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RESEARCH ARTICLE

BIOMASS AND CARBON ALLOMETRY FOR *KANDELIA OBOVATA,* SHEUE, LIU AND YONG PLANTATION IN NORTHERN VIET NAM

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ABSTRACT

Despite the known potential of *Kandelia obovata* Sheue, Liu & Yong plantation in sequestrating carbon dioxide from the atmosphere, there are relatively few studies including precise estimates of the amount of carbon in these plantations. In this study it was determined the biomass-carbon conversion factors for stems, branches, leaves and roots of *Kandelia obovata* Sheue, Liu & Yong plantation in the coastal provinces of Northern Vietnam. We developed allometric equations to estimate the total and different tree component amount of carbon and biomass. A total of 101 sample trees were fell, measured and sampled for biomass and carbon analysis at a single tree level. The biomass-carbon conversion factor for stem, branch, leaf and root components and total tree were 49.48%, 48.41%, 51.94%, 49.46% and 49.55%, respectively, which are slightly greater than the values in other studies and smaller than the generic value commonly used (50%). The best-fit allometric equations to estimate the aboveground, belowground and total amount of carbon and biomass were also determined.

INTRODUCTION

Kandelia obovata Sheue, Liu & Yong is a key species and mainly planted in the coastal provinces of Northern Vietnam, e.g. Hai Phong, Nam Dinh, Thai Binh, Ninh Binh. In the natural development and ecological succession of mangroves, this species and others are grown together in natural mangrove forest (Phan Nguyen Hong *et al.*, 1999). Therefore understandings of ecological characteristics, especially biomass and carbon estimates of this species could significantly contribute to sustainable management of this forest. Scientists have developed a number of methods to estimate biomass of both inland and mangrove forests. Those methods are divided into three categories: 1) the harvest method, 2) the mean-tree method and 3) the allometric method. The harvest method cannot be easily used in mature forests because measuring trees in the field is time and human power consuming. Moreover, harvest method is not reproducible because all trees must be destructively harvested. The mean-tree method is utilized only in forests with a relative homogeneous tree size distribution.

The allometric method uses equations to estimate the whole and partial weight of a tree from measurable tree dimensions, including stem diameter and height. This method is useful for estimating temporal changes in forest biomass by subsequent measurements (Komiyama *et al.*, 2008). However, the allometric equations are site- and species-specific. As we have known that, only few researches about allometric equations for *Kandelia obovata* Sheue, Liu & Yong were published and cited. Our research presented in this paper is one of the first studies in Vietnam on allometric equations for *Kandelia obovata* Sheue, Liu & Yong in both total and component biomass and biomass. In this paper, we also determined the biomass-carbon conversion factors for stem, branches, leaves and roots of *Kandelia obovata* Sheue, Liu & Yong plantation in the coastal provinces of Northern Vietnam.

MATERIALS AND METHODS

Study site

The present study was carried out on plantation of *Kandelia obovata* Sheue, Liu & Yong in coastal region of Ninh Binh, Nam Dinh, Thai Binh and Hai Phong provinces. This coast receives sediments from Red River, Thai Binh River and Van Uc River, thus it is relatively flat with a thick layer of alluvial sediments.

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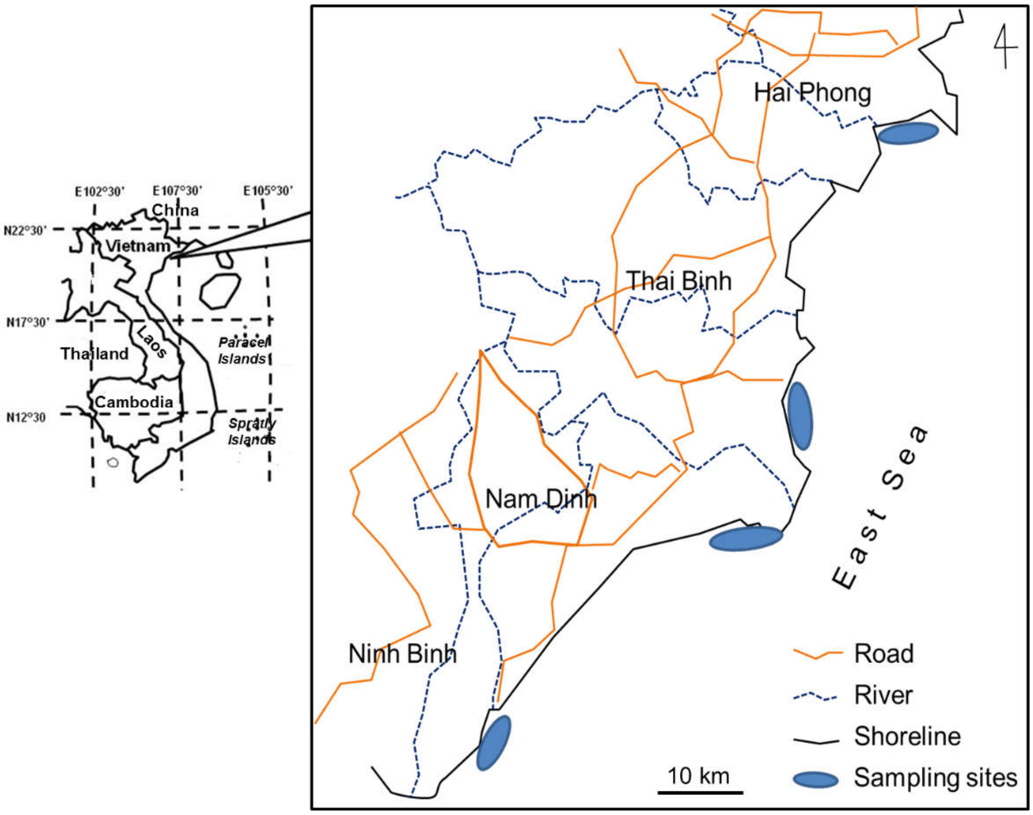

