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# *Carbon Sequestration, Tree Biomass Growth and Rubber Yield of PB260 Clone of Rubber Tree* (Hevea brasiliensis) *in North Sumatra*

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*It is desirable to supply the rising demand for industrial crop materials without increasing the amount of land cultivated for crops, if possible. Quantitative information about biomass growth and carbon sequestration by crops is fundamental knowledge that can be used to improve crop yield per unit of cultivation area. In the present study, we measured trunk diameter, tree height and biomass of a PB260 clone of the Pará rubber tree,* Hevea brasiliensis *(Willd.) Muell. Arg. The natural rubber from this tree is used mainly to make tyres and is one of the most important industrial crop materials. We also measured the soil carbon in stands that had been planted from two to 20 years earlier in northern Sumatra, Indonesia. The biomass of each tree was estimated from the measurement of the trunk diameter and these data were combined with the rubber yield data in order to estimate the amount of carbon sequestered annually by the estate as a whole. The tree biomass growth and rubber yield rates peaked at eight and ten years after planting, respectively. After that point, the tree growth rate declined more rapidly than the rubber yield rate. As a result, the percentage of the tree's overall biomass composed by rubber consistently increased from 5% in a three year old tree to 40% in a 20 year old tree. The estimated annual carbon sequestered as tree biomass and as rubber were 4.2 tC ha$^{-1}$ year$^{-1}$ and 1.9 tC ha$^{-1}$ year$^{-1}$, respectively.*

**Keywords:** Allometry; biomass; carbon sequestration; *Hevea brasiliensis*; PB260 clone; rubber yield; trunk diameter

It is vital to reduce our emission of greenhouse gases such as carbon dioxide ($CO_2$). Intergovernmental Panel on Climate Change (IPCC) reported that $CO_2$ is one of the greenhouse gases causing global warming[1]. Therefore, following environmentally sound procedures and ensuring sustainability are major concerns for economic enterprises. At the same time, the demand for materials produced by industrial crops continues to increase. To avoid increasing the land area that is devoted to crops and to supply the increasing demand for the crop materials, it is necessary to improve the crop yield per unit of cultivated

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areas. This improvement relies on having accurate quantitative information about crop biomass and carbon sequestration by various crops. However, there is little information about biomass or carbon sequestration of industrial crops, such as the rubber tree[2–12] or oil palm (*Elaeis guineensis* Jacq.)[13,14].

Natural rubber harvested from the Pará rubber tree, *Hevea brasiliensis* (Willd.) Muell. Arg., is one of the most important industrial crops that is mainly used to make tyres. Rubber estate owners, managers, rubber tree breeders and researchers need basic data of not only rubber yield but also tree growth, biomass production and carbon partitioning. The information is essential for them to understand the mechanics of the rubber yield, to develop new agricultural technologies and to breed trees with increased yield. However, growth and biomass data are not reported with rubber yield data because yield data are usually confidential. Thus, only growth data without the rubber yield have been reported previously, making it difficult to draw conclusions about carbon sequestration.

In the present study, we measured the growth and biomass of rubber trees and the soil carbon in a stand of trees ranging in age from two to 20 years old. The biomass growth data were combined with the rubber yield data in order to estimate the amount of carbon sequestered by the rubber estate.

## MATERIALS AND METHODS

### Study Site and Plants

The study was conducted in an 18,000 ha area of P. T. Bridgestone Sumatra Rubber Estate (BSRE) (3º12' N and 99º12' E) in northern Sumatra, Indonesia. BSRE was established in 1917. The study site, situated at an altitude of approximately 180 m, is characterised by a tropical climate without an obvious dry season. From 2006 to 2012, monthly rainfalls ranged from 21 mm to 428 mm and mean annual rainfall was 2,499 mm. The average maximal and minimal air humidity were 93% and 54%, respectively. The average maximal and minimal air temperatures were 32ºC and 26 °C, respectively. The soil is Acrisol according to the classification of Food and Agriculture Organisation of the United Nations (FAO)/ United Nation Educational, Scientific and Cultural Organisation (UNESCO) (1991) and the soil texture is light clay. *Mucuna bracteata* DC. ex Kurz was planted on the rubber forest floor as a cover crop to avoid weed development and compensate nitrogen supply. The cover crop disappeared when the canopy of rubber trees closed.

