Soil Nutrient Status in *Nauclea diderrichii* and *Terminalia superba* Plantations in Forestry Research Institute of Nigeria, Oyo State, Nigeria

Olajiire-Ajayi, B. L., Fadipe, O. B., Akintola, O. O., Ogidan, O. A., Ogundana, O. A., and Olubayo, O. O*

Federal College of Forestry, Jericho, Ibadan

KEYWORDS

Mixed plantation,
Monoculture plantation,
Sustainable
Forest management,
Soil nutrient status,
Soil physical properties.

***CORRESPONDING AUTHOR**

jiirebolanle@gmail.com;
+2348030785074

ABSTRACT

This study assessed the soil nutrient status of Nauclea diderrichii and Terminalia superba plantations in the Forestry Research Institute of Nigeria, Oyo State, Nigeria, to address the limited knowledge on soil nutrients in monoculture plantations in the region. Soil samples were systematically collected from five points at 50m intervals at two depths (0-15 cm and 15-30 cm). The samples were analysed for particle size distribution, Water Holding Capacity (WHC), pH, nitrogen (TN), Available Phosphorus (AP), Organic Carbon (OC), exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}), cation exchange capacity (CEC), and micronutrients (Fe^{3+}, Cu^{2+}, Mn^{2+}, Zn^{2+}). Nauclea diderrichii exhibited slightly lower pH (6.3) and higher WHC (76.52%) compared to Terminalia superba (pH 6.8, WHC 62.25%). The mean OC, TN, and AP were higher in Terminalia superba (35.25 4.79; 2.95) compared to Nauclea diderrichii (25.24; 2.21; 3.32). The study found a strong correlation between the soil chemical ($r = 0.962$; $p < 0.01$) and physical properties ($r = 0.989$; $p < 0.01$) under Nauclea diderrichii and Terminalia superba, indicating that both species influence soil nutrient status and structure. For exchangeable cations and CEC, Nauclea diderrichii showed higher values, with Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and CEC at 3.58; 1.56; 0.51; and 6.3, respectively, compared to Terminalia superba. These findings indicate that Nauclea diderrichii plantations have higher soil nutrient accumulation, suggesting better soil fertility. The study recommends that this species be prioritized in afforestation and reforestation programs in Nigeria to enhance soil fertility and support sustainable forest management.

INTRODUCTION

The nutrient status of tree plantations is a critical factor that influences tree growth, forest productivity, and overall ecosystem health (Mazo *et al*., 2020). Nutrient availability directly impacts growth rates, carbon sequestration, and the broader functioning of the ecosystem. Essential nutrients like nitrogen (N), phosphorus (P), and potassium (K) are vital for the growth of plantation species, while secondary nutrients such as calcium (Ca) and magnesium (Mg) are crucial for maintaining soil structure and supporting various biochemical processes (Brady and Weil, 2010). However, nutrient dynamics are shaped by the types of trees, their ecological characteristics, and the management practices applied (Ume *et al*., 2020).

According to Berg and McClaugherty (2008), the availability of nutrients in a particular soil is mostly determined by the dynamics of organic matter decay. Nutrient cycling is typically a result of decomposition. Through photosynthesis, nutrients are taken up and stored by forest leaves, and as those leaves fall and disintegrate, the nutrients are released back into the ecosystem. This is how nutrients are released into the environment. Because of this, the majority of the organic matter found in the soil of any terrestrial ecosystem comes from the creation and build-up of fine litter, which needs to break down and release nutrients (Leon and Osorio, 2014; Ume *et al*., 2020). Consequently, the organic matter present in the soil of any terrestrial ecosystem is majorly from the production and accumulation of fine litter which must decompose and release nutrient (Leon and Osorio, 2014; Ume *et al.*, 2020). As a result, litter fall and the decomposition of vegetation contribute humus and nutrients to the soil, which in turn affects soil structure and nutrient status (NRCS, 2007). This has heightened interest among plantation managers and researchers in improving soil nutrient levels and ensuring sustainability by identifying the most suitable tree species mixtures for successful, long-term plantation management (Ojo, 2005).

The sustainable management of plantation and soil will depend to a large extent on the thorough understanding of the trends, and dynamics of soil characteristics. Therefore, a systematic understanding of the nutrient dynamics under different forest plantation is essential in predicting the impact of different forest plantation type on soil nutrient status.

