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Original Article

Comparative Effects of Wood Ash and Calcium Carbonate on the Physicochemical Properties of Soils

Mofor Nelson Alakeh[1,2], Njoyim Estella Buleng Tamungang[1,2], Mbene Kenneth[3], Mboloh Edward Ngoyeh[1] & Fai Joel Alongifor[1]*

[1] The University of Bamenda, P. O. Box 39, Bambili, Cameroon.
[2] University of Dschang, P. O. Box 146, Dschang, Cameroon.
[3] University of Yaounde, P. O. Box 47, Yaounde, Cameroon.
[*] Author for Correspondence Email: nelsonmofor@yahoo.com

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ABSTRACT

Soil acidity is one of the soil degradation problems that affects the productivity of soils in Cameroon and Awing in particular and this has led to a steady decline in crop yields in such acid soils. This research aimed to evaluate the effects of two liming materials (wood ash and calcium carbonate) on the physicochemical properties of volcanic-influenced soils of Meupi-Awing, Northwest Cameroon. Two surface soil samples (0–30 cm) were collected and analysed for physicochemical properties before liming. Twenty-four sub-samples (six samples each) were limed separately with wood ash and calcium carbonate respectively for 3 and 6 weeks in a greenhouse incubator in the field and analysed for some physicochemical properties using international standard methods. Correlation analyses were done using SPSS version 20. The effects of liming materials on the soil physicochemical properties showed an increase in pH (from 5.0 to 9.1), electrical conductivity (from 0.03 to 0.60 mS/cm), sum of exchangeable bases (from 7.01 to 48.53 cmolc/kg), available phosphorus (from 5.81 to 86.11 mg/kg) and a decrease in the exchangeable acidity (from 0.26 to 0.00 cmolc/kg). Between the two liming materials, wood ash was generally more effective than calcium carbonate in the amelioration of soil properties, even though the differences were not significant ($p > 0.05$). This may be due to the fact that wood ash is natural lime that is rich in bases whereas $CaCO_3$ contains only the Ca^{2+} and CO_3^{2-} ions. Liming of these soils enhances the availability of nutrient anions and cations for plant uptake while trace elements reported in the study area are decreased from toxic to normal levels since their solubility in the soils is reduced at higher soil pH, hence reducing soil pollution. A minimum lime application rate of 2.70 g/kg soil for calcium carbonate and 7.72 g/kg soil for wood ash is recommended in the study area and in other areas with similar soil types.

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INTRODUCTION

Soil acidity is a serious factor affecting soil health, plant growth, and agricultural productivity in many regions worldwide and it is the most yield-limiting factors that affect crop productivity (Anchal et al., 2024**)**. This is mainly because acidic soils reduce the availability of several vital nutrient elements in soil such as phosphorus, P, through P fixation, while increasing the toxicity level of others, such as aluminium, Al, by altering numerous chemical and biological reactions in the soil (Nwite et al., 2011; Sumner and Noble, 2003). Soil acidity reduces exchangeable bases required for plant growth and may result in phytotoxic concentrations of soluble aluminum (Enesi et al., 2023). In response to the continually increasing population and energy cost, the development of alternative management practices to alleviate soil acidification and maintain crop productivity is imperative. Acidic soils have been estimated to occupy about 30% of the global land surface (Sumner and Noble 2003) and 50% of the global farming land area (Dai et al., 2017). Yerima et al. (2020), have indicated that declining crop yields in the Western Highlands of Cameroon is largely attributed to soil acidity. Various factors could contribute to soil acidification; such as natural processes, industrial pollution and agricultural production (Holland et al., 2018; Fageria and Nascente, 2014). Particularly, more than 50% of the world's cropland has been acidified by agricultural intensification alone, mainly through monoculture farming and excessive use of synthetic fertilizers (Onah et al., 2023; Mutert et al., 2010). Soils with high acidity have the tendency of aluminium, hydrogen ion and manganese toxicity as well as nutrient deficiencies of calcium and magnesium (Otobong et al., 2016). Soil acidity is a condition of the soil when the exchange complex is dominated by hydrogen and aluminium ions (Fageria et al., 2014; Brady and Weil, 2008)

Volcanic soils are formed by the weathering of volcanogenic materials, and these soils generally possess good fertility and support the livelihood of millions of people through good crop yield. However, improper use of these soils may result in severe degradation of their intrinsic qualities and, consequently negative environmental effects, thus necessitating effective soil management (Nkouathio et al., 2008). Mount Lefo, found in Awing village, Santa subdivision of the Northwest Region of Cameroon, is a volcanic mountain. At the foot of this mountain is found Meupi quarter, containing

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volcanic-affected soils and intensive farming is currently being practiced there. Mofor et al. (2017), carried out studies on the physicochemical and heavy metal properties of these soils and reported that the soils were very acidic, with high exchangeable acidity and a high concentration of some heavy metals such as Fe and Mn. An interview with farmers in the study area revealed that agricultural yields have dropped, and they have repeatedly farmed the same farmlands over the years. This repeated farming, amongst other factors mentioned, has led to the acidification of this soil.

In order to decrease soil acidity to acceptable levels, the hydrogen ions must be replaced by metallic cations. The use of agricultural and local lime to neutralize soil acidity and immobilize toxic levels of Al, Mn and Fe is the cheapest and most effective approach in ameliorating the fertility status of strongly acidic soils (Fageria and Baligar, 2008; Kunhikrishnan et al., 2016). Liming is a soil management strategy of applying substances (organic or inorganic) that are rich in calcium and magnesium to manage or raise the pH of the soil to a favourable level (Nwite et al., 2011). There are various liming materials that can be used and these include inorganic (calcium or magnesium hydroxides and carbonates) and organic (wood ash) lime. The soils of Awing Village are developed from alluvial and fluvial sediment materials deposited by rivers and are strongly weathered, leached and highly acidic in nature (Mofor et al., 2017). Studies around this area have recommended the use of liming materials to remediate the problem of soil acidity, but such studies have not shown which liming materials and lime application rates are most suitable for the enhancement of soil physicochemical properties. Thus, the main objective of this study was to evaluate the effects of two liming materials on the physicochemical properties of volcanic-influenced soils of Meupi-Awing in the Northwest region of Cameroon.

