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Assessment of biomass carbon storage potential and oxygen release of Beema bamboo (*Bambusa balcooa*) plantations

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Abstract
In order to offset the ever increasing emission of greenhouse gases especially CO_2 into the atmosphere and the demand for oxygen, tree cultivation has become more obligatory. Trees are considered to be the major capital assets as they provide myriad of benefits. Being one of the most productive and fastest growing trees on the planet, bamboo potentially acts as a valuable sink for carbon storage. In this context, observations were recorded in the bamboo clumps at TNAU, Coimbatore to assess the amount of carbon dioxide sequestered and oxygen released by Beema bamboo (*Bambusa balcooa*) plantations. Through non-destructive allometric method, the volume of clump, above-ground biomass, below-ground biomass, total biomass, total carbon storage, total CO_2 sequestration potential and total amount of oxygen released from the Beema bamboo clumps were estimated. The results indicated that with the above-ground biomass of 20.45 t ha^{-1} yr^{-1}, the bamboo could able to store 12.88 t ha^{-1} yr^{-1} of carbon. Also, the amount of CO_2 sequestration was found to be 47.29 t ha^{-1} yr^{-1} and the amount of oxygen released was quantified as 34.53 t ha^{-1} yr^{-1}. The present study revealed that *Bambusa balcooa* could be used as a potential tree crop to mitigate the climate change by trapping more amount of CO_2 from the atmosphere and also by generating significant level of oxygen.

Keywords: Beema bamboo, carbon storage, carbon dioxide equivalent, oxygen release, non-destructive allometric method

1. Introduction
The global climate changes such as increasing greenhouse gases, rise in temperature and rainfall variability possess high threats to living organisms on the earth. The global air pollution is another major threat to human being in the earth and thus necessitates us to improve the Earth's environment by growing more trees in non-forested area to reduce the air pollution and climate change impacts and sustenance of human being. Trees are the carbon reservoirs as well as oxygen producer on earth and they play a vital role in carbon and oxygen biogeochemical cycle by exchanging CO_2 and oxygen to the atmosphere. It also regulates the temperature and rainfall of the particular region. They can able to store huge amounts of carbon and release more oxygen that regulate the carbon and oxygen cycle by exchange of CO_2 and O_2 with atmosphere. Vast research has been done on the carbon trading potential of different tree species, while little has been done on woody bamboo species (Lobovikov *et al.*, 2012). Bamboos are adaptable resources that can assist us in dealing with and adapting to climate change. With its fast growth and high annual regrowth after harvesting, the bamboo forest has a high carbon storage potential (Zhou and Jiang, 2004). The sequestered carbon by Bamboo would not return quickly to the atmosphere due to longer life span of durable bamboo products made by modern technologies.
The bamboo can be grown in a tropical, subtropical and temperate climates around the globe. In world, bamboo has 1000 different species and in India, 136 species of bamboo has been recorded (Basumatary *et al.*, 2015). Among the bamboo varieties, the Beema bamboo (*Bambusa balcooa*) is one of the fastest growing woody grasses which has huge potential for carbon sink as well as an oxygen generation. *Bambusa balcooa* is a thick-walled, thorn-less, clump-forming bamboo with an underground sympodial rhizome system. Due to its thick walled nature, it could sequester high amount of carbon during photosynthesis and store the excess carbon as biomass. If the carbon dioxide uptake during photosynthesis exceeds carbon dioxide release during respiration, the tree would accumulate carbon. As a result, a tree that accumulates a net amount of carbon over the course of a year (tree growth) also produces a net amount of oxygen.

Bambusa balcooa generates enormous quantity of oxygen that serves as an elixir for our livelihood. Based on the above lines, the study was carried out to estimate the biomass allocation and quantification of the amount of oxygen released in Beema bamboo plantation.

