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Carbon density and accumulation in woody species of tropical dry forest in India

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ABSTRACT

We studied the carbon density and accumulation in trees at five sites in a tropical dry forest (TDF) to address the questions: how is the TDF structured in terms of tree and carbon density in different DBH (diameter at breast height) classes? What are the levels of carbon density and accumulation in the woody species of TDF? Is the vegetation carbon density evenly distributed across the forest? Does carbon stored in the soil reflect the pattern of aboveground vegetation carbon density? Which species in the forest have a high potential for carbon accumulation? The WSG among species ranged from 0.39 to 0.78 g cm^{-3}. Our study indicated that most of the carbon resides in the old-growth (high DBH) trees; 88–97% carbon occurred in individuals $\geqslant$19.1 cm DBH, and therefore extra care is required to protect such trees in the dry forest. *Acacia catechu, Buchanania lanzan, Hardwickia binata, Shorea robusta* and *Terminalia tomentosa* accounted for more than 10 t ha^{-1} carbon density, warranting extra efforts for their protection. Species also differed in their capacity to accumulate carbon indicating variable suitability for afforestation. Annually, the forest accumulated 5.3 t-C ha^{-1} yr^{-1} on the most productive, wettest Hathinala site to 0.05 t-C ha^{-1} yr^{-1} on the least productive, driest Kotwa site. This study indicated a marked patchy distribution of carbon density (151 t-C ha^{-1} on the Hathinala site to 15.6 t-C ha^{-1} on the Kotwa site); the maximum value was more than nine times the minimum value. These findings suggest that there is a substantial scope to increase the carbon density and accumulation in this forest through management strategies focused on the protection, from deforestation and fire, of the high carbon density sites and the old-growth trees, and increasing the stocking density of the forest by planting species with high potential for carbon accumulation.

1. Introduction

The total carbon pool in the forest ecosystems is estimated to be about 1150 Gt, of which 49% is in the boreal forests, 14% in temperate forests and 37% in tropical forests (Malhi et al., 1999). Since, among the terrestrial ecosystems, forests are the most productive and have a long lived woody character, they are highly attractive in the context of global climate change mitigation (Nabuurs et al., 2007). Estimates indicate that annual net carbon sequestration by tropical forests and savanna together accounts for 60% global terrestrial photosynthesis (Field et al., 1998). Tropical forests are also important because the carbon is portioned more or less equally between vegetation and soil, whereas in high latitude forests, especially in boreal zone, 84% of the carbon is in soil organic matter, and only 16% in the active living biomass (Malhi et al., 1999). A recent estimate indicates that tropical forests account for 247 Gt vegetation carbon, of which 193 Gt is stored aboveground (Saatchi et al., 2011). About 42% of the landmass in the tropics belongs to tropical dry forests (Miles et al., 2006), which are estimated to have 110 Gt vegetation carbon compared to 134 Gt vegetation carbon in tropical rainforest (Foley, 1995). Tropical dry forests are characterized by seasonal rainfall, with several months of severe drought in the annual cycle (Mooney et al., 1995). Among the major tropical forest types, tropical dry forests are the most threatened, about 90% of these forests are exposed to a variety of threats largely resulting from human activity (Miles et al., 2006). Further, while tropical rainforests are the most studied among the tropical forest types, the seasonally dry tropical forests have been seriously neglected (Dirzo et al., 2011). In India, tropical dry forest is quite extensive and accounts for 38.2% of the total forest cover (MoEF, 1999).

The stored carbon in the forests is substantially reduced and released into the atmosphere as carbon dioxide (CO_2) by deforestation and forest degradation. During the 1990s, tropical deforestation released approximately 1–2 billion tonnes of carbon per year, which was roughly 15–25% of annual global greenhouse gas emissions and higher than the transportation sector (Gibbs et al., 2007; Madeira, 2008). Deforestation and forest degradation are the largest source of greenhouse gas emissions in most tropical countries. For example, in Africa, deforestation accounts for nearly 70% of total emissions (FAO, 2005). Climate change mitigation

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requires the management of terrestrial carbon (C) either by creating new C sinks or by preserving existing ones (Malhi et al., 1999).

Forestry is recognized by the Kyoto Protocol as a sink measure for greenhouse gases in the atmosphere under the Clean Development Mechanism (CDM) in terms of afforestation and reforestation (Singh et al., 2011). It is increasingly being realized by the international community that the mitigation of global warming will not be achieved without the inclusion of forests in the mitigation plan. In this context, Reducing Emissions from Deforestation and Forest Degradation (REDD) is a new initiative of United Nations Framework Convention in Climate Change (UNFCCC), led by forest-rich developing countries that calls for economic incentives to reduce the emissions of greenhouse gases from deforestation and forest degradation in developing countries (Gibbs et al., 2007). The developing countries need to have well-authenticated estimates of forest carbon stocks for successful implementation of mitigating policies to take advantage of the REDD programme (Saatchi et al., 2011; Salimon et al., 2011). Canadell and Raupach (2008) consider increasing the carbon density of existing forests also as an important option.

During the past few years, carbon sequestration and biodiversity protection have been high priorities in the scientific, governmental and civil-society agendas for mitigating climate change (Diáz et al., 2009). Developing countries are starting plantation programmes, which along with carbon credits, also generate significant income (Niles et al., 2002). The market for CDM has a large potential for reforestation and afforestation activities in developing countries beyond 2012 (De Koning et al., 2005). These activities are only involved in new plantations and protection of young forests but the old-growth forests are not protected because it is generally thought that they cease to accumulate carbon (Kira and Sihdei, 1967; Odum, 1969). However, on the basis of global data sets, Luyssaert et al. (2008) reported that the old-growth forests continue to accumulate carbon, contrary to the old view that they are carbon neutral, and will lose much of this carbon to the atmosphere if they are disturbed.

