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NUTRIENT INPUT IN LITTERS AND SOIL OF *BAMBUSA VULGARIS* STANDS IN A SECONDARY RAINFOREST, ILE-IFE, NIGERIA

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Nutrient contents in litter and soil were assessed in four 0.06 ha plots of *Bambusa vulgaris* stands in a secondary rainforest at Ile-Ife, Nigeria, with a view to providing information on nutrient availability that was generally lacking in the forest ecosystem. The collected litter were sorted into leaves and twigs, oven-dried at 70 °C to a constant weight, ground and analysed for nutrients. Leaf litter had higher concentration of Ca, K, Na, P, Mn, Zn and Cu, while C, Mg, Fe and N were higher in twig litter fall fraction. Exchangeable cations, pH, sand content and organic C were significantly lower ($p < 0.05$), while total N, available P, silt and clay contents were higher in the soil dominated by bamboo stands. *Bambusa vulgaris* is a better conserver of C, N and P compared to areas dominated by trees and shrubs species in the secondary forest.

Keywords: Deposition, litter fall, nutrients, season, soil properties

INTRODUCTION

The capacity of the environment to perpetuate nutrient supply and substrate quality, combined with the regenerative potential, resource use and recycling efficiency of the plants, determine the sustainability of a forest system (Verwijst 1996). Management of the natural bamboo forests in the tropics in general and particularly in tropical Africa, should aim to alleviate the prevalent shortages of forest products and to safeguard their potential for sustainable production (Kigomo 1988). Previously, forests were mainly assessed in terms of the commercial value of timber. Forest components like bamboo was not considered to be of a major economic importance. In the 20th century, when vast areas of tropical forests were denuded of timber for local use and exportation, bamboos and other non-wood products were usually discarded or destroyed during logging operations. However, there is a growing consensus that non-woody forest products are not only crucial to the ecosystem, but also valuable for the livelihood of surrounding communities (Kigomo 1988). In view of the need to reduce Nigeria's dependence on imported wood products, the deployment of bamboo as a basic raw material, in line with developments in most parts of the world, has become imperative (Ogunwusi 2011). A recent study revealed that as many as half of the world's bamboo species may be vulnerable to extinction as a result of massive forest destruction (Bystriakova et al. 2004). This practice is common in Nigeria where most bamboo species are exploited from the forests with no consideration of replacement, as they are regarded cheap materials readily available, and this poses a threat to its existence.

Bamboo play a major role in ecosystem dynamics (Clark 1995). Soil and climate are the most important factors for growth and development of bamboo. Bamboo species require optimum conditions for their growth and development such as temperature, rainfall, humidity, soil structure, texture, drainage, soil moisture, soil nutrients, altitude and physiographic features (Tewari 1992). Natural disturbances or specific types of soil may also create suitable environments to bamboo colonisation (Griscom & Ashton 2006).

Bamboo is a heavy nutrient feeder among the grass family (Shanmughavel et al. 2001). Thus, nutrient availability is the most important soil chemical properties governing the growth and yield of bamboo. Nutrients are taken up by plants for their growth and development and a portion of these nutrients is accumulated in plant body (Hasanuzzaman et al. 2014). Conversely, a considerable amount of nutrients is returned to the soil through litter fall which has an important role in the biogeochemical cycling of nutrients (Mahmood & Saberi 2005).

The importance of forest floor components to productivity is well known (Nautiya et al. 2009). However, there are few reports on the nutrient status of litter standing crop of bamboo in tropical rainforests. There are hardly any studies on site productivity in terms of nutrient availability where bamboo stands thrive in Nigeria. Attention has always been focused on the contribution of nutrients by trees and shrub species through litter fall towards the forest ecosystem. After exploitation of bamboo vegetation, the soil has been found useful in reclaiming degraded land, conserving soil structures, mitigating water pollution, improving the environment and carrying out drought proofing (Zhou et al. 2005). However, the alarming rate of forest degradation, deforestation and rampant exploitation of bamboo stands in this area has attracted attention. Therefore, there is a need to evaluate its nutrient status as it is continuously harvested from the forest ecosystems. This study, therefore, provided information on the nutrient status and returns of the litter fall, litter standing crop and soil of *B. vulgaris* stands, and compared soil nutrient concentration in *B. vulgaris* stands with other areas dominated by trees and shrubs species in the secondary rainforest situated in Ile-Ife, Nigeria.

MATERIALS AND METHODS

Study Area

The study was carried out in the secondary rainforest within the Biological Gardens of Obafemi Awolowo University, Ile-Ife, Nigeria. Ile-Ife lies within latitudes 7° 30'–7° 35' N and longitudes 4° 30'–4° 35' E. The coordinates of the study areas are: latitude 7° 31'–7° 31' N, and longitude 4° 31'–4° 31' E. The elevation of the areas ranges from 302 m to 329 m above sea level. There are two prominent seasons in the Ile-Ife area, the rainy season (March–November) and the dry season (November–March). The most recent climatic survey conducted in 2013 by the Atmospheric Physics Research Group (APRG), Department of Physics and Engineering Physics, Obafemi Awolowo University, Ile-Ife, showed that the annual rainfall averaged 1302 mm year^{-1}, with relative humidity of 82.80%, average temperature of 25.5 °C, solar radiation of 164.30 Wm^{-2} and average wind speed of 2.06 km hr^{-1} (APRG 2013).

