Relationship Between Tree Height-Diameter at Breast Height (DBH) and Crown Diameter-DBH of Fruit Trees in Bogor Botanical Gardens

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Abstract. Ex-situ conservation of Bogor Botanical Gardens (BBG) represents a collection of predominantly Indonesian species and constitutes an exceptional tropical garden. The gardens' living collections, which include fruit trees, were mostly native to the forest and uncultivated, preserving their original characteristics. The study's aim was to examine the relationship between tree height and breast height diameter and breast height diameter and canopy diameter of fruit trees at BBG. Three individuals from each of the fifteen selected fruit species were measured for their diameter breast height (DBH), crown diameter, and tree height. The highest mean of all parameters was for *Durio zibethinus***,** while the lowest mean of all parameters was for *Garcinia mangostana***.** Mostly fruit tree species have a positive and strong correlation. The highest and the lowest relationship between tree height and DBH was for *C. burmanii* (R^2=99.88%) and for *C. nucifera* (R^2=1.21%). The highest and the lowest relationship between crown diameter and DBH was for *C. burmanii* with linear regression (R^2=99.94%) and for *A. catechu* with logarithmic regression (R^2=24.06%). There was a positive relationship between DBH and tree height and between crown diameter and DBH for the growth prediction of fifteen fruit trees in BBG.

Keywords: *Tree height, diameter breast height, crown diameter, Bogor Botanical Gardens, correlation*.

1 Introduction

Plants are fundamental for ecosystems and human well-being [1] however human activities cause habitat loss, emergence of new harmful pathogens, environmental pollution, climate crisis, etc. It is about 40% of the world's plants are confronted with the risk of extinction, including plant species in Indonesia. Indonesia, a country with rich biodiversity, has about 40,000 plant species or 15,5% of world plants [2], and needs a strategic method to conserve biodiversity. The loss of plant diversity will cause damage to biological groups including humans, so more effective protection of threatened plants is urgently needed.

In-situ conservation and ex-situ conservation are two essential means for plant diversity conservation. Ex-situ conservation, an important supplementary means of in-situ conservation, can make up for the limitations of in-situ conservation and also is a progressive direction of Indonesia's plant protection work [3]. Ex-situ conservation is to transfer living plants or seeds from the natural habitat to an artificial environment for preservation, so as to prevent plants from being damaged by natural or human factors. Botanical gardens protect plants by introduction and cultivation, and germplasm banks preserve plant seeds in vitro with a low-temperature technique [4].

One of the main tasks of Indonesian botanical gardens is the ex-situ conservation of plant species. Indonesian botanical garden has been conserving at least 24% of Indonesian native species listed in the Global IUCN Red List. Botanical gardens also grow many exotic species of plants, some of which are threatened in their native range [5]. Somehow, exotic species are of great benefit to humankind such as fruit tree species. For example Durian (*Durio zibethinus* L.), Rambutan (*Nephelium lappaceum* L.), Kelapa (*Cocos nucifera* L.), etc.

The Bogor Botanical Gardens (BBG) is not only the most prominent in Indonesia /or in Southeast Asia but represents one of the world's outstanding gardens and features a considerable plant collection of offers 17,000 species representing tropical trees, palm trees, orchids, etc [6]. This botanical garden is the oldest ex-situ conservation area in Southeast Asia, with a total collection of 14,057 specimens belonging to 213 families, 1248 genera, and 3404 species. The plant collections are arranged in a combination of taxonomic

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and thematic classification patterns. This botanical garden is focused on conserving lowland humid and wet plant species. BBG collections originate from Indonesia and abroad [7]. The botanical garden's living collection is mostly of uncultivated origin (native to the forest) and keeps the original characteristics of the species. It is critical to conduct a study on the growth processes of living collections at the BBG, especially fruit trees. All living and herbarium collections are documented and arranged based on the taxonomic, bioregion, thematic or combination pattern of those patterns for conservation, research, education, tourism and environmental services [9]. The aim of this study was to investigate a relationship between tree height-diameter at breast height and diameter at breast height-crown diameter on fruit trees in the BBG.

