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INFLUENCE OF NIMBIA FOREST BIOMASS ON SOIL PROPERTIES IN SOUTHERN KADUNA

*[1]Mande Kato Hosea, [2]Barnabas W. Qurix, [3]Akeem O. Olaniyia and [4]Mercy Richard

[1,3,4]Department of Environmental Management, Faculty of Environmental Sciences, Kaduna State University, Nigeria.
[2]Bingham University, Abuja, Nigeria.

*Corresponding Author Email Address: hosea.mande@kasu.edu.ng

ABSTRACT

Changes in Forest biomass frequently influence the physicochemical composition of soil. In the Nimbia Forest Reserve, Southern Kaduna, certain physical and chemical soil parameters were investigated across changes in the forest biomass sequence. The objective was to ascertain how changes in forest biomass will impact on soil properties. In order to represent changes in forest biomass stages. Soil samples (0–20 cm depth) were taken from three different forest plots: (Plot A, Plot B, and Plot C). Between 2021 and 2022, soil samples were examined for the following soil properties: soil organic matter (SOM), soil microbial biomass carbon (SMBC), pH, NH4 +-N, available potassium (K), available phosphorus (P), and microelements (available copper (Cu), available zinc (Zn), available iron (Fe), and available boron (B)). The findings demonstrated that the changes in forest biomass had higher amounts of SOM, SMBC, Cu, Zn, Fe, and B. (Plot B). In contrast, P and pH were higher in the Plot A but lower in the Plot B. While SOM, Zn, Cu, Fe, and B increased with increasing forest biomass, pH, NH4 +-N, P, and K decreased. In the three different forest plots, the soil pH was less than 4.5, which showed that Nimbia's surface soil was acidic, a consistent tendency.

Keywords: Biomass, Carbon, Forest, Microelements, Soil organic matter.

INTRODUCTION

The two primary elements of terrestrial ecosystems are forest and soil, and changes in soil characteristics frequently accompany changes in forest biomass (Reiners *et al.* 1994). In relation to the interaction feedback between soil and forest, soil supplies vital nutrients for trees growth and development, which may in turn be a contributing factor in some of the changes in soil formation and modification (Toriyama *et al*. 2007).

One of the key elements influencing the distribution patterns of forest biomass is thought to be the qualities of the soil (Toriyama *et al.* 2007). The two main justifications for changes in the forest biomass are soil characteristics from forest biomass, which increase in organic matter and profile development, together with modification of the environment (Goudie, 1989). In order to access the whole supply of nutrients in the soil, changes in forest is crucial (Werner, 1984). According to a study conducted in South Eastern Malaysia's evergreen forests, soil total N and P increased as the forest became older (Yan *et al.* 2006). Land degradation, a regressive forest, can also be used to demonstrate how forest affects soil. Huang *et al.* (2007) opined that, land degradation is associated with biotic changes such as a decline in species diversity, chemical changes such as a reduction in soil nutrients, and physical changes such as changes in infiltration, percolation, aeration, and finally erodibility.

For the sustainable management of forests in a climate change situation, as well as for soil rehabilitation, it is essential to comprehend the link between forest biomass and soil nutrient dynamics (Zhou *et al.* 2006). Additionally, management techniques like cultivation, harvesting, and burning frequently have an impact on soil, making an understanding of soil biogeochemistry crucial for the stewardship of the ecosystem services that soils provide. As a result, studying forest biomass and soil environments has gained popularity in ecological research. Research in this area has primarily focused on understanding how soil properties change over time (Reiners *et al.* 1994), evaluating soil fertility (Moran *et al.* 2000), and figuring out how nutrients in the soil are influence by changes in forest biomass (Berendse, 1998).

