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PHYSICO-CHEMICAL PROPERTIES OF TOPSOIL UNDER INDIGENOUS AND EXOTIC MONOCULTURE PLANTATIONS IN OMO BIOSPHERE RESERVE, NIGERIA

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Abstract

Sustainable management of soil in plantations to a large extent depends on a thorough understanding of the trend and dynamics of soil properties under them. This study evaluated selected physico-chemical properties of topsoil under monoculture plantation of an indigenous tree species - Nauclea diderrichii, and those of four exotic tree species – Theobroma cacao, Gmelina arborea, Pinus caribaea and Tectona grandis, located in Omo Biosphere Reserve, Ogun State, Nigeria. Percentage sand, silt and clay did not vary significantly ($p > 0.05$) among monoculture plantations at the 0-5 cm depth while significant variations were observed at lower soil depths in some of the plantations. Iron, Zinc, Copper and Manganese varied significantly ($p < 0.05$) among monoculture plantations. Zinc and Copper were highest in Gmelina arborea Plantation at the 0-5cm depth, while Iron and Manganese were highest in Theobroma cacao and Nauclea diderrichii Plantations respectively at the same depth. Organic matter and total nitrogen varied significantly ($p < 0.05$) among plantations and were highest in Theobroma cacao, Tectona grandis and Nauclea diderrichii at the 0-5, 5-10 and 10-15cm depths respectively. Available phosphorus varied significantly ($p < 0.05$) among plantations and was highest in Nauclea diderrichii, Theobroma cacao and Gmelina arborea at the 0-5, 5-10 and 10-15cm depths respectively. Indices of change (%) based on average values of soil properties for the three sampled depths revealed a degradation of organic matter, total nitrogen, available phosphorus, potassium, sodium, iron, and pH in most of the exotic plantations, while calcium, zinc, copper and manganese improved except in Pinus caribaea plantation. The use of Nauclea diderrichii for plantation establishment and taungya farming in the reserve is recommended for soil conservation.

Key Words: *Monoculture, indigenous species, exotic species, Omo, soil properties*

Introduction

Sustainable forest management demands a thorough knowledge of the impact of land use practices on soil properties. All the vital properties of soils more or less influence the nature of the vegetation, both natural and man-made and *vice versa* (Aweto 1981, Verma *et al*. 1982, Hornung 1985, Kadeba and Advayi 1985, Lescure and Boulet 1985). Studies in the tropics have shown significant changes which affect soil fertility following conversion of natural forest into cultivation (Brown and Lugo 1990, Dominy *et al*. 2002). According to Lepsch *et al*. (1994) and Yimer *et al*. (2007), forested lands converted into cultivated areas in tropical regions undergo important changes in soil properties such as decrease in pH, exchangeable cations, etc.

Litters play a fundamental role in the nutrient accumulated in the upper- most layer of the soil (Singh 1971). Following canopy closure of trees up to the time of final felling, the tree crop and its ecological characteristics exert a dominant influence on soil and nutrient dynamics along with the management practices. According to Emadi *et al*. (2008), the most relevant parameter for soil organic matter building up could be the amount of standing litter on the soil which integrates litter fall and decomposition.

Although a number of studies on soils under different land use and land cover types had been conducted (Evans 1976, Chijioke 1980, Singh 1985, Allen 1986, and Chima *et al*., 2009), no study has been conducted to evaluate and compare topsoil properties under monoculture plantations of indigenous and exotic tree species in Omo biosphere reserve. This study examined selected soil physico-chemical properties in monoculture plantations of an indigenous tree species - *Nauclea diderrichii,* and those of four exotic tree species – *Theobroma cacao, Gmelina arborea, Pinus caribaea and Tectona grandis*. Apart from providing baseline data upon which future comparative studies will be based, the study in the interim provides relevant information that

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will aid management decisions on sustainable soil management.

