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ESTIMATING THE CHANGE OF STEM BIOMASS AND CARBON WITH AGE AND STEM VOLUME OF *Tectona grandis* Lin. f.

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Abstract: Enhancement of carbon storage in tree biomass through the establishment of man-made forests is considered as a viable option to reduce atmospheric CO_2 levels. Therefore the present study was conducted to estimate the biomass and carbon contents of the main stem of *Tectona grandis* Lin. f. (Teak) plantations in Sri Lanka using a non-destructive sampling technique. Harvesting of *T. grandis* is scheduled in Sri Lanka after 35 years of planting and therefore it is considered as a long rotation species. Allometric models were built to predict the variation of stem biomass and carbon of *T. grandis* with age and stem volume. A separate model was also built to predict the stem carbon change with the stem biomass.

23 *T. grandis* plantations were selected covering all three climatic zones, viz. dry, intermediate and wet of Sri Lanka for necessary data collection. Breast height diameter and height were measured for the sampled trees. Stem volume was calculated by a volume function which used diameter and height as the explanatory variables. Stem biomass and carbon contents were calculated converting those values of core samples obtained from the trees using a tree increment borer.

Results revealed that the average stem carbon content is 55% from the biomass. However, there were variations of this value for certain plantations of different ages. All allometric models built in this study had high R^2 values which were over 90%.

Keywords: Allometric modelling, Core sample analysis, Stem biomass, Stem carbon, *Tectona grandis*

1 Introduction

Forests play an important role in global carbon budget as carbon sinks and by reducing the atmospheric CO_2 content (Sedjo 1990; Xiao and Ceulemans, 2004). Forests hold two third of terrestrial carbon and as the forest biomass increase over the time, the sequestered carbon stock also increases in the standing forests. However, old growth forests, which may have large stock of carbon may only have small or negligible flows, since net biomass growth is modest or negligible. Alternatively, a young forest may have a relatively modest carbon stock due to its low biomass, but at the same time generate substantial flows into that stock due to the rapid growth (Rodger *et al*., 1997). Therefore the managed forest plantations can function as net sinks for atmospheric CO_2.

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Brown and Lugo (1992) estimated that the carbon content of the trees is about 50% of the biomass. However, certain studies showed that it can be different from 50% (e.g., Subasinghe and Munasinghe, 2011). The carbon content stored in trees represents the potential amount of carbon that can be added to the atmosphere as CO_2 when the forest is cleared. Therefore accurate biomass estimations are very important to calculate the sources and sinks of carbon to develop carbon inventories and be a carbon trader in climate change mitigation programs and to measure the impact of forest degradation or deforestation (Litton and Kauffman, 2008; Lu *et al*., 2012). There are two main methods to estimate above ground biomass of a tree, viz. direct using destructive or excavation methods and indirect using allometric model based methods. Estimation of biomass of a sample of trees using direct methods involves felling the trees, excavating their root systems and drying and weighing the biomass. Such practices may be very expensive and therefore much attention has been paid to the development of techniques to estimate tree biomass building allometric relationships with easily measurable tree characteristics. In non-destructive methods, small wood or core samples are extracted from the trees to determine the biomass of a unit volume. Then the tree volume is converted to biomass, relating the weight of the unit volume to the stem (Murali *et al*., 2005).

Biomass equations for individual trees have appeared frequently in the ecological and forestry literature over the last few decades because biomass estimation is a prerequisite for productivity studies, carbon estimations, nutrient cycling etc. of the forests. A more direct and cost effective approach in this scenario would be to establish a linkage between forest inventory measures, outputs from growth and yield models and biomass and carbon stock estimates (Bi *et al.*, 2010).

Some studies have attempted to develop common allometric models for all woody species present in specific forests or regions (e.g., Brown *et al*., 1996; Chave *et al*., 2005) to reduce the difficulty levels in developing a large number of models for each species growing in a single forest. However, such models are not accurate due to the high morphological diversity of different tree species (Litton and Kauffman, 2008). Therefore, developing separate equations for each species is very important for accurate biomass estimations (Ambagahaduwa *et al*., 2009).

Tectona grandis (Teak) is the most widely planted forest trees species in Sri Lanka, especially in the dry and intermediate zones. Approximately about 46,000 ha of *T. grandis* plantations are managed by Forest Department and Department of Wildlife Conservation of in Sri Lanka. This species is also favoured in the homegardens (Ariyadasa, 2002). Therefore

T. grandis is considered as a plantation species which contributed to the highest carbon storage among all forest plantation species in Sri Lanka.

