BIOMASS AND CARBON STOCK ESTIMATION INVENTORY OF INDONESIAN BANANAS (*Musa* spp.) AND ITS POTENTIAL ROLE FOR LAND REHABILITATION

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ABSTRACT

Bananas (*Musa* spp.) are widely cultivated in Indonesia. They are extensively grown in backyards, home gardens, intercropped with short term crops and also in agroforestry system. The potential of bananas to sequester carbon has been reported but there is limited knowledge on the performance of various cultivars. An inventory of biomass and C-stock estimation on banana accessions has been conducted in *Musa* germplasm plots - Purwodadi Botanic Garden, Pasuruan. Estimation on biomass and C-stock have been conducted for 42 individual banana accessions, comprised 5 wild banana species and 37 cultivars using non-destructive method i.e. allometric equation for banana. The objectives of this study were to conduct inventory on the biomass and C-stock estimation of Indonesian bananas in germplasm collection of Purwodadi Botanic Garden, to make the projections of time average above ground for C-stock of banana farming system in Indonesia and to discuss the potential role of bananas in land rehabilitation. The results showed that estimation value of biomass and C-stock varied from one banana accession to another. Wild *Musa balbisiana* species had higher biomass and C-stock value than wild *Musa acuminata* species. Banana cultivars containing one or two "B" genome (ABB and AAB) were more vigorous and contributed higher biomass and C-stock than AAA and AA cultivars. Among cultivars, the highest C-stock was contributed by Pisang Kepok Bung (average of 6.92 kg C/plant) whereas the lowest C-stock was contributed by Pisang Rayap (average of 0.67 kg C/plant). In average, various Indonesian bananas studied contributed around 2.26 kg C/plant or 0.98 tonnes C/ha. The growing area of bananas increased from 73,539 ha in 2000 to 101,822 ha in 2010, which was decreased to 100,600 ha in 2014, contributing C-stock around 72.28 tonnes C in 2000 increasing to 100.07 tonnes C in 2010 with a decrease to 98.97 tonnes C in 2014. These numbers are still limited only to the recorded areas. Banana plants in combination with woody tree crops, are potential as important component of agroforestry, home gardens and mixed farming systems to rehabilitate and reforest landscape, to decrease carbon emission in atmosphere in the form of biomass and C-stocks and to meet the economic needs for local surrounding community.

Keywords: banana, biomass, carbon stock (C-stock), estimation, *Musa acuminata*, *Musa balbisiana*, Purwodadi Botanic Garden, rehabilitation

INTRODUCTION

Climate change is an environmental issue that has always been discussed. Climate change is caused by energy absorbed from sun as short wave then reflected in atmosphere as infrared long wave radiation. Greenhouse gases effect absorbs infrared radiation which is retained in atmosphere as heat energy causing the increase of the earth's temperature, therefore, efforts to mitigate greenhouse gases are needed (Saharjo & Wardhana 2011). In 2003, World Bank stated that the earth's CO_2 concentration was about 27 billion metric ton, which was a 19% increase from the year 1990. IPCC (2014) noted that the earth's temperature from 1880 to 2012 showed an increase from 0.65 °C to 1.06 °C. A study by Ollivier *et al.* (2014) reported that countries contributing a large amount of CO_2 in atmosphere were China (29%), USA (15%), European Union (11%), India (4.4%), Brazil (6.2%) and Indonesia (2.3%). The peat and forests fires in Indonesia were estimated responsible for the released of CO_2 emission to the atmosphere about 0.81 Gt C to 2.57 Gt C in 1997 (Page *et al.* 2002). Particular in Borneo

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Island, the annual average carbon emission from forest fires was estimated about 0.02 to 0.06 Gt C per year (Kuntoro *et al*. 2015).

Process of decreasing CO_2 amount in the atmosphere through the process of plant photosynthesis is called carbon sequestration. In the photosynthetic process, CO_2 in the atmosphere is absorbed by plant, transformed to carbohydrates compound and dispersed to all parts of plant. Carbon sequestration describes long-term storage of CO_2 or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change. It has been proposed as a way to slow the atmospheric greenhouse gases, which are released by burning fossil fuels (Hairiah & Rahayu 2007). Therefore, it is important to conduct study to examine the ability of different plant species to absorb carbon, especially in the climate change mitigation efforts.

