# Bamboo Biomass: A Strategy for Climate Change Mitigation and Adaptation, and Forest Landscape Restoration (FLR) in Cameroon

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**Abstract** Studies suggest that bamboo is an excellent biological resource with the capacity to sequester and stock carbon while providing direct and indirect services that support human well-being. Cameroon, despite having a huge bamboo potential, has not benefited from these offers with respect to Forest Landscape Restoration (FLR) and climate combat. This chapter aimed at estimating carbon stocks of *Oxytenanthera abyssinica* **(A. Rich.) Munro** in the High Guinea Savannah of Cameroon; compared with carbon stocks of different dominant bamboo species in different forest strata in Cameroon; assessed the place of bamboo for possible use for FLR, and valued bamboo carbon monetarily. Data were destructively collected for carbon assessment. 14 circular plots of 100 m$^2$ were set up. 5% of bamboo of different age classes were harvested for biomass, separated into components, weighed, and subsampled oven-dried for dry mass. The results showed that *O. abyssinica* means

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culm density and above-ground carbons were about 10,343 ± 4910 $ha^{-1}$ and 27.45 ± 17.22 $tC.ha^{-1}$, respectively. Literature showed that total bamboo carbon in Cameroon ranges from 16.41 to 157.93 $tC.ha^{-1}$. High carbon was found with *Bambusa vulgaris* and *Phyllostachys aurea*. The total bamboo carbon stocks were less than those of forest strata, but similar to those of agroforestry and plantations and greater than that for woody savannah, grasslands, shrublands, and pastures. The total carbon of bamboo in Cameroon was estimated at 82.47 $tC.ha^{-1}$ and corresponded to a monetary value of 272 \$ $USD.ha^{-1}$. Policymakers can consider this and integrate bamboo into sustainable strategies to restore degraded lands in Cameroon.

**Keywords** *Oxytenantera abyssinica* · Forest landscape restoration · Climate change · mitigation and adaptation · Carbon farming · Carbon credit · Carbon stocks · Cameroon

## 1 Introduction

Global warming is one of the serious problems that the world is facing at present [46]. The rising $CO_2$ level in the atmosphere is the prime contributor to global warming [18]. Efforts at International levels are being initiated to address the problem of global warming and climate change. The United Nations Framework Convention on Climate Change (UNFCC) passed a landmark resolution in 2015 in Paris [62]. The resolution of Paris agreement is to limit the average temperature on earth from rising above 2 °C from the level of the pre-industrialization period [61]. Many countries since then have been mainstreaming this accord into their Nationally Determined Contributions (NDC) to mitigate and adapt to climate change. Within this context, the research on identifying cost-effective managed ecosystems that can substantially remove atmospheric $CO_2$ while providing essential societal benefits has gained momentum since the Kyoto Protocol of 1997 [47]. Studies suggest bamboo as a complementary crop to address global warming [7, 18, 79].

Bamboo is one of the fastest-growing plants on earth belonging to the Family of Poaceae. It is widely distributed across tropical and subtropical regions; and within and outside forests in Africa, Asia, and Central and South America [4, 10, 36, 64]. There are more than 1,663 species belonging to 123 genera of bamboo throughout the world [41, 81]; with 115 known species in Africa [21]. Up to 35 million ha of the global land area is covered by bamboo forests, which represent approximately 1% of the total forest area [23], with at least 7.2 million hectares of bamboo across Africa [26].

Many bamboo species are important in local economies; their most important economic uses include food, handcrafting, fencing, and cottage industry [1]. As such bamboos are a major commodity in domestic trade and subsistence use, generating over US\$ 4.6 billion per year globally [6]. In 2019, Africa exported USD 19.2 million of bamboo products [26]. In addition, they contribute to soil and water management, and biodiversity conservation [68]. Most importantly, bamboo plays a crucial role as a carbon sink, thus contributing to climate change mitigation [45, 70, 84].

A number of studies have reiterated that among the perennials, bamboo can particularly be a powerful tool in carbon farming [9, 47, 49, 68], rural livelihoods [37] as well as multiple Ecosystem Services and benefits that support human well-being [64]. Because bamboo grows back quickly after being harvested, it can store carbon in a large number of durable products, as well as in the plant itself. Over time, this means that bamboo can sequester more carbon than some tree plantations [25, 80]. Thus, bamboo has a multifaceted potential in supporting the fight against climate change, supporting the livelihoods of the local people, and providing ecosystem services.

The Government of Cameroon, through the Ministry of Environment, Protection of Nature and Sustainable Development (MINEPDED) contributes to the sustainable development goals (13 and 15), which support the fight against climate change and life on land respectively; to achieve the restoration of 12 million ha of degraded landscape as a commitment to a number of international initiatives such as the Bonn Challenge, Afr100 initiative, Great Green Wall by evaluating the restoration opportunities of some sub-landscapes (Waza, Mbalmayo, and Douala-Edea) in Cameroon estimated at about 700 000 ha excluding protected areas [27, 34, 44]. Among these landscapes is the Waza landscape in the Sudano-Sahel region of Cameroon. MINEPDED in its program « the restoration initiative (TRI)» solicited bamboo as a candidate for restoration.

This choice raises the next question « which bamboo species is best for restoration in this landscape». Nfornkah et al. [53] report of Oxythenanthera abyssinica (A. Rich.) Munro species is a native dominating bamboo species in the High Guinea Savannah (HGS) and Sudano-Sahel (SS) regions of Cameroon. Other studies further observe that it is a lowland bamboo, indigenous species, and sequestrates carbon of 16.28 $tC.ha^{-1}$ [51], which is greater than Savannah grassland, which sequesters 10.78 $tC.ha^{-1}$ [61]. The data provided by Nfornkah et al. [54] was not enough to appreciate the potential of O. abyssinica for carbon sequestration and its use as the main restoration bamboo species in the landscape.

This study is, therefore, initiated to (1) evaluate the density and carbon stocks potential of O. abyssinica in the HGS; (2) Compare the carbon stocks of O. abyssinica with those of different bamboo species estimated in different forest strata or agroecological zones of Cameroon; (3) Compare the carbon stocks of O. abyssinica with those of other crop plantations and agroforestry systems, and forest strata ecosystems; (4) monetize bamboo carbon in Cameroon. These results permit this study to propose bamboo species suitable in supporting the restoration initiative in Cameroon, but also carbon farming through the integration of bamboo in agroforestry systems and plantations in different agroecological zones of Cameroon.

# 2 Bamboo for FLR, Carbon Farming, and Trading: Concepts Definition

## 2.1 *Forest Landscape Restoration*

There is an urgent need to accelerate the recovery of degraded ecosystems for the benefit of humans and nature, which requires a comprehensive and inter-sectoral approach. This has to be done through restoration. Restoration is any intentional activity that initiates or accelerates the recovery of an ecosystem from a degraded state [64]. Looking at the FLR interventions of the IUCN-Bonn Challenge, they include natural regeneration, silviculture, agroforestry, planted forest and woodlots, improved fallows, mangrove restoration, watershed protection, and erosion control. A number of studies earmarked bamboo as a great biological resource for restoration [3, 17, 18, 49, 64, 65].

Bamboo forests are an important forest type ecologically, socioeconomically, and culturally in the subtropical and tropical regions of the world [44]. Due to its biological characteristic and growth habits, bamboos are not only an ideal economic investment that can be utilized in many different manners but also has enormous potential for the eco-restoration of degraded lands [13, 45, 49, 64, 65]. Bamboos are one of those communities which rapidly colonized disturbed lands due to their adaptability and nutrient conservation ability [16, 19, 45, 50]. Bamboo protects steep slopes, soils, and waterways, prevents soil erosion, sequesters carbon, and brings many other ecosystem benefits [45, 64, 65, 84].