2 Materials and Methods

2.1 Study sites

In order for data collection, 23 even-aged *T. grandis* plantations varying of age from 7 to 42 years were selected using FORDATA database maintained by the Sri Lanka Forest Department (Figure 1).

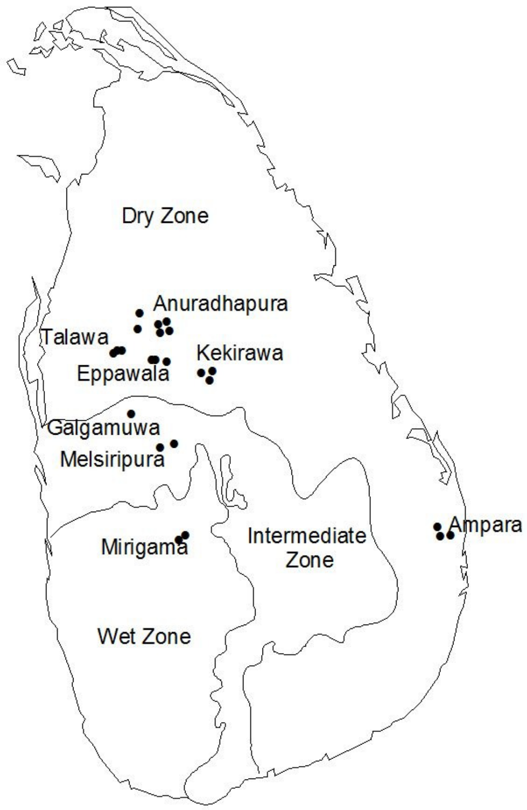

Figure 1: Sri Lanka map with the sample locations

This species is growing in large-scale in the dry zone of Sri Lanka and therefore 18 plantations were selected from the dry zone and three plantations were selected from the intermediate zone. In addition to that, two plantations were selected from the wet zone. The age series of those plantations were 7, 9, 14, 18, 23, 28, 35 and 42 years. The elevations of all the selected plantations were below 1,000 m from the mean sea level.

Dry, intermediate and wet climatic zones of Sri Lanka are differentiated by using annual rainfall and mean temperature. The annual rainfall figures are 1,000-1,5000, 1,500-2,000 and 2,000-2,500mm and the mean annual temperature values are >27.5, 27.0 and 25.0^{0}C for the dry, intermediate and wet zones respectively.

2.2 Sampling and measurements

Ten trees were randomly selected from each plantation and diameter at breast height (dbh) and total height were measured. A 10 mm diameter core sample was taken from each tree at the breast height, i.e., 1.3 m above ground, by using a tree increment borer. Diameter of the core sample was considered as equal to the inner diameter of the increment borer and the length of each core was accurately measured. The green weight of each core sample was measured accurately at the laboratory. Then those were oven-dried at 72^{0}C until a constant weight was achieved.

The accuracy of the biomass estimation for the samples extracted by the increment borer was tested by comparing the biomass of 12 stem cross sections obtained from 7, 9 and 18 year old harvested *T. grandis* trees of Ampara Forest Division. A volume similar to the core sample was cut from the stem disks obtained at breast height from those 12 trees and the biomass values were compared with that of the samples obtained from the increment borer method using two sample *t*-test. The results did not show a significant difference and therefore, core sample method was used to estimate the biomass and carbon contents throughout this research. The carbon amount of the core samples were analysed using Walkley and Black method.

2.3 Calculations used

Stem volume

Stem volume was calculated using the volume function (equation 1) built by Subasinghe (2004) for *T. grandis* growing in dry, intermediate and wet climatic zones of Sri Lanka.

$$\sqrt{v} = 0.564\sqrt{(g \times h)} \quad (1)$$

where: g = tree basal area, m^2 (calculated using dbh, cm)

h = total tree height, m

v = stem volume, m^3

Stem biomass

Stem biomass was estimated by converting the weight of the core sample and its volume to tree stem volume (equation 2).

$$w_{tot} = (w_{core}/v_{core}) \times v) \qquad 2$$

where: v_{core} = green volume of the core sample, m^3

w_{core} = dry weight (biomass) of the core sample, kg

w_{tot} = stem biomass, kg

Carbon content of the stem biomass

Carbon content was estimated by using the Walkley and Black method for the core sample and that was converted to stem carbon content by using equation 3.

$$C_{stem} = (C_{core}/w_{core}) \times w_{tot} \qquad 3$$

where: C_{core} = carbon content of the core sample, kg

C_{stem} = carbon content of the stem, kg

w_{core} = dry weight of the core sample, kg

Construction of allometric models

Allometric models were constructed to predict stem biomass and stem carbon by using tree age and stem volume for this study. In addition to that, another model was built to predict stem carbon from stem biomass using MINITAB 14.1.