The tropical forest known as Nimbia Forest Reserve is located in Southern Kaduna. Despite disturbances, this forest has a history of more than 40 years with a variety of forest communities at various phases of changes in biomass (Zhou *et al*. 2006). Long-term research suggests that old forests can still store carbon in soils while being in a late stage of changes in biomass. For example, the Nimbia forest in southeast Kaduna is playing a significant role as a carbon sink (Zhou *et al*. 2006). The long-term study also raises crucial issues about how other nutrients, such as N, P, and soil organic matter (SOM), behave during the changes in biomass process and whether they follow the same pattern as carbon. Research has demonstrated that as forests grow older, the nutrients in the soil alter (Fang et *al.* 2009). Despite these investigations into the dynamics of nutrients in the forest biomass, more research is still required to accurately forecast how the changes in forests biomass will affect the nutrients in the soil.

MATERIALS AND METHODS

Site Description

The study was conducted in Nimbia Forest Reserve located in the Southern Guinea Savanna Zone of Nigeria. It lies between longitudes 8° 30' and 8° 35'E and latitudes 9° 29' and 9° 31'N with an elevation of about 600m above sea level (Figure 1).

The forest reserve is situated in Kaduna State's Jema'a Local Government Area, 70 kilometers south-east of Jos on the Jos-Kafanchan route. There are approximately 2,282.4 hectares of land in Nimbia Forest Reserve.

The original Jema'a Native Authority destroyed the natural vegetation in 1957 and replaced it with mostly Teak (Tectonagrandis) and a few Gmelinaarborea stands. The first teak trial plantation reportedly began in 1957, and between 1958 and 1966, 98.42 hectares of teak were planted, according to Bacci (2004). The final planting was completed in 1991, with the planting continuing through the 1970s (Basuki *et al*., 2009).

Topographic rain is caused by Nimbia's location in relation to its altitude (600 m above sea level). The cooler temperatures are a result of Nimbia Forest Reserve's height. Its coldest temperatures range between 12.90°C and 110°C, while the hottest month (March) has maximum temperatures of 25°C. When the rain is the strongest, in July and August, the reserve's humidity value is at its maximum (Ayuba, 2006).

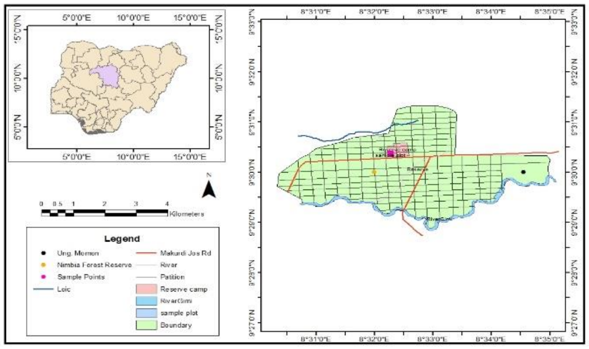

Figure 1: Nimbia Forest Reserve in Regional and Local Settings
Source: Author's Fieldwork, 2021.

Soil Samples Collection

On each of the forest study plots, soil samples were taken in the month of October, 2021 (the start of the dry season) between October, 2021 and August 2022 (Fig 1). Using a soil auger with a 5 cm diameter, 9 randomly selected soil cores were taken from each plot, down to a depth of 20 cm, at intervals of 5 m. The soil layer between 0 and 20 cm is where the majority of bacteria are found and where the greatest organic matter is accumulated. The amount of nutrients is significantly reduced below 20 cm. To reduce the variation at each site, this sample strategy was used. To create a composite sample, the nine cores were completely combined. An immediate subsample of this composite sample was weighed using an electronic balance to ascertain its fresh weight before being oven dried for 48 hours at 105°C to acquire its dry weight. By measuring the relative difference in weight between fresh and dried soil subsamples, water content was gravimetrically calculated. Another fresh soil subsample from the composite sample was put through an 8 mm sieve, and a subsample weighing about 100 g was air dried, put through a 0.15 mm sieve, and kept at room temperature in the dark for storage and subsequent analysis of the chemical total element content. Prior to the analysis of the accessible elements, a different subsample was air dried, put through a 2 mm diameter sieve, and kept at room temperature in the dark. The results were weighted on an oven-dry basis.