MATERIALS AND METHODS

Site Description and Sample Collection

Awing village is located in the grass field zone of Cameroon, precisely in Santa Subdivision of the Northwest Region of Cameroon. It is situated at about 21 km south-east of Bamenda town. Awing has a surface area of about 480 km^2 and as of the year 2010, its population density stood at 115.2 people/km. Located between latitudes 05°47′ and 06°00′ North of the equator and longitudes 10°10′ and 10°22′ East of the Greenwich Meridian. Awing has an elevation of about 1206 m above sea level. (Mofor et al., 2017). Sampling was done in February 2022 in Meupi, along the Flank of Mount Lefo-Awing. Two sampling sites were chosen for sample collection. In each site, a representative soil profile was dug, and composite soil samples were collected in the 0-30 cm surface soil layer using a spade and stored in polyethylene bags. The sampling sites are Meupi East (ME) and Meupi West (MW). The soils of this area are classified according to the U.S Taxonomy, World Reference Base (WRB) and the French Classification systems respectively as Oxisol (Eutrudox), Ferralsol (Xanthic Ferrasol) and Sol ferrallitique rouge (Sol ferrallitique rouge fortement désaturé) (Mofor et al , 2017). Meupi East is located on Longitude 10°13′20″E and Latitude 05°50′6.0″N, with an elevation of 1436 m above sea level. Meupi West is located on Longitude 10°13′22″ E and Latitude 05°50′0.2″ N, with an elevation of 1426 m above sea level.

Laboratory Analysis

Recently collected soil samples were air-dried for five days in the laboratory, ground in a porcelain mortar using a pestle and sieved through a 2 mm sieve. The soil samples were then analysed for various physicochemical properties using international standard methods prior to liming (Pauwels et al. 1992; Jones, 2003; Dipak and Abhijit, 2005).

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Soil pH was measured using a pH meter in a 1:2.5 soil-water solution ratio for pH-H_2O and then rinsed in 1 N KCl and immersed in a 1: 2.5 soil-KCl (1 N) solution for pH-KCl. Exchangeable acidity (H^+ and Al^{3+}) was determined by titration with NaOH after extraction with 1 N KCl solution in a soil-solution ratio of 1:20. Electrical Conductivity (EC) was determined after extraction with distilled water in the ratio of 1:5 with a conductivity meter (WTW model). Exchangeable bases were determined by the method of Schollenberger by percolating 2.5 g of soil sample with 100 mL of 1 N ammonium acetate, after which sodium and potassium ions were determined by flame photometry, while calcium and magnesium ions were estimated by complexometric titration. Cation exchange capacity (CEC) was estimated by percolating 2.5 g of soil sample with 100 mL of 1N ammonium acetate and then with 1 N KCl, and the collected NH_4^+ ions were then determined by distillation and titration with a 0.01 N sulphuric acid solution. Total nitrogen was estimated by exploiting Kjeldahl's distillation method, while soil organic carbon (SOC) was estimated by oxidation with potassium dichromate and titration with iron (II) sulphate. Particle size distribution was determined by the hydrometer method. Available phosphorus was determined by the Bray II method.

Wood Ash Characterization and Calculations of Calcium Carbonate Equivalence (CCE)

Calcium Carbonate Equivalence **(CCE)** was determined following the procedure described by (Tsutomu et al., 1992)**.** 1.00 g of dried wood ash sample was weighed into a 250 mL Erlenmeyer flask and 20 mL of 0.5 N HCl was added and covered with a watch glass and the wood ash-acid mixture was boiled for 5 minutes, to ensure complete reaction. After boiling, 50 mL distilled water was added and the mixture was allowed to cool, and 2-3 drops of phenolphthalein indicator were added. The mixture was then titrated with 1 N NaOH solution while swirling the flask and the endpoint of the titration was the appearance of a faint pink colour. The process was repeated three times and the mean value was obtained for the titre. The Calcium Carbonate Equivalence (CCE) was determined using Equation 1.

$$\text{CCE (\%)} = \left(\frac{VaNa - VbNb}{Mw} x 0.05 x 100\right) \quad (1)$$

Where

V_a= Volumes of HCl

V_b = Volumes of NaOH

Na = Normality of HCl

Nb = Normality NaOH

M_w = mass of wood ash in gram.

The value for the CCE % of the wood ash sample obtained was used to calculate the equivalent masses of wood ash for given masses of inorganic lime ($CaCO_3$).

Liming Procedure

The most acidic soil sample was replicated into twenty-four (24) sub-soil samples, each weighing 250 g. Twelve (12) of the soil samples were analysed after three (3) weeks of liming and the remaining 12 were analysed after six weeks of liming. To each set of twelve samples, an increasing rate of inorganic lime ($CaCO_3$) was added to six samples and an increasing rate of organic lime (wood ash) was added to the other six samples. The mixtures were then homogenised and distilled water was added. The soil-lime-water mixtures were allowed at room temperature for three and six weeks. Soil samples were collected from the first set of sub-samples after three weeks and the second set

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after six weeks and taken to the laboratory for analysis of pH, EC, available P, exchangeable bases and exchangeable acidity. Each field treatment was repeated, and the mean values were used to plot the curves. A control set up with zero lime application was used. Table 1 gives detailed representations of the limed soil samples with the different liming materials ($CaCO_3$ and wood ash). The results of CCE (35%) were used to calculate the quantity of wood ash that corresponds to a given quantity of $CaCO_3$ i.e. for any chosen mass of $CaCO_3$, the equivalent mass of wood ash was mass of $CaCO_3$ divided by 0.35. From L1 to L5, each mass of $CaCO_3$ is 3 times the previous one and L6 (3.000g) were taken as the maximum mass because at this lime rate, most of the soil properties had improved to an appreciable level.

