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Changes in soil physicochemical properties and nutrient dynamics under liming acid soils

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Abstract

Area specific investigation of impacts derived from liming acid soils and the consequent effects on plant nutrient bioavailability and soil physicochemical properties is important. This work aimed at investigating dynamics of nutrient bioavailability and changes in soil physicochemical properties under liming acid soils in the west Wallaga zone of western Ethiopian high rainfall regions. Lime requirements were calculated for all soil samples using the acid saturation procedure. Then, important physicochemical properties of the soils and bioavailability of nutrients were determined following standard procedures. The highest changes observed as a result of liming were 36.59 to 37.19 cmol Kg^{-1} *for CEC, 0.97% to 0.47% for SOC, 1.76 to 1.40 g cm*$^{-3}$ *for bulk density, 30.31 to 37.21% for porosity, 30.25 to 34.55* μ*S cm*$^{-1}$ *for EC, 2.56 to 0.26 cmol Kg*$^{-1}$*for EA, and 0.08 to 0.02% for TN. This is attributed to the relatively higher CEC of clayey soils. It was observed that liming conditions, CEC, EC, EA, SOM, TN, and AP have significant* ($p < 0.001$) *correlations amongst themselves and with some other soil physicochemical properties such as porosity, bulk density, and C/N ratio. Bioavailability of P, N, S, Ca, K, and Mg were significantly positively* ($p < 0.01$) *enhanced by liming. This is due to improved mineralization of organic compounds, solubilization of some K, Ca, and Mg compounds, and input of Ca and Mg through liming. More research may be necessary to create a further understanding of the long-term effects of liming acidic soils on innate sources of nutrients and biological properties.*

Keywords/Phrases: Acid soil, Effect of liming, Nutrient bioavailability, Physicochemical properties

1 Introduction

These days, soil acidity is one of the main challenges in crop productivity in the high-rainfall regions of the world. Globally, soil acidity is expanding and causing more than half of the globally available arable lands are increasingly less productive (Kochian*et al*., 2015; Holland *et al*., 2018; Opala *et al*., 2018). Particularly in humid tropics and sub-tropics, basic cations are leached by long-term rainfall and gradually replaced by iron or aluminum cations. This aggravates soil acidity (Fekadu *et al*., 2021). Besides this natural phenomenon, other human-induced causes such as deforestation, cultivation of soils potentially containing acidic sulphate, removing all harvested plant materials, and excessive application of ammonium-based fertilizers cause soil acidity (Mekonnen *et al*., 2020).

Soil acidity changes the proportions of macronutrients and micronutrients in the soil, and this, in turn, leads to a deficiency of some macronutrients while micronutrients become available in large quantities that could cause toxicity to plants (Abdulkadir *et al*., 2014). Soil acidity also causes abnormal plant growth and inefficient water use (Holland *et al*., 2018). At higher levels, aluminum affects phosphorus availability and absorption by plants by fixing it into insoluble oxides. In addition, it affects several biochemical processes which are important for general plant growth. It also causes plant roots to have a flabby appearance by shortening and inflaming them Opala *et al*., 2018).

In Ethiopia, particularly in the high-rainfall western and southwestern highlands, soil acidity is increasingly becoming a severe menace to crop production (Achalu*et al.*, 2021; Abdena, 2013; Wakshuma*et al.*, 2019). As some studies indicated, about half of arable lands are becoming acidic in Ethiopia (Tamene *et al.*, 2017; Eyasu, 2016). What worsens soil acidity is that it is closely related to Al^{3+} toxicity, which in turn affects plant production. This leads to low soil fertility and high H^{+} and Al^{3+} toxicity, which in turn leads to low crop production and unsustainable agricultural production in general in the western and southwestern high-rainfall regions of Ethiopia. Especially in the west Wallaga zone of the Oromia region, even though excess natural and synthetic fertilizers have been applied, soil productivity and plant production have been decreasing from time to time (Abdena, 2013; Wakshuma*et al.*, 2019).

The main causes of severe soil acidity in the western high rainfall region, particularly the west Wallaga zone, are high rainfall, severe soil erosion, deforestation, cultivation of potentially acid sulphate soils, removing all harvested plant materials Achalu*et al.*, 2012;Abdena, 2013). Similarly, Legesse *et al.* (2013) reported that there are high concentrations of Al^{3+} and Fe^{3+} oxides in western Wallaga soil, and this brings significant P-fixing problems.

