The 2nd ISATrop2021
IOP Publishing
IOP Conf. Series: Earth and Environmental Science 918 (2021) 012015
doi:10.1088/1755-1315/918/1/012015

Tree form morphometrics of *Agathis dammara* and *Acacia mangium* in the IPB’s Dramaga Landscape Campus, Bogor

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Abstract. Tree growth comprises diverse tree forms and crown shapes that are influenced by the growing space and are related to biomechanical responses. Due to the complex structures of tree forms and crown architecture, more understanding of their functions is necessary. The study aimed to evaluate the morphometrics of two tree species of contrasting tree forms. Each represents excurrent and decurrent crown architectures located in the Dramaga Campus Landscape, Bogor. Morphometric analysis was conducted on those two species, namely excurrent agathis (n=23 trees) and decurrent mangium (n= 15 trees). The morphometric analysis was carried out for several basic growth variables such as diameter at breast height, total height, and crown height. In addition, other variables and parameters were also assessed, namely live crown ratio, slenderness ratio, crown diameter, crown projection area, crown index, and coefficient of space for growth. The results showed that the average diameters of agathis and mangium trees in this study were 0.49 and 0.48 m, respectively, while the average heights were 24.63 m and 18.23 m, respectively. The live crown ratio of both trees was more than 80%. The average slenderness ratio for agathis trees was 50.66 higher than that of mangium trees (40.64). The crown projection areas for agathis and mangium were 37.60 m² and 69.69 m², respectively. On the other hand, the crown index of agathis was 3.20, and mangium was 1.84. The coefficient of space for the growth of agathis and mangium was 0.14. and 0.19. The information related to tree morphometry is important for tree management, especially in evaluating healthy and steady tree stands.

1. Introduction

Tree morphometry is important knowledge in determining tree shape dynamics [1,2]. This is related to the quantitative analysis of tree form. [3,4] stated that the morphometric index is important in afforestation planning and urban forest management and tree growth dynamics and parameters that influence vegetation density [5]. This parameter is also important for functional trade-offs in wind resistance [3]. The morphometry itself provides information about the adaptation and the nature of each species.
Trees grow and respond to their mechanical environment. The mechanical design of a plant is fundamental to its growth and reproductive performance and so to its fitness. The crown morphology and the resulting canopy structure determines among others, the within-stand environmental conditions, stand productivity, stand stability and resilience, habitat structure, and even the aesthetic value of a stand [6,7] explained that in defining trees and tree forms, total above ground size, stem and crown shape, and crown composition (number of branches, branchlets, and twigs, and their relative positions) are key. In tree growth characteristics, the crown shape, apical dominance, shoot growth leaf scars, and branching are general knowledge that can aid in maintaining proper forest stocking, in pruning and limb manipulation, in making aesthetic choices, and in selecting appropriate growth measurements to monitor individual tree growth and forest health [8]. In tree stability, a close relationship between stem form and crown characteristics influenced the tree biomechanics. There are two important tree forms of apical dominance, which are considered as growth habits, i.e., decurrent and excurrent models [9]. Decurrent known as deliquescent is tree forms with many dominant branches with a spreading crown form caused by lateral branches growing at similar rates as the main axis terminal. It means no one central axis develops but many spreading branches. At the same time, excurrent is a tree form with a single dominant axis (leader) and forms a conical shaped crown as the terminal elongates more annually than lateral branches. The tree model points out a distinct main axis and many short secondary branches [7].

IPB University is one of the universities with a wide landscape and higher biodiversity with a large area of 684 Ha, where 382 Ha is a green open space area [10]. Tree stands to become an important feature in developing landscapes. The existing trees have played an important role in the environmental sustainability that can be seen from the function of trees to absorb carbon, improve air quality [11] as well as reduce interception in the rainfall [12].

