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Pedogenic Loss and Uptake of Calcium by Gmelina Growing in an Isohyperthermic Kandiudult

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Abstract: This study evaluated temporal soil calcium loss within the soil and uptake by plants using *Gmelina arborea* form 2002 to 2006 at a watershed in Owerri, Southeastern Nigeria Forty pedons were dug and sampled at a regular grid of 400×400 m while 10 *Gmelina* plants were marked and used for the temporal evaluation of calcium (Ca). Standard analyses were performed on both soil and plant samples. Data obtained were subjected to analysis of variance (ANOVA) and correlation analyses using standard computer software. Results showed significant ($p\leq 0.05$) differences in elemental ratios with depth and time. Leaf Ca also varied significantly ($p = 0.05$) temporally. There were significant positive correlations between soil and plant Ca in 2002 and 2003, non-significance in 2003 while significant negative correlations ($p<0.0001$) in 2005 and 2006.

Key words: Calcium, Kandiudult, pedogenesis, plant uptake, vertical variation

INTRODUCTION

Land degradation is a topical issue, especially in the lowland states of southeastern Nigeria where soil erosion by the agency of water has dissected the landscape. Igwe (2003) identified rainfall as a major component contributing to land degradation. High rainfall amount and duration favour leaching of soil nutrients including calcium from upper horizons to deeper part of the pedon. This translocatory pedogenic loss via leaching was attributed to soil aggregate instability (Igwe, 2000). These losses lead to declining productivity of soils especially in arable agriculture as nutrients are leached away from the rhizosphere. It was also reported (Jandl *et al*., 2004) that deposition of large amounts of atmospheric sulphur and nitrogen promoted loss of calcium in soils of central European forests. The danger in calcium loss is that uptake of some other basic cations, such as magnesium is retarded (Osemwota *et al*., 2003). Despite the ability of trees to extend their taproots to deeper layers of soils, calcium loss has been reported (Huntington, 2000) and Ca deficiency (Rothe *et al*., 2002) showed by plants due to insufficiency of soil exchangeable calcium.

The choice of Gmelina was due to its dominance and use for conservation of the Otamiri river. *Gmelina arborea* is a relatively fast growing tree when compared with most of the indigenous watershed plants. But it was observed that most other plant types associated with these Gmelina-dominated vegetation show a variety of deficiency symptoms. Remarkable deficiency symptoms are exhibited by arable crops cultivated under these trees after seasonal pruning. In line with the above, the study investigated vertical distribution of calcium in soils of Otamiri watershed and related the soil calcium concentration to calcium content of leaves of *Gmelina arborea*.

MATERIALS AND METHODS

The study site is part of Otamiri watershed in Imo State, southeastern Nigeria, lying between latitudes $4°15^1$ and $7°05^1$ North and longitudes $5°50^1$ and $9°30^1$ East. This investigation was conducted from 2002 to 2006 although a reconnaissance part of the study commenced in 2001 in the above watershed in Owerri, Imo State, Southeastern Nigeria. It represents a 70 ha large, 30 year old Gmelina-dominated vegetation. The geology is dominated by deeply weathered coastal plain sands (Benin formation) of the Oligocene-Miocene era. The watershed is a typical humid environment. The average precipitation in the area is 2500 mm with 3 distinct months of dryness, while the average annual temperature ranges from 26-29°C. Soils of the study site are very sandy and acidic and classified as isohyperthermic Kandiudults (Soil Survey Staff, 2003) and correlated to FAO-classification (FAO, 1998) as Dystric Nitisols. Riverside farming is a major socio economic activity.

Since 2002 precipitation was sampled with 20 open thoroughfall collectors with a cross section area of 300 cm^2. The thoroughfall collectors were arranged along a transect at a 2 m interval. Soil solutions were collected fortnightly from June 2001 at the study site at fixed sampling depths of 20 and 100 cm using ceramic suction Iysimetres at a tension of 40 KPa (P-80, Berliner Porzellanmanufaktur, Germany). Twenty replicate Iysimeters per sampling depth were installed, each located adjacent to a throughfall sampler. Forty pedons (soil profile pits) were dug and sampled along a regular grid of 400×400 m. Soil samples were collected from the bottommost pedogenic horizon based on pedogenetic differentiation. Soil samples from each pedon were analyzed individually. Exchangeable cations, namely calcium (Ca); magnesium (Mg), potassium (K), sodium (Na), manganese (Mn), aluminium (Al) and iron (Fe) were estimated by inductively coupled plasma atomic emission spectrometer (ICP-AES) (Integra XMP, GBC, Arlington Heights, IL). Base Saturation (BS) was computed as a sum of exchangeable basic cations divided by CEC (cation exchange capacity). The CEC was determined by percolating 2.5 g of soil with 100 mL of 1 m ammonium chloride for about 4 h. Before percolating the soil sample, samples were soaked with extraction solution overnight. Soil pH was measured using a glass electrode in deionized water (pH_{DDI}) at a soil solution ratio of 1:2.5.

