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Estimation of Biomass and Carbon Stock of Woody Plants in Different Land-Uses

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Abstract

A substantial increase in the number of forest plantations has been observed in the last two decades owing to a greater awareness on climate change and global initiative of REDD and REDD+ (Reducing Emissions from Deforestation and forest Degradation) programs. In light of this, biomass and total carbon stocks of woody plants were estimated in five study sites–four plantations and a natural forest at Puthupet, Tamil Nadu, India. The aboveground biomass in the study sites were 32.7, 38.1, 121.1, 143.2and 227.2 (Mg/ha) in *Anacardium occidentale, Casuarina equisetifolia, Mangifera indica, Cocos nucifera* and natural forest respectively. In the natural forest, *Pterospermum canescens* contributed to the greatest aboveground biomass (55.54 Mg/ha), whereas the least was from *Diospyros ferrea* (1.07 Mg/ha). The maximum carbon stock was reported from the natural forest site (131.8 Mg/ha) while the minimum was from *Anacardium occidentale* plantation (19.5 Mg/ha). A significant positive relationship was observed between basal area with biomass and total carbon. The low values of biomass and carbon stocks in plantations maybe due to less stand age structure. Our results suggest that besides the natural forests, plantations also have great potential for carbon sequestration in the coastal areas and suggest developing more plantations and retaining it for a longer period of time will be helpful in reducing the atmospheric carbon dioxide concentrations.

Keywords: Climate change; Natural forest; Forest plantations; Aboveground biomass; Tropical dry evergreen forest

Introduction

During the last two decades, forest plantations have been gaining importance due to their key role in mitigating atmospheric carbon dioxide (CO_2) in the global context of climate change [1-4]. As CO_2 drastically enhances greenhouse effect [5] and global warming, which in turn trigger climate change, forests prove to be promising means of combating this undesirable phenomenon by their unique ability to store large volumes of carbon (C) in their biomass [4-8]. However, a rapid rise in the rate of deforestation especially in the tropics reduces the CO_2 mitigation potential of tropics posing a possible peril of converting them from being a global carbon sink to a net carbon source [3,9,10]. In this crucial scenario, plantation forestry has turned out to be a preferential option for climate change mitigation [11,12]. The total C storage potential of the forest plantations has been recently estimated to be around 11.8 Pg C [13]. Therefore, various activities on forestry were often proposed in tropics, as tropical climate promotes rapid vegetation growth, which would result in more carbon sequestration [14].

This apart, one other important reason for growing plantations is to meet the ever-increasing demand for forest and forest products, which has proved to be an outcome of population explosion. Plantations produce wood and other products sooner than the natural forests [15] and they also help in soil and water conservation [16]. Although their contribution in total terrestrial carbon storage is very less (3.8% or 140 million ha of the world's total forest area [17], they have been known to reveal considerable potential in absorbing and storing C which helps in mitigating climate change [18]. All the aforesaid reasons have made plantations to become an interesting topic of research in the present scenario.

The C sequestration potential of a forest is determined by its biomass production. While the rate of biomass production (i.e., increase of forest biomass per year) indicates the potential of a forest to absorb atmospheric CO_2 and reduce global warming, the standing biomass of a forest reflects on the amount of C sequestered during its lifetime. Therefore, the present study has been carried out with the objective, to estimate and comparing the biomass and total C stocks of woody plants in five study sites viz., four plantations and a natural forest at Puthupet, Tamil Nadu, India.

Materials and Methods

Site Description

The study was conducted in five sites viz., four plantations (*Cocos nucifera, Anacardium occidentale, Mangifera indica* and *Casuarina equisetifolia*) and a natural forest at Puthupet, located 15 km north of Puducherry (Table 1 and Figure 1). The mean annual temperature

Name of species	Location	No of individuals/ha	BA (m²/ha)
Anacardium occidentale	N=12° 05' 627" E= 79° 85' 899"	244	5.8
Casuarina equisetifolia	N=12° 05' 564" E= 79° 86' 794"	3200	6.7
Cocos nucifera	N=12° 05' 862" E= 79° 86' 32"	232	15.8
Mangifera indica	N=12° 05' 376" E= 79° 86' 967"	204	14.5
Natural forest	N=12° 05' 702" E= 79° 87' 148"	660	28.1

Table 1: Density and BAof tree species in four plantations and natural forest at Puthupet, Tamil Nadu, India.

