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Efficient and Cost-effective Methods of Lime Application to Alleviate Soil Acidity in Banja District, Northwestern Ethiopia

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Abstract

Liming of acidic soil is not effective in Ethiopia due to vast amount of lime recommendation, inadequate transportation, and cost of lime. Therefore, efficient and cost-effective methods of lime application play a crucial role in agriculture. This study was carried out to enhancing acidic soil through efficient and cost effective methods of application in Awi Nationality Administrative Zone, North West Ethiopia. Broadcast, drilling and micro-dosing methods of application and eight treatments were used in the field experiment. The experiment was laid out in Randomized Complete Block Design (RCBD) with four replications. Soil samples were collected and analyzed pre-planting and post harvesting of crop. Data were analyzed with SAS 9.3. The result showed that application of lime significantly ($p \leq 0.01$) affected selected soil chemical properties. Liming was significantly increased soil pH from 5.21to 7.01, available P from 8.48 to 19.42 mg kg $^{-1}$, and Cataion exchange capacity (CEC) from 23.6 to 37.48 $Cmol_{(+)}kg^{-1}$. On the other hand, exchangeable acidity decreased from 3.78 to 0.26 $Cmol_{(+)}$ kg $^{-1}$, respectively. Micro-dosing methods (MDM) of lime application was 15,24,19,95, 55 and 34 times efficient than full dose of buffer methods (FDBM) in broadcast application of lime in the selected chemical properties of soil pH, exchangeable acidity, exchangeable Al, CEC, available P and OC, respectively. Moreover, the net benefit and the MRR of MDM was 110,892 Birr ha $^{-1}$ and 2216%, respectively. This confirmed MDM of lime application was efficient and cost-effective than broadcast and drilling lime application methods. Therefore, it is recommended that small scale farmers could be used micro-dosing application of lime (0.1 t ha $^{-1}$) to improve the chemical properties of soil with a minimum expenditure.

Keywords: Broadcast, Drilling, Liming, Micro-Dosing, Soil acidity

1. Introduction

Agricultural production covers 40% of world's land area (Alston and Pardey, 2014). However, soil acidity is is one of the crop production limitations across the world (Caires *et al*., 2015; Fageria and Nascente, 2014). It represented a widespread phenomenon, encompassing a staggering 40% of the world's total arable land area. (Yadav *et al*. 2020). It is possible to say that, soil acidity is a primary limiting factor; it impedes the optimal growth and development of crops (Msimbira & Smith, 2020). Even though, agriculture is the backbone of Ethiopia economy (Yigezu, 2021), which represents about 33.88% of the national GDP (Plecher, 2020); soil acidity is one of the limited factors in the sector (Regassa and Agegnehu, 2011). It covers over 43% of the country's farmland (Oumer *et al*., 2023).

Acidic soils, a host of essential nutrients vital for robust plant growth and development are found to be deficient. Nitrogen (N), Phosphorus (P), Potassium (K), Sulfur (S), Calcium (Ca), Magnesium (Mg), and Molybdenum (Mo) are among the key elements affected by soil acidity (Neina, 2019). Additionally, in acidic soil the presence of aluminum (Al^{3+})' Manganese (Mn^{2+}), and Hydrogen (H^{+}) ions in the soil can lead to increased toxicity levels, hindering crops from absorbing crucial nutrients like Calcium (Ca), magnesium (Mg), Molybdenum (Mo), and Phosphorus (P) (Takala, 2019). Recognizing and addressing by using acid-neutralizing materials like lime is crucial in agriculture when soil acidity inhibits optimal growth (Bolan *et al*., 2023). Lime is a material/substance that contains substances like $CaCO_3$ or $MgCO_3$, neutralizes acids, adjusting soil pH. This mitigates aluminum toxicity, improves root growth, and releases phosphorus, increase crop productivity and yields (Fageria and Baligar, 2008). Furthermore, Liming materials improve soil physicochemical and biological properties, thereby enhancing soil fertility and plant growth (Bolan *et al*., 2023). The incorporation of liming materials stands as a paramount strategy in mitigating soil acidity, effectively counteracting the deleterious effects of acid reactions within the soil (Oumer *et al*., 2023; Mahmud and Chong, 2022). Through a process of chemical neutralization, the carbonate component within these materials reacts with the surplus hydrogen ions in the soil solution, thereby elevating the pH levels of the soil. This fundamental mechanism serves as the cornerstone of soil acidity amelioration, offering a reliable and widely adopted long-term solution to address this pervasive issue (Junior *et al*., 2020). The efficacy of liming in restoring soil pH levels has been extensively documented in the scientific literature (Bolan *et al*., 2023; Ejigu *et al*., 2023; Msimbira and Smith, 2020; Fageria and Baligar, 2008), affirming its status as a proven and indispensable technique in agricultural practices. Lime has incorporated into the soil in broadcast application (involves spreading lime uniformly over the soil surface), drilling (directly into the soil through vertical or horizontal channels) and micro-dosing (applying small quantities of lime directly to individual plants or rows) methods of placements (Ejigu *et al*., 2023; Alemu *et al*., 2022). However, conventional liming approach has limitations, including high costs, vast amount of lime recommendation, limited accessibility of lime, inadequate transportation infrastructure and labor-intensive processes (Oumer, *et al*., 2023; Zeng *et al*., 2017; Middendorf *et al*., 2017). Moreover, excess lime reduces the efficacy of lime (Sun, *et al*., (2022). Therefore, micro-dosing lime represents a paradigm shift in lime application. It involves the precise and targeted application of smaller quantities of lime, optimizing its efficacy (Dejen *et al*., 2022).

