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การเปรียบเทียบสมการความสัมพันธ์ระหว่างความสูงต้นไม้กับเส้นผ่าศูนย์กลางลำต้นและประมาณค่าปริมาณคาร์บอนในมวลชีวภาพของป่าเต็งรังสองพื้นที่ในภาคเหนือของประเทศไทย

Comparison on Tree Height-Stem Diameter Allometric Equations and Biomass Carbon Estimation of Two Dry Dipterocarp Forests in Northern Thailand

Teuanchay Phongkhamphanh[1*], Soontorn Khamyong[2] and Kriangsak Sri-ngernyuang[3]

[1] Plant and Soil Sciences Department, Faculty of Agriculture, Chiang Mai University, Chiang Mai 50200

[2] Highland Agriculture and Natural Resources Department, Faculty of Agriculture, Chiang Mai University, Chiang Mai 50200

[3] Faculty of Architecture and Environmental Design, Maejo University, Chiang Mai 50290

[*] Corresponding Author, E-mail: pteuanchay@yahoo.com

บทคัดย่อ

การศึกษาเปรียบเทียบสมการความสัมพันธ์ระหว่างความสูงต้นไม้กับเส้นผ่าศูนย์กลางลำต้นและการประเมินค่าปริมาณคาร์บอนในมวลชีวภาพพันธุ์ไม้ของป่าเต็งรังสองแห่งในภาคเหนือของประเทศไทยได้ดำเนินการบริเวณศูนย์ศึกษาการพัฒนาห้วยฮ่องไคร้อันเนื่องมาจากพระราชดำริ (พื้นที่ 1) และป่าชุมชนตำบลแม่ทา อำเภอแม่ออน จังหวัดเชียงใหม่ (พื้นที่ 2) ทำการวางแปลงสุ่มตัวอย่างขนาด 40 x 40 เมตร จำนวน 12 แปลงในพื้นที่ 1 และ 15 แปลง ในพื้นที่ 2 โดยใช้วิธีการวางแปลงแบบสุ่ม เก็บข้อมูลเส้นผ่าศูนย์กลางลำต้นที่ความสูง 1.3 เมตรจากพื้นดินและวัดความสูงต้นไม้ในแปลงสุ่มตัวอย่าง 11 แปลง ของพื้นที่ 1 และจำนวน 5 แปลง ของพื้นที่ 2 โดยใช้เครื่องมือวัดเป็นแท่งเสา (Measuring Pole Height Stick) และเครื่องยิง (Haga) นำข้อมูลเส้นผ่าศูนย์กลางลำต้นและความสูงต้นไม้ของพันธุ์ไม้เด่น 9 ชนิดสร้างสมการแอลโลเมทรีของพันธุ์ไม้ในแต่ละพื้นที่และนำสมการที่ได้คำนวณปริมาณมวลชีวภาพของพรรณไม้ในแปลงสุ่มตัวอย่าง เปรียบเทียบความแตกต่างของปริมาณมวลชีวภาพของพันธุ์ไม้เด่น 9 ชนิด และของป่าเต็งรังสองแห่งที่คำนวณได้จากสมการของสองพื้นที่ พันธุ์ไม้เด่น ได้แก่ ไม้เต็ง รัง เหียง พลวง ประดู่ เก็ดดำ-ชิงชัน มะเกิ้ม เหมือดหลวง และ รักใหญ่ พบว่าปริมาณมวลชีวภาพและคาร์บอนที่กักเก็บในป่ามีความแตกต่างกันบ้าง ความสูงต้นไม้ของพันธุ์ไม้เด่นส่วนใหญ่ในพื้นที่ 1 มีค่าต่ำกว่าพื้นที่ 2 ยกเว้นประดู่ มะกอกเกลื้อนและรักใหญ่ การใช้สมการแอลโลมีทรีของพื้นที่หนึ่งกับอีกพื้นที่หนึ่งทำให้การประมาณค่าปริมาณมวลชีวภาพและการกักเก็บคาร์บอนในป่ามีความแตกต่างกัน ปริมาณเฉลี่ยของคาร์บอนในพื้นที่ 1 ที่คำนวณโดยใช้สมการแอลโลมีทรีของพื้นที่ 2 มีค่าสูงขึ้นจาก 44.77±5.39 เป็น 48.73±5.88 เมกกะกรัมต่อแฮกแตร์ (สูงขึ้น 3.96 เมกกะกรัมต่อแฮกแตร์) แต่เมื่อนำสมการของพื้นที่ 1 ใช้คำนวณของพื้นที่ 2 พบว่ามีค่าต่ำลงจาก 61.97±26.61 เป็น 59.57±25.05 เมกกะกรัมต่อแฮกแตร์ (ลดลง 2.70 เมกกะกรัมต่อแฮกแตร์) แต่ไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ

ABSTRACT

The tree height-stem diameter (H-D) allometric equations and tree biomass carbon estimation of two dry dipterocarp forests (DDF) in northern Thailand, were compared. Study areas included two sites, the Huai Hong Khrai Royal Development Study Center (Site 1) and the Mae Tha sub-district community forest (Site 2). Twelve sampling plots, each of size 40 x 40 m, were used for tree survey at Site 1 and fifteen plots for Site 2, and the plots were arranged in the both study area by a random sampling method. Tree data were obtained by measuring stem diameters at breast height (DBH) 1.3 m above ground in all sample plots, and total heights of all trees that height over 1.5 m were measured in 11 plots for Site 1 and 5 plots for Site 2 using a Measuring Pole Height Stick and Haga hypsometer. The stem diameter and tree heights of 9 dominants tree species were used for making H-D allometric equations of each site, and apply it for calculate tree biomass within the plots. Some different biomass amounts were obtained from the equations of same species and the two-site of DDF. These species included *Shorea obtusa, Shorea siamensis, Dipterocarpus obtusifolius, Dipterocarp tuberculatus, Pterocapus macrocarpus, Dalbergia assamica-Dalbergia oliveri, Canarium subulatum, Aporosa villosa,* and *Gluta usitata.* The H-D allometric equations of these species in the two sites indicated some differences of biomass and carbon stock in the forests. The heights of most mature dominant tree species in Site 1 were lower than Site 2, except for *Pterocarpus macrocarpus, Canarium subulatum* and *Gluta usitata*. Application of the H-D allometric equations of one site to another caused the different estimation of biomass and carbon stock found in the forest. average carbon stock in tree biomass of Site 1 calculated using the equations of Site 2 showed overestimation, 44.77±5.39 to be 48.73±5.88 (+3.96 Mg ha^{-1}) while turnover biomass of Site 2 obtained by using the equations of Site 1 presented lower estimation, 61.97±26.61 to be 59.57±25.05 (-2.70 Mg ha^{-1}). However, these differences were not significant statistic.