Agroforestry system is a cultivation practice combining trees and annual crop or other farm activities adopted by smallholders to meet their needs for food, medicine, timber, fuel, fodder and market commodities. It also provides valuable environmental services such as soil fertility replenishment, water catchment protection, carbon sequestration, biodiversity conservation and landscape restoration (Garrity 2004). Bananas (*Musa* spp.) are extensively grown in backyards, home gardens, agroforestry system and are intercropped with short term crops. Bananas are the most favorite plants grown in agroforestry system intercropped with other important tree crops commodities (coffee, cacao, rubber), fruit trees and timber. About 9.5% of bananas species occur in home gardens system contributing to the ecosystem services. Only a handful of individual smallholder agroforestry systems store small amount of carbon per area, while the basic systems store as much carbon as several secondary forests (Roshetko *et al*. 2002).

The potential of bananas to sequester carbon has been reported by Daphine (2014) on East African Highland bananas, but there is limited knowledge on the performance of various cultivars in Indonesia. Being part of the primary center of origin and diversity so that has large number of bananas (Musaceae) both wild seeded species and edible seedless or cultivar with many local names and synonimies (Espino *et al.* 1992; Valmayor *et al*. 2000). There is no less than 200 local cultivars cultivated and developed across Indonesia archipelago (Nasution & Yamada 2001). The objectives of this study were to conduct inventory on the biomass and C-stock estimation of Indonesian bananas in germplasm collection of Purwodadi Botanic Garden, to make the projections of time average above ground for C-stock of banana farming system in Indonesia and to discuss the potential role of bananas in land rehabilitation.

MATERIALS AND METHODS

Study Site

The study was conducted at banana collection plots of Purwodadi Botanic Garden – Indonesian Institute of Sciences from April to May 2012. Purwodadi Botanic Garden has a collection of *Musa* germplasm both wild species and cultivated varieties through exploration, plant exchange, grants and community or personal contribution from several regions all over Indonesia, mostly from Eastern Indonesia. Current collections in 2014 is about 134 accessions comprised 7 wild species and 127 cultivated varieties.

Materials

The materials studied were 42 selected banana accessions of Purwodadi Botanic Garden collections comprised 5 wild species and 37 cultivars. The diameter at breast height (DBH) of the individual pseudostem was measured at mature age (already flowering) using tape meter with minimum of two replications per accession. As reported by Daphine (2014) that C-stock of banana plants was significantly influenced by growth stages in which maturity stage was the optimal stage to be measured (Daphine 2014).

Biomass and C-Stock Estimation

Biomass was estimated using non-destructive method i.e. allometric equation for banana (Kurniawan *et al*. 2010) and then C-stock was estimated by crossing its biomass to average value of C-stock in plants which is 0.46 (Hairiah *et al.* 2010). The development of allometric equations has been investigated based on specific condition, species and or plant communities (Ketterings *et al.* 2001; Wibowo *et al.* 2010):

$Y = 0.0303 \times D^{2.1345}$
$Z = Y \times 0.46$

where:
Y = Plant biomass (kg)
D = Diameter at breast high (cm)
Z = C-stock (kg C/plant).

RESULTS AND DISCUSSION

Biomass in plants was affected by interaction of genetic and environmental factor. In this study, the Purwodadi Botanic Garden provides homogenous environmental condition, i.e. soil type, water supplies and culture practices. Therefore, the biomass results were mostly affected by its genetic factor. The results showed that the estimation value of biomass and C-stock tended to vary from one banana accession to another. Pseudostem DBH was confirmed as the best predictor for biomass estimation in banana plants and it is recommended to be used in most carbon related studies. The more vigorous banana plants contribute higher estimation value of biomass and C-stock (Fig. 1).

C-stock level is related to plant photosynthesis process. Based on its photosynthesis pathway, banana plants are classified as C3 plant. In C3 plants, CO_2 and water from the environment are enzymatically combined with a five-carbon acceptor molecule to contribute two molecules of a three-carbon intermediate. C3 plants respond favorably to higher concentrations of carbon dioxide than C4 and CAM. C4 plants include corn, sugar cane and many other tropical grasses, whereas CAM plants include orchids, bromeliad and succulent plants (Taiz & Zeiger 2002).

Biomass and C-stock Inventory Results in Wild Banana Species

Wild bananas are pioneer plants and can grow in various conditions. It commonly grows wild in the forests, road sides and river banks. Wild *Musa balbisiana* species is also being cultivated by farmers to get the leaves for various wrapping purposes. The immature fruits are also edible for any traditional side dishes. Wild *Musa acuminata* is rarely cultivated. There are also some other species of bananas (not studied here) such as *Musa velutina*, *Musa ornata*, *Musa borneensis* etc. that are commonly cultivated for ornamentals due to its beautiful performances (Nasution & Yamada 2001; Hapsari *et al.* 2015a).