Table 1: Lime Rate of Soil Samples Using $CaCO_3$ and Wood Ash

Nº	L1	L2	L3	L4	L5	L6
$CaCO_3$ (g)	0.025	0.075	0.225	0.675	2.025	3.000
Wood ash (g)	0.070	0.210	0.640	1.930	5.790	8.570

L1, L2, L3, L4, L5 and L6 *are labels on the soil samples indicating increasing amounts of liming materials*.

Statistical Analysis

A paired sample t-test was used to compare the means of soil parameters resulting from $CaCO_3$ with those from wood ash at a 95% confidence interval. Pearson correlation analysis was also used to relate the change in soil parameters with liming. Origin 2018 software was used to plot graphs and Statistical Package for Social Sciences (SPSS) version 20 was used for correlation analysis.

RESULTS AND DISCUSSION

Soil Physicochemical Properties Before Lime Application

Table 2 presents the results of soil physicochemical properties before liming. Results of soil physicochemical properties showed that the soils were strongly acidic with pH water values ranging from 5.0 for Meupi West (MW) to 5.1 for Meupi East (ME). The acidic nature of the soils will tend to limit plant growth because when the soil is acidic, the availability of nitrogen, phosphorus, and potassium is reduced (Silva and Uchida, 2000), and most crops grow best when the soil pH is between 6.0 and 8.2. The low amounts of nitrogen, phosphorus, and potassium may be due to the presence of oxides and hydroxides of iron and aluminium present in these acidic soils which tend to fix these nutrients (Spargo et al., 2013; Njoyim et al., 2016; Horneck et al., 2011). These low pH values could result from the decomposition of organic matter since farmers at Meupi use organic amendments to increase soil fertility.

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Table 2: Soil Physicochemical Properties Before Liming

Sample	pH (H_2O)	pH (KCl)	ΔpH	EC (mS/cm)	%OC	% OM	%N	C/N	Na (cmolc/kg)	K (cmolc/kg)	Ca (cmolc/kg)
MW	5.0	4.0	-1.0	0.03	2.99	5.16	0.141	21.0	0.52	0.73	4.40
ME	5.1	4.1	-1.0	0.02	4.17	7.20	0.183	22.0	0.52	0.51	4.88
Sample	**Mg (cmolc/kg)**	**SEB**	**CEC (cmolc/kg)**	**Avail. P (mg/kg)**	**EA (cmolc/kg)**	**Sand(%)**	**Silt(%)**	**Clay(%)**	**Textural class** (FAO, 2006)		
MW	1.36	7.01	31.84	5.81	0.26	66.5	25.0	8.5	sandy loam		
ME	2.00	7.90	43.04	5.47	0.26	55.0	33.5	11.5	sandy loam		

MWC = Meupi West, MEC = Meupi East, ΔpH = pH_{KCl} - pH_{H2O}, EC = Electrical Conductivity, OC = Organic Carbon, OM = Organic Matter, N = Total Nitrogen, C/N = Mineralisation factor, SEB = Sum of Exchangeable Bases, CEC = Cation Exchange Capacity, EA = Exchangeable Acidity.

Thus, pH results showed that the soils need liming in order to raise soil pH to an optimum level needed for crop growth. The sign and magnitude of ΔpH, which relates to the sign and magnitude of soil surface charge, were negative for the soils, indicating that these soils were above their point of zero charge. This shows that they had net negatively charged surfaces, resulting in a net CEC at field pH (Yerima, and Van Ranst, 2005).

Exchangeable acidity (EA) was 0.26 cmolc/kg for both soil samples. To effectively raise the pH of the soils studied, both active and exchangeable acidity must be neutralized. Exchangeable acidity is directly related to the quantity of lime required to increase the pH of the soil from its current level to the target level determined by the selected crop (Spargo et al., 2013).

The electrical conductivities of the soils were low, with the highest value being 0.03 mS/cm for Meupi West and this could be seen from the low values of soluble salts present in the soils and also from the soil texture (sandy loam) which can easily leach away ions responsible for conductivity.

Organic matter was found to be high; 5.16% for Meupi West and 7.20% for Meupi East and these could result from the organic amendments added by farmers to increase soil fertility. These values are in line with the standard values reported by (Vitinotes, 2006). Organic matter plays an important role in these soils because it ameliorates other soil physical properties such as structural stability, soil's water retention capacity and the colour of the soil (Riches et al., 2013). As soil organic matter increases, so does CEC, soil total N content, and other soil properties such as water holding capacity and microbiological activity (Horneck et al., 2011).

Total nitrogen content was very low in all the soils (<1% N). According to (Lanyon et al., 2004), these soils (<1% N) are said to be nitrogen deficient. The C/N ratio for the soils was 21.0 for Meupi West and 22.0 for Meupi East, indicating that the organic matter was in equilibrium between mineralization and immobilization. The lower the C/N ratio, the more rapidly nitrogen will be released into the soil for immediate crop use.

The exchangeable bases were low; Na: 0.52 cmolc/kg for both sides, K: 0.73 cmolc/kg for Meupi West and 0.51 cmolc/kg for Meupi East, Mg: 1.36 cmolc/kg for Meupi West and 2.00 cmolc/kg for Meupi East and Ca: 4.40 cmolc/kg for Meupi West and 4.88 cmolc/kg for Meupi East. If soil calcium levels are less than optimal and lime is not required, gypsum (calcium sulphate) may be recommended (Clark, 2004). If Mg is low and lime is not required, magnesium sulphate may be recommended. When a soil test indicates that fertilizer potassium is required, the rate of fertilizer recommended is intended to satisfy crop needs and build soil potassium levels to the optimum range (Lanyon et al., 2004).