คำสำคัญ: การสะสมคาร์บอน ป่าเต็งรัง H-D แอลโลเมทรีค เส้นผ่านศูนย์กลาง มวลชีวภาพต้นไม้

Keywords: Carbon stock, dDry dipterocarp forest, H-D allometric equation, Stem diameter, Tree biomass

INTRODUCTION

Allometry is defined as the growth of a part of tree in relation to the growth of the whole tree or some parts of it (Niklas, 1994). Tree height (H) was found to be correlated with stem diameter at breast height (D), and the relation of H to D in forests has proved to follow the H-D hyperbola equation, irrespective of species (Ogawa et al., 1965). Tsutsumi et al. (1983) also confirmed the same result for the mixed deciduous-dry evergreen forest in Thailand, as well as the result of tropical rain forest in Indonesia (Yamakura et al., 1986). The H-D hyperbola relation can be obtained in the old-growth forest where mature trees are abundant. However, this relation may be not occurred for the secondary forest since most mature trees were cut in the past, and remains only small and immature tree individuals. Dry weights of stem, branch, leaf and root per tree were most closely correlated with the product of H and the square of D, and allometric equations were made from this relation for estimation of standing tree biomass in tropical forests (Ogino et al., 1967; Tsutsumi et al., 1983; Yamakura et al., 1986). Since tree species can be divided into small, intermediate and big trees, the H-D relation may be different among species, and vary with sites for the same species. Reports of allometric equations for biomass estimation of each species in the forest particularly dominant species are unavailable. Tree height is controlled by a group of genes and environmental variables (Kimmins, 2004). The equations of the same species are assumed to be different among the sites influenced by the environmental factors such as light, temperature, moisture, soil, parent rocks, etc. Tree density usually influence on tree height in the forest.

In this study, an assumption is that the H-D relation is different among tree species in a forest and the same forest of different sites. Two sites of the DDF were selected for this investigation, the Huai Hong Khrai Royal Development Study Center (Site 1) and the Mae Tha sub-district community forest (Site 2). These secondary forests had some differences of species richness, composition and diversity, tree densities, tree biomass and forest conditions index. The forests were destroyed through forest concession and illegal cutting, and now are protected for 32 years for Site 1 and 23 years for Site 2. The DDF covers on xeric sites having various soils and parent rocks. Different soil types influence on variation of tree communities in the forest grown on different sites: species composition, richness, diversity, tree growth and yield. Other factors such as rainfall amount, topography, altitude, microclimate, etc., are also important factors. The soils under sub-type DDF varied from Order Entisols (very shallow) to Inceptisols (shallow to moderately deep) and Ultisols (deep). Four dipterocarps are dominant tree species in the forest: *Shorea obtusa*, *Shorea siamensis*, *Dipterocarpus obtusifolius* and *Dipterocarpus tuberculatus* (Phongkhamphanh et al., 2015; Khamyong et al., 2016).

The research objectives are to compare tree height (H) - stem diameter (D) allometric equations of dominant tree species and biomass carbon estimation of two-site of dry dipterocarp forests in northern Thailand as a basis information for further study.

MATHERIALS AND METHODS

Study areas

The research was conducted in two areas of Chiang Mai province, northern Thailand. These included the Huai Hong Khrai Royal Development Study Center (HHKRDS, Site 1) and the Mae Tha community forest (Site 2). Site 1 is located in the Doi Saket district while Site 2 is in the Mae On district. The HHKRDS Center established in 1984 is designed as the center of study, experiment and research on integrated watershed management by King (Rama 9)'s initiation and recommendations to find out suitable development approaches for northern Thailand as to extend knowledge to farmers in the surrounding villages and northern region. Before 1984, the forest including dry dipterocarp forest and mixed deciduous forest was degraded caused by forest concession and illegal cutting in the past. The forest has been protected as head watershed at the upstream, and downstream areas are agriculture and fisheries. The forest is recovered for 32 years.

As for Site 2, forest concession was taken during 1901 and 1959 by private companies for timber especially wood sleeper for railways and fire wood supplied to tobacco factory. These activities caused forest degradation, and the critical drought was happened in 1991 and 1992. The community forest was established in 1993. It is accepted as a good-managed community forest by the government, and different from other community forests because it is the united community forest at the sub-district level (seven villages), not belong to a single village. The villagers in this sub-district have organized their members to work closely with the Mae Tha Sub-district Administration Office. The forest has been conserved for 23 years.

Vegetation sampling

A method of tree community analysis was used for vegetation survey in the DDF of two sites. Twelve sampling plots, each of size 40 x 40 m, were applied for Site 1 and fifteen plots for Site 2. These plots were randomly distributed in the forest. In each plot, stem diameters at breast height (DBH, at 1.3 m above ground) were measured using a diameter tape, and tree heights were determined within eleven plots for Site 1 and five plots for Sites 2 using a measuring pole and Haga hypsometer for all tree species with height over 1.5 m. Then, the H-D equations of nine abundant tree species were made for each site, and used for calculating tree heights in the remained plots. The heights of other tree species were calculated by the H-D equation of these nine species.

The H-D allometric equations

In these secondary forests, most mature trees were cut in the past. The H-D relation was assumed to be a linear regression (Hosmer and Lemeshow, 1989; Shiver and Borders, 1996), and not follow a hyperbola equation. It is a statistical method for studying the relationship between two variables. The variables are used to analyze the quantitative variables. The relationship of the two variables is D (stem DBH) and H (tree height). The correlation coefficient (r^2) can be considered as the amount and how much of a relationship as the correlation means: 0.85 to 1.00, with most relationships; 0.71 to 0.84 has high relations; 0.51 to 0.70 has little relationship, and 0 to 0.50, relationship is the minimum.

