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Original Article

Culm Density and Biomass Variation across Forest Type and Age Gradient of Oxytenanthera abyssinica (A. Rich.) Munro, in north-western Ethiopia

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ABSTRACT

Lowland bamboo (*Oxytenanthera abyssinica*) forest resources are most promising in Northwestern Ethiopia. The area's surrounding bamboo forest is significant both environmentally, economically, and socially. Nonetheless, no particular research has been done to ascertain the differences in biomass for the various sections of bamboo in both plantations and natural bamboo stands. Therefore, the purpose of this study was to determine the culm density and biomass variation across forest type and age gradients of *Oxytenanthera abyssinica* stand in Pawe, northwestern Ethiopia. One hundred eight (108) bamboo culms (54 from the plantations and 54 from the natural bamboo stands) were sampled destructively. After that, each of the specimens was divided into three sections (leaf, branch, and culm). The fresh weight of the sample and the total fresh weight of each portion were ascertained instantly. Then, samples were brought to the testing center for dry weight analysis, bundled in a paper bag. The data was subjected to descriptive statistical analysis employing R software. As the result showed, the mean height and diameter for the plantation stand ranged between 9, 13.2 m, 3.4 cm, and 6.4 cm, respectively, and the natural bamboo forest has mean height and diameter ranging between 6.35 and 12 m and 2.0 and 4.4 cm, respectively. The mean density of 0.51 g/cm^3 for plantations and 0.41 g/cm^3 for natural bamboo forests was recorded. Compared to natural forests, managed bamboo forests (stands) exhibit an increase of 17% in overall biomass production. While density rose with age, the medium-aged bamboo group in both forest types accumulated more above-ground biomass than the younger and older age groups.

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INTRODUCTION

The common term "bamboo" refers to a member of a particular biological group within the Poaceae and Bambusoideae subfamily of big perennial grasses. All over the world, there are thought to be more than 1642 different species of bamboo (Vorontsova et al., 2016). It is the fastest, renewable, widely available and environmentally friendly species. Bamboo has a substantial impact to reduce poverty and safeguard the environment (Yen et al., 2010). This exceptional growth ability makes bamboo a valuable carbon sink. It has critical socioeconomic and environmental benefits, notably climate change adaptation by carbon sequestration, biodiversity conservation, and larger ecosystem adaptability to its distinctiveness (Embaye et al., 2005; Abebe et al., 2023; Alemayehu and Hido, 2023).

Bamboo can be found on every continent except Antarctica, where plants have difficulty surviving. Worldwide, thirty-five million hectares of land are covered in bamboo (FAO, 2020; Mulatu et al., 2012). In Africa, there are around 115 bamboo species identified in 48 nations, which covers a total of 4.56 million hectare. Ethiopia, along with Kenya and Uganda, accounts for 86% of African bamboo resources. The area of all bamboo forests worldwide is made up of 7% and 67%, respectively, by Ethiopia alone, making Ethiopia the most significant African country in bamboo production. Ethiopia has two indigenous bamboo species. This are highland bamboo (*Oldeania alpine)* and low land bamboo (*Oxytenanthera abyssinica)* (Yigardu et al., 219). As the International Bamboo and Rattan Organization (INBAR) recently announced, Ethiopia's bamboo reaches 1.47 million hectares (EEFCCC and INBAR, 2020) and is spread across the nation (Kassahun et al., 2015). From the total area, about 85% is covered *by Oxytenanthera abyssinica*, whereas *Oldeania alpina* makes up 15% of the overall bamboo cover. Afromontane forests with volcanic soils are the ideal environments for growing highland bamboo (Yigardu et al., 2019). It mainly grows in Amhara, Oromia, and SNNP. On the other hand, lowland bamboo is found mostly in the North and South Western regions like Benishangul Gumuz, Amhara, Gambella and Oromia, where it grows naturally in groves (Mulatu and Fetene, 2014; Lin et al., 2019; Yigardu et al., 2019; Alemayehu and Hido, 2023).