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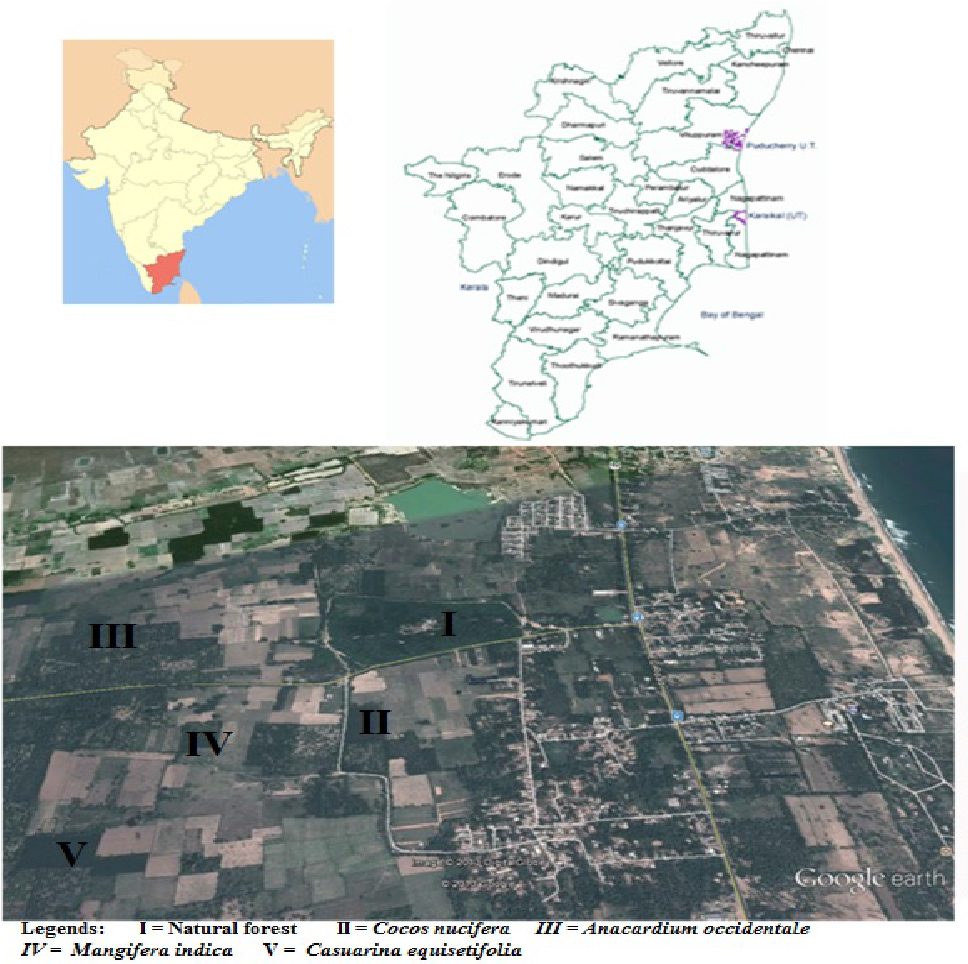

Figure 1: Aerial view of Puthupet, Tamil Nadu, India showing different landscapes (source –Google earth).

and annual rainfall of the sites were 28.5°C and 1311 mm, respectively. The forest types were selected due to the fact that plantations are monoculture and another is natural forest which is undisturbed. The experimental plots lie between 12° 05' 627" N latitude and 79° 85' 899" E longitude. The Figure 1 is a Google-earth generated map and the exact geographic locations of all the study sites are given in the Table 1.