2 Methods

2.1 Study Site

The study was conducted at the BBG located in Bogor, West Java, Indonesia (60 35’51.46” S, 1060 47’58.45” E) with an altitude of 230–270 m above sea level (Fig. 1). Bogor has a tropical climate with an average temperature of 25–27.4 °C, average humidity of 80%, and rainfall of 3658 mm/year.

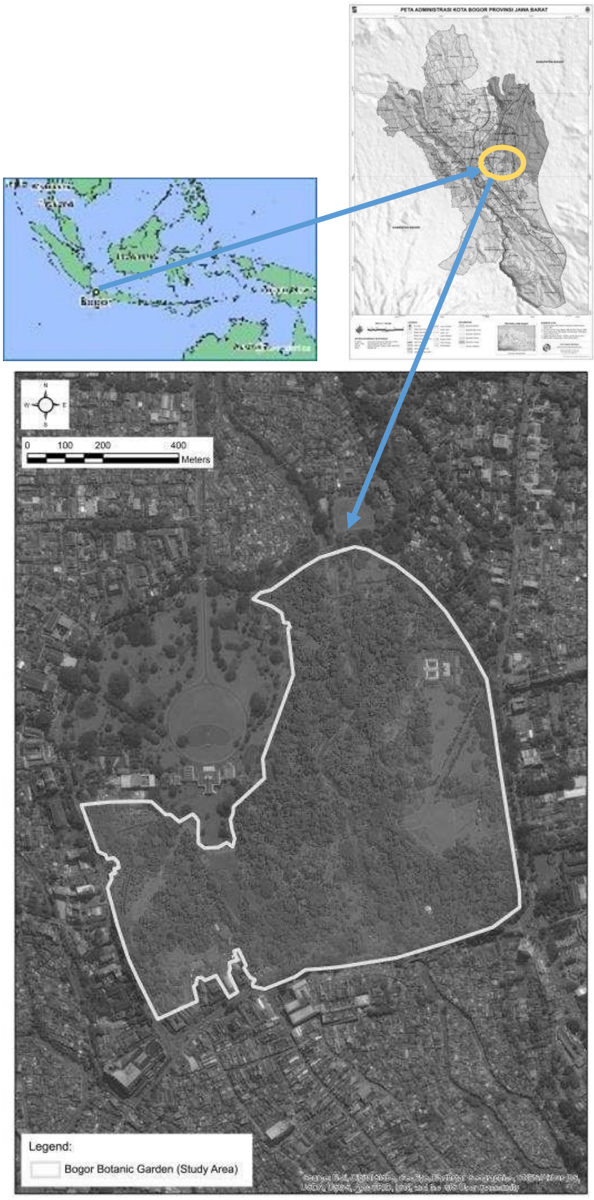


Fig. 1. Research site in Bogor Botanic Gardens. Source [8,9]

2.2 Data sampling

For data collection, the sampling method was used where three trees for each species had the possibility to be selected. After selecting trees, DBH, crown diameter, and total tree height were measured. A total of 45 trees were measured as the sample of the total population (three trees for fifteen fruit species). The DBH, tree height, and crown width were taken as independent and dependent variables for data analysis. The determination of the model of the architect's tree crown model was also observed by Halle and Oldeman [10].

2.3 Data collection

Data were collected from July to August 2023 in the gardens. All data needed for this study were collected by non-destructive measurements. Three persons were involved in height, DBH, and crown diameter measurements. Height (m) was measured by the ruler arch according to the formula for measuring tree height.

Tree diameter at breast height (DBH) was measured by diameter tape (1.3 m from the ground level) with intensive care. The crown diameter (m) was measured by taking the arithmetic average of the horizontal crown diameter on the north-south axis and on the east-west axis measured by measuring tape. The crown shape was also identified using manual instruction.

2.4 Data analysis

Data were compiled, and Pearson's correlations, as well as these regression models, were investigated using Microsoft Excel and SPSS of version 26. The complete dataset provided information for developing regression models between DBH and tree height as well as between DBH and crown diameter. Models were fitted using the enter method in SPSS of version 26.

Table 1. The equation used to develop the model of the correlation between height and crown diameter with diameter at breast height (dbh).