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Available phosphorus was low and deficient in the soils (Lanyon et al., 2004) as its levels ranged from 5.47 mg/kg for Meupi East to 5.81 mg/kg for Meupi West. Inadequate P levels could lead to stunted plant growth as P plays critical roles in cell division, seedling and root growth and development (Lanyon et al., 2004).

Cation Exchange Capacity (CEC) was high in the soils and ranged from 31.84 to 43.04 cmolc/kg. This shows that the soils have a high ability to retain and supply nutrients, specifically the positively charged nutrient ions called cations. CEC can range from below 5 cmolc/kg in sandy, low organic matter soils to over 15 cmolc/kg in finer textured soils and those high in organic matter. Low CEC soils are more susceptible to cation nutrient loss through leaching (Spargo et al., 2013).

The base saturation which is the percentage of the soil CEC that is occupied by basic cations (calcium, magnesium, potassium, sodium) at the current soil pH value was very low (22.06% and 18.36% for MW and ME respectively) for the soils, a fact which shows that the soils studied are acidic and require liming. Results of particle size analysis showed that all of the soils were sandy loam in texture with the sand component highly dominant. This shows that the soils are susceptible to nutrient leaching. Results of soil physicochemical properties conform to those reported by (Mofor et al., 2017) in the same area, who carried out a study to assess the physicochemical and heavy metals properties of some agricultural soils of Awing-North West Cameroon.

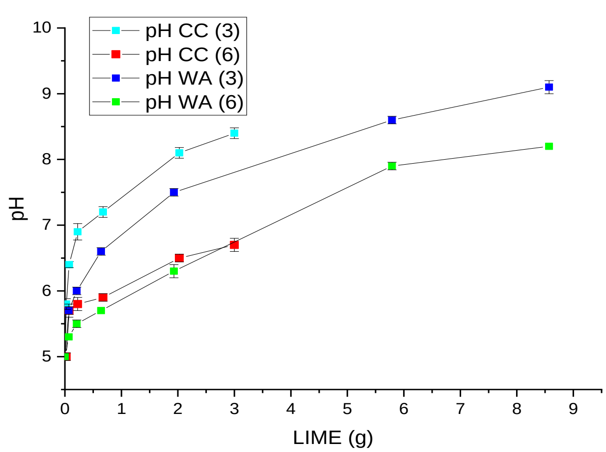
Soil Physicochemical Properties After Liming

Meupi West soil sample with a pH value of 5.0 was chosen for liming because it was the more acidic soil. Results of soil physicochemical properties analyzed 3 weeks and 6 weeks after the addition of different liming materials are presented in the figures that follow.

Effect of Liming on Soil pH

Figure 1 shows the variation of soil pH_{water} measured at different time intervals after the addition of lime. As the most important and effective management practice for the reduction of soil acidity, the primary purpose of liming is to neutralize excessive hydrogen ions from the soil solution (Bolan et al., 2003; Pagani, and Mallarino, 2012; Anchal et al., 2024). A significant relationship exists between the response ratio of soil pH and liming rate. It was found that the optimal liming duration should be approximately 3 weeks because the maximum pH effect was typically found within 3 weeks after liming.

Figure 1: Variation of Soil pH_w With Wood Ash and $CaCO_3$ After 3 and 6 Weeks



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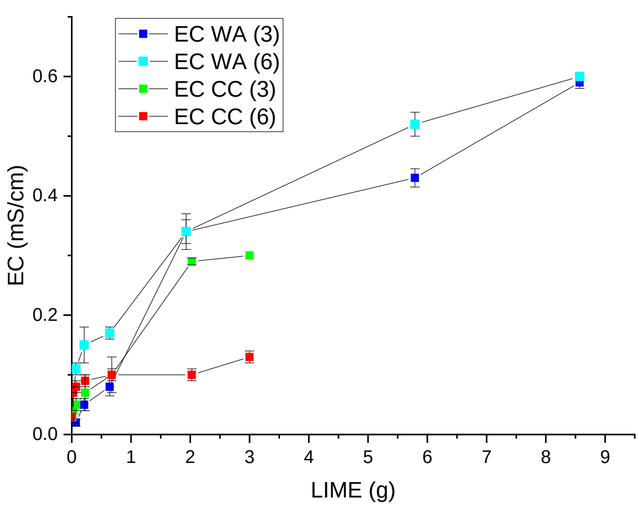
pH CC (3) = Soil pH$_W$ measured 3 weeks after application of $CaCO_3$,
pH CC (6) = Soil pH$_W$ measured 6 weeks after application of $CaCO_3$,
pH WA (3 = Soil pH$_W$ measured 3 weeks after application of Wood ash,
pH WA (6) = Soil pH$_W$ measured 6 weeks after application of Wood ash.

These results conform to those obtained across many studies with a variety of management and environmental conditions (Rippy et al., 2007; Woodard et al., 2010). Regardless of the liming materials, the increasing application of lime increased the soil pH. The use of wood ash changed the soil pH-H_2O from 5.0 to 9.0 with a mean value of 6.93 ± 0.57 and $CaCO_3$ from 5.0 to 8.4 with a mean value of 6.83 ± 0.56. Comparing the two mean values using a t-test showed that there was no significant difference ($p > 0.05$) between wood ash and $CaCO_3$ as far as their effects on soil pH are concerned (Table 3). Hence, farmers in the study area are advised to use wood ash to increase soil pH since it is more readily available and cheaper.

Effect of Liming on Electrical Conductivity (EC) of the Soil

Figure 2 shows the variation of soil electrical conductivity measured at different time intervals after the application of wood ash and $CaCO_3$. The electrical conductivity of the soil increased as a function of the amount of lime added. It increased from 0.03 to 0.30 mS/cm and 0.03 to 0.13 mS/cm after three and six weeks respectively for $CaCO_3$ and from 0.03 to 0.59 mS/cm and 0.03 to 0.60 mS/cm after three and six weeks respectively for wood ash. This increase in EC can be due to the addition of lime which contains Ca^{2+} ions which is one of the main ions comprising soluble salts responsible for EC.