Materials and Methods

Study Area

Five sites bearing monoculture plantations of *Nauclea diderrichii, Theobroma cacao, Gmelina arborea, Pinus caribaea and Tectona grandis* located within Omo biosphere reserve (6°35' to 7°05'N and 4°19' to 4°40'E) were purposively chosen for the study. The *Nauclea diderrichii* plantation (NUDI) is located at 6°50'16.11"N and 4°22'05.56"E within and around the Project Management Unit (PMU) residential quarters. The plantation was established in 1975 and has not been logged. The *Theobroma cacao* plantation (THCA) is located at 6°52'49.82"N and 4°24'48.91"E near Temidire Camp. The plantation was established in the year 2000. The *Gmelina arborea* plantation (GMAR) is located at 6°54'13.94"N and 4°22'30.44"E towards the right of Mokore Branch, along the road leading to Oshoko. The plantation was established in 1983 and had been logged severally. The *Pinus caribaea* plantation (PICA) is located at 6°50'03.54"N and 4°22'00.65"E near Mile 1 camp. The plantation was established in 1997 and bears a pineapple orchard. The *Tectona grandis* plantation (TEGR) is located at 6°50'08.37"N and 4°21'39.92"E near Mile 1 Camp. The plantation which was established in 1989 had been logged and now bears mainly coppices. These plantations were chosen to enable comparison of topsoils that developed under the influence of indigenous and exotic tree species. Figure 1 is the map of Omo biosphere reserve showing the study sites.

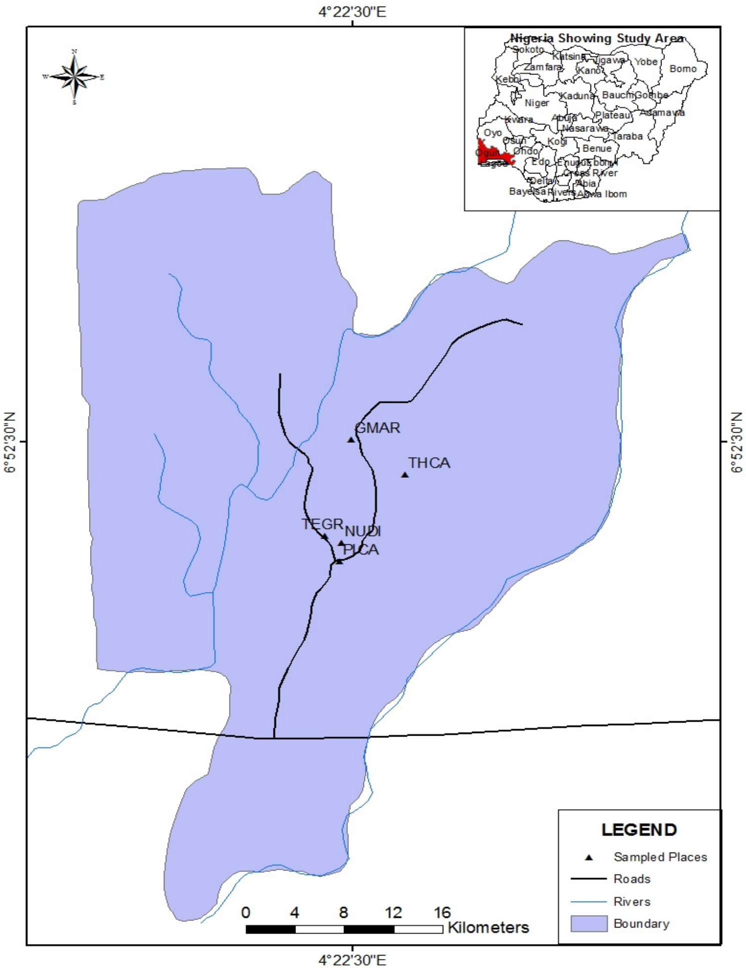

Figure 1: Map of Omo biosphere reserve showing the study sites (Inset: Map of Nigeria showing study area)

Soil Sampling

In each monoculture plantation, soil samples were systematically collected from five auger points at 20-metre intervals and three soil depths (0-5cm, 5-10cm, and 10-15cm) in each of three directions - North-South, East-West and diagonally from North-West to South-East. Soil samples from each site, were bulked for each soil depth/direction, enclosed in polybags and taken to the laboratory for analysis.

