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Nutrient Distribution of GMELINA ARBOREA L. Plantation on the Slopes of UKPON River Forest Reserve of Cross River State, Nigeria

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***Abstracts**: A total of 20 stands (10–28 years) of Gmelina arborea plantations in Upper and Lower slopes of the Ukpon river forest reserves, Cross River State, Nigeria, was used to investigate the effect of Gmelina arboreaplantation development on site nutrients and nutrient accumulation. The size and age of trees did not significantly affect nutrient concentration in tree components. Nitrogen, Ca and Mg contents in tree tissue increased in the order of foliage >stem >branches while that of K and P increased in the order of foliage >branches >stem. Tree tissue nutrients concentration exhibited little change with stand development. Stand nutrient accumulation followed the same trend as standing biomass, with about 80% of each nutrient stored in the stem and 20% in branches and foliage. The accumulation of nutrients in stem, branches and foliage followed the order: Mg >N >Ca >P >K >Na. Though soil nutrients were slightly depleted between 10 and 19 years and re-built up afterwards, the overall effect of stand development on soil nutrients was not statistically significant, implying that the development of Gmelina arboreaplantations did not adversely affect the soil nutrient status. Consequently, productivity during the next rotation will most likely be affected by harvesting methods of current stands and management practices of the next rotation. The 20% accumulation of aboveground nutrients in branches and foliage implies that apart from the already replenished site nutrients, there will be an additional 20% nutrient input into the soil if the branches and foliage are left on the site after harvest. For long-term site quality and sustainability of production, successive plantations should be managed on 25 years rotation as lower rotation will most likely lead to steady depletion of site nutrients.*

***Keywords:** Forest plantation; Gmelina arborea; Nutrient accumulation; Soil management; Nutrient cycling; Biomass*

I. Introduction

Globally, the area of forest plantations has witnessed a phenomenal growth since the middle of the 20th century, especially within the past three decades (Pandey, 1987; Evans, 1998; Carnus et al., 2003; Evans and Turnbull, 2004). For example, the global forest plantation estate increased from 17.8 million ha in 1980 to 43.6 million ha in 1990 and from 124 million ha in 1995 to 187 million ha in 2000 (FAO, 1992; Pandey, 1995; Evans, 1998; FRA, 2000). This represents an increase of about 95% within 20 years (1980 and 2000).

Forest plantations possess the capacity of producing between 3 and 10 times greater commercial biomass (timber) per ha than natural forests (Pandey, 1995; Evans, 1999a; Evans and Turnbull, 2004). For example, while the maximum m,$^{-1}$earn annual volume increment (MAI$_v$) in a natural tropical forest in Nigeria is 5m^3 ha^{-1} year^{-1}that of an adjacent *Nauclea diderrichii* (indigenous species) and *Gmelina arborea* (exotic species) plantations are 16 and 51m^3 ha^{-1} year,$^{-1}$ respectively (Lowe, 1997; Onyekwelu, 2001). Some plantation species (e.g. *Eucalyptus spp., Acacia mangium, G. arborea, Pinus caribaea* and *Pinus oocarpa*) have MAI between 30 and 55m^3 ha^{-1} year^{-1} (FAO, 2001b; Onyekwelu, 2001; Evans and Turnbull, 2004). This high productivity of tropical forest plantation species has contributed to making them very important in meeting the world's growing demand for wood products, especially industrial wood (FAO, 2001a). Recent estimates reveal that 34% of global industrial wood is sourced from forest plantations. The contribution of forest plantations to global wood supply is expected to increase in the next decades due to increasing rate of plantation establishment and re-establishment.

Understandably, this high growth rate and productivity of forest plantation species imply high demand on the nutrient base of the site, since actual stand productivity is determined by how well trees capture site resources. This is the anchor of the concern of biological sustainability or otherwise of forest plantations, which has been an issue of wide interest and a subject of much debate. For example, report of 30% yield decline in second rotation *P. radiata* plantations in Australia emerged in the early 1960s (Keeves, 1966) cited in (Evans, 1999a) and (Khanna, 1998) noted that repeated loss of nutrients from site during site preparation and in harvested *Eucalyptus* and *Acacia* wood adversely affected soil fertility and long-term productivity. Contrary to the above observations, (Stewart et al. 1985) noted no loss of productivity in *Eucalyptus* stands while (Evans, 1998) concluded that plantation forests are likely to be sustainable in terms of wood yield provided that good practices are maintained. However, much of the concern about sustainability of production in forest plantations focuses on the question of depletion or improvement of the nutrient status of the site, especially during the second and subsequent rotations. Kimmins (2004)showed that the nutrient capital of a forest ecosystem can be restored to its original status, provided that whole tree harvesting is not practiced and the forest ecosystem is managed on a long rotation. Thus, for plantation to be sustainable it will mean no significant depletion of adsorbed stores of base cations, depletion phosphorus and that the C/N ratio stays constant. In other words, no noticeable negative changes in the soil physical, chemical and biological conditions. Evans (1999b)identified two approaches usually adopted in assessing these changes: (1) observational—which compare sites in carefully matched pairs or observe changes over time on the same site (chronosequences) and (2) deductive—by modelling ecosystem dynamics such as the nutrient budgets, followed by testing theory with field experimentation. The former is more widely used and will be adopted in this investigation, which aims to assess soil physical and chemical conditions of G. arborea monoculture plantations in Ukpon RiverForest Reserves Cross River State, Nigeria, as well as stand productivity and nutrient storage in different tree components in Gmelina plantations at different slopes.