In IPB’s landscape, there are two tree species which are many planted along the roadside and the green space area, i.e., agathis tree (*Agathis dammara* (Lamb.) Poir.) and mangium (*Acacia mangium* Willd.). Those trees represented two tree forms based on the grown habit of decurrent and excurrent models. Agathis and mangium are tree species that are tolerant of environmental stresses [13]. [14] stated that acacia or mangium is a species originating from Australia (North Queensland) [15] and is one of the species that are in demand by China as an urban forest tree. This is due to the type of mangium with a high growth rate, tolerates poor soil, and can make greening in urban forest areas. In addition, mangium has a high carbon absorption ability. On average, mangium has a high carbon absorption capacity of 179.44 tonnes/ha [16], while agathis trees have a carbon absorption capacity of 22,808 tonnes/ha [17].

### 2. The aim of this study
The aim of this study was to evaluate the morphometric characteristics of decurrent model trees of agathis (*Agathis dammara*) and excurrent model of mangium (*Acacia mangium*) at the landscape of IPB University Campus, Dramaga. The morphometrics evaluation was carried out to found the basic differences between the two canopy shapes. The database will be the basic data for analyzing tree biomechanics.

### 3. Method of research
The agathis and mangium trees are spread in the area of IPB’s landscape (figure 1). The tree’s location represented almost the whole campus area, such as the graduation building area, coin spot area, and area around the student dormitory.
Figure 1. Distribution of agathis and mangium tree species in the IPB’s landscape.

Agathis and mangium are two species with different growth habits that are commonly found in the study area. Total 23 agathis trees and 15 mangium trees that we have chosen randomly. The trees were used with no signs of pruning and without intertwined canopies so that the full development of the canopy and its characteristic architecture could be evaluated. All target trees identified their geographic position or coordinates using the Garmin 60Csx Global Positioning System (GPS) Map and given a special mark in the form of a 6 cm x 5 cm mica plastic label tied in a circle the tree. Tree diameter was measured using a phi band at the height of about 130 cm above the ground, known as the diameter of breast height, dbh. The total height of the tree and the lowest canopy height were measured using a hypsometer from above ground level to the end of the tree height and the height of the first living branch, respectively, with a measurement distance from the main trunk of the tree to the outer circumference of the area about 20 m. The tree’s canopy dimensions were measured as diameter crown based on distance crown radii to have the longest and the shortest canopy through the crown dripline. The dbh, total height, height to the lowest canopy as crown height, the width of the longest and most truncated canopy were then called dendrometry variables used as the basis for analyzing morphometric characteristics [2]. The illustration of tree dendrometry measurement is shown in figure 2.
Remarks:

dbh: Diameter of breast height (cm)
H: Total tree height (m)
h₁: Crown height
h₂: The trunk height to the first living branch (m)
D₁ and D₂: Areal of the crown or canopy for four directions in the dripline (m)

Figure 2. The illustration of measurement dendrometry of trees.

As mentioned before that tree biomechanics analysis was based on tree physical performance referring to tree morphometry, which developed from dendrometry characteristics, consisting of live crown ratio (LCR), slenderness (slenderness), mean crown diameter (DCR), crown eccentricity, or crown roundness (CrE), crown projection area (CPA) or horizontal projection of the crown, crown index (CI), coefficient of space for growth (Csg), relative space for the growth of the tree (Rsg). Besides height and diameter, r as the radius is the distance from the trunk center to the dripline was also measured. Those parameters were explained in the following formulas referring to [18,19].

\[
\text{LCR (\%)} = \frac{\text{crown height}}{\text{total height}} \quad (1)
\]
\[
\text{Slenderness} = \frac{\text{total height}}{\text{dbh}} \quad (2)
\]
\[
\text{DCR} = \frac{D_1 + D_2}{2} \quad (3)
\]
\[
\text{CrE} = \frac{r_{\text{min}}}{r_{\text{max}}} \quad (4)
\]
\[
\text{CPA} = \frac{\text{DCR}^2 \times \pi}{4} \quad (5)
\]
\[
\text{CI} = \frac{\text{crown height (m)}}{\text{DCR (m)}} \quad (6)
\]
\[
\text{Csg} = \frac{\text{DCR (m)}}{\text{dbh (cm)}} \quad (7)
\]
Rsg = \frac{DCR (m)}{\text{total height m}} \quad (8)

3.1. Data analysis
Comparative data on the morphometric characteristics based on the growth habits from tree form was analyzed using a comparison test of independent t-test analysis. The test was carried out to analyze two independent or unpaired, i.e., agathis and mangium trees. IBM's SPSS 25.0 software was used in processing data analysis.