Soil Analysis

The soil analysis covered the following parameters: Particle size distribution, pH, Total nitrogen, Available phosphorus, Organic carbon, Ca, Mg, K, Na, Fe, Mn, Cu, and Zn. The particle size analysis was done using the hydrometer method (Bouyoucous 1951). Exchangeable bases were determined by the summation method (lITA 1979). Available phosphorus was determined by Bray No. 1 method (Bray and Kurtz 1945). Organic carbon was determined by Walkley Black wet oxidation method (Allison 1965) and organic matter derived there from by multiplying with 1.72 (Agbenin 1995). Total nitrogen was determined by Kjedahl method (Bremner 1965), and Soil pH determined in 1:1 soil: water ratio.

Data Analysis

A one-way analysis of variance was used to test for significant differences in soil properties among the monoculture plantations for each soil depth using the Statistical Package for Social Sciences (SPSS) as described by Oloyo (2001). Duncan Multiple Range Test (DMRT) was used for mean separation for those soil properties that differed significantly at 0.05 level of significance.

Indices of change (%) were computed for selected soil properties after Islam and Weil (2000), Chima *et al*. (2009), and Awotoye *et al*. (2011). In computing the indices of change, average values of soil properties under the *Nauclea diderrichii* plantation – which is an indigenous species, were used as benchmarks. The formula used is given below.

Change Index (%) = $(\overline{X} - \overline{X}_i / \overline{X}) \times 100$

Where: $\overline{X}$ = mean of a soil property in the *Nauclea diderrichii* plantation

$\overline{X}_i$ = mean of the same soil property in the plantation of exotic species

Results

Particle size distribution of soils under different monoculture plantations is shown in Table 1. Percentage sand decreased with increasing soil depth while percentage clay increased with increasing soil depth in all the monoculture plantations. Silt did not show any regular pattern of distribution with respect to soil depth. Percentage sand, silt, and clay did not vary significantly among monoculture plantations at the 0 -5 cm depth while significant variations were observed at lower soil depths in few plantations.

Table 1: Particle size distribution under different land use types

Soil Depth (cm)	Monoculture Plantation	% Sand	% Silt	% Clay	Silt/Clay ratio
0 – 5	NUDI	86.00^{a}	4.00^{a}	10.00^{a}	0.40^{a}
	THCA	86.00^{a}	4.00^{a}	10.00^{a}	0.40^{a}
	PICA	85.00^{a}	5.00^{a}	10.00^{a}	0.50^{a}
	GMAR	87.00^{a}	4.00^{a}	9.00^{a}	0.44^{a}
	TEGR	85.00^{a}	4.00^{a}	11.00^{a}	0.36^{a}
5 -10	NUDI	83.00^{ab}	6.00^{a}	11.00^{b}	0.55^{a}
	THCA	85.00^{a}	4.00^{ab}	11.00^{b}	0.36^{b}
	PICA	81.00^{bc}	3.00^{b}	16.00^{a}	0.19^{c}
	GMAR	80.00^{c}	5.00^{ab}	15.00^{a}	0.33^{b}
	TEGR	82.00^{bc}	6.00^{a}	12.00^{b}	0.50^{a}
10 -15	NUDI	79.00^{ab}	4.00^{c}	17.00^{a}	0.24^{d}
	THCA	80.00^{a}	7.00^{ab}	13.00^{b}	0.54^{b}
	PICA	77.00^{b}	5.00^{bc}	18.00^{a}	0.28^{c}
	GMAR	78.00^{ab}	5.00^{bc}	17.00^{a}	0.29^{c}
	TEGR	79.00^{ab}	8.00^{a}	13.00^{b}	0.62^{a}

Values are means of triplicate samples

Means on the same column with the same alphabet for each soil depth are not significantly different (P > 0.05)

