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Extractable Aluminium Relationships to some Soil Properties in Sub-humid Forest Zone of Southern Nigeria

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Abstract

Thirty-four surface soil samples (0-15cm) twenty-four from the Coastal Plain Sands (CPS) and ten from the Meander Belt Delta Soils (MBD) were collected from two geophysiographical different areas in the Rivers State of Southern Nigeria. The relationship of extractable Aluminium with some soil properties (i.e. % clay, % silt, % organic matter and pH) are considered. The KCl extractable Al of Coastal Plain sand (CPS) soils largely Ultisols were significantly correlated with all soil properties while the NH_4OAc pH 4.8 extractable Al, in some CPS soils were not significantly correlated with any of the soil properties. However, the Meander Belt Delta (MBD) soils largely ENTISOLS & INCEPTISOLS with higher pH, Al-extracted by both KCl and NH_4OAc showed striking relationship to soil properties.

Two soil samples (one CPS — Ultisols and the other MBD Entisols) were amended by addition of cattledung or poultry or piggery manure and/or with lime ($CaCO_3$) material and incubated at 50% moisture level for six weeks, and were processed for determination of KCl and NH_4OAc extractable Aluminium. Results obtained showed that poultry and/or piggery manure were more effective amendment materials for the management of pH and active Aluminium pool in the soils considered. More future indepth work using various organic manure/wastes with lime mixtures is suggested.

Introduction

Many factors causing low crop yields in much of the humid tropical forest soils are associated with high soil acidity. These include toxic concentration of Al and Mn, deficiencies of Ca and Mg, leaching of K and sorption of phosphates, sulphate and molybdate (Fox 1980, and Jackson 1967). Coleman and Thomas (1967) reported that Aluminium rather than hydrogen is the predominant cation in acid soils with less than pH 5.0.

The exchangeable acidity affecting plant growth was that extracted with a neutral unbuffered salt solution. At pH 5.5 and above soils contained essentially no potassium chloride exchangeable Aluminium. Extractable Al is considered (Pionke & Corey 1967; Mclean 1965) to consist of exchangeable (INKCl extractable) and nonexchangeable IN NH_4OAc, pH 4.8 extractable Al) minus (INKCl extractable Al) Al forms. According to Barnhisel and Bertsch (1982) exchangeable or extractable Al ions are most commonly displaced with unbuffered salt solutions such as INKCl, $CaCl_2$ or $BaCl_2$. Most mineral soils with pH values less than 5 contain the exchangeable Al that should be reduced to provide suitable condition for plant growth.

Extraction techniques using unbuffered salt solutions are probably best suited for estimating truly exchangeable Al. Other complexing agents and acid and acid salt solutions extract Al from both exchangeable and nonexchangeable sources including structural hydroxy polymeric organically bound species and other nonmetastable forms. The later forms represent a plant active "Al-pool" usually considered in lime recommendations (Arai, 1975 and Juo and Kamprath 1979). Many methods can be used to estimate active Al-pools but it is essential to note that they are soil specific and require extensive calibration before they are effectively implemented. In earlier studies Juo & Kamprath (1978) had used copper chloride as extractant to estimate the reactive Al pool in acid soils, which showed that the nonexchangeable Al in some soils may be four times higher than the exchangeable Al. Thus Al extracted by IN $CuCl_2$ probably gives a fair estimate of the total Al pool but over estimates liming needs of crops with significant degrees of Al tolerance the reactive 'Al pool' in acid soils. The values showed that the nonexchangeable Al in some soils may be four times higher than the exchangeable Al. Thus Al extracted with IN $CuCl_2$ probably gives a fair estimate of Al pool inexcess of active Al-pool usually estimated for liming needs of crops with significant degrees of Al tolerance (Pionke & Corey 1967 and Kamprath 1970). Although this distinction implies that NH_4OAc, pH 4.8 extractable Al is often equal or higher than KCl extractable Al. data on some tropical soils have shown otherwise (Juo & Kamprath 1979). Exchangeable Al is still a major cation in many acid soils particularly at pH 4.5 or less. It occupies a large proportion of the effective CEC in these acidic soils. Aluminium toxicity poses problems in many tropical acid soils — depending on the clay mineral present and the exchangeable Aluminium content (Juo & Kamprath 1979).