The goal of managing native bamboo ecosystems in the tropical regions, and tropical Africa specifically should be to prevent a worldwide shortage of forest products and maintain the sustainable production capacity of these forests (Mulatu & Kindu., 2010; Terefe et al., 2016). In developing nations, for example, Ethiopia, forest destruction and its repercussions have hampered socioeconomic development as well as growth (Sharma & Baral, 2018; Embaye et al., 2003). Thus, wise utilization of forest resources is critical in these nations to conserve forests on a 'use or lose' basis (FAO, 2020).

According to Yen (2016), forests ought to be managed to achieve maximum productivity without substantially compromising their capacity for long-term expansion and provision of environmental service. The long-term viability of the forest ecosystem is determined by the capacity of the environment to deliver enough nutrients, the quality of the base material, its capacity for regeneration, and the effective use and reuse of plant material (Verwijst et al., 2013). Li et al.

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(2000) and Verwijst et al. (2013) claim that silvicultural management suggestively affects the fluctuations in vegetative growth of bamboo. For instance, within two to three months, the rhizome system-connected trees' nutrient supply will be entirely responsible for the establishment of new shoot. This indicates the influence of management on biomass production and the carbon stock potential of bamboo forests.

Embaye et al. (2005) examined the biomass and dynamics of bamboo growth in planted forests. Yebeyen et al. (2022) used allometric equation models to compute the biomass and carbon storage prospective of high land bamboo forests in south-western Ethiopia. Similarly, Abebe et al. (2021) examined the biomass accumulation and carbon storage capability of highland bamboo. Terefe et al. (2016) investigated the growth characteristics and biomass accumulation of *Oxytenanthera abyssinica*, in West Shoa, Ethiopia. Despite this, biomass and culm density variation across age gradients in natural and plantation bamboo forests of Africa and specifically to Ethiopia have not been well studied (Terefe et al., 2016; Li et al., 2000). The two indigenous bamboo species have significantly contributed to Ethiopia's carbon sequestration potential, even though the sequestration potential varied across age, forest type, and vegetative parts of the culm.

Thus, the aim of this study was to inspect the biomass variation and culm density across forest type and age gradients of lowland bamboo in Pawe, north-western Ethiopia. The study mainly focused on describing the variations in biomass and carbon storage across age gradients and forest types (plantation and natural). The researchers ultimately addressed some biomass variations and carbon in bamboo components such as culm, branch, and leaves of bamboo forests and culm density with silvicultural management and in natural, unmanaged forests.

MATERIALS AND METHODS

Study area description

This investigation was done in lowland bamboo (*Oxythenathera abyssinica*) stands that were naturally occurring as well as plantations owned in Pawe District, northwestern Ethiopia (*Figure 1*). The area is about 563 km away from Addis Ababa and 2 km from Pawe town. The study site lies at an altitude of approximately 1120 masl and has topography between 36° 16' and 36° 36' longitude and 11° 8' and 11° 34' latitude.

The area experiences hot, muggy weather all year round, with unimodal rainfall patterns that include heavy, torrential downpours from May through October. Three types of soil are found there: vitriol, luvisol, and nitisol. The minimum and maximum temperature is about 19.4°C to 37.6°C, and the mean annual rainfall is 1586.32 mm (Gashaw, 2000). The study area is categorized under Combretum-Terminalia broadleaved deciduous woodland, with the dominant species being *Combretum, Terminalia, Oxytenanthera abyssinica, and Boswellia papyrifera* (Bekele, 2007).

Since 1984, indiscriminate fire, increased agricultural practices, and the removal of wood for fuelwood and building materials have resulted in the deforestation of the study site's natural forest (Gashaw, 2000). The plantation bamboo forest has been established since 2011 with a 2 m x 2 m spacing. On the plantation stand, management activities such as weeding, thinning, fertilization, and the like have been implemented. The Ethiopian Agricultural Research Institute has established the plantation forest, which is currently owned by Ethiopian Forestry Development. The aim of the planation was to develop technologies for bamboo shoots and timber stand management. The main reason for selecting this forest site is the presence of a well-managed plantation forest and a natural forest of *O. abyssinica* in the same district of the study area.