Tree biomass estimation

The data of stem diameters and tree heights of all tree species in the sampling plots were also used for calculation of biomass amounts in stem, branch, leaf and root using allometric equations studied in deciduous forests of Thailand by Ogino et al. (1967).

$$W_S = 189\,(D^2H)^{0.902}$$

$$W_B = 0.125Ws^{1.204}$$

$$1/W_L = (11.4/Ws^{0.90}) + 0.172$$

When W_S = stem biomass in kilogram

W_B = branch biomass in kilogram

W_L = leaf biomass in kilogram

A unit of stem diameter (D) and tree height (H) was in meter. The root biomass was calculated by an equation of Ogawa et al. (1965) $W_R = 0.026\,(D^2H)^{0.7750}$. Units were used in kilogram for root biomass (W_R), centimeter for D and meter for H.

Carbon storage in tree biomass

Amounts of carbon stored in tree biomass of all tree species in the two-site DDF were calculated by multiplying the biomass amounts with average carbon contents in tree organs studied by Tsutsumi et al. (1983). The average carbon contents in stem, branch, leaf and root of 62 tree species in Thailand were reported to be 49.90%, 48.70%, 48.30% and 48.12%, respectively.

RESULTS

Results included two parts: comparison on H-D allometric equations and tree biomass estimation between two sites of the DDF.

1. The H-D allometric equations of dominant tree species

Table 1 shows H-D allometric equations of nine dominant and abundant tree species in Site 1 and Site 2. Most species were big trees except a shrubby tree of *Aporosa villosa*. The correlation values (r^2) of both sites were different among species, however, all of them had the high values of reliability of correlation category: 0.7242 to 0.9117 for Site 1 and 0.7097 to

0.8509 for Site 2. The same equation was applied for *Dalbergia assamica* and *Dalbergia oliverli*, because of the same genus and each of them had the low population. *Shorea obtusa* was the most abundant species in the DDF of both sites. The lesser abundant tree species in Site 1 were *Shorea siamensis*, *Dipterocarpus obtusifolius*, *Gluta usitata* and *Dipterocarpus tuberculatus*, respectively. As for Site 2, abundant values were in the following order: *Shorea siamensis, Dipterocarpus obtusifolius, Dipterocarpus tuberculatus.* Different number of sampling plots was used for making the equations in these sites, 11 plots for Site 1 and 5 plots for Site 2. Thus, the number of trees used for making the equations of the same species was different. However, their correlation coefficients were high to very high which implied to the high and most relationships of the two variables, D (stem diameter) and H (tree height).

Table 1 Allometric equations of H-D relation and their correlation values in the two-site DDF

Plant species	Site 1			Site 2		
	Equation 1	r^2	n	Equation 2	r^2	n
1. *Shorea obtusa*	H = 0.5259D + 2.2362	0.7242	913	H = 0.6181D + 1.6507	0.7097	350
2. *Shorea siamensis*	H = 0.5591D + 2.3336	0.7498	742	H = 0.6109D + 2.3741	0.7511	257
3. *Dipterocarpus. obtusifolius*	H = 0.5566D + 2.0346	0.8320	366	H = 0.6227D + 2.1808	0.8399	218
4. *Dipterocarpus tuberculatus*	H = 0.6569D + 0.3909	0.8242	161	H = 0.7101D + 0.4912	0.7805	179
5. *Pterocarpus macocarpus*	H = 0.6126D + 2.1933	0.9104	63	H = 0.5240D + 3.0914	0.7515	92
6. *Dalbergia assamica and Dalbergia oliveri*	H = 0.5870D + 1.7983	0.9085	300	H = 0.6403D +1.8574	0.8509	75
7. *Canarium subulatum*	H = 0.6208D + 1.5409	0.9117	154	H = 0.5338D + 2.6126	0.7199	71
8. *Aporosa villosa*	H = 0.3076D + 2.0633	0.8154	52	H = 0.3741D + 2.5838	0.6615	128
9. *Gluta usitata*	H = 0.4506D + 2.0686	0.7886	190	H = 0.3986D + 3.6466	0.7221	60

Note: H = tree height (m), D = stem diameter (cm), r^2 = correlation, n = number of sampling trees

2. Comparison on H-D allometric equations of the two-site DDF

In Fig. 1, the H-D allometric equations of the same species having the same stem DBH by calculation using equation 1 (Eq. 1 for Site 1) and equation 2 (Eq. 2 for Site 2) were compared. As the stem DBH increased, the height of tree species also increased continuously. The heights of bigger trees of the same species calculated by Eq. 1 and Eq. 2 were observed for the differences. It is found that tree heights of bigger trees of four dipterocarps (*Shorea obtusa, Shorea siamensis*, *Dipterocarpus obtusifolius* and *Dipterocarpus tuberculatus*) calculated from Eq. 1 were a little lower than those from Eq. 2. *Aporosa villosa* and *Dalbergia assamica-Dalbergia oliveri* had the same result as dipterocarps species. However, the species of *Pterocarpus macrocarpus* and *Canarium subulatum* had the opposite result that their tree heights calculated from Eq. 1 was higher than Eq. 2, while *Gluta usitata* had no differences.

Different tree heights of a species especially dominant and abundant species in the DDF of two sites will affect biomass estimation using allometric equations studied by Ogino et al. (1967) and Ogawa et al. (1965). Many factors are thought to be the causes of different tree heights of the same species among sites including tree density and substrate quality.