II. Materials And Methods

Study Area: The study was carried out in Ukpon River Forest Reserve, in Obubra local Government Area of Cross River State, Nigeria. It lies on latitude $5^0 57^l$ N and longitude$8^0 28^l$ E, with a total area of 129.50km^2 (12950 hectares). It was declared a forest estate by government gazette order 56 of 1930 (Annon, 1985) and is managed by the Cross River State Forestry Commission. The annual rainfall of the area ranges between 2000-2500mm, with eight (8) months duration which starts from late march to late October (Udo,R.K. 1986). The annual temperature ranges from 23.2^{0}C in July to 33^{0}C in February; strong wing usually marks the on-set of dry season which is caused by Northeast wind which is hot and dry. The reserve lies within lowland rainforest with fresh water swamp at the fringes of Ukpon River and derived savanna north of the reserve. The floristic composition is highly heterogeneous in nature. The savanna areas are believed to have been derived from moist evergreen forest by a process of degradation which arises through farming activities and annual grass fiber. It is also possible that the vegetation type reflects soil condition to some degree (Greaves, 2003). Some common shrubs, herbs and grass found within the vegetative area includes *Lophira lanceolata, Erythrophyleum sauvaeolens, Daniela oliverii, Fagara zynthoxyloids, Steriulia trangancantha, Scotellia* and *Anthocleistra spp. Heymenocardia acida, Penisetum spp. Hyperthenia* and *Athropogen spp.* for the tree species they includes *Ricinodendron spp., Terminalia spp., Triplochiton scleroxylon, Sterculia spp., Pterocarpus spp., Khaya ivorensis, Chlorophora excelsa, Garcinia cola, Chrystophyllum spp., Astonia spp., Ceiba petandra, Gambia albidium*etc. The soil have been developed on sedimentary rocks mostly unconsolidated sand and sandstone, flats to gently rolling country, slopes 1-3%, brown, reddish and brown and red ferralitic sands (Nsor, M. E. 2011). Vine (1956), in a description of the deep, porous, well drained, non mottled and non concretionary reddish brown soils which covers much of the area, noted that the topsoil are usually moderately acidic in cultivated forest or savanna and the sub-soil strongly acidic (pH 4.66) and deficient in plant nutrient. The area is gently sloping with an average height of 709.9m to 1350m above sea level. A low ridge runs on the southern portion of the southern border of the reserve. It drains northward into the river cross and westward into the Ukpon River.

Field data collection: A total of 20 age series of *Gmelina arborea* stands were selected for this study, along the slopes of gradient 206m to 709.0m above sea level. The chosen plantations were divided into 22.5m x22.5m (about 0.05ha) temporary sample plots, from which two sites were randomly selected, making a total of 30 plots per study site and60 for this study.A6m x 6m sub-plot was laid at the center of each sample plotfor soil sample collection. Each sub-plot was divided into 2mgridlines and soil samples collected from any three of the fourmeeting points of the gridlines. With reference to Smyth andMontgomerry (1962), soils samples were collected at four fixeddepth of 0–15, 15–30, 30–45 and 45–60 cm, using a soil augerof 7.5 cm in diameter. The first depth (0–15 cm) consisted ofthe thin O horizon and part of A horizon with the second depth(15–30 cm) accounting for the remaining part of the A horizon,while the third and fourth depths (30–45 and 45–60 cm)corresponded to B and C horizons, respectively. Soils fromsimilar depths within each plot were thoroughly mixed, fromwhich composite samples were collected and labelled. Samplesfor bulk density determination were only collected from 0 to15 cm depth, using a sharp-edged steel cylinder (4.8 cm highand 5.6 cm diameter), which was forced manually into the soil.Due to the absence of pre-planting soil data, it was decided tocollect soil samples from adjoining natural forests, which haveremained relatively undisturbed since the commencement ofplantation establishment in Ukpon river forest reserves.These served as control and were used for the purpose ofevaluating the possible changes undergone by soil of the studysites due to plantation establishment. As much as possible, soilsamples (in the study sites) were only collected from sites thatare free of rock outcrops, with relatively flat ground(elevation ≤ 100 m), and with good drainage.