Onochie (1979) reported that Ile-Ife area lies in a dry deciduous forest zone. White (1983) also describes the vegetation as Guineo-Congolian drier type. The most frequently occurring plant families in the secondary rainforest are Apocynaceae, Eurphorbiaceae, Mimosaceae, Moraceae, Rubiaceae and Sapindaceae (Awokoya 2003). The soil has been classified as Lixisols (FAO/UNESCO 1974) and Ultisols (USDA 1975). The soils, which are usually acidic, contain less than 10% clay which is mainly Kaolinite, and hence characterised by low cation exchange and water holding capacity (Ayodele 1986). The map of the secondary forest (right) where the bamboo stands are located is shown in Figure 1.

Data collection

Four study plots were established within the secondary rainforest. Each sampling plot, 25 m × 25 m, was marked out using a measuring tape and demarcated with narrow cut-lines. Ten litter traps were randomly positioned in the four established plots of *B. vulgaris* stands in the secondary rainforest.

Litter fall collections

In each of the sampling plot, ten 1.0 m × 1.0 m × 30 cm litter traps made of nylon mesh (1 mm mesh size) were randomly placed in the *B. vulgaris* stands, which was fixed at about 1 m above ground level using pegs. Litter fall was collected for a period of one year (June 2014–May 2015). The litter materials within the litter traps were emptied fortnightly into polythene bags, and labelled and transported to the laboratory, and sorted into two fractions, i.e. leaf and twigs (≤ 3.25 cm). The litter samples were oven-dried at 70 °C to a constant weight. After determining the dry weights of the fractions for individual traps, the two fortnight litter fall collections from the four plots were pooled together, at the end of each month, to give a monthly litter fall nutrient data. The oven dried samples of all litter components (leaf and twigs) were ground and passed

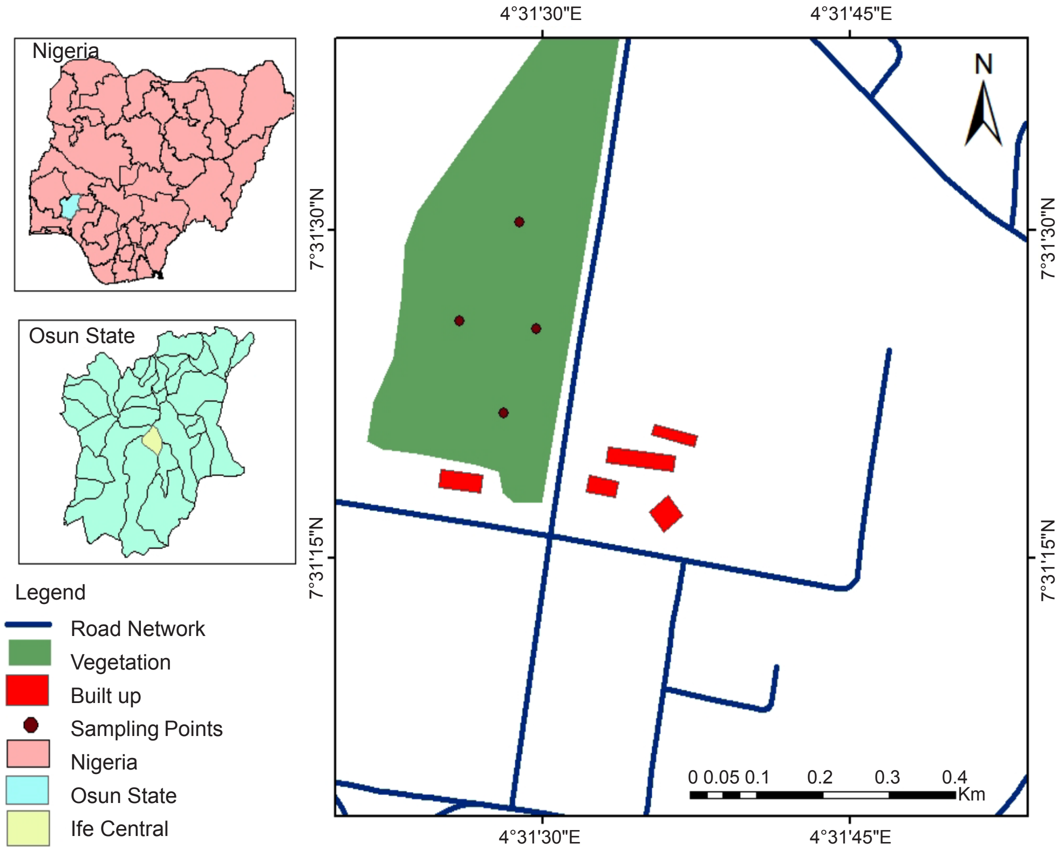

Figure 1 Map of secondary forest (right) where the bamboo stands are located

through a 0.5 mm sieve for chemical analyses. The weights were used to calculate monthly litter fall and total nutrient content. Nutrient deposition was calculated from the monthly litter production of each component (leaf and twig) and mean monthly nutrient concentrations of the corresponding components, adding over the year. The accumulated values were used to obtain the annual nutrient deposition.

Litter standing crop

The litter standing crop was sampled at the peaks of rainy season (September 2014) and dry season (January 2015). To estimate the litter standing crop, the location of sampling collection sites was marked to avoid repeated collections from the same point. On each occasion five 50 cm × 50 cm quadrat were randomly laid on the ground of each plot. The litter standing crop within the quadrat was collected into polythene bags, labelled and transported to the laboratory, and sorted into leaf and twig (≤ 3.25 cm diameter). These fractions were oven–dried at 70 °C to a constant weight, and weighed. The dried litter standing crop samples were then ground and passed through a 0.5 mm sieve for chemical analyses. The weights were used to evaluate the litter standing crop at the peaks of the season and their total nutrient content.