There is a need for information on the soil nutrient status of plantations within the Forestry Research Institute of Nigeria (FRIN). Current literature lacks detailed analysis of the nutrient status of *Nauclea diderrichii* and *Terminalia superba* within the FRIN plantations. While studies such as those by Sinclair *et al*. (2010) and de Vries *et al*. (2009) highlight general nutrient management in tropical plantations, they do not address the specific needs and conditions of these species in Nigeria. Thus, this study assessed and compared the nutrient status of *Nauclea diderrichii* and *Terminalia superba* plantations in Forestry Research Institute of Nigeria (FRIN).

By evaluating the nutrient status of *Nauclea diderrichii* and *Terminalia superba* plantations, this study closes the knowledge gap on nutrient dynamics and advances our understanding of tropical plantation ecosystems, which are becoming more and more important for biodiversity conservation and carbon sequestration. Finally, by ensuring that these important species continue to flourish throughout time, this research will help FRIN's continued efforts to optimize plantation management practices, which will benefit Nigeria's forestry industries and environmental sustainability.

MATERIALS AND METHODS

Description of study area

The study was conducted within the Forestry Research Institute of Nigeria, located between longitudes 3°51'20" – 3°51'45" E, and latitudes 7°23'18" – 7°55'43" N (Nurudeen *et al*., 2014). This region experiences a bimodal rainfall pattern, with peak periods in June and July, as well as September and October, averaging around 1548.20 mm annually with temperatures ranging from 39 °C to 24.9 °C and relative humidity averages approximately 82% between June and September, and drops to around 60% from December to February (Ugwu and Ojo, 2015; Salami *et al*., 2020). The topography is characterized by undulating terrain, underlain by ferruginous sandy loam soil on the crystalline rock of the undifferentiated Pre-Cambrian basement complex (Salami *et al*., 2020).

The two sites selected are monoculture plantations of *Nauclea diderrichii* and *Terminalia superba* planted in 2010. *Nauclea diderrichii* plantation is located at 7.38746°N and 3.85762°E while the *Terminalia superba* is located at 7.38782° N, 3.85872° E with each covering an area one hectare (Figure 1).

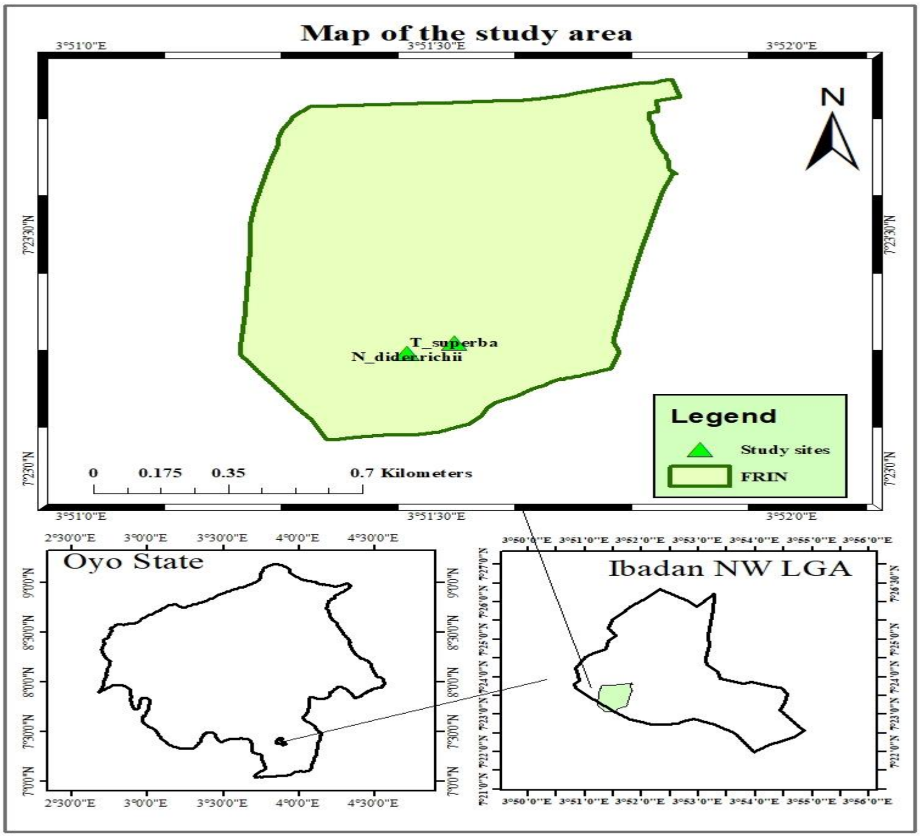

Figure 1: Map showing location of plantations within the Forestry Research Institute of Nigeria

Sampling techniques

Soil samples were systematically collected using a soil auger from five locations arranged in a diagonal pattern, with sampling points spaced 50 meters apart. Samples were taken at two depths: 0-15 cm (topsoil) and 15-30 cm (subsoil). In total, ten samples were collected from each plantation, yielding 20 samples per plantation. The samples were immediately placed in labelled polythene bags. To prepare for analysis, the individual samples were thoroughly mixed to create composite samples. These composite samples were air-dried, sieved through a 2mm mesh, and taken to the laboratory for analysis.