Data for selected micronutrients are shown in Table 2. Micronutrients decreased with increasing soil depth in all monoculture plantations. The highest concentration of Fe was observed at the 0 – 5cm depth in THCA. There was no significant difference between the concentration of Fe in THCA and NUDI at 0 -5 cm depth. The highest concentration of Zn was observed at the 0 – 5cm depth in GMAR. There was no significant difference between the concentration of Zn in THCA and PICA at 10 – 15cm depth. The highest concentration of Cu was observed at the 0 – 5cm depth in GMAR. However, no significant difference was observed in Cu among NUDI, GMAR and TEGR at 0 – 5cm, and between NUDI and PICA at 10 – 15cm depth. Manganese (Mn) varied significantly among monoculture plantations at different soil depths with the highest concentration observed in NUDI at the 0 – 5cm depth.

Table 2: Micronutrients under different land use types

Soil Depth (cm)	Monoculture Plantation	ppm			
		Fe	Zn	Cu	Mn
0 – 5	NUDI	40.01^{a}	4.02^{c}	4.02^{b}	31.12^{a}
	THCA	41.01^{a}	5.73^{b}	5.01^{a}	29.76^{c}
	PICA	39.56^{c}	3.72^{d}	3.72^{c}	29.73^{d}
	GMAR	36.68^{d}	6.18^{a}	4.08^{b}	27.08^{e}
	TEGR	36.22^{e}	4.00^{c}	4.00^{b}	30.21^{b}
5 – 10	NUDI	10.13^{b}	0.68^{d}	0.68^{d}	8.12^{b}
	THCA	10.21^{a}	0.96^{a}	0.96^{a}	7.99^{c}
	PICA	9.78^{d}	0.20^{e}	0.53^{e}	1.87^{e}
	GMAR	10.02^{c}	0.74^{c}	0.74^{c}	8.19^{a}
	TEGR	9.76^{d}	0.81^{b}	0.81^{b}	7.57^{d}
10 -15	NUDI	8.67^{b}	0.16^{d}	0.43^{b}	2.12^{e}
	THCA	7.12^{e}	0.50^{b}	0.33^{d}	5.98^{d}
	PICA	8.12c	0.51^{b}	0.41^{b}	7.01^{b}
	GMAR	8.73^{a}	0.60^{a}	0.47^{a}	7.56^{a}
	TEGR	7.41^{d}	0.36^{c}	0.36^{c}	6.13^{c}

Values are means of triplicate samples

Means on the same column with the same alphabet for each soil depth are not significantly different ($P > 0.05$).

Soil pH and exchangeable bases for different monoculture plantations are shown in Table 3. There were significant differences in Soil pH and exchangeable bases between some plantations at the different depths.

Table 3: Soil pH and exchangeable bases under different land use types

Soil Depth (cm)	Monoculture Plantation	pH (H_2O)	cmol (+) Kg^{-1}			
			Ca	Mg	K	Na
0 -5	NUDI	8.3^{a}	2.33^{e}	1.04^{ab}	0.73^{a}	0.51^{a}
	THCA	7.9^{c}	2.51^{c}	1.12^{a}	0.70^{a}	0.20^{b}
	PICA	8.2^{a}	2.46^{d}	1.00^{b}	0.70^{a}	0.49^{a}
	GMAR	8.2^{a}	7.38^{a}	1.06^{ab}	0.64^{a}	0.15^{b}
	TEGR	6.8^{c}	3.02^{b}	1.11^{a}	0.71^{a}	0.51^{a}
5 – 10	NUDI	6.9^{a}	1.20^{b}	0.59^{c}	0.34^{ab}	0.29^{b}
	THCA	6.3^{b}	1.42^{a}	0.71^{a}	0.32^{ab}	0.43^{a}
	PICA	5.7^{c}	0.76^{c}	0.39^{e}	0.35^{a}	0.11^{c}
	GMAR	6.7^{a}	1.21^{b}	0.54^{d}	0.31^{ab}	0.31^{b}
	TEGR	6.8^{a}	1.30^{ab}	0.67^{b}	0.30^{b}	0.31^{b}
10 – 15	NUDI	5.8^{ab}	0.82^{d}	0.43^{b}	0.48^{a}	0.10^{b}
	THCA	5.2^{b}	0.86^{c}	0.31^{c}	0.10^{d}	0.09^{b}
	PICA	5.9^{ab}	0.93^{b}	0.41^{b}	0.15^{c}	0.10^{b}
	GMAR	6.5^{a}	0.97^{a}	0.48^{a}	0.21^{b}	0.12^{a}
	TEGR	5.5^{b}	0.78^{e}	0.30^{c}	0.11^{cd}	0.09^{b}

