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Original Article

Carbon storage of medium-sized tree: a case study on Dillenia collection in Purwodadi Botanic Garden

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Abstract

Dillenia is a medium-sized tree which has high species diversity in tropical regions especially in Southeast Asia. Dillenia in Purwodadi Botanic Garden are collected from native habitats in Java, Kalimantan, Sulawesi and Papua which planted on the area of 17 x 55 m^2. The purpose of this research is to study the above ground carbon storage in Dillenia collection in Purwodadi Botanic Garden. Carbon storage estimation was established by measuring stem carbon stocks from plant collections with plant age ranging between 12-30 years. Twelve years old collection contributed carbon storage of 7.35 tonnes/ha for *D. sumatrana*. Twenty years old species had the lowest carbon storage of 2.17 kg/plant for *D. serrata* and the highest of 51.9 kg/plant for *D. auriculata* with a range of carbon storage of 3.47 to 41.072 tonnes/Ha. Thirty years old plant contributed 39.465 kg/plant and carbon storages of 63.14 tonnes/ha for *D. serrata* and 135.59 kg/plant and 216.94 tonnes/ha for *D. philipinensis*. Overall, Dillenia collections in Purwodadi Botanic Garden contributed 793.94 kg carbon storages, store carbon on average of 30.54 kg/plant and 46.46 tonnes/ha. The increase of carbon storage in the second 10 years was higher than in the first 10 years. It indicated that Dillenia had growth strategy in the early growth then alocated more mass after 10 years. Carbon storage of Dillenia was high and different in age. *D. serrata*, *D. papuana* and *D. auriculata* are recommended species as a priority in planting trees based on carbon sink.

Keywords: Dillenia, carbon storage, medium-sized, tree, Purwodadi

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Introduction

According to Hairiah *et al*. (2011), carbon sequestration is the ability of a system to store carbon from the atmosphere during a certain period. Plants through the process of photosynthesis have a function as an absorber of carbon emissions in the atmosphere and store it in the form of biomass. Generally, there are two kinds of carbon sequestration, which is below ground such as by soil microbes and roots, and above ground plant biomass mainly by tree stems (De Jong dkk., 1995; Cannell, 2003; IPCC, 2006). Climate change mitigation innitiatives recommend the reforestation programs and diversification of plant species for improving the ecosystems quality of degraded areas and for greening urban areas (IPCC, 2006; UNFCCC, 2007). Selection of plant species in agroforestry programs based on carbon sink is important because plants could run various ecological functions and increase plants diversity as well (Diaz, 2009). Native species was proved of running more diverse environmental services compared to non-native species. In addition to its function as a carbon sink, native species are able to maintain the hydrology of an area, restore the food chain and native vegetation by associating with other local species.

Researches on carbon stocks of diverse plant species or groups, both native and non-native species in their natural habitat have been carried out. Siregar and Darmawan (2011) examined the carbon sequestration of Dipterocarpaceae in Central Kalimantan, and argued that the dipterocarp forests can store carbon 928.86 tonnes C/ha or 20.64 tonnes/plant. In the dipterocarp family, the variations of their carbon storages are quite high. This can be caused by different species constituent, genetic factors that influence the allocation of nutrient storages and allocations, plant age and environmental factors (Diaz, 2009). Imiliyana *et al*. (2012) reported that mangrove is capable of storing 232.59 tonnes C/ha while according to Pramudji (2011) Acacia is capable of storing 56.05 tonnes C/ha.

Dillenia is one of medium-sized tree which has high species diversity in the tropics. This plant group has about 60 species distributed from Madagascar to Australia and is one of a vegetation component of tropical forest in low land areas. The leaves are oval to elliptical with prominent leaf midrib. The flowers are large with five petals and many stamens (Lemmens and Wong, 1995). Dillenia is utilized for many economic purposes such as wood products (most of Dillenia species), craft, and medicine such as *Dillenia suffruticosa* for anti-inflamatory (Shah *et al*., 2015), *D. philiphinensis* and *D. indica* for antimicrobial (Ragasa, 2009; Apu *et al.*, 2010). Many previous studies on tree carbon storage did not use the growth size as a diagnostic characters to distinguish carbon stored in plants. Growth size of trees is controlled by gene and it influences common maximum tall and large of tree stem in which carbon stored. A group of trees which have a characteristic as medium-sized tree commonly grow to around 10-40 m tall, while group of large trees can grow up to 50 m tall even hundred m tall (Lemmens and Wong, 1995). The study on carbon storages of local plant species based on its growth size can increase the understanding of biology of trees and reveal the significant contributions of diverse plant species to carbon sequestration in reducing global carbon rising in the atmosphere.