The available P, K, Fe, Cu, Zn, and B as well as the soil's bulk density, pH, organic matter, and microbial biomass carbon (SMBC) levels were also measured. Using a pH electrode with a fresh volume ratio of 1:2 in 0.01 M $CaCl_2$, soil pH was measured from the air-dried 2 mm-sieved subsamples, and soil bulk density was determined using the core sampling method (Blake & Hartge 1986). The 2 mm-sieved, air-dried subsamples were used to isolate soil organic matter (SOM) in accordance with the procedures outlined by Cambardella & Elliott (1992). Micro diffusion was used to measure the amount of NH_4 +-N (Liu 1996). Following NH_4F-HCl extraction, available P was measured using molybdenum-antimony colorimetry. Utilizing azomethine colorimetry, available B was calculated. After extraction with ammonium acetate, available K, Fe, Cu, and Zn were measured using an atomic absorption spectrophotometer (Liu, 1996).The chloroform fumigation-extraction method was used to measure the soil microbial biomass carbon (SMBC) (Joergensen & Brookes 1990).

Statistical Analysis for Soil

Using a one-way ANOVA with the forest plots as the fixed variable, group means for soil parameters assessed in the three different forest plots were compared. For the purpose of identifying any differences in the various plots, the three types were first evaluated independently. When the F test proved significant, LSD was used for multiple comparisons (across forest plot). With the help of statistical program SPSS version 25 (SPSS, Inc., Chicago, Illinois), data analyses, including the correlation analysis, were performed. A P0.05 significance threshold was used. The data consistently passed the normality test, so no additional data processing was required.

RESULTS

Soil Microbial Biomass Carbon (SMBC)

On soil characteristics and processes, soil microbial biomass has a significant influence. Figure 2 displays the average monthly soil microbial biomass carbon (SMBC) for the three forest plots over the study period. In June, the SMBC reached its greatest value of 800 mg kg-1, while February saw its lowest value of 200 mg kg-1. Plot C had the greatest SMBC, which persisted over the course of the trial. There were significant differences between plot C and plot B and plot A (P 0.01), but not between plot B and plot A (P > 0.05).

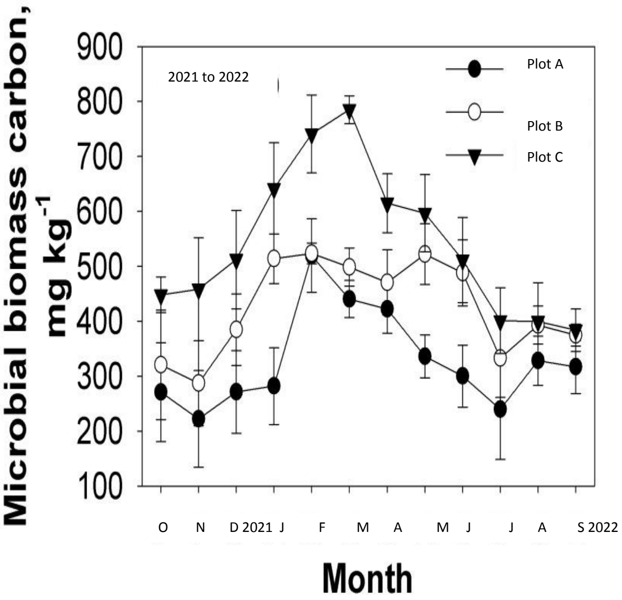

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Figure 2: Mean monthly dynamic of soil microbial biomass carbon in the three forest plots

Al^{3+}, Na^+, and H^+ are cations (with pH 5.5). During the course of the investigation, the three the various forests' plot soil pH values fluctuated between 3.8 and 4.0. (Table 1). The biomass and soil pH had a weak negative and significant correlation (P0.001, r2=0.45). Between October, 2021 and April 2022, there were no appreciable changes in soil pH, however after April 2022, the plot A values started to decline. Between June and July 2022, a similar pH drop was seen in plot B and plot C (Figure 2). Amongst 4% available P and 59% coefficient of variance, certain soil chemical characteristics varied significantly between the various forests available Fe. NH4 +-N and available-cations both showed similar variances (K, Zn, Cu and B). SOM and available Fe were the variables that varied the most among the forests.