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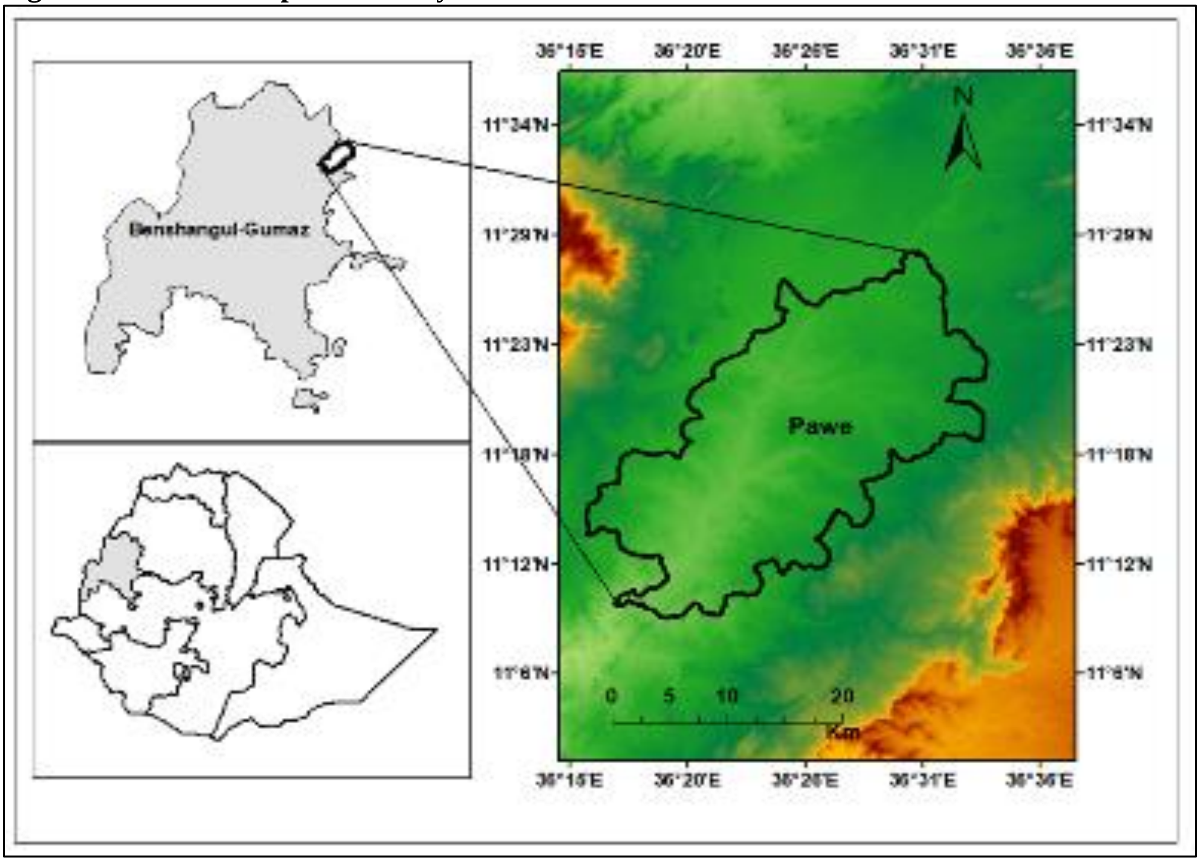
Figure 1: Location map of the study area



Sample Collection and Designing Techniques

As Singhar et al. (2015) stated typical sampling is appropriate in limited forest areas with discrete distribution, as random, systematic, or cluster patterns are not practical or required. Thus, 12 circular plot each having 100 m^2 and radius of 5.64 m were constructed to carry out thesurvey. We established circular plots due to their efficacy since the actual circumference of circular plots are smaller than that of square or rectangular plots.

In a circular plot, the number of culms situated on the verge of the plot is limited, which makes it simple as compared with others (Yen et al., 2010). For every plot, the culms were numbered after being classified based on age. Nine culms per plot were chosen at random for each age assemblage. A calliper was used to measure the culms' diameter (height of 1.3 meters), and a meter tape was used to estimate their height. The outside color, culm cover features, and the existence of branches and leaves were used to calculate the culm age (Singnar et al., 2015).

