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Evaluation and Validation of Simple and Quick Methods of Lime Rate Determination under Acid Soil-Affected Areas of West Shewa Zone, Ethiopia

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Abstract: Liming acid soils is one of the available intervention options to amend soil acidity and increase crop production and productivity. The selection of a lime requirement determination easy and cheap method that is suitable to the soil conditions in a particular area is a pressing issue. Three lime requirement (LR) estimation methods i.e. (Exchangeable acidity, laboratory pH, and portable pH/Artikilee 3000) methods with one control treatment were tested in acid soils of the dhumuga learning watershed. A field study was conducted to verify the lime requirement (LR) by using portable pH methods and investigate the wheat response to lime. The treatments were laid out in an RCBD design with two farmers' replications. The result showed that there a was significant ($p<0.05$) yield response to the liming. The highest grain yield of 5512.3kg ha 1 was obtained from lime treated with the pH method statistically at par with Exchangeable acidity and article 3000 methods. LR rates estimated by the Exchangeable acidity method were lower than those estimated by laboratory pH and portable pH/ Artikilee 3000. However, both methods (laboratory pH and portable pH/ Artikilee 3000) overestimated the lime requirements of the study soil. The exchangeable acidity method was lower than the LR estimated with the article 3000 method by an average of 38 %, which indicates article 3000 methods overestimated the LR for the present study area, while exchangeable acidity methods were found to be reliable estimation LR. Lime rates determined with the three lime testing methods (pH method, Portable pH or Artikilee 3000 and exchangeable acidity) gave yield advantages of 31.94, 24.93 and 20.45%, respectively over the non-limed treatment. From the results of this study, it was concluded that the exchangeable acidity method gives a more reliable estimation of the lime requirements of acid soils of the study area.

Keywords: Exchangeable Acidity, soil pH, portable pH/Artikle, Soil acidity, and wheat.

Research Paper

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1. INTRODUCTION

Soil acidity is one of the land degradation problems that reduce land's ability to provide ecosystem services which has stayed as an eminent problem limiting crop production and productivity in Ethiopia. In Ethiopia, vast areas of land in the Western, Southern, Southwestern, and Northwestern and even the central highlands of the country, which receive high rainfall, are thought to be affected by soil acidity (Ethiosis, 2014 and ATA, 2007). The summation of different anthropogenic and natural processes including leaching of exchangeable bases, basic cation uptake by plants, decomposition of organic materials, application of commercial fertilizers, continuous cropping (in many areas mono-cropping) without the use of the required amount of inputs, the concentration of CO_2 in the atmospheric, and other farming practices produce acidic soils (Brady and Weil, 2002). The major soil-forming factors that include; climate, vegetation, and parent material, are among the major factors that increase soil acidity in the country (Mesfin, 2007). The problem of soil acidity in the country is apparently increasing both in area coverage and severity of the problem. A recent study showed that about 43% of Ethiopian arable land is affected by soil acidity (Ethiosis, 2014).

Soil acidity is quantified on the basis of H+ and Al^{3+} concentrations of soils. For crop production, soil acidity is a complex of numerous factors involving nutrient deficiencies and toxicities, low activities of beneficial microorganisms, and reduced plant root growth, which limits the absorption of nutrients and water (Fageria and Baligar, 2008). However, Al^{3+} toxicity is one of the major limiting factors for crop production on acid soils by inhibiting root cell division and elongation, thereby, reducing water and nutrient uptake (Wang *et al.*, 2006), affecting mycorrhizal infections (Delhaize *et al*., 2007), consequently leading to poor plant growth and yield of crops. Increased soil acidity causes solubilization of Al^{3+}, which is the primary source of toxicity to plants at pH below 5.5, and deficiencies of P, Ca, Mg, N, K, and micronutrients (Kariuki *et al*., 2007; Mesfin, 2007).