The use of exchangeable Al as the criterion on which to base lime rates has been proposed for mineral soils with low permanent and a relatively high pH dependent charge. The main purpose of liming is therefore to remove Al toxicity as a soil constraint to crop growth (Reeve and Summer 1970 and Kamprath 1967). Lime rates on a chemically equivalent basis are added as multiples of the amount of exchangeable Aluminium. Various studies have shown that lime rates chemically equivalent to 1.5 to 3 times the exchangeable Al must be added to neutralize the Aluminium, using the buffering properties of acid soils. Exchangeable Al is responsible for buffering in the pH range of 4.0 to 5.6, while hydroxy Aluminium and Aluminium-organocomplexes control buffering mainly in the pH range of 5.6 to 7.6. In some other studies with Ultisols, when the pH was about 5.3, lime reacted with both exchangeable Al and pH dependent sources of acidity (Kamprath 1970 and Jackson 1963). To neutralize all of the Al, lime must be added at rates chemically equivalent to twice the exchangeable Al usually at unaffordable cost to small farmers — holdings. According to Schnitzer and Skinner (1963) organic matter complexes Aluminium and Manganese, and thereby decreases the amount of Al and Mn in soil solution large amounts of easily decomposable plant residues or manures incorporated into acid soils as humified material can also decrease Aluminium concentration in soil solution through the formation of organocomplexes. Higher rates of organic matter addition would be required in order to have beneficial effect in reducing toxicities in acid soils

This approach can be readily adapted to sourcing of available farm manure with great advantage on small farms where supplies of organic matter, crop residues, livestock manures are plentiful, labour abundant and lime materials in limited supply and high priced.

Extractable Al has been shown to be related to soil organic matter (Hoyt, 1977, Thomas, 1975, Pionke & Corey 1967), soil pH (Thomas, 1975 Pionke & Corey, 1967), and Clay (Pionke & Corey 1967) in soils of the temperate region having predominantly 2:1 clays. Such relationships have not been investigated in details in tropical African soils except for the simple correlation studies of extractable Al and soil pH in some West African soils (Juo 1977). Better understanding of these relationships will be useful in developing more efficient utilization of organic manure and lime in the management of acid soils. The objective of this work is to elucidate the relationship between the extractable Al with pH, organic matter, clay and silt in humid tropical soils. The soils are predominantly of Kaolinitic mineralogy, and are tested further to demonstrate the effects of organic manure and lime addition on reducing extractable Al concentration in arable acid soils.

Materials and Methods

Geography of Sampled Area and Materials Used

Rivers State is one of the Coastal States of Nigeria, located within 4°20' and 5°45'N latitude and 5°22' and 7°35'E longitudes, occupies about 19429km^2 or 2.1% of the total land area of Nigeria. About 80% of the State is in the Niger Delta with the balance area of 20% in the Coastal Plain terrace sands largely within the Imo River Basin (Ojanuga et al 1986).

Geomorphologically Rivers State land area consist of two physiographic units. They are the Niger Delta — riverine (including the Upper/Lower Delta Plains, Tidal flats and Beach Ridges) and the Upland smaller unit of relatively drier land — (which includes — the Coastal Plain Terrace, and Sombreiro-Warri Terrace Land).

Soils developed from Coastal Plain Sands (CPS) are markedly leached, deep well drained argillic soils. They are sandy loams, sandy clay loams, loams and sandy clays with sand to sandy loams surface layers mostly typic Paleudults and so on (Ojanuga et al 1986, and Omenihu 1989). The soils are very strongly to strong acid in reaction (pH 4.2 — 5.2) highly deficient in bases (Ca, Mg, K and Na).

Soils of the Upper/Lower Delta Plains are mainly flood plains. They include the Meander Belt and Levees of the Niger flood plains as the larger of the two groups. Meander Belts and Levees (MBD) soils are seasonally or permanently flooded by fresh-water annually. They are therefore poorly drained yellowish brown or light grey sands, loamy sands, sandy clay loams with strong acid reaction. (Mordi 1986 and Kamalu 1989).