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Heng and Onichandran (2014), reported that *Dillenia suffruticosa* in degraded area in Sarawak, Malaysia has slightly low biomass and carbon storage in the early forest formation (5.2 tonnes/ha). However, the highest proportion of biomass on this species was on the stem, and it increased with tree size and age. Dillenia can be a good recommendation for afforestation for both conservation and tree planting in urban areas, but its carbon storage have not been studied well. Therefore, the aim of this research is to study 1) carbon storage of a medium-sized tree in a case of Dillenia collection in Purwodadi Botanic Garden and 2) the effect of different age on the carbon storage of Dillenia collection in a garden system, especially in Purwodadi Botanic Garden.

Method

Plant Materials

Dillenia collection examined in this study comprised of 10 species. The collections were planted on an area approximately of 17 x 55 m^2. List of plant species studied together with the origin of the collection and distribution of the species are presented in Table 1.

Table 1. Species list, origin of plant collection and plant distribution of Dillenia collection in Purwodadi Botanic Garden.

No.	Plant species	Origin of plant collection	Distribution
1.	*D. serrata* Thunb.	Mollucas, Centre Sulawesi, North Sulawesi, South East Sulawesi	Sulawesi, Muna, Buton
2.	*D. papuana* Martelli	Papua	Papua
3.	*D. auriculata* Martelli	Papua	Papua
4.	*D. ovalifolia* Hoogland	Sulawesi, Morotai, Mollucas	Papua, South East Asia, Sulawesi, Mollucas
5.	*D. ochreata* (Miq.) Teijsm Binn. Ex Martelli	North Sulawesi	North Sulawesi
6.	*D. philippinensis*	Philipines	Endemic to Philipines
7.	*D. suffruticosa* (Griff.) Martelli	Sumatera, West Java	Sumatera, Java, Asia Tenggara
8.	*D. celebica* Hoogland	Centre Sulawesi	North Sulawesi to Centre Sulawesi
9.	*D. sumatrana*	East Kalimantan, South Kalimantan	Malaysia, Indonesia
10.	*D. reticulata* King	Malaysia, Sumatera, Borneo	Malaysia, Sumatra, Borneo, Philipines

(Source : Catalog of plant collection in Purwodadi Botanic Garden-LIPI, 2012; Lemmens and Wong, 1995)

Biomass measurement

Biomass was measured using allometrics method which can be estimated from stem diameter at breast height of adult trees so called DBH and trees height of each Dillenia collection in Purwodadi Botanic Garden-LIPI. Three replications were used in the measurement for each species. Biomass was obtained by calculating using the formula of biomass for plants in dry climates habitat and allometric equation for Dillenia as follows:

(Hairiah *et al*., 2010)

$$\text{Biomass (kg)} = 0{,}122\ (rD^2H)^{0.916}$$

Where r = wood density (Zanne *et al*., 2009)
D = diameter (cm)
H = plant height (m)

Carbon stock values were obtained by multiplying the values of biomass with allometric values for carbon stock i.e. 0.46 (Hairiah *et al.*, 2010). Carbon storage per hectare was converted using the total of area and plant spacing of collection in Purwodadi Botanic Garden i.e. 2.5 x 2.5 m.

Data Analyses

Biomass and carbon stocks of 10 Dillenia species were analyzed using the variance test (ANOVA) at the 95% confidence level to determine the variation of biomass and carbon stocks among species in Dillenia collections. The data analyses were also conducted on the biomass and carbon stocks among species in different age level (12, 20 and 30 years).

Results

Carbon Storage in Dillenia

Table 2 showed the carbon storage of Dillenia collection in Purwodadi Botanic Garden estimated from their DBH and biomass. The statistical analyses are also conducted to show the differences of carbon stocks among Dillenia species. Based on the ANOVA test on a 95% confidence level, DBH of 10 species of Dillenia were significantly different amongs species with a P value of 0.004 ($P < 0.05$). The statistical tests were conducted on the DBH of individuals in various age ranges (12-30 years). The data of biomass and carbon stocks were abnormal based on the normality test on a confidence level of 95%. Therefore, the data only can be read descriptively. The 30 years old *D. philipinensis* have the highest

DBH while the twelve years old *D. sumatrana* has the lowest DBH. The species which are 20 years old have a range of DBH between 18.15 cm for *D. ovalivolia* to 54 cm for *D. papuana*. It showed that in the same age, plant species within genus may have different DBH and carbon storage.

