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Standing carbon stock estimation in different tree species grown in dry tropical forests of vindhyan highland, Mirzapur, India

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ABSTRACT

This study was carried out to investigate total carbon sequestration in ten dominant tree species grown in Rajiv Gandhi South Campus, Banaras Hindu University, Barkaccha, Mirzapur, India having an area of 2760 acres. To estimate biomass from selective tree species, it is not advisable to cut them for this reason, non-destructive method is employed. The essential parameters required for the measurement of biomass and carbon stock is height, girth and wood density. Height measurement is based on shadow method and girth taken as Diameter at Breast Height (dbh) as 1.36 meter high above the ground. The study revealed that the height (0.70**) and girth (0.93**) showed positive correlation with carbon stock of selective tree species and has advantage over destructive method used for biomass and carbon stock estimation. Carbon storage in individual tree species varies from 0.04 tonnes (*Acacia catechu*) to 25.65 tonnes (*Madhuca longifolia*)

Key words : Tree biomass, Carbon sequestration, Correlation coefficient, Climate change.

Introduction

Global surface mean temperatures have increased by 0.8°C since the late 19th century and eleven out of the twelve warmest years on record have occurred since 1995 (IPCC, 2007). Earth's mean temperature is projected to increase by 1.5 to 5.8 °C during the 21st century (IPCC, 2001). The culprit behind these and other observed climate changes are reportedly caused by emission of greenhouse gases (GHGs) through anthropogenic activities including land use change, deforestation, forest fire, draining of wetlands, soil cultivation and fossil fuel combustion. CO₂ concentration in the atmosphere has increased from 280 ppm in 1750 to 380 ppm in 2005; this is the cause of global warming. Global warming would vary between regions causing diverse impacts on agriculture, forestry, human health and biodiversity.

For example, tropical regions would be more affected by a decrease in agricultural production, while temperate regions would face the expansion of vector-born diseases like malaria and dengue fever, and would confront higher temperatures and more frequent heat waves during summer (IPCC, 2001). Facing these threats and the costs of adaptation to be borne by future generations, mitigation measures have been proposed within international agreements like the Kyoto Protocol (UNFCCC, 1998). As a general classification, mitigation is divided into two groups: first, the reduction of GHG emissions in the energy sector and industrial process and second, the enhancement of carbon sinks.

This paper emphasis on trees of ten dominant species act as major CO₂ sink which captures carbon from the atmosphere and acts as sink, stores the same in the form of fixed biomass during the growth

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process. Active absorption of CO₂ from the atmosphere in photosynthetic process and its subsequent storage in the biomass of growing trees or plants is the carbon storage (Baes *et al.*, 1977 and Mathews *et al.*, 2000). Carbon sequestration implies transfer of atmospheric CO₂ into other long lived global pools including oceanic, pedologic, biotic and geological strata to reduce the net rate of increased atmospheric CO₂ concentration (Lal, 2008). Owing to its numerous ancillary benefits (e.g., improved soil and water quality, restoration of degraded ecosystem, increased crop yield) tree carbon sequestration is often termed as win-win or no regrets strategy (Lal *et al.*, 2003). Therefore, growing trees (especially high carbon sequester) in proper land use pattern can be a potential contributor in reducing the concentration of CO₂ in atmosphere by its accumulation in the form of biomass. Replacing diverse ecosystems with single-species timber plantations may generate greater carbon accumulation. However, increasing the number of trees might potentially slow the accumulation of atmospheric carbon (Moulton and Richards, 1990).

The objective of this research is to measure the sequestration potential of different tree species grown in the natural ecosystem without any tree management practices so as to develop a carbon neutral and healthy environment to sustain life in a better way.

Materials and Methods

Study area

Present study was carried out in Mirzapur district (Uttar Pradesh, India) at Rajiv Gandhi South Campus (BHU), Barkaccha [lat. 25°10', long. 82°45'] covering about 11.2 km² area. This area is characterized with seasonally dry tropical climate dominated by a typical monsoonal character. Mean monthly temperature ranges from 13.3–30.5 °C (minimum) to 23.2–40 °C (maximum). The annual rainfall averages 1035 mm, of which 85% precipitates during rainy season from the South– West monsoon. The annual cycle experiences an extended dry period of about nine months. The region is an erosional surface where the landscape is marked by plateau, summit, valley bottoms, ridges, isolated hills and sediments. The soils are residual, ultisol, sandy to sandy loam in texture and reddish brown in colour. The intensively leached soil is shallow, low in nutrients and organic matter and has moderate water holding ca-

pacity (WHC) (Singh *et al.*, 1989). Mostly dominated by xerophytic shrubs and fragmented forests.

