INTRODUCTION

Cultivating plantation crops like Pinang (Areca catechu), Coffee, Pepper, Cardamom and Cocoa have many elements of ecosystem services of trees such as shade, support, wind break, soil and water regulation such as hydrological services and carbon sequestration in the form of mitigating the global climate change impacts. In global scale, (Zomer et al., 2016) reported that C storage with tree cover at agricultural land is estimated to be 45.3 PgC, whereas at the period of 2000 to 2010 the increasing tree biomass are recorded at 3.7 %, resulting the raising of biomass carbon from 20.4 to 21.4 t C ha⁻¹. Therefore, plantation cropping system is a potential land use system to explore carbon sequestration and biodiversity conservation. The cultivation of Areca-nut is mainly confined to Southeast Asia with India as the maximum area of cultivation (Sujatha & Bhat, 2013).

Devakumar, Babu, Eashwar Reddy, & Anand (2012) conducted a study in Kodagu district where carbon content in the shade trees of cardamom plantation was 162.33 t ha⁻¹ which was the highest, followed by Areca nut (127.3 t ha⁻¹). In comparison to Coffee plantation, it varied from 92.41 to 138.83 t C ha⁻¹ with a mean of 119.4 t C ha⁻¹ the C sequestration is lower than Areca nut. The total of carbon stock of the country in Coffee, Cardamom and Areca nut plantations is 59.42; 14.22 and 37.49 Mg C respectively. Report on Areca nut production from several parts of India have been published by Sujatha & Bhat (2013).

Pinang (Areca catechu L.) is a major agroforestry crops in Papua with high economic value. This study developed allometric equations for estimating Pinang biomass on the basis of stem diameter and height by destructive sampling inagroforestry systems. Aboveground biomass was measured and linked to plant stem diameter at various heights (0.13 and 130 cm above the ground) and plant height. The resultant equation was used for biomass estimates in various agroforestry systems with Pinang trees, with total of 18 plots differentiated in bottom, middle and upper slope positions. As expected for palm trees, plant height is a better predictor (Y = 0.816 H¹.42; R² = 0.89) of biomass than stem diameter, with equal results for diameter measurements at 13 or 130 cm height (Y = 0.0689 D².59; R² = 0.74). Best results were for an equation combining diameter and plant height: Y = 0.03883*H*D¹.2; R² = 0.96. Agroforestry systems on the upper slopes had the highest carbon stocks (38.8 Mg ha⁻¹) than the middle and lower slopes (25.9 and 22.5 Mg ha⁻¹, respectively). Aboveground carbon stocks of Pinang in study area ranged from 0.96 to 20.9 kg C tree⁻¹ with an average of 10.1 kg C tree⁻¹.
improve soil fertility, and contribute to carbon stocks (C). Carbon sequestration in agroforestry systems was reviewed by Kumar (2006), oil palm; Kiyono et al. (2015), various forest species (Calvo-Alvarado, McDowell, & Waring, 2008; Cole & Ewel, 2006).

The spatial extent of agroforestry systems in Indonesia is not accurately known, as it is not a legend unit on standard forest and land use maps, provided an estimate of 5 million hectare, including 2 million hectare as a jungle rubber agroforestry system (Penot, Chambon, & Wibawa, 2017). As comparison, in Kerala (India), Pinang is commonly grown in agroforestry systems together with coconut (Cocos nucifera) and other crops (Kumar, 2006). Pinang tree is also a common component of agroforestry systems with coconut tree (Cocos nucifera) and Liberica coffee in Tanjung Jabung Barat (Jambi), as described in Mulla, Widayati, Suyanto, Agung, & Zulkarnain (2014), with C stocks of 32 t C ha⁻¹. This value is slightly lower than the time-averaged aboveground C stock of oil palm plantations in Indonesia (40 t C ha⁻¹) (Dewi, Khasanah, Rahayu, Ekadina, & van Noordwijk, 2009; Khasanah, van Noordwijk, & Ningsih, 2015). Coffee-based agroforestry systems in Indonesia may store around 41 t C ha⁻¹ (Hairiah & Rahayu, 2007), while in jungle rubber agroforests the values may reach 100 t C ha⁻¹ (Rahayu, Khasanah, & Asmawan, 2011). In Papua, Arecanut is commonly found in mixed agroforests along with other fruit trees species like mango, durian, rambutan or endemic plants such as matoa. To facilitate measurements of agroforestry systems containing Arecanut based system, specific allometric equations are needed, as palms do not expand their stem diameter during growth and no relation between stem diameter and aboveground biomass may be expected.