Climate

The climate of the area is tropical dissymmetric. The rainy season starts from October to December and extends up to January. About 80% total annual rainfall occurs during this period.

Methods

The study was carried out to estimate the aboveground biomass of woody plants in plantations and natural forest at Puthupet, Pondicherry. Total of 15 sample plots of 50×50 m (0.25 ha) each were laid out in all the five study sites. The aboveground biomass of tree species was estimated by the following the species specific allometric equations of tropical dry deciduous forest developed by Chave et al. [19]. For a few tree species where no species specific allometric equations were available, we used equations for similar species.

$$AGB=\rho \times \exp(-0.667+1.784\ln(D)+0.207(\ln(D))2- 0.0281 (\ln(D))3)$$

Whereas AGB=aboveground biomass, ρ=wood specific gravity, D=Diameter

Belowground biomass (BGB) was estimated by following the allometric equation of Cairns et al. [20].

$$BGB=\exp(-1.0587+0.8836\times\ln AGB)$$

The total C was computed by using the following formula

Carbon (C Mg ha^{-1})=Biomass (Mg ha^{-1})×Carbon%

The AGB C was calculated by assuming that the C content is 50% of the total AGB by following Brown and Lugo [21].

The C contained in the biomass is taken as 50% of the AGB estimates.

Species specific wood specific gravity was used for all the tree species [22-24].

Statistical analysis

Regression analyses were used to test the relationship among the following variables: number of individuals with basal area (BA), biomass and total C; BA with AGB and total C.

Results

The AGB in plantations ranged between 32.7 and 143.2 Mg/ha with lowest value in *Anacardium occidentale* and the highest value in *Cocos nucifera* plantations. However, the natural forest accounted for (227.2 Mg/ha) AGB (Table 3). In natural forest site, *Pterospermum canescens* (55.54 Mg/ha) contributed the highest AGB whereas, *Diospyros ferrea* (1.07 Mg/ha) contributed the lowest AGB (Table 4). The BGB in plantations ranged between 6.3 and 23.5 Mg/ha with lowest value in *Anacardium occidentale* and the highest value in *Cocos nucifera* plantations. The natural forest accounted for the greatest BGB (36.3 Mg/ha) among all the study sites. The maximum C stock was recorded from the natural forest 131.8 (Mg/ha) while the plantations of *Anacardium occidentale, Casuarina equisetifolia, Mangifera indica* and *Cocos nucifera* have stocked 19.5, 23.9, 70.5 and 83.3 Mg C/ha, respectively. Among the plantations, the highest C was estimated in *Cocos nucifera* (83.3 Mg C/ha) plantation whereas the lowest was estimated in *Anacardium occidentale* plantation (19.5 Mg C/ha).

The tree density and BA varied significantly among all the five study sites – viz., four plantations and a natural forest. As shown in Table 1, the minimum and maximum tree density were recorded from *Mangifera indica* (204 stems/ha) and *Casuarina equisetifolia* plantations (3200 stems/ha). The densities of *Cocos nucifera* plantation, *Anacardium occidentale* plantation and that of the natural forest were 232 stems/ha, 244 stems/ha and 660 stems/ha respectively. In the natural forest site, *Memecylon umbellatum* was the dominant species in terms of density (252 stems/ha out of the total 660 stems/ha; Table 2).

Name of species	No of individuals	BA (m^2/ha)
Agalia elaeagnoidea	56	0.912
Albizia amara	8	0.538
Azadirachta indica	24	3.342
Calophyllum inophyllum	20	1.034
Diospyros ferrea	4	0.130
Diospyros ebenum	76	2.222
Drypetes sepiaria	76	2.222
Memecylon umbellatum	252	5.014
Pongamia pinnata	32	4.066
Pterospermum canescens	88	8.293
Walsura trifolia	24	0.300

Table 2: Density and BA of tree species in natural forest in the Puthupet, Tamil Nadu, India.