Figure 2: Variation of Soil EC with Wood Ash and $CaCO_3$ After 3 and 6 Weeks



EC WA (3) = Soil electrical conductivity measured 3 weeks after application of wood ash,
EC CC (3) = Soil electrical conductivity measured 3 weeks after application of $CaCO_3$,
EC WA (3) = Soil electrical conductivity measured 6 weeks after application of wood ash,
EC CC (3) = Soil electrical conductivity measured 6 weeks after application of $CaCO_3$.

The increase in EC was higher for soils limed with wood ash, indicating that wood ash also contains other basic ions like Na^+, K^+ and Mg^{2+} which are absent in pure $CaCO_3$. Figure 2 shows that wood ash is more effective in increasing the EC of the soil than $CaCO_3$, with the highest value of 0.60 mS/cm

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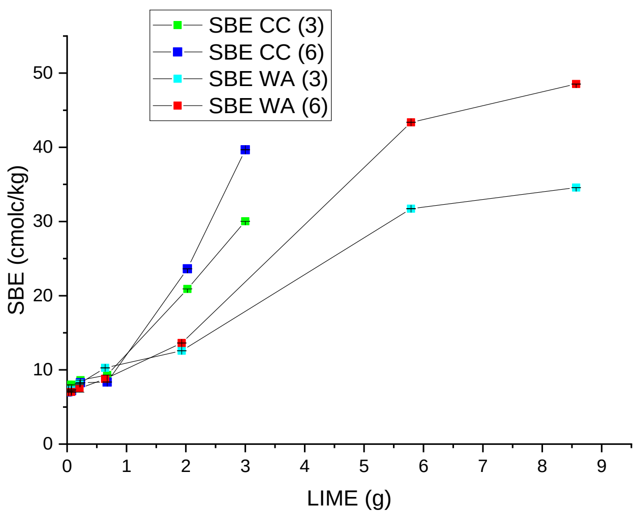
recorded at pH 8.2. Horneck et al. (2011), reported that soil with EC values less than 1 mS/cm is suitable for crop production.

Effect of Liming on Exchangeable Bases

Figure 3 shows the variation of the soil sum of exchangeable bases measured at different time intervals after the application of wood ash and $CaCO_3$. This study revealed that wood ash and $CaCO_3$ contain significant amounts of plant nutrients apart from possessing the ability to increase pH levels, thus making them more suitable as liming materials.

Figure 3: Variation of Soil Sum of Exchangeable Bases with Wood Ash and $CaCO_3$ After 3 and 6 Weeks



SEB WA (3) = Soil sum of exchangeable bases measured 3 weeks after application of wood ash,
SEB CC (6) = Soil sum of exchangeable bases measured 3 weeks after application of $CaCO_3$,
SEB WA (3) = Soil sum of exchangeable bases measured 6 weeks after application of wood ash,
SEB CC (6) = Soil sum of exchangeable bases measured 6 weeks after application of $CaCO_3$

The increase in soil nutrients obtained in this study as a result of applying lime to acidic soils confirmed the assertion made by (Udoh and Otobong, 2018) that liming lowers the solubility of acidic cations (H^+, Al^{3+}) while raising the solubility of P, K, Na and Mg in mineral soils. The increase in the sum of exchangeable bases for wood ash after six weeks (7.01 to 48.53 cmolc/kg) compared to 7.01 to 39.67 cmolc/kg for $CaCO_3$, indicated that wood ash contained other bases such as Na and K, which are absent in $CaCO_3$. Application of lime with quantities ≥2.025 g for $CaCO_3$ and ≥5.79 g for wood ash made the soil to be high in both Ca and K (Ca > 10 and K >1 cmolc/kg) and moderate in Mg and Na (Mg >5 and 0.5<Na<1).

Effect of Liming on Available Phosphorus of the Soil

Figure 4 shows the variation of soil available phosphorus measured at different time intervals after the application of wood ash and $CaCO_3$. An increase in liming leads to a decrease in exchangeable acidity which in turn increases soil pH and available P. As seen in Figure 4, the phosphorus concentration was found to have increased drastically after liming with wood ash and $CaCO_3$.

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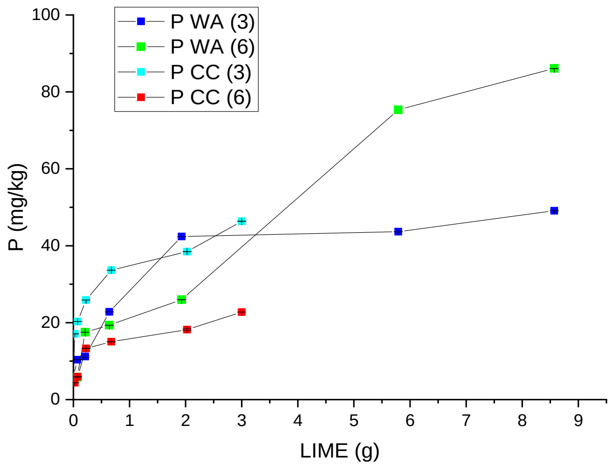
Figure 4: Variation of Soil Available P with Wood Ash and $CaCO_3$ After 3 and 6 Weeks



P WA (3) = Soil available phosphorus measured 3 weeks after application of wood ash,
P CC (6) = Soil available phosphorus measured 3 weeks after application of $CaCO_3$,
P WA (3) = Soil available phosphorus measured 6 weeks after application of wood ash,
P CC (6) = Soil available phosphorus measured 6 weeks after application of $CaCO_3$.