However, a number of studies have warned of a number of risks involved in planting bamboo, including invasiveness of species, decrease biological diversity, food scarcity, soil pollution due to fertilizers and pesticides, land grabbing nature of bamboo [3, 7, 67, 73, 83]. In order to mitigate the risks involved, the International Bamboo and Rattan Organization (INBAR) and a team of experts/researchers working in this domain have documented and made available on its website a number of Manuals, voluntary standards guidelines, and standards to guide every plan of investment in the whole value chain of bamboo from seedlings production, planting, management, harvesting, transformation, bioenergy, construction, trade overviews, research and development [18, 19, 25, 32].

Without over-emphasizing the importance of bamboo over other plants for restoration, Net Primary Production (NPP) is an important indicator of forest biomass accumulation and carbon sink capacity. Some studies show that NPP from bamboo forests have gained much attention because of their high carbon sequestration potential and supply capacity of other Ecosystem Services [11, 39, 73]. Comparing NPP in a bamboo-dominant forest to a neighbouring secondary evergreen broad-leaved forest in South China using the space-for-time substitution method, Song et al. [73] concludes that the mean NPP of the former was 51.5% greater than that of the latter cycles. Similarly, several studies in semi-arid, dryland ecosystems and agroforestry systems show bamboo forests have high NPP compared to many forests and sole crops [14, 67]. This study results shall propose bamboo species proper for landscape restorations, justifying the choices for landscape restoration.

## 2.2 Carbon Farming

Carbon farming allows farmers and investors to generate tradable carbon offsets from farmlands and forestry projects through carbon trading. Carbon farming involves implementing practices that are known to improve the rate at which $CO_2$ is removed from the atmosphere and converted to plant material and/or soil organic matter. Thus, carbon sequestration has the potential to offset fossil-fuel emissions by 0.4–1.2 gigatons of carbon per year, or 5–15% of the global fossil-fuel emissions [20, 33]. It is a method of capturing $CO_2$ from the atmosphere or from a point source like a fossil-fuel-based power plant and storing it for a very long duration under the earth's surface. $CO_2$ Sequestration from the atmosphere through plants is a very effective, natural, and inexpensive process [43].

Among the terrestrial ecosystems, agroforestry and forest ecosystems have been given priority for carbon trading based on the efficiency of particular land use in reducing emissions or capturing carbon by storing it. Reforestation, afforestation, and reducing deforestation and forest degradation (REDD) are also eligible for carbon trading [22, 29]. To date, most of the studies have been done on the carbon trading potential of tree species/forest/agroforest, but little on woody bamboo species [37]. Meanwhile, the present review suggests that bamboo offers tremendous opportunities for carbon farming and tradable carbon under CDM and REDD schemes. Ecosystem carbon storage and sequestration rates of 94–392 $tC.ha^{-1}$ and 8–14 $tC.ha^{-1}$ $yr^{-1}$ [47, 49, 79, 84], respectively, in woody bamboos are comparable with agroforestry and forest ecosystems. This study's results shall put to evidence tradable carbon in Cameroon with respect to agroforestry and forest ecosystems.

## 2.3 Carbon Trading

Carbon trading is pertinent to climate negotiations by decelerating the climate change phenomenon. Carbon farming is successful when carbon gains resulting from enhanced land management and/or conservation practices exceed carbon losses [71, 72]. Carbon trading, part of carbon farming, as described in the Kyoto Protocol, is a voluntary and mandatory emission trading market for greenhouse gases [70, 74, 77].

Bamboo ecosystems can provide an income stream to rural communities from dual sources (i) selective harvest and selling of bamboo products (e.g., for scaffolding purposes, to the papermaking industry, bamboo crafts) and, (ii) from carbon credits (Certified Emission Reductions) under various afforestation/reforestation mechanisms under CDM and REDD [18, 47, 49]. Certified emission reductions can be traded in the national and international markets that have committed to reducing their carbon footprint. The 20th Session of the Conference of the Parties of the UNFCCC, held in Lima in December 2014, incorporated under any program of activities, an unlimited number of component project activities across a sector, country, or region can be registered under a single administrative umbrella [49]. Considering its role in climate change adaptation and mitigation, its noteworthy contribution to the social, and economic aspects of rural life, and numerous other environmental services, woody bamboos warrant serious consideration for carbon farming and carbon trading. Integrating woody bamboo with carbon trading will promote the cultivation and management of woody bamboo in agroforestry and forest ecosystems and, therefore, generate another income stream for rural communities [49]. Additional research is needed to determine bamboo biomass, vegetation, and soil carbon capture and storage by incorporating improved methodological protocols to enable precise estimation of bamboo ecosystem carbon storage and sequestration rate [49].

The result of this study shall bring out the possibilities of considering carbon farming in forest landscape restoration to produce tradable carbon in Cameroon using an indigenous bamboo species *Oxytenanthera abyssinica,* especially in the High Guinea Savannah and Sudano-Sahel regions of Cameroon.

## 3 Materials and Methods

### *3.1 Study Area*

This study was carried out in Ndoumdjom and Ndem-ndem, located in Bankim Sub-Division Mayo–Banyo Division, Adamaoua Region of Cameroon. It is geographically located on latitude 5°9’–8°35’ North and longitude 11°15’–11°48 East (Fig. 1). This area is characterized by a tropical humid climate, with two seasons, that is a rainy season from mid-March to mid-November (over 8 months) and a dry season from mid-November to mid-March. The average annual rainfall is 1700 mm with a standard deviation of 210.82 mm during August–September-October, and with average temperatures of about 23 °C [62]. The soils are essentially ferralitic and hydromorphic. The relief is essentially made up of plains (Tikar Plain), with altitudes varying from 500 to 800 m. In the hinterland, there are a few isolated hills that are scattered throughout the area, with granite outcrops. In the western part of Nigeria, we note the presence of a mountainous chain (the Mambila Mountains) which culminates at 1662 m. The piedmont zone presents volcanic rocks, which certainly testify with the other hills and depressions of the relief of an eventful geological past. The hydrographic network is mainly made up of two rivers, the Mbam, which runs along the entire eastern boundary of the Municipality and forms the boundary with the Ngambé Tikar, and the Mapé, which forms the boundary with the Magba area. They are also several lakes, including Mbegou, Tantou, Houmtchie, Wouemi, Wui, Kongui Nduoh [35, 62]. Bankim constitutes a transition zone between the forest and the savannah