Biomass estimation

Above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter are the major carbon pools in any ecosystem (FAO, 2005; IPCC, 2006).

Aboveground and belowground biomass in the selected tree species was estimated by carbon percentage and by measuring the tree height, DBH and wood density. The carbon concentration of different tree parts was rarely measured directly, but generally assumed to be 50% of the dry weight (Losi *et al.*, 2003; Jana *et al.*, 2009; Chavan and Rasal, 2011).

Estimation of Aboveground biomass

The biomass of a tree is the sum of the biomass of its roots, trunk, branches, leaves and reproductive organs- flowers and fruits. For an accurate measure of biomass the tree would have to be felled. To avoid destruction, the standing woody biomass has been estimated by allometric equation based on diameter and height. Height was measured through shadow method. True trees are defined by girths at breast height (GBH) of more than 30cm. The corresponding GBH (Girth at Breast Height 1.3 m) and height for each individual tree were noted. The trees with girth above 30 cm were considered. Besides, saplings with a girth of over 20 cm were also taken into consideration, as young saplings sequester carbon at a faster rate and their chance of survival is high. Three representative trees were selected from each species for girth and height measurement. The aboveground biomass (AGB) has been calculated by multiplying volume of biomass and wood density (Ravindranath and Ostwald, 2008). The volume was calculated based on diameter and height. The wood density value for the tree species were obtained from web (www.worldagroforestry.org).

$$\text{Bio-volume} = b = 0.4 \times [(GBH)/2] \times H$$

$$\text{Biomass} = \text{Specific gravity of wood} \times b$$

Where,

(GBH) is girth at breast height 1.3 m, assuming the trunk to be cylindrical. H = Height (m). As the wood density of some tree species was unavailable; the standard average of 0.6 gcm⁻³ was taken.

Estimation of Belowground biomass

The Below Ground Biomass (BGB) includes all biomass of live roots excluding fine roots having < 2

mm diameter (Chavan and Rasal, 2011). The belowground biomass (BGB) has been calculated by multiplying above-ground biomass with 0.26 as the root to shoot ratio (Chave et al., 2005 and Ravindranath and Ostwald, 2008).

Tree height measurement

Shadow method

To estimate the tree height one should have to measure the length of the tree's shadow, observer's shadow and his height at the same time (Fig 1) and calculate as:

$$\text{Tree's height} = (\text{Tree shadow} / \text{observer's shadow}) \times \text{observer's height}$$

Note: Measurement of girth must be taken 1.3 meter above the ground of only those trees having diameter >10 cm. For trees in forest stands, average diameter at breast height growth was estimated as 0.38 cm/year.

Estimation of carbon sequestration in terms of CO₂

The carbon sequestration is multiplied to one ton of carbon percentage and this is converted to CO₂ per hectare by factor of 3.67 (Jindal et al., 2007; Soderblom, 2009; Hairiah, 2008; Kumar et al., 2009; Sherill and Bratkovich, 2011 and Jasmin and Birundha, 2011). One ton of Fresh biomass converts into 4.6 tons of CO₂.

Estimation of Growth rates of trees

Growth rates were adjusted based on tree condition. For trees with fair to excellent condition, growth rates were multiplied by 1 (no adjustment); poor condition tree growth rates were multiplied by 0.76; critical trees by 0.42; dying trees by 0.15; and dead trees by 0 (Nowak, 2002)

Statistical analyses

All data were subjected to the analyses of variance

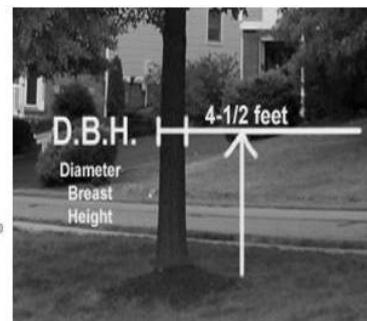
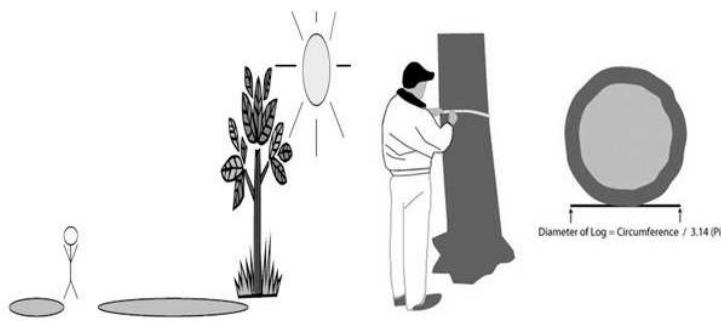


Fig 1. Tree height, girth and diameter at breast height measurement on field site.