Soil acidity is often also an insidious soil degradation process, developing slowly, although indicators, such as falling yields, leaf discolorations in susceptible plants, and lack of response to fertilizers may show that soil pH is falling to critical levels. To counteract this problem sustainably, the development of a regenerative agricultural strategy that aimed not simply at sustaining the current state of soils and ecology, but rather at enhancing an array of different schemes such as conservation agriculture, integrated soil fertility management technology comprising inorganic and organic soil amendment and others are substantial.

The adjustment and maintenance of soil acidity is a very important management of acidic soils to increase crop production using different mechanisms (approaches). Acid-infertile soils may be corrected through liming (Verde *et al.*, 2013). Lime is the major means of ameliorating soil acidy (Anetor and Ezekiel, 2006), because of its very strong acid-neutralizing capacity, which can effectively remove existing acid, stimulate biological activity, and reduce the toxicity of heavy metals. However, lime applications depend on obtaining good (accurate) lime requirement determination. Many laboratory methods for the determination of lime requirements of acid soils have been developed and evaluated in many parts of the world. Lime requirement measurement methods include soil-lime equilibrations, soil-base titrations, and soil-buffer equilibrations. These methods are time-consuming and, therefore, unsuitable for routine test programs.

In Ethiopia, lime requirement determination is usually based on buffer pH and exchangeable acidity (E.A) methods that need a collection of bulk samples from different farmers and transport to soil laboratories. The soil sample collection from fields and analysis in the laboratory is time taking, expensive, and at times laborious. Therefore, there must be a quick test method for the determination of lime requirement that can be applicable under on-farm conditions. Hence, a quick and easy method of lime determination based on pH using a pH tester provides an option. The experiment on a quick and easy method of lime determination based on pH using a pH tester was conducted at different centers of acidic soil areas of Ethiopia for the last two consecutive cropping seasons (2016 and 2017) to identify the best, cheap, easy, and easy methods of lime determination on different crop productivity. The Portable pH testers of the lime determination method could increase crop yield significantly and improve soil chemical properties in acidic soil conditions with equal amounts with other lime determination methods. Hence, this experiment was designed to verify /validate and demonstrate the Portable pH/ article 3000 lime determination method for crop productivity and soil property improvement in the dhumuga learning watershed.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The study was carried out at the Ambo Agricultural Research Center dhumuga learning watershed during the 2021-2022 main cropping season. The center is located 114 km away from Addis Ababa in the west Shewa Zone of the Oromia Regional National State. And Dhumuga Watershed is found at a distance of 12 km from Ambo town in the south. Geographically dhumuga watershed is located between 8^{o}54’ 0” N to 8^{o} 55’ 0” N latitude and 37^{o}49’30” E to 37^{o}50’30” E longitude at an altitude range from 2189 – 2555 m.a.s.l. and mean annual temperature ranges from 12.7 to 30 ^{0}C. (Fig. 1 & 2). With the catchment area coverage of 564 ha

Distribution of Soil Acidity in the Study Districts

In the study area soil acidity is apparently increasing both in area coverage and the severity of the problem. The acidity status of Ambo districts of the study area indicates that more than 75% of cultivated land is highly affected by soil acidity (Figure below).

According to the below figure and sample size about 55 % of the Ambo woreda, (the study district) cultivated land is affected by soil acidity, and of this soil, 26.92 % is dominated by very strong acidic and around 38.46 % are strong acid soils.

2.1.2. Soil Sampling, Preparation, and Analysis before Planting

Prior to the field experimentation both undisturbed and disturbed samples were collected. Three undisturbed samples were taken by the core sampler. Fresh weight and an oven-dry weight at 105 ^{o}C and used to determine the bulk density (Baruah *et al*., 1997). A representative composite soil sample was collected from the selected site using an auger from a plow layer (0-20cm) of the whole experimental field before treatment application to measure the threshold level of soil acidity and for estimation of the liming rate. The soil samples were air-dried, thoroughly mixed, and ground to pass through a 2 mm sieve, and the analysis for soil pH, soil texture, and Exchangeable acidity followed standard laboratory procedures.