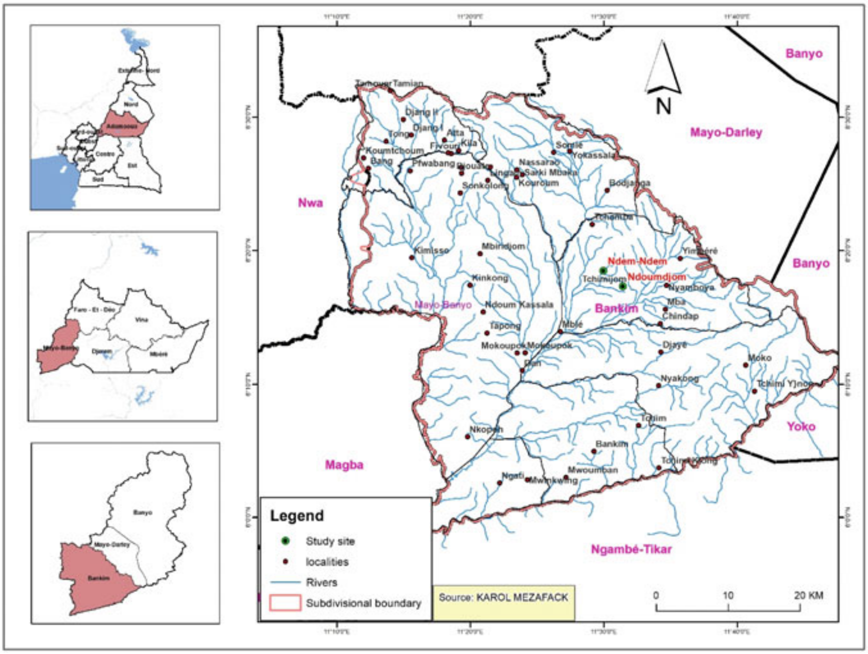

Fig. 1 Map of the study area

and therefore has a fragile ecology, it has only the remnants of highly degraded forests and other ecological units, including the tree and shrub savannahs; forest galleries along the rivers, dense humid forests; and the flooded grassy savannahs. The forest galleries are mainly along the watercourses, and tree and shrub savannahs are in their major part. The forest species, although in clear decline, remains varied, and include *Kaya grandifoliola*, *doussie pachiloba*, *Termminalia superba*, *Lovoa trichiloides*, *Milicia exelsa*, *Afzelia grandis,* and *A. bipendensis*. The vegetation cover of the Bankim is under great threat due to the Mapé dam, which has swallowed up thousands of hectares of forest; the destructive effect of bushfires; the poor cultivation methods that are intensifying with the increase in population; and the illicit exploitation of the remains of the forests [35]. In terms of wildlife, it witnesses a rarefaction of species due to the combined action of poachers and bushfires, and especially to the invasion of gallery forests, the animals' retreat to the zone by the dam's water.

## 3.2 Methodology

A literature review was carried out through search engines such as Google, Google Scholar, and Scopus database, grey data from project documents (working papers, technical reports, national strategy, and project/program documents) were used to collect data on bamboo carbon stocks tree carbon stocks in different tree ecosystems (forests, savannah agroforestry, and plantations).

Primary data on carbon stocks of *O. abyssinica* bamboo in the natural bamboo forests were collected in the Ndoumdjom and Ndem-Ndem villages in Bankim. For biomass inventory of *O. abyssinica,* it was carried out destructively. For that inventory, 14 circular plots of 100 $m^2$ were sampled as recommended by Nfornkah et al. [54]. In each circular plot of 100 $m^2$, 5% of bamboo with respect to age group was felled for sampling. It is important to note that for each plot sampled, bamboo culms collected were grouped into 3 age classes ($\leq$1 year, $\leq$ 2–3 years, and > 3 year-old) culms as recommended by Devi et al. [14, 15]. Morphologically, *O. abyssinica* culm colour changes, and the abundance of primary, secondary, and tertiary branches aided in identifying these different age groups under 3 years old [3]; but above 3 years, it appears difficult to distinguish the bamboo age, thus grouped under this class. For each culm sampled, in addition to specimen collection, dendrometrics parameters like total height and the diameter at 1.50 cm were recorded as recommended by Huy and Trinh [25]. Additional data like girth (m) and the number of culms ($N_{culm}$) were also collected using a clump-based sampling design (Fig. 2). Then, the harvested bamboo was sorted out into components (such as culms, branches and leaves), and weighed with an electronic suspension scale (capacity 300 kg) separately for the Total Fresh Biomass (TFW) of the bamboo. Subsamples of the different bamboo components: culm (at 3 positions on the culm: root collar, middle and top); branches and leaves with approximately 100–300 g (using an electronic scale of precision 0.1 g) were collected as Sample Fresh Weight (SFW) for each bamboo sampled. These subsamples were oven-dried at 105 °C in an oven until constant weight (SDW) was obtained in the laboratory of Rural Engineering of the University of Dschang, Cameroon; for biomass ratios.

In addition to the data collection of *O. abyssinica*, we used primary data of other bamboo species considered such as *Bambusa vulgaris, O. abyssinica* and *Phyllostachys aurea* with respect to their different agroecological zones of Cameroon made available by their authors (Kaam et al., Submitted; Chimi et al., Submitted) for use in this study.

## *3.3 Data Analysis*

Data analysis was done using R software version 4.1.1. Descriptive analysis was done for measurement variables and bamboo biomass of components.

### 3.3.1 Bamboo Density Calculation

The calculation of the number of clumps and culms per hectare of *O. abyssinica* was done using the following formulae respectively:

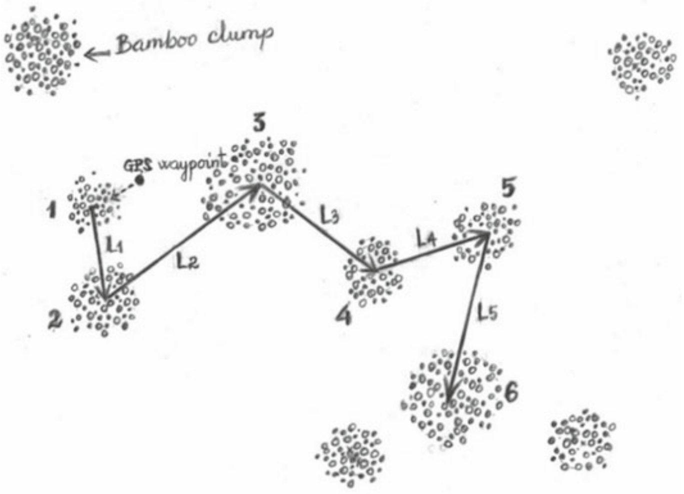

**Fig. 2** Clump-based sampling for clumping bamboo with very dense culms [25]

$$\mathrm{N_{clump}ha^{-1}} = \mathrm{N_{clump}} \times \frac{10^4}{\text{plot area}\left(\mathrm{m}^2\right)} \tag{1}$$

$$\mathrm{N_{i\ culm}ha^{-1}} = \mathrm{N_{i\ culm}} \times \mathrm{N_{clump}ha^{-1}} \tag{2}$$

### 3.3.2 Bamboo and Biomass and Carbon Stocks Calculation

The total dry weight of each component (for each culm bamboo sample) was determined using the following formulae by FAO [23]

$$\mathrm{TDW} = \frac{SDW}{SFW} \times \mathrm{TFW} \tag{3}$$

where; TDW = total component dry weight; SDW = subsample dry weight; SFW = subsample fresh weight; and TFW = total component fresh weight.

Culm bamboo above-ground biomass ($\mathrm{AGB_{bamboo}}$) corresponds to the sum of the total dry bamboo biomass of the culm ($\mathrm{AGB_{cl}}$, kg), branches ($\mathrm{AGB_{br}}$, kg) and leaves ($\mathrm{AGB_{le}}$, kg) [25]:

$$\mathrm{AGB_{bamboo}} = \mathrm{AGB_{cl}} + \mathrm{AGB_{br}} + \mathrm{AGB_{le}} \tag{4}$$

The above-ground clump biomass ($\mathrm{AGB_{clump}}$) was calculated by the formula:

$$\mathrm{AGB_{clump}} = AGB_{bamboo} \times \mathrm{N_{i\ culm}} \tag{5}$$

The extrapolation factor was used to extrapolate the clump above-ground biomass calculation of each plot at the hectare.

$$\mathrm{AGB}\ \left(\mathrm{t.ha}^{-1}\right) = \ \mathrm{AGB}\ \mathrm{x}\frac{10^4}{\text{plot area}\ \left(\mathrm{m}^2\right)} \tag{6}$$

AGB corresponds to the bamboo above-ground biomass in 100 $m^2$.