Soil sampling

Soil sampling was carried out in April 2015. Five soil samples were randomly collected, using a soil auger at 0–15 cm depth, in the established plots, four plots dominated by bamboo stands and four plots dominated by trees and shrub species in the secondary forests. The soil samples were collected into polythene bags, labelled and transported to the laboratory, where they were air-dried and passed through a 2-mm stainless steel sieve. The samples from each of the four plots were bulked and analysed for pH, particle size distribution, organic carbon, organic matter, total nitrogen, phosphorus, iron, manganese, zinc, copper and exchangeable cations (Ca^{2+}, K+, Mg^{2+} and Na^{+})

Chemical analysis

Ground litter fall were digested using mixed acid (nitric-perchloric-acid) digestion procedure (Allen et al., 1974). Sub-samples (0.2 g) of each ground samples were digested in 7.0 mL of the digestion mixture. The digest were analysed for calcium, magnesium, manganese, iron, zinc and copper using atomic absorption spectrometer. Potassium and sodium were determined using flame photometer. Organic C was determined by dichromate oxidation and titration with ferrous ammonium sulphate (Moore & Chapman 1986). Lignin and cellulose were also determined using the procedures of chemical analysis described by Dence (1992) and Adams (1965) respectively. Total nitrogen and phosphorus of the ground litter samples were determined at the International Institute of Tropical Agriculture, Ibadan, according to the method of Tel & Rao (1982).

The soil pH was determined in 0.01 M $CaCl_2$ (1:2 soil to solution ratio) and values were determined using a pH meter. Soil particle size distribution was determined by the hydrometer method, using hexametaphosphate as the dispersing agent (Buoyoucos 1961). Organic C was determined by dichromate oxidation and titration with ferrous ammonium sulphate (Moore and Chapman 1986). Sub-samples (0.5 g) of soil were digested in 7.0 mL of the digestion mixture using mixed acid (nitric-perchloric-acid) digestion procedure of (Allen et al. 1974). Soil organic matter content was calculated through the determination of carbon, using an elemental analyser. The organic matter content was then calculated from the soil carbon content on the assumption that soil organic matter contains 58% carbon. Total nitrogen and phosphorus, and cations (P, Na, Mn and Ca) were analysed using the same procedures illustrated above as in litter and litter standing crop samples. These were determined at the International Institute of Tropical Agriculture, Ibadan, Nigeria.

Statistical analysis

The monthly weight of litter fall was determined by adding the oven-dried weight of the individual traps of all leaf fractions, each month. One way analysis of variance (ANOVA) was used to test for significant monthly variation and differences in the nutrient concentration and deposition in litter fall fractions and litter standing crop. Descriptive statistics, i.e. mean, bar chart and line graphs were employed in presenting some of the results obtained from this study. The confidence limits and standard error of all the data were set by student's t-test at 95% confidence interval. The test was performed using system analysis software (SAS) version 8.0.

RESULTS

Nutrient concentration in litter fall and standing crop litter of the bamboo stands

There was a significant ($p \leq 0.05$) difference in the monthly concentrations of all nutrient elements between litter fall fractions. Leaf litter had higher concentrations of Ca, K, Na, P, Mn, Zn, Cu and C. Twig litter had higher concentrations of Mg, Fe and N. Thus, in terms of the order of nutrient concentration between litter fractions, Ca, K, Na, P, Mn, Zn and Cu in leaf litter were higher than concentrations in twig litter, whilst C, Mg, Fe and N were higher in twig litter than leaf litter. Monthly variation in concentrations of nutrient elements showed different trends in the components of litter fall (Figure 2). In leaf litter fall, Mn concentration was at the peak in January, Cu in February, Ca, Mg and Fe in March, N, Na and Zn in April, K in May, P in June and C in December. In twig litter fall, the concentration of Cu was at the peak in January, Fe in March, K in April, P, Na and Mn in May, N, Mg and Zn in July, Ca in September and C in December (Figure 2). All the nutrient concentrations showed significant monthly variations ($p \leq 0.05$).

The monthly lignin content in the litter fall components of bamboo stands ranged between 12.36–48.15% and the cellulose content showed significant monthly variation, with values ranging between 12.34–69.18 % (Figure 3). There was no significant difference ($p > 0.01$) in the lignin and cellulose content between the litter fall components, but they showed significant monthly variations ($p \leq 0.05$). The monthly variation in the lignin content indicated that it was at its peak in the month of December and least in April (Figure 3). The cellulose content in the leaf was significantly higher in January (dry month) and least in September (rainy month), while in the twig it was highest in December and least in June.