Soil Samples

Thirty-four surface soil samples (0 — 15cm), twenty-four from the Coastal Plain Sand (CPS) unit and ten from the Meander Belt Delta (MBD) soils unit, were collected from the two geophysiographically different areas in Rivers State Nigeria. The soil samples were air dried in the Laboratory routinely and stored in well labelled containers for subsequent use in this study.

Soil Amendment Materials

For this study other amendment materials procured included poultry droppings and manure, piggery manure, and cowdung manure. All the manures were obtained from the Faculty of Agriculture Teaching and Research Farm, Port Harcourt and air dried in the Laboratory for up to 4 days, crushed, sieved and stored in bottles for use in the experiments.

Laboratory Procedures

Soil samples were analyzed for pH (1:1 water/soil ratio) using a Pye Unicam pH meter equiped with a combined glass electrode, organic matter by the wet oxidation method described in Allison (1965), and particle sizes (Day 1965). Extractable Al forms were removed by INKCl (Mclean 1965) and pH 4.8 1M NH_4OAc (Mclean 1965) methods and Al in the extracts was determined by the Aluminium procedure.

Incubation Experiment

Fifty gram samples of two soils, (one from the Coastal Plain Sands (CPS) with organic matter 2.0%, pHw, 4.8 and clay 27% and the other soil from the Meander Belt Delta (MBD) area with organic matter 1.8%, pHw 5.0, and clay 23%) were amended with 3g dried poultry manure or piggery manure and/or 3g dried cowdung manure respectively to bring their final organic matter content up to above 6%. The sample mixtures were moistened and incubated at 50% moisture levels for six weeks.

Each treatment including the control with no organic manure added was replicated twice. Two more samples from each soil (CPS or MBD) were treated in a similar manner with 0.10g $CaCO_3$ to determine the effect of lime application on extractable Al.

All samples were air dried at the end of the incubation period and INKCl and 1M NH_4OAc pH 4.8 extractable Al were determined.

Results and Discussion

The properties of 34 surface soil samples collected from two main physiographic units of the Rivers State are given in Table 1. Samples include Coastal Plain Sands (CPS) mainly of the Ultisol order (USDA Taxanomy) and represented by 24 samples, and the Meander Belts (MBD) dominated by Entisols and Inceptisols numbering up to ten samples. In Table 1, it is also indicated that both geophysiographic soil sample groups are of Kaolinitic clay mineralogy, mixed at different concentrations with traces of vermiculite, quartz, illite and other common minerals (see Table 1). The soil pH range from 4.0 to 5.4 for CPS and 4.3 to 5.6 for MBD while the average organic matter content for both are 2.29 and 2.40% respectively. These soils with a pH less than 5.5 and an organic matter less than seven per cent are acid mineral soils (Cochraine, Salinas and Sanchez 1980).

Regression Studies on Extractable Al relationship to Soil Properties

Simple correlation coefficient for the relationship of extractable Al with % clay, % silt, % organic matter and pH are given in Table 2.

In CPS soils, KCl — extractable Al (primarily exchangeable Al or soil solution Al) = KCl — Al = was significantly correlated with all soil properties tested,

TABLE 1: PROPERTIES* (MEANS AND RANGES) OF THE SOILS USED

Geomorphology	No. of Samples	Clay (%)	Silt (%)	Organic Matter (%)	pH (1:1 H_2O)	INKCl extract-able Al (ppm)	pH 4.8 NH_4OAc extractable Al (ppm)	Clay Mineralogy	Classifi-cation
Coastal Plain Sands (CPS)	24	16.8 (.5.6-30.0)	11.6 (1.1-56.4)	2.29 (1.13-4.38)	4.56 (4.00-5.40)	112 (10.335)	197 (10-425)	Kaolinite (dominnant) with traces of vermiculite quartz and illite	Ultisols
Meandar Belts (MBD)	10	22.5 (15.8-34.0)	37.2 (16.8-47.9)	2.40 (1.07-4.04)	4.95 (4.30-5.60)	147 (7-360)	227 (60-580)	Kaolinite dominant with other common mineral smectite illite and quartz	Entisols and Incepsols