Name of species	AGB (Mg/ha)	BGB (Mg/ha)	TB (Mg/ha)	TC (Mg/ha)
Anacardium occidentale L.	32.7	6.3	39.0	19.5
Casuarina equisetifolia L.	38.1	9.8	47.9	23.9
Cocos nucifera L.	143.2	23.5	166.7	83.3
Mangifera indica L.	121.1	19.8	140.9	70.5
Natural forest	227.2	36.3	263.6	131.8

Table 3: Biomass and C stock in four plantations and natural forest at Puthupet, Tamil Nadu, India.

Name of species	AGB (Mg/ha)	BGB (Mg/ha)	TB (Mg/ha)	TB C (Mg/ha)
Agalia elaeagnoidea	7.52	1.47	8.98	4.49
Albizia amara	2.77	0.48	3.25	1.63
Azadirachta indica	31.79	4.56	36.35	18.18
Calophyllum inophyllum	6.90	1.12	8.02	4.01
Diospyros ebenum	18.98	3.26	22.24	11.12
Diospyros ferrea	1.07	0.19	1.26	0.63
Drypetes sepiaria	18.98	3.26	22.24	11.12
Memecylon umbellatum	40.58	7.39	47.97	23.98
Pongamia pinnata	40.66	5.70	46.36	23.18
Pterospermum canescens	55.54	8.44	63.98	31.99
Walsura trifolia	2.43	0.48	2.91	1.46

Table 4: Biomass and C stock in a natural forest at Puthupet, Tamil Nadu, India.

The lowest and the highest BA was reported from *Anacardium occidentale* plantation (5.8 m^2/ha) and the natural forest (28.1 m^2/ha). *Pterospermum canescens* is mainly accountable for the maximum basal area with 8.3 m^2/ha in the natural forest while Memecylon umbellatum trails behind with 5.1 m^2/ha.

In the natural forest site, a significant positive correlation was observed among the following variables: number of individuals with BA, biomass and total C and also basal area with AGB and total C (Figure 2).

Discussion

It is important to obtain more accurate and precise biomass estimates for tropical dry forests in order to improve our understanding of the role of tropical dry forests in global cycle. The results of the present study are well within the limits of tropical dry forests reported worldwide as well as from various other tropical forests in India. In the present study, the total BA reported for all the four plantations are coherent with the results observed by Chaturvedi et al. [25] and Jha and Singh [26]. The results obtained with regards to the natural forest are well within the range as observed by Mani and Parthasarathy [23] in tropical dry evergreen forests. The total AGB estimated in the present study has marginally increased from plantation to the natural forest.

The C stocks of the four plantations and the natural forest are consistent with various other studies in tropical forests in India and Thailand [25,27-30] and also with the teak plantations of a dry tropical region in India as documented by Karmacharya and Singh [31] and in Thailand by Meunpong et al. [30].

A significant positive correlation between BA and biomass, as well as between BA and total woody C as inferred in the current study is substantiated by several other studies [21,23,25,31-33] which have also reported a high correlation of biomass with diameter at breast height.

The results of the present study prove that plantations acting as storehouse of carbon by stocking C in their tissues, thereby lowering the levels of atmospheric greenhouse gases as stated by Brown et al. [21]. Natural forests have proven to possess even a greater potential of reducing the concentration of these gases as they are undisturbed ecosystems. The current study is in accordance with the results of Mani and Parthasarathy [23] in relation to carbon storage of natural forests in Puducherry. The variation in the biomass and the lesser values of C among the plantations may be due to differences in age structure, species composition, storage potential, stage of development and site characteristics according to Kumar et al. [29].

Our results imply that although unmatchable with natural forests, plantations too have a great potential to store C in their biomass and it could be suggested that increase in their number and maintenance over a long time period will mitigate the atmospheric CO_2 concentrations, apart from the standpoint of conservation.