Laboratory analyses of soil samples:Prior to analyses, soil samples were air-dried, ground in aWiley mill to pass through a 2mm sieve. Particle size analysis was performed using the hydrometer method, with sodium hexameta-phosphate (Calgon) as dispersing agent (Black et al., 1965). The USDA particle size classes classification viz. sand(2.0–0.05mm), silt (0.05–0.002mm) and clay (<0.002mm) were followed in expressing the particle size fractions of soils. Soils were assigned into textural classes with the aid of textural triangle. After drying the core cylinder samples at 105^0C for two days, soil bulk density was calculated as the ratio of oven dry weight of soil (Mg) to the cylinder volume (m^3). Soil pH was determined with a digital pH meter using 1:2 soil/water solutions. Organic carbon content was estimated using Walkley and Black method (Walkley and Black, 1934). Organic matter was obtained by multiplying organic carbon content by a conversion factor of 1.724. Samples for total N determination were digested using micro Kjeldahl method with selenium catalyst (Bremner, 1965). The digested samples were distilled after addition of sodium hydroxide and the ammonia thus released was determined by simple acid–base titration. Due to the suitability of the molybdenum-blue method for samples of low P content, the method was used for available P determination. Extracts for available P were prepared using ammonium fluoride and the blue color was developed using ascorbic acid and Murphy and Riley solution (Murphy and Riley, 1962). For exchangeable cations determination (Ca, Mg, K and Na), soil samples were first leached with 1N ammonium acetate solution (pH 7.0). Available Ca and Mg were determined by atomic absorption spectrophotometer (AAS), while available Na and K were determined by digital flame photometry.The bole, branch and leaf samples were oven dried to aconstant weight at 80 ^{0}C and ground to pass through 2mm sieve. After sieving, the three stem samples were bulked together before nutrient analyses. Total N concentration was determined by the micro Kjeldahl method on a Technicon Auto-analyser II. Following nitric acid digestion, the concentrations of Ca and Mg in the digest were determined by AAS while K and Na were determined by digital flame photometry (Black et al., 1965; Lemenih et al., 2005). Phosphorus content was determined using ammonium molybdate blue method. Nutrient accumulations in tree components (stem, branch and foliage) were obtained as the product of each tree component biomass and the average nutrient concentrations in that component. Nutrient accumulation was then extrapolated to per ha basis by multiplying with the standing biomass per ha of each component.

III. Results:

Soil physical and chemical properties:Sand content of Gmelina arborea plantation sites of Upper and Lower slopes of Ukpon river forest reserves decreased with increase in soil depth, while clay and silt contents indicated a reversed trend (Table 1). At similar depth, sand, clay and silt contents of the soils in the two plantation sites were comparable. For example, at 0–15 cm depth, sand, clay and silt contents ranged between 63.9–71.7, 19.3–25 and 9.0–11.3%, respectively, across the different plantations at the Upper slopes while they varied between 60.5–76.5% (sand), 14.6–27.6% (clay) and 6.6–12.9% (silt) in the stands at the Lower slopes. These comparable results at 0–15 cm soil depth were also found to exist in other soil depths in both sites (Table 1). Except 45–60 cm depth at the Lower slopes, where a significant difference was found to exist between the silt contents of different age series, particle sizes (sand, clay and silt contents) at similar depth were not significantly different between the different stands in both Upper and Lower slopes (Table 1). The sand and clay contents of the soils of both sites indicated that soil texture is sandy loam to sandy clay loam, especially to the depth of 30 cm, beyondwhich texture tended towards sandy clay.Soil bulk density was found to vary from 1.41 to 1.56 Mg m^{-3}in the Upper slope and from 1.43 to 1.59 Mg m^{-3} in the Lower slope and showed no significant difference ($p> 0.05$) across the various ages in both plantation sites (Table 1).The soils of both reserves could be described as neutral to slightly acidic (pH range of 7.2 and 6.0 in the Upper slope and 7.1 and5.7 in the Lower slope of the plantation), with the soil becoming increasingly acidic as one digs deeper (Table 2), implying that sub-soil is more acidic than topsoil. The pH of similar soil depths were not statistically significant ($p> 0.05$) between the different plantations in both sites (Table 2). Except exchangeable Na, which increased with increasing soil depth, all other exchangeable cations (K, Mg and Ca), available P, total N as well as organic matter contents generally decreased with increasing soil depth (Figs. 1 and 2, Table 2). Figs. 1 and 2reveal that concentration of P, K, Mg, Ca, N as well as organic matter had similar developmental trends in Gmelina arboreastands at the Upper and Lower slopes.