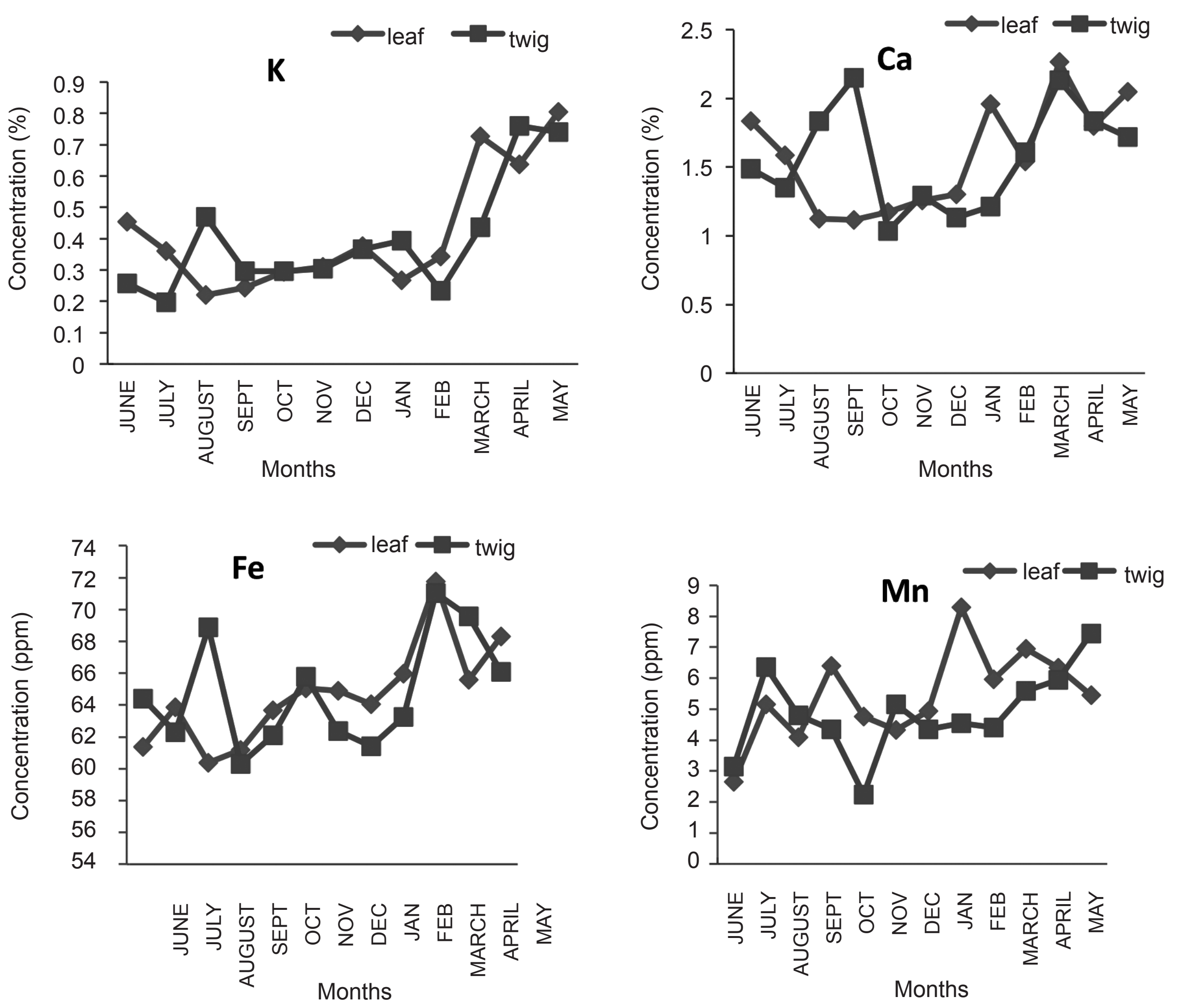

Figure 2A Monthly nutrient concentration of litter fall in bamboo stands in a secondary rainforest within the Biological Garden of Obafemi Awolowo University, Ile-Ife

Nutrient concentration in litter standing crop of the bamboo at the peak of seasons

There was a significant ($p \leq 0.05$) difference in the nutrient concentrations of the litter standing crop components, and between the peak of seasons (dry and rainy), where the litter standing crop at the peak of dry seasons were higher than the rainy seasons. At the peak of each season (dry and rainy), carbon exhibited the highest concentration while sodium exhibited the least of the nutrient element concentration (Table 1). At the peak of the dry season (January), leaf litter had higher concentrations of N, Mg, Fe and Zn, while twig litter had higher concentrations of P, C, Ca, K, Mn, Cu and Na. A similar trend was observed during the peak of the rainy season (September) where leaf litter had higher concentrations C, P, K and Cu, while twig litter fraction had Zn (Table 1). The elements were grouped according to their order of concentrations in the litter fractions: C > Ca > N > K > Mg > Fe > P > Zn > Mn > Cu > Na in leaf litter during the peak of dry season (Table 1). Similar trend was observed in the twig litter, with nutrient concentration Mn > Zn. In the peak of the rainy season, the order of element concentration was C > N > K > Ca > Mg > Fe > P > Mn > Zn > Cu > Na in leaf litter (Table 1).

Nutrient deposition through litter fall in bamboo stands

There was a significant difference in the deposition of the elements by litter fall components ($p \leq 0.001$). Highest amount of carbon and least