4. Result and discussion
*Agathis dammara* (Lamb.) Poir. synonym with *Agathis loranthifolia* Salish., called agathis, includes in the family of Araucariaceae. The tree is native to Moluccas and Celebes (Indonesia) and Philippines [20]. Agathis is a type of tree used as an environmental controller because of its high carbon absorption ability [17]. Agathis is a type with an excurrent header shape. Trees with excurrent canopy type have one main trunk as the center of all existing branches [21]. Excurrent is generally found in gymnosperms. With large branches and forks precluded, an excurrent growth form (spire, cone, sphere, and half-sphere) is the only form available [22]. The feature of the agathis tree grown in IPB’s landscape is shown in figure 3.

\textbf{Figure 3.} Crown illustration of the excurrent model (a) and feature of *Agathis dammara* (b).

*Acacia mangium* Willd. or mangium is a tolerant species on the degraded soil conditions [23] and adaptive to extreme environmental conditions such as soil conditions with high acidity and dense soil [24,25]. Figure 4 shows the crown shape of the mangium, which resembles the decurrent canopy model. This tree model is influenced by growth habit, which points out the oval form as multiple scaffold branches (primary branches) originate from the trunk. Many trees have branches with a diameter of more than 1 m and a long projection up to 10 m [21].
Figure 4. Crown illustration of the decurrent model (a) and feature of *Acacia mangium* (b).

The comparison of the dendrometry characteristics of both excurrent model of agathis and decurrent of mangium was pointed out in table 1. Those values were important to evaluate morphometry parameters.

| Dendrometry characteristics | *Agathis dammara* (n=23) | *Acacia mangium* (n=15) | t-test analysis (α=5%) |
|-----------------------------|---------------------------|-------------------------|-----------------------|
| Dbh (m)                     | 0.49 (± 0.09); 19.94%     | 0.48 (± 0.15); 31.44%   | 0.818**               |
| H (m)                       | 23.89 (± 3.55); 14.88%    | 18.23 (± 2.23); 12.21%  | 0.000*                |
| h2 (m)                      | 2.80 (± 0.60); 21.33%     | 3.53 (± 1.01); 28.54%   | 0.000*                |
| h1 = H - h2 (m)             | 21.09 (± 3.33); 15.80%    | 14.70 (± 2.43); 15.55%  | 0.000*                |
| D1 (m)                      | 9.22 (± 1.39); 15.12%     | 12.27 (± 4.29); 34.96%  | 0.000*                |
| D2 (m)                      | 4.64 (± 0.90); 19.43%     | 5.55 (± 2.67); 48.21%   | 0.000*                |

Remarks: Dbh (diameter breast height), H (total tree height), h2 (trunk height), H-h2 = h1 = crown height), D1 (the longest crown), D2 (the shortest crown). Values in parentheses points out standard deviation, values in percentage points out coefficient variation, ns (no-significant difference), ** (significant difference)
From table 1 was obtained the average Dbh of agathis and mangium trees were 0.49 m and 0.48 m, respectively. The average height of agathis was 23.89 m and mangium 18.23 m. The crown height crown of the agathis tree was 21.57 m, while and mangium was 14.70 m. These values showed the difference from the tree's total height, with the lowest crown height indicating the true crown height [18]. This founds that agathis trees have a higher proportion of crown length than mangium species.

Only Dbh was revealed no significant difference between agathis and dammara, while the other variables were found to a significant difference. Both agathis and mangium are known as fast growing species with a mean annual increment of about 2 cm/year for mangium [26] and about 1.5 cm/year for agathis [27]. It seems that the significant variables of diameter and height were related to the growth characteristics. Site adaptation by tree species and environmental control were the factors that led the dendrometry to vary significantly. Bobrowski and Biondi [4] mentioned the variation does not exceed 10 % for several different tree species grown in under a controlled environment, especially in man-made control, while research by [2] have considered no intervention control growth for trees in urban forest management, especially in tree species differences have led the variation more than 20%.

