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RESEARCH ARTICLE

Estimation of Nutrient Levels and Nitrogen Stock of *Bambusa vulgaris* in Secondary Forest, Southwestern Nigeria

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Abstract: This study estimated the nutrient levels, nitrogen stock and biomass of Bamboo (*Bambusa vulgaris*) in Obafemi Awolowo University's secondary forest, southwestern Nigeria. Two study plots (25 m × 25 m) were established within the secondary forest in *Bambusa vulgaris* stands. The collections of litter materials were done using quadrats of 50 m × 50 m. The collected litter was sorted into leaf, twigs and trash, oven-dried at 80 °C to a constant weight and weighed. The results showed the order of nutrient accumulation in culm (live and dead) as follows: twig > bract > leaf. In the culm, the trend of nutrients was N > P > K. The total aboveground biomass in *Bambusa vulgaris* determined by destructive sampling was found to be 9.59 Mg ha^{-1} (addition of all components). Nitrogen stock was found to be 0.22 Mg ha^{-1}, with the highest in live culm (0.14) compared to other components and the lowest in dead culm (0.03 Mg ha^{-1}). The results revealed that the aboveground biomass using the allometric equation was 59.12 Mg ha^{-1}, and belowground biomass was 15.98 Mg ha^{-1}. These results implied that *Bambusa vulgaris* is a good nutrient and nitrogen store, especially in live culms and therefore has high potential in cycles of carbon and nutrients.

Keywords: Forest, Bamboo, Biomass, Nutrient levels, Nitrogen stock, Litter

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Introduction

The worldwide importance of bamboo (*Bambusa vulgaris*) as a fast-developing, renewable, and ecologically resilient plant has received great recognition in recent years, particularly within the context of sustainable land use and carbon sequestration (Ayer, 2025). Estimating the biomass, nutrient levels and nitrogen stock of *Bambusa valgaris* is vital for understanding the importance of this plant species in ecosystem carbon dynamics and functioning. Besides influencing plant growth and photosynthetic capacity, biomass and nutrient levels regulate microbial activity and soil fertility (Vitousek *et al*., 2010; Zhang *et al*., 2024). Bamboo species are known to efficiently cycle and absorb nutrients, and their litter can increase soil organic matter and nutrient availability (Singh *et al*., 2020).

Destructive sampling and allometric models have been reported to estimate biomass in bamboo, evaluating both above-ground biomass and below ground biomass components such as culms, branches, leaves and rhizomes (Yiping *et al*., 2010; Nath *et al*., 2015; Kigomo *et al*., 2025). For modelling carbon sequestration, sustainable harvesting and evaluation

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of ecosystem services, an accurate evaluation is necessary. As such, measuring carbon stocks and nutrient status in bamboo (*Bambusa vulgaris*) helps in developing natural solutions for climate-smart agriculture and the restoration of forest landscapes (FAO, 2020; Vadalà *et al*., 2022).

However, in the southwestern regions of Nigeria, the rate of degradation of forest ecosystems poses a critical threat to biodiversity, soil fertility, and the natural carbon balance (Olabode and David, 2024). With the extensive loss of primary forest, the secondary forests have become increasingly crucial for carbon sequestration and sustainable land management (Bieng *et al*., 2021). The previous research on bamboo (*Bambusa vulgaris*) biomass and nutrient dynamics was centred on Nigeria as a whole and plantation-based systems, with little attention paid to bamboo (*Bambusa vulgaris*) growing in a secondary forest at Obafemi Awolowo University, southwestern Nigeria.

Obafemi Awolowo University (OAU) Ile-Ife is characterized with a notable expanse of secondary forest, yet its capacity for contributing to ecosystem restoration and climate change mitigation remains underexplored. One of the most prominent plant species that grows in Obafemi Awolowo University Ile-Ife secondary forest is a bamboo species known as *Bambusa vulgaris*, which has been particularly noted for rapid growth, high biomass production, and purported improvement of soil nutrients and structure. The availability of empirical data on nutrient accumulation, nitrogen stock and biomass yield of *Bambusa vulgaris* in natural or semi-natural stands is scanty in southwestern Nigeria, particularly in the Obafemi Awolowo University environment. This prevents the development of site-specific forest restoration models and devalues the role of bamboo in campus-based climate resilience programs. Hence, this study estimates the biomass, nutrient levels and nitrogen stock of bamboo (*Bambusa vulgaris*) in southwestern Nigeria using Obafemi Awolowo University Ile-Ife secondary forest as a case study, not only to understand its ecological contributions but also to enhance its integration into sustainable landscape restoration, and inform forest carbon accounting initiatives in southwestern Nigeria and beyond.