3 Results

3.1 Variation of stem biomass and carbon with age

Results showed that both biomass and carbon contents increased for *T. grandis* even at the age of 42. The highest carbon percentages to the stem biomass were observed at the age 18 (75.44%) and 9 (60.41%) respectively (Figure 2). However, for all other ages tested, the variation of carbon content from the stem biomass was around 50%.

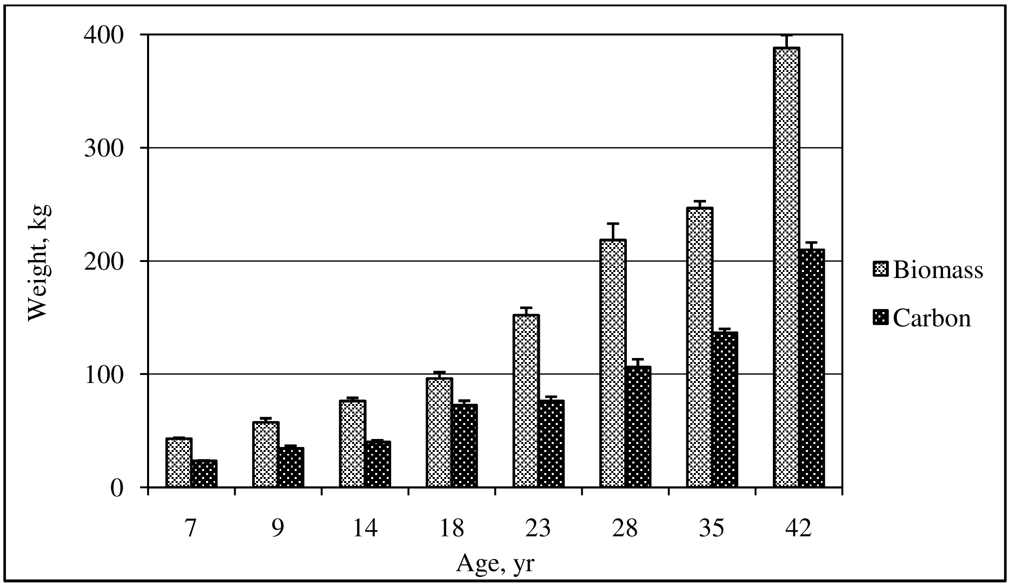

Figure 2: Difference between biomass and carbon contents at each age (±SE) for *T. grandis*.

3.2 Relationships between stem biomass and stem carbon with age

Although data at older ages indicated higher variations comparatively to that of young trees, for both biomass and carbon, the resultant allometric models were in linear form with good R^2 values which were above 90% (Figure 3 and 4). Intercepts were not significant for both models.

