Carbon Stock Potential of Highland Bamboo (*Yushania alpina*) Over Plantation Niches of a Tropical Highland, Northwestern Ethiopia

Ayana Admass Jember

Bahir Dar University

Mintesinot Taye (✉ mintesinotazene@yahoo.com)

Bahir Dar University <https://orcid.org/0000-0002-9226-7225>

Gashaw Mulu

University of Gondar

Research

Keywords: climate change mitigation, carbon stock, Highland Bamboo, plantation niche, allometric model, tropical highland

Posted Date: May 4th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-422015/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
[Read Full License](#)

Abstract

The study analyzed the stand structure and carbon stock of the bamboo (*Yushania alpina*) over plantation niches of a tropical highland, Northwestern Ethiopia. Five sample plots (with a plot size of 10m*10m) in each of the niches (homestead, woodlot and riverbank) were selected randomly, and this was repeated in four different villages/sites for a total of sixty samples. Culm size (height and DBH), diameter (cm) and height (meter), density of clump (ha) and the number of the culms per clump, and age composition (year) were measured. The estimations of the above-ground and below-ground biomass were done based on allometric equation and root-to-shoot ratio of 1:5, respectively. For estimating the total carbon of the bamboo, the carbon fraction (0.47) was multiplied by the total biomass; and the total carbon was multiplied by 3.67 to estimate the carbon dioxide equivalent. A one-way ANOVA ($P < 0.05$) was used to test whether group mean difference exists among the niches. The measured value of the culm diameter ranged from 5.1 ± 0.1 cm – 6.1 ± 0.1 cm. The lowest and highest values were observed in the riverbank and the homestead plantation niches, respectively. The homestead niche represents the highest value of culm density ($27,945 \pm 34$ culms/ha), followed by the woodlot ($22,775 \pm 45$ culms/ha) and the riverbank ($20,375 \pm 36$ culms/ha) niches. The woodlot niche represents the highest value of clump stocking ($1,885 \pm 46$ clumps/ha), followed by the riverbank ($1,775 \pm 27$ clumps/ha) and the homestead ($1,562 \pm 11$ clumps/ha) niches. The mean value of the total biomass, carbon storage and carbon equivalent capacity of the bamboo over the niches ranged from 85.4 ± 6 – 92.6 ± 6 t/ha, 40.1 ± 3 – 43.5 ± 2.9 t C/ha, and 147.3 ± 11 – 159.7 ± 10 t CO₂/ha, respectively. A significant group mean difference was observed among the bamboo plantation niches in all parameters for the presence of different purposes and management practices. The highest and the lowest values in all the parameters were observed in the homestead and the riverbank niches, respectively. The bamboo plantation needs to be adopted for land restoration and climate change mitigation.

1. Introduction

In the face of rapid climate change [1, 2], climate variability [3, 4], meteorological drought [5, 6], and misuse of land and land degradation [4, 7], agroforestry and plantations are essential for enhancing economic growth and ecosystem services. Forest stand is useful for a wide range of products and services, from timber and non-woody products to various environmental services [8, 9]. In forest inventories, it is common to evaluate forest area, crown cover, tree species, the number of trees (culms per hectare), diameter at breast height (centimeter) and total height (meter) [10, 11]. Bamboo is an evergreen, erect, and perennial grass categorized into the plant family of Poaceae which includes ~ 1200 species and grows in tropical and subtropical regions of the world [12–14]. It is one of the fastest-growing plants to meet the increasing needs of human population [15]. The global land bamboo resource covers an area of ~ 14 million ha of lands [16]. Out of the total cover, Africa's share is estimated to be ~ 1.5 million ha of land with ~ 40 species.

Highland bamboo (*Yushania alpina*) and lowland bamboo (*Oxytenanthera abyssinica*) are the two major indigenous bamboo species in Ethiopia [13, 17]. The total area covered by the two species is estimated to

be 1 million ha which accounts for 67% of the African bamboo [16, 18]. The highland bamboo and lowland bamboo covered ~ 100,000 ha and 800,000 ha, respectively [19]. The highland bamboo grows naturally in the southern, southwestern, central and Northwestern highlands of the country with altitudes ranging from 2200m to 4000m a.s.l.; whereas the lowland bamboo grows in the western part along major river valleys and in the lowland within altitudinal range of 1100–1700m.a.s.l [20, 21].

The highland bamboo could be cultivated in various niches like farmlands, riverbanks, woodlot boundaries, and homesteads [22–24]. It is also an important agroforestry species cultivated around homesteads. Farmers are experienced in planting the highland bamboo in different plantation niches. About 2.5 billion people globally cultivate the highland bamboo for multiple purposes including for food [25]. This fast-growing tree species has been recognized as one of the adaptable resources in Africa, Asian and South America [15].