Materials and Methods

Study area

This experiment was conducted in the secondary rainforest in the Biological Garden, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. Ile-Ife is located at a latitude of 7° 31' N and longitude 4° 30' E. Ile-Ife lies between 215 and 475 m above sea level (Hall, 1969). The current study location is located at latitude 7° 31.417' to 7° 31.422' N and longitude 4° 31.422' to 4° 31.455' E. The elevation of the areas varies between 302 and 329 meters above sea level. The tropical climate of Ile-Ife has two seasons: the dry season (November-March) and the rainy season (March-November). The annual rainfall is bimodal, peaking in July and September, and the mean temperature varies between 27 and 34 degrees Celsius (Oke and Isichei, 1997). Rainfall averages 1400 mm yr^{-1} per year. However, the average annual rainfall was 1302 mm, and the 2013 climatic survey, by the Atmospheric Physics Research Group, Department of Physics and Engineering Physics, Obafemi Awolowo University, Ile Ife, reported the average temperature to be 25.5 °C, the average relative humidity to be 82.80, the average solar radiation to be 164.30 Wm^{-2} and the average wind speed to be 2.06 km/h. According to Onochie (1979), the Ile-Ife region is situated in a dry deciduous woodland zone. White (1983) classifies the vegetation as a Guineo-Congolian drier type. The plant families most frequently found in the secondary rainforest are the Apocynaceae, Euphorbiaceae, Mimosaceae, Moraceae, Rubiaceae, and Sapindaceae (Awokoya, 2003). The geologic rock strata is dominated by granite, gneiss, schists, and minor types of rocks, such as pegmatite.

The soil is either Oxisols or Ultisols (USDA, 1975). Soils that have less than 10% clay with kaolinite as the dominant type have reduced cation exchange capacity and low water retention capacity (Ayodele, 1986). Fig. 1 indicates the map of the study area.

Data collection and sampling procedures

Two study plots, each 25m x 25m and with *Bambusa vulgaris* stands were marked with thin cut-lines in the secondary rainforest.