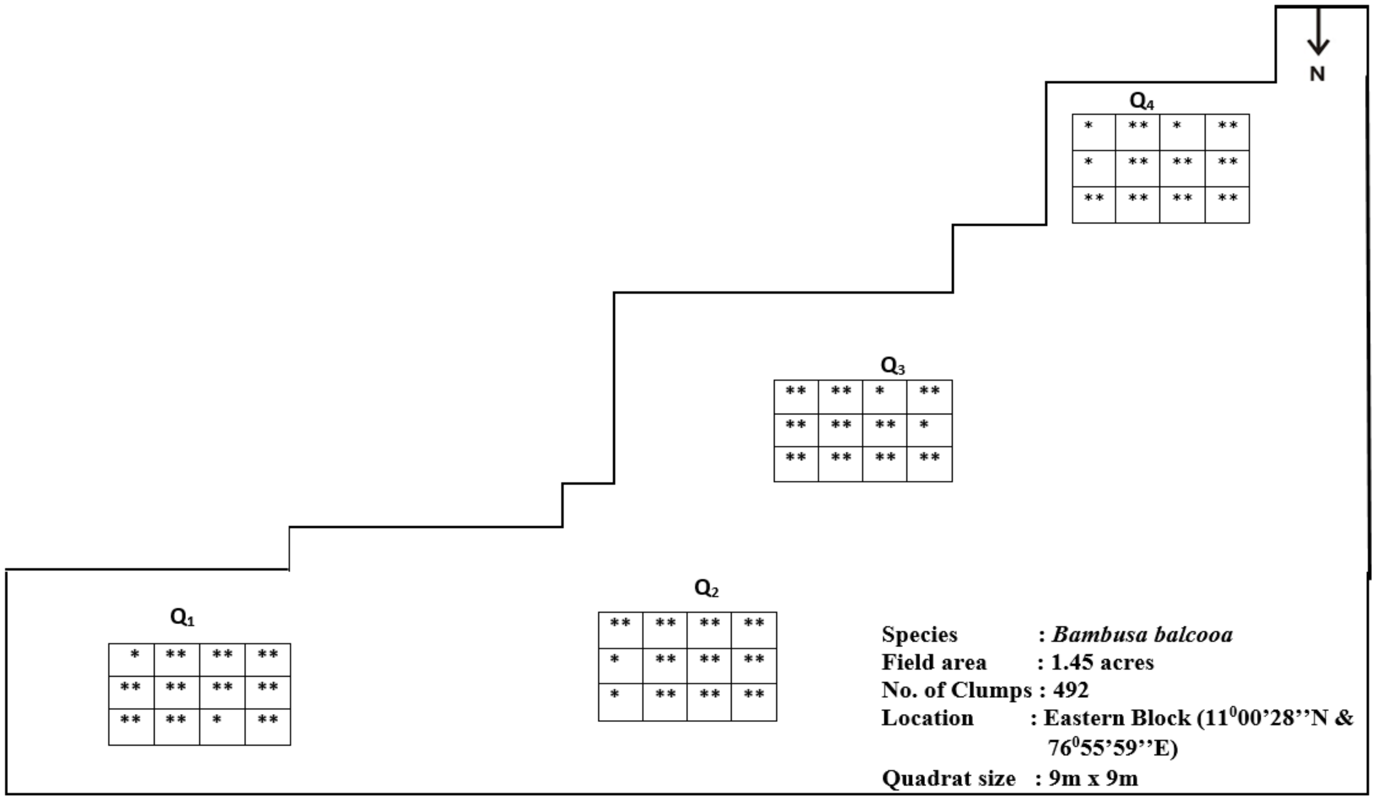
2. Materials and Methods

2.1 Investigation region

The present study was carried out in an "Oxygen Park" with Beema bamboo established at Tamil Nadu Agricultural University, Coimbatore ($11^0$00'28''N latitude and $76^0$55'59''E longitude). The study is located in the Eastern Block Farm (Field No: 67B) of the University premises.

2.2 Spotting the Clumps

The bamboo clumps were marked by employing quadrat method. Totally, 4 quadrats were formulated with a size of 9m x 9m each in the entire 1.45 acres to pick representative clumps. In each quadrat, 10 clumps were labelled and the biometric observations were taken in the labelled clumps.



(Q –Quadrat, ** - labelled clumps, *- clumps)

Fig 1: Field Layout

2.3 Biomass assessment and CO_2 sequestration

Assessment of biomass and carbon-dioxide sequestration under Beema bamboo plantation was done by using non-destructive allometric model (Dhanush and Murthy, 2020). For this, the following traits were recorded.

2.3.1 Height: The culms height was measured using Haga altimeter and expressed in meters.

2.3.2 Girth: Diameter at breast height (DBH) was measured at 1.37m above ground level by using measuring tape and expressed in centimeters.