Currently, several management options are being tried in Ethiopia to alleviate soil acidity and reduce its severe effect on agricultural production. Among the management options, lime application, and organic amendments, including the application of farmyard manure, crop husks, and compost, are mentioned (FAO, 2017; Habtamu, 2015; Fekadu *et al.*, 2014). However, for severe soil acidity amelioration, aggressive liming is the best management option since it has a relatively higher capacity to neutralize the acid and reduce Al^{3+} toxicity. However, few works were done to investigate the holistic effects of liming acid soils in the highly acidic soils of West Wallaga. The main aim of this work was to investigate the impacts of liming acid soils on physicochemical properties, plant nutrients bioavailability, and lime requirements in soils of Nedjo and BodjiDirmaji Districts, Western Wallaga Zone, Oromia Region.

2 Materials and Methods

2.1 Sampling Areas

Samples were collected from six areas of BodjiDirmaji and Nedjo districts of western high rainfall region of Ethiopia, located at around 480 - 590 Km from Addis Ababa to the west. Purposively six locations - BikiltuDilla (BD), KutallaBildimma (KB), AmumaAgalo (AA), KoteGennasi (KG), NasisGennasi (NG) and WalitateGidda (WG) – were selected. These sampling areas are specifically soil acidity-affected areas and found between latitude of 09^{o}25’33” and 09^{o}33’16” N and longitude of 35^{o}24’32” and 35^{o}36’28” E. The vernacular name of the soil in the area is “Biyyo Dima”,which means red soil. The soil of this region is highly acidic, and its fertility is very low. These areas are part of tropical and subtropical high-rainfall regions. Soils of West Wallaga in general and those of the study areas in particular are characterized by high P-fixing capacity, high content of Fe oxides, strongly structured and low-activity clays, and soils with these properties are most likely classified as Nitisols according to WRB soil classification system (EthioSIS, 2014). The natural vegetation of the area ranges from tropical rainforests to desert savannas. Several cereal crops, oil crops, pulses coffee, and fruits are produced in the regions.

2.2 Sampling procedure

The random sampling strategy was followed to take a total of eighteen (triplicate) surface soil samples (0-35 cm) to assume topsoil depth, and 6 kg each were collected. The total area coverage of the sampling sites was about 300 hectares from the two districts. The samples were collected from farmlands to determine lime requirement, nutrient availability, and physicochemical analysis. For bulk density measurement, eighteen core samples were collected. For moisture analysis, eighteen composite cane samples were collected. After bringing it to the soil laboratory, about 1.0 kg of soil was taken from each sample and dried in open air, then ground and sieved using 0.25 mm mesh. The prepared samples were kept in labeled sample holders for physicochemical analysis. For greenhouse experiments and control experiments, 1 kg and 3 kg samples were arranged for liming experiments in greenhouse incubation pots in a randomized complete block design.

2.3 Instruments, reagents, and chemicals used

Analytical-grade reagents and chemicals were used throughout the study. These include sodium hydroxide solutions ($NaOH$), 10 N, concentrated H_2SO_4, and saturated boric acid solution (H_3BO_3) for nitrogen determination using the Kjeldahl procedure. Ammonium acetate Solution (1 NNH_4OAc), for extraction of Ca, Mg, and K; 0.005 M EDTA (Ethylenediamine tetra acetic acid), 6 N hydrochloric acid (HCl), 0.1 M TEA (Triethanolamine), 0.1 $MCaCl_2$ (calcium chloride) for extraction of micronutrient cations (Fe, Zn, Mn, Cu) and $HNO_3 - HClO_4$ di-acid mixture for digestion of samples for micronutrients determination; 2 $\%NaCN$ (Sodium cynide) to prevent interference of Fe, Zn, Mn, Cu while measuring Ca and Mg with atomic absorption spectrophotometer (AAS). Hydrochloric acid (HCl), 0.05 N for boron (B) determination; 0.4 $NK_2Cr_2O_7$ solution (2:1) H_2SO_4: H_3PO_4 mixture, mercury (II) oxide (HgO), phenalthroline indicator and 0.2 N ferrous ammonium sulfate for determination of carbon were used. Standard stock solutions of all elements to develop a calibration curve for each element. Regarding instruments, cations such as Mg, Ca, Zn, Fe, Cu, Mn, and Mo were determined by AAS. Flame atomic photometer (FAAS) was used for the determination of K; Uv-Vis was used spectrophotometer for the determination of B, P.