Hence, bamboo BGB was estimated using the following formula:

The ratio of belowground to above-ground biomass of *O. abyssinica* is 1:4 (25%) [24] for *B. vulgaris* = 0.32 and for *P. aurea* = 1.33 [82]. With the value of AGB and BGB, total bamboo biomass corresponds to the sum of these 2 biomass components (AGB + BGB). According to Huy & Trinh [25] the carbon fraction in bamboo represents the default value proposed by IPCC [32] for trees = 0.47. Furthermore, bamboo carbon stocks per hectare were estimated with the following formulae:

$$\text{Carbon stock}\ \left(\mathrm{t\ C.ha}^{-1}\right)\ =\ \text{biomasses}\ \left(\mathrm{t\ ha}^{-1}\right)\ \mathrm{x}\ 0.47 \tag{7}$$

With respect to the fact that 1tC = 3.67 $tCO_{2eq}$, the following formulae was used for bamboo $CO_2$ stocks.

$$\text{Stock } CO_2\left(tCO_2eq\ .^{-}\right)\ =\ \text{Carbon stock}\ \left(\mathrm{t\ C\ ha}^{-1}\right)\ \mathrm{x}\ 3.67 \tag{8}$$

### 3.3.3 The Monetary Value of Ecosystem Services Linked to the Carbon Stocks Potential of Bamboo

According to Busch & Engelmann [5] and Cannon [8], carbon prices could take the form of some combination of taxes on emissions or payments for emission reductions in tropical forest countries, with the potential to receive external funding from international carbon markets or public funds. We adopted the following conversion: 1 t $CO_{2eq}$ = 3.3 USD [18]; which is found in the REDD + framework.

# 4 Results

## *4.1 Density and Above-Ground Carbon of* O. Abyssinica

The mean density of *O. abyssinica* culms and clumps per ha was 10,343 ± 4910 and 264 ± 93, respectively. The average AGB of culm was 4.61 ± 1.73 kg per culm. AGC and BGC of *O. abyssinica* found in the study area were 27.45 ± 17.22 t $C.ha^{-1}$ and 6.86 ± 1.31 $tC.ha^{-1}$, respectively. The total $CO_{2eq}$ per ha of *O. abyssinica* was 125.93 ± 79.00 (Table 1).

**Table 1** Descriptive statistics of the density of culm and clump, AGB culm and the clump of *O. abyssinica* in the High Guinea Savannah

| Descriptive statistic | Mean | Min | Max | Sd |
|---|---|---|---|---|
| $N_{culm}$ ($N.ha^{-1}$) | 10,343 | 3700 | 18,500 | 4910 |
| $N_{clump}$ ($N.ha^{-1}$) | 264 | 100 | 400 | 93 |
| Average $AGB_{culm}$ (kg) | 4.61 | 2.20 | 13.63 | 1.73 |
| $AGC_{bamboo}$ (t $C.ha^{-1}$) | 27.45 | 7.66 | 61.43 | 17.22 |
| BGC $_{bamboo}$ (t $C.ha^{-1}$) | 6.86 | 1.915 | 15.36 | 4.31 |
| TC $_{bamboo}$ (t $C.ha^{-1}$) | 34.31 | 9.58 | 76.79 | 21.53 |
| $AGC_{bamboo}$ (t $CO_2.ha^{-1}$) | 125.93 | 35.14 | 281.81 | 79.00 |

N/B: $N_{culm}$ ($N.ha^{-1}$) = number of culms in one hectare; $N_{clump}$ ($N.ha^{-1}$) = number of clumps in one hectare, Average AGB.plant$^{-1}$ (kg) = average total above-ground biomass of a bamboo plant; $AGC_{bamboo}$ (t.C $ha^{-1}$) = total above-ground carbon of bamboo in one hectare; and $AGC_{bamboo}$ (t $CO_2.ha^{-1}$) = total above-ground carbon dioxide ($CO_2$) in one hectare, $BGC_{bamboo}$ (t $C.ha^{-1}$) = mean belowground carbon of bamboo on one hectare, TC $_{bamboo}$ (t $C.ha^{-1}$) = total bamboo carbon stocks in tons on one hectare

## 4.2 *Comparative Analysis of Carbon Stocks of* **O. Abyssinica** *Relative to Carbon Stocks from Other Bamboo Species in Different Forest Strata in Cameroon*

The density and carbon stocks of *O. abyssinica* with respect to other bamboo species estimated by similar studies are summarized in Tables 2 and 3. *O. abyssinica* density (10,343 ± 4910) in the High Guinea Savanah agroecological zone of Cameroon is 4.5 times higher than the density of *B. vulgaris* (2296 ± 2631) of the Tropical evergreen rain forest of Cameroon (Monomodal rainfall forest). However, it was not too far from those of *B vulgaris* (13,330 ± 7718) in the WH, which is approximately 4 and 2 times less than the density of *P. aurea* (38,010 ± 3361) in the Western Highlands (Guinea Savannah) of Cameroon; and *B. vulgaris* (20,679 ± 14,835) in the Tropical Semi Deciduous Humid Forest (Bimodal rainfall forest) of Cameroon respectively.

The average culm biomass of *O. abyssinica* found was 4.61 ± 1.73 kg. Compared to those of other species, it appears to be similar to those of *P. aurea* which is a running bamboo and not different from those found by Nfornkah et al. [53] of the same bamboo species. However, *O. abyssinica* biomass found in this study was 3–6 times less than those of *B. vulgaris* found in diverse AEZs in Cameroon (Chimi et al. submitted; Kaam et al. submitted; Nfornkah et al. [52, 53].

Regarding the total carbon of bamboo per ha; the mean TC of *O. abyssinica* (34.31 ± 21.53) was greater than 16.41 ± 8.60 of *O. abyssinica* in Beyala; but less than *B. vulgaris* (39.10 ± 2.55) in the Tropical evergreen rain forest; 81.38 ± 30.45 in Tropical semi-deciduous humid Forest; and *P. aurea* (125.42 ± 45.20; 157.93 ± 23.63) in the Western Highlands.

**Table 2** Descriptive summary of bamboo density and carbon stocks in Cameroon

| Forest stratum | Bamboo species | Descriptive statistics | Mean | Minimum | Maximum | Stand.dev | References |
|---|---|---|---|---|---|---|---|
| HGS | *O. abyssinica* | N$_{\text{culm}}$ (N.ha$^{-1}$) | 10,343 | 3700 | 18,500 | 4910 | This study |
| | | N$_{\text{clump}}$ (N.ha$^{-1}$) | 264 | 100 | 400 | 93 | |
| | | Average AGB$_{\text{culm}}$ (kg) | 4.61 | 2.2 | 13.63 | 1.73 | |
| | | AGC$_{\text{bamboo}}$ (t C.ha$^{-1}$) | 27.45 | 7.66 | 61.43 | 17.22 | |
| | | BGC $_{\text{bamboo}}$ (t C.ha$^{-1}$) | 6.86 | 1.915 | 15.36 | 4.31 | |
| | | TC $_{\text{bamboo}}$ (t C.ha$^{-1}$) | 34.31 | 9.58 | 76.79 | 21.53 | |
| | | AGC$_{\text{bamboo}}$ (t CO$_2$.ha$^{-1}$) | 125.93 | 35.14 | 281.81 | 79.00 | |
| | *O. abyssinica* | N$_{\text{culm}}$ (N.ha$^{-1}$) | 4374 | 1600 | 9300 | 2604 | This study; Nfornkah et al. [53, 54] |
| | | N$_{\text{clump}}$ (N.ha$^{-1}$) | 184 | 100 | 300 | 83 | |
| | | Average AGB$_{\text{culm}}$ (kg) | 6.39 | 3.55 | 14.09 | 3.44 | |
| | | AGC$_{\text{bamboo}}$ (t C.ha$^{-1}$) | 13.13 | 3.68 | 23.66 | 6.88 | |
| | | BGC $_{\text{bamboo}}$ (t C.ha$^{-1}$) | 3.28 | 0.92 | 5.92 | 1.72 | |
| | | TC $_{\text{bamboo}}$ (t C.ha$^{-1}$) | 16.41 | 4.60 | 29.58 | 8.60 | |
| | | AGC$_{\text{bamboo}}$ (t CO$_2$.ha$^{-1}$) | 60.23 | 16.88 | 108.54 | 31.56 | |
| WH | *B. vulgaris* | N$_{\text{culm}}$ (N.ha$^{-1}$) | 13,330 | 5600 | 30,000 | 7718 | |
| | | N$_{\text{clump}}$ (N.ha$^{-1}$) | 133 | 56 | 300 | 77 | |
| | | Average AGB$_{\text{culm}}$ (kg) | 15.73 | 6.69 | 27.74 | 5.29 | |
| | | AGC$_{\text{bamboo}}$ (t C.ha$^{-1}$) | 92.96 | 42.05 | 170.69 | 43.73 | This study; Chimi et al., submitted |
| | | BGC $_{\text{bamboo}}$ (t C.ha$^{-1}$) | 29.75 | 13.46 | 54.62 | 13.99 | |
| | | TC $_{\text{bamboo}}$ (t C.ha$^{-1}$) | 122.71 | 55.51 | 225.31 | 57.72 | |
| | | AGC$_{\text{bamboo}}$ (t CO$_2$.ha$^{-1}$) | 450.34 | 203.71 | 826.89 | 211.85 | |
| | *P. aurea* | N$_{\text{culm}}$ (N.ha$^{-1}$) | 38,010 | 31,200 | 43,200 | 3361 | |
| | | Average AGB$_{\text{culm}}$ (kg) | 4.18 | 0.72 | 4.18 | 0.73 | |