The disturbed composite soil samples were analyzed for particle size distribution (soil texture), which was done by the Bouyoucos hydrometer method as described by Bouyoucos (1962) are among the physical soil parameters, while soil exchangeable acidity and soil pH for soil chemical analysis were selected. The soil pH was determined in a soil water suspension of 1:2.5 (soil: water ratio) using a pH meter, as described by Van Reeuwijk (1992). Exchangeable acidity was determined by saturating the soil samples with potassium chloride solution and titrating with sodium hydroxide as described by Mclean (1965).

2.1. 3. Treatments, and Experimental Procedures

The experiment was conducted on a farmer's field found in the Dhumuga learning watershed (based on the soil acidity of the site) covered by the activity of the center in a 4m*4m plot area. The treatments comprised three lime determinations methods namely: exchangeable acidity, laboratory pH, and Portable pH/Artikilee 3000 methods, and one control treatment. The treatments were laid out in an RCBD design with two farmers' replications. The materials used as chemical soil acidity ameliorant were ground limestone/ Calcium carbonate. The lime requirement was calculated based on soil exchangeable acidity, laboratory pH, and portable method of equation regression employing the lime rate estimation technique. The soil acidity conditioners were applied to a well-prepared experimental plot one month ahead of planting and mixed with the soil in the plow depth. The planting materials used in the experiment was a recently released variety of wheat (wane variety). Both the recommended Phosphorus and nitrogen fertilizer were applied uniformly for all treatments. Phosphorus fertilizer was applied at planting and mixed with the soil, whereas nitrogen was applied twice in a split form. All the recommended cultural practices were used for the management of the experimental plot uniformly.

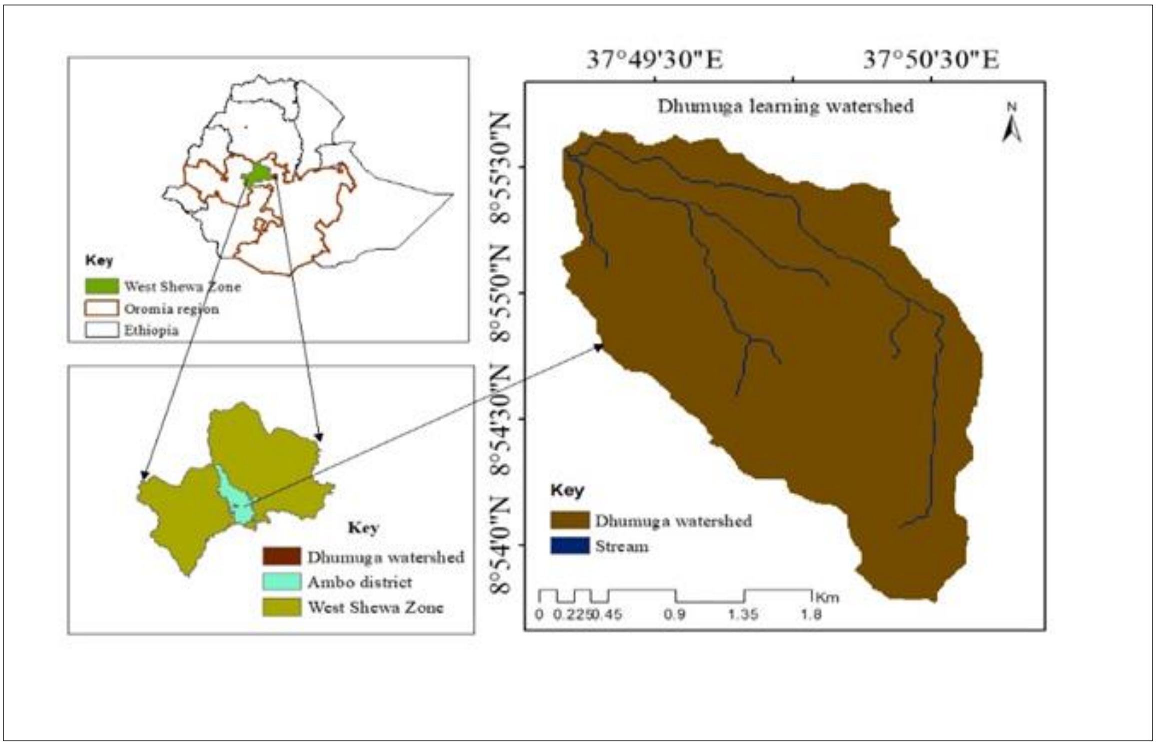

Figure 1: Location Map of the study area (Dhumuga watershed; Ambo)