Despite the extensive documentation of the efficacy of liming in restoring soil pH levels, particularly, in agricultural contexts and limited factor of liming, there remains a gap in research regarding efficient and cost-effective methods of application in Banja District, Awi Nationality Administration Zone, North West Ethiopia. While various studies have explored the application of lime through different methods in Ethiopia (Dejene *et al*., 2023; Haile *et al*., 2023; Warner *et al*., 2023; Taye *et al*., 2020), there is limited specific research focusing on alleviating soil acidity in efficient and a cost-effective manner in the study area. Therefore, this study aimed to investigate efficient and cost-effective methods of liming to reduce soil acidity in the Banja district of Ethiopia. By evaluating various application techniques and their economic feasibility, it is possible to provide valuable insights and recommendations for optimizing soil management practices in the This research seeks to fill the existing gap in knowledge regarding practical and economical approaches to soil acidity reduction, ultimately contributing to sustainable agricultural development of Ethiopia.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was conducted in *Banja* district, *Awi* Nationality Administrative Zone, Amhara National Regional State, Ethiopia. Geographically, Banja District lies within 10^{o} 52to 11 3’N latitude and 36 38’to 37 8’E longitudes at a distance of 440 km Northwest of Addis Ababa and 120 Km South of Bahir Dar, the capital of Ethiopia and National Regional State, respectively (Figure 1). The altitude of the study site ranges from 2502 to 2792 meters above sea level.