Methods of soil Nutrient analysis

The particle Size Distribution was analysed using the Bouyoucos hydrometer method (Gee and Or, 2002). Soil pH was measured using a pH meter. Organic carbon content was determined using the Walkley-Black method. Total nitrogen was measured by digesting the samples in sulphuric acid, with CuSO4 used as a catalyst. The nitrogen was converted to ammonia (NH_3), which was then distilled and titrated. Available phosphorus was determined using the Bray I method (Bray and Kurtz, 1945), while total nitrogen was measured using the Kjeldahl method (Bremner and Mulvaney, 1982). Exchangeable cations such as Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+) were extracted with 1N neutral ammonium acetate. Exchangeable Ca^{2+} and Mg^{2+} were measured using an atomic absorption spectrometer, while K^+ and Na^+ were determined using a flame photometer. Extractable micronutrients of Manganese (Mn^{2+}), Zinc (Zn^{2+}), Copper (Cu^{2+}), and Iron (Fe^{3+}) were leached with 0.1N HCl using the method by Wear and Sommer (1948) and measured with an atomic absorption spectrophotometer. Cation Exchange Capacity (CEC) was calculated by summing the exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+) and the exchangeable acidity (Al^{3+}, H^+) (Choo and Bai, 2016).

Data Analysis

The result of the laboratory analysis was analyzed using Analysis of Variance (ANOVA) and student t-test at 5% significant level.

RESULTS

Physical Properties

Soil particle size distribution

Sand content as presented in Table 1 is higher under both species in the topsoil (0–15 cm) and decreases with depth, consistent with typical leaching of finer particles with sand content at the 0-15 cm depth being 793.5 g/kg under the *Nauclea diderrichii* and 816.5 g/kg under the *Terminalia superba* while it was 736.5 g/kg and 788.0 g/kg under the *Nauclea diderrichii* and *Terminalia superba* at the 15-30 cm depth. *Nauclea diderrichii* soils had higher clay content at both depths (141.5 g/kg at 0–15 cm; 175.5 g/kg at 15–30 cm) compared to *Terminalia superba* soils (75.5 g/kg and 93 g/kg, respectively). Conversely, sand content was higher under *Terminalia superba* soils, particularly at 0–15 cm (816.5 g/kg). The silt content at the 0-15 cm under the *Nauclea diderrichii* was 65.0 and 109.0 under the *Terminalia superba* plantations while it was 85.0 and 118.5 at the 15-30 cm under the *Nauclea diderrichii* and *Terminalia superba* respectively.

The WHC (Table 1) was higher under *Nauclea diderrichii* (76.52% at 0–15 cm; 74.26% at 15–30 cm) compared to *Terminalia superba* (62.25% and 60.52%). This trend reflects the influence of clay content and organic matter under *Nauclea diderrichii*.

Soil pH varied under the different plantations (Table 1). *T. superba* soils were slightly more alkaline (pH 6.92 at 0-15 cm) compared to *N. diderrichii* soils (pH 6.14 at 0-15 cm). Soil pH influences nutrient availability and microbial activity; slight alkalinity can enhance the availability of certain nutrients.

Table 1: Soil parameters under *Nauclea diderrichii* and *Terminalia superba* plantation at 0-15 cm and 15-30 cm soil depths

Parameters	Nauclea diderrichii		Terminalia superba	
	0-15cm	15-30cm	0-15cm	15-30cm
sand (g/kg)	793.5	736.5	816.5	788
silt (g/kg)	65	85	109	118.5
clay (g/kg)	141.5	175.5	75.5	93
pH (H_2O)	6.14	6.41	6.92	6.71
WHC (%)	76.52	74.26	62.25	60.52
OC(g/kg)	43.2.16	32.13	20.53	26.23
OM (%)	7.49	4.56	3.49	3.46
TN(g/kg)	4.79	3.32	2.95	2.21
AP(Mg/kg)	19.5	18.7	16.54	15.31
Ca^{2+} (cmol/kg)	3.81	3.18	3.21	2.72
Mg^{2+} (cmol/kg)	1.72	1.39	1.42	1.42
K^{+} (cmol/kg)	0.41	0.62	0.44	0.37
Na^{+} (cmol/kg)	0.37	0.27	0.29	0.26
CEC	6.2	7.35	5.99	5.22
Cu^{2+} (Mg/kg)	1.95	1.59	1.64	1.21
Fe^{3+} (Mg/kg)	197.33	121.93	106.67	103.33
Zn^{2+} (Mg/kg)	2.32	2.48	1.83	1.37
Mn^{2+} (Mg/kg)	109	103.62	100	83.67