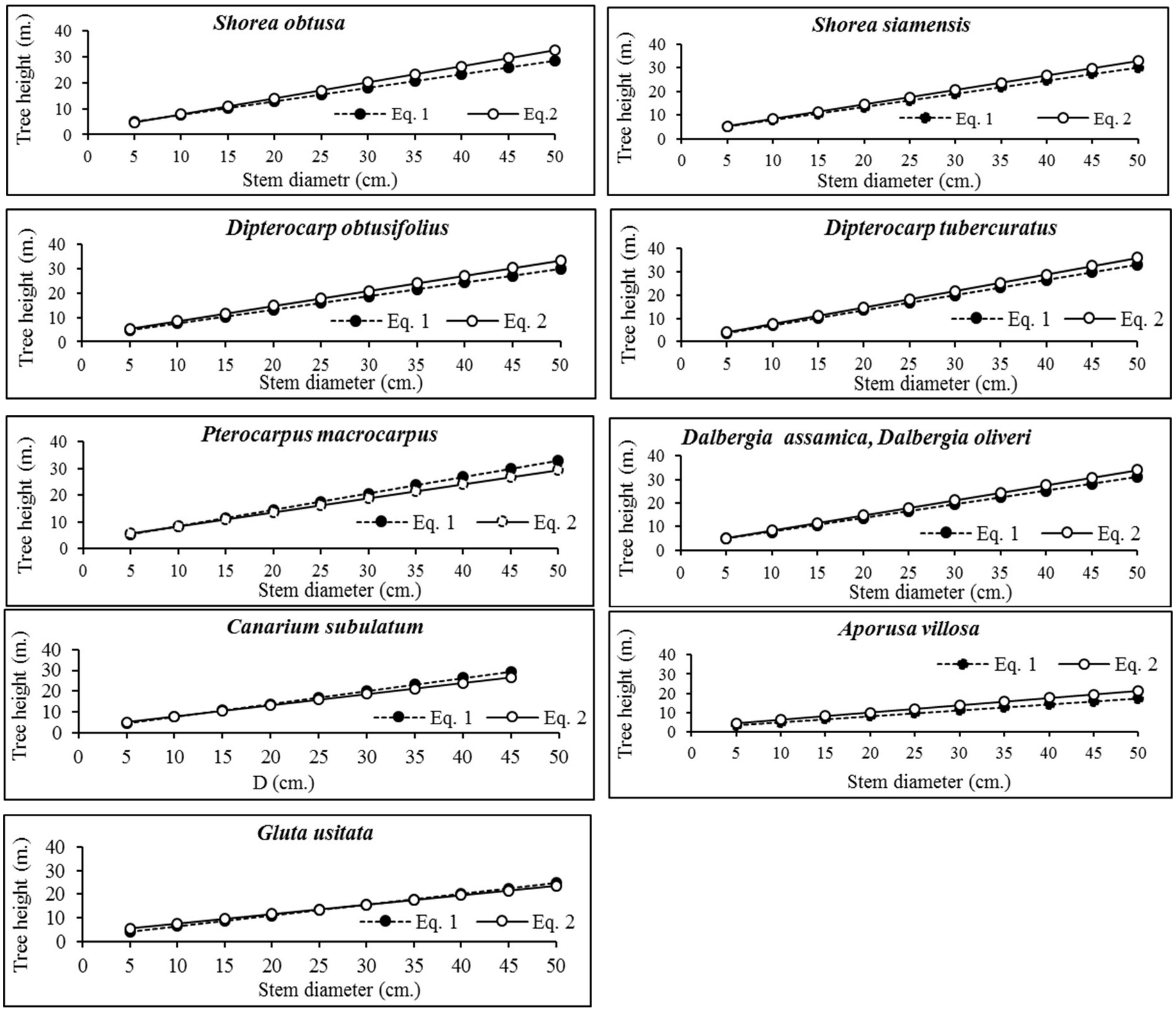


Fig. 1 Comparison on H-D allometric equations of same species using Eq.1 and Eq. 2

3. Comparison on biomass estimation in the two-site DDF

3.1 Biomass amounts by calculation of abundant tree species

Fig. 2 shows differences of biomass amounts of the nine tree species by calculation using Eq. 1 and Eq. 2. As the stem girths increased from 0 cm to 40 cm, the biomass of tree species increased continuously too. The biomass amounts of four dipterocarps (*Shorea obtusa*, *shorea siamensis*, *Dipterocarp obtusifolius* and *Dipterocarp tuberculatus*) calculated from Eq. 1 were lower than those from Eq. 2. *Aporosa villosa* and *Dalbergia assamica-Dalbergia oliverli* had also the same result. The species of *Pterocarpus macrocarpus, Canarium subulatum* and *Gluta usitata* had the opposite result when the biomass amounts calculated from Eq. 2 were adversely higher than those from Eq. 1. These results will further affect biomass estimation of all tree species in the DDF of two sites