Figure 1. Location and map of Study site

The study site is also specified by the diurnal tide, sea level 0.1 - 3.9 m, the temperature of 24^{o}C, the rainfall nearly 1500 mm/year, air humidity of about 82% and salinity 18.0 - 28.3‰.

Data collection

A total of 39 sample plots were established within *K. obovata* plantation by stratified sampling method. The study sites was divided into different compartments corresponding to the ages of mangrove stands (*K. obovata* 1 - 13 years). Three sample plots (10 × 10 m) within each compartment were surveyed. A total of 101 sample trees (at least one tree per sample plot) were fell down and dug roots in the 2008, 2009 and 2013 to measure the diameter, total and component (above ground, below ground and total) dry weight. Before falling sample trees, we measured and recorded the diameter at 30 cm above widening base of stem. The sample trees were cut, separated and weight fresh above ground component including stems, branches and leaves, and roots. About 5-10 g samples of each component was subsampled and weighed for its exact fresh weight. The subsamples then were taken to the laboratory and dried to constant weight. The ratio of the fresh weight and dry weight of each subsample was used to calculate the dry weight of each component. Total dry weight of stems, branches and leaves is aboveground biomass. Total biomass of a tree is the sum of the total dry weight of all above ground components and roots. The biomass of each sampled component was converted to carbon using the carbon content, which was obtained in the laboratory using a wet-oxidation technique.

Data analysis

Allometry is based on the fact that there is proportionality between the relative growth rates of two different parts of the plant (Huxley, 1972). The relationship between the two variables can be expressed by the following equation:

$$\frac{\frac{dy}{ydt}}{\frac{dx}{xdt}} = k \qquad \text{……………………(1)}$$

where x is the independent variable (e.g. stem diameter, tree height or both of them), y is dependent varibale (e.g. biomass), and b and k are the allometric constants. The equation can be simplified as follows.

$$\text{(1)} \quad \Leftrightarrow \quad \frac{dy}{y} = k\frac{dx}{x}$$

$$\Leftrightarrow \quad \int\frac{dy}{y} = k\int\frac{dx}{x}$$

$$\Leftrightarrow \quad \ln y + c_1 = k(\ln x + c_2)$$

$$\Leftrightarrow \quad \ln y = \ln x^k + \ln b$$

$$\Leftrightarrow \quad y = bx^k \qquad (2)$$

In this study, we used diameter at 0.3 m height (D) as the independent variables because it is easy to measure in the field by using caliper rule or tape measure. Tree height was not used in the equation because measuring the height of mangrove trees is a big challenge, i.e. inadequate accuracy and time/man power consuming. In the latest guidelines on carbon assessment of mangroves, CIFOR (Center for International Forestry Research) also recommended that the allometric equation should be developed and used with one independent

Table 1. Biomass and amount of carbon in different components of sample trees

Statistics	Biomass (kg)					Amount of carbon (kg)				
	Leaf	Stem	Branch	Root	Total	Leaf	Stem	Branch	Root	Total
Minimum	0.22	0.68	0.51	0.40	2.28	0.10	0.35	0.24	0.19	1.14
Maximum	1.40	5.40	1.81	1.20	7.84	0.71	2.75	0.92	0.64	3.97
Mean	0.46	2.42	0.95	0.81	4.65	0.24	1.20	0.46	0.40	2.30
C.V.	39.29	51.50	24.61	14.45	29.40	38.99	51.03	25.55	15.38	29.47
SE%	2.18	2.86	1.37	0.80	1.63	2.17	2.84	1.42	0.85	1.64