Litter standing crop

Each plot of the *Bambusa vulgaris* was randomly

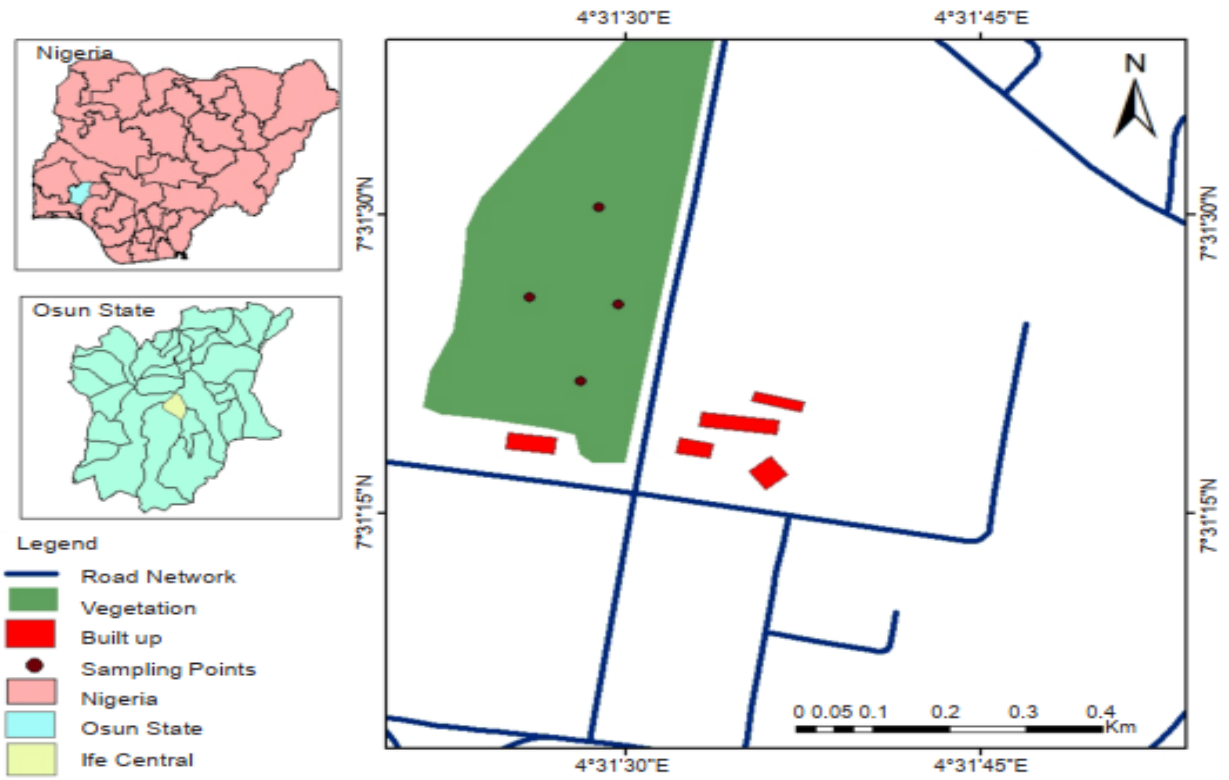

Fig 1. Map of the study area , Source: Borisade and Odiwe (2018)

covered with three 50 cm x 50 cm quadrats. All litter in each quadrat was collected, stored in polythene bags, labelled, and carried to the laboratory where it was separated into three fractions: ie., leaves, twigs and rubbish (less than 3.25 cm in diameter). Samples were oven dried overnight at 80 °C and weighed at periodic intervals till a constant weight was attained. Following the determination of the oven-dried weight of each fraction for each plot, the leaf fractions were pooled separately from the twig fractions for subsequent analysis. The litter components were dried in the oven and ground to a fine powder before chemical analysis was done using a 0.5 mm screen. They were tested for nitrogen, potassium, sodium, phosphorus, and calcium.

Plant collection

Samples of bracts, dead culm, and live culm were collected from each clump, emptied into polythene bags, tagged, and transported to the laboratory. Samples were oven dried overnight at 80 °C and weighed. at periodic intervals till a constant weight was attained. The samples were ground after ovendrying to a constant weight and their calcium, phosphorus, sodium, potassium, and nitrogen contents were measured (Anderson and Ingram, 1994).

Soil sampling

A soil auger was used to collect the six soil samples from randomly selected sites in the bamboo stand. The samples were collected from the top and sub soils and at depths of 0-15 and 15-30 cm. The exchangeable cations (Na^+, Ca^{2+}, K^+), total nitrogen and phosphorus in the dried soil samples were determined. The soil samples were collected and labelled with a polythene bag and taken to the laboratory. The samples of the soil were filtered using a chrome steel sieve with a diameter of 2 mm and allowed to air dry in the laboratory (Anderson and Ingram, 1994; Agbede, 2009).

Soil bulk density

The core method was used for soil bulk density estimation as defined by Blake and Hartge (1986). Each survey plot was sampled by collecting undisturbed soil using a soil core sampler and dried at 80 ^oC until reaching a constant weight and then computed.

Bulk density = weight of soil (g) / Volume of the soil (cm)

Estimation of biomass

Bamboo stand biomass was estimated by the non destructive / indirect approach as outlined by Vashum and Jayakumar (2012). Ten clumps were sampled, and samples of live, dead, and bract culms from each clump were collected, labelled, and their fresh and dry weights determined in the laboratory. The height of twenty culms from each clump was measured and recorded, as was the diameter of the culms at breast height (1.36 m) using a measuring tape and the data was fitted to three different allometric models that are being generally used for biomass estimation of *Bambusa vulgaris* in secondary forests. To assess the strength of their link, bivariate analysis was applied to these equations.