Table 2. The value of DBH, biomass, per plant and per ha carbon stocks of 10 species of Dillenia in Purwodadi Botanic Garden.

No.	Spesies	Age (year)	DBH (cm) *)	Biomass (kg) **)	C/plant**)	Tonnes C/ha**)
1.	*D. serrata*	20	38 [ab]	8.58	39.46	63.15
2.	*D. papuana*	20	54 [ab]	1.13	51.9	83.05
3.	*D. auriculata*	20	44 [ab]	8.13	37.42	59.87
4.	*D. ovalifolia*	20	18.15 [b]	1.11	3.41	8.19
5.	*D. ochreata*	20	23.3 [b]	1.69	7.79	12.47
6.	*D. philipinensis*	30	80 [a]	29.47	135.58	216.94
7.	*D. suffruticosa*	20	45.5 [ab]	3.34	15.37	24.60
8.	*D. celebica*	20	26.23 [b]	1.84	8.47	13.55
9.	*D. sumatrana*	12	21.93 [b]	0.99	4.59	7.35
10.	*D. reticulata*	20	25 [b]	1.67	11.49	18.39

*) Statictical analyses using ANOVA in the confidence level of 95%. Same letters in one column showed no significant difference among species
**) These data are not normal and not random based on the normality and randomity test, thus the variance analysis can not be performed.

D. philipinensis has the highest biomass (29.47 kg) and contribute the total carbon storage of 135.58 kg C/plants or 216.94 tonnes C/ha. Twelve years old *D. sumatrana* has DBH 21.93 cm with 0.99 kg of biomass and carbon stocks of 4.59 kg/plant or 7.35 ton C/ha. This size is quite large compared to other 20 years old species (Fig 1 and Table 2). Figure 3 showed the carbon stored per hectare of Dillenia collection in Purwodadi Botanic Garden. Carbon storage of *D. ovalifolia* is the lowest among other species studied especially compared to other species at the same age (20 years old). At 20 years old, *D. papuana* has the highest carbon storage of 51.9 kg C/plant.

Figure 1. The trees of Dillenia collection in Purwodadi Botanic Garden. a) The 12 years old *D. sumatrana* with height around 3 m tall and DBH 11 cm. b) The 20 years old *D. auriculata* with trees height around 9.1 m tall and DBH 40 cm. c) 30 years old *D. philipinensis* with trees height 8.9 m tall and DBH 80 cm.

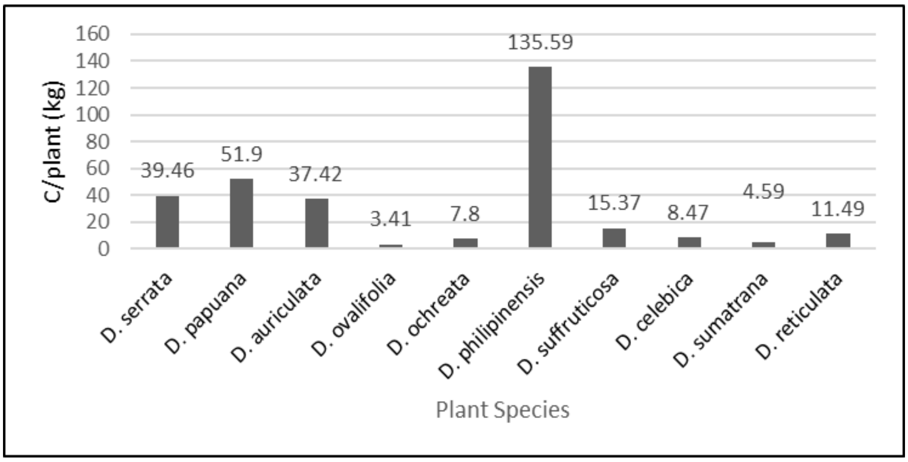

Figure 2. Per plant carbon stocks of 10 Dillenia species collections in Purwodadi Botanic Garden.