The theoretical and practical relevance of forest stand structure is recognized among scholars. For instance, it is used to understand productivity and thereby to estimate the products [26]. Bamboo is a vital and unique component of forestry and plays a very important role in ecological and environmental improvement, sustainable development, and poverty alleviation. Bamboo can be categorized under the most productive and the fastest-growing plants. This unique growing capacity makes bamboo a valuable sink for carbon storage. Bamboo is useful for socioeconomic development of the local people, for environmental protection such as adaptation to global climatic change through carbon sequestration, and for biodiversity conservation [16, 27].

Analysis of stand structure, carbon stock and their productivity is crucial to plan, implement and improve sustainable resource use [28]. Owing to its biological characteristics, bamboo is not only an ideal economic investment that can be utilized in many different manners but it has also enormous potential for alleviating both environmental and social problems facing the world today [29, 30].

Highland bamboo resources can be adapted to different niches and are under pressure due to overgrazing and climate change [31]. This resulted in a severe degradation and unsustainable utilization of these resources [32, 33]. Some studies have been carried out on bamboos in China and India [34], but little has been done in Ethiopia. The highland bamboo forests are among the most productive ecosystems in the highlands of Ethiopia providing different socioeconomic and ecological significance. Yet, the highland bamboo forest has undergone high rate of degradation and overexploitation due to increased bamboo-based products and uncommon practice of planting bamboo [35]. Various studies have been conducted on utilization, seed characteristics and propagation techniques of the bamboo forest in Ethiopian [13, 16, 18, 36, 37].

It is essential to estimate the carbon stock and develop appropriate management for maximizing carbon stock in forest ecosystems [38]. To date, there are limited studies on the characterization and evaluation of highland bamboo productivity over the various niches [39]. The current study, therefore, analyzed the role of plantation niches on the stand structure and carbon stock of the highland bamboo in a tropical highland, considering the case of the Northwestern highlands of Ethiopia.

2. Research Methodology

2.1 The Study Site

The study was conducted in two highland districts (termed *Woredas* in Amharic) (Banja *Woreda* and Guagusa- Shikudad *Woreda*) of the Awi Administrative Zone, Amhara National Regional State, in the Northwestern highland part of Ethiopia. The study districts are situated within 10° 50' 0"–10° 58' 0" N and 36° 57' 0" – 37° 9' 0" E. The study site is located at a distance of ~ 120 km northwest of Bahir Dar, the regional capital, and ~ 490 km northwest of Addis Ababa, the national capital. Its geographical area is ~ 8,585 km² (Fig. 3.1).

The agro-climatic class of the study sites is *Dega* (80%) and *Woinadega* (20%) with the altitudinal range of 1800–2953 m a.s.l. The district has the annual temperature of 11°C–24°C. It has a unimodal rainfall distribution pattern during the summer season ranging from June to September. With an average annual rainfall of 2300 mm, the land use pattern of the district is 25.62% cultivated land, 44.12% grazing/pasture land, 25.77% forest area and the rest 4.49% is used for other purposes. Common farming systems of the district are crop production, livestock farming and forestry [40].

The dominant soil types in the study area are brown (55%), red (45%) and black (2%) [41]. The common land use types in the study area are cultivable land, grazing land, forest land, woodland and plantation land [7]. The vegetation type in the study site falls under dry Afro-montane forest [41]. The total population of the entire study site is estimated to be 200,000 [42]. Similar to the reports of the previous studies [4] that were conducted in the places nearby the Northwestern highlands of Ethiopia, the livelihood of the people in the current study area depends on rain-fed subsistence agriculture: crop production, animal rearing and scanty plantation.

2.2 Methods and Materials

2.2.1 Sampling

The sample sites (villages) were selected purposively after conducting a reconnaissance survey on the coverage of the highland bamboo across the villages in the Awi Administrative Zone, northwest highlands of Ethiopia. The survey was made with the support of the local farmers and experts. Five sample plots (with a plot size of 10m*10m) in each of the niches (homestead, woodlot and riverbank) were selected randomly, and this was repeated in 4 different villages/sites for a total of 60 samples. In order to eliminate any influence of the edge effects on the forest biomass, all the sample plots were at least 50m away from the nearest roads. Square plots are preferred to make easier the task of separating the sample plots.

2.2.2 Data Collection and Analysis

The current study adopted the established data collection methods and tools that were used in the previous studies [13, 16, 37, 43, 44] to analyze the stand structure, biomass and carbon stock of the

highland bamboo parameters over the plantation niches. For collecting the stand structure, diameter at breast height of all bamboo forest culms in the sample plots was measured at 1.3m height, and the age of each plant was identified and grouped into three age classes: <1 year, 1–3 years and >3 years. A pair of calipers was used for measuring the diameter at breast height, whereas height was measured from samples taken from bamboo felled for biomass. Age was identified based on a manual (Ronald, 2005) and local experience. According to the manual and local experience, the main criteria for age determination were internode color, internode cover, internode epiphytes, culm sheaths, sheath ring at node and branches.