No	Equations	Form
1	$y = b_0 + b_1(dbh)$	Linear
2	$Y = b_0 + b_1(dbh) + b_2(dbh^2)$	Quadratic
3	$y = b_0 \ln(dbh) - b_1$	Logarithmic
4	$y = b_0(dbh)^{b1}$	Power
5	$y = b_0e^{b1(dbh)}$	Exponential

Note : y = tree height or crown diameter (m); x = diameter at breast height (cm); b_0, b_1 = constant. Source : [11].

3 Results and discussion

3.1 Distribution of tree height, diameter at breast height and crown diameter

As a tropical botanical garden, the existence of BBG remains important for its records of local floras. This work is the essential basis for all other studies of plants, whether scientific or technical. The planting management in BBG might have different methods for other commercial or private plantations. BBG's living collection is the result of field expeditions or other countries' donations. Every living collection has a record of the origin, planting location, date of planting in the garden, date of flowering and fruiting, and date of death (if applicable). Collected data of DBH, tree height, and crown diameter for forty-five individuals from fifteen species were analysed in this study. The fifteen species were Durian, Rambutan, Kelapa, Kakao (*Theobroma cacao* L.), Kopi (*Coffea arabica* L.), Pala (*Myristica fragrans* Houtt.), Manggis (*Garcinia mangostana* L.), Kayu Manis (*Cinnamomum burmanii* Ness & N. Tees) Blume, Cengkeh (*Syzygium acuminatisimum* (Blume) DC), Belimbing (*Averrhoa carambola* L.), Jamblang/ Duwet (*Syzygium cumini* (L.) Skeels), Nangka (*Artocarpus heterophyllus* Lam.), Mangga (*Mangifera indica* L.), Cempedak (*Artocarpus integer* (Thunb.) Merr.), and Aren (*Areca catechu* L.). Three individuals were selected for each species and they were in the same treatment management in the garden. The fifteen fruit species were chosen due to their fruit has high potential in the market but limited information about their performance using growth model prediction. Distribution tree height, DBH and crown diameter were varied but they were chosen according to the exact provenance for each species (Table 2).

Table 2. Distribution tree height, diameter at breast height and crown diameter of fifteen fruit species

No	Species	Parameters	Max	Min	Mean
1	*Durio zibethinus*	Tree Height DBH Crown	26 450 20.5	20 280 17.25	23.33 343.33 18.82
2	*Nephelium lappaceum*	Tree Height DBH Crown	13.1 74 10.05	10.04 54 8.1	11.7 66 9.21
3	*Cocos nucifera*	Tree Height DBH Crown	15.5 103 10.4	12.3 95 9.12	13.63 98.66 9.80
4	*Theobroma cacao*	Tree Height DBH Crown	10 24.18 10.4	4.2 13.17 4.75	7.3 17.86 6.83
5	*Cofeea arabica*	Tree Height DBH Crown	16.8 56.04 16.55	6.6 26.33 6.35	5.6 18.68 5.51
6	*Myristica fragrans*	Tree Height DBH Crown	8.1 22 3.89	5.8 12.75 3.59	6.96 17.25 3.76
7	*Garcinia mangostana*	Tree Height DBH Crown	6.6 22 4.75	2.54 10 1.97	4.17 15 3.16
8	*Cinamomum burmanii*	Tree Height DBH Crown	17 134 10.1	7.7 46 6.07	10.8 76 7.42
9	*Syzygium acuminatisimum*	Tree Height DBH Crown	20 400 14.8	5 12 3.14	14.33 237.33 9.86
10	*Averrhoa carambola*	Tree Height DBH Crown	12 128 12	10 61 6.75	11 89.33 8.78
11	*Syzygium cumini*	Tree Height DBH Crown	14.6 123 13.15	5 14.5 4.36	8.86 54.14 7.80
12	*Artocarpus heterophyllus*	Tree Height DBH Crown	11.2 60 7.75	6.6 25 4.23	8.76 46 6.39
13	*Mangifera indica*	Tree Height DBH Crown	11.2 130 12.25	6.2 46 5.62	8.63 84 8.27
14	*Artocarpus integer*	Tree Height DBH Crown	13 130 10.4	12 69 7.62	12.5 100 8.62
15	*Areca catechu*	Tree Height DBH Crown	19.3 60 3.31	4.35 30 2.15	10.71 45 2.71