Among the wild species studied, *Musa balbisiana* species contributes much higher level of biomass and C-stock estimation than *Musa acuminata* species (Table 1). *Musa balbisiana* is considered to be more vigorous and robust, as well as drought and disease resistant, while *Musa acuminata* species is slender but has more attractive morphology (Daniells *et al.* 2001; Nasution & Yamada 2001). *Musa balbisiana* species (Pisang

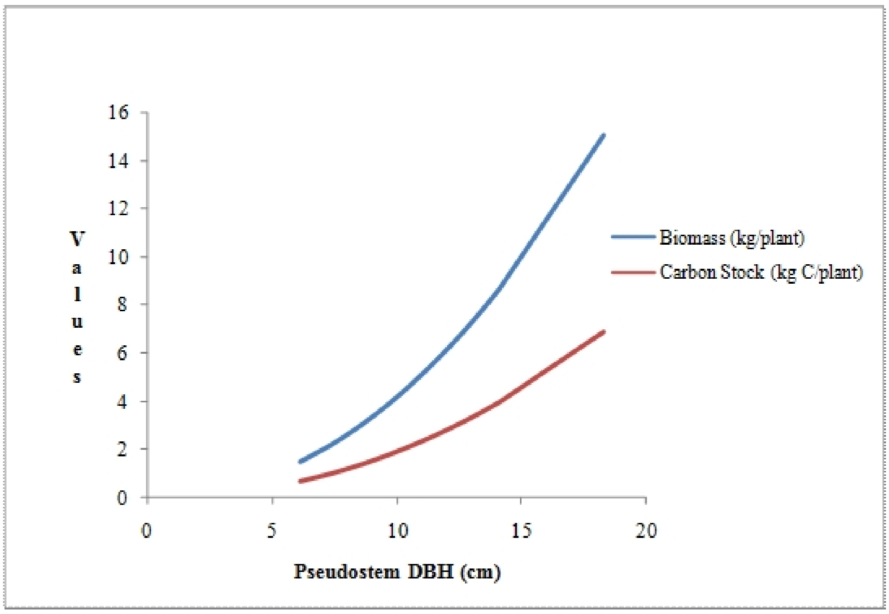

Figure 1 Positive correlation of pseudostem DBH to biomass and C-stock values in banana plants

Table 1 Pseudostem DBH, biomass and carbon stock estimation of wild banana species

Species	Local name	Pseudostem DBH (cm)	Biomass (kg/plant)	C-stock (kg C/plant)
Musa balbisiana	Klutuk Wulung	21.47	21.09	9.70
Musa balbisiana	Klutuk Ijo	15.35	10.30	4.74
Musa acuminata var. *alasensis*	Pisang Hutan	6.78	1.80	0.83
Musa acuminata var. *rutilifes*	Pisang Cici Hutan	4.99	0.94	0.43
Musa acuminata var. *tomentosa*	Unti Darek	7.07	1.97	0.91

Klutuk Wulung) has large pseudostem diameter (21.47 cm) contributing around 21.09 kg/plant biomass and around 9.7 kg/plant C-stock. *M. acuminata* var. *rutilifes* with slender pseudostem (4.99 cm) contributed around 0.94 kg/plant biomass and around 0.43 kg C/plant C-stock (Table 1).

Biomass and C-stock Inventory Results in Various Banana Cultivars

Edible banana cultivars have lower biomass and C-stock values than wild bananas. The genetic composition of *Musa balbisiana* is the combination of wild *Musa acuminata* (donor A genome) and *Musa balbisiana* (donor B genome). Genomic composition can be identified using morphology (Jumari & Pudjoarinto 2000) and genetic (Hapsari *et al.* 2015b). Banana cultivars containing one or two "B" genome (ABB and AAB cultivars) are more vigorous and contribute higher biomass and C-stock than the AAA and AA cultivars.

Pisang Kepok Bung (ABB) is the most vigorous cultivar with pseudostem diameter of 18.32 cm contributing around 15.04 kg/plant biomass and around 6.92 kg C/plant C-stock. Pisang Rayap (AA) is the most slender cultivar with pseudostem diameter of 6.14 cm contributing around 1.46 kg/plant biomass and around 0.67 kg C/plant C-stock. Pisang Triolin having AAB genome contributed biomass and C-stock values in between Pisang Kepok Bung (ABB) and Pisang Rayap (AA) (Fig. 2). The average value of C-stock contributed by banana plants per genome group from the highest to the lowest values are as follows: BB wild (7.22 kg C/plant), ABB cultivars (2.74 kg C/plant), AAB cultivars (2.11 kg C/plant), AAA cultivars (1.73 kg C/plant), AA cultivars (1.55 kg C/plant) and AA wild (0.72 kg C/plant).