(continued)

**Table 2** (continued)

| Forest stratum | Bamboo species | Descriptive statistics | Mean | Minimum | Maximum | Stand.dev | References |
|---|---|---|---|---|---|---|---|
| | | $AGC_{bamboo}$ (t $C.ha^{-1}$) | 53.83 | 27.18 | 80.16 | 19.4 | |
| | | $BGC_{bamboo}$ (t $C.ha^{-1}$) | 71.59 | 36.15 | 106.61 | 25.80 | |
| | | $TC_{bamboo}$ (t $C.ha^{-1}$) | 125.42 | 63.33 | 186.77 | 45.20 | |
| | | $AGC_{bamboo}$ (t $CO_2.ha^{-1}$) | 460.31 | 232.42 | 685.46 | 165.89 | |
| | *P. aurea* | $N_{culm}$ ($N.ha^{-1}$) | 38,017 | 31,200 | 42,500 | 4510 | This study; Kaam et al., submitted |
| | | Average $AGB_{culm}$ (kg) | 3.79 | 3.16 | 4.44 | 0.54 | |
| | | $AGC_{bamboo}$ (t $C.ha^{-1}$) | 67.78 | 49.85 | 80.16 | 10.14 | |
| | | $BGC_{bamboo}$ (t $C.ha^{-1}$) | 90.15 | 66.30 | 106.61 | 13.49 | |
| | | $TC_{bamboo}$ (t $C.ha^{-1}$) | 157.93 | 116.15 | 186.77 | 23.63 | |
| | | $AGC_{bamboo}$ (t $CO_2.ha^{-1}$) | 579.59 | 426.27 | 685.46 | 86.71 | |
| TEF | *B. vulgaris* | $N_{culm}$ ($N.ha^{-1}$) | 2296 | 1675 | 5293 | 2631 | This study; Nfornkah et al. [51] |
| | | $N_{clump}$ ($N.ha^{-1}$) | 20 | 19 | 25 | 3 | |
| | | Average $AGB_{culm}$ (kg) | 29 | 23.21 | 37.08 | 649 | |
| | | $AGC_{bamboo}$ (t $C.ha^{-1}$) | 29.62 | 2.2 | 31.99 | 1.93 | |
| | | $BGC_{bamboo}$ (t $C.ha^{-1}$) | 9.48 | 0.70 | 10.24 | 0.62 | |
| | | $TC_{bamboo}$ (t $C.ha^{-1}$) | 39.10 | 2.90 | 42.23 | 2.55 | |
| | | $AGC_{bamboo}$ (t $CO_2.ha^{-1}$) | 143.49 | 10.66 | 154.97 | 9.35 | |
| TDF | *B. vulgaris* | $N_{culm}$ ($N.ha^{-1}$) | 20,679 | 8871 | 57,229 | 14,835 | This study; Kaam et al., submitted |
| | | $N_{clump}$ ($N.ha^{-1}$) | 257 | 75 | 402 | 112 | |
| | | Average $AGB_{culm}$ (kg) | 10.3 | 3.54 | 13.5 | 11.37 | |
| | | $AGC_{bamboo}$ (t $C.ha^{-1}$) | 61.65 | 14.77 | 92.47 | 23.07 | |
| | | $BGC_{bamboo}$ (t $C.ha^{-1}$) | 19.73 | 4.73 | 29.59 | 7.38 | |
| | | $TC_{bamboo}$ (t $C.ha^{-1}$) | 81.38 | 19.50 | 122.06 | 30.45 | |

(continued)

**Table 2** (continued)

| Forest stratum | Bamboo species | Descriptive statistics | Mean | Minimum | Maximum | Stand.dev | References |
|---|---|---|---|---|---|---|---|
| | | $AGC_{bamboo}$ (t $CO_2$.ha$^{-1}$) | 298.66 | 71.55 | 447.96 | 111.76 | |

N/B: $N_{culm}$ (N.ha$^{-1}$) = number of culms in one hectare; $N_{clump}$ (N.ha$^{-1}$) = number of clumps in one hectare, Average AGB.plant$^{-1}$ (kg) = average total above-ground biomass of a bamboo plant; $AGC_{bamboo}$ (t.C ha$^{-1}$) = total above-ground carbon of bamboo in one hectare; and $AGC_{bamboo}$ (t $CO_2$.ha$^{-1}$) = total above-ground carbon dioxide ($CO_2$) in one hectare, $BGC_{bamboo}$ (t C.ha$^{-1}$) = mean belowground carbon of bamboo on one hectare, TC $_{bamboo}$ (t C.ha$^{-1}$) = total bamboo carbon stocks in tons on one hectare. HGS: high guinea savannah; WH: western highlands; TEF: tropical evergreen rain forest; TDF: tropical semi-deciduous humid forest

**Table 3** Bamboo mean densities and carbon stocks in Cameroon

| Descriptive statistics | HGS | | WH | | | TEF | TDF |
|---|---|---|---|---|---|---|---|
| | ***O. abyssinica*** | ***O. abyssinica*** | ***B. vulgaris*** | ***P. aurea (Chimi* et al.*)*** | ***P. aurea (Kaam* et al.*)*** | ***B. vulgaris*** | ***B. vulgaris*** |
| $N_{culm}$ (N.ha$^{-1}$) | 10,343 | 4374 | 13,330 | 38,010 | 38,017 | 2296 | 20,679 |
| $N_{clump}$ (N.ha$^{-1}$) | 264 | 184 | 133 | na | na | 20 | 257 |
| Average $AGB_{culm}$ (kg) | 4.61 | 6.39 | 15.73 | 4.18 | 3.79 | 29 | 10.3 |
| $AGC_{bamboo}$ (t C.ha$^{-1}$) | 27.45 | 13.13 | 92.96 | 53.83 | 67.78 | 29.62 | 61.65 |
| BGC $_{bamboo}$ (t C.ha$^{-1}$) | 6.86 | 3.28 | 29.75 | 71.59 | 90.15 | 9.48 | 19.73 |
| TC $_{bamboo}$ (t C.ha$^{-1}$) | 34.31 | 16.41 | 122.71 | 125.42 | 157.93 | 39.10 | 81.38 |
| $AGC_{bamboo}$ (t $CO_2$.ha$^{-1}$) | 125.93 | 60.23 | 450.34 | 460.31 | 579.59 | 143.49 | 298.66 |