Allometric equation for palm tree species have been developed specifically for Attalea cohune, Sabal sp., Attalea phalearata, Euterpe precatoria, and Phanekos permumquinensis, (Brown, Delaney, & Shoch, 2001; Delaney, Brown, & Powell, 1999). Khasanah, van Noordwijk, & Ningsih (2015) provided allometric equations for oil palm based on stem height, number of leaves and unit leaf weight, but modifications may be needed for Arecanut. Thus, the research had two questions: 1) which allometric equations using stem diameter and palm height can characterize Arecanut and, 2) how much C is stored in Pinang in the existing mixed agroforestry systems in Papua province?. Rate of C-accumulation commonly conducted in tropical rain forests in America, Africa and South-east Asia (Baker et al., 2004; Chave et al., 2005; Lewis et al., 2004; Lewis et al., 2009; Návar, 2009). However, such studies are scanty from tropical rain forests of the major specific crop in Papua province such as a limited Arecanut smallholder agroforestry system.

MATERIALS AND METHODS

The research was conducted in several agroforestry system belonging to farmers in the village of Wambena (2º24’47.14” S and 140º24’29.56”E), Depapre District, Jayapura Regency, Papua Province from September 2014 to September 2015. The study area is on the NE slope of the Cyclops mountain range and had slopes from 10% - 45%, at 100 to 200 m above sea level. The map of the location is presented in Fig. 1. This study was separated two stages: (a) Development of allometric equations based on results of destructive sampling, (b) Application of these equations for Pinang in selected agroforestry plots.

A direct measurement of aboveground biomass of pinang was made by cutting the palms on the soil surface. The full range of plant age, tree stem diameter (DBH) and plant height accessible was used for samples of the existing variation. A total of 9 palms were measured, as summarized schematically in Fig. 2. Three palms each were measured in classes with stem diameter (DBH) of < 6 cm, 6-9 cm, 9-11 cm and > 11 cm. Measurements included total plant height (Ht), stem length below the leaf canopy (Hbc), stem diameter at a height of 0 m from ground level (D0), stem diameter at a height of 1.3 m (D1.3), middle trunk diameter (Dt), stem diameter directly below the leaf canopy (DBC), stem/trunk fresh and dry weight (WBT), and leaf dry weight (Wd). Existing fruits and flowers is taken into account. Total aboveground biomass (AGB) was derived as WBT + Wd.

Fresh weights were measured directly in the field using a balance (50-100 kg scale), while the height/length of the plants was measured by using a roll-meter (50-100 m scale). Samples of leaves and stem (about 500 g for each plant tissue) were brought to the World Agroforestry Centre (ICRAF), Bogor office and dried in an oven at a temperature of 80 °C until a constant dry weight was achieved.

A number of equations were compared using the various height and diameter measurements, to find the best way to represent the measured
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biomass. Allometric equation results obtained from the field destructive measurements are compared to equations for other palm trees species (Brown, 1997; Frangi & Lugo, 1985)

Fig. 1. Map of the study site in Wambena village-Papua Province

Fig. 2. Areca nut parameterization for developing allometric equation

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Areca nut based agroforestry systems were sampled around Wambena village. Three plots were selected in which Areca nut dominated, and had 70-80% of the total stem population. Each plot was separated into three sections, at the bottom, middle and upper slope position, respectively, with two replicates of each. Soil at the bottom of the slope is expected to have a higher level of soil fertility (colluvial soil formation and deposition of sediment eroded uphill) and farmers have more opportunities for managing Pinang here due to easier access. Sampling followed the standard rapid carbon stock appraisal (RACSA) protocol (Hairiah et al., 2010) with some modifications. Plot size was reduced to 10 m x 10 m. The carbon concentration of dry weight was estimated to be 46%.