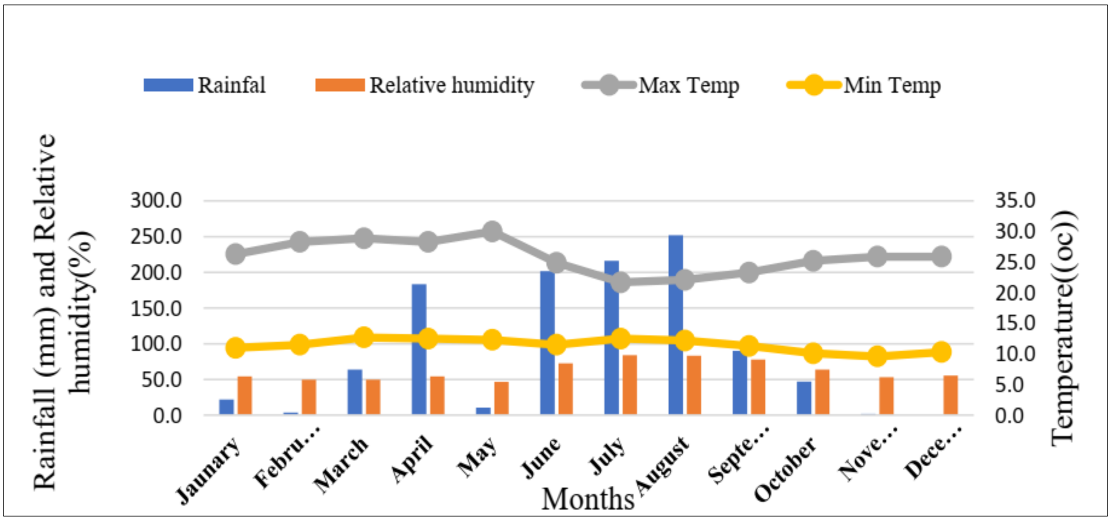

Figure 2: Relative humidity (%), Rainfall, and temperatures (°C) in the Dhumuga watershed during the crop growth period (2022)

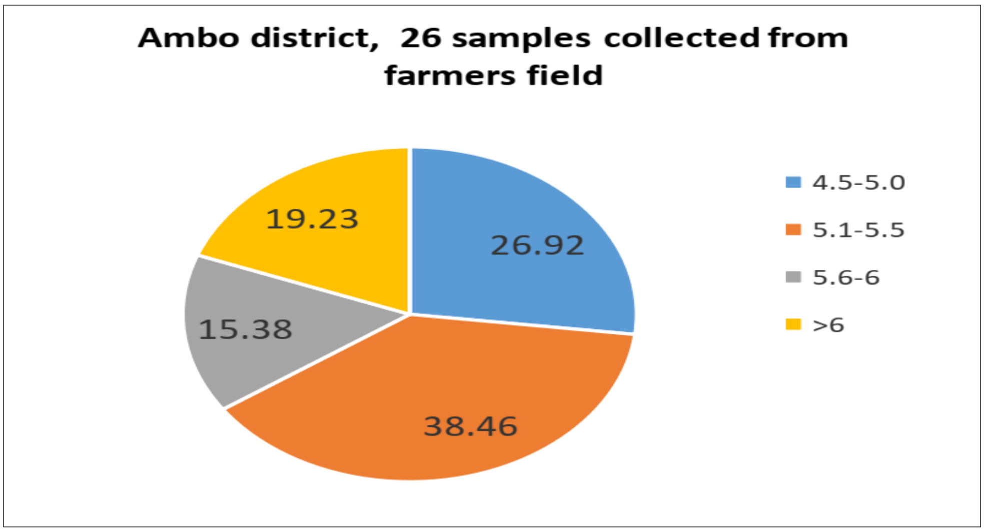

Figure 3: Acidity status of Ambo Districts based on the sample size evaluated.