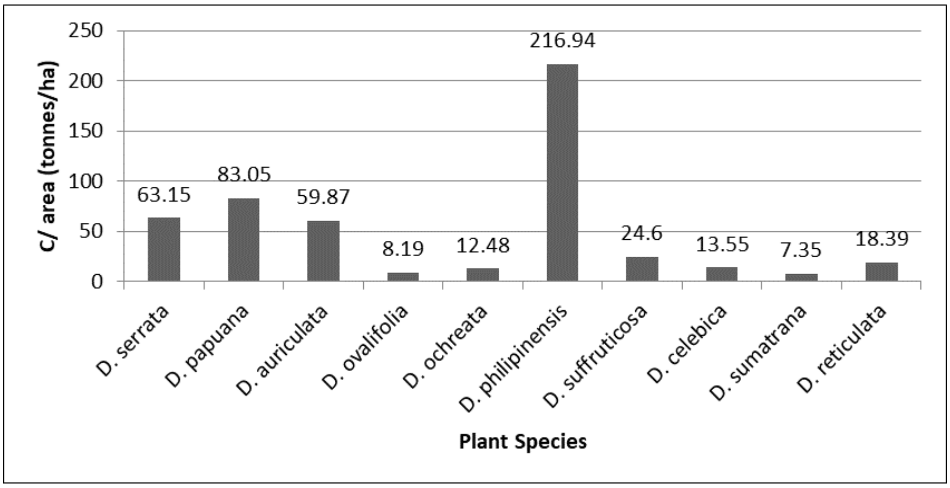

Figure 3. Per Ha carbon stocks of 10 Dillenia species collections in Purwodadi Botanic Garden.

Carbon storage of Dillenia at different age level

Figure 3 showed a comparison of biomass, C/plant and C/ha of Dillenia collections at three different age levels, which are 12, 20 and 30 years. The increase of carbon storages in 20-30 years old was higher than the increase of carbon storages in 10-20 years old.

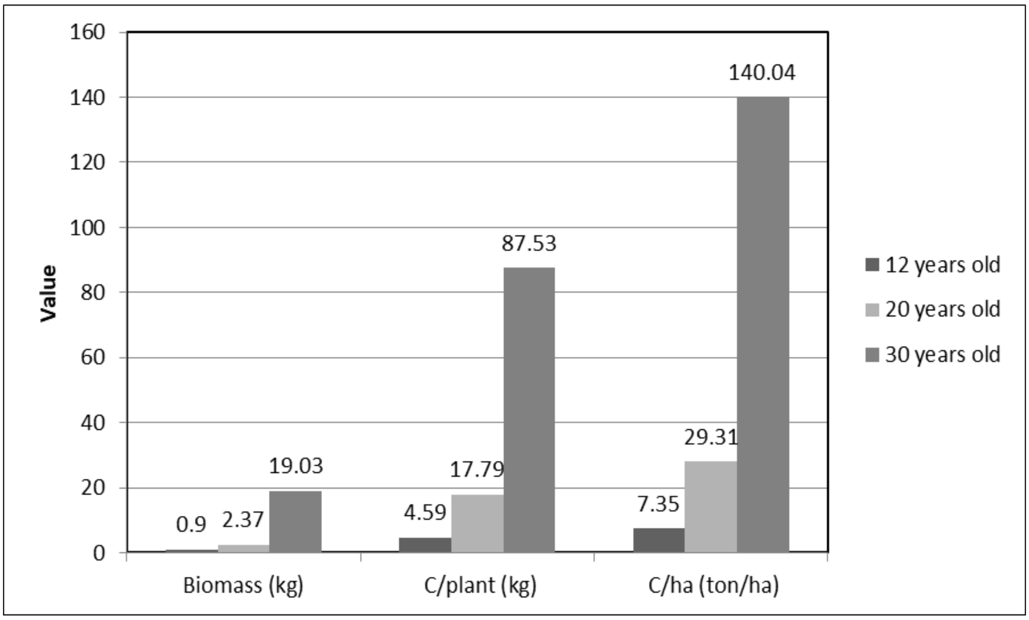

Figure 4. Biomass, per plant and per Ha carbon storage of 10 species of Dillenia in different age, collected in Purwodadi Botanic Garden.

Carbon Storage of Medium-sized tree : Dillenia

Carbon storage of a medium-sized tree, Dillenia collections in the garden was compared to carbon storage of both medium-sized, large-sized tree, herbaceous and clumped trees. Additionally, it is also compared to secondary forest in the early successions (Table 3).

