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Effects of local liming materials on soil properties and yield of waterleaf (*Talinum fruticosum* (L.) Juss.) in an ultisol of southeast Nigeria

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ABSTRACT

Soils of the tropics are generally acidic mainly due to high and intensive rainfall which causes excessive loss of the basic cations. High soil acidity is often a limiting factor for plant growth. Liming is the most widely used method to neutralize acidity and improve crop performance. Field trial was conducted at two locations in the University of Calabar Teaching and Research Farm, Calabar to determine the effects of local liming materials on soil properties and yield of waterleaf. Seven treatments consisting of wood ash (WA), oil palm bunch ash (OPBA), cocoa pod ash (COPA), periwinkle shell ash (PSA), cassava peels ash (CAPA), and carbide waste (CW) each applied at 8 t/ha and a control (no lime applied) were laid out in a randomized complete block design with three replications. The result showed increased in soil pH from 4.5 before experiment to 5.93 in plot treated with wood ash. Soil organic carbon, available phosphorus, basic nutrients (Ca, Mg, K, Na) and base saturation were significantly ($P < 0.05$) increased in plots treated with lime materials. Plant height, number of leaves, number of branches, stem girth, leaf area, fresh and dry matter yield of waterleaf were significantly increased. The highest mean fresh yield of 4.61 t/ha obtained from WA treated plot was not significantly ($P > 0.05$) higher than the yield of 4.36 t/ha obtained from OPBA treated plots but was higher significantly from other treatments. The fresh yield increase was 61, 58, 46, 45, 39 and 35% while the dry matter yield percentage increase was 63, 56, 53, 50, 42 and 22 for WA, OPBA, COPA, PSA, CAPA and CW. Therefore, for amelioration of soil acidity and better crop performance in an acid Ultisol of Southeast Nigeria, application of either wood ash or oil palm bunch ash is recommended.

Keywords: Ash, soil acidity, soil properties, yield, waterleaf, *Talinum fruticosum*

1. INTRODUCTION

The soils of southeastern Nigeria that are developed on sand stones or coastal plain sand parent materials are strongly weathered, leached and highly acidic in nature. This is mainly due to excessive loss of basic cations by high and intensive rainfall. Soils with high acidity have the tendency of aluminum, hydrogen and manganese toxicity as well as nutrient deficiencies of calcium and magnesium (Iren *et al.*, 2016; Udoh and Iren, 2018). Soil acidity is a condition of the soil when the exchange complex is dominated by hydrogen (H^+) and aluminium (Al^{3+}) ions (Brady and Weil, 1999). It is one of the most important soil fertility problems. Soil acidity is common in all regions where rainfall is high enough to leach appreciable amounts of exchangeable bases (K, Ca, Mg) from the surface layers of soils. Soil acidity has a negative effect on crops mainly through phosphorus (P) unavailability from P fixation. Strongly acid soils are not productive for most crops, exception are the acid loving plant.

In order to decrease soil acidity the hydrogen ions must be replaced by metallic cations. This is commonly done by adding agricultural limes. The use of agricultural lime to neutralise soil acidity and eliminate toxic levels of Al, Mn and Fe is the cheapest and most effective approach in ameliorating the fertility status of strongly acid soils. The use of agricultural lime is not just to raise soil pH to favourable level but also to enhance other soil conditions such as increase in microbial activity, CEC and base saturation, which enhances nutrient availability especially phosphorus. Liming will lower the solubility of acidic cations (H, Al, Fe, Mn) while raising the solubility of P, K and Mg in mineral soils (Udoh and Iren, 2018). Liming is a soil amendment 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.

Waterleaf is extensively grown in Southeast Nigeria, particularly in Cross River and Akwa Ibom States and is used in soups as softener and other delicacies in combination with other vegetables such as African joint or afang (*Gnetum Africana*), bush apple or atama (*Heinsia crinata*), editan (*Lasienthera bulchozianum*) and fluted pumpkin (*Telfaria occidentalis*). Apart from being used as a softener, it is also used as a colouring agent in okra soup and also used to treat measles. It grows best under humid conditions with a mean temperature of about 30 °C. Growth is most profuse when water content of the soil is close to field capacity (Schippers, 2000). High temperature (>35 °C) and drought negatively affect the number of leaves, leaf area, stem size and number of branches. The soil pH range for optimum growth and yield of waterleaf is 6.1 – 7.5 (Schippers, 2000).