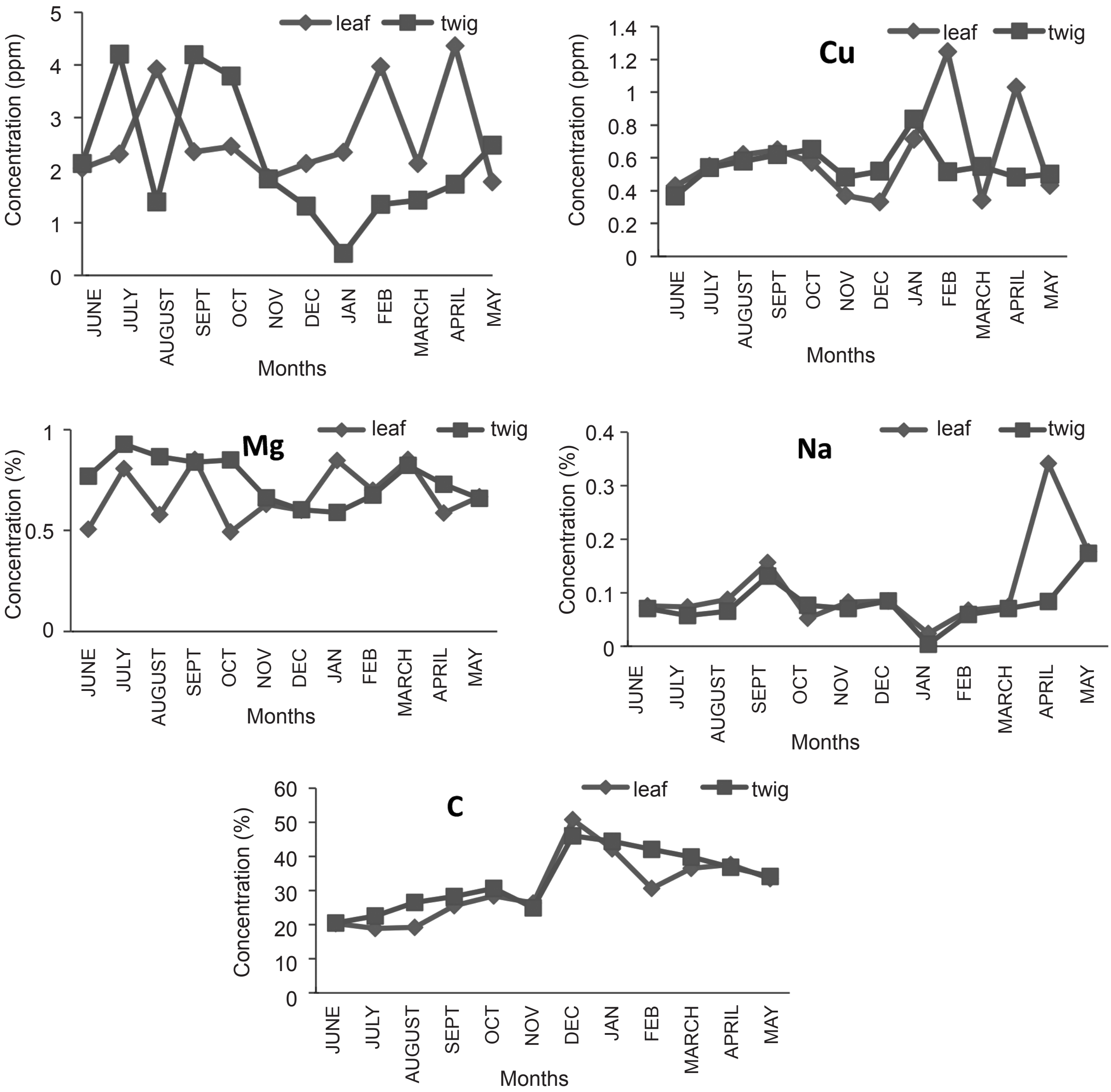

Figure 2B Monthly nutrient concentration of litter fall in bamboo stands in a secondary rainforest within the Biological Garden of Obafemi Awolowo University, Ile-Ife

amount of N were deposited in bamboo stands of the secondary rainforest, through litter fall (Table 2).

The leaf litter fraction deposited higher nutrients than twig litter. The annual deposition of nutrients in total litter fall of bamboo stands (kg ha^{-1} yr^{-1}) was: C (4529.5) > Ca (213.2) > N (186.9) > Mg (94.3) > K (56.2) > Fe (0.90) > P (0.40) >Mn (0.07) > Zn (0.03) > Cu (0.009) > Na (0.001). The litter fall components were grouped in the order of their deposition of elements within the bamboo stands as leaf litter > twig litter (Table 2).

Soil properties of the plots

Soil properties of the plots studied are shown in Table 3. There was a significant ($p < 0.05$) difference in soil pH between bamboo stands and other areas of the forest. The soil pH in bamboo stands was moderately acidic (5.80), while plots in other areas were alkaline (7.48). The soil particle size showed that the sand fraction was dominant in the plots. There was a significant difference in percentage of sand, clay and silt between the plots, where silt and clay content were higher in bamboo plots than other areas. The textural class