For determining the above- and below-ground biomass, it was essential to demarcate plots and determine the age of each culm. Permanent markers were used to write the age of the plants on the culm. Culms were grouped into three age classes as < 1, 1–3 and > 3 years of age. Then twelve plants were randomly selected and their diameter at breast height and height were measured from each age group and plot. The methods and tools employed to measure the above-ground and total biomass, and to estimate the below-ground biomass, total carbon and carbon dioxide equivalent of the bamboo are stated and described as follows:

In order to estimate the above-ground and total biomass, the allometric relationship between diameter at breast height and total dry weight of biomass of culm for the three age groups were selected. The method is selected by considering the reports of previous literatures and its mathematical simplicity. The allometric Eq. (equation) developed by [37] was used to estimate bamboo biomass. The basic reason for using allometric equation for estimating biomass is related to the chemical composition of bamboo along the age of the culm [45]. The estimation was done by using the models stated herewith (Eq. 1– Eq. 8).

AGTDW (< 1 Year) = exp (0.172*DBH)	Eq. 1
TDW (< 1Year) = exp (0.202*DBH)	Eq. 2
AGTDW (1–3 Years) = exp (0.289*DBH)	Eq. 3
TDW (1–3 Years) = exp (0.310*DBH)	Eq. 4
AGTDW (> 3 Year) = exp (0.30*DBH)	Eq. 5
TDW (> 3 Year) = exp (0.320*DBH)	Eq. 6
$AGTDW_j = \sum_{i=1}^n (\exp (B_i * DBH_i))$	Eq. 7
$TD = \sum_{i=1}^n (\exp (B_i * DBH_i))$	Eq. 8

Where TDW = total dry weight, AGTDW = above-ground total dry weight, j = the j^{th} age-group, i = the i^{th} plant in age-group j , B_i =coefficient of the predictor variable DBH, DBH = Diameter at Breast Height (1.3m).

The below-ground biomass estimation is much more difficult and time-consuming than estimating the above-ground biomass. Measurements of root biomass are indeed highly uncertain, and there is a lack of guidelines for measuring carbon stocks in forests. Empirical values for this type of biomass have for decades been a major weakness in ecosystem models. Yet, in the current, the estimation was done based on the currently existing method of estimation; that is, considering the root-to-shoot ratio of 1:5, with the assumption that the below-ground biomass is estimated to be 20% of the above-ground biomass [37, 46–48] (Eq. 9). Accordingly, the total biomass will be the sum of the below- and above-ground biomass (Eq. 10).

$$\text{Below-ground biomass (t/ ha)} = 0.2 \times \text{above-ground biomass (t/ ha)} \quad \text{Eq. 9}$$

$$\text{Therefore, the total biomass (t /ha)} = \text{AGB (t/ ha)} + \text{BG (t /ha)} \quad \text{Eq. 10}$$

For estimating the total carbon of the bamboo, the carbon fraction (0.47) was multiplied by the total biomass (Eq. 11); and the total carbon was multiplied by 3.67 (Eq. 12) to estimate the carbon dioxide equivalent following the methods employed in the previous study [49]. A one-way ANOVA ($p < 0.05$) was used to test whether group mean difference exists among the plantation niches.

$$\text{TC (t /ha)} = 0.47 \times \text{TB (t C/ha)} \quad \text{Eq. 11}$$

$$\text{TCO}_2\text{E (t/ ha)} = \text{TC (t /ha)} \times 3.67 \text{ (t CO}_2 \text{ /ha)} \quad \text{Eq. 12}$$

Where: TC = total carbon and TCO₂E = Total CO₂ equivalent

3. Results And Discussions

In this section of the study, firstly, the measured values of stand structure of the highland bamboo with the indicated parameters are presented. Then after, the values of the above- and below-ground biomass, total biomass, and carbon stock of the plantation that were estimated from the stand structure are shown.

3.1 Stand Structure

3.1.1 Diameter and Height

The result of the study revealed that the size class distribution of the highland bamboo culm diameter in the homestead plantation niches was positively skewed as compared to the riverbank and woodlot niches. This indicates the predominance of big culms with a diameter of 4 – 7.5 cm (Fig. 2). The result

shows the dominance of thicker bamboo culms; and therefore, the result of the current study is consistent with that of the previous study [45].

As per the field observation, the predominance of the bamboo with bigger diameter class over the homestead niches is associated with the farmers' decision on maintaining marketable culm sizes, and the application of cow dung and mulching.

In terms of culm diameter size, the result of the current study shows the existence of spatial heterogeneity among plantation niches. The heterogeneity could be associated with the purposes of the plantation (market, fencing and buffering) and the harvest time. The bamboo planted for market purpose was found to be better in culm diameter size than the bamboos planted for other purposes. Harvesting during the period between June to September and in the month of April could also have a negative effect on the culm diameter size in all plantation niches. The same effects of plantation purpose and harvest season on the culm diameter size had also been reported in the previous study [45].