The Pará rubber tree originates in the Amazon basin forest. The PB260 clone bred in Malaysia was used in this study because this clone is the type that is mainly cultivated in Indonesia and has a high rubber yield. The planting density is approximately 500 trees per ha and replanting is conducted around 20 years after planting in BSRE.

### Biomass Measurement

Biomass measurement was conducted from April to September 2009. Ten stands of different ages were selected for biomass measurement. The trunk diameters of 20 trees in each stand were measured at 1.2 m from the ground (D). In each stand, three trees whose respective diameters were large, mid-sized and small were selected for the biomass measurement (except for one stand in which only two trees were measured). In all, 29 trees were cut down and the tree heights (H) were measured. Leaves, branches and trunks were separated and fresh weights measured. The roots were also excavated and their fresh weights were measured. Samples of each part were dried at 85ºC for two days and the dry weights were measured. The ratio of dry/fresh weight was used to calculate the dry mass of all samples. D or $D^2 \times H$ were used to estimate the biomass by allometric relationships.

**Amount of Carbon in Soil**

Soil sampling was conducted at the surface and at depths of 15, 30, 50, 75 and 100 cm from the ten stands. The bulk density and the carbon contents were measured with an elemental analyser (vario MAX, Elementar Analysensysteme GmbH, Hanau, Germany).

**Measurement of Trunk Diameter and Tree Height**

The trunk diameter at 1.2 m from the ground (D) and the total tree height (H) were measured for 954 trees from 44 stands that were 2, 3, 9, 11, 17, 18, 19 and 20 years old.

**Estimation of Rubber Yield**

In BSRE, the rubber yield data for various stands has been recorded every month since 1988. These data include stand area and location, planting year, number of tapping trees, clone, dry rubber yield, tapping panel, hormonal stimulation and so on. Mass of the dry rubber was used as biomass of the rubber. The rubber carbon content was taken to be 88% of the dry rubber weight, using a proportion given by the chemical formula of isoprene ($C_5H_8$).

**Statistical Analyses**

Non-linear regression analyses were performed with R 2.15.1 software (http://www.r-project.org/).

RESULTS

**Growth Curves**

To estimate the trunk diameter (D) and tree height (H) from the tree age, the Gompertz equation was used. The relationships between D or H as well as tree age and obtained growth curves are shown in *Figure 1a* and *b*. The equations are shown as follows:

$$D\ (cm) = 26.8 \times \exp[-1.89 \times \exp(-0.193 \times \text{age})] \quad \ldots 1$$

$$H\ (m) = 22.9 \times \exp[-1.79 \times \exp(-0.183 \times \text{age})] \quad \ldots 2$$

The greatest trunk diameter and tree height were 27 cm and 23 m, respectively, for PB260 in BSRE.

**Allometric Equations**

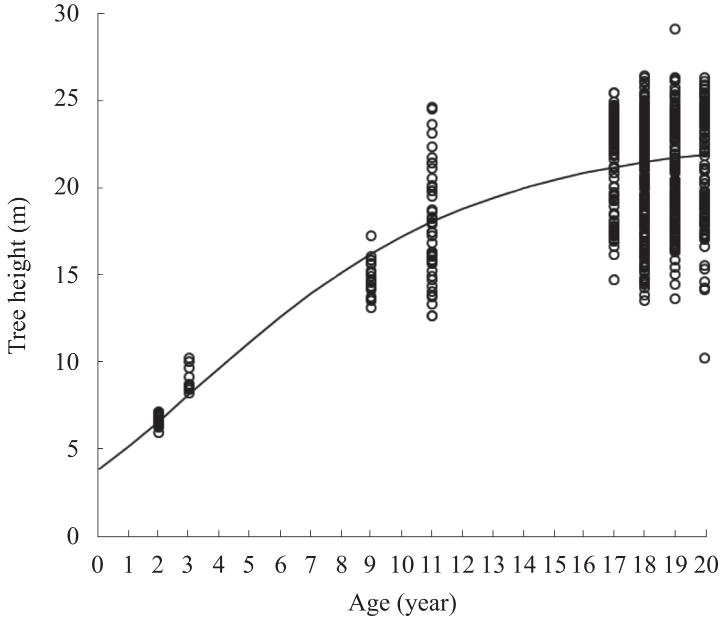
Using the biomass, trunk diameter (D) and tree height (H) data for 29 trees from 10 stands, we calculated the relationships between tree biomass and D (cm) or $D^2 \times H$ ($m^3$) (*Figure 2a* and *b*). The allometric equations are:

$$\text{Tree biomass (kg tree}^{-1}) = 0.144 \times D^{2.40} \quad (r^2 = 0.976) \quad \ldots 3$$