Estimation of above-ground biomass

The above-ground biomass of the live culm was calculated using an already-reported allometric equation as follows;

AGB (kg) = ln Y = 4.298 + 2.647 ln DBH (Kumar *et al*., 2005) …….(1)

The dry weights of the samples were converted to Mg/ha to determine the aboveground biomass of other components, such as dead culm, litter, and sand bracts. The optimum allometric equations for estimating the total biomass of the bamboo stand in the forest ecosystem were predicted using regression analysis. The following allometric equations were used in the estimations:

Y = - 3225.8 + 1730.54 DBH (Kumar *et al*., 2005) .....(2)

Y = 245.389 + 131.714 (D^2H) (Borisade *et al.,* 2018) ...(3)

Y = 11.403 + 0.0006 (D^2H) (Sohel *et al.,* 2015) ……(4)

Where Y = biomass (kg), D = DBH (cm)

H = height, $r^2 = 0.88$

Estimation of below-ground biomass

Based on the assumption of the root-to-shoot ratio, the above-ground biomass was multiplied by 0.27 to estimate the below-ground biomass (BGB) for each clump (Snowdown *et al*., 2000; Ravindranath and Ostwald, 2008) i.e.

BGB (kg) = 0.27 × Above-ground biomass (kg)... (5)

The equations proposed by Kumar *et al*. (2005) and Sohel *et al*. (2015), and Borisade *et al*. (2019), were chosen to be used since they had been developed on *Bambusa vulgaris* and related species of bamboo in a tropical setting. These models also use diameter at breast height (DBH) and, in some instances, culm height (D^2H), hence uses measurable information in estimating biomass components, such as live, dead and bract culms. They are have been used in other similar ecological settings, such as secondary forest environments where bamboo makes up a significant part of the vegetation.

Any difference between directly measured biomass and biomass estimated with the use of allometric equations could be because of site-specific distribution of culm density, age structure, and growth conditions, which affect the precision of the generalized equations.

Estimation of nitrogen stock

The bulk density (g/cm^3), nitrogen concentration (%), and depth (30 cm) were multiplied to determine the soil nitrogen stock. The carbon stock of the standing crop litter was calculated by multiplying the biomass (kg) by the nitrogen concentration (%), and then multiplying the result by 0.01 to convert it to Mg ha^{-1} (Batjes, 1996; Jobbágy and Jackson, 2000; Barnard and Bauerle, 2013).

Data and statistical analysis

The t-test was used to determine whether the amount of nutrients in the live and dead culms differed significantly. To ensure that the analysis of variance (ANOVA) assumptions were fulfilled, the data were first checked for homogeneity and normality. One-way analysis of variance was used to determine whether the bamboo's leaves, twigs, and bracts differed significantly, and the Tukey post-hoc test was used to distinguish between the significant mean. SAS version (8.0) was used to analyze the data, and the significance level was set at $P < 0.05$.

Results

Nitrogen, sodium, potassium, calcium and phosphorus concentrations (%) in the litter component of bamboo stands in secondary forests

The results indicated a significant difference ($p < 0.05$)

in the concentrations of nitrogen, sodium, potassium, calcium, and phosphorus in the litter components (leaf, twig, and bract), with the leaf showing significantly lower levels compared to the twig and bract. However, there was no significant difference between the twig and bract components. The results revealed that the concentrations of these nutrients followed the order: twig > bract > leaf (Fig. 2).

Nutrient concentration (%) in culms (Live and Dead)

The results showed that there was no significant difference ($p < 0.05$) in the nitrogen, sodium, potassium, calcium, and phosphorus concentrations in the live and dead culms (Fig. 3).

Estimation of biomass in the bamboo stand

The results obtained from multiple regression analysis of the tree allometric equations used for estimating the biomass of *Bambusa vulgaris* in the secondary forest showed that allometric equations B and C had similar values. These equations were further subjected to bivariate analysis to evaluate the strength of their relationship ($r = 1$, $p = 4.418E10\text{-}32$). The results indicated a perfect relationship between the two equations (B, C), and therefore, both the models were found to correctly estimate the biomass of the *Bambusa vulgaris* stands in the forest (Table 1)

Biomass estimation and nitrogen stock of Bambusa vulgaris stands

The results indicated that the biomass of different components determined by measurements in the *Bambusa vulgaris* was significantly higher in live culms (5.75 Mg ha^{-1}) than in dead culms (0.19 Mg ha^{-1}), litters (2.06 Mg ha^{-1}), and bracts (1.63 Mg ha^{-1}). The total aboveground biomass in *Bambusa vulgaris* determined by measurement was found to be 9.59 Mg ha^{-1} (sum of all components). The findings showed that aboveground biomass estimated using the allometric equation was 59.12 Mg ha^{-1}, followed by belowground (15.98 Mg ha^{-1}). The results revealed that the total nitrogen stock was found to be 0.189 Mg ha^{-1}, with the highest recorded in live culms (0.14) compared to other components and the lowest in dead culms (0.0036 Mg ha^{-1}) (Table 2).