With regard to the age class comparison, the highest culm diameter size was observed in the younger age class (< 1 year) than in the older age classes (1–3 years, and > 3 years) in all of the plantation niches (Fig. 3). Likewise, the study observed a negative relationship between the culm age and height of the bamboo in all of the plantation niches (Fig. 4). That is, the height of culm decreases as its age increases. The height and diameter of the older bamboo culms were found to be below the aggregated mean of the bamboo culms. As shown in Fig. 3 and Fig. 4, the mean values of culm diameter and height with age classes were ~ 6cm and ~ 13m, respectively. Taking into account age classes with culm diameter and height, the bamboo was found to be unique from other tree species in all of the plantation niches.

3.1.2 Culm Size (Height and DBH)

As shown in the result of the current study, a significant mean group difference ($p = 0.001$) was observed in culm size (height) among the plantation niches. The homestead niche shows the highest value (13.6 ± 0.3 m), followed by the woodlot (12.8 ± 0.3 m) and riverbank (10.9 ± 0.4 m) niches (Fig. 5). The reason could be related to the existence of variation in the purposes and management of the bamboo plantations among the niches. The height of the bamboo culm in the current study site was found to be higher than that of the height value reported by the previous study [39]. The reason for this could be related to the existence of mixed plantations of different tree species with different canopies that leads the bamboo culms to compete for light.

Like that of the observed height variation, the study found different values of culm diameter among the plantation niches. The value of culm diameter ranged from 5.1 ± 0.1 – 6.1 ± 0.1 cm. The lowest and highest values were observed in the riverbank and homestead plantation niches, respectively. The reason for the variation in culm diameter could be associated with the presence of different purposes and management of the plantations in the niches. Unlike the case of the homestead plantation niches, productivity was not the major purpose of planting the bamboo in the riverbank niches. Farmers planted the bamboo for

buffering, protection and fencing in the riverbank. This implies the existence of poor management practices in the riverbank plantation niches. The same result was reported by the previous study [35].

3.1.3 Culm Density

As the result of the current study shows, a significant group mean difference ($p = 0.000$) was observed in culm density among the bamboo plantation niches. The homestead niche represents the highest value ($27,945 \pm 34$ culms/ha), followed by the woodlot ($22,775 \pm 45$ culms /ha) and riverbank ($20,375 \pm 36$ culms/ha) niches (Table 1). The average culm density of the plantations in the study site was $23,698 \pm 72$ culms/ha. This result is consistent with the report of the previous study [50] that was conducted in highlands of Ethiopia, but it is inconsistent with the result of the other study [16]. Like the case of culm size, the culm density of the bamboo can be affected by the purposes of the plantations and management practices. The same justification was forwarded for the indicated variation among the plantation niches [14]

Table 1
Culm density of the bamboo over
plantation niches (Mean $\pm$ SE).

	Niche	Culms Density /ha
1	Homestead	$27,945 \pm 34^a$
2	Riverbank	$20,375 \pm 36^c$
3	Woodlot	$22,775 \pm 45^b$
	Mean	$23,698 \pm 72$

3.1.4 Clump

Like the case of culm density, the study shows a significant group mean difference ($p = 0.002$) in clump stocking among the bamboo plantation niches. The value of clump stocking ranged from $1,562 \pm 11$ – $1,885 \pm 46$ clumps/ha in the entire niches. The woodlot niche represents the highest value ($1,885 \pm 46$ clumps/ha), followed by the riverbank ($1,775 \pm 27$ clumps /ha) and the homestead ($1,562 \pm 11$ clumps/ha) niches (Table 2), respectively. This result is consistent with that of the previous study [51]. As shown in the same table, the clump stock was found to be inversely proportional to the culm number. For instance, the lowest clump ($1,562 \pm 11$ clumps/ha) and the highest culm (25 ± 1.0 culm clump⁻¹) were observed in the homestead niches. As the result of the study shows, the bamboo could be considered as unique in terms of its coppicing ability, a clump with several culms.

Table 2
Density of clump and the number of culms per
clump over the niches (mean $\pm$ SE).

	Niche	Clump/ ha	Culm Clump ⁻¹
1	Homestead	1,562 $\pm$ 11	25 $\pm$ 2.0
2	Riverbank	1,775 $\pm$ 27	21 $\pm$ 1.0
3	Woodlot	1,885 $\pm$ 46	23 $\pm$ 1.0

3.1.5 Age Composition

With regard to age class comparison, the mean values of culms/ha were found to be 3,967 $\pm$ 38 (17%) – 11,218 $\pm$ 80 (47%) for age class of > 3 years and age classes 1–3 years, respectively, in all of the plantation niches (Fig. 3). This result is congruent with that of the previous study of [52] that was conducted in the northeast part of India but it is incongruent with the report of another study [53] that was conducted in the Northwestern highlands of Ethiopia.