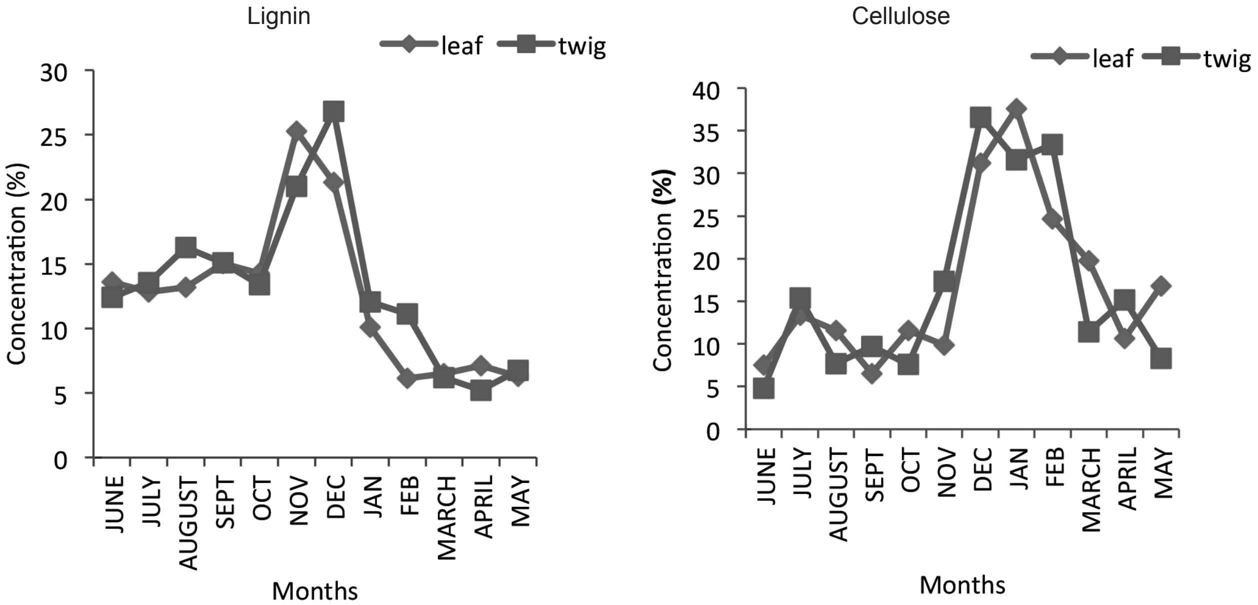

Figure 3 Monthly concentration of lignin and cellulose in litter fall in the bamboo stands in a secondary rainforest within the Biological Garden of Obafemi Awolowo University, Ile-Ife

Table 1 Variation in concentrations of nutrient elements in the litter standing crop components of bamboo stands at the peak of the two seasons in a secondary rainforest within the Biological Garden of Obafemi Awolowo University, Ile-Ife, Nigeria

Parameters	Season			
	Dry		Rainy	
	Leaf	Twig	Leaf	Twig
Ca (%)	1.86 ± 0.04[a]	1.87 ± 0.04[b]	0.46 ± 0.02[d]	0.58 ± 0.03[c]
Mg (%)	0.41 ± 0.02[a]	0.32 ± 0.01[b]	0.18 ± 0.01[c]	0.16 ± 0.01[d]
K (%)	0.64 ± 0.03[b]	0.77 ± 0.02[a]	0.59 ± 0.02[c]	0.43 ± 0.01[d]
N (%)	1.70 ± 0.03[b]	1.16 ± 0.02[c]	1.76 ± 0.02[a]	1.13 ± 0.01[d]
C (%)	29.21 ± 0.15[b]	30.60 ± 0.20[a]	21.66 ± 0.18[c]	19.47 ± 0.11[d]
Na (ppm)	0.07 ± 0.001[a]	0.08 ± 0.001[a]	0.07 ± 0.001[a]	0.08 ± 0.001[a]
P (ppm)	6.12 ± 0.005[a]	8.96 ± 0.004[b]	3.54 ± 0.003[c]	2.73 ± 0.002[d]
Mn(ppm)	2.07 ± 0.002[b]	2.63 ± 0.002[a]	1.38 ± 0.001[d]	1.65 ± 0.002[c]
Fe (ppm)	63.7 ± 0.09[a]	55.71 ± 0.07[b]	39.34 ± 0.04[c]	34.71 ± 0.03[d]
Zn (ppm)	2.31 ± 0.02[a]	1.41 ± 0.01[b]	0.94 ± 0.01[c]	1.26 ± 0.02[d]
Cu (ppm)	0.59 ± 0.02[a]	1.29 ± 0.04[b]	0.43± 0.01[c]	0.37 ± 0.01[d]
Lignin (%)	6.03 ± 0.02[c]	10.14 ± 0.01[b]	5.74 ± 0.03[d]	11.32 ± 0.01[a]
Cellulose (%)	32.01 ± 0.05[a]	5.65 ± 0.02[d]	29.86 ± 0.03[b]	8.61 ± 0.01[c]

*Values with the same alphabet, along a row for each parameter, were not significantly different ($p > 0.05$), analysed using Duncan Multiple Range Test (DMRT)

in the plots was sandy clay. The percentage of organic carbon and organic matter was 0.54 and 0.94 % in bamboo plots, and 1.89 and 3.26 % in other areas. The percentage of organic carbon and matter was significantly lower in bamboo plots than other areas (Table 3).

Total nitrogen content, available phosphorus and potassium showed significant difference between the plots ($p < 0.05$) (Table 3). Total nitrogen content and available phosphorus were significantly higher in bamboo plots than other plots, but significantly lower in potassium. The

Table 2 Annual nutrient element deposition (Kg ha^{-1} yr^{-1}) via litter fall and percentage contribution of litter components of bamboo stands in a secondary rainforest within the Biological Garden of Obafemi Awolowo University, Ile-Ife, Nigeria

Elements	Total	Leaves		Twig	
	Kg ha^{-1} yr^{-1}	Kg ha^{-1} yr^{-1}	%	Kg ha^{-1} yr^{-1}	%
Ca	213.19	158.76	74.47	54.43	25.53
Mg	94.29	67.99	72.11	26.3	27.89
K	56.23	41.65	74.07	14.58	25.93
Na	0.00138	0.00111	80.43	0.00027	19.57
P	0.44	0.34	77.27	0.11	22.73
Mn	0.075	0.057	76	0.018	24
Fe	0.87	0.64	73.56	0.23	26.44
Zn	0.0333	0.0257	77.18	0.0076	22.82
Cu	0.009	0.006	66.67	0.003	33.33
N	186.98	143.5	76.75	43.48	23.25
C	4529.46	3376.59	74.55	1152.87	25.45