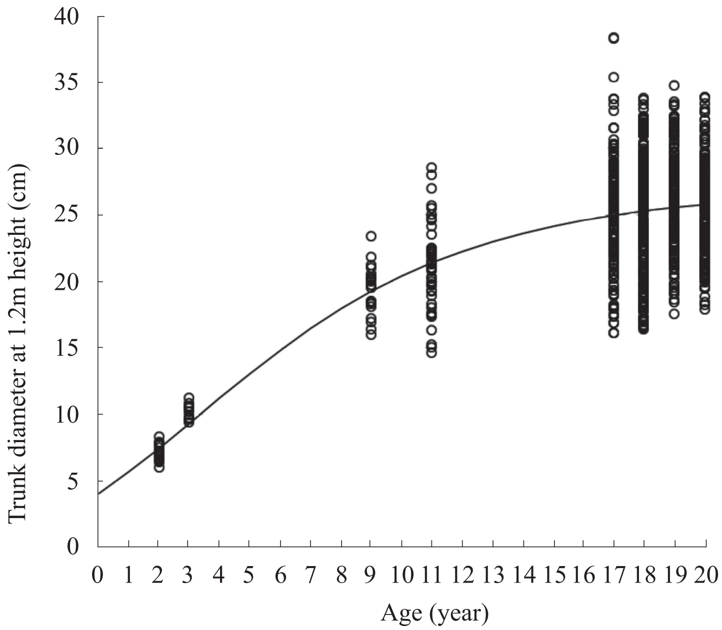
$$\text{Tree biomass (kg tree}^{-1}) = 279 \times (D^2 \times H)^{0.867} \quad (r^2 = 0.976) \quad \ldots 4$$

The determination coefficients of both equations were the same. Therefore, *Equation 3*, which uses only the trunk diameter data, was used to estimate the tree biomass.

Relationships between the biomass of tree organs such as leaf, branch, trunk or root and D are also shown in *Figure 3a*. The proportions of various parts are shown in *Figure 3b*, which indicates that the trunk and the leaf occupied




(a)




(b)

*Figure 1. Relationships between (a) tree height, (b) trunk diameter and age (n = 954). Solid lines show growth curves according to the Gompertz equation.*