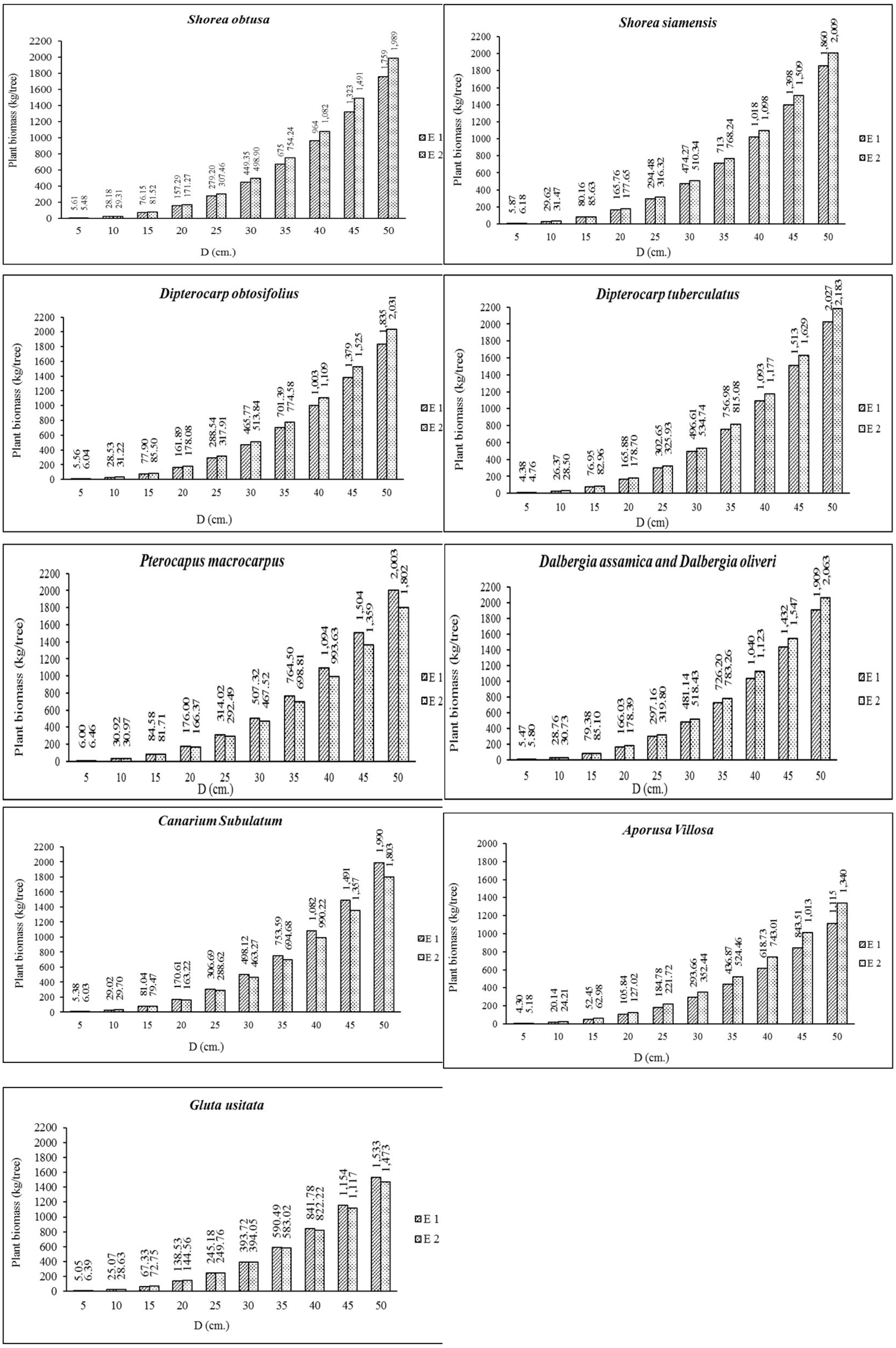


Fig. 2 Comparison on total biomass of tree species with the same stem diameter calculated by Eq.1 and Eq.2

3.2 Tree biomass in the two-site DDF

3.2.1 Tree communities of the two sites

The two-site DDF had some differences of species composition, richness and diversity. These included density, dominance and important values index of the nine species (Phongkhamphanh et al., 2015; Khamyong et al., 2016).

Site 1: The DDF in this site was studied in detail by Khamyong et al. (2016). Tree species sampled within 12 plots each of 0.16 ha were identified to a total of 60 species (50 genera and 31 families) with average density of 2,839 tree ha^{-1}. It was divided into four stands based on the most dominant species. Most area in the forest was dominated by the *Dipterocarpus obtusifolius* stand, while the stands of *Shorea siamensis*, *Dipterocarpus tuberculatus* and *Shorea obtusa* covered in some sites. The species with the highest density was *Dipterocarpus obtusifolius*, 959 tree ha^{-1}, followed by *Shorea obtusa* (447), *Gluta usitata* (357), *Memecylon scutellatum* (352), *Shorea siamensis* (267), *Tristanopsis burmanica* (226), *Dipterocarpus tuberculatus* (221), *Dalbergia oliverli* (166), *Anleslea fragrans* (146), *Aporosa villosa* (125), *Wendlandia tinctoria* (83) and *Canarium subulatum* (70). *Dipterocarpus obtusifolius* had the highest importance value index (23.71% of all species), followed by *Gluta usitata*, *Shorea obtusa*, *Dipterocarpus tuberculatus*, *Shorea siamensis,* etc.

Site 2: The DDF in Site 2 was studied by Pongkhamphanh et al. (2015). A total number of 83 tree species (69 genera and 42 families) and average density of 2,241 tree ha^{-1} were found. It was divided into five stands based on the most dominant species: *Shorea obtusa*, *Shorea siamensis*, *Dipterrocapus obtusifolius*, *Dipterocarpus tuberculatus* and *Pinus merkusii*. These stands had variations of species composition, species richness, tree population and forest condition. *Shorea obtusa* had densities of 575 to 1,313 tree ha^{-1}; dominances, 3.44% to 55.04% and important values index, 27.29% to 46.29%. *Shorea siamensis* had densities of 706 to 1,244 tree ha^{-1}; dominances, 52.98% to 68.98% and important values index, 28.24% to 54.10%. *Dipterocarpus obtusifolius* had 550 tree ha^{-1} density; 64.13% dominance and 48.93% important value. *Dipterocarpus tuberculatus* had densities, 288 to 713 tree ha^{-1}; dominances, 28.29% to 46.86% and important values, 21.71% to 42.80%.

In Table 2 and Fig. 3, tree densities with different stem DBH classes (<8, 8-16, 16-24 and >24 cm) of nine species were different between two sites. For dipterocarps, densities of *Shorea obtusa, Shorea siamensis* and *Dipterocarpus tuberculatus* in Site 1 were lower than Site 2, but *Dipterocarpus obtusifolius* density in Site 1 was higher than Site 2, while *Pterocarpus macrocarpus, Canarium subulatum* and *Dalbergia assamica-Dalbergia oliverli* had the same result as the three dipterocarps. *Gluta usitata* in Site 1 had also the higher density than Site 2. The density of *Aporosa villosa* in two-sites were nearly the same. The differences of tree communities between two sites affect to total of biomass estimation using Eq. 1 and Eq. 2.

Table 2 Comparison on densities of dominant and abundant tree species in the DDF of two sites.