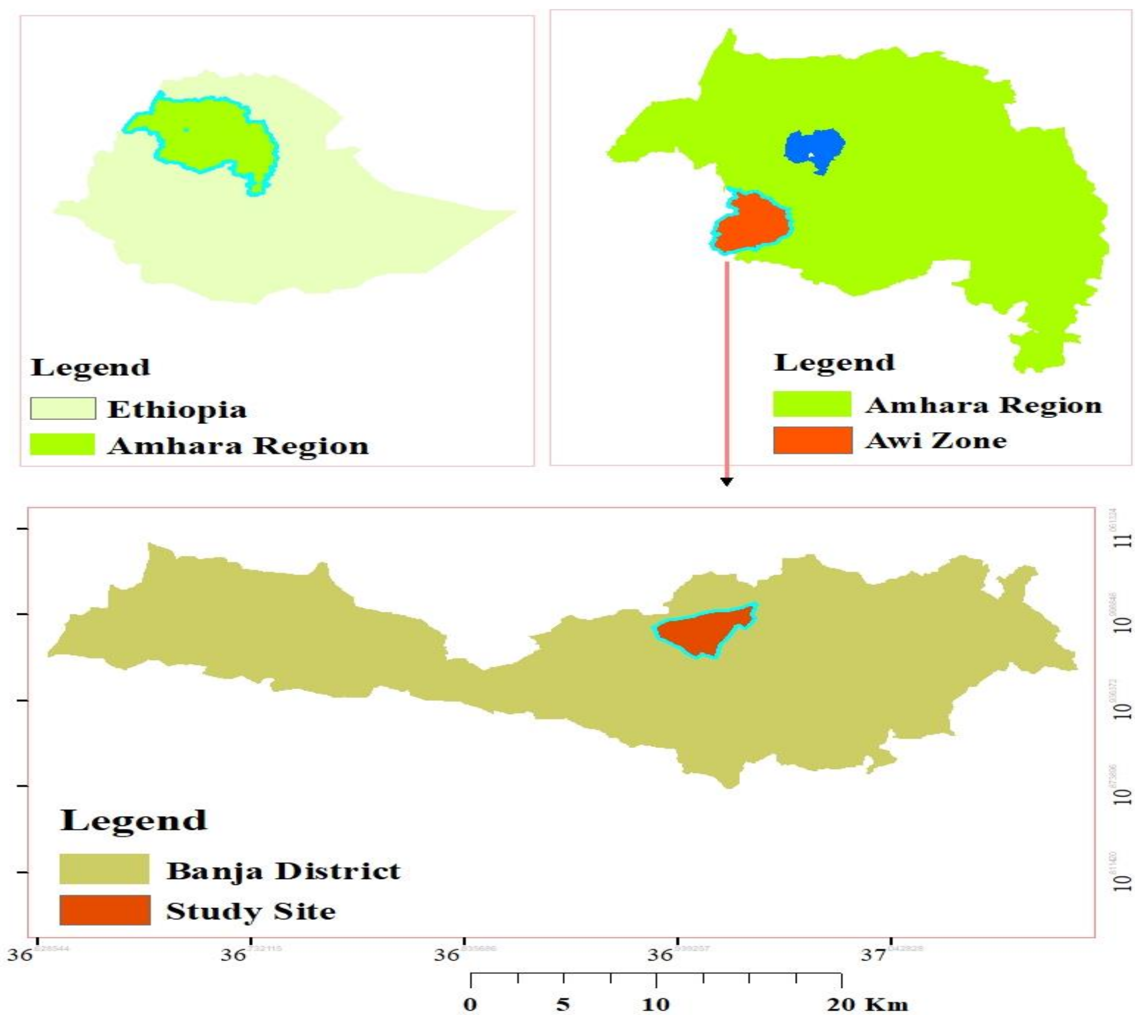

Figure 1. Location Map of the study area, Banja District, North west Ethiopia

According to the Bahir Dar (North West Meteorological Service) of Ethiopia, annual rainfall in the District ranges from 2200 to 2521 mm per annum and the mean annual temperature ranges from 10.8 – 24.2 ^{o}C (Figure 2).

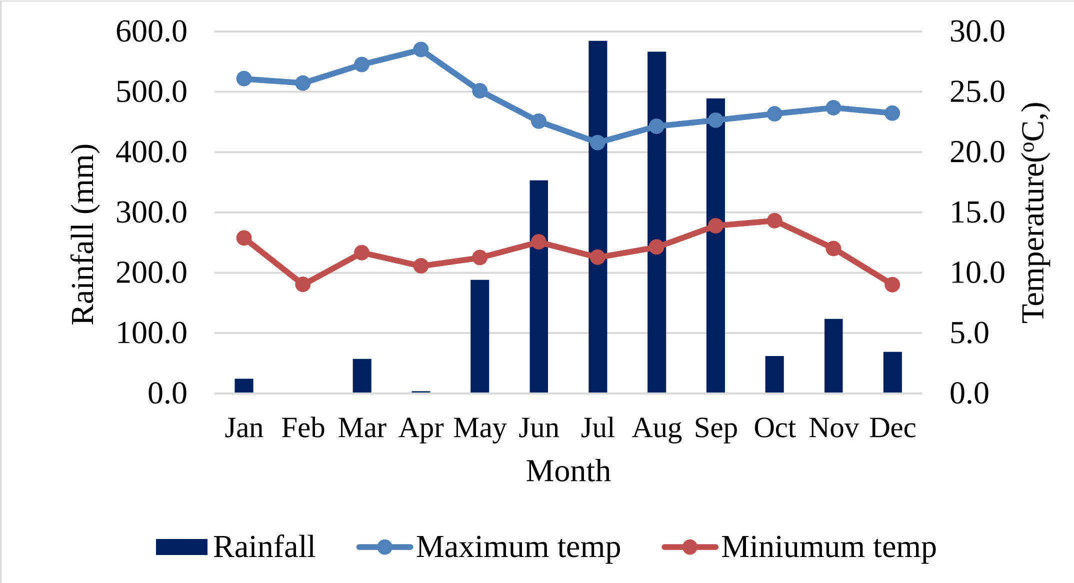

Figure 2 Two Decade (1999 to 2018) Mean monthly rainfalls and mean monthly maximum and minimum temperatures of the Banja district.

2.2. Soil sampling

Representative soil samples were collected before planting and after harvesting. Pre-planting composite soil samples were collected in a diagonal pattern from a depth of 0-20 cm. Uniform volumes of soil were obtained from each sub-sample (n=10) by vertical insertion of auger. Then the samples were packed in a plastic bag with inside and outside labeling, 1 kg of each soil were taken to soil laboratory for analysis soil samples were also collected from each plot in replications (n= 32) after harvest.