2.4 Physicochemical analysis of the soils

Standard procedures were followed to measure some important physical and chemical characteristics of the soils. Thus, the pH values of the soils were determined by using combined-glass electrodes in H_2O and 0.01M $CaCl_2$ suspension before and after lime application. Neutral 1N potassium chloride was used to leach hydrogen and aluminum ions from the soil and exchangeable acidity by titrating the acidity brought into solution with a standard solution of 0.02M $NaOH$ (Van Reeuwijk, 1992). Again, this was done before and after the lime application. Organic matter was determined by using the Walkely and Black methods. The CEC of the soils was determined by the ammonium acetate method and electrical conductivity (EC) (1:1 H_2O) by following the methods described by Rowell (Van Reeuwijk, 1992). The cations such as Na and K were determined using FAAS, Ca, Mg, Cu, Fe, Mn, and Zn were analyzed using AAS after being extracted using 1N Ammonium acetate (NH_4 OAC at pH 7). The available form of P was determined following Bray I (Bray and Kurtz, 1945), Mehlich 3-P (Mehlich, 1984), Olsen method (Olsen and Sommers, 1982), and $CaCl_2$ extraction methods depending on soil pH results.

2.5 Determination of lime requirement

Lime requirement (LR) of each soil was estimated with the acid saturation method to predict the amount of lime material to be added to every soil to reach target pH values of 5.4, 6.0, and 7.4. This method was chosen for its relatively simple laboratory procedures. These target pH values are within the optimum pH ranges for the growth of many crops, and this is why they were chosen as target pH values (Bouman *et al.*, 1995; Brown *et al.*, 2008).

In the acid saturation method, exchangeable acidity (Ex.Ac), effective cation exchange capacity (ECEC), and permissible acid saturation (PAS) were used to determine the quantity of the lime material to be added. Then, the LR was computed as follows (Manson and Katusic, 1997):

$$LR = LRF[EX.Ac - (ECEC * PAS)] \qquad (1)$$

where, LR = Lime requirement (kg ha^{-1}); LRF is the lime requirement factor (kg lime ha-1) to lower the exchangeable acidity by 1cmol. The accepted value of LRF is 3000 kg lime ha^{-1}cmol^{-1} for most Ethiopian soils (Farina 1991; Sertsu& Bekele, 2000); Ex. Ac = exchangeable acidity ([Al^{3+}] + [H^+]); PAS is permissible acid saturation, and its value is 20% for maize (Manson *et al.*, 2004), and ECEC is effective cation exchange capacity (Exchangeable acidity + Exchangeable bases).

Calcium carbonate ($CaCO_3$) powder was used as liming material. For each target pH value, the quantities of $CaCO_3$ ha^{-1} (in mmolc) added were computed, and the field level was expressed in kg of equivalent $CaCO_3$ ha^{-1}. Then, from each sample, 4 kg of soil was taken into pots and incubated with three levels of liming. The soils in the incubating pots were carefully mixed, and water was supplied until field capacity (30 kPa) was attained. Replicate treatments were made for all samples. Totally, 54 pots (6 soils x 3 lime levels 3 replicates) were arranged in a completely randomized design (CRD) in an illuminated greenhouse.

The soils were incubated in the greenhouse for four months until the targeted pH values (5.5, 6.5, and 7.2) reached pH by both pH (H_2O) and pH (KCl) methods. Four-month incubation was chosen, which corresponds to one growing season of the most common crops. All-important parameters were determined before and after liming and incubation.

2.6 Instrument calibration and method validation

All the instruments AAS, Uv-Vis, FAAS, and procedures were calibrated by recovery tests for each plant nutrient. Thus, the efficiency of the methods was tested by spiking each sample with a known concentration (< 10%) of each nutrient into the number of samples to be analyzed. For Fe and Mn 0.5 mg L^{-1}, for B, Cu, Mo, and Zn 0.05 mg L^{-1}, for Ca, Mg, and K, for P and N 0.5 mg, L^{-1} were added to the weighed amount of sample prepared for extraction. After measurement, percentage recovery was calculated for each method by subtracting the amount before the spike from the amount after the spike, dividing the difference by the amount spiked, and then multiplying by 100. The detection limits of the methods were tested by seven blank samples in the same procedure in which the samples were treated. Standard deviations of the readings from the seven blanks were multiplied by 3 to obtain the detection limit of the methods. Then, calibration curves were prepared for each element within the detection limits of the methods. The instruments were calibrated by measuring all parameters in non-spiked and spiked soil samples to check the consistency and effectiveness of the measuring instruments and processes. To obtain the best working procedure, all working conditions were optimized. Then, optimum conditions were used for the next nutrient determination (Houba*et al.*, 1989).