Table 1: Treatment and Description

Different lime requirement determination methods		**Lime applied in tons**
Treatment 1	Control	0 ton /ha
Treatment 2	Exchangeable acidity	1.633 ton /ha
Treatment 3	Portable pH or Artikilee 3000	2.667 ton /ha
Treatment 4	pH methods	1.960 ton /ha

Treatment 1: Control: without lime applications. However, all other inputs and management were similar to other below treatments.

Treatment 2:

Exchangeable acidity method: The amounts of lime applied were determined based on the exchangeable acidity, mass per 0.15m furrow slice, and bulk density of the soil (Shoemaker *et al.*, 1961; Van Lierop, 1983), considering the amount of lime needed to neutralize the acid content (Al + H) of the soil up to the permissible acid saturation level for wheat growth.

$$LR,\frac{CaCo3kg}{ha} = Cmol\frac{EA}{Kg} of\ soil * 0.15m * 10,000m^2 * BD\left(\frac{g}{cm^3}\right) * 1000 * crop\ factor = 1633\ kg/ha$$

2000 Equation ----------- 1

Where: BD = bulk density, EA = exchangeable acidity (exch. H^+ + Al^{3+}), LR= lime requirements, 0.15m= plow depth/depth of lime incorporation. Crop factor = 1.5.

Treatment 3:

Portable pH or Artikilee 3000 method: Lime requirement (LR) as predicted by curvilinear regression equations against soil pH and LR determined by the exchangeable method.

For central Ethiopia: LR= $11.1pH^2$-133.2 pH+401.3=2667 kg/ha (Regression equations developed at/by HARC for central Ethiopia) (Quick method of lime requirement determination as an option for management of soil acidity in Ethiopia user manual by Musefa Redi, Hirpha Legesse (Ph.D.), Getahun Dereje and Temasgen Desalegn (Ph.D.) (January 2021). Equation------------2

Treatment 4:

pH method: soil pH was measured potentiometrically using a digital pH meter in the suspension of 1:2.5 soils to liquid ratio (Page, 1982) and calculated based on this formula: LR (t/ha) = (target pH-current pH) ×soil texture factor=1960 kg/ha. The soil texture of the site: Sandy clay loam=4. Equation----------------3

Table 2: Pre plant soil analysis result/ physicochemical properties of the experimental soil prior to cropping

Parameters/physiochemical properties	**Unit**	**Value**
pH (H_2O) based on laboratory	-	5.51
pH based on portable	-	4.0
Exchangeable acidity	(Cmol(+)/kg)	1.12
Bulk density	(g/ cm^{-3})	1.3

2.1.4. Data Collection and Measurements
Growth, Yield, and Yield Data Collections

Table 3: Data collection and methods of collection/measurement

Parameters	Methods used
Plant height(cm)	to evaluate the effect of the treatments on wheat development, five plants per plot were randomly selected before harvest and their heights were measured using a tape measure, and the mean height of the five plants was recorded as plant height in cm
Grain yield (kg/ha)	was measured by harvesting the crop from the net plot area of the middle five rows. The moisture content of the grain was adjusted to 12.5% and then the weight was converted to kg $ha^{-}1$.
Above-ground dry-biomass (t ha^{-1})	the total above-ground biomass of the middle five rows of the net plot area was determined by harvesting close to the soil surface at physiological maturity by sun-drying to gain a constant weight. Finally, the biomass yield of the selected middle five rows was converted to per hectare and expressed in t ha.
Spike length(cm)	to evaluate the effect of the treatments, five plants per plot were randomly selected before harvest and their spike length was measured using a tape measure the mean length of the five plants' spikes was recorded as spike length in cm.
The number of seeds per spike	was counted from five randomly selected plants from five middle rows at harvest maturity and expressed as an average of each plant

2.1.5 Statistical Analysis

Analysis of variance was conducted for each year separately and combined analysis over the two years. Analyses of variance were performed using the Statistical Analysis System (SAS) statistical program. Whenever the ANOVA detected significant differences between treatments, mean separation was conducted using the least significant difference (LSD).