2.3. Soil sample analysis

The samples were air-dried on the shelve of a shaded room until the weight becomes constant after which the samples were ground using pestle and mortar and sieved through a 2 mm sieve for analysis of soil pH, exchangeable aluminum (E.Al), exchangeable acidity (E.A), cation exchange capacity (CEC), available phosphorous (P), organic carbon (OC) while for total nitrogen (TN) a soil passed through 0.5mm sieve was used.

Soil pH was measured in a 1:2.5 (soil: liquid ratio). Then buffer pH was measured by adding 20 ml Shoemaker, McLean and Pratt (SMP) buffer solution in the soil water solution. Exchangeable acidity was determined by saturating the soil samples with a potassium chloride solution and titrating with sodium hydroxide as described by McLean (1965). For the estimation of exchangeable Al^{3+}, 10 ml of 1M NaF was added and titrated with 0.*1M* HC1 until the pink color disappeared (Thomas, 1982). Cation exchange capacity (CEC) was measured after saturating the soil with 1*N* ammonium acetate (NH_4OAc) and displacing it with 1*N* NaOAc (Chapman, 1965). Available P was determined by Olsen methods (Olsen, 1954); organic carbon was determined using the method developed by Van Reeuwijk (1992) and Total N was determined by Kjeldahl method (Jackson, 1958).

2.4. Treatments and Experimental Design

As shown in Table 1, three methods of lime application and eight treatments were used in (RCBD) with four replications.

Table 1 Treatments, methods of lime application and amount of lime used in the experiment

No	Treatments	Abbreviation	Method of application	Amount of Lime ($t\ ha^{-1}$)
1	Control	NL		Without lime
2	Full doses of buffer method	FBM	Broadcast	12
3	Full doses of exchangeable acidity method	FEAM	Broadcast	4
4	0.5 Full doses of buffer method	0.5 FBM	Broadcast	6
5	0.5 Full doses of exchangeable acidity method	0.5 FEAM	Drilling	3
6	0.25 Full doses of buffer method	0.25 FBM	Drilling	3
7	0.25 Full doses of exchangeable acidity method	0.25 FEAM	Drilling	1
8	Micro-dosing method	MDM	Micro-dosing	0.1

The field experiment was conducted for one cropping season of 2018 by rain fed system of production on acidic Nitisols of *Banja* district *Awi* Nationality Administrative Zone, North West Ethiopia. A gross plot size of 3 m x 3.75 m = (11.25 m^2) was used. The spacing between blocks and plots were each 1 m.

2.5. Determination of lime requirement for buffer and exchangeable acidity methods

Lime requirement based on buffer method: Lime requirement was obtained from the SMP soil-buffer pH. Shoemaker *et al*. (1961) calibrated the SMP soil-buffer pH to the lime requirement for achieving a target soil pH of 6.5. The initial buffer pH of the soil was 5.6.

$$LR\ (t\ ha^{-1}) = 1.867\ (\text{Buffer pH})^2 - 31.82\ (\text{Buffer pH}) + 131.23 \quad \ldots\ldots 1$$

Lime requirement based on Exchangeable Acidity: The amount of lime was applied and calculated on the basis of the mass of soil per 15 cm hectare-furrow-slice, soil bulk density and exchangeable Al^{3+} and H^{+} of the site. Assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$. The amount of lime consumed was determined by using the formula given by Kamprath (1984).

$$LR, CaCO_3\ (kg/ha) = \frac{EA * 0.15\,m * 10^4\ m^2 * B.D. * 1000}{2000} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where LR = Lime requirement, EA= Exchangeable acidity (3.78 $Cmol_{(+)}$ kg^{-1}) BD= Bulk density (1.41 Mg m^{-3})

2.6. Land preparation, planting and inputs application

The land was prepared by ploughing four times. Based on the amounts required, finely powdered lime a 0.045 mm was thoroughly incorporated into the plot and mixed with furrow slices depth of soil to ensure higher reactivity (full reaction) with the soil before planting for the six treatments, but for the 7th treatment (micro dosing) of lime, 2.25 g of lime for each plant with basal application was applied. The spacing between the rows and the potato plant was 0.75 and 0.3 m, respectively.

2.7. Statistical and Economic Data Analysis

The collected data were subjected to analysis of variance (ANOVA) by using SAS version 9.3. Least Significance Difference (LSD) test at 1% and 5% probability levels were used for mean comparison. When treatments show significant differences, mean separation were accomplished by using Duncan Multiple Regression Test (DMRT).