Discussion

The exchangeable cations (Na^+, Ca^{2+}, K^+), total nitrogen (N) and phosphorus (P) are some of the major soil nutrients that determine the soil fertility, soil structure and food production. Exchangeable cations are positive-charged ions, which are adsorbed to negatively charged surfaces of clay and organic matter, which affect soil chemistry and nutrient retention (Brady *et al*., 2008). Calcium (Ca^{2+}) promotes growth of the root, cell wall, and soil structure by flocculating the clay (Tisdale and Nelson, 1966), while potassium (K^+) by controls the osmotic potential, enzyme activities, and drought tolerance (Sparks, 2003). Though not essential, sodium (Na^+) to some extent substitutes potassium, but in excessive content, causes soil sodicity, which lowers permeability and fertility (Sumner and Naidu,

Table 1. Multiple regression analysis of allometric equations used for estimating the biomass of *Bambusa vulgaris* in the secondary forest

Variable	N	R^2	Multiple R^2 adjusted	F	P
A	10	- 0.53	- 0.96	- 1.21	1
B	10	1	1	1.971E08	7.47E-28
C	10	1	1	1.971E08	7.47E-28

A = kumar *et al*., 2015

B = Borisade *et al*., 2018

C = Sohel *et al*., 2005

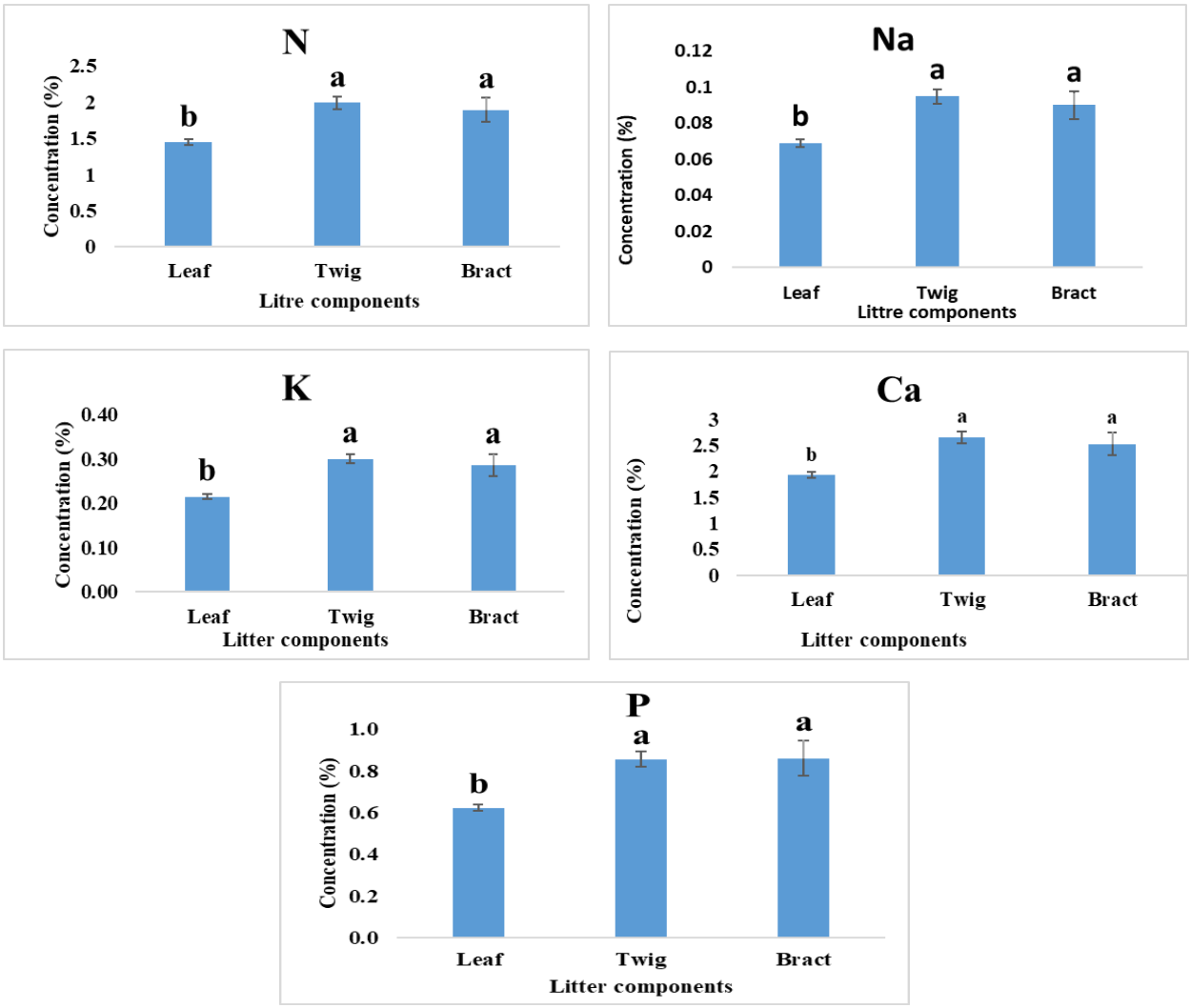

Fig 2. Concentrations (%) of nitrogen, sodium, potassium, calcium and phosphorus in the litter components (leaf, twig and bract) of bamboo stands

1998). These cations, in their proportions, determine the cation exchange capacity (CEC) and base saturation, which determine nutrient buffering and availability. Total nitrogen is an inorganic and essential element of proteins, nucleic acids, and chlorophyll that is present in organic and inorganic forms and is available under the condition of mineralization (Stevenson and Cole, 1999; Brady *et al*., 2008). Nitrogen aids litter decomposition and microbial processes in forest and bamboo ecosystems, which increases carbon sequestration (Cheng *et al*., 2022). The macro nutrient phosphorus, which is essential in the transfer of energy, development of roots, and division of cells, is frequently bound by Fe^{3+} and Al^{3+} in acidic soils, thus it becomes inaccessible. Nevertheless, bamboo is efficient in phosphorus recycling, litter breakdown, and root turnover processes, which keep soil fertile (Sanchez, 2019).