*Range in parenthesis

TABLE 2: SAMPLE CORRELATION COEFFICIENTS OF KCl EXTRACTABLE Al (KCl — Al) AND NH_4OAc EXTRACTABLE Al (NH_4OAc — Al) WITH SOIL PROPERTIES

Soil Group	KCl — Al				NH_4OAc — Al			
	Clay	Silt	Organic Matter	pH	Clay	Silt	Organic Matter	pH
Costal Plain Sands (24 samples) [CPS]	0.4407*	0.7111***	-0.5016*	-0.4209*	-0.0091	0.1909	0.1455	-0.1185
Meander Belts (10 samples) [MBD]	0.6293*	0.3787	0.6567**	0.8257**	0.8129*	0.2468	0.8568***	0.8804***

*, **, ***, represents significant at P = 0.05, 0.01, and 0.001 respectively.

whereas NH_4OAc pH 4.8 extractable Al (major portion of both exchangeable and non-exchangeable forms of Al) = NH_4OAc — Al; did not correlate significantly with any of the soil properties. Evans and Kamprath (1970) and Brenes and Pearson (1973) explained that soil solution Al and percentage Al saturation are related in acid mineral soils. This further re-enforced the observation that no exchangeable Al is found in acid mineral soils [⊏ ∠ pH 5.4 and ∠ 7% OM] see McCart and Kamprath 1965, Pratt and Alvahydo 1966 and Cochrane et al 1980].

As we consider the relationship of NH_4OAc—Al, it should be remembered that organic matter complexes Al and convert it to non-exchangeable form as pH increases above 5.6 up to 7.6— and this helps account for the negative relationship of KCl — Al with pH in CPS soils (Jackson, 1963; Pionke & Corey 1967 and Kamprath 1970). Some of the soils properties are related to each other, nonetheless partial correlation analyses have been considered useful in this study by revealing the true picture of the relationships between soil properties tested and extractable Al , as shown in Table 3. Again in CPS soils KCl-Al is significantly related to all soil properties, and NH_4OAc — Al is related to none. Pionke and Corey (1967) determined the active Al-pool or exchangeable Al by substracting KCl-Al from NH_4OAc-Al. They correlated values obtained with soil properties to determine relationship of non-exchangeable Al and soil properties. It appears they assumed NH_4OAc — pH 4.8 extracted both exchangeable and non-exchangeable-Al with KCl extracting only exchangeable Al. In some samples of this study, KCl-Al was found to be higher than NH_4OAc-Al. In such cases no efforts were made to compute values for non-exchangeable Al as Pionke & Corey (1967) did. Even though Juo & Kamprath (1978) used $CuCl_2$ to extract total Al pool, that was considered an over-estimate of liming needs of crops with good degree of Al tolerance, Juo & Kamprath (1979) also obtained similar higher values for KCl-Al than NH_4OAc-Al in series of tropical soils.

The Meander Belt Delta (MBD) soils in Table 1, had higher pH mean of 4.95, with range of 4.3 to 5.6, and with 22.5% clay and average organic matter of 2.40% account for the absence of relationship between KCl-Al with organic matter in contrast to the case with CPS. At high pH values the organic matter provided negative charges which promoted formation of organic complexes — (see Kamprath 1970 and Jackson 1963). The ranges within clay and silt contents in MBD soils are not as

TABLE 3: MULTIPLE REGRESSION OF KCl EXTRACTABLE Al (KCl – Al) AND NH_4OAc EXTRACTABLE Al (NH_4OAc – Al) ON

% CLAY (X_1) % SILT (X_2), % ORGANIC MATTER (X_3), AND pH (X_4)

	KCl – Al						NH_4OAc – Al					
	Partial Regression Co-efficients					R_2	Partial Regression Co-efficients					R^2
	a_0	a_1	a_2	a_3	a_4	a	a_0	a_1	a_2	a_3	a_4	
Coastal Plain Sands – CPS (24 samples)	299	4.19***	2.41***	-38***	-28.9*	0.8387	319	-1.83	1.62	33.0	-40.75	0.1110
Meander Belts MBD (10 samples)	1108	-1.40	3.64	18.52	224***	0.8127	1098	1.48	-0.92	112***	-230***	0.9877

*, **, ***, represent significance at P = 0.05, 0.01 and 0.001 respectively.

$$Y = a_0 + a_1X_1 + a_2X_2 + a_4X_4$$

wide as CPS to produce any significant effects as in CPS. Partial regression analysis (Table 3) showed that only pH effect was statistically significant under both KCl-Al and NH_4OAc-Al in MBD soils.