2.3.3 Above-Ground Biomass (AGB)

The AGB was estimated by the formula as given below;

AGB (t ha^{-1}) = Volume of Clump (tree) [m^3] x Wood (Culm) density [g cm^{-3}] (Pandya *et al.*, 2013)

Volume of Clump (m^3) = Basal area (cm^2) x Height (m) (Holmgren, 2004).

2.3.4 Below-Ground Biomass (BGB)

The BGB was estimated by the following formula;

BGB (t ha^{-1}) = 0.26 X AGB (t ha^{-1})

Since the BGB includes all live roots, 0.26 is the root shoot ratio (Pandya *et al.*, 2013).

2.3.5 Total Biomass

The total biomass was calculated by adding the above-ground biomass and below-ground biomass (Pandya *et al.*, 2013).

Hence, the Total Biomass (t ha^{-1}) = AGB (t ha^{-1}) + BGB (t ha^{-1}).

2.3.6 Weight of Carbon in the bamboo

Generally, 50% of the tree's total biomass is considered as carbon storage. Hence, the weight of carbon is calculated as given below;

Wt. of carbon (t ha^{-1}) = Total Biomass (t ha^{-1}) x 0.50 (Dhanush and Murthy, 2020) [20].

2.3.7 CO_2 sequestered in the bamboo

Weight of carbon dioxide sequestered (CO_2 is composed of one molecule of Carbon and 2 molecules of Oxygen. The atomic weight of Carbon is 12.001115 and the atomic weight of Oxygen is 15.9994). Hence, weight of CO_2 is C + (2 X O) = 43.999915, while the ratio of CO_2 to C is 43.999915/12.001115 = 3.6663.

Hence, the Wt. of CO_2 sequestered (t ha^{-1}) = Wt. of carbon (t ha^{-1}) x 3.6663 (Eneji *et al.*, 2013).

2.4 Oxygen release potential
The quantity of oxygen released by the bamboo clumps can be estimated from the net carbon sequestration based on the atomic weights. The ratio of O_2 to C is about 2.67.
Therefore, the net O_2 release (t ha^{-1}) = net C sequestered (t ha^{-1}) x 32/12 (Nowak *et al.*, 2007).

3. Results and Discussion
3.1 Above-ground, below-ground and total biomasses
Assessment of carbon sequestration and storage potential of 492 clumps belonging to *Bambusa balcooa* comprising an area of 1.45 acres within the TNAU campus were investigated. Here, the above-ground and below-ground live biomasses were estimated. The mean values for all the observed characters are shown in Table 1. Above-ground biomass was calculated from the culm height and diameter. The average above-ground biomass of the 40 sampled clumps was found to be 44.66 kg/clump and hence, the total AGB was about 20.45 t ha^{-1} yr^{-1}. The below-ground biomass was calculated as 11.61 kg/clump and hence, the total BGB was about 5.32 t ha^{-1} yr^{-1}. The total live biomass was estimated as 56.27 kg/clump and the total biomass was about 25.77 t ha^{-1} yr^{-1}. Similarly, the AGB of the perennial clump-forming bamboo (*Gigantochloa scortechnii*) from Malaysia was 36.36 t ha^{-1} in a 3-year old plantation (Shanmughavel and Francis, 1996). The average aboveground carbon storage is 99.5 ± 42.5 t ha^{-1} for China fir forests and 40.6 ± 10.7 Mg ha^{-1} for moso bamboo forests (Yen and Lee, 2011). The above-ground biomass (AGB) and below-ground biomass (BGB) of all the trees in the Amity University campus are equivalent to 63,136.8 and 9470.5 kg, respectively and the total biomass accumulated is 72,607.3 kg (Sharma *et al.*, 2020). In the relationship between clump height and amount of CO_2 sequestration, second quadrat and third quadrat has high correlation. But in the first quadrat, even the clump height is lesser compared to other three quadrats, the amount of CO_2 sequestration was found to be higher (Fig. 2.). This shows that the clump height is not the determinant factor for the amount of CO_2 sequestration potential. As the diameter of species increases the plant biomass, the carbon storage capacity is also increased which removes more carbon dioxide from the atmosphere. Eneji *et al.* (2014) [14] indicated that there is no significant direct relationship between tree height and CO_2 sequestration although the height of a tree contributes to the volume of the tree which can be related to the mass and consequently to the CO_2 sequestration potential of the trees.