The highest mean of tree height, DBH and crown diameter was for *D. zibethinus*, while the lowest mean of tree height, DBH and crown diameter was for *G. mangostana* (Table 2). Species *D. zibethinus* is a commercial fruit crop grown in several Southeast Asian countries, including Indonesia [12]. The minimum, maximum, and mean tree height for *D. zibethinus* were recorded at 20m, 26m, and 23.33m, respectively, in this study. In contrast, the minimum, maximum, and mean DBH for *D. zibethinus* recorded were 280cm, 450cm, and 343.33cm, respectively. Besides this, the minimum, maximum, and mean crown diameters of *D. zibethinus* evaluated were 17.25m, 20.50m, and 18.82m, respectively. Species *D. zibethinus* has a high ability to adapt to the BBG in this study. The optimal growing circumstances for *D. zibethinus*'s tree height, DBH, and crown diameter influence the amount of fruit produced [13]. The minimum, maximum, and mean tree heights for *G.mangostana* were recorded at 2.54m, 6.6m, and 4.17m, whereas the minimum, maximum, and mean tree DBH were 10cm, 22cm and 15cm.

The plantings of the BBG were fairly dense, hence some species were frequently shaded by tree species higher above them. Species *T. cacao* is one type of fruit tree that provides shade. In this study, the species *T. cacao* showed limited growth in mean height (7.3m), mean DBH (17.86cm), and mean crown diameter (6.83m). A previous study showed shade trees had a net negative effect on *T. cocoa* tree growth. However, *T. cocoa* yields were not significantly decreased under shade trees. Shade tree traits such as litter quality or tree morphology were also found to have significant effects on aggregate formation and the stabilization of nutrients in different aggregate-size classes, confirming the potential for soil improvements under shade trees [14].

Furthermore, shaded trees affect the photosynthetic process and are the main reason that influences diameter growth in plants. Photosynthetic results in carbohydrates that were stored as leaf replacement, root growth, and tree height. As a result, the difference in growth between these fifteen species of fruit trees can be influenced by both hereditary and environmental variables [15]. The environmental factors such as growth sites for soil mineral content, soil moisture, and sunlight. The internal factors such as the genetic factor for each species, as well as the balance of genetic traits between growth in tree height and DBH.

3.2 Relationship between tree height and diameter at breast height (DBH)

There were fifteen regression statistics in different models developed from tree height, DBH, and crown diameter. Tree height was used as a dependent variable and DBH as an independent variable. The highest relationship between tree height and DBH is for *C. burmanii* (R^2=99.88%), and the lowest was for *C. nucifera* (R^2=1.21%). Mostly fruit tree species have a positive and strong correlation (R^2 above 70%). Only two species (*C. nucifera* and *M. fragrans*) have weak correlation, they were 1.12% and 28.94%, respectively. Therefore, this study concluded that there was a probability of increasing height with increasing DBH but not for *C. nucifera* and *M. fragrans*. The size and growth of tree diameter were strongly correlated to DBH, which could be used for the growth model in trees. Growth equations of trees were indispensable for modelling tree functions as critical components of ecosystem services and directly depend on tree size and growth rate [16].

The plant growth model was commonly to illustrate the relationship between tree height and DBH. They come in various shapes and sizes depending on the species, research location, and other factors [17]. Besides shaded trees and photosynthesis having an effect on plant growth, the other abiotic factors, such as temperature and precipitation, are major climatic elements that generally influence tree height development. The results model of fifteen fruit species varied from linear regression to exponential regression. It illustrates that fifteen fruit species have their own growth characteristics in BBG.