Age Characterization

As age has a greater effect on bamboo growth performance, it has been taken as a sample selection criterion (Kaushal et al., 2022). There were three age groups for the bamboo plants: less than a year, one to three years, and more than three years, in both natural and plantation forests. Based on the parameters of Kaushal et al. (2022), the age was ascertained in the field by asking the elders who had knowledge of bamboo development. Culms under one year old are identified by their smooth and dark green trunks, which are covered by a fresh-looking bark. They are covered by a fresh-looking bark. The entire thatched roof shows no evidence of lichen or moss growth, and the knots are hairy. Younger trees have relatively smaller leaves and fewer branches.

Bamboo shoots aged between 1 and 3 years old have been identified by their light green, slightly rough texture, and lack of dirt or sheath. In this age group, there is some moss at the nodes, and the branches and leaves are fully grown. Culms over 3 years old can be distinguished by their

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light-yellow culm cover as well as their dry and rough appearance. Mosses and lichens are common on joints and burns in normal environments without any disturbance (Plate 1).

Plate 1: Age categories of low land bamboo (less than 1 year, 1-3 years, and greater than 3 years, respectively)



Destructive Sampling Technique

Within every clump, similar-aged culms are identified and clustered together. Following meticulous marking of the culms collected for investigation in both forest types, three culms for each age group were chosen at random. 108 bamboo culms were sampled and dispersed (54 bamboo trees from planted forests and 54 from natural forests). The DBH of every culm was measured using a digital clipper at a height of 1.3 meters prior to culm cutting, while the height was measured from felled bamboo to estimate biomass. According to Yen (2016), plants were deemed fully grown when their breast height measured at least 1.5 cm and they had reached a typical growth age of at least two months.

Laboratory Analysis and Biomass Calculations

The felled culm was partitioned into different components (leaves, branches, and culms). Then, fresh aliquots of leaves and branches were randomly taken from each sampled culm. Similarly, representative culm aliquots were taken at the bottom (above 0.3 cm/stump height), middle, and top of each sampled culm. Using a sensitive scale, the fresh weight of every section was promptly determined in the field (Plate 2). All samples were then put into labeled paper bags showing information on sample plot/clump code, sample culm code, culm component type, and sample name. Then, samples were transported, stored in the laboratory, and located in an oven at an adjusted temperature of 105 °C and is important to eliminate the moisture content and identify the biomass.

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Plate 2: Sampled vegetative parts of lowland bamboo

After a period of two days, the dried portions of the culm, branch, and leaves were measured to ensure their stability. Subsequently, the dry culm, branch, and leaf aliquots were assessed using an automated weighing scale, and the measured values were coded on a separate sheet of paper. The above-ground biomass for the entire bamboo has been computed by summing the dry biomass of all compartments. The moisture content (MC) of each examined branch and leaf (i) was ascertained in the manner described below:

$$\text{MC\_branch and leaf, i} = \frac{B\ aliquot\ fresh\ branch\ and\ leaf,i}{B\ aliquot\ dry\ branch\ and\ leaf,i}$$

Here, B aliquot fresh branch and leaf, i represent the undried biomass of branches and leaves, and B aliquot dry branch and leaf, i denote the oven-dry biomass (oven dried) for the branch and leaves.

The MC of the culm was derived by dividing the fresh biomass (B) aliquot of a culm by its corresponding dry biomass (B) aliquot for the dry culm.

$$\text{MC\_culm, i} = \frac{B\ aliquot\ fresh\ culm,i}{B\ aliquot\ dry\ culm,i}$$

Here, B aliquot dry culm, i represents the dried biomass for the culm and B aliquot fresh culm, i represents the biomass of the culm, which is fresh.

Total biomass for the individual section (culm, branch and leaf) was calculated based on (Borisade et al., 2018):

$$\text{TDW} = TFW * \frac{SDW}{SFW}$$

Where: TDW (total biomass) (dry mass), TFW (Total Fresh Weight), SDW (Dry Weight of subsample), SFW (Fresh Weight of sample). The total of all components (sections) collectively characterizes the total biomass of the bamboo forest.