Table 3
Age composition and the number of culms over the niches.

Plantation Niches		Age of the Culm			
		< 1 Years	1–3 Years	> 3Years	Total (Proportion)
1	Homestead	8,750 $\pm$ 59	11,540 $\pm$ 88	4,187 $\pm$ 85	27,945 31:41:15
2	Riverbank	7,810 $\pm$ 65	11,360 $\pm$ 81	3,760 $\pm$ 11	20,375 33:46:17
3	Woodlot	8,915 $\pm$ 92	10,755 $\pm$ 80	3,955 $\pm$ 31	22,775 38:47:17
Total		8,491 $\pm$ 75	11,218 $\pm$ 80	3,967 $\pm$ 38	23,698 36:47:17
Proportion		36	47	17	36:47:17 36:47:17

3.2 Above- and Below-Ground Biomass

3.2.1 Estimation of the Above-Ground Biomass

As per the result of the current study, a significant group mean difference ($p = 0.010$) was observed in the above-ground biomass among the bamboo plantation niches. The mean value of the above-ground biomass ranged from 71.1 $\pm$ 5–77.2 $\pm$ 5 t/ha in the entire niches. The homestead niche represents the highest value (77.2 $\pm$ 5 t/ha), followed by the woodlot (72.5 $\pm$ 4 t/ha) and the riverbank (71.1 $\pm$ 5 t/ha) niches (Table 4), respectively. This result is consistent with the report of the study [46] that was

conducted in the southwestern highlands of Ethiopia, but it is inconsistent with the report of another study [54] that was conducted in the same part of Ethiopia.

Table 4
The value of biomass and carbon and of the bamboo over the niches.

Plantation		Carbon Pools of the Bamboo Culms				
Niches		AGB	BGB	TB	TC	TCO ₂ eq.
		t/ ha	t/ ha	t/ ha	t C/ ha	(t CO ₂ /ha)
1	Homestead	77.2 ± 5 ^a	15.4 ± 1	92.6 ± 6 ^a	43.5 ± 2.9 ^a	159.7 ± 10 ^a
2	Riverbank	71.1 ± 5 ^c	14.2 ± 1	85.4 ± 6 ^c	40.1 ± 3 ^b	147.3 ± 11 ^c
3	Woodlot	72.5 ± 4 ^b	14.5 ± 0.1	87 ± 5 ^b	40.8 ± 2.7 ^b	150 ± 10
Mean		73.6 ± 2.9	14.7 ± 0.6	88 ± 3.5	41.5 ± 1.6	152 ± 6.2 ^b
AGB = above-ground biomass, BGB = below-ground biomass, TB = total biomass, TC = total carbon, CO ₂ eq.= carbon dioxide equivalent.						

3.2.2 Estimation of the Below-Ground Biomass

As per the result of the current study, a significant group mean difference ($p = 0.003$) was observed in the below-ground biomass among the bamboo plantation niches. The mean value of the below-ground biomass ranged from 14.2 ± 1 – 15.4 ± 1 t/ha across the entire niches. The homestead niche represents the highest value (15.4 ± 1 t/ha), followed by the woodlot (14.5 ± 0.1 t/ha) and the riverbank (14.2 ± 1 t/ha) niches (Table 4), respectively. This result is consistent with the report of the study [54] that was conducted in the southeastern highlands of Ethiopia.

3.3 Total Biomass and Carbon Stock

As per the result of the current study, a significant group mean difference ($p = 0.000$) was found in the total biomass among the niches. The mean value of total biomass ranged from 85.4 ± 6 – 92.6 ± 6 t/ha in the entire niches. The homestead niche represents the highest value (92.6 ± 6 t/ha), followed by the woodlot (87 ± 5 t/ha) and the riverbank (85.4 ± 6 t/ha) niches (Table 4), respectively. Similarly, a significant group mean difference ($p = 0.004$) was found in the total carbon among the niches. The mean value of total carbon ranged from 40.1 ± 3 – 43.5 ± 2.9 t C/ha in the entire niches. The homestead niche represents the highest value (43.5 ± 2.9 t C/ha), followed by the woodlot (40.8 ± 2.7 t C/ha) and the riverbank (40.1 ± 3 t C/ha) niches (Table 4), respectively. This result is consistent with the report of the study [55] that was conducted in the southwestern highlands of Ethiopia.