Discussion: Although the entire Upper and Lower slope of the forest reserves were designated for forest plantation establishment, a considerable portion has remained under natural forest condition till date. Some sections of these natural forests have remained relatively undisturbed, with no case of encroachment, timber exploitation activities or deforestation reported (Onyekwelu et al., 2005). Consequently, we assumed that if Gmelina plantations had not been established, its site conditions will most probably be the same as that of the natural forest. This assumption was necessary as pre-planting soil data for both study sites was not available. The absence of pre-planting soil data necessitated the use of natural forest soil data as baseline soil data/control for the purpose of evaluating the effect of plantation development on site nutrients. Tropical rainforest soils are typically nutrient-poor, as a result most of the nutrients in the soils are held in the living organisms, especially in the above aground components. Because nutrients are swiftly leached by heavy precipitation, tropical rainforests have developed very efficient nutrient cycling system, aided by the warm and moist conditions in the forest, which are ideal for breaking down organic materials. This rapid decomposition of organic materials (Nwoboshi,2000) result to very thin or totally absent O horizon (litter andhumus layer) as was the case in the plantation sites in this study. Following decomposition, carbon and oxygen in the decomposing material are returned to the atmosphere, while N, P, K, Ca, and other nutrients are returned to the soil. The decreasing trend of nutrients concentrations and organic matter content as one digs deeper into the soil of the study sites is an indication of nutrient richer upper soil horizons (A and E) than lower ones (B and C). This is to be expected since the upper horizons(especially the A horizon) is the place of accumulation and decomposition of mineral and organic matter as well as incorporation of decomposed organic and mineral matter into the soil (FAO, 1998). The rapid decomposition and concentration of organic and mineral matters in the upper soil horizons is explained by the active presence and activities of decomposers (e.g. earthworms) in this zone as well as the warm and moist conditions under tropical rainforests.The slightly lower soil nutrient concentrations in young and middle-age forest plantations than natural forest site is an indication of slight depletion of nutrients in these plantations while the similarity of soil nutrients of natural forest sites and that of old-aged plantations reveal the ability of *Gmelina arborea*plantations to replenish its site nutrients at old age. This slight decrease of nutrients in young and middle-age plantations and subsequentbuild up in older ones indicated by Figs. 1 and 2is consistentwith reports in literature. It has been pointed out that the years preceding canopy closure in forest plantations are characterized by major shift of nutrients from soil to tree biomass but subsequent to this, efficient internal re-use of nutrients means that there can be a rapid recharge of soil exchangeable nutrients (Attiwill, 1979; Miller, 1995, both cited in Evans, 1999b), which describes the observed trend in the study sites. The implication of the results is that if the plantations had been harvested for pulpwood after 10–12 years as previously planned, depletion of site nutrient resources would have resulted. This ‘‘failure’’ has therefore translated to a ‘‘win situation’’ for the site. This result is in consonance with the view of Kimmins (2004), who observed that stands managed on long rotations have the ability of restoring site nutrients to their original levels. The period of slight depletion in soil nutrient concentrations coincides with the period of active growth (i.e. higher MAI) while the period of build-up coincides with that of growth recession in *Gmelina arborea*plantations in both sites (Onyekwelu et al., 2003). It has been demonstrated that the overall long-term response of soils to deforestation and subsequent conversion to agricultural lands in the tropics is decline in soil quality with increase in age (Islam and Weil, 2000; Lemenih et al., 2005). However, this does not appear to be the case with forest plantation establishment as demonstrated by our results. Though, the nutrients of the soils of young and middle-age plantations were generally slightly lower than those of older plantations and that of natural forest sites, no significant difference existed in soil nutrient concentrations of plantations of different ages, thus implying that plantation development in the study areas has no significant adverse effect on their soils. The nutrient status of the site has not been depleted to the extent that decrease in productivity during the next rotation would be anticipated. These findings agree with a host of others, with some reporting improvement in soil properties as the plantations advanced in age (Chijioke, 1980; Trouve et al.,1994; Mishra et al., 2003; Swamy et al., 2004). Trouve et al.(1994)found a progressive increase in organic matter under Eucalyptus spp. plantations in Congo DR while Chijioke (1980)and Swamy et al. (2004) reported a significant improvement insoil nutrients status under *Gmelina arborea* plantations in Nigeria andIndia, respectively. Even without additional nutrient inputduring a single rotation, Gmelina does not appear to exhaust thenutrient base of its site. Nwoboshi (1987 cited in Nwoboshi, 2000) revealed that out of the total site nutrient stock of 2771,412, 5782 and 2124 kg ha^{-1} of N, P, K and Ca, respectively,average nutrient requirement for *Gmelina arborea* in one rotation is 960,371, 2425 and 615 kg ha^{-1} of N, P, K and Ca, respectively.

IV. Conclusion

The continued growth of Gmelina arboreaplantations in both sites of the Upper and Lower slopes, for about three decades has not adversely affected soil properties. Though an initial depletion of soil nutrient pool was observed, there was a build up (recharge) in older stands. Since the plantations did not adversely affect soil nutrient status, productivity during the next rotation will most likely be affected by harvesting methods of current stands and management practices of the next rotation. However, for site nutrient pool in the next rotation to be maintained at the original level, whole tree method should not be used in harvesting current stands. Apart from the nutrient built-up in older stands, an additional 20% of aboveground nutrient accumulation will be available for next rotation if the branches and foliage are left on the site after harvesting, which could be improved upon by debarking the harvested stems on the site. To ensure long-term site quality and sustainability of production, successive plantations should be managed on longer rotation 25 years. If the rotation age is not extended to 25 years, successive plantations will most likely lead to steady depletion of site nutrients, which will make intensive and expensive site fertilization unavoidable if the high productivity of the species is to be maintained.