Economic Analysis**:** Marketable tuber yield of potato for the selected treatments were used in the marginal rate of return analysis. The field price of 1 kg of potato that farmers receive from the sale of the crop was taken as the market price of potato at Injibara near the experimental site. $CaCO_3$, Urea and NPS were applied as a source of lime, nitrogen and P fertilizers, respectively. The price of lime and mineral fertilizers was based on the sale in Birr kg^{-1}. The Gross benefit was calculated as marketable tuber yield (kg ha^{-1}) multiplied by the field price that farmers receive for the sale of the marketable tuber yields. Total variable cost is the sum of the cost that was variable or specific to a treatment against the control. Net benefit was calculated by subtracting total variable cost from the gross benefit. Then the marginal rate of return was calculated using the procedures described by CIMMYT (1988) as follows :

$$MRR = \frac{\text{NI from superior dominant plot} - \text{NI from preceding inferior dominant plot}}{\text{TVC of a superior dominant plot} - \text{TVC of the preceding inferior dominant plot}}$$

Where, MRR = marginal rate of return, NI = net income and TVC = total variable cost

3. Results and Discussion

3.1. Selected Soil Chemical Properties (before liming)

The soil in the experimental site is strongly acidic, with a pH of 5.21 and exhibits a very high level of Exchangeable Al^{3+} at 2.44 Cmol $_{(+)}$ kg^{-1}, (Table 2) very low in available phosphorous (8.48 mg kg^{-1}) and low in total nitrogen (0.11%) (EthioSIS, 2016). Based on the classification of Landon (1991), Cation exchange capacity was 23.6 Cmol $_{(+)}$ kg^{-1}, indicating a medium level and low in Organic carbon (2.11%) (Table 3). The observed variability in soil types and climatic conditions emphasizes the necessity for tailored agricultural interventions and soil management strategies.

3.2 Effect of lime application method and its efficiency on selected chemical properties of soil

Soil pH

Based on the analysis of variance (ANOVA), pH of all limed plots showed a significant difference ($P \leq 0.01$) as compared to the control plot. The highest pH-H_2O was registered (7.01) in broadcast application using FBM while the lowest pH (5.19) was registered in the control plot which reduced by 0.02 units from the value measured before liming (Table 2). The efficiency of pH per kg of lime application was 0.3 and 0.02 % with the application of FBM in broadcast and MDM of application of lime, respectively. MDM of application of lime was 15 and 6 times efficient than FBM in broadcast and 0.25 FEAM in drilling application of lime, respectively. Application of full dose of lime increases the pH of soil. However, micro dose application of lime increased pH more efficient. The increments of pH was associated with the presence of basic cations particularly Ca^{2+} and replaced H^{+} on exchangeable site resulting to the rise of pH (Fageria *et al*., 2014). Moreover, the author Twomlow *et al.* (2010) who stated that micro-dosing provides sufficient nutrients, especially on poor soils or degraded lands reducing application cost and maintaining favorable environment. The Duncan multiple regression test showed significant difference between the unlimed plot and micro-dose application of lime. Therefore, small scale farmers could afford MDM application of lime with limited expenditure by increasing its pH significantly from unlimed plot. Costs associated with liming materials have posed a significant obstacle to lime application (Middendorf *et al*., 2017; Haile, and Box 2009). This result is in line with previous studies (Alemu *et al*, 2022).

Exchangeable Acidity (E.A) and Exchangeable Aluminum (E.Al)