3. RESULTS AND DISCUSSION

There were highly significant differences ($p \leq 0.01$) among treatments that received lime and unlimed(control) for plant height, spike length, number of seeds per plant, yield, and above-ground biomass of wheat (Table 4). However, for most of the parameters except for grain yield the lime received treatment/both lime requirement methods were statistically at par with each other.

Table 4: Mean squares of Treatments and Error for plant height, spike length, number of seeds per plant, grain yield, and above ground biomass of wheat at dhumuga learning watershed; Ambo

No	Mean squares		
	Parameters	**Treatments**	**Error**
1	Plant height (cm)	221.16*	19.7
2	Spike length(cm)	6.64**	0.25
3	Number of seeds/plants (№)	377*	32.61
4	Biomass (t ha^{-1})	5.54**	1.20
5	Grain yield (kg/ha)	2187339.61**	219851.56

Effect of Lime Determined with Three Different Methods on Plant Height and Spike Length of Wheat

The result indicated that the effects of the application of lime rates determined with three different lime estimation methods had a significant effect on the plant height of wheat when compared lime-treated plot with a control plot (Table 5). Numerically the longest plant height (95.95cm) was recorded from lime estimated by laboratory pH methods (1.96ton/ha). While the shortest plant height (79.4 cm) was recorded from the control treatment. However, those treatments that received lime are statistically at par. The growth parameter (plant height) response to the application of lime was most likely attributable to a rise in the soil pH and elimination of the possibility of exchangeable Al^{3+} toxicity due to liming and also liming neutralized soil acidity, which in turn might have improved the availability of plant nutrients, particularly phosphorus and calcium and lowered the concentration of toxic cations, mainly Al^{3+} ions. This, in turn, improves plant growth, most likely resulting from enhanced conditions for seedling growth.

The increase in plant height with the lime application could be due to the improvement of soil microbial activity like nitrification and improved nitrogen which is considered as one of the major limiting nutrients in plant growth adequate supply of it promotes the formation of chlorophyll which in turn results in higher photosynthetic activity, vigorous vegetative growth, and taller plants. This result is supported by Osundw *et al.*, (2013) reported that the increase in the agronomic yields due to liming might be attributed to the increases in soil pH, reduction in the ion toxicity of H or Mn, and reduction in nutrient deficiency (Ca, P, or Mo). The results are similar to the results of Kisinyo *et al.*, (2016) who reported that the growth of plants is increased on acid soil in response to the application of lime.

Table 5: Effect of different lime rates on wheat plant height at Dhumuga watershed

Treatments	Plant height (cm)	Spike Length(cm)
pH methods	95.95a	5.97a
Portable pH or Artikilee 3000	94.2a	6.15a
Exchangeable acidity	90.70a	5.45a
Control	79.4b	3.35b
Mean	90.06	5.23
$LSD_{0.05}$	7.00	0.79
CV%	4.93	9.6

CV= Co-efficient of variation, note: Means with the same letters are statistically not significant ($p > 0.05$) different from each other

Similarly, the reason for the better spike length development with the lime application was due to the increase in photosynthetic activities of the plant on the account of releasing fixed phosphorous and improving the process of nitrification (improving nitrogen) when pH is corrected and the nitrogen is an essential requirement of spike growth which had an impact on yield. An increase in spike length at lime application could be due to a good photo-assimilates supply which facilitates photosynthesis and aids in seed formation.