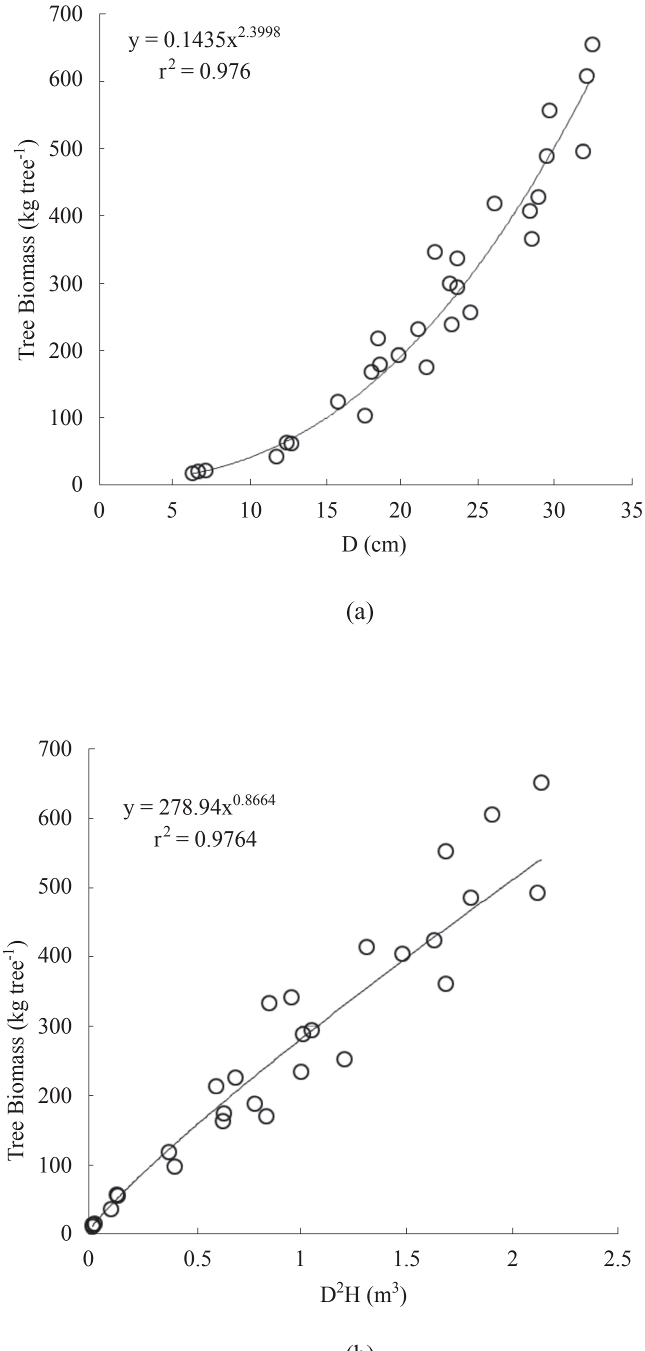
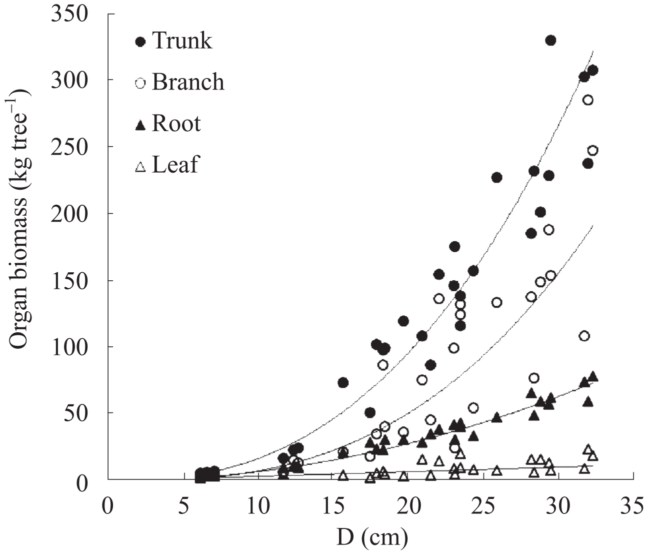
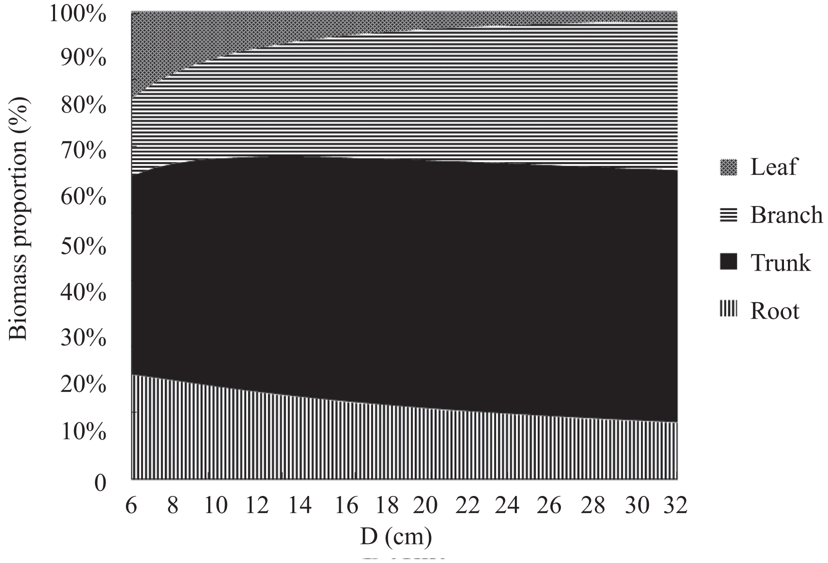