Tropical forests constitute as much as 86% of the forested area in India, of which 53% is dry deciduous, 37% moist-deciduous and the rest is wet-evergreen or semi-evergreen (Singh and Singh, 1991). These forests, however, are strongly impacted by anthropogenic activities, particularly, excessive grazing, trampling and firewood removals (Champion and Seth, 1968; Singh et al., 1991), and in many parts are being converted into dry deciduous scrub and savanna. The disturbance intensity is not uniform across the forest. These forests have been traditionally managed through selection felling, i.e., harvesting of individuals above a certain diameter which varies from species to species and leaving a few mother trees for regeneration (Upadhyay and Srivastava, 1980; Harikant and Ghildiyal, 1982). Low intensity ground fire occurs every 2–3 years (Upadhyay and Srivastava, 1980; Harikant and Ghildiyal, 1982). These forests are characterized by a patchy distribution of tree assemblages (Jha and Singh, 1990) and therefore it could be expected that the biomass will also have a patchy distribution. Since tropical dry forest (TDF) is rather extensive, it is important to know the amount of carbon stored in these forests. The above-ground living biomass of trees has the largest pool of stored carbon and is directly impacted by deforestation and degradation (Gibbs et al., 2007). Thus, the most critical step in quantifying carbon stocks and fluxes from tropical forests is the estimation of above-ground carbon density (i.e. carbon in biomass per unit land area) and its accumulation rate (Gibbs et al., 2007). Although above-ground live carbon is not the only carbon pool, it is by far the largest and the most dynamic carbon pool in forest ecosystems (D'Amato et al., 2011). Further, the live carbon increment is frequently considered a measure of carbon sequestration (D'Amato et al., 2011). The estimation of aboveground tree carbon stock is also important because in most cases it is directly linked with the carbon stock in other pools, e.g. the root biomass is 20% of the above-ground forest carbon stocks, the dead wood or litter carbon stocks (down trees, standing dead, broken branches, leaves, etc.) are equivalent to 10–20% of the above-ground forest carbon estimate in mature forests (Gibbs et al., 2007). Singh and Singh (1991, 1993) found 82% of the total vegetation carbon density in the perennial aerial structure, 4% in foliage and 14% in coarse roots of the tree species in the TDF of India; the turnover time of litter and fine roots is $\leqslant$1 yr.

The carbon stored in the above-ground tree biomass at a particular location can directly be estimated by harvesting all trees of the area, drying them and weighing the biomass. The carbon of the biomass can then be calculated by using an appropriate factor. This method is time-intensive, expensive and destructive (Gibbs et al., 2007). The other method is to use allometric equations relating destructively measured tree biomass and field measurements of circumference at breast height (CBH) or diameter at breast height (DBH) (Chaturvedi et al., 2010). This method also poses a significant problem for regional-scale comparisons because the coefficients a (intercept) and b (slope) in the allometric equations vary from species to species and site to site (Chaturvedi et al., 2010). Therefore, for the study of regional variations in tree biomass estimates, those aspects of forest structure that vary significantly at regional scales should be used in the estimator. In this study we used the non-destructive equation having wood specific gravity (WSG) in the estimator to assess the stem biomass of the woody species of the dry forests of the Vindhyan highlands.

Assessing soil organic carbon (SOC) is important because the SOC is the largest terrestrial carbon pool and an indicator of soil quality and productivity (Bauer and Black, 1994; Krishan et al., 2009). The soils store approximately 70% carbon and greater than 90% of the nitrogen in the terrestrial biosphere (Schlesinger, 1986). According to the global estimates of soil organic carbon, about 1500 Gt carbon is conserved in the top 1 m soil layer (Adams et al., 1990; Anderson, 1992; Eswaran et al., 1993; Batjes, 1996). The estimates for total SOC pools in Indian forests range from 4.13 Pg C for top 50 cm depth to 6.18 Pg C for the top 1 m soil depth (Chhabra et al., 2002). Nitrogen and phosphorus contents of soil are considered as the most important limiting elements for vegetation and therefore for carbon increments (Vitousek, 1984; Chapin et al., 1986; Vitousek and Howarth, 1991; Manzoni et al., 2010). All natural ecosystems are affected by the amount of plant available nitrogen and phosphorus (Seneviratne, 2000). Vegetation on older, highly weathered soils tends to be phosphorus limited, while the plants growing on young soils are often nitrogen limited (Vitousek, 1984; Jobbágy and Jackson, 2000; Reich and Oleksyn, 2004). These trends in soil features associated with small scale heterogeneity in soil–vegetation interactions results in large variations in the availability of nutrients to plants, affecting plant growth and chemical composition of plant tissues and residues (Vitousek and Howarth, 1991; McGroddy et al., 2004; Reich and Oleksyn, 2004; Townsend et al., 2007). Therefore, carbon stored in soil on these five sites has also been assessed. We address the following questions:

(1) What are the levels of carbon density and accumulation in the stem component of woody species in the TDF?
(2) How is the TDF structured in terms of tree and carbon density in different DBH classes?
(3) Is the vegetation carbon density evenly distributed across the forest?
(4) Does carbon stored in the soil reflect the pattern of above-ground vegetation carbon density?
(5) Which species in the forest have greater potential for carbon accumulation?