This is due to the nature of the existence of phosphorus in soil. The existence of P is highly limited by soil pH. At pH < 5.5, P exists in the form of $AlPO_4$ and $FePO_4$, while at pH > 5.5 it exists in the form of $Ca_3(PO_4)_2$, $H_2PO_4^-$ and HPO_4^{2-}. On the other hand, there is a high competition between acid cations such as Al^{3+}, Fe^{3+} and basic cations such as Na^+, K^+, $Ca^{2+}$and Mg^{2+} to be bonded to PO_4^{3-}. According to (Haynes, and Ludecke, 2001), at low soil pH (< 5.5), Al and Fe are highly soluble and react with phosphorous to form insoluble $AlPO_4$ and $FePO_4$, which are precipitates and cannot be absorbed by plant roots. Absorption of PO_4^{3-} by plant roots depends on root length and hairs (branches). This is due to the less mobile nature of phosphate ions in the soil solution (Yihenew, 2002). In this study, the mean P concentration in the soils limed with wood ash was 40.66 mg/kg and was far higher than the P concentration before liming (5.81 mg/kg). This result is in good agreement with those reported by (Adane, 2014)**,** who showed that liming increases soil pH with a consequent increase in available phosphorus.

Effect of Liming on Exchangeable Acidity (EA) of the Soil

Figure 5 shows the variation of soil exchangeable acidity, measured at different time intervals after the application of different liming materials (wood ash and $CaCO_3$).

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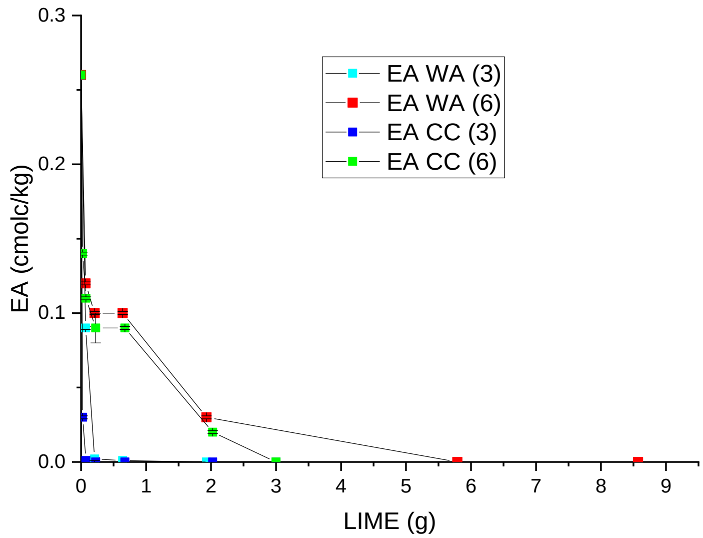
Figure 5: Variation of Soil Exchangeable Acidity with Wood Ash and $CaCO_3$ After 3 and 6 Weeks



EA WA (3) = Soil exchangeable acidity measured 3 weeks after application of wood ash,
EA CC (6) = Soil exchangeable acidity measured 3 weeks after application of $CaCO_3$,
EA WA (3) = Soil exchangeable acidity measured 6 weeks after application of wood ash,
EA CC (6) = Soil exchangeable acidity measured 6 weeks after application of $CaCO_3$.

There was a general reduction in exchangeable acidity of the soils after liming. This is in agreement with the findings of other researchers who reported a reduction in the exchangeable acidity level of soils by applying liming materials in acidic soils (Otobong et al., 2016; Onyebule et al., 2012; Nwachukwu et al., 2012; Hamel et al., 2010; Akinmutimi, and Osodeke, 2013; Nwite et al., 2011). It was observed that increasing the quantity of lime reduced exchangeable aluminium in the soil; which may be due to the complexation of Al with organic matter by the presence of more negative complexing sites. As a matter of fact, when pH is increased, the –COOH and –OH groups of the organic compounds found in organic matter become $–COO^-$ and $–O^-$ respectively which are complexing sites for Al^{3+} thus resulting in a reduction of extractable Al. It may also be due to the precipitation of exchangeable Al into Al_2O_3 (Bolan et al., 2003).

The effects of liming on soil physicochemical properties showed that a minimum lime application rate of 2.70 g/kg soil (0.675 g $CaCO_3$ in 250 g soil) for calcium carbonate and 7.72 g/kg soil (1.930 g wood ash in 250 g soil) for wood ash is good for the amelioration of soil properties in the study area. This is evident from Figures 1 to 5 where it is observed that the minimum lime application rates proposed improved most of the soil properties appreciably. These results conform to the findings of Nwite et al. (2011) and Nnadi et al., (2020) who studied the contributions of different ash sources to the improvement in properties of degraded Ultisol and maize production in Southeastern Nigeria and growth and yield responses of high-density coverage sweet potato to liming and fertilizer combinations for sandy-loam Ultisols at Nsukka, Southeastern Nigeria respectively and showed that soil properties and crop yields increased after the application of various liming materials.

When lime is added to these soils, the following chemical reactions will occur

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$$CaCO_{3(s)} + H_2O_{(l)} \longrightarrow Ca^{2+}_{(aq)} + 2OH^-_{(aq)} + CO_{2(g)} \quad (2)$$

Newly produced Ca^{2+} will exchange with Al^{3+} and H^+ on the surface of acid soils as shown in equation 3:

$$3Ca^{2+}_{(aq)} + 2AlX_{3(s)} \longrightarrow Ca_3X_{2(s)} + 2Al^{3+}_{(aq)} \quad (3)$$