Water extractable sulphate was estimated by 5 sequential batch extractions of moist soil with distilled water at a soil: Solution ratio of 1:5 and sulphate in the extracts were measured by ion chromatography.

The vegetation of the site was dominated by *Gmelina arborea*, thus was used as indicator plant for the study. Leaves were sampled from the upper canopy at the end of the rainy season (October through November) for 2002, 2003, 2004, 2005 and 2006. Leaves from 10 trees were harvested each year, separated according to age and analyzed using composite mixed samples per leaf age and tree. The same tree stands were marked and used throughout the study. Leaf samples were milled after drying at 60°C and 100 mg was digested in 1 mL of 1 M HNO_3 at a temperature of 170°C for cation analysis using ICP-AES.

Data Analysis

Soil data were subjected to analysis of variance (ANOVA) and multiple comparison of means for the experimental period was conducted using the procedure of GLM, Duncan test). Individual statistical analysis of pedogenic horizons was done and differences were considered significant at $p<0.01$. The temporal trend of the Ca concentration in leaves *Gmelina arborea* was calculated as linear regression (procedure REG). Differences between years were tested with a repeated measures analysis of variance (procedure GLM, SAS Institute, 1989). A linear regression was used to relate soil and leaf data. Derived equations were tested for significance by ANOVA with the statistics module of Sigma Plot for Windows 2001 (SPSS Science, Chicago, IL).

RESULTS AND DISCUSSION

Soil Properties

Results on soil chemical parameters are shown in Table 1. Soil horizons were well-differentiated and very deep. Bulk density increased with depth. Soils were strongly to moderately acidic while

Table 1: Selected soil properties of the study site (mean values)

Horizon	Depth (cm)	BD (mg m^{-3})	pH (DDI)	CEC (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	NO_3^- (mg kg^{-1})	SO_4^{2-} (mg kg^{-1})	BS (%)	Alsat (%)
A	0-11	1.31	5.10	11.20	1.60	0.90	113	126	44.00	51.00
E	11-20	1.35	3.60	6.30	0.40	0.60	90	118	24.00	75.00
Bt_1	20-25	1.41	4.90	9.10	0.90	0.30	124	356	54.00	45.00
Bt_2	55-80	1.43	5.30	10.00	2.70	0.40	189	380	58.00	40.00
Bt_3	80-140	1.47	5.60	8.30	2.90	0.60	280	406	60.00	38.00

BD = Bulk Density, CEC = Cation Exchange Capacity, BS = Base Saturation, Alsat = Aluminium Saturation

Table 2: Ratios of exchangeable cations in soils of the study site

Depth (cm)	Ca/Mg	Ca+Mg/Al+H	Ca/Al
0-11	1.77	0.91	0.62
11-20	0.66	0.79	0.43
20-55	3.00	0.83	0.56
55-80	6.75	0.76	0.82
80-140	4.83	0.69	0.88
LSD (0.05)	0.09	0.05	0.06

Table 3: Temporal variability in the distribution cationic ratios (pedon analysis)

	Ratios		
Years	Ca/Mg	Ca+Mg/Al+H	Ca/Al
2002	3.26	0.79	0.94
2003	2.83	0.56	0.62
2004	2.21	0.51	0.44
2005	1.51	0.39	0.36
2006	0.92	0.26	0.29
LSD (0.05)	0.04	0.06	0.03

Table 4: Relationship between some measured parameters of soils with time (n = 200)

Parameters	r	r^2	Level of significant
Ca Vs pH	0.48	0.23	*
Ca Vs SO_4^{2-}	0.67	0.45	*
Ca Vs Mg	0.63	0.39	*
Ca Vs NO_3^-	0.82	0.67	**
Ca Vs Alsat	-0.85	0.77	**
Ca Vs BD	0.15	0.02	NS

**: Significant at p = 0.01; *: Significant at p = 0.05; NS = Not Significant

Cation Exchange Capacity (CEC) was low and showed no defined trend in distribution. Results on CEC and pH are consistent with the findings of Onweremadu *et al*. (2006a). Starting from the eluvial horizon, exchangeable calcium increased with depth while exchangeable magnesium indicated an irregular trend. Base Saturation (BS) increased with depth and the reverse was the case for aluminium saturation (Al_{sat}).

Elemental Ratios

Elemental ratios were used as indicators to infer nutritional balance (Table 2). There were significant reductions ($p = 0.05$) in Ca/Mg and Ca+Mg/Al+H ratios in the vertical distribution of these ratios. Significant ($p = 0.0$) variation in horizon distribution was observed in Ca/Al ratios in the site. In a similar study, Oti (2002) reported a consistent decrease in Ca+Mg/Al+H ratio in the same region.