The order of nutrient accumulation that was observed in this study was live culms > twig > bract > leaf > dead culm which is consistent with the trend that was reported for other bamboo species (Rao and Ramakrishnan, 1989 for *Dendrocalamus strictus* and *Dendrocalamus hamilonii*). The trend of N > P > K obtained in the culm, leaf, twig and bracts in this study differs from the trend of K > N > P that was reported by Seth *et al*. (1963) and Rao and Ramakrishnan (1989). Pai-hui (1985) also reported a different trend of N > K > P. Nutrient distribution is influenced not only by species but also by age, management intensity, and site-specific edaphic

factors (Estrada-Villegas *et al*., 2020; Becker *et al*., 2023). These differences call for localized nutrient profiles to facilitate bamboo-based nutrient budgeting methods and ecological restoration.

The total biomass (aboveground + belowground) obtained in this study using allometric equations (75.06 Mg ha^{-1}) is higher compared to the range of 30.8 – 36.1 Mg ha^{-1} reported by Yen (2015) for *Dendrocalamus hamiltonii*; 6-7 Mg ha^{-1} for *B. vulgaris* by Clinte (1965); 36.67 Mg ha^{-1} reported by Clinte (1965) for 3 year old bamboo plantation; 51.4 Mg ha^{-1}, 48.5 Mg ha^{-1}, 46.8 Mg ha^{-1} reported for *D. hamiltonii*, *B. vulgaris* and *D. membranaceus,* respectively (Alemayehu *et al*., 2015). However, the result of biomass in this study is smaller compared to the values of 297 Mg ha^{-1} by (Yen, 2015); 110 Mg/ha (Embaye, 2003) and 99 Mg ha^{-1} (Yigardu, 2012) for different bamboo species. The lower values obtained in this study might be a function of the lower estimated biomass and different sample size used in other studies. Values of biomass vary widely with species ecological conditions, age and methodology emphasizing the call for site-specific assessments in the evaluation of biomass (Ibitoye *et al*., 2023; Biah *et al*., 2025).

