and 16.8 t ha^{-1} calcite lime, respectively. Study conducted at Bedi having an initial soil pH of 4.8 was improved to a pH of 5.9 with the application of 2.2 t ha^{-1} calcite lime determined through exchangeable acidity based lime requirement method (Getachew et al., 2017). Although lime requirement can be determined both through incubation and exchangeable acidity methods best suitable method should further identified through verifying under field conditions.

CONCLUSIONS

The pH of the soil progressively increased with increasing lime rate. However, incubation period did not show any clear trend although the highest pH was observed after four weeks of incubation implying that pH optimization period for calcite at any lime rate would be one month before planting. Incubation method completely changeed soil pH from extremely acidic to nearly neutral level; even though it required much more lime compared to the lime requirement determined through exchangeable acidity method. Hence, it can be used as an alternative method of lime requirement determination especially for farmers affording more lime. By applying 12.6, and 16.8 t ha^{-1} lime to acidic soils having initial pH of 3.85, the pH of the soil could be raised to near optimal pH of 6 and 6.5, respectively.

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