There are various liming materials that can be used to raise the pH of soils to desired level or to correct soil acidity. Liming material is any material added to the soil for the purpose of neutralizing or reducing soil acidity. They include inorganic (calcium or magnesium oxide) and organic (ash) limes. Although liming is a well-known technology by agriculturists, farmers rarely adopt its use. Reasons for low adoption include poor understanding of the full role of lime in the soil, scarcity of the inorganic source and the relatively high cost of the product. The use of organic source of lime especially various ash sources holds the promise in Ultisols because of the multi-beneficial qualities including supplementary balanced nutrient supply for improved soil health, increased crop yields and very cheap to acquire (Iren *et al.*, 2016). Ultisols are acid soils of low fertility status formed from intense weathering and leaching processes in the humid tropical regions. Sustainable crop production on these soils requires judicious use of agricultural lime to neutralize excess acidity and eliminate toxic levels of Al, Mn and Fe in order to improve the low fertility status of strongly acid soils.

This study, therefore, compares the effectiveness of ashes from different materials on soil properties, growth and yield of waterleaf in an acidic Ultisol.

2. MATERIALS AND METHODS

2. 1. Experimental site

The experiment was conducted in two locations within the University of Calabar Teaching and Research Farm, Calabar. Calabar lies between latitude 5° 32' and 4° 27' N and longitude 7° 15' and 9° 28' E in Nigeria with annual rainfall of 2000 to 3000 mm. The mean temperature ranges between 23 and 33 °C while the mean relative humidity is 60 to 90%. The soil is an Ultisol according to the United States Department of Agriculture (USDA) system of classification (Soil Survey Staff, 1999).

2. 2. Land preparation, experimental design and treatments

The experimental site was manually cleared, tilled and plots measuring 2 m × 1.5 m marked out. An alley of 1 m was left between blocks and 0.50 m between plots. The experiment was laid out in a randomized complete block design with three replications. There were seven treatments consisting of wood ash (WA), oil palm bunch ash (OPBA), cocoa pod ash (COPA), periwinkle shell ash (PSA), cassava peels ash (CAPA), and carbide waste (CW) each applied at 8 t /ha and a control (no lime applied).

2. 3. Field studies

Prior to land preparation, one composite soil sample was collected from 0 to 15 cm depth using soil auger for physico-chemical analysis. The various local liming materials were evenly spread and incorporated into the soil and allowed for two weeks to equilibrate before planting (Iren *et al.*, 2016). Waterleaf was planted manually at a spacing of 5 cm × 5 cm using stem cuttings of about 10 cm length (Iren *et al.*, 2015) with leaves still attached. Weeding was done manually by hand pulling within the plots and using hoe to weed around the plots.

Ten plants from the centre row of each plot were randomly selected, tagged and used in growth measurements. Growth parameters measured were plant height, number of leaves per plant, number of branches per plant, leaf area and stem girth. These parameters were assessed after 4 weeks of planting (WAP) and subsequently at three weeks intervals. Weights of freshly harvested waterleaf were taken from an area of 50 cm × 50 cm within each experimental plot at 4, 7 and 10 WAP. Composite soil samples were taken per plot at the end of the experiment for laboratory analysis.

2. 4. Laboratory studies

The composite soil samples collected before and after experiment were air-dried and sieved through a 2 mm mesh. The following analyses were carried out on the samples using standard procedures as outlined by Udo *et al.* (2009): Particle size distribution was determined by the Bouyoucous hydrometer method, using sodium hexametaphosphate as a dispersant. Soil pH was determined using a ratio of 1:2.5 in soil-water medium and read with a pH meter. Organic carbon content was determined by Walkley-Black dichromate oxidation method. Organic matter was obtained by multiplying total carbon by a factor of 1.724. Total nitrogen

(N) was determined by the micro-kjeldahl method. Available phosphorus (P) was extracted by the Bray 1 extraction method, and the content of P was determined colorimetrically using a Technico AII auto analyser (Technico, Oakland, Calif). Exchangeable bases was determined by the neutral ammonium acetate extraction method and read with an atomic absorption spectrophotometer (AAS). Exchangeable acidity was determined by the 1 N potassium chloride (KCl) extraction method and titrated with 1 M sodium hydroxide (NAOH) using phenolphthalein as an indicator. The effective cation exchange capacity (ECEC) was the summation of total exchangeable bases and exchangeable acidity. Base saturation was calculated by dividing the sum of exchangeable bases by ECEC and multiplying by 100.