Soil Organic Carbon, Total Nitrogen, Available Phosphorus

The OC at the 0-15 cm depth (Table 1) was 20.16 g/kg under the *Terminalia superba* plantation while it was 43.53 g/kg under the *Nauclea diderrichii*. At the 15-30 cm, the value was 20.13g/kg and 26.23 g/kg for the *Terminalia superba* and *Nauclea diderrichii* plantation respectively. The value of OC decreased with increasing depth. At the 0-15 cm depth, the Total Nitrogen (TN) was 4.79 g/kg under the *Nauclea diderrichii* plantation and 2.95g/kg under the *Terminalia superba* plantation. At the 15-30 cm depth, the total Nitrogen value was 3.32 g/kg for *Nauclea diderrichii* and 2.21 g/kg under the *Terminalia superba* plantation. TN increased with increasing depth under the *Nauclea diderrichii* while it decreased with increasing depth under the *Terminalia superba* plantation. Available Phosphorus (AP) was higher under the *Nauclea diderrichii* plantation with a value of 19.54 Mg/kg at the 0-15 cm depth and 18.7 Mg/kg at the 15-30 cm depth while it was 16.54 Mg/kg and 15.31 Mg/kg under the *Terminalia superba* plantation at the 0-15and 15-30 cm depth respectively. AP decreased with increasing depth under the two plantation types. OC, TN and AP were significantly different under the two plantations at $p>0.05$.

Soil Exchangeable bases

At the 0-15 cm depth (Table 1), exchangeable base of Ca^{2+} was 3.81 cmol/kg under the *Nauclea diderrichii* plantation while it was 3.21 cmol/kg under the *Terminalia superba* plantation. At the 15-30 cm depth, the values are 3.17 cmol/kg and 2.72 cmol/kg for *Nauclea diderrichii* and *Terminalia superba* plantation respectively. Ca^{2+} decreased with increasing depth under the *Nauclea diderrichii* and *Terminalia superba* plantations. Mg^{2+} at the 0-15 cm depth was 1.39 cmol/kg and 1.42 cmol/kg under the *Nauclea diderrichii* and T*erminalia superba* plantation respectively while it was 1.72 cmol/kg for *Nauclea diderrichii* and 1.42 cmol.kg for *Terminalia superba* plantation at the15-30 cm depth. Mg^{2+} remained constant with increasing depth under the *Terminalia superba* plantation (1.42 cmol/kg) while it increased with increasing depth under the *Nauclea diderrichii* plantation. K^+ at the 0-15 cm was 0.41 cmol/kg under the *Nauclea diderrichii* plantation and 0.44 cmol/kg under the *Terminalia superba* plantation while at the 15-30 cm, it was 0.62 cmol/kg and 0.37 cmol/kg under the *Nauclea diderrichii* plantation and *Terminalia superba* plantation respectively. At the 0-15 cm depth; Na^+ was 0.37 cmol/kg and 0.29 cmol/kg under the *Nauclea diderrichii* and *Terminalia superba* plantations respectively while the values are 0.27 cmol/kg and 0.26 cmol/kg under the *Nauclea diderrichii* and *Terminalia superba* plantation respectively.

Soil Micronutrients

Cu^{2+} at the 0-15 cm is 1.95 Mg/kg under the *Nauclea diderrichii* plantation and 1.64 Mg/kg under the *Terminalia superba* plantation while at the 15-30 cm depth, it is 1.59 Mg/kg and 1.21 Mg/kg under the *Nauclea diderrichii* and *Terminalia superba* plantations respectively. Fe^{3+} at the 0-15 cm depth was 197.33 Mg/kg and 106.67 Mg/kg under the *Nauclea diderrichii* and *Terminalia superba* plantation respectively while at the 15-30 cm depth, the values are 121. 93 Mg/kg and 103.33 Mg/kg for *Nauclea diderrichii* and *Terminalia superba* plantation respectively. At the 0-15 cm depth, Zn^{2+} was 2.32 Mg/kg under the *Nauclea diderrichii* plantation and 1.83 Mg/kg under the *Terminalia superba* plantation while at the 15-30 cm depth, it is 2.48 Mg/kg and 1.73 Mg/kg for *Nauclea diderrichii* and *Terminalia superba* respectively. Mn^{2+} at the 0-15 cm was 109.0 Mg/kg and 100.0 Mg/kg for *Nauclea diderrichii* and *Terminalia superba* plantation respectively while at the 15-30 cm depth it is 103.62 Mg/kg under the *Nauclea diderrichii* plantation and 83.67 Mg/kg under the *Terminalia superba* plantation (Table 1).