Effect of Lime Determined with Three Different Methods on Grain Yield, Number of Seeds per Plant, And Above Ground Biomass of Wheat

As shown in the below table (Table 6), the highest mean grain (5512.3 kg ha-1) yields were obtained from the application of lime rate determined with the pH method**.** And also, the highest biomass (11.14 t ha-1) was obtained from the application of lime rate determined with the pH method and Portable pH or Artikilee 3000 followed by an insignificant difference by the biomass (10.33t ha-1) yields obtained from the application of lime determined with exchangeable acidity methods (Table 6)**.** Application of lime rates determined with the above three lime testing methods (pH method, Portable pH or Artikilee 3000 and exchangeable acidity) gave yield advantages of 31.94, 24.93 and 20.45%, respectively over the non-limed treatment.

It is clear from the result that grain yield increased in response to lime application possibly due to higher plant height, number of seeds per spike or plant, and spike length. The increase in grain yield could be attributed to the beneficial influence of yield-contributing characters. Lime increase the availability of nutrients in the soil and modification of soil environments that resulted in better vegetative growth which in turn enabled the crop to produce greater photo-assimilate. The positive response of wheat to the applied lime might be also due to the probability of obtaining the available P from decomposed OM by microorganisms when the pH value of the soil improved due to liming, which might have resulted in increased grain yield. The improvement of phosphorus with the lime application is particularly important for stimulating early root formation and growth, functions in plant macromolecular structures as a component of nucleic acids and phospholipids, with crucial roles in energy metabolism, participation in signal transduction pathways via phosphorylation and controlling key enzyme reactions (Marschner 2011). Temasgen *et al*., (2017) also reported that the highest wheat grain yield was obtained under the application of 2.2 t/ha lime than unlimed. Tigist (2017) reported a 172.7 % decrease in the grain yield of soybean under unlimed plots relative to lime-treated plots. Achalu *et al*., (2012) also reported increased crop yield in response to the application of lime, which might be attributed to the neutralization of $Al^{3+,}$ supply of $Ca^{2+}$and increasing availability of some plant nutrients like P.

The increase in the number of seeds per plant (Table:6) might be due to the availability of phosphorus and another plant nutrient with the application of lime which is required for better growth and development of plants, especially phosphorus for seed development and seed production. An increase in the number of seeds per plant was also due to an increase in spike length and plant height with optimum lime application with accurate lime determination methods.

The application of lime rates determined with the above three lime testing methods (pH method, Portable pH or Artikilee 3000, and exchangeable acidity) gave Above ground biomass advantages of 22.03, 22.03 and 15.9%, respectively over the non-limed treatment. The liming amendment might improve the ability of the plant to absorb P when Al toxicity has been eliminated and enhanced the vegetative growth of wheat which resulted in increased dry biomass yield. Temasgen *et al*., (2017) reported that the highest dry biomass of barley was recorded on lime-amended soil with 2.2 t ha^{-1} application of lime compared with unlimed plots. Osundw MA, *et al*., (2013) reported that amendment of soil acidity with lime addition, increased grain yield significantly ($p=0.05$) and the lowest grain yield of 1.27 t/ha were found on control treatment compared with lime treated plot. In line with this result, Workneh (2013) also reported a significant increase in straw yield of soybean by 16.3%, due to soil liming at the rate of 2.6 t ha^{-1}. The improvement of plant nutrients helps in the synthesis of carbohydrates, which are required for the formation of protoplasm, thus resulting in higher cell division and cell elongation. Thus, an increase in biomass yield might have been on account of overall improvement in the vegetative growth of the plant due to the application of lime with recommended plant nutrients.