Table 1: Soil physical properties of Gmelina arborea plantations in Upper andLower slopes of Ukpon river forest reserves

Plantation age (years)
Remark

10 11 121416 1921 232528
Upper slope forest reserve
Sand content (%)
0–15 63.9 ±13.2 67.5 ±2.868.1 ±6.5 71.7 ±4.3 70.5 ±1.0 64.8 ±0.7 70.7 ±2. 6 7.9 ±5.9 65.9 ±6.2 66.1 ±2.8 ns
15–30 58.1 ±12.1 61.5 ±2.8 64.2 ±2.2 65.5 ±7.5 67.9 ±3.761.9 ±0.560.7 ±2.1 68.5±5.1 63.5 ±4.2 61.9±3.0 ns
30–45 55.8 ±7.4 58.0 ±7.8 56.7 ±19.6 63.2 ±6.5 61.9 ±6.662.1 ±1.1 57.2 ±12.6 63.1 ±4.2 54.5 ±1.3 58.1±5.7ns
45–60 52.1 ±2.2 53.9 ±9.3 53.8 ±7.1 58.8 ± 10.660.9 ±6.651.1 ±1.2 53.3 ±7.155.2 ±1.2 47.1 ±10.5 52.3 ±2.5 ns
Clay content (%)
0–15 25.0 ±6.3 21.6 ±1.4 22.0 ±6.6 19.3 ±5.6 19.3 ±2.9 25.2 ±0.5 19.7 ±3.7 20.7 ±0.9 24.4 ±7.1 24.7± 0.9 ns
15–30 29.0±6.125.4 ±4.625.0 ±8.0 23.3 ±5.5 21.3 ±2.8 27.0 ±3.4 29.2 ±2.6 22.3 ±1.5 26.9 ±3.5 28.5±1.2ns
30–45 31.1 ±3.2 28.4 ±3.1 30.4 ±10.7 25.4 ±5.7 23.6 ±2.5 26.3 ±4.3 32.4 ±7.1 26.4 ±1.4 30.5 ±7.3 29.0 ±0.5 ns
45–60 33.4 ±5.8 31.6 ±9.8 31.9 ±6.4 27.3±5.6 24.4 ±1.4 33.4 ±4.5 34.2 ±3.1 30.1 ±6.0 38.3 ±8.6 33.4 ±3.0 ns
Silt content (%)
0–15 11.2 ±7.0 10.8 ±1.4 9.9 ±0.1 9.0 ±1.3 10.1 ±2.910.0 ±0.6 9.5 ±3.8 11.3 ±6.8 9.8 ±0.9 9.1 ±3.6 ns
15–30 12.9 ±6.0 13.1 ±1.8 10.8 ±4.2 11.3 ±2.0 10.8 ±6.5 11.1±3.8 10.1 ±0.5 9.2 ±6.6 9.6±7.8 9.6 ±4.2 ns
30–45 13.1 ±4.2 13.5 ±4.7 13.0 ±6.9 11.5 ±0.9 14.6 ±4.0 11.5 ±4.4 10.5 ±5.5 10.6 ±2.8 15.0 ±8.6 12.9 ±6.2 ns
45–60 14.5 ±8.0 14.5 ±0.6 14.3 ±0.7 13.9 ±5.0 14.8 ±5.1 15.6 ±3.3 12.6 ±4.0 14.7 ±7.3 14.6 ±4.9 14.3 ±5.4 ns
Bulk density (Mg m-^{3})
0–15 1.56 ±0.15 1.42 ±0.23 1.46 ±0.22 1.42 ±0.31 1.47 ±0.19 1.44 ±0.20 1.51±0.13 1.41±0.28 1.42±0.05 1.41 ±0.16 ns