C.V.: coefficient of variance, SE%: relative standard error

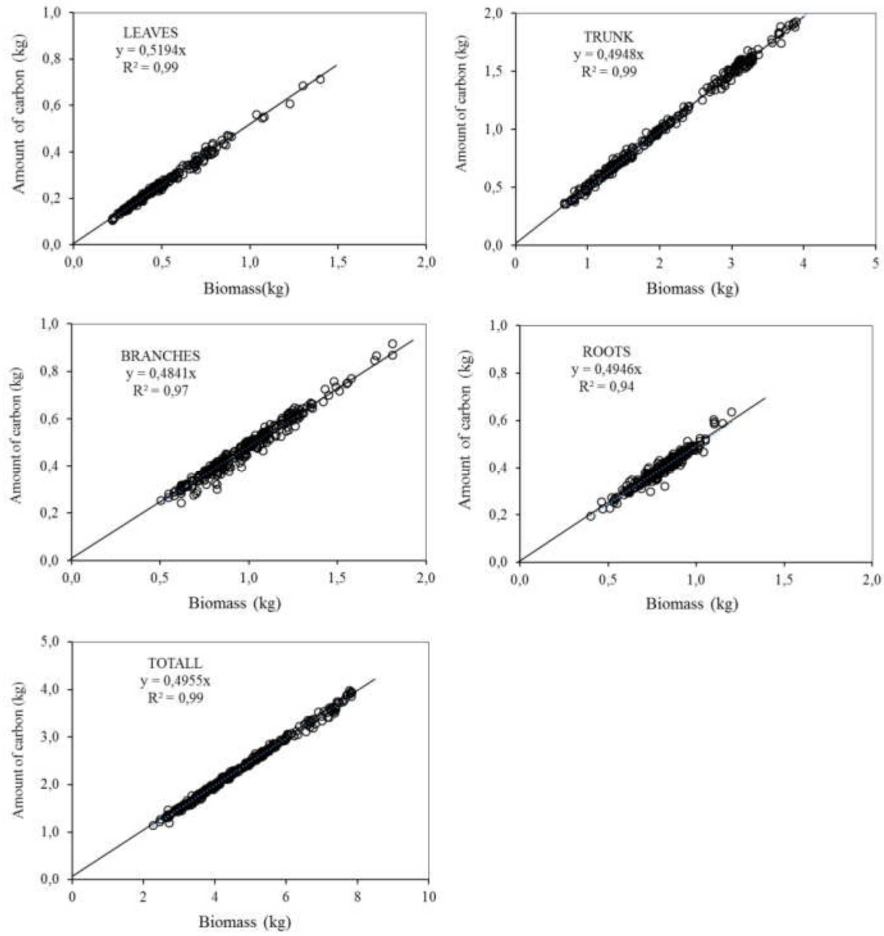

Figure 1. Relationship between amount of carbon and biomass for *K. obovata*

variable – diameter (Kauffman and Donato, 2012). A non-linear ordinary least squares-regression analysis was used to fit the models to the data. To select the models the following evaluation criteria were used: the coefficient of determination (R^2), mean squared error (*MSE*) and mean error of estimate (*bias*).

Bias, R^2 and *SEE* were calculated by equation (3), (4) and (5) respectively. R^2 is a statistic that would give information about the goodness of fit of the allometric equations (i.e. R^2 is a statistical measure of how well the regression curve/line approximates the real data points. An R^2 of 1 indicates that the regression curves/lines perfectly fit the data.

SSE and *bias* are errors of estimates by allometric equations compared with the true values.

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{N} (y_i - y_i')^2}{\sum_{i=1}^{N} \left(y_i - \frac{1}{N} \sum_{i=1}^{N} y_i \right)^2} \right) \quad (3)$$

$$SSE = \sum_{i=1}^{N} (y_i - y_i')^2 \quad (4)$$

$$bias = \frac{\sum_{i=1}^{N} (y_i - y_i')}{N} \quad (5)$$

where is biomass of i^{th} tree measured in the field, is biomass of i^{th} tree by allometric equation and N is total number of sample trees.