The percentage contribution (59.87%) of live culms to the total aboveground biomass of *B. vulgaris* recorded in this study is similar to the values of 50.32% and 67% recorded for *Dendrocalamus hamiltonii* by Alemayehu *et al*. (2015) and Yen (2015), respectively, However, it was higher than the value of 18.82% for *Guadua amplexifolia* reported by Alemayehu *et al*. (2015); lower compared with the value of 82% reported by by Isagi *et al*. (1997); 82% by Sohel *et al*. (2015) for *B. vulgaris* and 85.13% reported by Borishade *et al*. (2015) in the same secondary forest. The difference between the values obtained in this study and the previous study in the same forest might be a function of the methodology used. Borisade *et al*. (2015) used destructive methods and recorded the dry weights of the components, unlike the non-destructive method that was used in this study. Recent studies from Ghana's humid forests report culm contributions averaging 77 % of aboveground biomass (Adu-Poku *et al*., 2023). These more recent findings affirmed that live culms commonly dominate bamboo biomass allocation, with percentages various by species, stand density, and ecological situations. Differences among this and earlier values possibly stem from methodological differences: destructive sampling often yields higher culm proportions as compared to non-destructive estimations employed

Table 2. Summary of the biomass estimation and nitrogen stock of *Bambusa vulgaris* stands in Obafemi Awolowo University's secondary forest

Components	Biomass (Mg ha^{-1})	Nitrogen Stock (Mg ha^{-1})
Above-ground biomass (by measurement):		
Live culm	5.75	0.14
Dead culm	0.19	0.03
Litter	2.08	0.06
Bract	1.63	0.05
BGB	Not determined	
Total	9.59	0.21
AGB by allometric equation	59.12	59.18
Below-Ground Biomass:	15.98	15.99
Soil	----	114.39