Plantation age (years)
Remark

11 13 1516 19 20 21 24 25 26
Lower slope forest reserve
Sand content (%)
0–15 72.1 ±1.4 70.2 ±6.4 76.0 ±4.9 60.5 ±24.0 69.6 ±7.1 70.4 ±1.4 70.6 ±12.7 67.5 ±8.5 70.2 ±2.876.5 ±5.4 ns
15–30 62.5 ±7.1 61.5 ±2.8 67.2 ±5.7 56.0 ±12.0 65.5 ±11.3 65.8 ±8.5 60.5 ±15.6 58.6 ±7.1 62.8 ±8.560.5 ±9.9ns
30–45 57.3 ±5.7 60.0±0.7 54.5 ±4.2 53.6±2.8 60.0 ±10.6 58.5 ±9.9 60.4 ±15.6 51.1±0.7 58.5±4.2 58.5 ±9.9 ns
45–60 55.9 ±2.8 53.2 ±3.1 56.3 ±7.1 46.9 ±7.1 54.5 ±18.4 56.5 ±14.7 54.3 ±4.2 49.5 ±4.2 48.1 ±6.4 49.4 ±7.1 ns
Clay content (%)
0–15 18.9 ±8.5 18.6 ±4.0 15.1 ±3.5 27.6 ±18.4 19.5 ±11.316.7 ±2.8 22.8 ±14.1 21.6 ±9.9 19.7 ±5.7 14.6 ±2.8 ns
15–30 29.6 ±1.4 20.6 ±8.5 18.9 ±5.7 28.6 ±19.8 21.6 ±9.9 23.5 ±9.9 24.6 ±11.3 29.4 ±7.1 25.5 ±2.8 27.1 ±4.9 ns
30–45 34.9 ±0.7 20.6 ±1.4 24.6 ±9.3 31.8 ±1.4 24.8 ±7.1 26.6 ±11.3 25.7 ±7.1 34.6 ±2.8 29.6 ±7.1 28.1±6.2 ns
45–60 35.5 ±4.2 27.0 ±3.1 21.7 ±7.1 34.4 ±8.527.6 ±18.4 27.6 ±13.0 29.8 ±7.1 33.6 ±1.4 35.6 ±9.9 32.7 ±1.4 ns
Silt content (%)
0–15 8.9 ±7.1 11.2 ±3.1 8.8 ±1.4 11.8 ±5.7 10.9 ±4.2 12.9 ±4.2 6.6 ±1.4 10.9 ±1.4 10.1 ±2.8 8.8 ±1.4 ns
15–30 7.8 ±5.7 17.8 ±5.7 13.9 ±0.715.3 ±7.8 12.8 ±1.4 10.7 ±1.4 14.8 ±4.2 12.0 ±0.7 11.7 ±5.7 12.3 ±4.9 ns
30–45 7.8 ±4.9 19.3 ±2.1 20.8 ±7.1 14.6 ±4.2 15.3 ±8.4 14.8 ±3.1 13.9 ±8.5 14.3 ±3.5 11.8 ±3.1 13.3 ±4.9 ns
45–60 8.6 ±1.4 19.8 ±2.0 21.9 ±0.7 18.7 ±1.4 17.8 ±0.7 15.8 ±3.6 15.9 ±2.8 16.8 ±2.8 16.3 ±3.5 17.9 ±5.7*
Bulk density (Mg m^{-3})
0–15 1.44 ±0.09 1.45 ±0.15 1.47 ±0.13 1.44 ±0.31 1.43 ±0.15 1.50 ±0.29 1.55 ±0.07 1.49 ±0.03 1.45 ±0.17 1.44 ±0.19 ns

Values are means on three replicates _ standard deviation of the mean; ns: not significant at p >0.05.
* Significant at p <0.05.

Table 2: pH and sodium concentration of Gmelina arborea plantation sites in Upper and Lower slope of Ukpon river forest reserves

	Plantation age (years)										Remark
	10	11	12	14	16	19	21	23	25	28	
Upper slope forest reserve											
pH											
0–15	7.2 ±0.07	7.3±0.53	6.9 ±0.90	7.3 ±1.63	7.2 ±0.53	6.8 ±0.15	6.9 ±0.81	7.1 ±0.70	7.4 ±0.74	6.8 ±0.75	ns
15–30	7.0 ±0.93	7.1 ±0.68	6.8 ±0.58	6.3 ±0.35	6.9 ±0.95	6.5 ±0.35	6.5 ±0.70	6.7 ±0.46	7.3 ±0.42	6.4 ±0.50	ns
30–45	6.9 ±0.57	6.9 ±0.43	6.8±0.54	6.2 ±0.45	7.0 ±0.54	6.1 ±0.33	6.5 ±0.97	6.7 ±0.89	7.0 ±0.23	6.4 ±0.39	ns
45–60	6.8 ±0.78	6.9 ±0.50	6.6 ±0.67	6.2 ±0.56	6.8 ±0.12	6.0 ±0.34	6.3 ±0.80	6.7 ±0.53	6.3 ±0.05	6.3 ±0.45	ns
Exchangeable sodium (cmol kg-^{1})											
0–15	0.24 ±0.04	0.23 ±0.02	0.26±0.02	0.24 ±0.04	0.21 ±0.07	0.27 ±0.05	0.25±0.04	0.25 ±0.06	0.21 ±0.01	0.27 ±0.03	ns
15–30	0.21 ±0.03b	0.24 ±0.04ab	0.28 ±0.01a	0.26 ±0.06ab	0.25±0.02ab	0.28 ±0.01ab	0.27±0.04ab	0.23±0.01b	0.25±0.01ab	0.30±0.03a	*
30–45	0.25 ±0.08	0.27 ±0.10	0.28 ±0.02	0.26 ±0.01	0.27±0.02	0.28 ±0.12	0.28 ±0.04	0.27 ±0.01	0.27 ±0.07	0.30 ±0.02	ns
45–60	0.28 ±0.01	0.27 ±0.02	0.29 ±0.04	0.30 ±0.05	0.28 ±0.04	0.31 ±0.08	0.30 ±0.07	0.29 ±0.04	0.28 ±0.02	0.32 ±0.01	ns