*Figure 2. Relationships between tree biomass and trunk diameter (a) and square of the diameter times tree height (b) (n = 29). Solid lines show allometric curves. The allometric equations are also shown.*




(a)




(b)

*Figure 3. Average biomass of leaf, branch, trunk and root for each tree diameter. (a) Relationships between biomass of the respective organs and the trunk diameter (n = 29). The allometric curves are also shown. (b) Proportions of biomasses of the respective organs for each diameter size.*

the largest and smallest proportions of the total tree, respectively. The proportion of the total tree composed by the branch increased with tree size, whereas the proportion composed by a leaf or root decreased with increasing tree size. The allometric relationship between above ground biomass and the trunk diameter in this study was also compared with literature data (*Figure 4*).

**Biomass Production Curves**

The tree biomass growth with tree age was calculated by using *Equations 1* and *3*. Subsequently, we calculated net yearly tree biomass production by subtracting the previous year's biomass from the current year's biomass. The tree biomass production data were accompanied by dry rubber yield data (*Figure 5a*). Tree biomass production peaked when trees were eight years old and rubber yield peaked at ten years of age. After that point, the rate of the tree biomass production declined faster than did the rate of the rubber production. The partitioning of the biomass to tree growth and to rubber production is also shown in *Figure 5b*. The proportion allocated to the rubber increased with tree age and reached 40% in 20 year old trees. The average biomass production of the tree was 16.7 kg tree$^{-1}$ year$^{-1}$ and of rubber was 4.3 kg tree$^{-1}$ year$^{-1}$.

**Soil Carbon**

The relationship between soil depth and soil carbon content is shown in *Figure 6a*. The upper layers of soil had more carbon and the

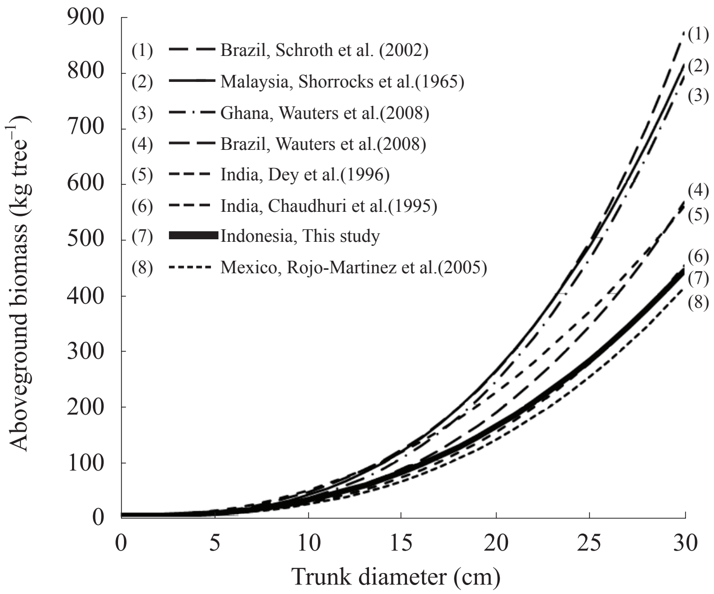



*Figure 4. Relationships between aboveground biomass and trunk diameter. The allometric relationship in BSRE is compared to the literature data in other countries. Respective curves of reference data are shown with number.*

amount of carbon decreased with increasing soil depth. The cumulative amounts of carbon from the soil surface to a 1 m depth were also plotted in relation to stand age (*Figure 6b*). The carbon content of the soil was independent of stand ages, suggesting that carbon amounts in the soil in BSRE were constant. The average amount of carbon in the soil was 90.8 tC $ha^{-1}$.

**Estimate of Carbon Sequestered by this Rubber Estate**

To estimate the amount of carbon sequestered by this rubber estate, we assumed that the carbon contents of a rubber tree and of dry rubber are 50% and 88%, respectively. The 50% is a standard value for carbon content, whereas the 88% comes from the chemical formula of isoprene ($C_5H_8$). The tree density was assumed to be 500 trees $ha^{-1}$, assuming that all planted trees had survived. The relationship between carbon storage as tree biomass or rubber and the stand age is shown in *Figure 7*. Although shapes of carbon sequestration curves are similar to those of biomass curves, the amount of rubber carbon relative to the amount of tree carbon increased because the rubber has higher carbon content. The proportion of rubber was over 50% in 18 year old trees. The estimated average amount of carbon stored as tree biomass and rubber were 4.2 tC $ha^{-1}$ $year^{-1}$ and 1.9 tC $ha^{-1}$ $year^{-1}$, respectively.