Temporal Variability

There were significant ($p = 0.05$) changes in elemental ratios with time (Table 3). A statistically significant ($p = 0.05$) decrease was observed during the period from 2002 to 2006 in all the elemental ratios at pedon levels of analysis. With the exception of bulk density (BD), other measured soil parameters had significant correlation with exchangeable calcium (Table 4), especially NO_3 and Alsat. Generally, calcium concentration in leaves of *Gmelina arborea* declined consistently with

Table 5: Temporal variability in elemental chemistry and sufficiency ranking of Ca in levels of *Gmelina asborea*

Years	Ca (mg g^{-1})	Yield ranking
2002	4.71	Clearly above sufficiency threshold
2003	3.90	Slightly above sufficiency threshold
2004	3.16	Slightly below sufficiency threshold
2005	2.61	Clearly below sufficiency threshold
2006	3.76	Clearly below sufficiency threshold
LSD (0.05)	0.08	

Ranking was adapted from the study of Bergmann (1992)

Table 6: Correlation coefficient between Ca-concentration in soils and leaves (n = 50)

Year	Correlation coefficient (r)	Level of significance
2002	0.39	<0.0001
2003	0.45	0.0391
2004	0.51	0.0632
2005	-0.61	<0.0001
2006	-0.72	<0.0001

time (Table 5). However, leaf Ca-concentration was above threshold limit (Bergman, 1992) for 2002 and 2003 years of plant life. Soil Ca had significant positive correlation coefficients in 2002 and 2003 ($p<0.05$) but was statistically non-significant in 2004 (Table 6). Conversely, there was significant negative correlation between both parameters in 2005 and 2006 (Table 6).

Calcium loss in soils of study site was significant ($p\leq 0.05$) as concentrations increased towards the deeper soil horizons. The losses were mainly from the surface and eluvial layers. In the surface layers, plant litter decomposed to release organic acids, such as fulvic acid which aid dissolution and consequent mobility of basic cations including Ca. In the eluvial horizon, leaching losses of soil Ca was permanent. Due to Ca loss, the Ca/Al ratio of E-horizon was least in all the sampled pedons. Soils Ca loss could be attributed to low Ca input and continued leaching of SO_4^{2-} and NO_3^- (Likens *et al*., 1996). The E-horizons were also associated with very high Alsat (mean = 75%), which implies high possibility of aluminium toxicity. High levels of soluble Al concentrations in soils is toxic to plants and becomes a serious productivity constraint when it reaches 60% or more (Styzcen, 1992). This may not be a serious problem to *Gmelina arborea* since it is deeply rooted, suggesting that the roots explore the illuvial Bt-horizons having high concentrations of soil Ca and exchangeable Ca. But for shallow rooted crops, such as maize, which is commonly grown in the watershed, performance may be low except when soil fertility is augmented. This is due to the low Ca/Mg ratio (below 3.00) in the rhizosphere. Earlier, Landon (1984) reported that Ca/Mg ratio below 3 results in the unavailability of Ca and phosphorus. Consistency in Ca/Mg, Ca+Mg/Al+H and Ca/Al ratios is suggestive of using these elemental ratios as indicators of degree of leaching losses in soil Ca in the humid tropics. Highly significant correlations ($p = 0.01$) between soil Ca with NO_3 and Alsat (Table 4) is predictive of the abundance of soil Ca and exchangeable Ca. Concentrations in leaf Ca decreased up to 2005 but increased to 2.76 mg g^{-1} in 2006. This is possibly due to greater ability of Gmelina taproot system to explore deeper horizons for nutrients, while it was unable to trap the translocating soil Ca. It is also possible that Gmelina may have derived part of its Ca-requirement by absorbing soil Ca released directly from parent materials (Jandl *et al*., 2004). However, association of Gmelina roots with mycorrhizal fungi could be beneficial to the plant since these fungi dissolve Ca from Ca-feldspars (Blum *e tal*., 2002). Although these Gmelina plants are having increasing leaf Ca with decreasing soil Ca (Table 6), it is a worrisome trend for arable crops and soil bacterial biomass which suffer soil acidification (Bladodatskaya and Anderson, 1999) and this could be why Onweremadu *et al.* (2006b) suggested the use ground seashells as liming materials on Isohyperthermic Arenic Kandiudult.

CONCLUSIONS

The study showed that leaching is a major pedogenic process influencing the distribution of soil calcium in the site. The Ca/Mg ratios were below 3.00 in surface horizons, indicating their unsuitability for arable agriculture while trees such as Gmelina with taproot system can extend roots to explore deeper layers. As a result of consistency in the results of elemental ratios, they could be used for predicting calcium abundance and exchangeability in the study area.

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