	Plantations age (years)										Remark
	11	13	15	16	19	20	21	24	25	26	
Lower slope forest reserve											
pH											
0–15	6.61±0.29	6.73 ±0.20	7.13 ±0.36	6.68 ±0.21	7.06 ±0.18	7.10 ±0.21	6.87 ±0.11	6.68 ±0.38	6.58 ±0.04	6.65 ±0.35	ns
15–30	6.57±0.04	6.34 ±0.18	6.66 ±0.16	6.30 ±0.91	7.00 ±0.32	6.62 ±0.76	6.49 ±0.26	6.70 ±0.51	6.02 ±0.38	6.33 ±0.26	ns
30–45	6.43 ±0.21	6.41 ±0.21	6.04 ±1.53	6.24 ±0.35	6.82 ±0.40	6.72 ±0.26	6.42 ±0.01	5.81 ±1.05	6.06 ±0.22	6.21 ±0.18	ns
45–60	6.17 ±0.66	6.25 ±0.73	6.17 ±0.09	6.20 ±0.21	6.59 ±0.45	6.14 ±0.54	6.16±0.06	5.66±0.45	5.91 ±0.30	6.28 ±0.49	ns
Exchangeable sodium (cmol kg-^{1})											
0–15	0.35 ±0.04	0.38 ±0.04	0.40 ±0.01	0.41 ±0.01	0.42 ±0.01	0.40 ±0.11	0.38 ±0.01	0.38 ±0.04	0.40 ±0.01	0.41 ±0.03	ns
15–30	0.40 ±0.08	0.39 ±0.03	0.37±0.02	0.43 ±0.03	0.45 ±0.05	0.43 ±0.10	0.41 ±0.01	0.40 ±0.05	0.41 ±0.09	0.42±0.01	ns
30–45	0.41 ±0.04	0.39 ±0.01	0.43 ±0.01	0.44 ±0.01	0.43±0.06	0.44 ±0.10	0.42 ±0.02	0.40 ±0.04	0.44 ±0.06	0.42 ±0.04	ns
45–60	0.41 ±0.07	0.42 ±0.03	0.43±0.01	0.48 ±0.17	0.46 ±0.04	0.47±0.05	0.43 ±0.06	0.43 ±0.06	0.45 ±0.07	0.44±0.01	ns

Each value is the mean of three replicates ±standard deviation of the mean; ns: not significant at p >0.05. Values followed by similar letters (a and b) are not significantly different (p≤0.05).
* Significant at p <0.05.