As revealed by the analysis of variance (ANOVA), there was a highly significant ($p \leq 0.01$) variation in exchangeable acidity among treatments. The result showed that, the highest exchangeable acidity (3.83 $Cmol_{(+)}$ kg^{-1}) value was measured from the control plot while the lowest (0.26, $Cmol_{(+)}kg^{-1}$) from a plot that received FBM of lime using the buffer method in the broadcast application method of lime (Table 2). Therefore, addition of lime from the lower rate to higher rates reduced exchangeable acidity. Even though the addition of lime from the lower rate to higher rates produced a reduction in exchangeable acidity, the reduction of the same by application of a kg of lime gave lower values from application of using FBM in broadcast application while the highest was obtained from the incorporation of lime MDM application of lime with values of 0.72 and 0.03 %, respectively (Table 4). This means MDM of application of lime was 24 times efficient than FBM in broadcast application of lime. The reduction of exchangeable acidity of the soil might be due to the increased replacement of Al by Ca in the exchange site and by the subsequent precipitation of Al as $Al\ (OH)_3$ (Halvin *et al.,* 2005). The other reason for the reduction of exchangeable acidity could be due to the increase in soil pH resulted from the application of lime (Ejigu *et al*., 2023). The lowering of exchangeable acidity and rising of pH can provide a wide range of benefits in terms of soil quality, notably by chemically improving the availability of plant nutrients, and in some cases by reducing the availability of detrimental elements such as Al (Brady and Weil, 2008). Similarly, there was a highly significant ($p \leq 0.01$) variation of exchangeable Al among the treatments. The highest value (2.74 $Cmol_{(+)}$ kg^{-1}) found in the control plot and the lowest (0.00 $Cmol_{(+)}kg^{-1}$) from the treatment that received in FBM in the broadcast application method of lime and the control, respectively (Table 2). The decreased efficiency of exchangeable Al per application of a kg of lime was 0.02 to 0.38 % from the incorporation of in the broadcast application method of FBM and MD of lime, respectively. The reduction in exchangeable acidity and aluminum can be attributed to the heightened displacement of aluminum by calcium in the exchange sites (Rahman *et al.*, 2018). Moreover, the solubility and release of Ca from lime in to the soil solution reduces the amount of exchangeable Al (Awkes, 2010: Fekad et al., 2017).

Table 2 Effect of lime application method and its efficiency on pH, exchangeable acidity and exchangeable Al

Activity	Treatments	pH§	E. A§	E. Al§	Efficiency (kg $^{-1}$) of lime (%)		
Methods of Application	Before Liming	5.21	3.78	2.44	pH	E. A	E. Al
	Control	5.19^{g}	3.83^{a}	2.74^{a}			
Micro-dosing	MDM	5.51^{f}	3.06^{b}	2.06^{b}	0.30	0.72	0.38
Drilling	0.25 FEAM	5.75^{e}	1.89^{c}	1.22^{c}	0.05	0.19	0.12
	0.25 FBM	6.41^{c}	0.85^{de}	0.11^{e}	0.04	0.10	0.08
	0.5 FEAM	5.98^{d}	1.14^{d}	0.87^{d}	0.04	0.13	0.08
Broadcast	0.5 FBM	6.82^{b}	0.46^{ef}	0.00^{e}	0.03	0.06	0.04
	FEAM	6.43^{c}	0.53^{ef}	0.00^{e}	0.03	0.08	0.06
	FBM	7.01^{a}	0.26^{e}	0.00^{e}	0.02	0.03	0.02
CV		0.66	11.81	15.36			
SE ±		0.12	0.23	0.19			
LSD(0.01)		0.08	0.36	0.27			
P		**		**			

CV= Coefficient of Variation; SE± =Standard error; LSD= Least significance difference, p=probability level; ** significantly different at p≤0.01. §Means followed by the same letters in a column are not significantly different at p≤ 0.01.

Cation Exchange Capacity (CEC)

The analysis of variance (ANOVA) showed that, there was a significant difference (p≤0.01) in CEC among treatments. The highest CEC value was 37.48 Cmol (+)kg-1due to the application of FBM lime; while, the lowest was 21.89 Cmol(+)kg-1CEC value in the control plots (Table 3). The extent of each treatment on CEC showed increasing trends with increasing amounts of lime. Application of FBM lime increased the CEC values by 13.88 Cmol $_{(+)}$ kg^{-1} from the control, and by 9.49 Cmol$_{(+)}$ kg^{-1} due to the application of micro-dosing of lime. The increment of CEC per kg of lime was more efficient in MDM application compared to the other treatments. The result showed that, MDM application of lime increased the efficiency of CEC by 9.5 % per kg of lime while, the efficacy of FBM lime in broadcast application increased the CEC value by 0.1 %. MDM of application of lime was 95 times efficient than FBM in broadcast application of lime. The increment of CEC with soil pH may be attributed to the presence of pH dependent negative charges which can increase CEC with increasing soil pH due to applied lime (Pionke and Corey, 1967). Moreover, the enhancement of CEC is a pivotal aspect of soil fertility and nutrient availability, and it is intricately linked to the release of initially blocked negative charges within the soil matrix (Peiris *et al*., 2022). Also the release of the initially blocked amorphous and interlayer substitutional negative charge by deprotonation of the variable charge minerals and functional groups of humic compounds increase the CEC value (Chimdi *et al*., 2012). The study showcased the effectiveness of MDM application techniques in increasing CEC in kg^{-1} lime. This suggests that MDM application could potentially optimize resource utilization by employing inputs in minimal quantities while ensuring optimal efficiency (Priyadarsini and Anitha, 2023).