The mean value of total carbon dioxide equivalents (TCO₂eq) was found to be in the range of 147.3 ± 11–159.7 ± 10 t CO₂ /ha in the entire niches. The homestead niche represents the highest value (159.7 ± 10 t CO₂ /ha), followed by the woodlot (150 ± 10 t CO₂ /ha) and the riverbank (147.3 ± 11 t CO₂ /ha) niches (Table 4), respectively. The result of this investigation indicates that the biomass accumulation, carbon stock and carbon dioxide equivalent capacity of the bamboo is by far higher than that of the other fast-growing tree species. For instance, as per the result of the study that was conducted in the Northwestern highlands of Ethiopia, the biomass accumulations of *acacia decurrens* at the age of four years and *eucalyptus globulus* at the age of six years were found to be 64.2 t CO₂ [56] and 34.6 t CO₂ [57], respectively.

4. Conclusions And Recommendations

For the fact that the highland bamboo was found to be fast-growing and has existed for a long period of time, the plantation could be taken as one of the potentials and priority species for carbon stock storage through sequestering a large amount of carbon in short period of time. The biomass storage potential of the bamboo was found to be in the range of CDM and REDD + schemes of 30–121 t/ha, which is equivalent with agroforestry and forest ecosystems. Since the plantation of homestead highland bamboo was found to be the most superior to that of the other two niches in terms of all the parameters of stand structure, more carbon stock is available in the homestead plantation niches across the tropical highlands. Accordingly, in order to ensure sustainable environmental services, it is advisable to expand plantations of highland bamboo over the barren highlands of Ethiopia and the larger tropical highlands. Further investigation is required on economic valuation and carbon trading for the bamboo plantation over various niches.

Declarations

Availability of data and materials

All data generated or analyzed during this study are available and could be accessed with a special request.

Competing interests

The authors declare they have no competing interests.

Funding

This work was supported by Bahir Dar University, Ethiopia

Authors' contributions

The first author generated the field data and wrote the first draft with the support of the other authors. The first and the second author produced the final version of the article. All authors read and approved the final manuscript.

Acknowledgments

The authors wish to thank Climate Change and Development Stream in the Institute of Disaster Risk Management and Food Security Studies, Bahir Dar University for funding the field survey of the study.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Evangelista P, Young N, Burnett J. How will climate change spatially affect agriculture production in Ethiopia? Case studies of important cereal crops. *Climatic change*. 2013;119(3-4):855-73.
2. Simane B, Zaitchik BF. The sustainability of community-based adaptation projects in the Blue Nile Highlands of Ethiopia. *Sustainability*. 2014;6(7):4308-25.
3. Berhane F, Zaitchik B, Dezfuli A. Subseasonal analysis of precipitation variability in the Blue Nile River Basin. *Journal of climate*. 2014;27(1):325-44.
4. Taye M, Simane B, Zaitchik BF, Selassie YG, Setegn S. Rainfall Variability across the Agro-Climatic Zones of a Tropical Highland: The Case of the Jema Watershed, Northwestern Ethiopia. *Environments*. 2019;6(11):118.
5. Bayissa Y, Tadesse T, Demisse G, Shiferaw A. Evaluation of satellite-based rainfall estimates and application to monitor meteorological drought for the Upper Blue Nile Basin, Ethiopia. *Remote Sensing*. 2017;9(7):669.
6. Taye MS, D.; Zaitchik, B.F.; Neka, M. . Evaluation of Satellite Rainfall Estimates for Meteorological Drought Analysis over the Upper Blue Nile Basin, Ethiopia. *Geosciences* 2020, 10, 352. *Remote Sensing*. 2020;9(7):669.
7. Taye M, Simane B, Selssie YG, Zaitchik B, Setegn S. Analysis of the Spatial Variability of Soil Texture in a Tropical Highland: The Case of the Jema Watershed, Northwestern Highlands of Ethiopia. *International journal of environmental research and public health*. 2018;15(9):1903.
8. Nasi R, Wunder S, Campos JJ. Forest ecosystem services: can they pay our way out of deforestation? ; 2002.
9. Lamarque P, Quetier F, Lavorel S. The diversity of the ecosystem services concept and its implications for their assessment and management. *Comptes rendus biologies*. 2011;334(5-6):441-9.
10. Philip MS. Measuring trees and forests: CAB international; 2008.
11. Padari A, Metslaid S, Kangur A, Sims A, Kiviste A. Modelling stand mean height in young naturally regenerated stands—a case study in Järvselja, Estonia. *Baltic Forestry*. 2009;15(2):226-36.