Samples of the ashes from different materials were also subjected to chemical analysis using standard procedures.

2. 5. Data analysis

Data were analyzed statistically and means were compared using Fisher’s Least Significant Difference (FLSD) at 5% probability level (Wahua, 1999).

3. RESULTS AND DISCUSSION

3. 1. Properties of the soil before experiment

The physic-chemical properties of the soil used for the experiment at the two locations revealed that the soils were extremely acid with a mean pH value of 4.5 and loamy sand in texture (Table 1). Acid soils can reduce plant growth and yield by increasing soil concentrations of Al, Fe and Mn to toxic levels and decreasing the availability of Ca, Mg and P (Udoh and Iren, 2018). The soil was low in organic carbon, total nitrogen, exchangeable cations, effective cation exchange capacity (ECEC) and base saturation. The low levels of nutrients obtained in the experimental soil indicate low fertility status and may be attributed to high temperature, high rainfall and leaching losses which characterize the tropical areas.

Table 1. Physicochemical properties of soil and nutrient content of the ashes used for the study.

Soil property		Nutrient content of ashes from the different liming materials						
Parameter	Value	Parameter	Value					
			WA	OPBA	COPA	PSA	CAPA	CW
Sand (%)	83.0	pH (H ₂ O)	12.4	10.8	12.6	10.5	9.3	11.9
Silt (%)	14.0	Organic carbon (%)	3.25	2.80	3.21	2.22	3.31	2.04
Clay (%)	3.0	Total nitrogen (%)	0.36	0.34	0.33	0.28	0.38	0.29
Texture	loamy sand	C: N ratio	9.03	8.24	9.73	7.92	8.71	7.03
pH (H ₂ O)	4.5	Total P (mg/kg)	46.87	41.75	36.25	23.00	20.25	9.50

Organic carbon (%)	1.09	Total Ca (mg/kg)	26.6	22.2	27.2	28.3	22.4	16.9
Total nitrogen (%)	0.01	Total Mg (mg/kg)	15.6	10.4	4.2	3.7	2.8	5.7
Available P (mg/kg)	7.00	Total Na (mg/kg)	0.13	0.12	0.11	0.12	0.12	0.12
Exch. Ca (cmol/kg)	3.40	Total K (mg/kg)	0.28	0.27	0.24	0.15	0.20	0.27
Exch. Mg (cmol/kg)	0.92							
Exch. Na (cmol/kg)	0.09							
Exch. K (cmol/kg)	0.12							
Exch. H (cmol/kg)	3.16							
Exch. Al (cmol/kg)	1.60							
ECEC (cmol/kg)	9.29							
Base saturation (%)	48.76							

WA = Wood ash, OPBA = Oil palm bunch ash, COPA = Cocoa pod ash, PSA = Periwinkle shell ash, CAPA = Cassava peels ash, CW = Carbide waste

3. 2. Nutrient contents of the ashes from different materials used for the study

The analysis of the liming materials revealed that the ashes contain significant amount of plant nutrients apart from possessing sufficiently high enough pH levels to make them suitable as liming materials (Table 1). Amongst the ashes, cocoa pod ash had the highest pH (12.6), followed by wood ash (12.4) then oil palm bunch ash (10.8) and the least was from the cassava peels ash (9.3).