Table 1: Effect of changes forest Biomass on soil chemical properties (Numbers represent mean values **± standard error**

Forest Type	**pH**	**SOM (g kg-1)**	**NH_4 $^+$-N (mg kg-1)**	**P(m) (mg kg-1)**	**K(m) (mg kg-1)**	**Zn(m) mg kg-1)**	**Cu(m) (mg kg-1)**	**Fe(m) (mg kg-1)**	**B(m) (mg kg-1)**
PMF	4.04±0.04^a	19.58±1.02^a	8.29±1.73^a	1.50±0.17^a	30.03±2.63^a	1.39±0.08^a	0.65±0.08^a	47.19±3.69^a	0.47±0.06^a
PBMF	3.83±0.04^b	26.11±2.01^b	6.84±1.18^a	1.37±0.14^a	37.05±2.16^b	1.31±0.07^b	0.79±0.10^b	122.80±6.52^b	0.68±0.05^b
MEBF	3.80±0.04^c	35.85±1.15^c	8.06±1.11^a	1.36±0.13^a	58.52±4.02^c	2.03±0.18^c	0.98±0.11^c	160.0±5.97^c	0.80±0.07^c

Source: Author Fieldwork

SOM and Ammonical Nitrogen (NH_4 $^+$-N)

SOM content increased as forest biomass changes. The lowest and largest SOMs, 19.58 g kg-1 and 35.85 g kg-1, respectively, were found in plot C and plot B. During the study period, SOM increased in the three forests plot. The three forest plots SOM concentrations varied significantly (P 0.001) from one another. SOM in the plot B showed a poor (P0.01, r 2=0.36) association with soil pH. SOM had a favourable connection with NH4 +-N, available Fe, and available B in the plot A (P 0.01, r 2 = 0.98), plot C, and plot B (P 0.01, r 2 = 0.98).

NH4 +-N declined in the three forests plot, in contrast to SOM. After 2021, the plot 2 had significantly (P0.001) higher NH4 +-N concentrations in the surface runoff than the other two forests. In plot A, plot B, and plot C, respectively, the mean NH4 +-N concentration across the time period was 8.29 mg kg-1, 6.84 mg kg-1, and 8.06 mg kg-1. Since plot A had the largest concentration of NH4 +-N, it is likely that most conifers prefer NH4 +-N while growing in acidic soil. The plot A location was adjacent to a residential neighbourhood, and the boundary zone was developed into farmland, where greater levels of NH4 +-N content had been detected. However, along the succession stages, no discernible alterations in NH4 +-N were found (lack of temporal variations). The availability of Cu in the plot A and plot B showed a negative connection with NH4 +-N in soil (P 0.05). In the plot C, an NH4 +-N and pH association was seen that was both favourable and significant (P 0.05).

Soil Available Cations (P, K, Zn, Cu, Fe and B)

As the forest's biomass increased, the amount of available phosphorus (P) dropped. P did not significantly differ between the three forests, though. In plot B and plot A, respectively, the greatest P of 2.45 mg kg-1 and the lowest P of 0.5 mg kg-1 were noted in 2021 and early 2022. The plot A experienced the largest P loss rate, which was 78.6%. In the plot B and plot C, available P showed a positive connection with pH. In plot B and plot C, available K and B showed positive correlations with soil pH (P0.01) and available P (P0.01), whereas available K in plot A showed a negative association (P0.01).

Between mid-2022 and August 2022, there was the greatest variance in K in the plot C, with values ranging from 90.52 mg kg-1 to 42.5 mg kg-1. Similar but less extreme variations were seen in the plot A and plot B, ranging from 48.14 mg kg-1 to 21.38 mg kg-1 to 55.64 mg kg-1 to 30.81 mg kg-1, respectively. The inter-annual patterns and available K content varied by forest type. The ratio of available K to available P was highly significant. Comparing the two forest types, plot A had a smaller K pool than plot C.