(ANOVA) with the SPSS v16.0 package. Pooled analysis of variance was performed to determine the significance of differences in the parameters. Mean of the parameters were compared using critical difference ($P<0.05$). Pearson correlation coefficient was computed to establish relationship between all parameters.

Results and Discussion

Interspecific variation in total carbon content of different tree species were highly significant (Table 1) indicating high variability in carbon sequestration among the different tree species (Table 1).

(Table 1. Please see at the end of this paper)

Carbon storage in individual tree species varies from 0.04 tonnes (*Acacia catechu*) to 25.65 tonnes (*Madhuca longifolia*) (Table 2). Gross sequestration rates ranged from 0.16 tC/year (*Acacia catechu*) to 94.13 tC/year (*Madhuca longifolia*). This study is in accordance with (Huston and Marland, 2003) showed that carbon sequestration depends not only on rates of productivity but also on the size of the tree.

Total carbon storage and sequestration within tree species generally increases with increased girth at breast height. Large healthy trees (greater than 100 cm in diameter) sequester approximately 150 times more carbon than small healthy trees (less than 100 cm in diameter). Large trees also store approximately 600 times more carbon than small trees; these results are in accordance with (Nowak, 2002). This relatively high standard error leads to less certainty of the carbon estimate. Although differences in the functional traits of tree species (such as average diameter at breast height, wood density, and life span) are a well-known principle of community ecology (Korner, 2005). The magnitude of the effect

Table 1. Pooled Analysis of Variance.

| Source of variation | DF | Mean Sum of Squares | | | | | |
|---------------------|----|-----------------------------|------------------|-----------------------------|-----------------------------|----------------------|------------------------------|
| | | Girth at breast height (cm) | Plant height (m) | Above ground biomass (Tons) | Below ground biomass (Tons) | Total biomass (Tons) | Above ground carbon (t/tree) |
| Replication | 2 | 150.53* | 0.001 | 0.20 | 0.005 | 0.27 | 0.04 |
| Tree species | 9 | 74230.62** | 18.49 | 840.35** | 18.9 | 1111.4** | 3.83 |
| Error | 18 | 40.46 | 0.18 | 2.69 | 0.06 | 3.56 | 0.54 |
| | | | | | 0.01 | 0.01 | 0.72 |
| | | | | | | | 9.73 |

*. **= significant at 5% and 1% level of significance, respectively.

of such differences on stand-level carbon storage is rarely emphasized in the context of C-sink initiatives (Balvanera *et al.*, 2005 and Bunker *et al.*, 2005). Carbon storage and sequestration in a region is a function of the amount of area under that tree species and percent tree cover (i.e. total amount of tree density) (Chave *et al.*, 2005; Ravindranath and Ostwald, 2008; Chavan and Rasal, 2011 and Nowak, 2002). The area under study was mostly dominated by xerophytic shrubs and fragmented forests.

The fact that the above ground biomass (particularly the stem) accounts for the largest amount of carbon from total tree biomass has been largely documented, with ranges going from 50 to 92% for different species from forest plantations (Perez and Kanninen, 2003; Redondo, 2007 and Redondo and Montagnini, 2006). Total carbon sequestration is significantly and positively correlated with biomass and carbon content ($r=1.0^{**}$) advocates that for reducing the atmospheric carbon dioxide level the tree species should be selected which is having high biomass *vis-a-vis* total carbon sequestration have significant and positive correlation with girth at breast height (GBH) ($r=0.93^{**}$) and a little bit low correlation with plant height i.e. tree species having high GBH may also play important role in reducing CO₂ from atmosphere rather than higher plant height (Table 3). That is why tree height is rarely used independently for measuring carbon stock (Pastor *et al.*, 1984, Bond-Lamberty *et al.*, 2002 and Martin *et al.*, 1998).

Overestimations are still more common when considering components less lignified such as fine necromass, tree leaves and herbaceous vegetation. These results are supported (Gifford, 2000 and Sarmiento *et al.*, 2005). Carbon content is in the range of 25.65 tC/tree and 0.04 tC/tree. Therefore, extrapolating on the assumption that all plant biomass has a constant carbon fraction will only lead to increased errors.

Conclusion

Forests play a significant role in reducing atmospheric carbon dioxide levels. More field measurements are needed in these areas to improve carbon accounting and other functions of forest ecosystems. In particular, more field data are required to assess regional variation in forest structure. Long-term permanent plot data are needed to assess forest growth, regeneration, and mortality.

