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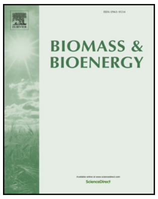

Research paper

Estimating biomass stocks and potential loss of biomass carbon through clear-felling of rubber plantations

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ABSTRACT

When latex production declines after 35–40 y, clear-felling of rubber (*Hevea brasiliensis*) plantations is a common management practice around the world. Although clear-felling can lead to significant losses in system carbon (C), such losses have not been adequately quantified in rubber plantations in India. The objectives of this work are to (1) develop and test models for estimating rubber tree biomass and C storage in situations where diameter at breast height (D 1.3 m) cannot be measured precisely due to the tapping artefact, and (2) estimate losses in biomass C due to clear-felling of mature plantation. Five biomass estimation models were tested using a total of 54 trees destructively sampled from 35 to 40 y old plantations in North East India. Then the amount of biomass and the potential C losses following clear-felling were estimated. The tree biomass predicted by our models was within 0.2 and 5% of our measured tree biomass. The mean biomass was estimated at 376.9 and 23.9 kg per tree for above and below ground parts, respectively. On an area basis, total tree biomass was estimated at 286.1 Mg ha^{-1}, which was more than that under jungle rubber (147 Mg ha^{-1}) but lower than the forests (384 Mg ha^{-1}) in the tropical regions. According to our estimate clear-felling of mature plantation can on an average remove C at a rate of 135 Mg ha^{-1}, which represents most of the C stored in aboveground tree biomass. In order to conserve the biomass C and to maintain environmental integrity, we recommend selective felling of 20% of total growing stock starting from plantation age of 35 years and replanting at two year cycle.

1. Introduction

Plantations of the rubber tree (*Hevea brasiliensis*) currently occupy ~100000 km^2 land in the tropical parts of the world [1]. Whilst traditionally grown on large estates, over the last century the cultivation of rubber has gradually moved to the small-holder sector which now accounts for more than 75% of the world's natural rubber production [2,3]. Rubber plantations are expanding rapidly throughout Asia, and the vast majority of these new plantations are monocultures as opposed to the traditional mixed rubber agroforestry systems [3,4]. More than 15000 km^2 of land has been converted into monoculture rubber plantations in Southeast Asia alone [5–7]. In India, 7600 km^2 of land is currently under rubber plantation and the annual increase in acreage is 3% [8]. The small-holder sector in India represents 91% of the total area under rubber and 94% of the total natural rubber production [8] implying the significance of small-holder farming in land use changes.

The risks of this land-use change may be high as rubber plantations have often been associated with various environmental issues including biodiversity loss [3,9], disruption of hydrological processes [5,6,10], and soil carbon (C) loss [7]. The conversion of forests with high biodiversity value to rubber plantations and expansion into marginal areas creates further opportunities for biodiversity loss [3,9] and disruption of nutrient cycles following clear-felling. For example, between 2005 and 2010 over 512 km^2 of land in Key Biodiversity Areas, 610 km^2 in protected areas and 1624 km^2 in conservation corridors was converted into rubber plantations [3]. Moreover, rubber plantations are also much bigger water consumers than rain forests and cause local water shortages [6]. Conversion of secondary forests into rubber plantations was also shown to lead to soil C loss by about 19% of the initial stock [7,11].

Rubber trees have been principally managed for commercial latex production up to their productive age followed by clear-felling and replanting [12]. The productive life of rubber plantations is approximately 40 y but productivity starts to decline after about 30 y [12,13]. Thus currently the common rotation length is 30–35 y [14]. However, the non-use values of these plantations, especially C sequestration, have not been fully appreciated. Despite their negative environmental impacts mentioned above, rubber plantations have immense potential for

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terrestrial C sequestration by accumulating C in woody biomass and organic matter in mineral soil [12,15–17]. This can play an important role in mitigating climate change. However, the amount of C sequestered in woody biomass is very much dependent on plantation age, stem density, site conditions, management practices and climatic condition [12,16,18].

In many places information about the biomass or C sequestration of rubber plantations is still scanty [17]. Clear-felling of trees at the end of plantations may result in significant losses in system C [19–22]. However, such losses have not been systematically quantified in rubber plantations, and many workers [6] have recommended further studies on C release. Therefore, it is important to estimate the biomass C stocks in plantations and biomass C lost through clear-felling.

Various destructive and non-destructive methods have been recommended for biomass estimation. Out of these methods, use of allometric model is a reliable and non-destructive means for assessing tree biomass [23,24]. Species- and site-specific biomass estimation models are preferred over generalized models because the former give more accurate predictions [24–26]. Species-specific models are usually developed using measurements of a single species at a particular site or across its range of distribution. Generalized models are developed using large global datasetsfrom mixture of species across a broad range of conditions. Therefore, the use of generalized models can lead to a bias in estimating biomass for a particular species. Although species-specific models are available for rubber elsewhere [11] such models are lacking for India. We also did not want to entirely depend on published models because such models are usually based on a small number of directly harvested trees and include very few large diameter trees [27], thus may not be suitable for application outside the area and range of tree size [28]. Therefore, the objectives of this work are to (1) develop and test models for estimating rubber tree biomass and C storage in situations where diameter at breast height (D 1.3 m) cannot be measured precisely due to the tapping artefact, and (2) estimate losses in biomass C due to clear-felling of mature plantation. In this study our focus was on estimation of biomass C losses after clear-felling and estimating changes in soil C was beyond the scope of this study. This is because it is often difficult to distinguish such changes from the large spatial variability in soil C unless repeated measurements are taken over a long period after clearing the plantation.