Table 6: Effect of different lime rates on a wheat number of seeds per plant, grain yield and above ground biomass at dhumuga watershed

Treatments	Number of seeds per plant	Grain Yield kg/ha	AGB ton/ha
pH methods	50.55a	5512.3a	11.14a
Portable pH or Artikilee 3000	50.40a	4997.8ab	11.14a
Exchangeable acidity (E.A)	45.35a	4716.1b	10.3375ab
Control	29.95b	3751.6c	8.685b
Mean	44.06	4744.44	10.34
$LSD_{0.05}$	8.99	738.74	1.7275
CV%	12.96	9.88	10.59

CV= Co-efficient of variation, note: Means with the same letters are statistically not significant (p > 0.05) different from each other

Economic Analysis

The open market price (45-birr kg-1) for wheat crops and the official prices of lime (3-birr kg-1) and the cost of transport was used for analysis (CIMMYT, 1988). The cost of transport for lime was taken to be 100-birr 100 kg-1. For each pair of ranked treatments, the percent marginal rate of return (MRR) was calculated. The MRR (%) between any pair of un-dominated treatments was the return per unit of investment in lime. It was calculated by dividing the change in a net benefit by the change in variable costs. 100% MRR means for every 1 birr invested in lime and transportation, farmers can expect to recover 1 birr and obtain an additional 1 birr (CIMMYT, 1988).

The highest MRR of 2096.15% was obtained from lime estimated by exchangeable acidity of 1.63-ton ha-1 lime followed by an MRR of 432.72 % from lime estimated by laboratory pH method of 1.96-ton ha-1 lime (Table 9). On other hand, the lowest net benefit (172573.6 ETB) was obtained from the control treatment/no lime applied treatments. Since the minimum acceptable rate of return assumed in this experiment was 100%, therefore lime estimated with exchangeable acidity (1.633 tons/ha) and lime estimated with laboratory pH methods (1.96 tons/ha) met the requirement (Table 9). The highest MRR 2096.15% was obtained from lime estimated with exchangeable acidity(1.633ton/ha). However, the recommendation might not (necessarily) be based on the highest MRR, because when farmers stopped there, they would miss the opportunity for further earning, at an attractive rate of return (CIMMYT, 1988).

Table 7: Partial budget with estimated Marginal rate of return (%) for d/t LR determination/rate effects on wheat grain yield at dhumuga watershed; Ambo

Treatments	Lime t/ha	Adj. GY kg/ha	GFB (ETB ha-1	TCV (ETB ha-1)	NB (ETB ha-1)	MRR (%)
Control	0	3751.6	172573.6	0	172573.6	-
Exchangeable acidity (E.A)	1.633	4716.1	216940.6	8328.3	208612.3	2096.15
pH methods	1.960	5512.3	253565.8	9996	243569.8	432.7258
Artikilee 3000	2.667	4997.8	229898.8	13601.7	216297.1	

Where; GFB=gross field benefit, TCV= total cost that varied, NB=net benefit, Adj. GY =adjusted grain yield.

4. CONCLUSION AND RECOMMENDATION

The exchangeable acidity, laboratory pH, and portable pH methods predicted the lime requirement at the rate of 1.66, 1.96, and 2.6 t/ha respectively. The result revealed that different lime rate determination methods generate different LR to raise the acid soil level to the desired level. It was found the pH, Artikilee 3000, and Exchangeable acidity methods effectively improved the productivity of wheat. Validation of the lime requirement method revealed that the LR predicted by Exchangeable acidity (1.96 t/ ha), portable pH/Artikile 3000 (2.6t/ha), and laboratory pH (1.96t/ha) methods increased wheat grain yield from 3751.6kg to 4716.1kg, 4997.8kg and 5512.3kg respectively. From an economic point of view, lime estimated with exchangeable acidity (1.633ton/ha) gave a higher acceptable MRR.

Because of its simplicity and rapid soil pH testing, no need to take bulk soil samples and transport to soil laboratories, ease to use by agricultural experts and development agents, give on spot lime recommendations, Artikilee 3000 method is good than the other, however, it is less accurate than others and overestimates the lime. The Exchangeable acidity methods predicted the LR at almost an appropriate rate. From the results of this study, the Exchangeable acidity method was found to be a more accurate/ reliable estimation than the other LR method for predicting the lime requirements of acid soils of the study area.

Therefore, farmers in the study area can use the Exchangeable acidity method to determine the lime rates required to amend their soils. However, to simplify the methods for our farmer the development of correlation and correction factors is required.

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