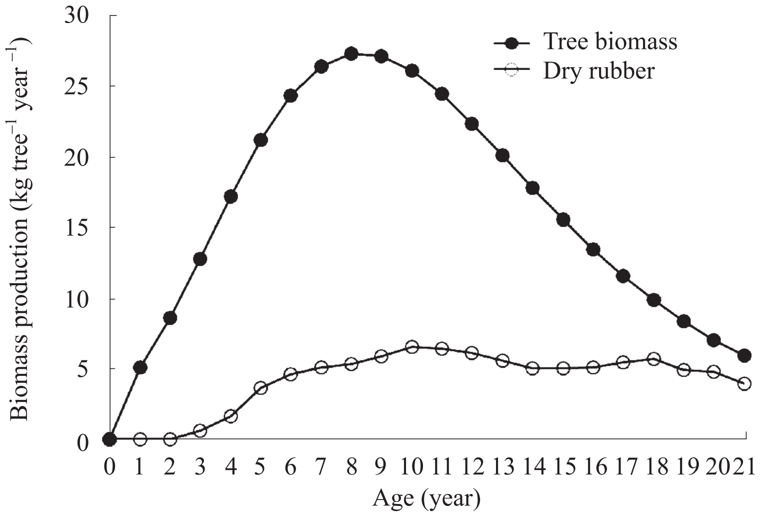
DISCUSSION

In this study, we measured the tree biomass and rubber yield of the PB260 clone of the rubber tree and estimated the annual amount of carbon sequestered by a rubber estate in Indonesia. The tree biomass could be estimated only by the trunk diameter (*Figure 2a*), not the height, because in BSRE, the tops of the trees were cut approximately every four years to prevent them from experiencing wind damage. Therefore, the tree height data did not represent the true heights to which each tree had grown over the years. Similar results were reported on rubber tree plantations in other countries, including Cambodia[8] and Mexico[7]. Our equations make it possible for estate managers to easily evaluate the growth and biomass of a tree on the basis of its trunk diameter alone.

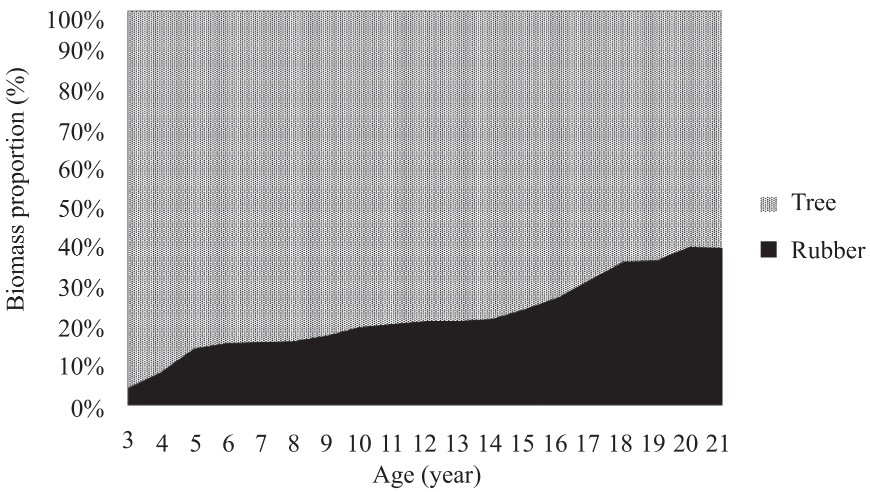
The proportions of the total tree composed of leaves and roots decreased with increasing tree size (*Figure 3b*). The proportion composed of roots ranged from 12% to 23%. The declinations of the root proportion were also shown in Malaysia[2] (from 36% to 15%), Brazil[9] (from 55% to 15%) and Ghana[9] (from 40% to 10%). The relatively low proportion of root biomass in BSRE might be due to greater precipitation in this study site, which lacks an obvious dry season, compared to other sites. The root biomass was proportional to the square of the trunk diameter (Root biomass = $0.0661\ D^{2.02}$, $r^2 = 0.98$: see *Figure 3a*). This finding could indicate that the root length was relatively constant when the roots had a constant bulk density and the "pipe model" or "Leonardo da Vinci's rule" was followed[15–17].