Where X = PO_4^{3-}, HPO_4^{2-} or $H_2PO_4^-$ ions

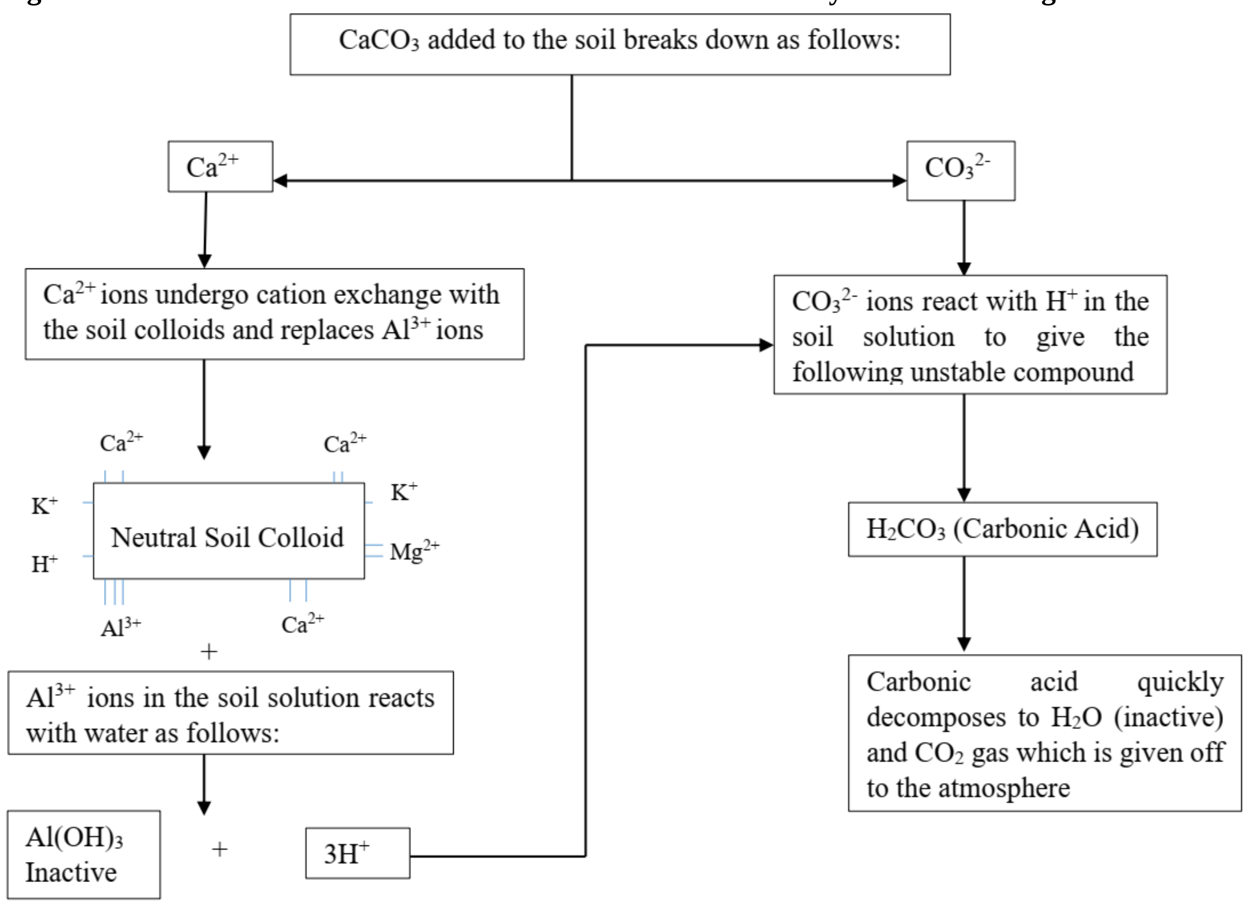
Lime-produced OH^- will react with Al^{3+} to form solid $Al(OH)_3$, or it will react with H^+ to form H_2O as shown equations 4 and 5:

$$3OH^-_{(aq)} + Al^{3+}_{(aq)} \longrightarrow Al(OH)_{3(s)} \quad (4)$$

$$OH^-_{(aq)} + H^+_{(aq)} \longrightarrow H_2O_{(l)} \quad (5)$$

The reaction mechanism of calcium carbonate in the soil system as a liming material is illustrated in Figure 6 below.

Figure 6: Reaction Mechanism of Calcium Carbonate in the Soil System as a Liming Material



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Liming impacts the transformation and uptake of nutrients and heavy metals by plants through its direct effect on the neutralization of soil acidity and its indirect effect on the physical, chemical and biological characteristics of the soils. Liming is increasingly being accepted as an important management tool in reducing the toxicity of heavy metals in soils. In this regard, Cd contamination of agricultural soils is of particular concern because this metal reaches the food chain through the regular use of Cd-containing fertilizer materials, such as single superphosphates. Also, it remains mobile even at about neutral pH (Fageria, and Baligar, 2008**;** Bolan et., 2003). Liming has been shown to reduce the amount of P fertilizer required to boost yield in some soils (Bolan et al., 2003; Enesi et al., 2023)**.** This reduction in P requirements results directly from an increased solubilisation of soil P and its subsequent uptake and/or indirectly from an increase in P uptake due to reduced Al and Mn toxicity (Bolan et al., 2004**;** Hamel et al., 2010)**.** Several reasons have been attributed to the lime-induced immobilization of heavy metals as elucidated by (Fageria, and Aligar, 2008**;** Bolan et al., 2003)**:** increases in negative charge (CEC) in variable charge soils; formation of strongly-bound hydroxy metal species; precipitation of metals as hydroxides; and sequestration due to enhanced microbial activity. The net effect of liming on heavy metal transformation in these soils largely depends on the extent of pH change and Ca release from the liming material. Lime-induced mobilization of nutrient ions and immobilization of heavy metals are important in sustainable agricultural production and soil environmental protection of the soils studied. Results of paired sample t-test are presented in Table 3.