2. Materials and methods

2.1. Study site

The study site (latitude 24°36′N; longitude 092°23′E) was located in Karimganj district in the state of Assam (Fig. 1). The site is located in North East India within the range of Himalayan foothills and Barak river basin. Karimganj district occupies an area of 1809 km^2. It is bordered on the Northeast by Cachar district, on the east by Hailakandi, on the south by Mizoram, on the southwest by Tripura state and on the west and northwest by Bangladesh. The mean annual precipitation is about 3538.4 mm. Temperatures vary from 13 to 37 °C while mean relative humidity is 93.5% [29]. The state of Assam is one of the rubber growing areas of India, and rubber occupies up to 66% of the smallholder area in the state [30]. Soils of the study area are classified as fine loamy, mixed, hyperthermic family of Fluvaquentic Endoaquepts [31].

2.2. Stand selection and sampling

In order to estimate the biomass stocks of rubber plantations, five quadrates of 25 m × 25 m area were selected from a single rubber plantation of 35–40 y old. Since dead and unhealthy saplings were replaced by new saplings during the initial stage (≤4 y old) of rubber plantations, a stand of 40 y old may consists of trees that are 35–40 y old. The mean stem density of the stand was 714ha^{-1}; with a range of 672–776 ha^{-1}. Measurements of total tree height and circumference at 2 m above the ground were recorded for a sample of live trees within the selected stands. Although the standard practice for measuring tree diameter is at breast height (D at 1.3 m) [32], in our case D could not be measured at 1.3 m because tree stems at this height were heavily deformed due to tapping for latex collection (Fig. 2). Therefore, the circumference of the stems at 2 m above the ground level was measured to avoid such artefact. During circumference measurement of the standing trees the following recommended practices [33] were followed: (i) circumference was measured carefully on the uphill side of trees when trees were found on slopes or uneven ground, (ii) circumference was measured parallel to the lean on the high side of the tree where the trees were found inclined, (iii) circumference of each stem was measured when the tree consisted of two or more stems forking below the circumference measurement level of the tree, and, (iv) circumference was taken just below the enlargement of the stem when forking occurred at or above the circumference measurement level of the tree. Then representative diameter classes were developed based on stem circumferences as follows: 61–70, 71–80, 81–90, 91–100,101-110 and 111–120 cm, and9 trees were felled from each circumference class.

A total of 54 trees thus felled were used for development of biomass estimation models. The leaf, branch and stem parts were separated and total fresh weights (kg) of each plant part (PFW) were recorded for the felled trees. For belowground biomass, coarse root (> 2.5 mm diameter) were extracted from a 1 m radius with 1 m depth around the felled tree stem. However, our study did not incorporate fine root biomass due to its difficulty in separation and sample collection. Fresh weights of extracted coarse roots were weighed after carefully removing the soil. Sub-sample (500 g) of each plant part was taken to the laboratory and oven dried at 65 °C for 72 h. Fresh weight and dry weight ratios (R) for each of the sub-sampled plant part were calculated after estimating their respective dry weight. Dry weight of each part of the sampled tree (PDW) was estimated as PDW = (Rx PFW). Total biomass (B) was obtained by adding all the calculated parts of the respective tree, i.e. as the sum of aboveground biomass (AGB) and belowground biomass (BGB).

2.3. Estimation of tree biomass and C densities

Models based on diameter at breast height (D at 1.3 m) alone or including total height (H) or/and wood density (ρ) are widely used in predicting tree biomass [24,26,28]. In this study, we first tested two types of species-specific models, namely (1) simple power-law (allometric) models that require either D or H as the only predictor, and (2) models that consist of compound variables. The simple power-law models have been demonstrated empirically and supported by emergent theories of macroecology [28]. Different theoretical models derived from physical and biological first principles predict universal scaling relationships between total tree biomass (B), H and D [28]. For this study, we explored allometric relationships between D at 2 m (hereafter D_2) and H expressing the relationships as follow:

$$ln(B) = ln(\alpha) + \beta(lnH) + \varepsilon \qquad \text{Model 1}$$

$$ln(B) = ln(\alpha) + \beta(lnD^2) + \varepsilon \qquad \text{Model 2}$$

where ε is the error. Back-transformation of model 1 and 2 gives a power function as $B = \alpha X^\beta \times CF$ where X is either H or D and CF is the correction factor calculated from the mean square of error (MSE) as exp $(MSE/2)$.

We also tested the performance of models that consists of compound variables. These models consist of various combinations of D, H and use wood specific gravity (ρ). For our purpose we chose the following two models as they have been used recently in estimating biomass of rubber trees [17] and other tree species [27,28].

$$ln(B) = ln(\alpha) + \beta(\ln(HD^2)) + \varepsilon \qquad \text{Model 3}$$

$$B = \alpha(\rho D^2 H)^\beta \qquad \text{Model 4}$$