Statistical data analysis

A one-way analysis of variance (ANOVA) was used to assess the effects of liming on soil-selected chemical properties and plant nutrient availability. The $F-test$was used to check whether there was a significant difference among the means. The level of correlations among soil properties was determined using simple correlation analysis. The SAS software package (SAS 2004). SASVR 9.1; Cary, NC) was used for statistical analysis.

3 Results and Discussions

3.1 Variation in pH and LR values

The LR values of the soils were dependent on the level of soil acidity and pH values, as shown in Table 1.

Table 1. pH and LR values of the six soils (Kg$CaCO_3$ ha^{-1})

Soils	pH of Soils	Target pH Values		
		5.4	6.0	7.4
		LR (Kg $CaCO_3$ ha^{-1})		
AA	4.72	4224	6282	7983
BD	4.54	4344	6541	8660
KB	4.46	4881	6683	8786
KG	5.21	3808	5870	6879
NG	4.97	4115	6164	7569
WG	5.14	3980	5642	6693

Note: AA= AmumaAgalo sample site; BD= BikiltuDilla sample site; KB= KutallaBildimma sample site; KG= KoteGennasi sample site; NG= NasisiGenasi sample site; WG= Walitate Gida sample site

The required amount of lime (kg $CaCO_3$ ha^{-1}) to increase the soil pH to target values of 5.4, 6.0, and 7.4 ranged from 3808 to 4881; 5642 to 6741 and 6693 to 8786 kg $CaCO_3$ ha^{-1},respectively for the six soils. The LR values of the soils corresponded to the levels of the Ex.Ac. The highest Ex.Ac (2.98 cmolc kg^{-1}) and LR values were that of KB soil. This result shows that the level of Ex.Ac in a soil determines its LR level.

3.2 Soil physicochemical properties as affected by liming

Variations in pH levels and liming have substantial (p <0.01) impacts on all the soil physicochemical properties investigated except the C:N ratio (Table 2). As a result of liming, the highest change in CEC (36.59 to 37.19 cmol kg^{-1}), SOC (0.97 to 0.47%), EC (30.25 to 34.55 μS cm^{-1}), EA (2.56 to 0.26 cmol kg^{-1}) and TN (0.02 to 0.08%), AP (1.76 to 6.79 mg kg^{-1}), were observed in the BikiltuDilla soil with clay textural class. This is because clayey soil usually has relatively greater CEC, the key soil property that plays a major role in amending soil physicochemical properties. Therefore, the effect of liming acid soils largely correlates to the CEC of the soils, which in turn depends on soil textural class. The TN contents were positively significantly (p< 0.01) changed by the addition of lime to all of the six soils. This is because nitrogen mineralization is enhanced when lime is added to acid soil (FAO, 2017).

In addition, the application of lime increases the pH, consequently, nitrogen-fixing bacteria get better conditions, and nitrogen fixation increases (Abdena, 2013). Liming not only improves the activity of rhizobia but also that of nitrifiers. Porosities and moisture holding capacity of the soils were positively significantly (p< 0.01) impacted by liming. On the contrary, bulk densities of the soils were negatively significantly affected by liming. This indicates that liming can also be used to improve soil structure (Getachew *et al*., 2017). The C:N ratio was not significantly affected by liming. This may be because the two components of SOM *i.e*,C and N, were proportionally affected by liming. Phosphorus availability of all the soils was positively significantly (P< 0.01) impacted by liming. This is because liming leads to substitution reaction of cations (Ca^{2+} and Mg^{2+}) in the liming materials with phosphorus fixing cations (Al^{3+} and Fe^{3+}) and converts phosphorus compounds into easily soluble ones.