DISCUSSION

Generally, particle size distribution is influenced to a large degree by parent materials as it is not impacted over a short time (Kiflu and Beyene, 2013). The parent material of soil under the plantation may have influence on the observed particle size distribution. It has been noted that apart from the soil induced property variability, edaphic factors such as parent material and the position of the soil on the catena also affect soil variability (Ume *et al*., 2020).

Soil pH (increased in acidity) with depth under the *Terminalia superba* plantation. This observation aligns with the finding reported by Chima and Adedire (2014a) in Omo Forest Reserve. However. Soil pH increased (reduced acidity) with depth under the *Nauclea diderrichii* plantation. The observed Soil pH pattern might due to the influence of exchangeable bases of Ca^{2+} and Na^+ (Chima *et al.*, 2014).

OC and OM were high under both plantations according to the Federal Fertilizer Department (2012) but, higher under the *Nauclea diderrichii* plantation compared to the *Terminalia superba* plantation. Akinde *et al.* (2020) and Sabina *et al*. (2020) observed that OM impact significantly on the total OC in soil for any land use. OC decreased with increasing depth under both plantation types. The decrease in OC and OM may be due to the abundance of fine roots. Shabhaz *et al*. (2017) stated that higher accumulation and density of plant material at the surface provide higher OC and OM within the top soil.

TN and AP were higher in the *Nauclea diderrichii plantation* compared to the *Terminalia superba* plantation. However, the FFD (2012) considered a TN range of 2.1-2.4 g/kg was moderately high. The higher concentration of TN observed under the *Nauclea diderrichii* could be attributed to factors such as a reduced rate of soil organic matter decomposition, limited leaching, and erosion, as suggested by Isienyi *et al*. (2021). Furthermore, this could be associated with higher content of Carbon which is the main source of TN (Toru and Kibret, 2019). AP was high in the top soil under both plantations. These values could potentially be attributed to the presence of available organic matter, parent material, and the extent of their weathering (Ajon and Anjembe, 2018).

There was no difference in the concentration of Mg^{2+} (1.42 cmol/kg) at both depth in the *Terminalia superba* plantation. The reverse is the case under the *Nauclea diderrichii* plantation. The value obtained for Na^+ (0.26-0.37 cmol/kg) in the two plantation falls within the range (0.29-0.36 cmol/kg) reported by Oyelowo *et al*. (2019) in their study on the physiochemical properties of soil in the sacred groves of Igbo-

Ile and Igbo-Oba. Also, the K^+ value (0.37-0.62 cmol/kg) in the two plantation is lower than the ranges of values (0.32-1.26 cmol/kg) obtained in this study. The lower concentration of K^+ and Na^+ in the two plantations suggest absorption of K^+ and Na^+ from the soil. CEC serves as an indicator of soil fertility, and the values are primarily influenced by the pH level (Yekini *et al.*, 2022). A CEC value of < 12 is considered as having a minimum value of soil fertility (Ajon and Anjembe, 2018) although Nigerian soils have reported to have a low CEC value (FAO, 2006). CEC was higher under the *Nauclea diderrichii* plantation compared to the *Terminalia superba* plantation. However, CEC decreased with soil depth under the *Terminalia superba* plantation which could be attributed to decrease in OC and OM content (Ume *et al*., 2020). Micronutrients of $Cu^{2+,}$ Fe^{3+}, Zn^{2+}, Mn^{2+} were considerably high under the two plantations. Ahmed *et al*., (2024) observed that increased plant growth enhances plant growth.

CONCLUSION AND RECOMENDATION

The accumulation of Total Nitrogen, Available Phosphorus, soil micronutrients of $Cu^{2+,}$ Fe^{3+}, Zn^{2+}, Mn^{2+} and soil fertility indicator of CEC was higher under the *Nauclea diderrichii* plantation compared to the *Terminalia superba* plantation. Therefore, soil under the *Nauclea diderrichii* could said to be higher in nutrient status. The study recommends that these species be prioritized in afforestation and reforestation programs in Nigeria to enhance soil fertility and support sustainable forest management.

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