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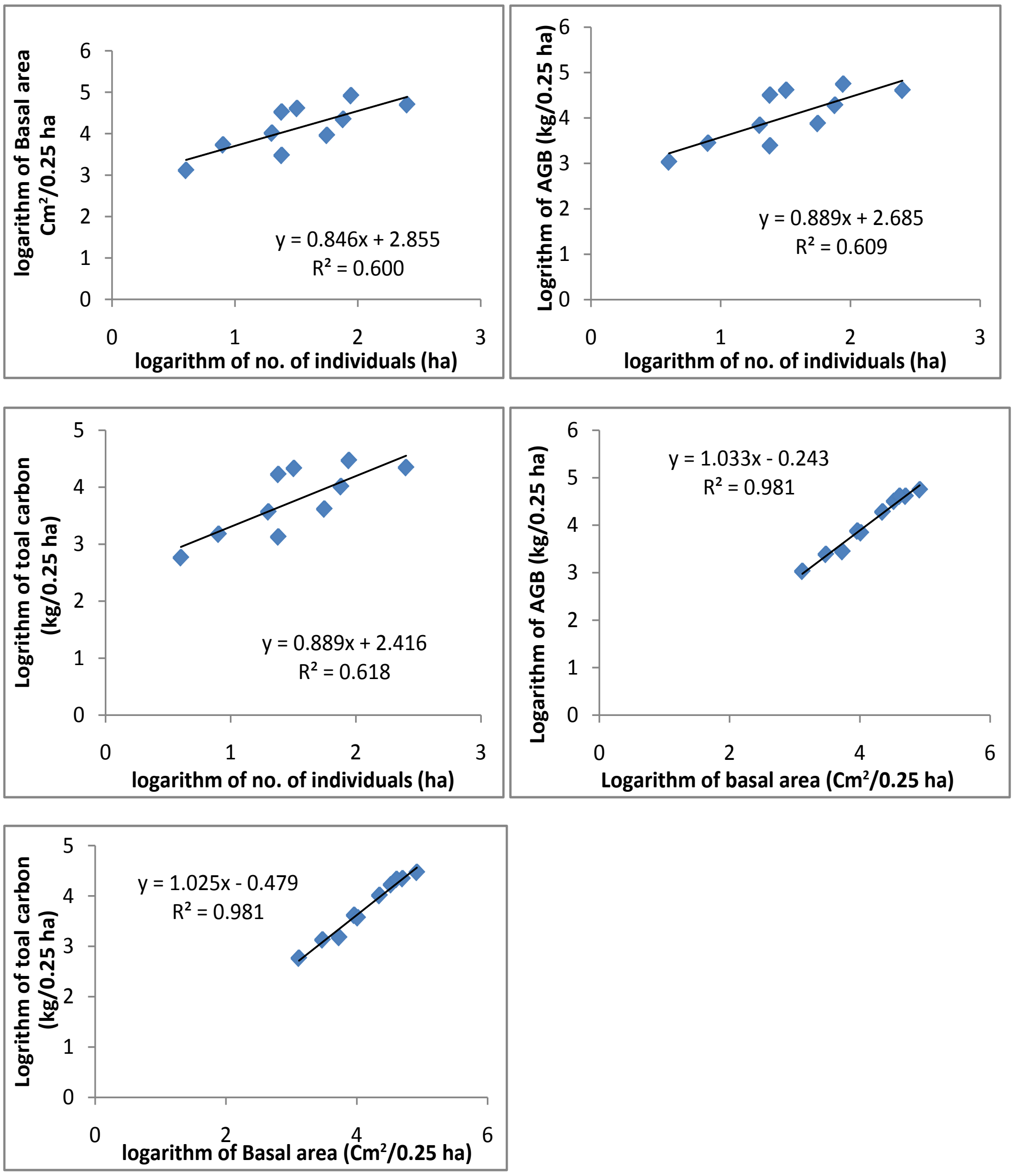

Figure 2: Regression between: a) number of individuals vs.BA, b) number of individuals vs.AGB and c) number of individuals vs.total woody C, d) BAvs. AGB, e) BA vs. total woody C in the natural forest at Puthupet, Tamil Nadu, India.

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