Table 2. Selected physicochemical properties within the six sample soils before and after liming

Sample Site	pH (H_2O)	Bd (g cm^{-3})	Porosity (%)	MC (%)	CEC (CmolKg^{-1})	EC (μS cm^{-1})	EA (Cmol Kg^{-1})	SOC (%)	TN (%)	TP (mg Kg^{-1})	C:N (%)	Textural Class
Physicochemical properties of the six sample soils before liming												
AA	4.72^{f}	1.45^{c}	37.22^{g}	21.12^{g}	28.14^{f}	32.43^{f}	2.45^{c}	0.89^{b}	0.06^{d}	1.67^{i}	14.83^{a}	Silty-Clay
BD	4.54^{g}	1.76^{a}	30.31^{h}	24.88^{e}	36.59^{b}	30.25^{g}	2.56^{b}	0.97^{a}	0.02^{e}	1.76^{h}	12.13^{d}	Clay
KB	4.46^{g}	1.47^{c}	40.94^{f}	28.23^{d}	27.24^{f}	28.41^{i}	2.98^{a}	0.99^{a}	0.09^{a}	1.87^{g}	11.00^{e}	Clay-loam
KG	5.21^{d}	1.66^{b}	47.16^{b}	30.21^{c}	34.71^{c}	37.34^{b}	2.14^{c}	0.86^{b}	0.07^{c}	1.93^{f}	12.29^{c}	Silty-Clay
NG	4.97^{e}	1.68^{b}	50.00^{a}	27.36^{d}	36.32^{b}	33.35^{e}	2.28^{b}	0.88^{b}	0.07^{c}	1.39^{k}	12.57^{b}	Silty-Clay
WG	5.14^{d}	1.48^{c}	39.80^{d}	30.62^{c}	29.37^{d}	35.31^{c}	2.12^{c}	0.98^{a}	0.08^{b}	1.54^{j}	12.25^{c}	Clay-loam
Physicochemical properties of the six sample soils after liming												
AA	6.80^{b}	1.31^{e}	43.39^{c}	23.22^{f}	30.34^{e}	34.46^{d}	0.65^{f}	0.28^{d}	0.02^{g}	2.68^{d}	14.82^{a}	Silty-Clay
BD	6.46^{c}	1.40^{d}	37.21^{g}	25.28^{e}	37.19^{a}	34.55^{d}	0.26^{g}	0.47^{c}	0.08^{b}	6.79^{a}	12.11^{d}	Clay
KB	6.42^{c}	1.23^{d}	43.00^{c}	30.43^{c}	29.44^{f}	29.49^{h}	1.18^{d}	0.45^{c}	0.06^{d}	4.88^{b}	11.02^{e}	Clay-loam
KG	7.12^{a}	1.43^{d}	47.34^{b}	33.26^{b}	36.72^{b}	39.24^{a}	0.64^{f}	0.27^{d}	0.03^{f}	3.79^{c}	12.22^{c}	Silty-Clay
NG	6.88^{b}	1.43^{d}	51.28^{a}	30.38^{c}	37.38^{a}	35.35^{c}	0.98^{e}	0.26^{d}	0.03^{f}	1.34^{k}	12.52^{b}	Silty-Clay
WG	7.22^{a}	1.30^{e}	42.35^{e}	34.78^{a}	30.39^{d}	37.35^{b}	0.65^{f}	0.48^{c}	0.04^{e}	2.14^{e}	12.21^{c}	Clay-loam
CV	0.555	1.50	0.525	1.630	0.844	0.126	0.897	1.870	1.831	1.114	1.111	
R^2	0.976	0.998	0.996	0.969	0.998	0.977	0.996	0.988	0.988	0.999	0.979	
LSD	0.016	0.012	0.015	0.018	0.018	0.018	0.017	0.018	0.019	0.017	0.018	
F-t	**	**	**	**	**	**	**	**	**	**	ns	

Note: AA = AmumaAgalo sample site; BD = BikiltuDilla sample site; KB = KutallaBildimma sample site; KG = KoteGennasi sample site; NG = NasisiGenasi sample site; WG = Walitate Gida sample site; Bd = Bulk density; MC = Moisture content; CEC = Cataion exchange capacity; EC = Electrical conductivity; EA = Exchangeable acidity; OC = Organic carbon; TN = Total nitrogen; LR = Lime requirement; AP = Available phosphorus; CV = Coefficient of variance; LSD = Least significance difference; ** = Significant at $p \leq 0.001$. Within a column, means with the same letters are not significantly different for each sample before and after liming.