With increasing forest biomass, soil-available zinc (Zn) and copper (Cu) showed an increasing tendency. Between February 2022 and August 2022, the Zn and Cu contents in the forest soils increased significantly. For soil-available iron (Fe), a similar trend was seen, with rising amounts in the various forests in the order plot C>plot B>plot A. Additionally, substantial variations in Fe were found (P 0.05) at various stages of forest succession. Soil in plot B demonstrated a decrease trend in comparison to Fe in December 2021, followed by an increase from January 2022 to February 2022. B and SOM in plot B and plot C, as well as available K in plot A, all showed a positive connection (P 0.01).

DISCUSSION

The findings of this study illustrate how important drivers of forest change, such as soil water availability, soil chemical properties, and soil microbial biomass carbon, are related to changes in soil properties during the change in the tropical forests biomass. According to the findings, each of these elements affects how soil changes over the changes stage, which can result in either positive or negative feedback between soil characteristics and forest biomass.

Forest Biomass and soil microbial biomass carbon (SMBC)

The various soil type had a substantial impact on soil microbial biomass carbon (SMBC) (Litton *et al.2003,)*. SMBC values of 280–480 mg kg-1 reported for African tropical forests (Pan *et al. 2000)* were higher than the SMBC range of 200–800 mg kg-1 seen in the three forests plot under study. The results surpass the 380.8 to 568.3 mg kg-1 ranges reported in rubber plantations, which are likewise located in a monsoon-dominated climate (Pan *et al. 2000).* However, compared to the 1080 mg kg-1 reported in temperate woods (Jenkinson & Powlson 1976), our SMBC rates are lower. The results of Pan *et al.,* (2000) published for rubber plantations (Pan *et al.2000)* are consistent with the finding that SMBC was lower during the dry winter season than the wet summer season. For the Nimbia forest Reserve, phenological observations show that most plants are in their budding stage from October 2021 to May 2022, and then they grow rapidly from April to September 2022. The addition of new organic matter is followed by the activation of diverse rhizosphere bacteria. These circumstances favour microbial development and metabolic activity. Consequently, a thorough abiotic and biotic interaction led to the formation of soil microbial biomass carbon.

Forest Biomass and Soil Chemical Properties

The findings revealed that the soils in Nimbia were primarily acidic, which can be attributed to a significant amount of litter decomposition, high soil nutrients, as well as the quick growth of heavy industries in the region. Previous studies *by* Ren et *al. (2000) and* Fang *et al. (2008)* have noted a high acid content in the rains in this region as a result of expanding industrial and agricultural activity. On the other hand, we have a tendency to believe that the phenomenon could also be explained by seasonal drought despite the heavy precipitation. In contrast to plot A, the pH of the soil was somewhat lower in plot B and plot C. Due to the comparatively lesser rainfall and lower humidity, there was less standing litter fall in the plot B and plot C soil, which is likely what caused the low pH. Previous investigations had revealed similar findings (Liu et *al.* 2001). As a result, the study make the speculative claim that soil pH may decline during the process of forest biomass changes, with litter fall influencing the pattern aside from any biotic or abiotic environmental driving forces. In order to fully understand the process of decomposition of litter fall in plot C, how the organic acid is produced, where the acid substance comes from, and whether it was caused by organic acid production of microorganisms or hydrogen ions (H+) produced by nitrification, more research is undoubtedly necessary. Environmental and geographic factors have an impact on different forest kinds, and consequently, so do soil characteristics.

SOM and readily available Fe were both abundant in the three plots, which may have been a result of the variations in the soil types and forest communities. Moreover, throughout forest biomass changes, litter fall nutrient fluxes dramatically increase. SOM is benefited by the increased inputs of organic matter and nutrients from litter fall. SOM has been demonstrated to be a reliable indicator of soil nutrient availability, improvement of soil characteristics, and suppression of soil erosion (Nave *et al.* 2010). Through co-precipitation and/or direct chelation, iron and organic carbon have a close relationship that helps keep organic carbon in the soil. SOM in lower tropical China was related to soil texture, with its quantity and quality fluctuating with different forest management options, as had been researched earlier in the Brazilian Amazon (Desjardins *et al.* 2004).