N/B: $N_{culm}$ (N.ha$^{-1}$) = number of culms in one hectare; $N_{clump}$ (N.ha$^{-1}$) = number of clumps in one hectare, Average AGB.plant$^{-1}$ (kg) = average total above-ground biomass of a bamboo plant; $AGC_{bamboo}$ (t.C ha$^{-1}$) = total above-ground carbon of bamboo in one hectare; and $AGC_{bamboo}$ (t $CO_2$.ha$^{-1}$) = total above-ground carbon dioxide ($CO_2$) in one hectare, $BGC_{bamboo}$ (t C.ha$^{-1}$) = mean belowground carbon of bamboo on one hectare, TC $_{bamboo}$ (t C.ha$^{-1}$) = total bamboo carbon stocks in tons on one hectare. HGS: high guinea savannah; WH: western highlands; TDF: tropical semi-deciduous humid forest; tropical evergreen rain forests

### 4.3 Comparative Analysis of Bamboo Carbon Stocks Relative to the Carbon Stocks of Other Plant Ecosystems in Different Forest Strata Cameroon

In the HGS, bamboo AGCs were about one to three times greater than those of the savannah grassland, same with the Neem agroforest but less than those in the shrubby savannah; Cashew agroforest and *Eucalyptus* agroforestry. In the WH, bamboo AGC varies from 53.83–93 t $C.ha^{-1}$. This carbon is greater than those of the coffee agroforestry but less than those of a sacred forest. In TEF, bamboo carbon was less than those of coffee agroforest; mangrove and secondary evergreen forest. In TDF, bamboo carbon was three times greater than those of Coffee agroforestry, but less than those of the t Cocoa agroforest and semi-deciduous forests (Table 4).

### 4.4 Monetizing Bamboo Carbon Stocks in Cameroon

Considering the carbon-free market, bamboo carbon stocks were monetized in US Dollars. In HGS recorded US Dollars ranging from 54 to 113; in WF 405–521; in TEF 129 and in TDF 269. Cameroon records a mean total of 82 t $C.ha^{-1}$ with an equivalent US Dollars 272 (Table 5).

## 5 Discussion

### 5.1 Density and Above-Ground Carbon of Oxytenanthera Abyssinica

Density and Carbon stocks of bamboo are crucial in carbon farming, and culm yields have enormous socioeconomic importance. This study was interested in the culm yields of *O. abyssinica* in the HGS of Cameroon, given that this species has been identified as dominating bamboo in the Northern part of Cameroon. This bamboo species is a drought-resistant species, and from observation, cattle eat the leaves as fodder. This is a species that can be integrated into the farming system (landscape restoration and agroforestry system) to supply feedstock for fodder, and culm for construction and also sustain its carbon sequestration potential because of its rapid growth rates and its durability when carefully processed into secondary products.

We found in the context of this study that this specie has a high mean culm density (10,343 $stems.ha^{-1}$) and AGC stock (27.45 $tC.ha^{-1}$). Nfornkah et al. [53, 54] reports 13.13 $tC.ha^{-1}$ AGC carbon for *O. abyssinica* in the same agroecological zone (HGS) of Cameroon. The AGC of our study is two times greater than that of Nfornkah et al. [53]. This difference may be a result of the difference in the microclimate, of the same HGS. Ndoumdjom and Ndem-ndem are found in the transition zone between WH and HGS while Beyala is found deep in the HGS region. Therefore, precipitation (1700 mm), altitude (500 to 800 m), temperature (23 °C), and location of Ndoumdjom

**Table 4** Carbon stocks of bamboo forests and other ecosystems in the different forest strata in Cameroon

| Forest strata | Ecosystem types | Carbon stocks t C.ha$^{-1}$ | References |
|---|---|---|---|
| HGS | Bamboo forest (*O. abyssinica*) | 27.45 | This study |
| | Bamboo forest (*O. abyssinica*) | 13.13 | This study; Nfornkah et al. [56] |
| | Savannah grassland | 10.78 | Noumi et al. [58] |
| | Shrubby savannah | 40.89–45.03 | Tchobsala et al. [75] |
| | Cashew agroforest | 40.02 | Noumi et al. [57] |
| | Neem agroforest | 28.24 | Noumi et al. [57] |
| | Eucalyptus agroforest | 64.46–108.51 | Noumi et al. [59, 60] |
| WH | Bamboo forest (*B. vulgaris*) | 92.96 | This study; Chimi et al. submitted |
| | Bamboo forest (*P. aurea*) | 53.83 | This study; Chimi et al. submitted |
| | Bamboo forest (*P. aurea*) | 67.78 | This study; Kaam et al. submitted |
| | Coffee agroforestry | 24.28–41.20 | Temgoua et al. [76]; Ngomeni et al. [55] |
| | Sacred forest | 129.78 | Louanang et al. [38] |
| TEF | Bamboo forest (*B. vulgaris*) | 29.62 | This study; Nfornkah et al. [49, 51] |
| | Coastal/mangrove | 189.31 | Ngueguim et al. [56] |
| | Evergreen secondary forest | 327.35 | Kabelong et al. [30] |
| | Coffee agroforestry | 34–45 | Ngomeni et al. [55] |
| TDF | Bamboo forest (*B. vulgaris*) | 61.65 | This study; Kaam et al., submitted |
| | Semi deciduous Forests | 235.88 | Temgoua et al. [73] |
| | Semi deciduous Forests | 369.77 | Kabelong et al. [31] |
| | Coffee agroforest | 20.67 | Ngomeni et al. [56] |
| | Cocoa agroforest | 78.43 | Noumi et al. [58, 60] |
| | Traditional cocoa agroforest | 113.5 | Madountsap et al. [39] |

HGS: high guinea savannah; WH: western highlands; TDF: tropical semi-deciduous humid forest; tropical evergreen rain forests

**Table 5** Monetary value of bamboo carbon stocks t $C.ha^{-1}$

| Forest strata | Bamboo species | Average total carbon of bamboo (t C.ha-1) | Amount (Dollars US) |
|---|---|---|---|
| HGS | *O. abyssinica* | 34.31 | 113 |
| | *O. abyssinica* | 16.41 | 54 |
| WH | *B. vulgaris* | 122.71 | 405 |
| | *P. aurea* | 125.42 | 414 |
| | *P. aurea* | 157.93 | 521 |
| TEF | *B. vulgaris* | 39.10 | 129 |
| TDF | *B. vulgaris* | 81.38 | 269 |
| Mean total | // | 82.47 | 272 |

HGS: high guinea savannah; WH: western highlands; TDF: tropical semi-deciduous humid forest; tropical evergreen rain forests

and Ndem-ndem vary from Beyala with precipitation (1200 mm), altitude (1000 to 1200 m), temperature (24 °C), and located on latitude North and between 13,10 and 14,12° from longitude East [63].

Other reasons may include differences in relief and periods during which data was collected. Similar studies in Cameroon have estimated bamboo densities and carbon stock potential confirming the results meaning that it is one of the bamboo species that have a high potential in terms of carbon stocks in Cameroon (Table 3). However, *O. abyssinica* has a less density and carbon stock potential compared to *Oldeania alpina* bamboo species in Ethiopia which, Shiferaw et al. (in press) reports for its density of 19,343 $stems.ha^{-1}$ and the carbon stocks estimated at 64.10 t $C.ha^{-1}$. Moreso, Devi and Singh [14] also estimate the density of *Bambusa tulda* and *Dendrocalamus longispathus* as >10 000 and >12 000 $stems.ha^{-1}$ respectively. According to this, we can confirm that bamboo density and carbon stocks varied greatly in terms of bamboo species, even if they are all belonging to the clumping bamboo.