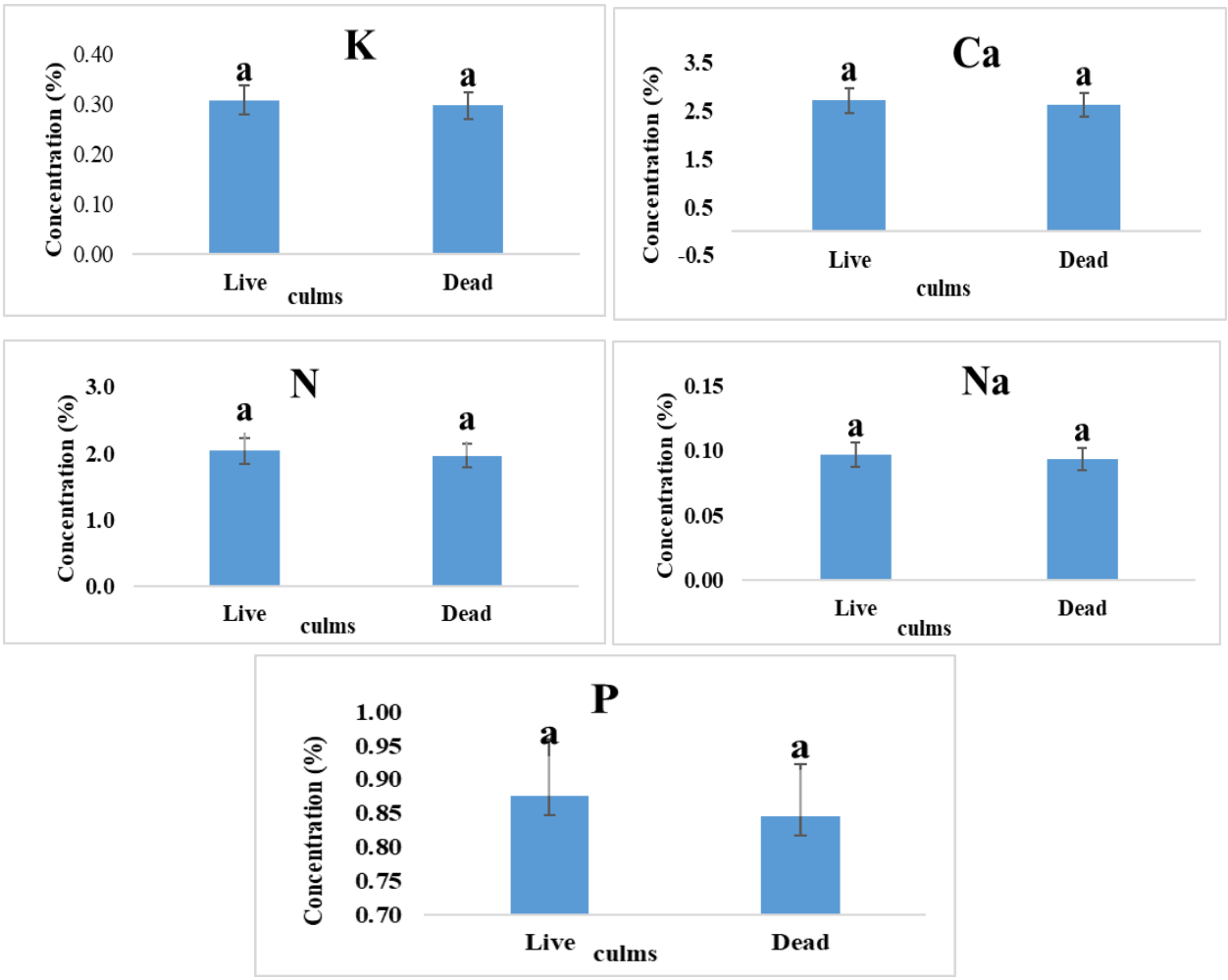

Fig 3. Concentrations (%) of Nitrogen, Sodium, Potassium, Calcium and Phosphorus in the culms, (live and dead) of bamboo stands

in the study.

The results showed that the aboveground biomass for *Bambusa vulgaris* (9.59 Mg ha^{-1}) greatly underestimates the true stand carbon pool, in contrast to allometric estimations (59.12 Mg ha^{-1} AGB; 15.98 Mg ha^{-1} BGB). The difference between directly measured biomass (9.59 Mg ha^{-1}) and biomass estimated with the use of the allometric equations (59.12 Mg ha^{-1}) could be because of site-specific distribution of culm density, age structure, and growth conditions which affect the precision of the generalized equations. Thus, these models can be applied to *Bambusa vulgaris* but the calibration by local parameters is suggested to enhance precision in estimations. The findings showed that while the biomass from live culms was the greatest (5.75 Mg ha^{-1}), followed by litter, bracts, and dead culms, the nitrogen stock was concentrated in live culms (0.14 Mg ha^{-1}). These trends are consistent with research conducted in Cameroon by Kaam *et al*. (2023), which found that culms made up almost 77% of AGB and that total carbon stocks were approximately 131 t C ha^{-1}. Studies in Nigerian secondary forests have proven that mature *B. vulgaris* stands can attain 60 t C ha^{-1} (Borisade *et al*., 2018; Isukuru *et al*., 2023). According to these comparisons, the observed lower measured biomass is possibly the result of non-destructive sampling or younger stands. Because differences in clump age, size, stem density and analytical approach have an extensive impact on biomass estimates and nitrogen stock, age- and site-specific allometric models are required for precise carbon estimation in bamboo stands.

Conclusion

This study provided valuable insights into the nutrient concentration, nitrogen stock, and biomass distribution of *Bambusa vulgaris* within the secondary forest ecosystem of Obafemi Awolowo University. The findings indicated that the nutritional elements were distributed hierarchically between the parts of the plant, with the levels of nitrogen, calcium, potassium, phosphorus, and sodium being much more concentrated in the bracts and the twigs compared to the leaves, and no difference was observed between the live and dead culms. Biomass assessment showed that there was a significant difference between directly measured biomass (9.59 Mg ha^{-1}) and the allometric model estimates (59.12 Mg ha^{-1} AGB and 15.98 Mg ha^{-1} BGB) which highlighted the weakness of the non-destructive methods in capturing the actual carbon pools. The highest proportion of total aboveground biomass (59.87) was live culms, and nitrogen stock was concentrated in the first component (0.14 Mg ha^{-1}), which is of great significance in the accumulation of nutrients and productivity of the ecosystem. The results showed that it is important to design localized, species and site-specific allometric equations to enhance the biomass and carbon stock estimation in the *Bambusa vulgaris* stands. Generally, the research contributes to the knowledge of the ecological value of the species in terms of nutrient cycling, carbon sequestration as well as its recovery potential in degraded tropical landscapes.

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