12. Lucas S. Bamboo: Reaktion Books; 2013.
13. Desalegn G, Tadesse W. Resource potential of bamboo, challenges and future directions towards sustainable management and utilization in Ethiopia. *Forest Systems*. 2014;23(2):294-9.
14. Darabant A, Haruthaithanasan M, Atkla W, Phudphong T, Thanavat E, Haruthaithanasan K. Bamboo biomass yield and feedstock characteristics of energy plantations in Thailand. *Energy Procedia*. 2014;59:134-41.
15. Mera FAT, Xu C. Plantation management and bamboo resource economics in China. *Ciencia y Tecnología*. 2014;7(1):1-12.
16. Embaye K. Ecological aspects and resource management of bamboo forests in Ethiopia 2003.
17. Kindu YMM. Status of bamboo resource development, utilisation and research in Ethiopia: A review. *Ethiopian Journal of Natural Resources*. 2010;1:79-98.
18. Mekonnen Z, Worku A, Yohannes T, Alebachew M, Kassa H. Bamboo Resources in Ethiopia: Their value chain and contribution to livelihoods. *Ethnobotany Research and Applications*. 2014;12:511-24.
19. Mulugeta M, Fantu W. Selection of Tree/Shrub Species for Biomass Based Energy Production. *Forestry and Forest Products in Ethiopia*. 2012:274.
20. Kelbessa E, Bekele T, Gebrehiwot A, Hadera G, Ababa A. A socioeconomic case study of the Bamboo sector in Ethiopia. INBAR Working Paper; 2014.
21. Terefe R, Samuel D, Sanbato M. Adaptation and growth performance of different lowland bamboo species in Bako, West Shoa, Ethiopia. *Journal of Natural Sciences*. 2016;6(9):61-5.
22. Yuming Y, Kanglin W, Shengji P, Jiming H. Bamboo diversity and traditional uses in Yunnan, China. *Mountain Research and Development*. 2004;24(2):157-66.
23. Lobovikov M, Ball L, Paudel S, Guardia M, Piazza M, Wu J, et al. World bamboo resources: a thematic study prepared in the framework of the global forest resources assessment 2005: Food & Agriculture Org.; 2007.
24. Kitalyi A, Wambugu R, Kimaro D. FAO characterisation of global heritage agroforestry systems in Tanzania and Kenya. *Agroforestry and development alternatives (AFOREDA)*, Tanzania FAO,–Rome. 2013.
25. Lipinski B, Hanson C, Lomax J, Kitinoja L, Waite R, Searchinger T. Reducing food loss and waste. *World Resources Institute Working Paper*. 2013:1-40.
26. Franklin JF, Spies TA, Van Pelt R, Carey AB, Thornburgh DA, Berg DR, et al. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management*. 2002;155(1-3):399-423.
27. Komiyama A, Pongpam S, Kato S. Common allometric equations for estimating the tree weight of mangroves. *Journal of Tropical Ecology*. 2005:471-7.
28. Mulatu Y, Fetene M. The effect of silvicultural management on regeneration, growth and yield of *Arundinaria alpina* (Highland bamboo) at Choke Mountain, East Gojam, Northwest Ethiopia.

- Ethiopian Journal of Agricultural Sciences. 2013;23(1-2):11-27.
29. Zhou, Mao-Yi F, Jin-Zhong X, Xiao-Sheng Y, Zheng-Cai L. Ecological functions of bamboo forest: research and application. *Journal of Forestry Research*. 2015;16(2):143-7.
30. Ceccon E, Ruiz PAG. Bamboos ecological functions on environmental services and productive ecosystems restoration. *Revista de Biología Tropical*. 2019;67(4).
31. Zegeye H. Climate change in Ethiopia: impacts, mitigation and adaptation. *International Journal of Research in Environmental Studies*. 2018;5(1):18-35.
32. Gautam G, Aryal R, Lamichhane P. Restoration of degraded land through Moso bamboo (*Phyllostachys pubescens*) plantation in the Mid-hills of Nepal. *Banko Janakari*. 2018:150-3.
33. Bessie S, Beyene F, Hundie B, Goshu G, Mengesha Y. Local Communities' Perceptions of Bamboo Deforestation in Benishangul Gumuz Region, Ethiopia. *Journal of economic & Sustainable Development*. 2014;5(24):148-62.
34. Zhang H, Zhuang S, Sun B, Ji H, Li C, Zhou S. Estimation of biomass and carbon storage of moso bamboo (*Phyllostachys pubescens* Mazel ex Houz.) in southern China using a diameter–age bivariate distribution model. *Forestry: An International Journal of Forest Research*. 2014;87(5):674-82.
35. Assaye Y, Selassie YG, Ayele B. Farmers' Perception on Highland Bamboo (*Yushania alpina*) For Land Resource Conservation in Banja District, Northwestern Ethiopia. *Woodpecker Journal of Agricultural Research*. 2014;3(1):001-9.
36. Sertse D, Disasa T, Bekele K, Alebachew M, Kebede Y, Eshete N, et al. Mass flowering and death of bamboo: a potential threat to biodiversity and livelihoods in Ethiopia. *Journal of Biodiversity and Environmental Sciences*. 2011;1(5):16-25.
37. Mulatu Y, Fetene M. Stand structure, growth and biomass of *Arundinaria alpina* (highland bamboo) along topographic gradient in the Choke Mountain, northwestern Ethiopia. *Ethiopian Journal of Biological Sciences*. 2013;12(1):1-23.
38. Majumder AF, Das AK, Nath AJ. Biomass Storage and Carbon Sequestration in Priority Bamboo Species in Relation to Village Physiography. *International Journal of Ecology and Environmental Sciences*. 2019;45(1):85-95.
39. Mulatu Y, Fetene M. Morphology and Biomass Variations of *Arundinaria alpina* Landraces in the Choke Mountain, Northwestern Ethiopia. *J. Bamboo and Rattan*. 2011;10(3&4):77-93.
40. Yismaw A, Gedif B, Addisu S, Zewudu F. Forest cover change detection using remote sensing and GIS in Banja district, Amhara region, Ethiopia. *International Journal of Environmental Monitoring and Analysis*. 2014;2(6):354-60.
41. Abere F, Belete Y, Kefalew A, Soromessa T. Carbon stock of Banja forest in Banja district, Amhara region, Ethiopia: An implication for climate change mitigation. *Journal of sustainable Forestry*. 2017;36(6):604-22.
42. Masresha G. Plant based biopesticides: safer alternative for organic food production. *J Fertil Pestic*. 2015;6(2).