3.3 Relationship among some soil physicochemical properties under lime treatments

The relationship (Pearson correlation matrix) among some soil physicochemical properties was analyzed as indicated in Table 3. Irrespective of the sample type, significant ($p < 0.01$) relationships were observed amongst the investigated soil physicochemical properties. As can be shown from the Pearson correlation matrix, CEC, EC, EA, SOM, T*N*, and A*P* have significant ($p < 0.01$) correlation amongst themselves and with some other soil physicochemical properties such as porosity, bulk density (Bd), and the *C*:*N* ratio. Available phosphorus had a significant ($p < 0.01$) positive correlation with all soil physicochemical properties except EA, with which it was significantly negatively correlated ($p < 0.01$). This is because when an exchangeable acidity increases, phosphorus becomes more and more fixed by aluminum and iron cations and becomes unavailable (Desalegn *et al.*, 2017). Except for *pH* and bulk density, SOM was significantly positively correlated with other soil properties. This is because as soil *pH* increases (acidity decreases), optimum soil conditions are created for the favors production of SOM by microorganisms (Adane, 2014).

Table 3. Pearson correlation (*r*) analysis for average soil physicochemical properties

	pH	Bd	Poro.	CEC	EC	EA	SOM	T*N*	*C*:*N*	A*P*
pH	1									
Bd	0.05	1								
Poro.	0.06	-0.87**	1							
CEC	0.53**	-0.32**	0.28*	1						
EC	-0.41**	0.18*	0.30*	0.33**	1					
EA	0.62**	0.30*	0.21*	-0.22*	-0.26*	1				
SOM	-0.67**	0.30*	0.45**	0.86**	0.42**	0.24*	1			
T*N*	-0.63**	0.26*	0.48**	0.68**	0.02	-0.32**	0.98**	1		
C:*N*	0.24*	0.18*	0.46**	0.57**	0.03	-0.16*	0.89**	0.65**	1	
A*P*	0.68**	0.14*	0.13*	0.48**	0.16*	-0.69**	0.66**	0.43**	0.38**	1

Bd= Bulk density; Poro= porosity; CEC= Cation exchange capacity; EC= Electric conductivity; EA= Exchangeable acidity; SOM= Soil organic matter; T*N*= Total nitrogen; *C*:*N*= Carbon to nitrogen ratio; A*P*= Available phosphorus. ** and * = Significant correlations at p= 0.01 and p= 0.05 respectively.

3.4 Nutrient bioavailability as affected by liming

Availabilities of macronutrients (*Ca*, *K*, and *Mg*) and the micronutrients (*Zn*, *Fe*, *Cu*, and *Mn*) were significantly ($p \leq 0.01$) affected liming, as shown in (Table 4). Potassium availability was increased significantly ($p \leq 0.01$) after liming and incubation of all of the soils. The initial status of available potassium ranged from 1.07 to 3.82 ppm, but after liming and incubation, it ranged from 4.05 to 5.68 ppm. This could be due to replacing potassium from the exchange sites by some cations, such as Ca^{2+} and Mg^{2+} from the liming materials, that increase its availability. After liming, the CEC of the soils was enhanced in soils with *pH*-dependent charges, and this improved the capacity of the soils to hold potassium. The available form of calcium showed increments ranging from 2.58 to 5.93 ppm before liming and ranged from 36.84 to 50.29 ppm. Liming the soil significantly increased the available form of calcium in the soil. This could be due to the application of Ca^{2+} from the liming materials and due to improvement in some soil physicochemical properties that determine calcium availability. The status of available Mg^{2+} ranged from 1.86 to 4.02 ppm before liming and ranged from 58.35 to 98.60 ppm after liming and incubating for 120 days. This indicates that liming brought a significant ($p \leq 0.01$) difference in Mg^{2+} availability. Similar to the case of Ca^{2+}, this could be due to the application of Mg^{2+}

from the liming materials and due to improvement in some soil physicochemical properties that determine Mg^{2+} availability (Opala *et al.*, 2018).

Regarding the effect of liming of availabilities of the micronutrients (Fe, Zn, Mn, Cu, and Mo), all of them showed a significant ($p \leq 0.01$) decrease after liming (Desalegn *et al.*, 2017). This can be attributed to the exchange of reduced ferrous iron and manganese ions from the exchange sites by the added Ca and Mg with liming materials and its subsequent precipitation. However, the effects of liming the soils were highly dependent on soil physicochemical properties (Adane, 2014).