3. 3. Effects of local liming materials on soil chemical properties

Changes in soil chemical properties after experiment are presented in Table 2. The liming materials used significantly ($P < 0.05$) improved the pH, organic carbon, total nitrogen, available P, exchangeable K, Mg, Ca and base saturation of the soil compared to the control (without lime). All the ashes applied except carbide waste significantly increased the soil pH relative to the control. However, the increases in pH by the different liming materials were not significantly different from one another. The soil pH was raised from an initial value of 4.5 to values greater than 5.0 with the highest pH value of 5.93 obtained in plots treated with wood ash, this was followed by cocoa pod ash treated soil (5.87), then oil palm bunch ash treated soil (5.82) and the least was from the control (4.60). The increases in soil pH obtained in all the treated plots proved that ashes of any origin have the tendency to raise the pH of soils. In this study, the ashes obtained from different materials confirmed the role of ash as a liming material and also an effective source of nutrients for crops. It has also been reported by many researchers (Onyegbule *et al.*, 2012; Bello and Udofia, 2013, Akinmutimi and Osodeke, 2013; Iren *et al.*, 2016) that ashes of varied origin have the potentials to reduce active acidity and salt-replaceable acidity in soils of southern Nigeria.

Table 2. Effects of local liming materials on soil chemical properties

Liming materials	pH (H ₂ O)	Org. C (%)	Total N (%)	Av. P (mg/kg)	Exchangeable bases (cmol/kg)				Exchangeable acidity (cmol/kg)		ECEC (cmol/kg)	BS (%)
					Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Al ³⁺	H ⁺		
Control	4.60	1.08	0.06	20.21	2.07	1.07	0.06	0.01	1.81	1.77	6.79	47.28
WA	5.93	1.80	0.29	38.32	3.33	2.27	0.10	0.13	0.32	1.02	7.17	81.31
OPBA	5.82	1.68	0.25	39.46	3.06	1.87	0.07	0.09	0.38	1.03	6.50	78.31
COPA	5.87	1.77	0.22	26.87	3.23	1.76	0.08	0.12	0.42	1.09	6.70	77.46
PSA	5.73	1.72	0.26	33.45	2.34	1.23	0.08	0.12	0.36	1.02	5.15	73.20
CAPA	5.68	1.42	0.22	31.67	2.47	1.33	0.07	0.11	1.14	1.82	6.94	57.35
CW	5.14	1.31	0.22	28.46	2.40	1.70	0.09	0.41	1.20	1.12	6.92	66.47
F-LSD	1.07	0.38	0.15	9.65	1.60	0.50	0.02	0.60	0.27	0.17	NS	12.80

WA = Wood ash, OPBA = Oil palm bunch ash, COPA = Cocoa pod ash, PSA = Periwinkle shell ash, CAPA = Cassava peels ash, CW = Carbide waste

The organic carbon contents of the soil were significantly ($P < 0.05$) affected by all the ashes applied excepting carbide waste (CW) treated soil relative to the control although no significant differences existed amongst the treatments. The highest value of 1.80% was obtained from WA treated plot. All the treated plots had significant increase in total nitrogen content relative to the control with highest value of 0.29 % obtained in WA treated plots closely followed by plots treated with PSA (0.26 %). There was also a significant increase ($P < 0.05$) in available P in plots treated with WA, OPBA, PSA and CAPA relative to control, with the application of OPBA recording the highest value of 39.46 mg/kg although not significantly higher than the other treatments. There were significant ($P < 0.05$) increases in the exchangeable calcium (Ca), magnesium (Mg) and sodium (Na) contents with the plot treated with wood ash giving the highest values of 3.33, 2.27 and 0.10 cmol/kg, respectively while the highest potassium (K) content was obtained in plot treated with carbide waste (0.41 cmol/kg). Onwuka *et al.* (2009), Akinmutimi and Osodeke (2013) and Iren *et al.* (2016) have shown that ash materials contain exchangeable cations, which are known to increase soil pH.