Table 3 Summary of soil properties of the study sites in a secondary rainforest within the Biological Garden of Obafemi Awolowo University, Ile-Ife, Nigeria

Soil property	Bamboo plots	Plots in other areas without bamboo
pH (0.01 M $CaCl_2$)	5.80 ± 0.07^b	7.48 ± 0.08^a
Sand (%)	71.00 ± 2.36^b	78.50 ± 2.40^a
Silt (%)	9.00 ± 1.74^a	7.30 ± 1.00^b
Clay (%)	20.00 ± 2.33^a	14.20 ± 1.51^b
Textural class	Sandy clay	Sandy clay
Organic carbon (%)	0.54 ± 0.08^b	1.89 ± 0.14^a
Organic matter (%)	0.94 ± 0.14^b	3.26 ± 0.26^a
Total nitrogen (%)	3.01 ± 0.21^a	0.27 ± 0.02^b
Available P (ppm)	207.27 ± 21.17^a	196.08 ± 4.50^b
Cations		
Ca (kg/ha)	828.89 ± 17.70^b	1878.6 ± 14.77^a
Mg (kg/ha)	171.45 ± 5.79^b	418.176 ± 5.74^a
K (kg/ha)	18.87 ± 4.26^b	127.22 ± 1.17^a
Na (kg/ha)	39.83 ± 0.016^b	104.60 ± 0.85^a
Mn (ppm)	16.85 ± 3.63^b	17.87 ± 3.44^a
Fe (ppm)	97.73 ± 20.19^b	150.78 ± 16.03^a
zn (ppm)	4.50 ± 1.56^b	8.39 ± 1.38^a
Cu (ppm)	1.07 ± 0.51^b	2.040.38^a

*Values with the same alphabet along a row were not significantly different ($p > 0.05$), analysed using DMRT; data are expressed as mean ± standard error

concentration of cations (Ca, Mg, K, Na, Mn, Zn, Fe and Cu) within the plots showed significant difference, where values recorded in bamboo stands were lower than soils in other areas within the forest.

The soils of the plots had a preponderance of calcium among exchangeable cations. The cations were in the following order: $Ca^{2+} > Mg^{2+} > Na^+ > K^+ > Fe^{2+} > Mn^{2+} > Zn^{2+} > Cu^{2+}$ (Table 3).

DISCUSSION

Nutrient concentration in litter fall and litter standing crop of bamboo stands

The higher concentration of C, than other nutrients, may be attributed to the high carbon sequestration ability of bamboo species which is consistent with previous findings (Anonymous, 1997, Zhou et al. 2005). The lower concentrations of Na, observed in litter component, was probably due to the fact that it might have been readily leached out before litter fall, as observed by Shanmughavel et al. (2001).

The proportion of nutrient concentrations was in the order of C > Ca > N > Mg > K > Fe > P > Mn > Zn > Cu > Na, except for twig, where the proportion of N was greater than Ca. The observations recorded in this study was similar to the trend reported by Pai-hui (1985), where the concentration of nutrients in the bamboo species (*Phyllostachys pubescens*) was in the order of N > K > P. However this contradicts the order of nutrient concentration (K > N > P) reported for different bamboo species (Seth et al. 1963, Rao & Ramakrishnan 1989, Joshi et al. 1990, Shanmughavel et al. 2001). The observation made in the twig component (N > Ca) is consistent with the findings of Shanmughavel et al. (2001).

The monthly lignin content in litter fall components of bamboo stands in secondary rainforest ranged from 12.36–48.15% in this study, compared with 20–25% for bamboo species (Liese 1992), 22.06 and 29.4% for *B. vulgaris* var. *vittata* and *B. vulgaris* var. *vulgaris* culm (Dora 2008), 23.8, 26.1 and 25.3% for *Phyllostachys bissetii*, *P. bambusoides* and *P. nigra* respectively (Scurlock et al. 2000) and 21.26% for *B. vulgaris* culm (Ekebafe et al. 2010).

The cellulose content ranged from 12.34–69.18% in this study, compared with 50–70% for bamboo species (Liese 1992), 44.33 and 40.67% for *B. vulgaris* var. *vittata* and *B. vulgaris* var. *vulgaris* culm respectively (Dora 2008), 26.2–28.5%, 24.3–27 % and 25.2–28.5% for *Phyllostachys bissetii*, *P. bambusoides* and *P. nigra* respectively (Scurlock et al. 2000) and 47.51% for *B. vulgaris* culm (Ekebafe et al. 2010).

The general higher plant nutrient concentrations in litter standing crops, recorded during peaks of the dry and rainy seasons, were consistent with published results for other bamboo species (Youdi et al. 1985, Weih et al. 2005) and with the seasonal activity pattern of monopodial bamboos (Pai-hui 1985). Weih et al. (2005) reported that rainy season is a growing season when nutrient dilution through growth is at its peak, and consequently nutrient concentration is low, while the dry season has higher nutrient concentrations. This could be a result of little or no decomposition and leaching of nutrients from litter during dry season, and the low levels of organic matter may also account for this phenomenon.