Values are means of triplicate samples

Means on the same column with the same alphabet for each soil depth are not significantly different ($P > 0.05$)

Organic matter, total nitrogen and available phosphorus in soils under different monoculture plantations are shown in Figure 2. Organic matter, total nitrogen and available phosphorus decreased with increasing soil depth in all monoculture plantations. Organic matter and total nitrogen were highest in THCA, TEGR and NUDI at the 0 – 5, 5 – 10 and 10 -15 cm depths respectively, while Available phosphorus was highest in NUDI, THCA and GMAR at the 0 -5, 5 – 10 and 10 -15 cm depths, respectively.

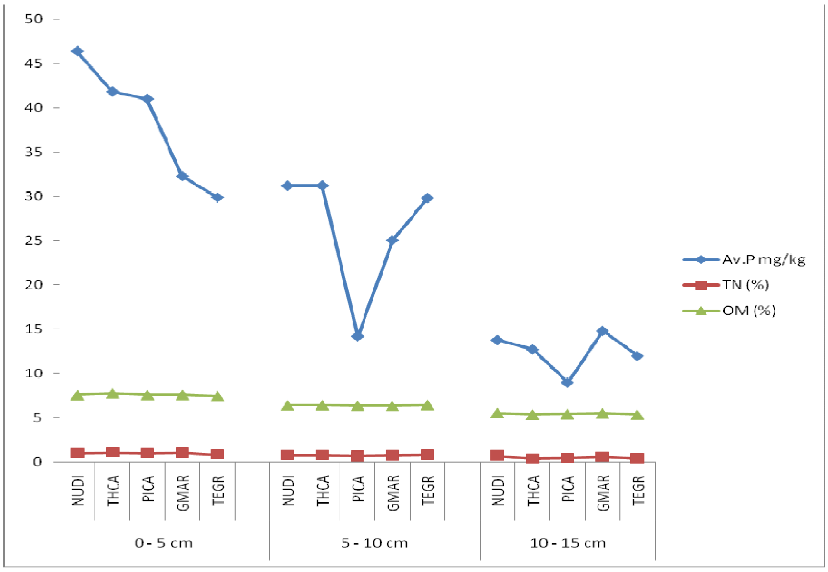

Figure 2: Organic matter, total nitrogen and available phosphorus under various monoculture plantations

Indices of change (%) in soil properties between the NUDI plantation and the exotic plantations are shown in Table 4. Average values of organic matter, total nitrogen, available phosphorus, potassium, sodium, iron and pH for the three sampled depths compared better in *Nauclea diderrichii* than in most of the exotic plantations; while calcium, zinc, copper and manganese were higher in the exotic plantations with the exception of PICA plantation.