Stem DBH (cm)	Total tree density (tree ha^{-1})										
		<8	**Net**	**8-16**	**Net**	**16-24**	**Net**	**>24**	**Net**	**Total**	**Net**
S. obtusa	Site 1	199	-65	99	-105	16	-6	2	-7	316	-183
	Site 2	264		204		22		9		499	
S. siamensis	Site 1	140	+34	48	-101	12	-40	9	-9	209	-116
	Site 2	106		149		52		18		325	
D. obtusifolius	Site 1	260	+216	266	+222	129	+99	33	+17	688	+513
	Site 2	85		44		30		16		175	
D. tuberculatus	Site 1	42	-60	96	-6	22	0	3	-9	163	-75
	Site 2	102		102		22		12		238	
Pterocarpus macrocarpus	Site 1	8	-52	3	-36	2	-7	1	-2	14	-98
	Site 2	61		39		9		3		112	
Dalbergia assamica and	Site 1	59	-20	27	+6	3	-3	1	0	90	-17
Dalbergia oliveri	Site 2	79		21		6		1		107	
Canarium subulatum	Site 1	32	+4	5	-22	4	-8	-	-2	41	-29
	Site 2	28		27		13		2		70	
Aporosa villosa	Site 1	80	+3	19	-9	2	-1	1	+1	102	-106
	Site 2	77		28		3		0		108	
Gluta usitata	Site 1	141	+119	122	+96	36	+31	8	+7	307	+253
	Site 2	22		26		5		1		54	
Others	Site 1	852	+489	48	-97	7	-19	2	-17	909	+356
	Site 2	363		145		26		19		553	
Total for all species	Site 1	1,813	+628	735	-49	232	+43	59	-22	2,839	+598
	Site 2	1,185		784		189		81		2,241	

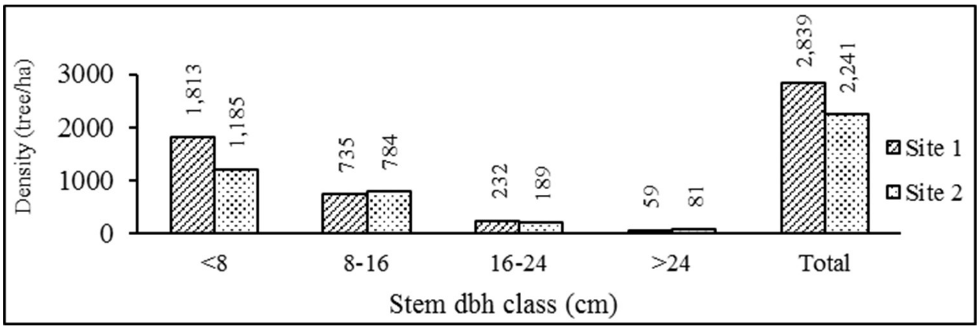


Fig. 3 Comparison on tree densities of different stem DBH classes in Site 1 and Site 2

3.2.2 Tree biomass estimation

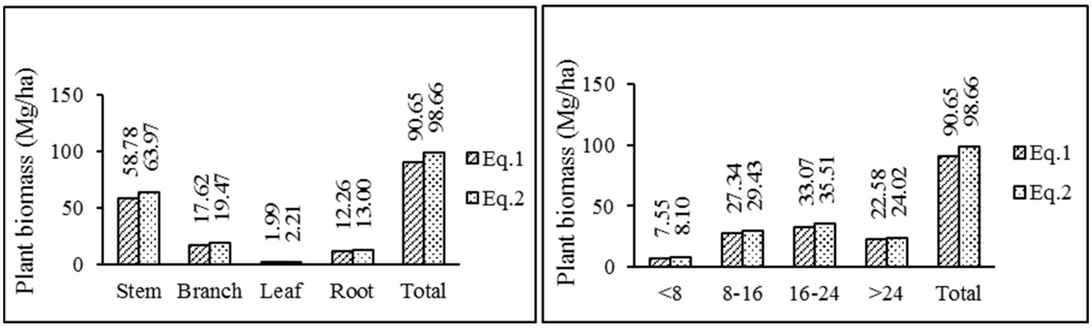
In Fig. 4, biomass amounts of all tree species in the DDF of two sites were estimated using allometric equation of Site 1 (Eq. 1) and Site 2 (Eq. 2).

Site 1: Total tree biomass in the forest of Site 1 calculated by Eq. 1 was 90.65 Mg ha^{-1} divided into stem, branch, leaf and root organs at 58.78, 17.62, 1.99 and 12.26 Mg ha^{-1}, respectively. The biomass amounts in stem DBH classes of <8 cm, 8-16 cm, 16-24 cm and

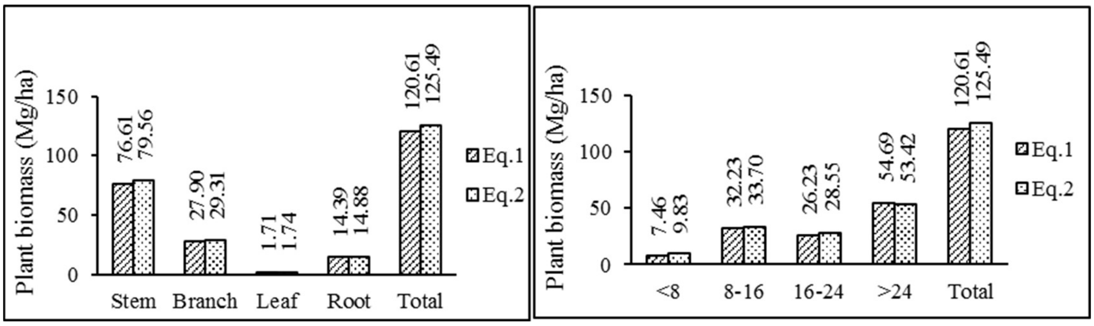
>24 cm were: 7.55, 27.34, 33.07 and 22.58 Mg ha^{-1}. Respectively. As calculation by Eq. 2, the total biomass was increased to 98.66 Mg ha^{-1} separated for these organs to be 58.78, 17.62, 1.99 and 12.26 Mg ha^{-1}, respectively. The biomass amounts in DBH classes of <8 cm, 8-16 cm, 16-24 cm and >24 cm were: 8.10, 29.43, 35.51 and 24.02 Mg ha^{-1} respectively. Therefore, the biomass was overestimation, 8.01 Mg ha^{-1}.