43. Thokchom A, Yadava P. Biomass, carbon stock and sequestration potential of *Schizostachyum pergracile* bamboo forest of Manipur, north east India. *Tropical Ecology*. 2017;58(1):23-32.
44. Thokchom A, Yadava P. Bamboo and its role in climate change. *Current Science*. 2015;108(5):762-3.
45. Chen T-H, Wang D-H, Wang S. The trend of growth characteristics of Moso bamboo (*Phyllostachys pubescens*) forests under an unmanaged condition in Central Taiwan. 2016;31(2):75-87.
46. Teshoma U. Carbon Storage Potential of Ethiopian Highland Bamboo (*Arundinaria alpina* (K. schum): A Case Study of Adiyo Woreda, South West Ethiopia. 2019.
47. INBAR. Bamboos. Grasses: Crops, Competitors, and Ornamentals. 2019:491-3.
48. MacDicken G, Pulhin F, Guillermo I, Sales R, Cruz R. Carbon stocks assessment of a selectively logged dipterocarp forest and wood processing mill in the Philippines. *Journal of Tropical Forest Science*. 2006:212-21.
49. IPCC. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, editors. 2006 IPCC guidelines for national greenhouse gas inventories, prepared by the national greenhouse gas inventories programme. Japan: IGES. 2006.
50. Mulatu Y, Alemayehu A, Tadesse Z. BAMBOO SPECIES INTRODUCED IN ETHIOPIA. 2016.
51. Thomas K. Population structure carbon sequestration litter dynamics and propagation of selected rare bamboos of Western Ghats. 2018.
52. Singnar P, Das MC, Sileshi GW, Brahma B, Nath AJ, Das AK. Allometric scaling, biomass accumulation and carbon stocks in different aged stands of thin-walled bamboos *Schizostachyum dullooa*, *Pseudostachyum polymorphum* and *Melocanna baccifera*. *Forest ecology and management*. 2017;395:81-91.
53. Mulatu. Growth, Morphology and Biomass of *Arundinaria alpina* (Highland Bamboo)(Poaceae) as Affected by Landrace, Environment and Silvicultural Management in the Choke Mountain, Northwestern Ethiopia: Addis Ababa University; 2012.
54. Embaye K, Weih M, Ledin S, Christersson L. Biomass and nutrient distribution in a highland bamboo forest in southwest Ethiopia: implications for management. *Forest Ecology and Management*. 2005;204(2-3):159-69.
55. Alemayehu A, Mulatu Y, Eshete N, Terefe M. Growth performance and biomass accumulation of four different introduced bamboo species in South-Western Ethiopia. *Growth*. 2015;5(3).
56. Wondie ea. Estimation of biomass and carbon stock of *Acacia decurrens* forest under farmers' management using allometric models. In A. A. and A. M. Wondie Menale (Ed.), *Proceedings of the 9th Annual Regional Conference on Completed Research Activities of Forestry*, Bahir dar: Amhara Region Agricultural Research Institution. science. 2017;322(5899):(pp. 252–68).
57. Emiru E. Emiru, E. (2018). Evaluation of Management and productivity of *Eucalyptus globulus* plantation under small scale and large-scale plantation in Lay gtnia district, Northeast highlands of Ethiopia. University of Gondar. *Agriculture, Ecosystems & Environment*. 2008;126(1-2):13-23.

Figures

Figure 1

Location of the study site. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning

the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

The frequency of diameter at breast height (DBH) for the bamboo over the plantation niches.

Figure 3

The relationship between culm age and diameter of the bamboo

Figure 4

The relationship between culm age and height of the bamboo

Figure 5

Height of the bamboo culm over the plantation niches.

Figure 6

Culm diameter of the bamboo over plantation niches.