Table 3: Paired Sample t-test Between Wood Ash and Calcium Carbonate on the Evolution of Soil Properties

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
pHWA - pHCC	0.117	0.449	0.183	-0.355	0.588	0.636	5	0.553
ECWA - ECCC	0.110	0.134	0.054	-0.030	0.250	2.017	5	0.100
SBWA - SBCC	3.285	4.170	1.703	-1.091	7.661	1.929	5	0.112
APWA - APCC	-0.372	7.031	2.870	-7.750	7.007	-.129	5	0.902
EAWA - EACC	0.010	0.024	0.002	-0.015	0.036	1.040	5	0.346

pHWA = pH in Wood ash, pHCC = pH in $CaCO_3$, ECWA = Electrical conductivity in Wood ash, ECCC = Electrical conductivity in $CaCO_3$, SBWA = Sum of bases in Wood ash, SBCC = Sum of bases in $CaCO_3$, APWA = Available phosphorus in Wood ash, APCC = Available phosphorus in $CaCO_3$, EAWA = Exchangeable acidity in Wood ash, EACC = Exchangeable acidity in $CaCO_3$

From the table of paired sample t-test (Table 3), the p values show that there is no significant difference in the mean values of all paired variables (since all p values are greater than 0.05). Thus, it can be concluded that wood ash and $CaCO_3$ have similar effects in the amelioration of soil properties.

Pearson Correlation Coefficient Between Soil Physicochemical Properties

Tables 4 and 5 present the Pearson correlation coefficients between the physicochemical properties of the soil obtained three weeks after liming using $CaCO_3$ and wood ash.

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Table 4: Pearson Correlation Coefficient Matrix Between Physicochemical Properties of the Soil Obtained 3 Weeks After Liming with $CaCO_3$

	Lime added	pH	EC	Na	K	Ca	Mg	P	EA
Lime added	1								
pH	0.870	1							
EC	0.976*	0.892	1						
Na	-0.781	-0.914	0.801	1					
K	-0.397	-0.433	-0.389	-0.291	1				
Ca	0.896	0.905	0.961*	-0.852	-0.479	1			
Mg	0.931	0.711	0.851	-0.559	-0.276	0.683	1		
P	0.876	0.988*	0.874	-0.943	-0.377	0.876	0.728	1	
EA	-0.362	-0.719	-0.402	0.691	-0.048	-0.835	-0.241	-0.716	1

* Correlation is significant at 0.05 level (2-tailed)

Table 5: Pearson Correlation Coefficient Matrix Between Physicochemical Properties of the Soil Obtained 3 Weeks After Liming with Wood Ash

	Lime added	pH	EC	Na	K	Ca	Mg	P	EA
Lime added	1								
pH	0.930*	1							
EC	0.954*	0.962*	1						
Na	0.961*	0.875	0.937	1					
K	0.992**	0.965*	0.967*	0.952*	1				
Ca	0.981*	0.935	0.932	0.945	0.983*	1			
Mg	0.879	0.748	0.730	0.854	0.859	0.924	1		
P	0.857	0.968*	0.954*	0.828	0.904	0.854	0.599	1	
EA	-0.431	-0.681	-0.499	-0.298	-0.511	-0.852	-0265	-0.638	1

*, ** Correlation is significant at 0.05 level and 0.01 level (2-tailed) respectively

From Tables 4 and 5, there were strong negative correlations between Ca and EA (r = -0.835 for $CaCO_3$ and r = -0.852 for wood ash) which described the competition between Ca and Al ions in the free forms in the soil solutions. At low pH, soil solution contains more Al^{3+} because of the solubility of its hydroxides and oxides. Furthermore, at low pH, the bioavailability of Ca is retarded by the high concentration of Al (Horneck et al., 2011; Bolan et al., 2003).

Both pH, EC, Na, K, Ca, Mg and P had a strong significant positive correlation with wood ash (r = 0.930, 0.954, 0.961, 0.992, 0.981, 0.879 and 0.857 respectively), which shows that increasing the amount of liming material increases the availability of these important plant nutrients (Fageria, and Aligar, 2008). The introduction of more Ca^{2+} goes to augment the concentration of soluble salts thus increasing EC (Borbe et al., 2006).

The strong positive correlations, between Ca and Na (r = 0.945) and between Ca and K (r = 0.983) in wood ash limed soils confirms the fact that wood ash in addition to containing Ca and Mg also contains Na and K, which are absent in $CaCO_3$ (indicated by negative correlations, r = -0.852 between Ca and Na and r = -0.479 between Ca and K (Bolan et al., 2003).

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CONCLUSION

Soil acidity associated with Al toxicity, soil erosion and soil nutrient depletion are the main soil-related constraints in parts of developing countries like Cameroon. The main objective of this research work was to evaluate the effects of two liming materials (wood ash and $CaCO_3$) on soil acidity and the evolution of soil properties in volcanic-influenced soils of Meupi-Awing, North West Region of Cameroon.

Results of some selected physicochemical properties analyzed 3 and 6 weeks after the application of increasing amounts of wood ash and $CaCO_3$ to the soil samples indicated that liming had positive effects on the acidic soils within 3 weeks. This was seen through the increase in soil pH, electrical conductivity, the sum of exchangeable bases, available phosphorus and a decrease in the exchangeable acidity of the soils.

This study has shown that the $CaCO_3$ and wood ash used served as liming materials and sources of plant nutrients. Soil acidity was reduced by increasing soil pH from 5.0 to 8.4 with $CaCO_3$ and 9.1 with wood ash and nutrients were released enhancing soil fertility. However, the best performance was obtained in wood ash-treated soils. Correlation studies ($p < 0.05$) also indicated that wood ash contains more elements like K ($r = 0.992$) and Na ($r = 0.961$), which are lacking in $CaCO_3$.

Therefore, for amelioration of soil acidity, improved soil nutrients and better performance of crops in farmlands in Meupi-Awing village in the Northwest Region of Cameroon and in other areas with similar soil types, a minimum lime application rate of 2.70 g/kg soil (0.675 g $CaCO_3$ in 250 g soil) for calcium carbonate and 7.72 g/kg soil (1.930 g wood ash in 250 g soil) for wood ash is recommended.

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Data Availability

All relevant data is inserted in this manuscript.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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