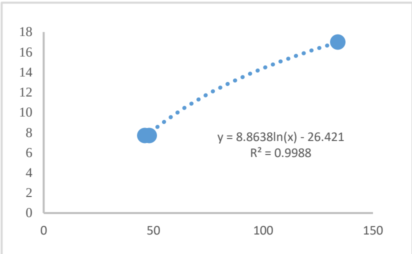
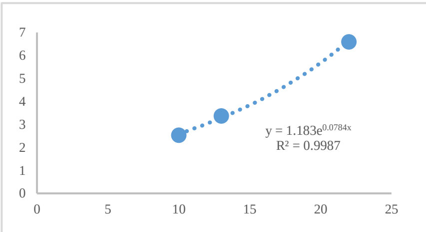
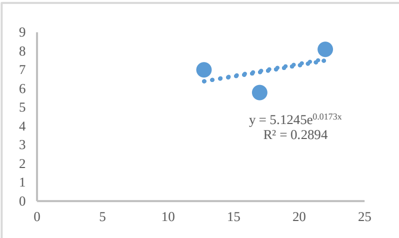
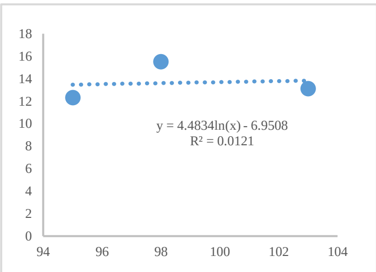
Table 3. Relationship between tree height and DBH for fifteen fruit tree species in Bogor Botanical Gardens

No	Species	Equations	R^2
1	*Durio zibethinus*	$Y = 9.97\ln(X) - 24.69$ (Logarithmic)	70.08%
2	*Nephelium lappaceum*	$Y = 5.94e^{0.01X}$ (Exponential)	86.22%
3	*Cocos nucifera*	$Y = 4.48\ln(X) - 6.95$ (Logarithmic)	1.21%
4	*Theobroma cacao*	$Y = 9.02\ln(X) - 18.44$ (Logarithmic)	83.88%
5	*Cofeea arabica*	$Y = -0.14X + 8.32$ (Linear)	76.87%
6	*Myristica fragrans*	$Y = 5.12e^{0.017X}$ (Exponential)	28.94%
7	*Garcinia mangostana*	$Y = 1.18e^{0.078X}$ (Exponential)	99.87%
8	*Cinamomum burmanii*	$Y = 8.86\ln(X) - 26.42$ (Logarithmic)	99.88%
9	*Syzygium acuminatisimum*	$Y = 4.97e^{0.0038X}$ (Exponential)	91.52%
10	*Averrhoa carambola*	$Y = 8.75e^{0.0025X}$ (Exponential)	92.44%
11	*Syzygium cumini*	$Y = 4.92e^{0.0089X}$ (Exponential)	97.91%
12	*Artocarpus heterophyllus*	$Y = 4.63e^{0.01X}$ (Exponential)	85.00%
13	*Mangifera indica*	$Y = 3.59X - 2.50$ (Linear)	94.17%
14	*Artocarpus integer*	$Y = 1.55\ln(X) + 5.37$ (Logarithmic)	98.64%
15	*Areca catechu*	$Y = 1.88X + 24.82$ (Linear)	93.81%

All fifteen fruit species showed three regression models, they were linear, logarithmic, and exponential regression models. No quadratic and power regression model in this study. There were five fruit tree species *D. zibethinus, C. nucifera, T. cacao, C. burmanii,* and *A. integer* showed a logarithmic regression model in this study. Furthermore, species *N. lappaceum, M. fragrans, G. mangostana, S. acuminatisimum, A. carambola, S. cumini,* and *A. heterophyllus* showed an exponential regression model. The rest of the three fruit tree species illustrated a linear regression model (Table 3). All of these models showed that the growth of DBH as an independent variable affected the growth of tree height positively but for species *C. arabica*. A previous study found a very strong relationship between DBH and height in species *D. zibethinus and T. cacao* [14,18].

In this study, only fruit tree species *C. arabica* showed an inversely proportional relationship between height and DBH. This species is a living collection from the Netherlands and it might be hard to survive in a new ecosystem in BBG. The difference in climate and temperature from the origin site is the main reason affecting the growth of this species. A previous study found abiotic stress, such as heat temperature and drought, greatly inhibit the growth and photosynthetic activity of coffee plants [19,20].