There was a general reduction in exchangeable acidity values in treated plots relative to control with the soil solution mostly dominated by H⁺. This is in agreement with the findings of many researchers (Onyegbule *et al.*, 2012; Nwachukwu *et al.*, 2012; Akinmutimi and Osodeke, 2013; Iren *et al.*, 2016) who reported reduction in exchangeable acidity level of soils by applying liming materials in Ultisols of South Eastern Nigeria. However, there was no significant ($P > 0.05$) increase in the effective cation exchange capacity (ECEC) of the soil by treatments. The base saturation (BS) levels of the treated soils were significantly ($P < 0.05$) increased to values above 50 % compared to 48.76 and 47.28 % obtained before experiment

and from control plot, respectively. The increases in soil nutrients obtained in this study as a result of applying lime to acidic Ultisols confirmed the assertion made by Udoh and Iren (2018) that liming will lower the solubility of acidic cations (H, Al) while raising the solubility of P, K, Na and Mg in mineral soils.

3. 4. Effects of local liming materials on growth parameters and yield of waterleaf

Table 3. Effects of local liming materials on growth parameters of waterleaf

Liming materials	Mean plant height (cm)			Mean Number of Leaves		
	4 WAP	7 WAP	10 WAP	4 WAP	7 WAP	10 WAP
Control	8.73	8.30	7.60	15.40	14.70	14.2
WA	11.30	14.70	15.52	22.60	31.30	32.6
OPBA	9.73	13.10	14.20	21.70	31.30	33.2
COPA	9.23	12.70	13.60	21.68	29.50	27.6
PSA	8.92	11.70	13.10	19.68	27.70	26.3
CAPA	8.89	11.00	12.80	19.30	27.80	24.6
CW	8.69	10.00	8.20	17.50	18.72	16.9
F-LSD	NS	3.6	1.0	NS	11.5	7.9
Liming materials	Mean number of branches			Mean stem girth (cm)		
	4 WAP	7 WAP	10 WAP	4 WAP	7 WAP	10 WAP
Control	2.40	2.50	3.00	1.2	1.3	1.3
WA	3.58	5.66	8.20	1.6	2.08	2.18
OPBA	3.71	5.48	7.10	1.6	2.02	2.07
COPA	3.50	4.82	6.00	1.4	1.93	1.82
PSA	3.60	5.41	5.91	1.4	1.90	1.80
CAPA	3.32	4.40	5.40	1.4	1.60	1.60
CW	2.62	2.60	4.80	1.4	1.40	1.40
F-LSD	0.2	0.9	1.5	NS	0.46	0.22

WA = Wood ash, OPBA = Oil palm bunch ash, COPA = Cocoa pod ash, PSA = Periwinkle shell ash, CAPA = Cassava peels ash, CW = Carbide waste

Table 3 presents the effects of local liming materials on growth parameters of waterleaf. Significant ($P < 0.05$) increases in heights of waterleaf were observed at 7 and 10 WAP but not at 4 WAP as a result of the ashes applied with the tallest plants observed in wood ash treated

soil across all the growth stages. At 7 WAP, the tallest plants were obtained in plots treated with wood ash, though not significantly taller than plants treated with OPBA, COPA and PSA but were taller than those planted in soil treated with CAPA, CW and the control. At 10 WAP, all the plants grown in treated plots except CW treated plot were taller significantly than the control

The control plots produced the shortest plants as they had to rely only on the native soil fertility which from the result of chemical analysis was deficient in nutrients. The highest plant height observed in this study from plants treated with liming materials agreed with the works of Onyegbule *et al.* (2012) who reported significant increase in soybean height as a result of liming the soil. The increased plant height associated with liming might be due to enhanced root growth and leaf expansion as pointed out by Sanchez (1979).

At 4 WAP, application of liming materials did not significantly increased leaf production of waterleaf although the highest number of leaves per waterleaf plant was in soil limed with WA and closely followed by plants grown in OPBA treated soil (Table 3). At 7 and 10 WAP, all the treatments applied except CW significantly ($P < 0.05$) increased leaf production of waterleaf compared with control plots. There was no significant difference ($P > 0.05$) in the number of leaves produced amongst the different liming materials except CW which was not significantly different from the control. Numbers of leaves per plant do directly affect the overall performance of crops as the leaves serve as photosynthetic organ of the plant.

Number of branches per waterleaf plant was significantly increased by all the treatments across all growth stages relative to control (Table 3). At 4 WAP, the highest value (3.71) was obtained by plants treated with OPBA though not significantly more than those treated with PSA (3.60) but was more than the plants treated with other liming materials. At 7 and 10 WAP, the highest number of branches per waterleaf plant was obtained in WA treated soil closely followed by OPBA treated soil.