Allometric relationship between aboveground biomass and the trunk diameter were also compared to other literature data (*Figure 4*). Aboveground biomass for a given trunk diameter in BSRE was relatively smaller than those of other literature data. Shorrocks *et al*. (1965) showed that the allometric relationships did not differ significantly among rubber clones[3]. The smaller biomass for a given trunk diameter in BSRE could be caused by cutting of tree tops to avoid wind damage in BSRE.

The tree biomass growth and rubber yield of the PB260 clone were also analysed in this study (*Figure 5a* and *b*). The tree biomass




(a)




(b)

*Figure 5. (a) Net increment of tree biomass and dry rubber yield variation with age.*
*(b) Proportions of the tree biomass increment and the dry rubber yield variation with age.*

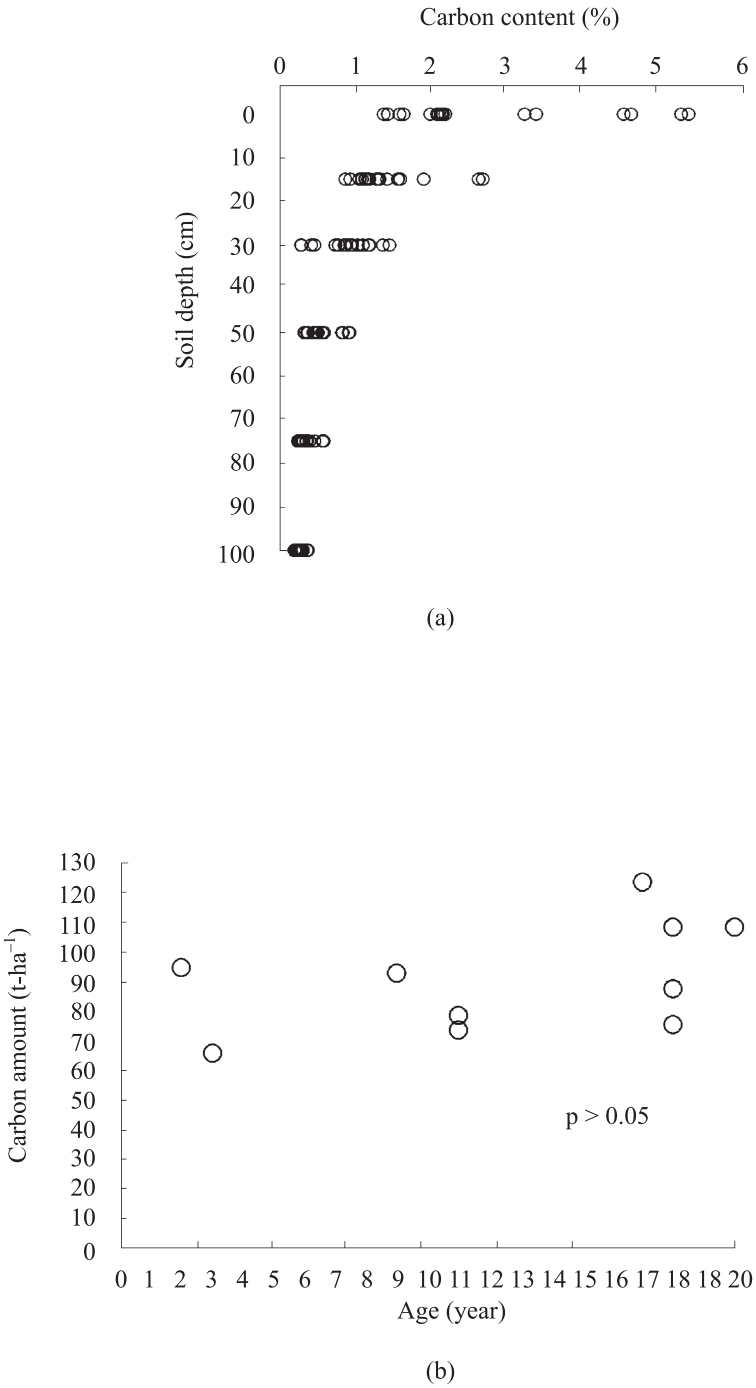



*Figure 6. (a) Soil carbon contents from surface to 1 m in depth (n = 10).*
*(b) Cumulative soil carbon amounts from surface to 1 m in depth for different stand ages (n = 10).*