Relationship of NH_4OAc-Al and soil properties in MBD are very striking the multiple regression equation (Table 3) has a R^2 value of O.9877 showing that about 99% of the variation in NH_4OAc-Al could be explained by the four soil properties. In Table 3, under the MBD, KCl-Al soil pH showed positive relationship (224) but under NH_4OAc-Al the significant relationship with pH is negative (—230) and positive (112) with organic matter. Similar observations were reported for Wisconsin soils (Pionke & Corey 1967). The positive significant relationship of NH_4OAc-Al with organic matter suggest that active Al-pool form is associated with organic matter (Hoyt 1977, Schnitzer & Skinner 1963).

Effect of Lime and Organic Manure additions on Soil Extractable Al

Correlation studies (Tables 2 and 3) have shown that pH and organic matter have strong influence on exchangeable Al, especially Table 2, on KCl-Al in both CPS and MBD soils. Similar influence is observed in MBD soils NH_4OAc-Al forms. Schniztser and Skinner (1963) had also shown that large amounts of easily decomposable manures when added to acid soils will decrease Aluminum concentration in soil solution. This incubation experiment in practical applicability as it would serve, small farms, where supplies of crop residues, livestock manures are plentiful, lime material in limited supply and high priced was demonstrated. One soil each from CPS and MBD to represent the physiographic areas, was selected and amended with organic manure or lime respectively. The results (Table 4) show that lime addition decreased both KCl-Al and NH_4OAc-Al as well as raised the soil pH from 4.80 — 5.45, and 4.90 to 6.05 in the two soils, affirming the correlation results.

Effect of manure addition on soil pH (Table 4) was better than liming, as pH of soil + lime increased from 4.80 — 6.05, for soil + piggrey manure the pH increased from 4.80 to 5.65 over the same period of incubation. Soil + cattle manure had little influence on soil pH of MBD as it only effected small change from 4.90 to 4.95 while MBD organic matter content was raised from 1.8% to 6.0%.

TABLE 4: EFFECT OF LIME AND ORGANIC MANURE ADDITIONS ON EXTRACTABLE Al IN TWO SURFACES SOILS FROM THE TWO GEOPHYSIOGRAPHIC REGIONS*

Treatments	pH (1:1 water) a^x	b^x	Organic Matter (%) a^x	b^x	KCl-Al ppm) a^x	b^x	NH_4OAc-Al (ppm) a^x	b^x
Soil alone	4.80	4.90	2.0	1.8	44.0	43.0	36.3	86.5
Soil + Lime	5.45	6.05	2.1	1.8	10.0	1.0	32.5	52.0
Soil + Piggery Manure	5.50	5.65	6.1	5.9	1.0	0.5	3.5	1.0
Soil + Poultry Manure	5.50	5.60	6.2	5.8	2.0	0.5	3.0	1.5
Soil + Cattle Manure	4.85	4.95	6.0	6.0	35.5	30.5	33.5	45.5

a — Coastal Plain Sands (CPS)
b* — Meander Belts (MBD)

KCl-Al in organic manure amended soils

The poultry and piggery manure respectively Table 4, decreased the KCl-Al in soil Al-pool from 44ppm to 2ppm in the CPS soils and from 43ppm to 0.5ppm in the MBD soils. The soil + cow-manure only decreased the KCl-Al slightly from 44ppm to 35.5ppm and 43ppm to 30ppm in both CPS and MBD soils respectively. The soil + lime mixture came next to piggery and/or poultry manure soil mixtures by decreasing Al concentration in solution from 44 to 10ppm Al in CPS and 43 to 1ppm in MBD similar trend is repeatedly observed under NH_4OAc-Al for various soil mixtures as shown in Table 4. The results show that poultry and piggery manures affect the soils to some extent and can be effective soil amendment materials for improving soil productivity in the tropics.

More future work using partially neutralized poultry and piggery manures to determine the optimum organic matter rates in the management and use of acid soils is needed.

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