Fig 2. Scatterplots showing trends in two of the highest species and two of the lowest species of the relationship of tree height and DBH.

No	Species	Scatterplots
1	*Cinamomum burmanii*	
2	*Garcinia mangostana*	
3	*Myristica fragrans*	
4	*Cocos nucifera*	

Species *C. nucifera* showed the lowest relationship between tree height and DBH in this study (Fig 2). This species was grown along the coasts and islands that are vulnerable to climate change-induced sea level rise. Growth, physiological processes, biochemical constituents and nutrient *C. nucifera* content were significantly affected by the increasing seawater treatment [21]. This case can be concluded that different ecosystems affect the growth of *C. nucifera* in BBG. Only 1.21% of the role of DBH influences the tree height of this species, the rest of *C. nucifera* growth was affected by other variables.

3.3 Relationship between crown diameter and DBH

Our study provides baseline information on the reliability of using equations established in other locations, as well as the possibility of examining how management practices impact the growth of fruit trees. Estimating accurate diameter growth rate and growth equations could improve the accuracy of evaluation on ecosystem services [16]. The majority of regression models for the relationship between crown diameter and DBH for eight fruit tree species was logarithmic. Only the species *Syzygium cumini* and *Mangifera indica* have exponential regression models in this study (Table 4). The best models of crown diameter and DBH both included predictor and their interactions. However, the contribution of the independent variable to deviance reduction differed significantly between the five models (linear, quadratic, logarithmic, exponential, and power). Here, the highest R^2 value was found in the linear regression model (R^2=99.94%) for *C. burmanii* and the lowest R^2 was found in the logarithmic regression model (R^2=24.06%) for *A. catechu* between crown diameter and DBH. Variables DBH affected crown diameter in plant growth and they showed a strong relationship. This relationship predicted the productivity of plant growth and the accuracy of fruit yields [11]. It means species with R^2 above 70% can be predicted to produce an abundance of fruit yield. Only four tree fruit species with R^2 below 70%, they were *C. nucifera*, *C. arabica*, *Myristica fragrans*, and *A. cathecu*.

Table 4. Relationship between crown diameter and DBH for fifteen fruit tree species in Bogor Botanical Gardens

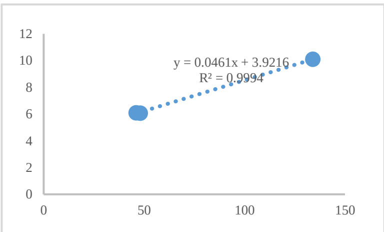
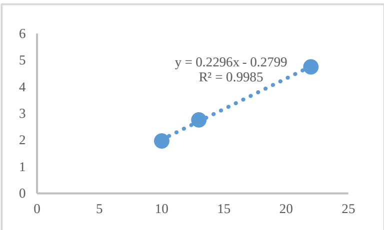
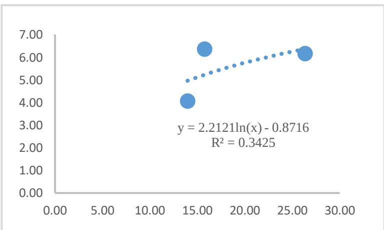
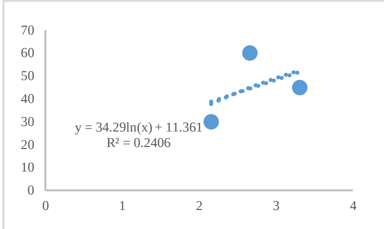
No	Species	Equations	R^2
1	*Durio zibethinus*	Y = 6.01ln(X) - 16.17 (Logarithmic)	98.71%
2	*Nephelium lappaceum*	Y = 537.91ln(X) – 1327.4 (Logarithmic)	81.19%
3	*Cocos nucifera*	Y = -0.11X + 20.95 (Linear)	50.54%
4	*Theobroma cacao*	Y = 1042ln(X) – 2289.2 (Logarithmic)	98.41%
5	*Cofeea arabica*	Y = 2.21ln(X) – 0.87 (Logarithmic)	34.25%
6	*Myristica fragrans*	Y = 0.41ln(X) + 2.59 (Logarithmic)	53.29%
7	*Garcinia mangostana*	Y = 6.22X – 0.27 (Linear)	99.85%
8	*Cinamomum burmanii*	Y 0.04X + 3.92 (Linear)	99.94%
9	*Syzygium acuminatisimum*	Y = 2.92ln(X) – 3.94 (Logarithmic)	88.99%
10	*Averrhoa carambola*	Y = 0.08X + 1.56 (Linear)	98.77%
11	*Syzygium cumini*	$Y = 4.29e^{0.008X}$ (Exponential)	95.31%
12	*Artocarpus heterophyllus*	Y = 0.10X + 1.69 (Linear)	99.80%
13	*Mangifera indica*	$Y = 4.11e^{0.0072X}$ (Exponential)	79.36%
14	*Artocarpus integer*	Y = -4.56ln(X) + 29.50 (Logarithmic)	89.26%
15	*Areca catechu*	Y = 34.29ln(X) + 11.36 (Logarithmic)	24.06%