Nutrient deposition of litter fall in bamboo stands

The annual nutrient depositions in this study were greater than the values reported for most studies carried out across the globe on bamboo species (Seth et al. 1963, Rao & Ramakrishnan 1989, Chandrashekara 1996, Isagi et al. 1997, Singh & Singh 1999, Kumar et al. 2005). The N content was similar but K and P content were relatively lower, ranging between 120–184, 10–16 and 101–183 kg ha^{-1} yr^{-1} for N, P and K deposition respectively, as reported by Shanmughavel et al. (2001) for *Bambusa bambos* plantation in India. In this study, the order of nutrient deposition was N > K > P. The annual deposition of nutrients through total litter fall for Ca and Mg was 213.2 and 94.3 kg ha^{-1} yr^{-1} respectively. These were greater than a previous study that reported a range of 60–91 and 66–96 kg $ha^{-1}yr^{-1}$ for Ca and Mg respectively, for *Bambusa bambos* plantation in India (Shanmughavel et al. 2001). The Ca content was relatively greater than most values reported for bamboo species across the globe.

The higher amounts of N, P and K deposition in this study, compared to other studies carried out across the globe, might be possible due to the nature of the species and climate, higher concentrations of nutrients in the litter fall and the age of the bamboo stands. The order, N > K> P, is in agreement with previous findings (Joshi et al. 1990, Tripathi & Singh 1994, Shanmughavel et al. 2001, Weih et al. 2005, Nath & Das 2012). The lower values observed in this study, compared to nutrient return in 4–6 years old *B. bambos* plantation, might be associated with the fast growth of *B. bambos* compared to other bamboo species, which produce more litter and consequently higher nutrients (Shanmughavel et al. 2001). The lower potassium deposition in this study, contrary to higher potassium deposition reported for different bamboo species across the globe, may be attributed to the fact that the stands were continuously harvested. These findings were consistent with the assertions that nutrient availability depends not only on the inherent fertility of soil, but also on whether bamboo stands were harvested, cultivated, and/or nutrients applied externally (Kleinhenz & Midmore 2001).

The higher carbon deposition in this study, compared to other elements, may be attributed to the higher carbon concentrations of the litter fall, and high carbon sequestration activity associated with bamboo. The age factor may play a key role towards greater nutrient input. Rao & Ramakrishnan (1989) reported that element storage in biomass and recycling of litter increased in older stands of bamboo. In this study, the maximum amount of nutrients were returned through leaf litter (74.57%) and minimum by twig litter (25.43%), which is in line with the trend observed by several authors (Joshi et al. 1990, Tripathi & Singh 1994, Shanmughavel et al. 2001, Weih et al. 2005, Nath & Das 2012). Maximum nutrients in the leaf may be attributed by the higher nutrient concentration of the leaves, than twig.

Soil properties of the plots

The results indicated that the soil of the bamboo plot was slightly acidic compared to other areas, which were slightly alkaline. Ayodele (1986) reported that the soil of the secondary rainforest was acidic, but contrary to this report, the findings revealed that it was slightly alkaline, with exemption of the bamboo stands. The general change from acidic to alkalinity in areas where the stands were not located, may be attributed to recovery from ground fire after 30 years, coupled with the fact that it contained a great deal of Na, Mg and Ca which influences soil alkalinity. The moderate acidity in bamboo stands, in contrast to the alkalinity reported in other areas, may be attributed to its ability to influence the soil pH where it thrives, and tends to favour an acidic environment. The results agree with observation made by Hariprasath et al. (2014), asserting that soil pH of *B. vulgaris* plantation was initially slightly alkaline but after five years, it became acidic.

The results of the particle-size distribution of the plots showed that the sand fraction was dominant, and the textural class was sandy clay. This implies that the particle size distribution is almost uniform across the soils of the Bamboo plots and other areas of the secondary rain forest. The higher percentage of organic carbon and matter observed in the soil of other areas, where the stands are not located, could indicate that they were more fertile than bamboo plots, as a result of higher decomposition of litter.

The higher total nitrogen content and available phosphorus, and lower available potassium in the soil of bamboo stand plots, compared to other areas, indicate that the soil in bamboo stands are better conservers of N and P. The result from the present study is consistent with the statement made by Rao & Ramakrishna (1989), who conclusively outlined that bamboos are conservers of nitrogen, phosphorus and potassium. However, the result was not applicable to K, where the lower concentrations observed could be attributed to the continuous harvesting of the bamboo stands.

The concentration of calcium was dominant among exchangeable cations in the Bamboo stands, probably due to higher calcium concentration accumulated through litter fall, which might have resulted in higher deposition. The higher exchangeable cations in other areas, compared to bamboo stand plots, could have influenced the fertility of the soil and distribution pattern characteristic in the secondary rainforest, as areas with high exchangeable cations were dominated by tree species, compared to areas where bamboo stands thrived.

CONCLUSION

Concentration of nutrients was higher in leaf (51.0%) than twig litter fall (49.0 %). In the litter standing crop, there was significant difference in the nutrient concentration between litter components and across the peak of dry and rainy season. The peak of dry season was significantly higher than the rainy season. The concentration of C was highest, while Na was lowest in both seasons. There was higher deposition of C and greater nutrient return, especially N and P, in litter fall components of the Bamboo stands. This gives an indication that Bamboo is a good conserver of nutrients. Continuous harvesting of the stands may have been the potent factor responsible for the lower pH and sandy soil, compared to other areas where the stands were not located, which might have influenced poor nutrient retention (organic C, organic matter and exchangeable cations). It is advisable to protect the stands from continuous harvesting as it could store N and P better, than other areas dominated by trees and shrub species, studied within the same secondary rainforest, which is crucial to the functioning of the forest ecosystem.

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