growth increased up to its peak at eight years from planting. Meanwhile, the rubber yield started at three to four years of age and peaked at ten years from planting. Interestingly, the decline of the tree growth rate was steeper than that of the rubber yield rate. The sink strength of growth could be greater than the rubber production during the tree's young phase, a pattern that would reverse during its mature phase. This trend would be caused by rubber tapping, which stimulates the tree to produce more rubber. As a result, the percentage of biomass allocated to rubber consistently increased from 5% at three years of age to 40% at 20 years of age (*Figure 5b*). On average, the annual biomass productions of the tree and of rubber alone were 16.7 kg tree$^{-1}$ year$^{-1}$ and 4.3 kg tree$^{-1}$ year$^{-1}$, respectively. This basic information about tree growth, rubber yield and to the partitioning of resources to growth *vs.* rubber should be very useful to select a new clone for rubber estate owners, managers, rubber tree breeders and researchers.

The pattern of carbon sequestration was similar to that of the biomass growth in these rubber trees (*Figure 7*). Estimated annual carbon sequestrations by a tree and as rubber were 4.2 and 1.9 tC ha$^{-1}$ year$^{-1}$, respectively.

Carbon sequestration and/or biomass of rubber plantations have been reported for some other countries, although there is little publicly available information[2–4]. The reported annual carbon sequestrations by rubber plantations averaged over 20 years, without the dry rubber, were 5.6 tC ha$^{-1}$ year$^{-1}$ in Malaysia, as calculated by Shorrocks *et al.*[2]; 3.5 tC ha$^{-1}$ year$^{-1}$ in Thailand, as calculated by Saengruksawong *et al.*[11]; 3.4 tC ha$^{-1}$ year$^{-1}$ in China as calculated by Méndez *et al.*[10]; and 5.3 and 2.7 tC ha$^{-1}$ year$^{-1}$ in Ghana and Brazil, respectively, as calculated by Wauters *et al.*[9] The rate of carbon sequestration by BSRE was relatively higher than the rate in other countries, except for Malaysia[2] and Ghana[9].

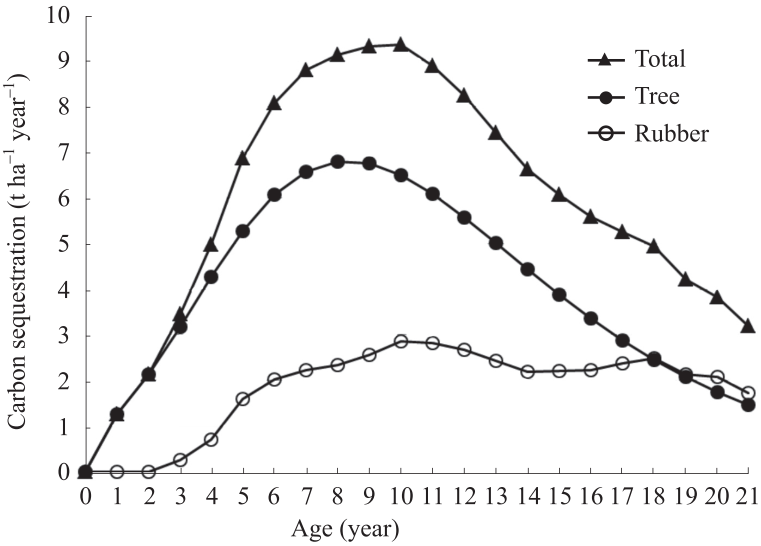



*Figure 7. Yearly carbon sequestrations by the stand of PB260 clones in BSRE for each stand age.*

The lack of information about carbon sequestration in rubber plantations increases the value of the basic data we present from our study.

The information we report on tree growth and rubber yield adds to our essential store of knowledge about the ecophysiological mechanisms of rubber production and may be useful in the development of new agricultural technologies and breeding to increase the yield.

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