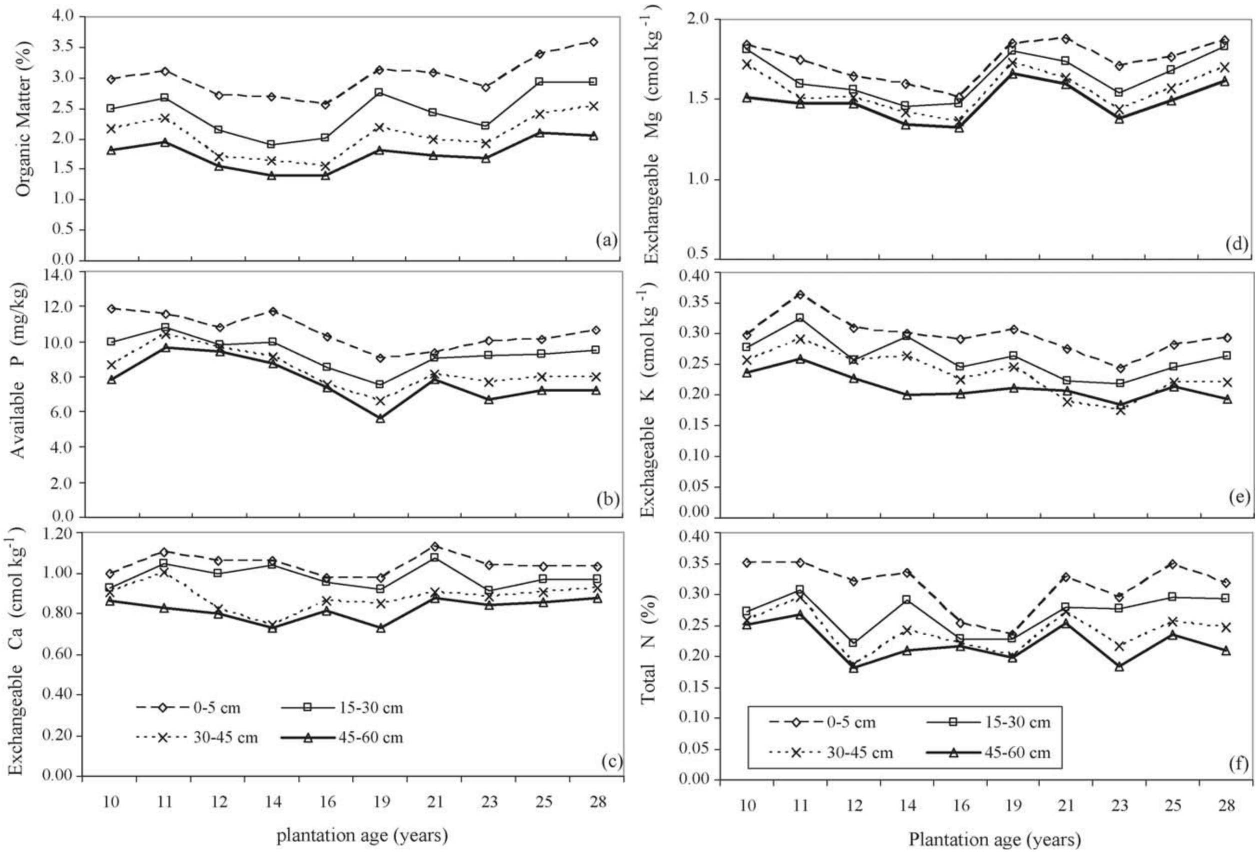

Fig. 1. Chemical properties of the soils of Gmelina arborea plantations at the Upper slope of Ukpon river forest reserve: (a) organic matter,
(b) available phosphorus, (c) exchangeable calcium, (d) exchangeable magnesium, (e) exchangeable potassium and (f) total nitrogen.

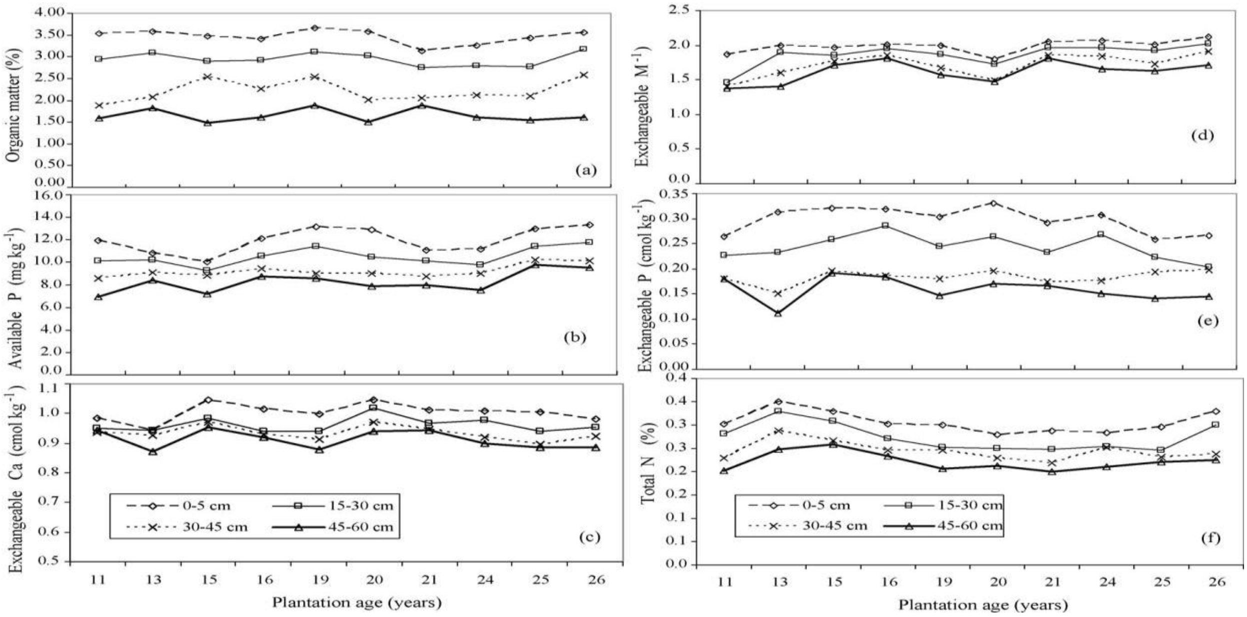

Fig. 2. Chemical properties of the soils of Gmelina arborea plantations at the Lower slope of Ukpon river forest reserve: (a) organic matter, (b) phosphorus, (c) calcium, (d) magnesium, (e) potassium and (f) nitrogen.

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