## *5.2 Comparative Analysis of Carbon Stocks of* **Oxytenanthera Abyssinica** *Relative to Carbon Stocks from Other Bamboo Species in Different Forest Strata in Cameroon*

The natural bamboo stands in Cameroon covers a surface area of about 1.2 M ha [51]. A number of studies estimate the carbon stocks of the dominating bamboo species across the agroecological zones of Cameroon [52–54]. A comparative analysis is necessary to make out the differences and similarities in terms of carbon stocks of different bamboo species. This gives a better understanding of how much carbon a bamboo species can sequestrate and stock in relation to the different agroecological zones where these studies were carried out.

This analysis shows that *O. abyssinica* recorded the least carbon stocks in the HGS and the highest was that of *B. vulgaris* in the WH. Despite having the least carbon stocks among the bamboo species in Cameroon, *O. abyssinica* is a lowland bamboo and equally an indigenous species in the three northern regions of Cameroon, the dominating bamboo species [51], as well as maintain particular biodiversity in its habitat, should be recommended for initiatives towards landscape restoration to fight desertification. It can also be integrated into bamboo-based agroforestry systems in the HGS, the Sudano-Sahel and the mining sites in the East region of Cameroon.

Some studies show that NPP from bamboo forests have gained much attention because of their high carbon sequestration potential and supply capacity of other ecosystem services [11, 40, 73]. Comparing NPP in a bamboo-dominant forest to a neighbouring secondary evergreen broad-leaved forest in South China using the space-for-time substitution method, Song et al. [73] concluded that the mean NPP of the former was 30.0 tC.ha$^{-1}$.yr$^{-1}$, which was 51.5% greater than that of the latter (19.8 tC.ha$^{-1}$ yr$^{-1}$) cycles. Also, a study in Japan shows bamboo forests have a higher productivity of production than Cedar forests [59, 68].

Many studies compiled bamboo carbon stocks to show their importance in terms of carbon potential thus: Amoah et al. [2] compare the stand distribution of *B. vulgaris*, *O. abyssinica*, and *B. vulgaris* var. *vitata* by estimating the AGC storage in different components of the bamboo species. They find the AGC in the bamboo to be 61% higher in *B. vulgaris* (115 tC.ha$^{-1}$) than in *B. vulgaris* var. vitata (71 tC.ha$^{-1}$) and is 27-fold that of *O. abyssinica.* Arun et al. [48] estimate AGC density in Bamboo Based Family Forests (BBFF) to be 16.38 tC.ha$^{-1}$for *B. cacharensis*, 38.42 tC.ha$^{-1}$ for *B. vulgaris* and 19.64 tC.ha$^{-1}$ for *B. balcooa.* In addition to the various ecosystem services provided by village-grown bamboo, total biomass (52.8 tC.ha$^{-1}$) and carbon (25.8 tC.ha$^{-1}$) storage in BBFFs can offer an opportunity for carbon farming. Yuen et al. [84] report of estimate plausible ranges for AGC biomass (16–128 t.C.ha$^{-1}$), BGC biomass (8–64 tC.ha$^{-1}$), soil organic carbon (SOC; 70–200 tC.ha$^{-1}$), and total ecosystem carbon (TEC; 94–392 tC.ha$^{-1}$). In addition, Yuen et al. [84] estimate the annual carbon accumulation rates ranging in the order of 8–14 tC.ha$^{-1}$, to about 4 t.C.ha$^{-1}$ after selective harvesting of stands commences following maturation. Nath et al. [47] report that the mean carbon storage and sequestration rate in woody bamboo range from 30 to 121 tC.ha$^{-1}$ and its productivity is estimated at 6–13 tC.ha$^{-1}$ yr$^{-1}$, respectively; and with such vigorous growth, it will complete its growth cycle between 120 and 150 days. According to Devi and Singh [15] they find in North-East India the carbon storage of *B. tulda* range from 36.34 to 64.00 tC.ha$^{-1}$ and those of *Dendrocalamus longispathus* range from 50.11 to 65.16 tC.ha$^{-1}$.

### 5.3 Comparative Analysis of Bamboo Carbon Stocks Relative to Agroforestry and Forest Ecosystems Carbon Stocks in Different Forest Strata Cameroon

Natural forests are disappearing in many tropical countries, resulting in loss of biodiversity and erosion of forest-dependent livelihoods. The maintenance and restoration of forests as well as a search for alternative natural resources that can concurrently improve the environment and enhance the incomes of local communities has become crucial. Bamboo is suggested as a resource which could substitute trees for socioeconomic and ecological purposes in developing countries in the (sub)tropics [60]. In fact, in addition to the goods and services that they provide for people, with its high capacity in terms of carbon stocks, it can represent a good opportunity in terms of carbon stocks in the market and payment of ecosystem services.

Our results suggest that bamboo carbon stocks range from 13.13 tC.ha$^{-1}$ for *O. abyssinica*, 122.71 tC.ha$^{-1}$ for *B. vulgaris* in Cameroon while carbon stocks from other land use ecosystems: agroforestry systems range from 20.67 tC.ha$^{-1}$ for Coffee agroforestry to 108.51 tC.ha$^{-1}$ for *Eucalyptus* agroforestry in Cameroon. Comparing bamboo to typical natural ecosystems, their carbon stocks range from 10.78 tC.ha$^{-1}$ for Savannah grassland to 369.77 tC.ha$^{-1}$ for semi-deciduous forests of Cameroon. These results suggest that bamboo can totally be integrated into the agroforestry systems in Cameroon because it has the capacity to sequestrate and stock carbon equivalent to the other agroforestry ecosystems used in this study with the specific example of the carbons 122.71 tC.ha$^{-1}$ and 108.51 tC.ha$^{-1}$ for *B. vulgaris* versus *Eucalyptus* respectively.

For the natural ecosystems, bamboo carbon stock sequestration was better than those of savannah grassland and shrubby savannah. This implies that bamboo can be carefully integrated into the restoration initiative of the Western Highlands and the High Guinea savannah agroecological zones to restore degraded forest landscapes and marginal lands in Cameroon, prone to desertification.

According to King et al. [31], studies on total ecosystem carbon (TEC) of certain woody bamboo species show that bamboo forest ecosystems can store between 94 and 392 tC.ha$^{-1}$ of carbon per hectare (t C.ha$^{-1}$): that is, significantly less carbon than in natural forest ecosystems (126–699 t C.ha$^{-1}$) but similar to tree plantation ecosystems (85–429 t C.ha$^{-1}$) and more than grassland or pasture (70–237 t C.ha$^{-1}$). This agrees with the results of Yuen et al. [84] that the total ecosystem carbon range is below that for most types of forests, on par with that of rubber plantations and tree orchards, but greater than agroforests, oil palm, various types of swidden fallows, grasslands, shrub lands, and pastures, which is similar to this results.

## 5.4 Monetizing Bamboo Carbon Stocks in Cameroon

Carbon trading, part of carbon farming, as described in the Kyoto Protocol, is a voluntary and mandatory emission trading market for greenhouse gases (GHGs) [69]. Among the terrestrial ecosystems, agroforestry and forest ecosystems have been given priority for carbon trading based on the efficiency of particular land use in reducing emissions or capturing carbon by storing it. Reforestation, afforestation, and REDD are also eligible for carbon trading [29]. Carbon trading is pertinent to climate negotiations by decelerating the climate change phenomenon. Carbon farming allows farmers and investors to generate tradable carbon offsets from farmlands and forestry projects through carbon trading [49]. Bamboo has the potential to generate carbon credits due to high carbon sequestration rates, which can be traded internationally [18]. Farmers can use Bamboo farming in sub-optimal land to generate additional income and improve the fertility of the land.