RESULTS AND DISCUSION

Biomass and carbon of sample trees

The biomass and amount of carbon in different components of sample trees are shown in Table 1. The stem is the component that contributed highly to the tree biomass (52.16%), followed by the branches (20.47%), roots (17.46%) and leaves (9.91%). The amount of carbon follows as the same pattern. The stem also contributed higher amount of carbon to the total carbon of tree, followed by the branches (20.00%), roots (17.39%) and leaves (10.43%). Kairo *et al.* (2009) in a replanted mangrove

Sonneratia and *Ceriops* obtained the highest biomass proportion in branches, 48.20% and 43.62% respectively. However, in *Avicennia* and *Rhizophora* trees, they found that stems (52.19%) and roots (30.28%) accounted for the greatest percentage of biomass. The divergence in the proportion of biomass and carbon allocation could be explained by the different site characteristics, species, age and stand management practices.

Those relationships can be used to correctly estimate the biomass of tree from stem diameter in the mangrove species (Ong *et al*. 1995; Putz and Chan, 1986). The results also indicated that the allometric equations could be fitted to the data using the amount of carbon as a dependent variable. The use of this variable instead of biomass was an attempt to allow the estimation of the total amount of carbon based solely on an easily measurable variable such as stem diameter.

Table 2. Biomass and carbon allometric regressions for K. obovata)

Equation	*D* (cm)	*N*	R^2	*MSE*	*bias*
Biomass					
$W_{TT} = 0.038D^{2.3149}$	0 – 14	101	0.82	1.53	0.13
$W_{AG} = 0.0901D^{1.7875}$	0 – 14	101	0.84	0.76	0.06
$W_{BG} = 0.0142D^{2.1215}$	0 – 14	101	0.73	0.19	0.009
Amount of carbon					
$W_{TT} = 0.0195D^{2.2964}$	0 – 14	101	0.68	0.76	0.06
$W_{AG} = 0.0723D^{1.6231}$	0 – 14	101	0.72	0.23	0,02
$W_{BG} = 0.0112D^{2.0314}$	0 – 14	101	0.67	0.58	0.003

Biomass-carbon conversion factor

Amount of carbon in forest biomass is calculated by multiplying the biomass by the biomass-carbon conversion factor (carbon content (%)). In this study, we collected and analyzed carbon from stem, branches, leaves, and roots of 101 *K. obovata* trees to analyze the relationship between amount of carbon and biomass for total and different components of tree. The biomass-carbon conversion factor is determined by the correlation coefficient shown in Figure 1. Figure 1 shows that biomass-carbon conversion factors for total and different components of tree are in the range of 0.48-0.51. A study with different mangrove species *B. gymnorhiza*, *R. apiculata* and *S. alba* reported an average carbon content for wood of 46.3%, 46.8% and 47.1% respectively (Kauffman et al., 2011). IPCC (2006) recommends that in the absence of specific biomass-carbon conversion factors, a default factor of 47% should be used to estimate the carbon fraction in the aboveground forest biomass. These conversion factors are low compared to the ones founded in this study, probably due to differences of species, site and other environmental conditions. Most of the studies that aim to estimate the carbon stock in plantations use a generic value of 50% to estimate the amount of carbon in biomass. The indiscriminate use of this value may have serious implications, especially under the Kyoto Protocol. Using these default conversion factors may lead to an under- or overestimation of carbon credit allocation in projects that are based on the use of forest resources.

Biomass and carbon allometry

Table 1 presents the allometric regressions obtained for total, above ground and below ground biomass and amount of carbon of *K. obovata*. The coefficient of determination (R^2) for all equations are greater than 0.65 indicating that a large proportion (over 65%) of the total, above ground and below ground biomass and amount of carbon of *K. obovata* could be explained by the diameter at 0.3 m height. The coefficients of determination (R^2) for the allometric equations developed for *K. obovata* of about 0.67 - 0.84 and small errors of estimate (bias ≤ 0.13) for all of obtained equations confirmed the earlier observations that power curve or allometric function ($y = bx^k$) can accurately describes the relationships of biomass and amount of carbon with stem diameter (Whittaker and Marks, 1975).

However, it is noticed that regression models vary between species, different localities and depending on site-specific factors such as tree density, management practices and whether it is a monoculture or mixed forest. The regression equations derived in this study for the mangrove plantations may not be appropriate for open natural mangroves

Conclusion

The present study was estimated the biomass and amount of carbon in different components of sample trees, biomass-carbon conversion factor for aboveground, belowground and total tree biomass of *K. obovata,* developed allometric equations to estimate the biomass and amount of carbon for *K. obovata*. The biomass-carbon conversion factors were slightly greater than other studies, probably due to differences related to the site and species. The total amount of carbon could be predicted by using the regression models based on an easily measurable variable such as stem diameter. However, it is noticed that regression models can vary with species and sites.

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