Available Phosphorus (P)

Application of lime significantly ($P \leq 0.01$) increased available P. The highest value was obtained from the application of FBM while the lowest value was in the control plot with the respective value of 19.42 and 8.54 mg kg^{-1} (Table 3). Application of lime at the MDM methods also raised available P to 13.96 mg kg^{-1}. The efficacy of P per kg application of lime was higher in MDM of lime (5.5 %) and the lower (0.1%) was with application of FBM lime in broadcast method of incorporation of lime. MDM of application of lime was 55 times efficient than FBM in broadcast application of lime.

The increment of available P in the soil might be due to the application of NPS fertilizer by farmers as a source of P and lime at different dose and its effect on the released of P fixation by Al and Fe and the direct relation of soil pH. During liming of acidic soil, P could be released due to the reduction of P fixation by Al and Fe (Chimdi *et al*., 2012). It revealed that available P was affected by lower pH and higher exchangeable acidity and Al. These might be due to the reduction in pH value of the control treatment that might have caused P fixation (Penn and Camberato, 2019).

Organic Carbon (OC)

Based on the analysis of variance (ANOVA), an application of lime was significantly ($P \leq 0.01$) affected soil OC. The highest value was 2.74% was registered due to the incorporation of FBM while the lowest value (2.29%) was from the control plot (Table 3). The efficiency of per kg of lime was 0.005 and 0.17 %, in FBM and MDM application of lime, respectively. This showed that MDM of application of lime was 45 times efficient than FBM in broadcast application of lime. The increment of OC in the soil might be the addition of lime on soil which increases the pH and it creates good environmental conditions for the activities of soil microorganism (Biasi *et al.,* 2008; Paradelo *et al.*,2015). Application of lime to acidic soil, increase the soil OC (Chimdi *et al.,* 2012; Abewa *et al.,* 2013). This is due to the rise of soil pH in a short period of time that favors soil microbes to decompose crop residues. This outcome aligns consistently with documented findings from prior studies (Paradelo *et al*., 2015; Biasi *et al*., 2008).

Total Nitrogen (TN)

Application of lime was significantly ($P \leq 0.01$) increased TN of the soil. The highest value was in FBM in broadcast application while the lowest value was obtained from the control plots, which were 0.14 and 0.11%, respectively (Table 3). The efficiency of per kg of lime was 0.001and 0.11%, in FBM and MDM application of lime, respectively. The increments of TN might be due to the direct relation of soil pH and OC which facilitates soil microbial activities releasing nutrients including nitrogen. The relationship between soil pH, microbial activities, and the decomposition of organic matter releases nitrogen (Bolan *et al*., 2023).

Table 3 Effect of lime application method and its efficiency on CEC, Available P, OC and TN

Activity	Treatments	CEC (Cmol$_{(+)}$ kg^{-1})§	Available P (mg kg^{-1})§	%OC§	%TN§	Efficiency (kg^{-1}) of lime (%)			
						CEC	P	OC	TN
Method of application	Before Liming	23.6	8.48	2.11	0.11				
	Control	21.89^{d}	8.54^{f}	2.11^{c}	0.11^{c}				
Micro-dosing	MDM	33.09^{c}	13.96^{d}	2.28^{bc}	0.11^{c}	9.5	5.5	0.170	0.110
Drilling	0.25 FEAM	31.24^{c}	13.56^{de}	2.67^{abc}	0.11^{c}	0.8	0.5	0.056	0.011
	0.25 FBM	36.97^{ab}	15.48^{c}	2.63^{ab}	0.13^{ab}	0.4	0.2	0.017	0.004
	0.5 FEAM	36.80^{b}	13.18^{e}	2.61^{b}	0.13^{ab}	0.7	0.2	0.025	0.006
Broadcast	0.5 FBM	38.01^{ab}	17.57^{b}	2.73^{a}	0.13^{ab}	0.2	0.2	0.010	0.002
	FEAM	36.30^{ab}	16.37^{c}	2.69^{a}	0.13^{ab}	0.3	0.2	0.015	0.003
	FBM	37.48^{a}	19.42^{a}	2.74^{a}	0.14^{a}	0.1	0.1	0.005	0.001
	CV	2.40	1.69	6.99	6.54				
	SE ±	0.94	0.11	0.04	0.00				
	LSD(0.01)	1.64	0.22	0.36	0.02				
	P	**	**	**	**				

CV= Coefficient of Variation; SE± =Standard error; LSD= Least significance difference, p=probability level; ** significantly different at $p \leq 0.01$. §Means followed by the same letters in a column are not significantly different at $p \leq 0.01$.