Site 2: The total tree biomass in the DDF of Site 2 calculated by Eq. 1 was 120.61 Mg a^{-1} divided into stem, branch, leaf and root at 76.61, 27.90, 1.71 and 14.39 Mg ha^{-1}, respectively. The biomass amounts in stem DBH classes of <8 cm, 8-16 cm, 16-24 cm and >24 cm were: 7.46, 32.23, 26.23 and 54.69 Mg ha^{-1} respectively. As calculation by Eq. 2, the total biomass was increased to be 125.49 Mg ha^{-1} partitioned into these organs at 79.56, 29.31, 1.74 and 14.88 Mg ha^{-1}, respectively. The amounts in DBH classes of <8 cm, 8-16 cm, 16-24 cm and >24 cm were: 9.83, 33.70, 28.55 and 53.42 Mg ha^{-1} respectively. Thus, the total biomass was underestimation, 4.88 Mg ha^{-1}.

A. Site 1



B. Site 2



Stem DBH class (cm.)

Fig. 4 Comparison on biomass amounts in different tree organs and stem DBH classes in Site 1 and Site 2 calculated by Eq.1 and Eq. 2.

3.4 Carbon storage in tree biomass

Fig. 5 shows the amounts of carbon stored in tree biomass of all tree species in the DDF of two sites calculated using the equations of Site 1 (Eq. 1) and Site 2 (Eq. 2).

Site 1: Total amount of carbon stored in tree biomass of the DDF in Site 1 calculated by Eq. 1 was 44.77 Mg ha^{-1} divided into stem, branch, leaf and root at 29.33, 8.58, 0.96 and 5.90 Mg ha^{-1}, respectively. The carbon amounts in trees having stem DBH classes of <8 cm, 8-16 cm, 16-24 cm and >24 cm were: 3.81, 14.29, 15.80 and 10.87 Mg ha^{-1} respectively. As calculation by Eq. 2, the carbon amount was increased to be 48.73 Mg ha^{-1} separated for these organs as

31.92, 9.48, 1.07 and 6.26 Mg ha^{-1}, respectively. The amounts in trees having DBH class of <8 cm, 8-16 cm, 16-24 cm and >24 cm were 4.21, 14.99, 17.46 and 12.06 Mg ha^{-1}, respectively. The amount of biomass carbon was overestimation, 3.96 Mg ha^{-1}.

Site 2: The total carbon storage in tree biomass in the forest of Site 2 calculated by Eq. 1 was 59.57 Mg ha^{-1} divided into stem, branch, leaf and root at 38.23, 13.59, 0.82 and 6.93 Mg ha^{-1}, respectively. The carbon amounts in stem DBH classes of <8 cm, 8-16 cm, 16-24 cm and >24 cm were: 3.88, 15.62, 14.46 and 25.60 Mg ha^{-1} respectively. As calculation by Eq. 2, the carbon amount was increased to be 61.97 Mg ha^{-1} partitioned into these organs at 39.70, 14.27, 0.84 and 7.16 Mg ha^{-1}, respectively. As for trees having DBH classes of <8 cm, 8-16 cm, 16-24 cm and >24 cm were: 4.05, 16.21, 15.15 and 26.56 Mg ha^{-1} respectively. Therefore, the carbon stored in tree biomass was underestimation, 2.40 Mg ha^{-1}.

A. Site 1

B. Site 2

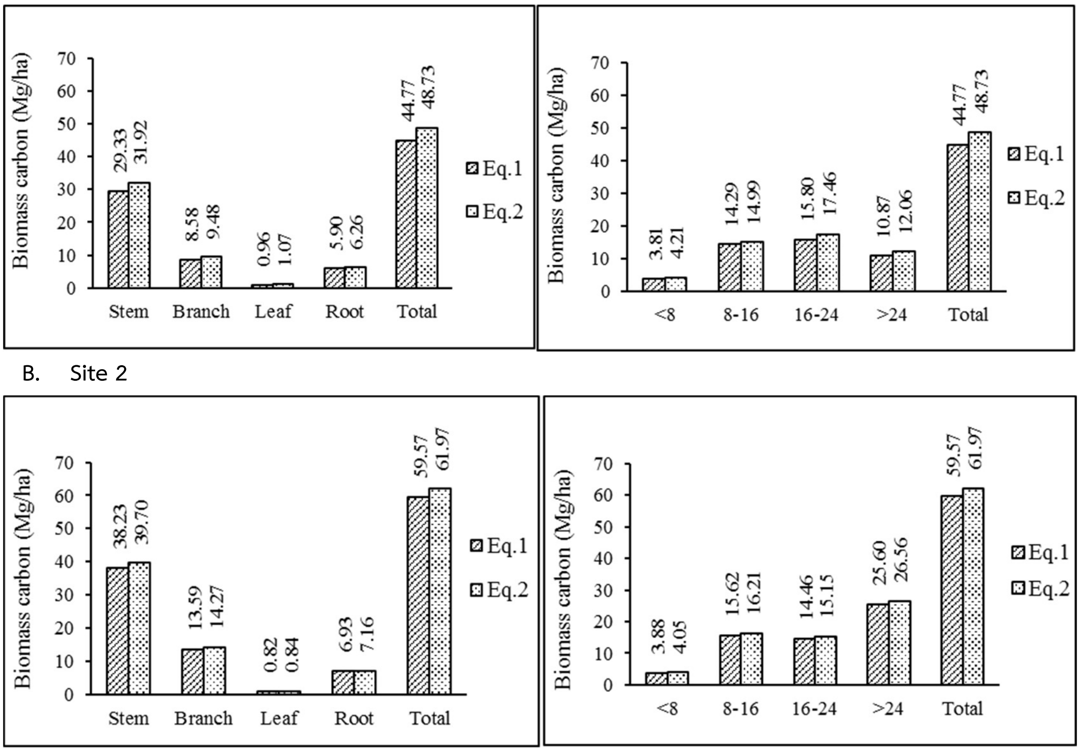


Fig. 5 Comparison on carbon storage in tree biomass in different tree organs and stem DBH classes in Site 1 and Site 2 calculated by Eq.1 and Eq. 2.