Forest Biomass and SOM and $NH_4{}^{+}$-N

The distribution of organic matter is heavily influenced by the quantity and rate of decomposition of litter, and an increase in the SOM content of a forests biomass series is mostly brought about by this process (Ouyang *et at.* 2007). The findings of this study demonstrated that SOM content rose with biomass changes. The acquired results were in line with earlier findings showing the top 0–20 cm layer of soil organic carbon concentration in old-growth forests that had been conserved increased with time (Zhou *et al.* 2006). This was in line with what the study predicted. Most forest ecosystems, particularly those in temperate regions, have nitrogen as a critical limiting nutrient (Wardle *et al*. 2004). In their varied stages of forest biomass changes, distinct forest ecosystems react differently to the N deposition. Although old-growth ecosystems are anticipated to lose more nitrogen during succession than younger ones, old-growth forests are anticipated to have more accessible N than young forests (Fang *et al.* 2009). The results of this study support past research findings that indicate nitrogen availability rises during primary change in biomass but that nitrogen transformation varies between various changes, Vitousek and Walker (1987). During forest biomass changes, nitrogen availability patterns changed, and any variation in availability can only be explained by the type of disturbance (Vitousek *et al*. 1989), as was demonstrated at the plot A site, which bordered a suburban neighbourhood and agricultural land. Thus, our research suggested that N nitrification tends to increase as forest biomass advances.

Forest Biomass and Available Cations (P, K, Zn, Cu, Fe and B)

The findings demonstrated a strong correlation between available K and available P, and that the plot A forest type's available K pool in the biomass changes was smaller than that of the plot C forest type in the peak of the biomass change. This was in line with the findings of a study conducted in Costa Rica on a tropical wet forest soil (Fernandes & Sanford 1995). Previous research (Jia *et al*. 2005) have noted that plant cover type has a significant impact on soil characteristics, with lowland tropical forests returning less P to the soil through litter fall. However, in stable situations, soil nutrient loss happens gradually in a humid climate, as was shown in Hawaiian ecosystems (Chadwick *et al.* 1999). The primary biotic and abiotic factors that affect differences in soil quality indices are forestry soil litter, microbial biomass and related activities, and the initial soil characteristics. Due to its stronger association with forest biomass changes in tropical forest ecosystems, soil properties are particularly complicated. The findings for this tropical forest are in line with research describing complex changes in soil characteristics with forest biomass change; nonetheless, long-term monitoring is necessary for a fuller understanding. The increase in organic matter, which offers more sites for cations to exchange with one another, or the impact of the pH level, as H ions are released during the decomposition of organic matter and by direct root exudation, are two explanations for the increasing tendency for available Zn, Cu, Fe, and B in the pattern of forest biomass. Due to competition for exchange sites, all four elements favour leaching of nutritional cations.

Conclusion and Recommendation

In conclusion, the changes in forest biomass have resulted to higher concentrations of SOM, soil microbial biomass carbon, NH4 +-N, and accessible cations (K, Zn, Cu, Fe, and B) plot C. In the early changes biomass change, only the available P and pH were higher (plot A). Only pH, SOM, and the amount of accessible P and Fe were impacted by the change at the plot A sites. However, the lengthening of plot B and plot C had an impact on all soil properties. The consequences of forest biomass changes appeared to vary depending on the initial qualities of the soil and the location of the site. But no one generalization was able to fully capture the variety of variability observed over the course of forest biomass change. Therefore, more investigation is required to understand the mechanisms behind forest biomass change and the interaction of various physical and chemical elements in tropical forest soils. To fully understand the mechanisms governing forest biomass changes and the interactions of the many physical and chemical elements in tropical forest soils, more research is required.

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