Data Analysis

The initial data were structured, arranged, and coded into Microsoft Excel. R software version 4.04 was then used to perform data analysis. Descriptive statistics were employed to explore variations in above-ground biomass among vegetative parts, forest types, and age classes in the bamboo forest.

RESULTS AND DISCUSSION

Stand structure and Culm Density of *Oxytenanthera abyssinica*

The result showed that the average height (Ht) and diameter (DBH) for the plantation stand ranged between 9 and 13.2 m; and 3.4 and 6.4 cm, respectively. Similarly, the natural bamboo forest has average height and DBH ranging between 6.35 and 12 m and 2.0 and 4.4 cm, respectively. The mean density of 0.51 g/cm^3 for plantations and 0.41 g/cm^3 for natural bamboo forests was recorded (*Table 1*). In comparing the two bamboo forest types, plantation bamboo has recorded higher values in all studied parameters (i.e., density, DBH, and height) than natural bamboo

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forest. So that the increments in those parameters result in total above-ground biomass. This implies that managing bamboo plantations could improve the growth performance of bamboo plants more than naturally regenerated and unmanaged natural bamboo forests. Similar findings were reported by Li et al. (2000), who discovered that, in comparison to naturally regenerated and unmanaged natural bamboo forests, the application of silvicultural management in bamboo forests has the potential to boost the growth performance of bamboo plants. However, for bamboo species such as *Fargesia demissa* and *Phyllostachys rubromarginata*, which are runner bamboo, and dwarf bamboo species like *Pleioblastus akebono* and *Pleioblastus viridistriatus' Chrysophyllus*, the management application may not cause significant differences in the biomass storage potentials of the species compared with the natural forest.

Table 1: DBH, Height, and density of plantation (n=54) and natural (n=54) *O. abyssinica* forests

statistics	Forest type	Predictor Variables		
		DBH (cm)	Height (m)	Culm density (g/cm$^{3)}$
Mean	Plantation	4.6	11.20	0.51
	Natural	3.4	7.95	0.41
Minimum	Plantation	3.4	9.00	0.31
	Natural	2.0	6.35	0.21
Maximum	Plantation	6.4	13.20	0.85
	Natural	4.4	12.00	0.75
S.E.	Plantation	0.084	0.148	0.07
	Natural	0.058	0.132	0.06

The total sample for the biomass (dry mass) analysis was 540 for both plantations and natural forests, consisting of 324 culms, 108 branches, and 108 leaves. The result shows that the ratio of dry to fresh mass is higher for culms in both plantations and natural forests (Table 2With a mean value of 0.44, for instance, culms have the highest ratio of dry to fresh mass in planted forests, followed by branches (0.41) and leaves (0.40). In the same manner, the results of dry mass analysis for natural bamboo forests show that the ratio of dry to fresh mass was highest for culms (mean value = 0.46) followed by branches (0.44) and leaves (0.42). The mean density of culm is estimated as 0.51 g/cm3 with a range (0.31–0.85) and 0.41 g/cm3 with a range (0.21–0.75) for plantations and natural forests, respectively. The result is directly in line with the findings of Kushal et al. (2022). This may be because the culm and branch of the bamboo were more lignified than the leaf, and it might have fewer amounts of water loss after oven drying. So, when the amount of water in the sample is very high, the fresh weight of the sample becomes too much, but the dry weight dramatically decreases after drying. Then, the dry-to-fresh weight ratio becomes too low. That means the amount of stored water during fresh weight in the leaf is greater than the branch and the culm.

Table 2: Dry-to-fresh mass ratio and density for the different components of *O. abyssinica*.