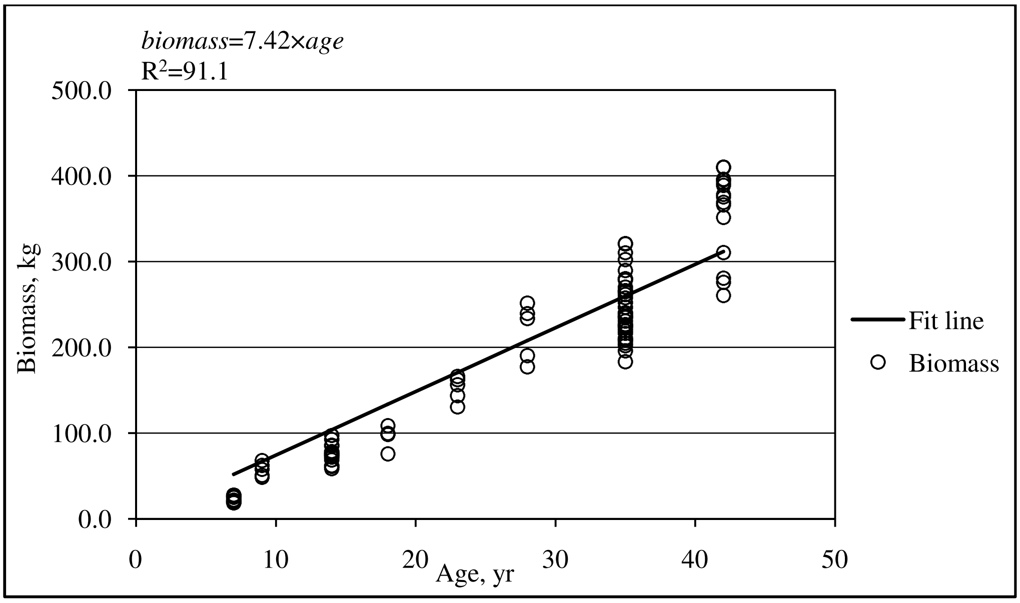

Figure 3: Variation of biomass contents and fitted line of *T. grandis* stem of with age.

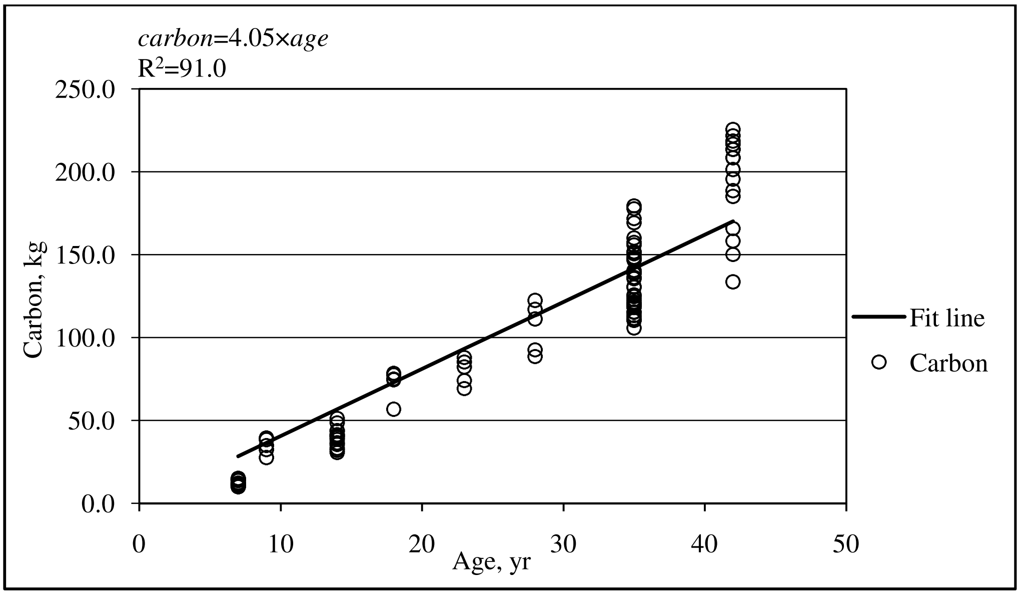

Figure 4: Variation of carbon contents and fitted line of *T. grandis* stem of with age.

3.3 Relationship between stem biomass and stem carbon with volume

R^2 values for both biomass and carbon modes built with stem volume as the explanatory variable were high, i.e., 95.8 and 95.7 respectively (Figure 5 and 6). Similar to the models built for biomass and carbon prediction by age, intercepts were also not significant for the current models.