As shown in Table 3, carbon stored per plant of Dillenia is 30.54 kg C, while the carbon stored per hectare reach 46.46 tonnes C/ha. Dipterocarpaceae in Central Kalimantan is capable of storing 928.86 tonnes C/ha or 20.64 tonnes/trees, mangrove is capable of storing 232.59 tonnes C/ha, while Acacia store 56.05 ton C/ha. Compared to carbon storages on the vegetation in natural habitat, carbon storage of Dillenia collection is low. Carbon storage of Dillenia collection is lower rather than established native vegetation such as Dipterocarpaceae, Mangrove and Acacia forests. However, Dillenia collection has more carbon storage compared to that of herbaceaous tree such as cultivated and wild Bananas (Danarto and Hapsari, 2015) and Bamboo (Sujarwo, 2016). Moreover, carbon storage of Dillenia collections in the garden was compared to that of secondary forest in early successions. Nine years secondary forest was assumed to have similar carbon storage as 10 years old Dillenia species. All Dillenia collections contribute more carbon storage than 9.5 years old secondary forest which has higher plant diversity but 10 years old Dillenia collections contribute lower carbon compared to this early stage secondary forest in Malaysia. Carbon storage of all Dillenia collection is lower than those of 17 years old secondary forest.

Table 3. Comparison between per plant and per Ha carbon storage of Dillenia with those of other plant groups and early stage secondary forest.

Plant group/ vegetation	Tree size/ growthform	C/plants (kg)	Tonnes C/ha
Dillenia (this study)	Medium	30.54	46.46
Dillenia sufruticosa (early succession) (Heng and Ochichandran, 2014)	Medium	-	5.2
Dipterocarpaceae (Siregar and Darmawan, 2011)	Large	2064	928.86
Mangrove (Imiliyana *et al*., 2012)	Medium	-	232.59
Acacia (Pramudji, 2011)	Medium	-	56.05
20 years old *Tectona grandis* (Kraenzel *et al*., 2003)	Large	-	120
Cultivated Bananas (Danarto and Hapsari, 2015)	Herbaceous	6.92	0.98
Wild Bananas (Danarto and Hapsari, 2015)	Herbaceous	2.26	-
Bamboo (Sujarwo, 2016)	Clump	-	43.67 mg/Ha
9.5 yr old secondary forest (Ewel *et al*., 1983)	Forest	-	39
17 yr old secondary forest (Kenzo *et al*., 2010)	Forest	-	118.8

(-) No data available

Discussions

Study on the carbon storage of trees in different growth size is important study beside other studies which focused on carbon storages among different growth forms, because plants including trees are genetically ordered by gene to have a small, medium to large size. The information about the carbon storages on different growth size could assist biological information of trees which has the highest carbon storage compared to other carbon reservoir. Dillenia is one of medium-sized tree which commonly compose natural vegetation of lowland to highland tropical forest with relatively wide range distributions in South East Asia. Thus, the carbon storage of this plant group may contribute important roles to ecosystem service.

DBH of Dillenia in this study are significantly different among species, while the data of biomass and carbon stocks can not be explained statistically because the datas were not normal and random and only can be explained descriptively (Fig. 2). The carbon storage of Dillenia species varies amongs species. The 30 years old species has the highest DBH, while the 12-years old species has the lowest DBH. However, the 20-years old species have a wide range of DBH (Table 2 and Figure 4). It showed that plants in similar successional stage and plants among species within genus may have different DBH and carbon storage. The different carbon storage link to the plant productivity, environment factors such as light, nutrients, water and stress tolerance. It also links to the growth properties of species i.e. fast or slow growing which is evolutionary controlled by gene. *D. papuana* is considered to have high carbon storage compared to other Dillenia species. Beside *D. phillipinensis* which has the highest carbon storage among species studied, three species of Dillenia, *D. serrata*, *D. papuana* and *D. auriculata* have a relatively high carbon storages in the level of 20 years, i.e. more than 30 kg C/plant. Therefore, these three species (*D. serrata*, *D. papuana* and *D. auriculata*) are recommended species as a priority in planting and reforestation programs. Based on the carbon storage, it indicated that these three species of Dillenia have fast growing properties, but further research on the growth properties are needed to confirm by studying the growth rate of each species.

The increase carbon stored per plant and per hectare of Dillenia collections in specific age were compared to each others. These results indicated that the increase of carbon storages in the 20-30 years was higher than the increase of carbon storages at 10-20 years. This may be due to in 20-30 years, these plants increase stem diameter and height simultaneously. This is understandable that up to 10 years, plants may have finished its expansion through widening the leaf area to capture the sunlight and absorb CO_2 and elongating the roots to absorb nutrients which developed as a growth strategy of plant species. From these results it can be assumed that, in the first 10 years, Dillenia is pursuing a growth strategy and at the second 10 years, these plant groups maximize the stem growth by allocating more carbons.