Live crown ratio (LCR) is crown length to total tree height [28]. Table 2 informed that the LCR value ranges from 0 for trees without crowns to 1 or 100% for trees with dense crowns. LCR expresses photosynthetic capacity [29], tree stability [35], as well as determines tree density [30]. The average LCR for agathis trees was 0.87 or 87%, while for mangium trees was 0.80 or 80% (table 2). LCR is an indicator of the fitness and photosynthetic ability of the tree. LCR more than 60% indicates a tree with good fitness. This condition denotes trees in good health and having good stability in terms of as a tree stand. Referring to the result, both types of trees have high fitness and are in good health. A high LCR showed the distribution of root well and to be broken or withstand a strong wind or heavy snow [31]. Schutz [32] said that the crown ratio < 30% very unstable, 30% < LCR < 50% unstable, > 50% stable. If the LCR was lower, the tree's growth also slows down, and shifts the center of the tree upwards, making it more susceptible to wind and snow damage [33].

Slenderness ratio between agathis and mangium. This value was related to the tree stability and wind resistance [31,34]. The slenderness ratio of the agathis tree was significantly higher than that of acacia. The average value of the slenderness ratio for agathis species was 50.66, while the mangium was 40.64 (table 2). The slenderness ratio value obtained is lower than European types such as Aspen, Balsam Poplar, White Spruce as an excurrent type canopy with a slenderness ratio ranging from 84% to 94% [32,35]. The tree safety value of slenderness ratio was in a range of 50 - 25. Slenderness ratios of more than 50 meant the trunk had a large risk of failure [33,36]. The low slenderness value was obtained by the less competition for growth space. For that reason, trees were allowed to grow more in tree diameter than the tree height [4]. Navratil [34], Šebeň, t al.[37] stated that the lower the value of the slenderness ratio, the faster the diameter growth was compared to the height of the tree so that it was stronger and more stable. The standard of slenderness ratio is based on the places of growth. Mattheck [38] said that the slenderness of more than 100 generally indicates low stability. For forest trees, a slenderness ratio below 80 indicated excellent stability, while for the urban tree, lower slenderness below 50 has been proposed.
Table 2. The morphometric parameters of the excurrent model of agathis (Agathis dammara) and decurrent model of mangium (Acacia mangium).

| Morphometric parameters                     | Agathis dammara (n=23) | Acacia mangium (n=15) | t-test analysis (α=5%) |
|--------------------------------------------|------------------------|-----------------------|-----------------------|
| Live Crown Ratio (LCR)-%                  | 88.15 (± 2.46); 2.7%   | 80.34 (± 6.06); 8.0%  | 0.000**               |
| Slenderness ratio                          | 50.66 (± 8.48); 16.74% | 40.64 (± 12.86); 32.00% | 0.010**               |
| Mean Crown Diameter (D_cr) - m             | 6.93 (± 0.97); 13.86%  | 8.91 (± 3.17); 36.00% | 0.032**               |
| Crown Eccentricity                         | 0.51 (± 0.10); 19.51%  | 0.46 (± 0.17); 37.00% | 0.394 ns              |
| Horizontal crown projection -m²            | 38.38 (± 10.61); 27.64%| 69.69 (± 0.70); 17.00%| 0.027**               |
| Crown Index (Ic)                           | 3.20 (± 0.56); 17.45%  | 1.84 (± 0.37); 37.00% | 0.000**               |
| Coefficient of Space for growth (Csg)      | 0.14 (± 0.02); 15.10%  | 0.19 (± 0.26); 26.00% | 0.005**               |
| Relative space for the growth of the tree  | 0.30 (± 0.06); 20.00%  | 0.49 (± 0.36); 36.00% | 0.001**               |

Remarks: Values in parentheses points out standard deviation, values in percentage points out coefficient variation, ns (no-significant difference), ** (significant difference)