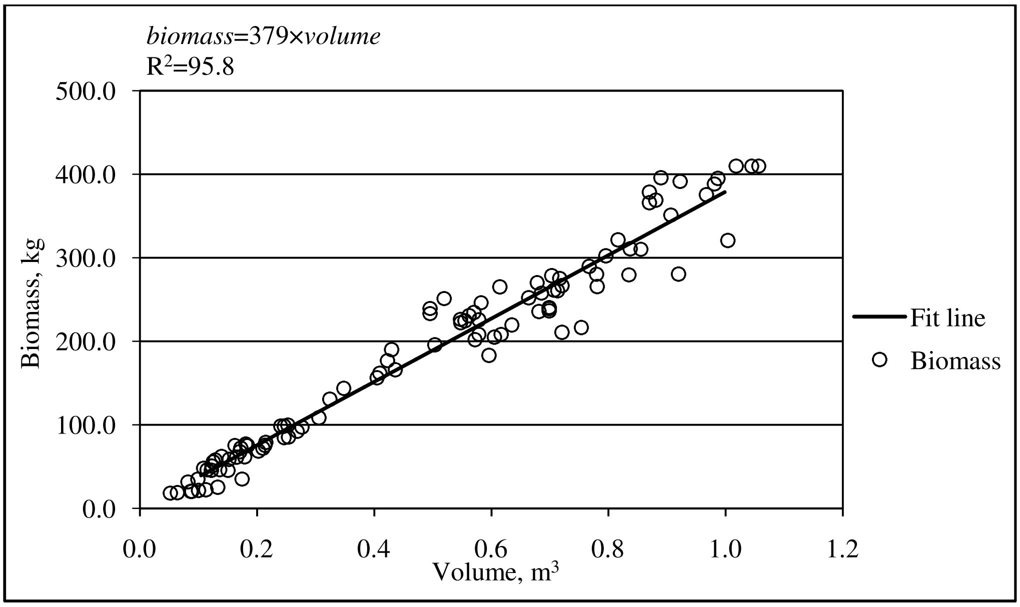

Figure 5: Relationship of biomass with stem volume.

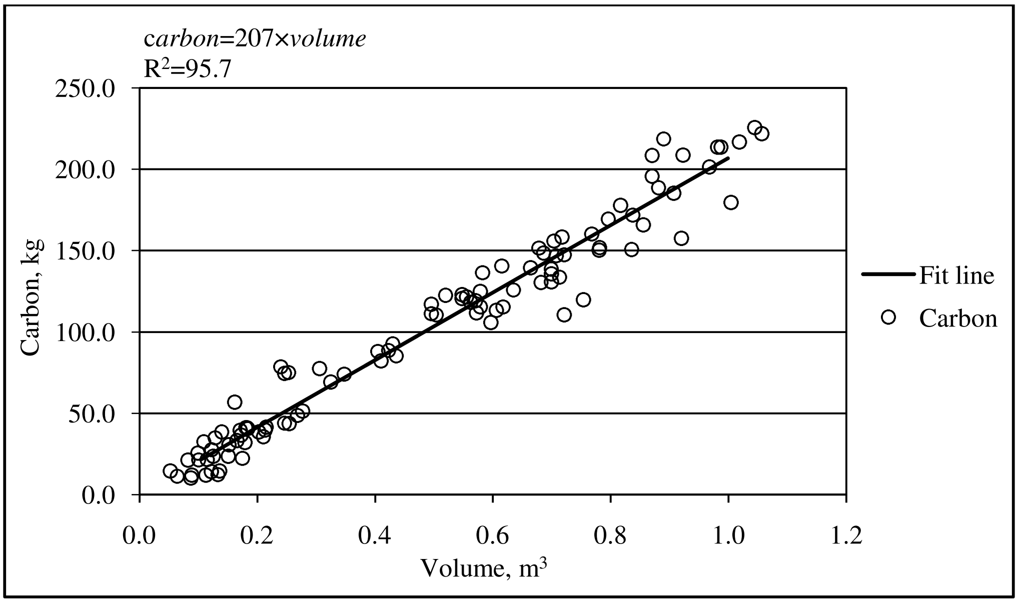

Figure 6: Relationship of C with stem volume.

3.4 Relationship of stem carbon with stem biomass

The resultant R^2 was 99.0 and the intercept was not significant for the carbon content prediction model by stem volume. According to that model, the average carbon-biomass ratio for the stems of *T. grandis* is 55% (Figure 7).