In traditional home gardens and in agroforestry, farmers plant various local cultivars. However, the commercial scale farmers plant bananas cultivars based on consumers' preference and agroclimate condition in an area. Pisang Kepok (ABB) is the most favorite cultivar to be cooked, while Pisang Raja (AAB), Pisang Ambon (AAA) and Pisang Mas (AA) are often processed for dessert. Wild species and cultivars studied contributed an average of 2.26 kg C/plant C-stock.

Time Average C-Stock in Banana Farming System in Indonesia

Banana farming system recognizes 3 different planting distances based on its canopy sizes, i.e. 6 x 6 m for wide canopy, 5 x 5 m for medium canopy and 4 x 4 m for small canopy (Cahyono 1996). Banana plants may contribute an average of 0.98 C tonnes/ha C-stock. This number is quite high if compared to C-stock contributed by understory of agroforestry system which only contributed 0.2-0.3 C tonnes/ha. However, agroforestry of coffea plants contributed higher C-stock than banana plants, i.e. 2.0-12.0 C tonnes/ha (FORDA 2010).

The growing area of bananas increased from 73,539 ha in 2000 to 101,822 ha in 2010, which was decreased to 100,600 ha in 2014 (Ministry of Agriculture 2015), contributing C-stock around 72.28 tonnes C in 2000 increasing to 100.07 tonnes C in 2010 with a decrease to 98.97 tonnes C in 2014. These numbers are still limited only to the recorded areas.

Potential Role of Banana Plants for Land Rehabilitation

Tropical forests in Southeast Asia are constantly changing as a result of logging and land conversion such as logging activities, complete deforestation, conversion from forest to grassland or annual crops, tree plantations and other woody perennial crops (Lasco 2002; Monde 2009). Those vast area of degraded land are in need of rehabilitation. Agroforestry system may become an approach to prevent deforestation by