The Crown is an important part of the canopy. Wang et al. [35], Troxel et al. [39] stated that most of the benefits provided by urban forests correlate with the canopy’s width. De Carvalho Maria [2] stated that trees with a large proportion of canopy could produce high evapotranspiration rates in urban forests. This is desirable in a growth process. In the tree species, the difference in the mean crown diameter (D_cr) was influenced by environmental conditions, spacing, age of the trees [36, 40], and inherent tree basic form characteristics. The mean crown diameter (D_cr) is the average of the two crown diameter directions [18]. The mean crown diameter of the Agathis tree was 6.85 m, while the species of mangium was 8.91 m (table 2). Mangium had a wider crown than agathis. It pointed out the crown width of mangium is 23% higher than agathis trees and significant difference. The mean crown diameter has a close relationship with the coefficient of space growth. In order to the canopy of mangium stretches out horizontally with an oval tend to round canopy as like characteristics of the decurrent model which tend to spread branches (figure 3 and figure 4).
Crown eccentricity (CrE) is the ratio between the longest and the shortest canopy [19, 6]. The crown eccentricity value shows the symmetry of the crown. The crown eccentricity value varies between 0 to 1. To the crown eccentricity= 1 is for symmetric crowns, and the value ≈0 for large eccentricity [19]. The average crown eccentricity of agathis trees was 0.51, and mangium trees were 0.46 (table 2). This showed that both agathis and mangium were in moderate eccentricity form.

The horizontal projection of crown or crown projection area (CPA) was influenced by the crown's mean diameter and the area covered by the crown [18]. The average crown projection area of agathis trees was about 37.60 m². It was a significant difference compared to mangium (69.69 m²), as shown in table 2. This was presumably influenced by the crown diameter (Dcr). These values were also related to the coefficient of space growth (Csg) and the relative space for growth (Rgs), where those values for acacia species were higher and significantly different than that of the agathis trees. The Csg of agathis and mangium were 0.14 and 0.19, respectively, while the Rgs of agathis were 0.30 and mangium was 0.49. The higher the crown diameter, the higher the coefficient of space growth [18]. The Csg was related to the growing space of the tree crown. The higher Csg, the higher expansion of the crown. From this study, although the growth habit of those species is different, it seems the ability of trees in crown expansion based on their characteristics is the same. In terms of relative space for growth (Rsg), it is related to treatments activity on the crown, such as pruning in terms of making canopy shapes [18]. Their study mentioned the Rgs with lower than 0.3 involved tree management. Agathis and mangium trees in our study had Rsg more than 0.3, which showed no intensive treatment for shaping the canopy.

The crown index (CI) points out the value of crown growth on crown diameter or how the crown is increasing in height or width [4]. In the managed forest of beech, they had small crowns, i.e., 1.28 to 2.55 [4]. The average crown index for agathis and mangium were ranged between 3.20 and 1.84, respectively (table 2). The crown index value shows the peak development in length and width. A low crown index value indicates that the maximum size of the tree has been reached.

According to the study, the values revealed that the grown habits model of excurrent (agathis) and decurrent (mangium) had mean crown diameter (Dcr), which differed, but the crown eccentricity (CrE) values were almost the same. It is interesting to explain that the canopy model of mangium tends to be oval shape while the agathis are more conical. This difference in the shape and coverage of the crown affects the function and recommendation of placement of those two types of trees. It seems agathis species are more suitable for trees that are in limited areas, while Acacia species are suitable for large areas.

5. Conclusion
Growth habits have an important role in tree growth. The excurrent model of agathis has to be considered when the site faces the worst wind related to its slenderness. Both the excurrent mode of agathis and the decurrent model of mangium have been in moderated eccentricity form. Decurrent models tend to develop asymmetry and irregularity in constructing the crown, as shown in the higher crown projection area. The lower value of the crown index in the decurrent model of mangium indicates that the maximum size of the tree has been reached. In terms of coefficient growing space, both excurrent of agathis and decurrent of mangium have been in maximum space for growth since developed in favorable conditions, as also expressed by LCR, which is more than 60%.

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Acknowledgments
This research was funded by the Indonesia Ministry of Research and Technology (RISTEK)/National
Research and Innovation Agency (BRIN) through Research Grants, FY 2021 (contract number:
8/E1/KPT/2021 and 1/E1/KP.PTNBH/2021).