3.2 Economic Analysis

Based on the analysis of variance (ANOVA) there was a significant difference ($P \leq 0.01$) observed in the amounts of marketable tuber yields due to application of different lime rates (Table 4). The highest marketable yield was gained from FBM in broadcast application of lime with tuber yield of 22.73 t ha^{-1}; whereas, the lowest was found in the control plot had (18.02 t ha^{-1}). The above result showed that the increments of lime application had the direct relation to marketable tuber yield of potato production. These indicated that lime might enhance the nutrient availability of the soil by increased soil pH and available P, CEC, OC and TN and reduced aluminum toxicity ((Ejigu *et al*., 2023; Alemu et al., 2022; Brady and Weil, 2008). The result also agreed with Kara (2002) who found that Nutrients enhance the quality of tubers and make them more marketable. Hence, the application of small quantities of lime through micro-dosing (0.06 t ha^{-1}) in acidic soil resulted in a non-significant yield of potatoes, even when doses of 4.064, 3.57, 2.032, and 1.016 t ha^{-1} of lime were applied. This might be the positive effects of micro-dosing the enhancement of soil acidity problems (Afework *et al*., 2023).

The economic analysis revealed that application of MDM and FEAM in broadcast application gave MRR values above 100% which is accepted. All the treatments were dominated by MDM and FEAM broadcast lime application. The net benefit and the MRR of MDM was 110892 Birr ha^{-1} and 2216%, respectively. On the other hand, FEAM in broadcast application was gained a net benefit of 115412 Birr ha^{-1} and MRR of 194%. The lowest net benefit was 83,662 Birr ha^{-1} was recorded from the control plot (Table 4). Therefore, micro-dosing application is the most economically affordable treatments after all treatments. Micro-dosing is one technology that can be affordable to farmers and ensures that poor farmers get the highest returns from is able to purchase. Micro-dosing techniques are particularly relevant in smallholder farming systems where resources are often limited, and the cost of inputs is a significant consideration (Vandamme *et al*., 2018). This approach offers a pragmatic and cost-effective means to provide essential nutrients to impoverished or degraded lands in a manner that is both environmentally sustainable and economically viable (Twomlow *et al.*, 2010; Kisinyo *et al*., 2015). The result is in agreement with (Alemu *et al*., 2022) who reported micro-dosing application of is economically feasible and acceptable rate in the amendment of soil acidity with a minimum cost of lime.

Table 4 Economic analysis of lime rate applications methods on potato yield

Treatments	MYT (t ha^{-1})	TVC (Birr ha^{-1})	GB (Birr ha^{-1})	NB (Birr ha^{-1})	Dominance	MRR
Control	18.02^{c}	6758	108120	101362		
MDM	19.68^{bc}	7188	118080	110892		2216
0.25 FEAM	19.72^{bc}	8598	118320	109722	D	
0.25 FBM	19.77^{bc}	11738	118620	106882	D	
0.5 FEAM	19.83^{bc}	10308	118980	108672	D	
0.5 FBM	20.42^{b}	16518	122520	106002	D	
FEAM	21.57^{ab}	14008	129420	115412		194
FBM	22.73^{a}	27058	136380	109322	D	
CV	5.79					
SE ±	0.28					
LSD (0.01)	1.99					
P	**					

LSD = Least significance difference, SE± = Standard error; CV = Coefficient of Variation, p = probability level; **significantly different at $p \leq 0.01$. *Means followed by the same letters in a column are not significantly different at $p \leq 0.01$. *D = Dominated treatment, MYT= Marketable Tuber Yield, TVC= Total Variable Cost, GB = Gross Benefit, NB= Net Benefit, MRR= Marginal Rate of Return.*

4. Conclusions

Micro-dosing as well as full rate application of lime in broadcasting and drilling application of lime affected selected soil chemical properties (soil pH, exchangeable acidity, exchangeable Al, available P, CEC, TN and OC). The study result demonstrated the substantial potential of micro-dosing of lime as a greater efficiency than broadcast and drilling application of in full dose 05, and 0.25 dose both in buffer and exchangeable lime determination methods. MDM technology of lime application was low cost, ease of transportation, possibility of mixing it to the soil during planting and save wastage of lime. The economic analysis result indicated that applying lime in micro-dosing was economically feasible. Therefore, micro-dosing application of lime is an efficient and economically affordable method for small scale farmers.

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