Table 1: Characteristics of Bamboo clumps in all the quadrats

Quadrats	NC	CH (m)	DBH (cm)	AGB (Kg)	BGB (Kg)	TB (Kg)	C (Kg)	CO_2 (Kg)	O_2 (Kg)
Q_1	16	3.32	3.65	45	11.7	56.7	28.35	104.04	75.95
Q_2	16	5.65	3.53	53.9	14.01	67.91	33.96	124.62	90.97
Q_3	15	5.43	3.61	50.47	13.12	63.59	31.80	116.69	85.18
Q_4	13	4.16	3.31	29.28	7.61	36.89	18.45	67.70	49.42
Mean	15	4.64	3.53	44.66	11.61	56.27	28.14	103.26	75.38

NC- number of culms, CH- culms height, DBH- diameter at breast height, VC- volume of the clump, AGB- above-ground biomass, BGB- below-ground biomass, TB- total biomass, C- weight of carbon in the bamboo, CO_2 – weight of carbon dioxide sequestered, O_2- quantity of oxygen released from the bamboo.

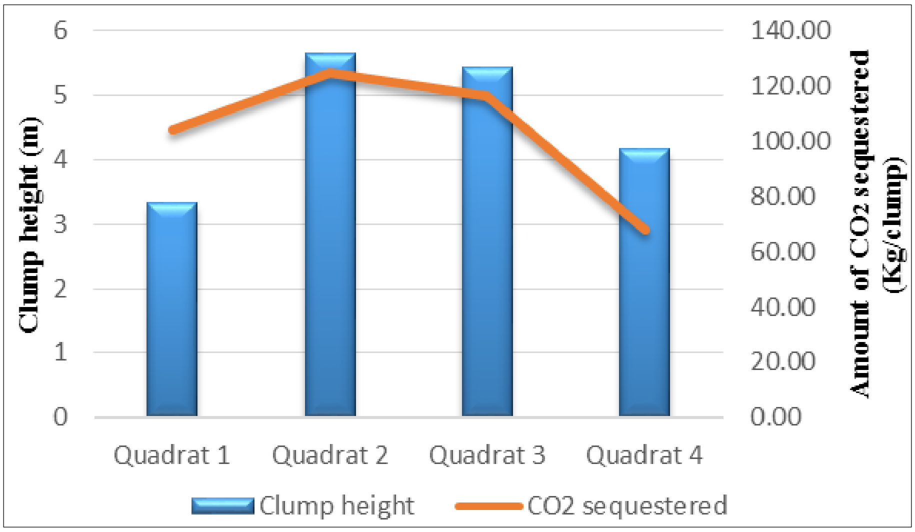


Fig 2: The relationship between the average clump height and amount of CO_2 sequestered/ clump.

3.2 Biomass Carbon storage, CO_2 sequestration and O_2 release potential
From our study, it was noticed that the height and diameter could be used to predict the bamboo biomass in reliable precision. The average biomass allocation is tabulated in Table 1. The average biomass carbon storage was found to be 28.14 kg/clump and the total biomass carbon storage was 12.88 t ha^{-1} yr^{-1}. The CO_2 sequestration potential was estimated as 103.26 kg/clump and the total CO_2 sequestration potential was about 47.29 t ha^{-1} yr^{-1}. The quantity of oxygen release was calculated as 75.38 kg/clump and the total quantity of oxygen release was about 34.53 t ha^{-1} yr^{-1}. Our study was also coincide with work of Nath *et al.*, 2015 [10], they revealed that mean carbon storage values for many bamboo species ranged from 30-121 t ha^{-1}. Sharma *et al.* (2020) [13] reported that the total biomass accumulated in the tree species of Amity University Campus, Noida was 72,607.3 kg, total carbon content of the campus trees was equal to 38,142.5 kg and the total carbon sequestered by all the trees in a year is 139.9 tonnes. A similar study performed in California State University, Northridge, revealed that the total carbon dioxide sequestered by campus trees was in the order of 154 t per year (Cox, 2011). Haghparast *et al.* (2013) also reported a total of 1694.5 tons of sequestrated carbon for 76 plots of Pune University campus. The oxygen production by trees is undoubtedly an important ecosystem service for

the betterment of environment. Mitra *et al.* (2017) [9] has reported that the yearly generation of oxygen by the 28 dominant species in Konnagar Municipality is 2959.68 t ha^{-1}. Non- destructive allometric methods are the powerful tools that are widely applied to estimate the volume, biomass, carbon storage and oxygen release of forests.