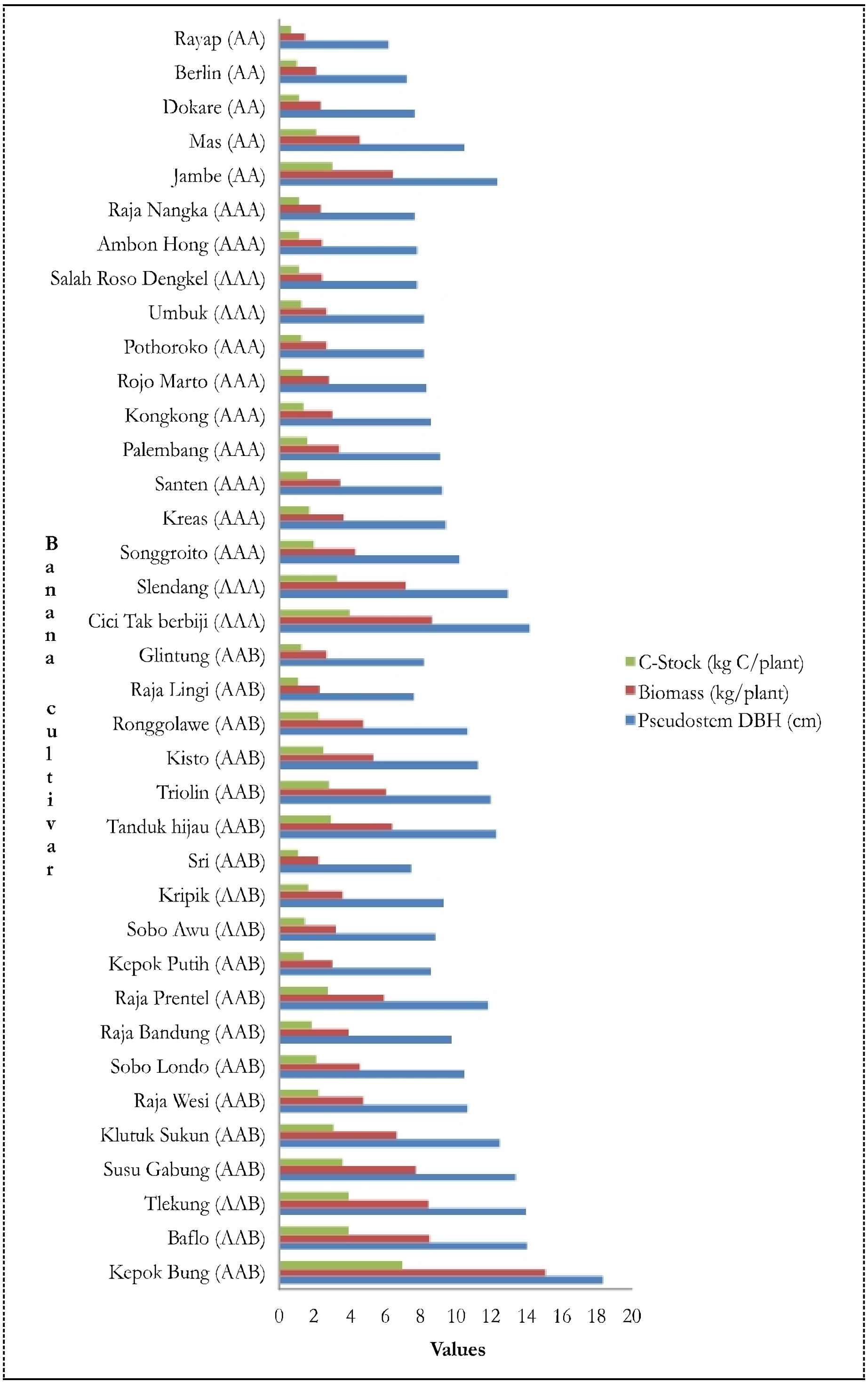

Figure 2 Pseudostem DBH, biomass and C-stock estimation of various Indonesian banana cultivars

providing on-farm trees sources. Agroforestry system provides better carbon storage than the usual annual crops farming system because agro-forestry system intercropped trees with annual crops, continuously giving much higher biomass and litters in varied quality (Utami *et al.* 2003).

Home garden as smaller level of agroforestry is species rich and tree-based system producing wood and non-wood products and therefore, producing high biomass. Due to high biomass produced, this system potentially offers carbon storage. In terms of aboveground biomass, home garden contains more carbon per hectare than *Imperata* grasslands, cassava fields and young rubber agroforestry (Roshetko *et al.* 2002).

Table 2 Time average C-Stock in Indonesia banana farming systems in 2000-2014

Planting distance	Number of plants/ha	C-Stock (C kg/ha)	Time average C-stock contribution		
			Year 2000 (C tonnes)	Year 2010 (C tonnes)	Year 2014 (C tonnes)
Wide canopy 6 x 6 m	278	628.67	46.23	64.01	63.24
Medium canopy 5 x 5 m	400	905.29	66.57	92.18	91.07
Narrow canopy 4 x 4 m	625	1,414.52	104.02	144.03	142.30
Average	434	982.83	72.28	100.07	98.87

Banana as a component of mixed agroforestry system has moderate C-stock contribution. This study showed that one hectare of banana plants store more carbon (0.98 tonnes) than cassava (0.5 tonnes) and *Imperata* grassland (0.7 tonnes) (Hairiah 1997).

Banana plants store much less carbon than perennial woody plants or trees, however, banana has high economic value and provide shades to tree crops commodities (coffee, cacao, rubber), fruit and timber (Roshetko *et al*. 2002). Also, banana plants produce fruit all year round which continuously contribute food to smallholder farmers in the area (Hapsari 2011).

The role of agroforestry in absorbing CO_2 as well as in storing and maintaining carbon stocks is lower than that of natural forests, but this system can increase carbon stocks on degraded lands (Widianto *et al*. 2003).

CONCLUSIONS

Banana accessions contributed varied estimated value of biomass and C-stock per accessions depending on their characteristics performance. Pseudostem DBH was confirmed as the best predictor for biomass estimation in banana plants and it is recommended to be used in most carbon related studies. The more vigorous banana plants contribute higher estimation value of biomass and C-stock. The C-stock value ranged from 0.67 kg C/plant to 6.92 kg C/plant. In average, various Indonesian bananas studied contributed around 2.26 kg C/plant or 0.98 tonnes C/ha. The growing area of bananas increased from 73,539 ha in 2000 to 101,822 ha in 2010, which was decreased to 100,600 ha in 2014, contributing C-stock around 72.28 tonnes C in 2000 increasing to 100.07 tonnes C in 2010 and decreasing to 98.97 tonnes C in 2014. Agroforestry is species rich and tree-based system producing wood and non-wood products and therefore, producing high biomass. Due to high biomass produced, this system potentially offers carbon storage. Banana plants in combination with woody tree crops, are potential as important component of agroforestry, home gardens and mixed farming systems to rehabilitate and reforest landscape, to decrease carbon emission in atmosphere in the form of biomass and C-stocks and to meet the economic needs for local surrounding community.

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