Remarks: The activity of developing allometric equations for Pinang involved the following steps:

A. Selecting plot location which then separated based on their positions: upper slope, middle slope, lower slope before grading into different stem diameter
B. Cutting Pinang stem on soil surface from selected representative plot
C. Taking out Pinang tree from the plot to a suitable location for destructive measurement
D. Measuring Pinang parameters (Ht, HBc, Dbc, Dt, D1.3, D0)
E. Separating leaves, branches, fruits, flowers from the tree stem and weighting using scale
F. Cutting tree stem and weighing using scale

Fig. 3. Activities for developing allometric equation for Pinang based Agroforestry system in Wambena
RESULTS AND DISCUSSION

Both DBH and plant height were closely to aboveground plant dry weight (biomass) (Fig. 4). The measurements of plant height (H) accounted for a larger share of the variation in biomass ($R^2 = 0.89$) than those using only DBH/D1.3 data ($R^2 = 0.74$). The best equation based on a single tree measurement is the total dry weight or TDW (AGB) = 0.8164 $H^{1.4202}$ ($R^2 = 0.89$). However, if the data about plant height is not available, acceptable biomass estimates can still be obtained from the equation of TDW (AGB) = 0.0689 $D^{2.5977}$ ($R^2 = 0.74$). Where both palm height and DBH data are available, a combine equation can be used: AGB = 0.03883 * $H * D^{1.2}$ ($R^2 = 0.96$). The trend of all equation follows the power patterns.

As indicated in the result that height is the major variable to consider in palm biomass equation, in which total height occasionally a better predictor than stem height (Goodman et al., 2013), but measurement of total height only without considering tree diameter is also resulting overestimating on total biomass. Estimating biomass of Areca nut as one of typical palm species using component of Diameter (D) and stem Height (H) was necessary for developing single species model even the relationship D-H are different across tree species. The scatter plot (Fig. 4) shows a non-linear trend for D as independent variable, trend for H is also detected using similar approaches. Using the simple D as independent variable in the allometric equations, the cubic showed the best fit ($R^2=0.997$) for estimating biomass of Dalbergia sisso Robx plantation in Bangladesh, higher than power or linear even the exponential trend (Khan & Faruque, 2010). In term of simplicity, for estimation biomass of Abies nephrolepis (Maxim) linear approaches of In (D) were used (Wang et al., 2011). Currently, height has been used to determine aboveground biomass in oil palm plantation (Corley & Tinker, 2003; Dewi, Khasanah, Rahayu, Ekadinata, & van Noordwijk, 2009), but for tropical forest the use of D is more preferable (Basuki, van Laake, Skidmore, & Hussin, 2009; Kenzo et al., 2009; Maulana, Wibisono, & Utomo, 2016).

In this study, the multiplication of tree height (H) and diameter (D) in the allometric equation gave the highest correlation to tree biomass of Arecanut (R = 0.96). This suggests that biologically tree diameter and height changed proportionally with the changes of tree size (Khan, Suwa, & Hagihara, 2005). Thus, the H is incorporated in the allometric equation for Areca nut cannot be neglected to obtain more precise result of biomass measurement. Comparison of our results with three existing allometric equations for palms in Table 1 and Fig. 5 show that the generic equation by Brown (1997) will lead to an overestimate by 50 %, while the equations of Delaney, Brown, & Powell (1999) and Frangi & Lugo (1985) suggest 4 and 4.5 times the biomass measured, respectively. Those above equation were tested to examine the accuracy of filed (destructive measurement). Both Brown (1997) and Frangi & Lugo (1985) used palm tree species whilst Brown, Delaney, & Shoch (2001) and Delaney, Brown, & Powell (1999) used Euterpe precatoria and Phenakospermum guianensis, respectively for developing their models, none of them using Areca cathecu species.

Remarks: DBH = Diameter of Pinang at breast height (1.3 m) (D1.3); TDW = Total Dry weight of Pinang tree

Fig. 4. The allometric equation for estimating Pinang tree (Areca catechuL.) biomass by using: (A) dbh, and (B) tree height
The result of aboveground measurement seem to be lower than those of four existing equation for palm species, thus the development of specific Pinang tree species is important, reducing overestimation of C-sequestration at the bigger scale. Recently, local allometric equation to estimate total aboveground biomass in Papua tropical forest has been also developed (Maulana, Wibisono, & Utomo, 2016), but not explained whether applicable for Areca nut biomass estimation, resulting an equation as follow: \( \log(\text{TAGB}) = 0.267 + 2.23 \log(\text{DBH}) + 0.649 \). As comparison for developing equation for palm species of *Astrocaryum mexicanum*, Da Silva et al. (2015) classified tree diameter into \( 4.1 < D < 6.2 \) cm which is comparable to Pinang diameter tree classification in this study. The final equation also consider D and H as a good predictor for biomass estimation following a formula: \( \text{AGB} = (0.167 \times D^2 H^{0.883}) \) (Da Silva et al., 2015). In the upper slopes the tree population was highest at 3650 trees ha\(^{-1}\), whilst in the middle and lower slopes it was 2933 trees ha\(^{-1}\) and 2033 trees ha\(^{-1}\), respectively (Fig. 6).