To detect the relationship among the discerned biometric observations, Pearson's correlation coefficient was generated (Table 2). A positive correlation was found among the most of the traits. Weight of the carbon dioxide sequestered had a highly significant positive correlation with the traits *viz.*, the culms height, diameter at breast height, volume of the culm, above-ground biomass, below-ground biomass, total biomass and weight of carbon in the clump. There was also a significant correlation among the traits contributing to carbon dioxide sequestration potential. The quantity of oxygen released from the clump had a highly significant positive correlation to all the observed traits except with the number of culms which had a significant positive correlation. The culm height was highly significant and positively correlated to many of the traits *viz.*, volume of the culm, above-ground biomass, below-ground biomass, total biomass, weight of carbon in the clump, weight of carbon dioxide sequestered and quantity of oxygen released from the clump. The volume of culm was also highly significantly positively correlated with all the observed traits except the number of culms. The total biomass and weight of the carbon in the clump were found to be highly significantly positively correlated to all the traits except with the number of culms. Yen *et al. (*2010) has reported the results in their study that the above-ground biomass and both DBH and height had a high correlation. However, there was a low correlation found between the above-ground biomass and age. This suggests that age is not a significant factor in the biomass estimation. They also revealed that DBH is the reliable dependent variable for the biomass prediction.

Table 2: Correlation Matrix (Pearson (n)) for the 10 traits

Traits	NC	CH	DBH	VC	AGB	BGB	TB	C	CO_2	O_2
NC	1.000	0.041^{NS}	0.194^{NS}	-0.102^{NS}	0.352^{*}	0.352^{*}	0.352^{*}	0.352^{*}	0.352^{*}	0.352^{*}
CH	0.041^{NS}	1.000	0.358^{*}	0.730^{**}	0.745^{**}	0.745^{**}	0.745^{**}	0.745^{**}	0.745^{**}	0.745^{**}
DBH	0.194^{NS}	0.358^{*}	1.000	0.870^{**}	0.708^{**}	0.708^{**}	0.708^{**}	0.708^{**}	0.708^{**}	0.708^{**}
VC	-0.102^{NS}	0.730^{**}	0.870^{**}	1.000	0.872^{**}	0.872^{**}	0.872^{**}	0.872^{**}	0.872^{**}	0.872^{**}
AGB	0.352^{*}	0.745^{**}	0.708^{**}	0.872^{**}	1.000	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}
BGB	0.352^{*}	0.745^{**}	0.708^{**}	0.872^{**}	1.000^{**}	1.000	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}
TB	0.352^{*}	0.745^{**}	0.708^{**}	0.872^{**}	1.000^{**}	1.000^{**}	1.000	1.000^{**}	1.000^{**}	1.000^{**}
C	0.352^{*}	0.745^{**}	0.708^{**}	0.872^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000	1.000^{**}	1.000^{**}
CO_2	0.352^{*}	0.745^{**}	0.708^{**}	0.872^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000	1.000^{**}
O_2	0.352^{*}	0.745^{**}	0.708^{**}	0.872^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000

(**Note:** *Significant at 0.05, ** Significant at 0.01, NC- number of culms, CH- culms height, DBH- diameter at breast height, VC- volume of the clump, AGB- above-ground biomass, BGB- below-ground biomass, TB- total biomass, C- weight of carbon in the bamboo, CO_2 – weight of carbon dioxide sequestered, O_2- quantity of oxygen released from the bamboo).

4. Conclusion

As a sustainable carbon sink, bamboo has begun to trap increasing attention. The present work was a sustainability initiative to inventory the oxygen park establishment of Beema bamboo in Tamil Nadu Agricultural University premises and compute their carbon storage capacity. The above-ground biomass, below-ground biomass and total biomasses were calculated by using the non-destructive method. The Beema bamboo plantation had the carbon storage potential of 12.88 t ha^{-1} yr^{-1} and the carbon dioxide sequestration potential of 47.29 t ha^{-1} yr^{-1}. Besides, the amount of oxygen released from the plantation was 34.53 t ha^{-1} yr^{-1}. The results of this study illuminate the value of Beema bamboo clumps, not only as a permanent green cover and a high biomass yielding plantations but also in mitigating the impacts of climate change at a local level. The findings in this study could be utilized to create the future on-campus greening initiatives and serve as a benchmark for future assessment of the campus carbon sink. Due to the rising demand for oxygen, the cultivation of Beema bamboo is becoming a viable option for organically supplying oxygen.

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