There was no significant difference ($P > 0.05$) in the stem girth of waterleaf at the initial growth stage (4 WAP) but significant increase was observed as the growth stages advanced when compared with the control (Table 3). The biggest stem girth of waterleaf at 7 and 10 WAP was obtained from WA treatment closely followed by OPBA treatment and the least by the control.

There was no significant increase in leaf area (Table 4) of waterleaf at 4 WAP but there were significant increases amongst treatments at 7 WAP relative to control with the highest leaf area obtained from plants treated with WA (6.59 cm²), followed by COPA treated plants (5.45 cm²) and OPBA treated plants (5.42 cm²). Similar trend was observed at 10 WAP.

The highest mean fresh yield of 4.61 t/ha obtained from WA treated plot was not significantly ($P > 0.05$) higher than the yield of 4.36 t/ha obtained from OPBA treated plots but was higher significantly than the yield obtained from other liming materials treated plants and the control (Table 4). The yield increase was in the order WA > OPBA > COPA > PSA > CAPA > CW > control. The highest dry matter yield (0.19 t/ha) was also obtained from plants receiving WA treatment, followed by OPBA treatment (0.16 t/ha) while the least (0.05 t/ha) was from the control (Table 4). The fresh yield increase was 61, 58, 46, 45, 39 and 35% while the dry matter yield percentage increase was 63, 56, 53, 50, 42 and 22 for WA, OPBA, COPA, PSA, CAPA and CW. The yields obtained from this study were relatively lower than the yield obtained by Ndaeyo *et al.* (2013) by the application of 5 t/ha of poultry manure (23.33 t/ha) in the cultivation of waterleaf in Akwa Ibom State, Nigeria, the yield obtained by Iren *et al.* (2015) by the application of 8 t/ha cassava peels and poultry manure-based compost (22.92 t/ha) and also the

yield obtained by Iren *et al.* (2017) by using 10 t/ha of organomineral fertilizer (24.9 t/ha). This means for optimum yield of waterleaf there may be need to combine liming materials with fertilizer in future research. Asawalam and Onyegbule (2009), Adekayode and Olojugba (2010), Nwachukwu *et al.* (2012) and Iren *et al.* (2016) have demonstrated the need to combine liming materials with fertilizer for profitable crop production in an acidic soil.

Table 4. Effects of local liming materials on leaf area, fresh yield and dry matter yield of waterleaf

Liming materials	Mean leaf area (cm ²)			Fresh yield (t/ha)	Percentage increase	Dry matter yield (t/ha)	Percentage increase
	4 WAP	7 WAP	10 WAP				
Control	2.28	2.01	1.70	1.81	-	0.07	-
WA	3.95	6.59	6.67	4.61	61	0.19	63
OPBA	3.84	5.42	6.12	4.36	58	0.16	56
COPA	2.97	5.45	5.72	3.35	46	0.15	53
PSA	2.98	4.67	4.46	3.29	45	0.14	50
CAPA	2.29	3.72	4.55	2.99	39	0.12	42
CW	2.23	3.77	3.15	2.79	35	0.09	22
F-LSD	NS	1.15	1.06	0.91	-	0.03	-

WA= Wood ash, OPBA = Oil palm bunch ash, COPA = Cocoa pod ash, PSA = Periwinkle shell ash, CAPA = Cassava peels ash, CW = Carbide waste

4. CONCLUSION

This study has shown that the varied ashes used served as liming materials and sources of nutrients. Soil acidity was reduced and nutrients released enhancing soil fertility. Hence the growth of waterleaf and yield were increased significantly. However, the best performance was obtained in wood ash (WA) and oil palm bunch ash (OPBA) treated soils. Wood ash was as effective as oil palm bunch ash in raising the soil pH, enhancing soil nutrient availability and yield of waterleaf.

Therefore, for amelioration of soil acidity, improved soil nutrients and better performance of waterleaf in an acid Ultisol of Southeast Nigeria, the application of either wood ash or oil palm bunch ash is recommended.

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