The result of this study suggests that, for a mean total bamboo carbon stock per ha in Cameroon estimated at 82.47 $tC.ha^{-1}$, the prize in the carbon market is US $ 272. Cameroon's subnational Forest landscape restoration opportunities stand at 720,991.50 ha (Table 5) [44]. Considering that bamboo was used to restore the 720,991.50 ha of restoration opportunities in Cameroon, and with the current carbon price used for this study, 44,269,062.3 $tC.ha^{-1}$ and US $ 12,041,184,945.6.

Bamboo farming to exploit these restoration opportunities in Cameroon shall be welcomed. Dwivedi et al. [18] suggest that bamboo farmers can improve financial conditions by utilization of cultivable wasteland and helping in climate change mitigation by avoiding deforestation, improving afforestation, and carbon sequestration. They report that farmers can earn up to US $800 per hectare annually by selling raw bamboo from their degraded land. Bamboo cultivation can generate around US $ 0.0002087 per hectare annually, which can be traded as carbon credits. Additionally, under-employed farmers can work as skilled workers in the bamboo handicraft industry and can earn up to US $2700 annually at current exchange rates, which is significantly higher than the present average income of US Dollars $1750 of farmers [18]. King et al. [33] report that carbon market methodologies do more than quantify the amount of carbon stored in a bamboo plantation, as they also guide project developers in determining project boundaries, setting baselines, assessing the addition of carbon stored or removed and quantifying the overall GHGs emissions reduced or removed under the project.

## 5.5 Managing Bamboo for Landscape Restoration

Land degradation is the temporary or permanent decline in the productive capacity of the land that will result in negative consequences for agriculture, biodiversity, and the environment [60]. Further, as it affects people who depend on land-based economic activities, land degradation could lead to increasing poverty in developing countries like Cameroon. Landscape restoration has received increased attention as a measure to tackle the land degradation crisis, as reflected in the UN Sustainable Development Goals (SDGs) and in conventions such as the United National Framework of the Convention on Climate Change (UNFCCC), the United Nations Convention to Combat Desertification (UNCCD), and the Convention on Biological Diversity (CBD). Initiatives such as the Bonn Challenge; Afr100, New York Declaration, REDD + strategy, and the Great Green Wall have committed to restoring 350 M ha of degraded landscape [65]**.** The results of this study permit us to suggest bamboo species for use in this initiative based on the availability and adaptations in the different forest strata. Table 6 summarizes the planning.

## 6 Conclusions

This study put to evidence the fact that *O. abyssinica* a native species, has substantial carbon stocks making it a complementary species for landscape restoration that can be capitalized on climate change mitigation strategies and also generating carbon credits from the carbon-free market; although its carbon stocks potential appears to be the least compared to those of the other bamboo species within the different forest strata or agroecological zones of Cameroon. Also, bamboo carbon stocks were proven to have similar or higher potential with respect to those of other agroforestry systems and plantations in the different forest strata or agroecological zones, or in certain cases higher than those of some natural ecosystems like the savannah grasslands and swidden fallows (HGS). These results serve as a baseline for further studies as well as data that can be exploited by policymakers and development planners in integrating bamboo in degraded landscape restoration initiatives for which Cameroon is counted among countries that have ratified conventions such as the Bonn Challenge, Afri100, REDD+ , which will contribute to climate combat and life on land (SDGs 13 &15) respectively.

**Table 6** Restoration initiative proposal in Cameroon

| Forest Strata | Bamboo species | Growth form | Origin | Comments | References |
|---|---|---|---|---|---|
| HGS, Sudano- Sahel and the abandoned mine sites in the East of Cameroon | *O. abyssinica* | Sympodial | Indigenous to Africa | Lowland bamboo and very adapted to the Sudano-Sahel regions. This is a great candidate to be integrated to combat Desertification in the Adamaoua, North and Far North of Cameroon. This can be done through initiatives like Afr100, Bonn Challenge, and Great Green wall | This study, Nfornkah et al. [51] |
|  | *B. vulgaris* | Sympodial | Exotic | This is a Pan tropical species. It has naturalized in Africa. It adapts to all tropical climates. In Cameroon, it is found in all Regions of Cameroon. It can be used for landscape restoration | This study, Nfornkah et al. [51] |

(continued)

**Table 6** (continued)

| Forest Strata | Bamboo species | Growth form | Origin | Comments | References |
|---|---|---|---|---|---|
| | *Dendrocalamus asper, and D. strictus* | Sympodial | Exotic | Introduced by INBAR (International Bamboo and Rattan Organization) in Cameroon. It's drought-resistant (fight desertification), has high carbon sequestration capacity, and large and medium-sized culm production bamboo species respectively. It can be used to support restoration initiatives in these forest strata | Chimi et al. [12], Ruth et al. [66] |
| WH | *B. vulgaris* | Sympodial | Exotic | It is highly recommended for bamboo-based agroforestry systems in the western Highlands of Cameroon | |

(continued)

**Table 6** (continued)

| Forest Strata | Bamboo species | Growth form | Origin | Comments | References |
|---|---|---|---|---|---|
| | *D. asper, and D. strictus* | Sympodial | Indigenous to Africa | It’s drought-resistant (fight desertification), has high carbon sequestration capacity, and large and medium-sized culm production bamboo species respectively. It can be used to support restoration initiatives in this forest stratum | Nfornkah et al. [51]; Ingram et al. [28]; Chimi et al. [12] |
| | *Yushiana alpina* | Amphipodia (Mixed) | Indigenous to Africa | Solicit this species for bamboo plantation, Agroforestry and home gardens. The demand for bamboo culm for constructions is very high in the towns and cities (Kribi, Edea, Douala, Nkongsamba etc | |

(continued)

**Table 6** (continued)

| Forest Strata | Bamboo species | Growth form | Origin | Comments | References |
|---|---|---|---|---|---|
| TEF | *B. vulgaris* | Sympodial | Exotic | Solicit this species for bamboo plantation, Agroforestry and home gardens. The demand for bamboo culm for construction is very high in the towns and cities (Kribi, Edea, Douala, Nkongsamba etc | Ingram et al. [28], Dwivedi et al. [18] |
| | *D. asper, and D. strictus* | Sympodial | Exotic | They have high carbon sequestration capacity, and large and medium-sized culm production bamboo species respectively. It can be promoted in agroforestry systems and bamboo plantations, for socioeconomic reasons | |

(continued)

**Table 6** (continued)

| Forest Strata | Bamboo species | Growth form | Origin | Comments | References |
|---|---|---|---|---|---|
| | *Bambusa sp longinternode* | Sympodial | Exotic | Introduced by INBAR in Cameroon. It’s a good species for home garden, agroforestry systems and bamboo plantations. Has the capacity of substitution of wood demand in construction and bioenergy | Chimi et al. 2021, Ruth et al. [66] |
| TDF | *B. vulgaris* | Sympodial | Exotic | Solicit this species for bamboo plantation, Agroforestry and home gardens. The demand for bamboo culm for construction is very high in the towns and cities (Yaounde, Bertoua, Ngoundal etc.) | Ingram et al. [28]; Dwivedi et al. [18] |

(continued)

**Table 6** (continued)

| Forest Strata | Bamboo species | Growth form | Origin | Comments | References |
|---|---|---|---|---|---|
| | *D. asper, and D. strictus* | Sympodial | Exotic | It has high carbon sequestration capacity, and large and medium-sized culm production bamboo species respectively. It can be promoted in agroforestry systems and bamboo plantations, for socioeconomic reasons | |
| | *Bambusa sp longinternode* | Sympodial | Exotic | It is a good species for home garden, agroforestry systems and bamboo plantations. Has the capacity of of substitution wood demand in construction and bioenergy | |

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