Table 4: Index of change for selected soil properties

Soil property	Change Index %				
	NUDI	GMAR	THCA	PICA	TEGR
Organic matter	-	0.31	- 0.31	0.77	0.92
Total nitrogen	-	3.61	9.64	14.46	18.07
Available P	-	21.01	6.11	29.72	21.54
Calcium	-	- 120.00	- 10.34	4.83	- 17.24
Magnesium	-	0.00	-2.90	13.04	0.00
Potassium	-	25.00	28.85	23.08	28.85
Sodium		36.67	20.00	23.33	0.00
Iron	-	5.71	0.77	2.30	9.18
Zinc	-	-54.94	-48.15	8.64	-6.17
Copper	-	-2.92	-22.81	9.36	-0.58
Manganese	-	-3.55	-5.73	6.67	-6.16
pH	-	-1.86	7.57	5.71	9.00

Negative (-) value indicates a corresponding percentage increase in average value of a soil property for the three soil depths in the respective plantations from the average value of the same soil property in NUDI

Discussion

This study revealed that percentage sand decreased with increasing soil depth while percentage clay increased with increasing soil depth in all the monoculture plantations. Silt did not show any regular pattern of distribution with respect to soil depth. This trend in particle size distribution has also been reported by Muoghalu and Awokunle (1994) and Chima *et al*. (2009) in the rainforest ecological zone of Nigeria. Although, significant variations were observed at lower soil depths between few plantations, percentage sand, silt and clay did not vary significantly among monoculture plantations at the 0 -5 cm depth. The little significant differences observed in soil texture among monoculture plantations may be attributed to similarity of parent materials of soils under the plantations. Van Breemen *et al.* (1997) noted that the spatial variability in soil texture and elemental composition is a parent material effect and cannot be explained by tree-induced processes.

Micronutrients as shown in the results improved in soils under the exotic plantations except in PICA and decreased with increasing soil depth in all monoculture plantations. The decrease in micronutrients with increasing soil depth could be attributed to the decrease in organic matter content with increasing soil depth. Follet (1969) confirmed that a blanket of partially decomposed needle, bark and other organic materials on the soil surface provided an environment for the concentration of extractable micronutrient particularly Zn, Fe and Mn in the surface soil. Sharmal *et al*. (2000) also reported a strong correlation between organic matter and extractable Zn, Cu, Mn and Fe. This explains why micronutrients decreased with increasing depth in all plantations. However, significant differences observed in micronutrient levels in some plantations may be attributed to variations in the nature and composition of litter produced by the different species.

Soil pH decreased down the soil depth in all the plantations. This trend could be as a result of decrease in the concentration of exchangeable bases - Mg, K, Na and Ca, with increasing depth. Muoghalu and Awokunle (1994) observed that the accumulation of these cations is likely to increase pH and that was also the case in this study. Although exchangeable bases generally decreased with increase in soil depth in all plantations, average values of K and Na for the three sampled depths were lower in GMAR, THCA, PICA, and TEGR plantations than in NUDI plantation which is an indigenous species. The lower concentration of K and Na in the soil indicates that exotic tree species absorb more K and Na from the soil than the indigenous tree species - *Nauclea diderrichii*. A similar trend was also observed in the case of Ca and Mg in soil under PICA plantation. Preferential immobilisation of the basic nutrients by exotic tree species had been reported by earlier workers (e.g. Nwoboshi 1972; Chijioke 1978, 1980).

With the exception of THCA, organic matter was lower in the exotic plantations than in NUDI. Higher organic matter in THCA than in NUDI is attributable to higher litter production and accumulation in the former. However, the decrease in organic matter with depth may be due to decrease in the abundance of fine roots (Post and Kwon, 2000).

There was a decrease in available phosphorus and total nitrogen under the four exotic plantations and down the soil depth. The decrease in available phosphorus with increasing depth could be attributed to the decrease in organic matter content of soil under these plantations down the soil depth. Organic matter has been known to influence the concentration of available phosphorus and total nitrogen. Awotoye *et al*. (2011) attributed increase in nitrate-nitrogen and available phosphorus to improved organic matter content via litter decomposition and mineralization.

Conclusion

Average values of organic matter, total nitrogen, available phosphorus, potassium, sodium, iron and pH for the three soil depths compared better in NUDI plantation than in most of the exotic plantations; while calcium, zinc, copper and manganese improved in the exotic plantations with the exception of PICA. The use of *Nauclea diderrichii* for plantation establishment and taungya farming in the reserve may be considered for soil conservation.

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