Table 2. Mean carbon sequestration by different tree species.

| Tree Sp. | Girth at breast height (cm) | Plant height (m) | Above ground biomass (Tons) | Below ground biomass (Tons) | Total biomass (Tons) | Above ground carbon (t/tree) | Below ground carbon (t/tree) | Total carbon (t/tree) | CO ₂ sequestered (t/tree) | Gross Sequest. (tons C/Yr.) |
|-------------------------------|-----------------------------|------------------|-----------------------------|-----------------------------|----------------------|------------------------------|------------------------------|-----------------------|--------------------------------------|-----------------------------|
| <i>Madhuca longifolia</i> | 440 | 10.52 | 49.57 | 7.44 | 57.01 | 22.31 | 3.34 | 25.65 | 94.13 | 94.13 |
| <i>Ficus bengalensis</i> | 308 | 11.53 | 26.63 | 3.99 | 30.62 | 11.98 | 1.80 | 13.78 | 50.58 | 50.58 |
| <i>Beutia monospermouseus</i> | 144.7 | 7.73 | 3.94 | 0.59 | 4.53 | 1.77 | 0.26 | 2.04 | 7.48 | 7.48 |
| <i>Ficus religiosa</i> | 314.3 | 8.35 | 20.10 | 3.02 | 23.12 | 9.05 | 1.36 | 10.40 | 38.18 | 38.18 |
| <i>Terminalia arjuna</i> | 440.3 | 6.72 | 31.77 | 4.76 | 36.53 | 14.29 | 2.14 | 16.44 | 60.32 | 60.32 |
| <i>Eugenia jumbolana</i> | 292 | 11.70 | 24.31 | 3.65 | 27.96 | 10.94 | 1.64 | 12.58 | 46.15 | 46.15 |
| <i>Azadirachta indica</i> | 53.3 | 6.25 | 0.50 | 0.07 | 0.57 | 0.22 | 0.03 | 0.26 | 0.95 | 0.95 |
| <i>Eucalyptus grandis</i> | 224.7 | 6.70 | 8.25 | 1.24 | 9.49 | 3.71 | 0.55 | 4.27 | 15.66 | 15.66 |
| <i>Acacia catechu</i> | 28 | 4.48 | 0.08 | 0.01 | 0.09 | 0.04 | 0.01 | 0.04 | 0.16 | 0.16 |
| <i>Acacia nilotica</i> | 35 | 5.99 | 0.17 | 0.03 | 0.2 | 0.08 | 0.01 | 0.09 | 0.33 | 0.33 |
| Mean | 228.0 | 8.0 | 16.5 | 2.5 | 19.0 | 7.4 | 1.1 | 8.6 | 31.4 | 31.4 |
| SE | 3.67 | 0.24 | 0.95 | 0.14 | 0.43 | 1.09 | 0.06 | 0.49 | 1.80 | 1.80 |
| CD (P< 0.05) | 10.91 | 0.72 | 2.82 | 0.42 | 1.27 | 3.24 | 0.19 | 1.46 | 5.35 | 5.35 |

Table 3. Correlation among the characters studied.

| Characters | Girth at breast height (cm) | Plant height (m) | Above ground biomass (Tons) | Below ground biomass (Tons) | Total biomass (Tons) | Above ground carbon (t/tree) | Below ground carbon (t/tree) | Total carbon (t/tree) | CO ₂ sequestered (t/tree) |
|-----------------------------|-----------------------------|------------------|-----------------------------|-----------------------------|----------------------|------------------------------|------------------------------|-----------------------|--------------------------------------|
| Girth at breast height | 1.000 | .629** | .933** | .933** | .933** | .933** | .933** | .933** | .933** |
| Plant height | | 1.000 | .702** | .702** | .695** | .702** | .701** | .702** | .702** |
| Above ground biomass | | | 1.000 | 1.0** | .995** | 1.0** | 1.0** | 1.0** | 1.0** |
| Below ground biomass | | | | 1.000 | .995** | 1.0** | 1.0** | 1.0** | 1.0** |
| Total biomass | | | | | 1.000 | .995** | .995** | .995** | .995** |
| Above ground carbon | | | | | | 1.000 | 1.0** | 1.0** | 1.0** |
| Below ground carbon | | | | | | | 1.000 | 1.0** | 1.0** |
| Total carbon | | | | | | | | 1.000 | 1.0** |
| CO ₂ sequestered | | | | | | | | | 1.000 |

*, **= significant at 5% and 1% level of significance, respectively.

Carbon sequestration is more in those species that have higher biomass and high girth at breast height (GBH). Hence to frame model for atmospheric CO₂ reduction in a specific habitat one should have to select these parameters for enhanced and accurate estimation of carbon sequestration.

In addition, research needs to develop better tree biomass equations, improve estimates of tree decomposition and maintenance emissions, and investigate the effect of forest soils on carbon storage and flux. A better understanding and accounting of forest ecosystems can be used to develop management plans and national policies that can significantly improve environmental quality and human health across the nation.

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