Statistics parameters	Forest type	Dry to fresh weight ratio in each component			
		Culm	Branch	Leaf	Density
Mean	Plantation	0.44	0.41	0.40	0.51
	Natural	0.46	0.44	0.42	0.41
Minimum	Plantation	0.25	0.27	0.30	0.31
	Natural	0.29	0.32	0.24	0.21
Maximum	Plantation	0.77	0.66	0.73	0.85
	Natural	0.78	0.64	0.73	0.75
S.E.	Natural	0.17	0.04	0.00	0.07
	Plantation	0.16	0.03	0.01	0.06

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Effect of Management on Above-ground Biomass Estimation (AGB)

Total above-ground biomass was the sum of the culm, brunch, and leaf-dry biomass. As shown in the result, the major proportion of bamboo above-ground biomass has been contributed by the culm both in plantations (88.35%) and natural (86.92%) forests, followed by branches (8.36% for the plantations and 8.59% for the natural forest) (*Table 3*). Similarly, a finding by Kaushal et al. (2022) described that the culm part contributed about 77%, followed by branch (13.0%) for the sympodial bamboo. In the other study, Shanmughavel et al. (2001) reported that AGB portioning for lowland bamboo was 76%, 13% and 10% for culms, branches, and leaves, respectively. In comparing the two bamboo forests, plantation bamboo has shown a greater proportion of biomass production than natural forest. In fact, biomass production can vary significantly with the same species due to different management interventions, but it still grows on the same unit of land. This might be a possible reason why the productivity of bamboo plantations is relatively high compared with natural forests. Bamboo plantations had 17% higher total biomass production than natural bamboo forests for this study. This is directly related to the result observed by Krug (2019), a study in the German forest, that the managed forest had increased productivity by 15.6% and greater biomass accumulation compared with the unmanaged forest.

The study by Embaye et al. (2005) at Masha's forest also reported that effective silvicultural management, especially timely harvesting operations, is essential for maintaining a productive bamboo forest. According to his study results in Masha Forest, one of the best imperative management measures was the successive exclusion of 25% to 50% of older trees (more than three years) annually. This is because the application of silvicultural management might improve the productivity and quality of shoots and culms, as with other plants (Kim et al., 2018). The balance between nitrogen and potassium could result in increments in the quantity and quality of bamboo shoots and other vegetative parts. Therefore, the increments in the dendrometeric variables' measurement value will also result in the increments in biomass storage and carbon sequestration potentials of the species.

Table 3: Proportion of biomass by the different above-ground segments of *O. abyssinica* in plantation and natural forest (n=108)

Age class	Forest type	The proportion of dry biomass (%) in each component		
		Culm (%)	Branch (%)	Leaf (%)
1st	Plantation	87.20	5.30	3.50
	Natural	86.31	6.34	3.35
2nd	Plantation	91.52	9.43	4.13
	Natural	89.45	9.48	4.09
3rd	Plantation	86.33	10.33	4.33
	Natural	85.00	9.96	5.00
Mean	Plantation	88.35	8.36	3.99
	Natural	86.92	8.59	4.15

The amount of dry mass per individual culm in the planted forests is higher than the amount of dry mass in the natural forest in all plant parts (i.e., in the culm, branch, and leaf), as presented in *Table 4*. This might be because the managed bamboo forest had better and more vigorous vegetative growth than the natural forest. According to Darcha & Birhane (2015), the above-ground biomass of three-year-old *O. abyssinica* bamboo was significantly greater than that of the one-year-old. However, in this study, the bamboo plant in the intermediate age group amassed more AGB than the earlier and older ages for the natural and planation stands. Meanwhile, the density increases with age (*Table 4*).

Table 4: The variations of ABG and density across natural and plantation of *O. abyssinica* forests under different age classes.

Parameters	Statistics	Plantation forest age class			Natural forest age class		
		1st	2nd	3rd	1st	2nd	3rd
AGB/kg	Max	7.090	7.830	6.500	6.401	6.601	3.001
	Min	5.200	4.801	4.034	1.801	2.131	1.670
Density (g/cm^3)	Mean	6.202	6.612	5.407	3.237	3.784	2.075
	Max	0.508	0.634	0.753	0.435	0.498	0.754
	Min	0.314	0.358	0.519	0.208	0.324	0.309

CONCLUSION

Biomass production of lowland bamboo varies significantly within species and age gradients, even when cultivated on the same site in both plantations and natural forests. Moreover, management made dramatic changes in the biomass production of the species. A managed bamboo forest had 17% increments in total biomass production compared with a natural forest. In both types of forests, the medium age group of lowland bamboo produced greater above-ground biomass than the younger and older ages. Conversely, as it gets older, the density rises.

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