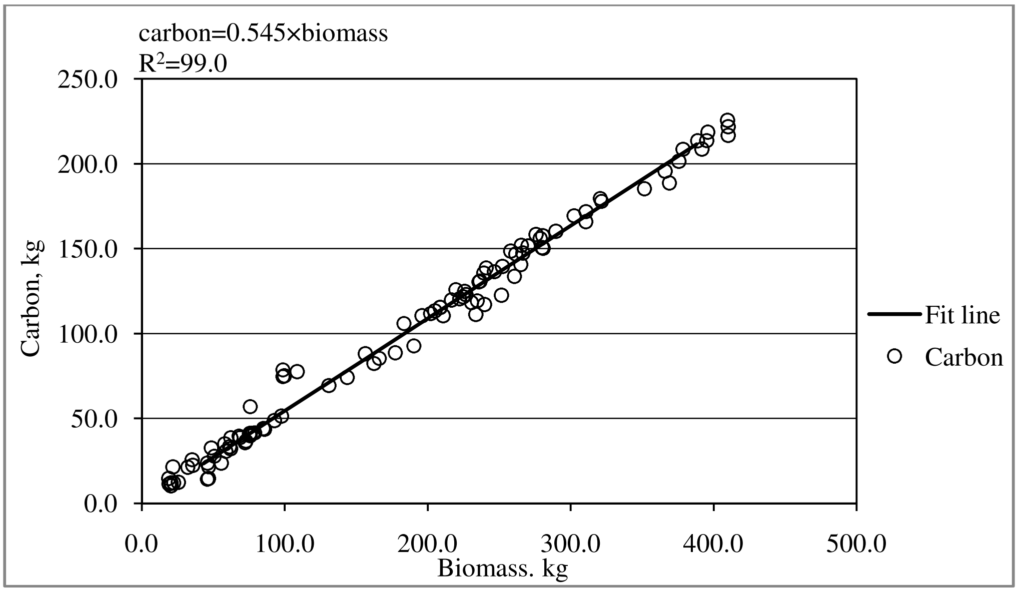

Figure 7: Variation of carbon content with biomass of *T. grandis* and fitted line.

4 Discussion

Both diameter at breast height and total tree height showed linear relationships with tree age for *T. grandis*. Tree growth of these plantations increases steadily even at the age of 42 years after planting, This proves that the *T. grandis* plantations of Sri Lanka are steadily growing even beyond the time of suggested regeneration felling.

The average carbon:biomass ratio estimated for *T. grandis* in this study was 55% which is close to the general ratio, i.e., 50% estimated by Brown and Lugo (1992) for forest species. This value for *Pinus caribaea* growing in lower elevations of Sri Lanka is 58% (Subasinghe and Munasinghe, 2011). However, at the age 9 and 18, the carbon:biomass ratio was estimated as 60.41% and 75.44% respectively for *T. grandis* in this study. A proper conclusion cannot be arrived for this reason at this stage because at the time of data collection, only one plantation was available to for each of 9^{th} and 18^{th} year old plantations.

Weighing the actual tree biomass in the field is undoubtedly the most accurate method to determine tree biomass. Destructive sampling should be employed for this reason and therefore that is generally restricted to small areas and small tree sample sizes (Ketterings *et al*., 2001). The use of allometric relationships yields a non-destructive and indirect measurement of biomass compartments, and is often the preferred approach since it is less time consuming and less expensive than direct measurements (Xiao and Ceulemans, 2004). Core sample analyses were successfully employed by Subasinghe and Munasinghe (2011) and Subasinghe and Haripriya (2014) to estimate the above ground biomass and carbon in forest plantation species in Sri Lanka.

Age was included from the beginning of the model construction for the present study as an essential explanatory variable. Adame *et al*. (2006) and Calama *et al*. (2003) emphasised the importance of data chosen for fitting the different functions containing all the possible combinations of variables. Age has become one of the essential explanatory variables for tree growth prediction in forestry (*e.g.*: Palahi *et al*., 2004; Salas and Garcia, 2006; Adame *et al*., 2006). Lee *et al*. (2004) stated that, although tree age is an important influencing variable on radial growth, it might simply be not available in practice. However, the attempts made by them to exclude the age from the explanatory variables to predict dbh growth of pine and oak were not successful and the resultant models indicated poor statistical performances.

Apart from aboveground vegetation, belowground tree root biomass, forest floor, and mineral soil provide considerable carbon pools (Johnson *et al*., 2003). However, there has been some disagreement in literature about whether or not an increase in soil carbon may be achieved through forest plantations. Due to the immense effort required in obtaining a precise estimate of tree root biomass, carbon storage in tree roots is often neglected or estimated from standard root to shoot ratios (Kurz *et al*., 1996; CarbonFix Standards, 2009). However, the allocation of biomass and carbon storage among tree carbon pools changes over the lifespan of a forest stand. Therefore, applying standard ratios to determine various biomass components (e.g. root to shoot ratio), or carbon accounting methods, that focus on few components only (e.g. inventory of merchantable stem wood) may lead to considerable errors in estimates of total ecosystem biomass and carbon storage (Peichl and Altaf Arain, 2006)

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