On the other hand, the effect of liming on nutrient availability was affected by some soil physicochemical properties such as soil texture, pH, CEC, and SOC. As can be seen from Table 2 and Table 4, nutrient availabilities were significantly affected ($P<$ 0.01) by the soil physicochemical properties such as textures, pH, CEC, and SOC. The highest values of availabilities for most of the nutrients were observed in clay loam, loam, and silty-clay soil textural classes with pH values greater than 6.5 after liming the soils. This can be attributed to the fact that clay-rich soils contain relatively higher CEC, a property that determines the reaction of liming materials with inherent cations in the soil exchange sites. With soils having higher CEC, there is a relatively higher chance for the cations in liming materials to replace exchangeable acid cations, hence improving nutrient availabilities (Kebede *et al.*, 2017).

Table 4. Exchangeable cations in the six different soils before and after liming (ppm)

Sample Site	K^+	Ca^{2+}	Mg^{2+}	Fe^{3+}	Mn^{2+}	Zn^{2+}	Cu^+	Mo	Al^{3+} mgL^{-1}
Exchangeable cations in the six different soils before liming									
AA	1.21^g	7.42^f	2.44^j	901.01^e	112.64^e	4.75^c	3.59^h	17.92^e	510.42^f
BD	1.07^g	5.93^g	3.33^h	921.87^d	113.58^e	4.63^d	2.96^i	12.09^f	641.01^c
KB	1.16^g	2.58^j	1.86^k	1120.11^a	122.64^c	3.44^g	4.89^f	20.05^d	621.74^d
KG	2.59^f	3.77^i	2.48^i	992.65^c	137.61^a	3.76^e	5.18^e	26.79^c	531.97^e
NG	3.82^e	5.65^g	4.02^g	1102.25^b	125.51^b	6.92^a	7.92^a	32.98^b	764.15^a
WG	2.76^f	4.47^h	1.86^k	1121.06^a	118.57^d	6.87^b	7.12^b	33.24^a	745.83^b
Exchangeable cations in the six different soils after liming									
AA	4.39^c	36.84^e	66.08^d	34.29^j	27.65^g	2.14^i	5.28^e	1.76^j	27.61^k
BD	4.05^d	36.93^e	58.35^f	33.57^k	27.75^f	2.36^h	4.11^g	1.26^k	27.86^k
KB	4.74^b	39.38^d	59.82^e	47.99^f	25.51^h	3.78^e	6.92^c	3.93^g	37.91^j
KG	5.68^a	45.43^c	76.84^c	35.02^i	23.52^j	3.52^g	7.18^b	2.01^h	42.01^h
NG	4.77^b	50.29^a	98.6^a	46.85^g	27.78^f	2.42^h	7.79^a	1.86^i	48.06^g
WG	5.66^a	48.96^b	91.4^b	44.21^h	25.35^i	3.46^g	6.32^d	1.17^l	41.94^i
CV	2.30	0.399	0.331	1.634	1.072	0.854	1.674	1.172	0.454
R^2	0.998	0.996	0.996	0.998	0.999	0.995	0.998	0.999	0.995
LSD	0.015	0.015	0.014	0.017	0.013	0.026	0.016	0.015	0.048
F-t	**	**	**	**	**	**	**	**	**

Note: AA= AmumaAgalo sample site; BD= BikiltuDilla sample site; KB= KutallaBildimma sample site; KG= KoteGennasi sample site; NG= NasisiGenasi sample site; WG= WalitateGidda sample site; CV= Coefficient of variance; LSD= Least significant difference; ** = Significant at $p \leq 0.01$. Within a column, means with the same letters are not significantly different for each sample before and after liming.

4 Conclusion

This study assessed the impacts of applying proper liming materials to acid soils on plant nutrient bioavailability and soil physicochemical properties. The results revealed that nutrient availabilities can be enhanced by using appropriate liming materials and proper liming rates. In addition, soil physicochemical properties can be amended by liming. In all of the six acid soils studied, the effect of liming was significant to improve nutrient bioavailability. In addition, the liming of acid soils can reduce the contents of toxic elements such as *Al*, *Fe*, *Mn*, and improve crop healthy growth and production. Therefore, area-specific investigation of soil acidity status and liming conditions can be of great importance for agricultural production. Some soils may show nutrient deficiency while inherently having a high amount of important plant nutrients. This is due to the fixation of nutrients in acidic conditions. Therefore, we recommend considering using liming instead of applying more inorganic fertilizers to enhance nutrient availability and efficient use.

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Conflict of Interest

There is no conflict of interest to be disclosed.

Data Availability

Portion or all the data will be available up on formal request to the author.

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