Table 1. Allometric equations to estimate biomass palm from previous studies and in the current study (*Areca catechu*)

<table>
<thead>
<tr>
<th>No</th>
<th>Allometric equation</th>
<th>Tree Species</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \text{AGB} = 0.1184 \times D^{2.530} )</td>
<td>Palm</td>
<td>Brown, 1997</td>
</tr>
<tr>
<td>2</td>
<td>( \text{AGB} = 4.5 + 7.7 \times H )</td>
<td>Palm</td>
<td>Frangi &amp; Lugo, 1985</td>
</tr>
<tr>
<td>3</td>
<td>( \text{AGB} = 6.666 + 12.826 \times (H^{1.3}) \times \text{LN}(H) )</td>
<td><em>Euterpe precatoria</em> and <em>Phenakospermum guianensis</em></td>
<td>Brown, Delaney, &amp; Shoch, 2001; Delaney, Brown, &amp; Powell, 1999</td>
</tr>
<tr>
<td>4</td>
<td>( \text{AGB} = 0.03883 \times H \times D^{1.2} )</td>
<td>Pinang (<em>Areca catechu</em>)</td>
<td>In this study</td>
</tr>
</tbody>
</table>

**Fig. 5.** Pinang biomass derived from four allometric equations Brown (1997), Delaney, Brown, & Powell (1999), Frangi & Lugo (1985) and developed model in this study)

The average tree size varied in opposite direction. Using the diameter based equation; carbon stocks of Pinang ranged from 0.96 to 20.86 kg C tree\(^{-1}\) with an average of 10.06 kg C tree\(^{-1}\). Carbon stocks at plot level (Table 2) shows significant differences (\( P < 0.05 \)) across different slope positions (upper, middle, and bottom slope). In all lower slope plots, the average C-stock at tree diameter < 6 cm are much bigger than those at middle and bottom slope, while at highest tree diameter (\( > 11 \) cm), the C-Stock are more dominant in lower/bottom slope.
Table 2. Carbon stock (kg C tree⁻¹) estimates for Pinang trees from different slope positions and tree diameter classes

<table>
<thead>
<tr>
<th>Slope position</th>
<th>Tree diameter (cm)</th>
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<tbody>
<tr>
<td></td>
<td>&lt; 6</td>
<td>6-9</td>
<td>9-11</td>
<td>&gt; 11</td>
</tr>
<tr>
<td>Upper</td>
<td>2.01</td>
<td>7.07</td>
<td>12.02</td>
<td>19.16</td>
</tr>
<tr>
<td>Middle</td>
<td>0.96</td>
<td>7.73</td>
<td>12.82</td>
<td>18.96</td>
</tr>
<tr>
<td>Bottom</td>
<td>0.71</td>
<td>5.54</td>
<td>12.90</td>
<td>20.86</td>
</tr>
</tbody>
</table>

The Areca nut tree biomass and its populations at landscape level were higher in upper slope position as compared to lower plot due to lowering disturbance to the plots and difficulties on human accessibility for harvesting the timber. In addition, the upper slope had much more tree density on the stem size of less than 6 cm indicated that the succession for re-generation of Areca nut is already established. At tree diameter of 9 to 11 cm total C-stock (kg tree⁻¹) are equal among landscape positions (upper, middle and bottom/lower).

CONCLUSION AND SUGGESTION

Allometric equation for Areca nut are best when both palm height and stem diameter data are available, but an acceptable relationship was found with stem diameter. Carbon stocks of Areca nut in this study ranged from 0.96 to 20.86 kg tree⁻¹ with an average of 10.06 kg tree⁻¹, it was higher in the upper than in the middle and lower slopes. It is necessary for estimating C-Sequestration on landscape or regional level based on the existing scenario implementing in different soil types and climatic or geographical distribution of Areca nut. A better understanding of historical background of landuse will give more detail information of land management and supporting information of social economic condition of Areca nut farming system is needed to be involved for further study.

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REFERENCES


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