DISCUSSION

Tree height-stem diameter relation

Investigation on the biological production and carbon storage of tree community in the forest needs a suitable method. A method of tree community analysis has been used for the study of species composition, richness and diversity in many forests in Thailand (Phongkhamphanh et al., 2015; Khamyong et al, 2014; 2016). The optimal size and adequate number of quadrat or plot are required as the representative data of tree community in the forest. Within a plot, tree census includes stem size at breast height (1.30 m above ground) in term of diameter at breast height (DBH) or girth at breast height (DBH) of tree species and tree height. The stem size can be measured exactly by using a tape, and tree height can be determined from a measuring pole or Haga hypsometer. However, tree height (H) was found to be correlated with stem diameter at breast height (D), and the relation of H to D in forests has proved to follow the H-D hyperbola equation, irrespective of species (Ogawa et al., 1965; Tsutsumi et al., 1983; Yamakura et al., 1986). This finding is important for estimating tree heights in the next census or the further monitoring study. Thus, tree heights can be estimated from the H-D equation of that location. In this study, the H-D equations of nine dominant and abundant tree species in two-sites of the DDF were made. The hyperbolic equations were not applied in the DDF of two sites because most mature and old trees had been cut in the last forest concession and illegal cutting, and they were the secondary forest. The relationship of tree height and stem DBH for these species was assumed to follow the linear equation.

Many factors may affect tree heights. In forest plantations, tree height is influenced by planting spacing and tree density. Tree height in the plantation with high density is usually taller than the lower density stand caused by sun light competition. However, forest plantation of a species with the same age grown on different sites may be affected by physical factors of environment particularly soil characteristics and moisture condition as called site index curves (Oliver and Larson, 1996). In the natural forest, soils under the DDF vary among subtype-communities. *Shorea siamensis* is usually dominant on shallow and young developed soil, Order Entisols. *Shorea obtusa* is dominant on the deeper soil, Inceptisols. *Dipterocarpus obtusifolius* occupied on shallow to deep soils depended upon parent rocks, whereas *Dipterocarpus tuberculatus* normally grows on the deep soil, Ultisols. The Entisols and Inceptisols contain a large amount of fragmented rocks and sandy texture. Different soil characteristics and moisture among locations are an important factor affecting tree growth, either stem size or height growth. Wattanasuksakul et al. (2012) reported that the DDF dominated by *Dipterocarpus tuberculatus* had the deep soil (2 m depth) derived from granitic rock. It had a fine texture and clay accumulation throughout soil depth which could store the higher moisture contents and nutrient storages than those shallow soils of the DDF.

Tree biomass and stored carbon estimation

The DDF on various locations in Thailand usually have different tree species composition, richness and diversity as well as biomass and stored carbon amounts related to subtype forest/communities (Phongkhamphanh et al., 2015; Khamyong et al., 2016). Most of this forest have been disturbed through forest concession in the past and illegal cutting. At the present, it is almost the secondary forest at different conditions. It is become the recovery forest due to protection and conservation as occurrence in the national parks and well-managed community forests whereas degraded forests were found in many areas caused by illegal cutting. The dry weights of stem, branch, leaf and root per tree were most closely correlated with the product of H (tree height) and the square of D (stem DBH), and allometric equations were made from this relation for estimation of standing tree biomass in the forest (Ogino et al. 1967; Tsutsumi et al., 1983; Yamakura et al., 1986). By the fact that tree species can be divided into small, intermediate and big trees, therefore, the H-D equation may be different and vary among species, and the same species grown on different sites. No publications of allometric equations of biomass estimation for each species particularly dominant species are available. In this study, the H-D allometric equations for biomass estimation of the same species were different between the two sites. The stem diameter and height growths of tree species in these sites might be different. These caused different tree heights of the same species having the same stem DBH.

The difference of H-D equations of the same dominant/abundant species between two sites of the DDF resulted in estimation of biomass and stored carbon amounts. The biomass amounts were varied among 12 plots in Site 1, 72.77 Mg ha^{-1} to 105.15 Mg ha^{-1} (90.62±10.91 Mg ha^{-1} on average) with the efficient of variance of 12.04%. Among 15 plots in Site 2, the values varied from 42.54 Mg ha^{-1} to 269.37 Mg ha^{-1} (125.49±53.88 Mg ha^{-1} on average), the coefficient of variance of 42.94%. Average amounts of biomass carbon of the DDF in Site 1 and Site 2 were 44.77±5.39 Mg ha^{-1} and 61.97±26.61 Mg ha^{-1}, respectively. There were greatly different values among plots of both sites caused by different levels of forest concession and illegal cutting in the past. As already described, application of the H-D allometric equations of one site to another resulted in some differences of biomass and stored carbon amounts. The amount of biomass carbon in Site 1 was overestimation at 3.96 Mg ha^{-1}. This value was less than standard deviation (±5.39 Mg ha^{-1}). As for Site 2, the carbon stored in tree biomass was underestimation at 2.40 Mg ha^{-1} while the standard deviation was higher, ± 26.61 Mg ha^{-1}. Therefore, the differences (overestimation and underestimation) of biomass carbon storages in both sites of the DDF calculated by Eq. 1 and Eq. 2 were varied in the range and non-significant.

CONCLUSION

These results can be concluded that H-D allometric equations of the same tree species in the DDF grown on two sites were different for dipterocarps and several dominant tree species, but some species had the same equations. Average amounts of biomass and stored carbon amounts of the same species calculated by allometric equations of the DDF of the two sites (Eq. 1 and Eq. 2) were different caused by the different tree heights, and showed some different results, overestimation or underestimation of the total amounts of biomass and stored carbon for all tree species in the two-site DDF.

The results of this study show that making the equation (H-D allometric equation) is so good and necessary in several area that have to often tree data collection at field, the researchers should make the H-D allometric equation for each site of the DDF before the study, if they need precise results. However, they can use the equation of other sites, and the results may have some differences, but not in statistical significance.

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