Carbon storages of Dillenia collections in an ex-situ conservation garden are also compared to study the differences of the carbon storage amongs different size trees and amongs different planting types such as secondary forest in various succession levels. Compared to other species of Dipterocarpaceae in their natural habitat, carbon storage of 20 years old *D. papuana* is low. This is caused by early age of Dillenia compared to dipterocarp trees in their natural habitat which can reach hundred years old. Moreover, Dillenia is a medium-sized tree that genetically only grows up to 30-40 m tall, while a large trees such as Dipterocarp can grow up reach 100 m tall (Lemmens and Wong, 1995).

For further comparisons, carbon stored in Dillenia is higher than those of carbon stored in Bananas and Bamboo. Trees are known to have greater productivity and mass alocation compared to herbaceous and clumped vegetation. Carbon storage of Dillenia would be better compared within plant species in medium-sized tree groups such as the family of Sapindaceae, Anacardiaceae, Ebenaceae and many others. However, the researches on the storage carbon storage for many groups of tree are still very limited. Dillenia collections contribute lower carbon compared to medium-sized tree which are Acacia and Mangrove in the forest area. It is caused by the different level of succession between an ex-situ garden and forest ecosystem. Forest ecosystem has more climax vegetation than an ex-situ garden such as a botanic garden. The plant age of Acacia and Mangrove plantation in the forest is various and unknown but predictably more than 30 years old, older than Dillenia collection in the garden.

All Dillenia collections in the garden contribute more carbon than 9.5 years old secondary forest which has higher plant diversity but 10 years old Dillenia collections contribute lower carbon compared to the early stage secondary forest. Carbon storage of all Dillenia collection is lower than those of 17 years old secondary forest (Table 3). It indicated that the 17 years old secondary forest tend to have more diverse species composition. Secondary forest is a forest area which has re-grown after a timber harvest, usually are caused by shifting cultivations and agricultures. It has a successional vegetation which rapidly grow in early stage and much slowly in later stage but trees are difficult to introduced into secondary forest (Blay, 2002). Early stage secondary forest (about 10 years old) consist of trees with very low DBH, but its diverse species constituent could contribute higher carbon sink (Ewel *et al*., 1983; Kenzo *et al*., 2010). It indicated that plant diversity is an important aspect should be included in the framework of carbon reduction innitiative and mitigation especially for forest restoration.

On a vegetation scale, the more established an ecosystem because of the age of plant constituent, the higher carbon storages are formed. However, at the same age, the plant species can contribute different carbon storage, because the plant water content usually varies in each weight of photosynthetic products across plant species. Moreover, photosynthetic products allocated as carbon storage in plants differ accross species. It relates to physiological strategies of plant growth which is controlled by gene. Thus the water content is an important component to consider in growth strategy of plant species (Cornelissen *et al*., 2003).

In depth study on species trait is very important to explain many plant roles in ecosystem services. Especially, traits of carbon sequestration are controlled by gene expression in structured communities. Hence, an understanding of ecosystem carbon sequestration requires the understanding of traits and trade-offs across trophic levels, connecting the gene expression in plant to ecosystem processes in space and feedback time (De Deyn *et al*., 2008). Furthermore, to estimate the carbon storages accurately on certain plant groups in an ecosystem, it is necessary to measure the carbon storage pattern in the next age range (30-40 and 40-50 years old), thus the regression pattern of carbon storages at different age level can be studied well. It is necessary to facilitate the estimation of carbon storage of diverse plant groups at different ages and assist the inventory of carbon storage in tropical forests in order to understand the carbon contribution of plant species in different stages of succession (Chave *et al*., 2005; Heng and Onichandran, 2014).

According to Albrecht and Kandji (2003), all vegetation type is potentially become a carbon reservoir if trees, as a main growthform which commonly contribute high carbon can be included into the planting systems. Purwodadi Botanic Garden is a conservation area which could serve as garden model and artificial forest contribute carbon to ecosystem services because trees and other collections are well planted, collected and managed. Furthermore, a botanic garden can be classified as a long-term carbon storage resevoir (over 50 years), because their wood products are not harvested regularly. A garden system with a long-term crop rotation such as Botanic Garden can be a good reservoir absorbent for pollutant, in this case, the high carbon concentration in the atmosphere.

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