This study found a strong relationship between crown diameter and DBH for eleven tree fruit species above

70% means that increasing the DBH has an effect on the growth of the crown diameter as well. Data on the dimensions and growth of trees were used to estimate ecosystem services, for example, crown size was correlated to the cooling effect of trees through shading and transpiration. The crown ratio can be calculated from stem DBH unless the crown ratio is defined differently. The size of DBH and crown diameter affect wind speed and attenuate stormwater flooding [16].

In this study, only two fruit tree species (*C. nucifera* and *A. integer*) have the inversely proportional relationship between height and DBH. It means that the bigger the DBH, the narrower the crown diameter. This finding was contrary to another study that said the positive relationship between crown diameter growth and DBH growth of tree species [15]. This study's site was in an ex-situ conservation area but many tree species had limited growth space due to the high density of garden collections. The previous study found high tree density on plantation sites causes light competition for diameter growth [18], including species *C. nucifera* and *A. integer*. Furthermore, living collections in BBG were not pruned as practical management as commercial plantation.

Fig 3. Scatterplots showing trends in two of the highest species and two of the lowest species of the relationship of crown height and DBH.

No	Species	Scatterplots
1	*Cinamomum burmanii*	
2	*Garcinia mangostana*	
3	*Cofeea arabica*	
4	*Areca catechu*	

Species *G. mangostana* was a tropical evergreen tree of the genus Garcinia in the Garcinaceae family. Mainly distributed in Indonesia, Thailand, Vietnam, and Malaysia. In this study, a linear regression equation of *G. mangostana* was obtained to determine the optimal DBH growth from the perspective of statistics, so as to improve the crown diameter growth (Fig 3). It means the DBH variable of *G. mangostana* influences almost the crown diameter growth variable. This behaviour was important because it allowed for estimating the survival and establishment of seedlings in the field. Similar to a previous study the variable DBH of *G. mangostana* serve as an alternative for evaluating the quality of this species growth [22].

Our results showed that the use of the allometric equations developed for this study on trees growing in botanical garden conditions was rarely undertaken in commercial garden management assessments. This may differ from commercial plantations where there is a risk of overestimating tree biomass unless empirical equations and field data include tree density indicators. This study showed that management practices impact the growth rate of fruit trees. To evaluate ecosystem services effectively, management practices and standards must be considered, as well as regional climate and differences between tree species. To increase the level of confidence in the diameter growth equation for these fifteen types of fruit trees, additional data was needed to estimate tree growth from height and planting year.

In conclusion, there was a positive relationship between DBH and tree height and between DBH and crown diameter in fifteen types of fruit trees in the ex-situ conservation area of the Bogor Botanical Gardens. The equations developed in this research provide a method for predicting DBH or tree height and DBH or crown diameter depending on the data and model used. This study concludes that predicting tree height and canopy diameter from DBH was easy to do because the measurements were easy to carry out for field inventory and determining stand structure. It should be used with caution outside these areas as the plant exhibits plasticity due to the origin of the seed, as well as climate and soil variability. With increasingly diverse site and stand conditions, future research is needed in addition to greater variations in tree size and age.

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