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Relationships of tree height-diameter at breast height (DBH) and crown diameter-DBH of *Acacia auriculiformis* plantation

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Abstract. *Dey T, Ahmed S, Islam MA. 2021. Relationships of tree height-diameter at breast height (DBH) and crown diameter-DBH of* Acacia auriculiformis *plantation. Asian J For 5: 71-75.* Measuring the height and crown diameter in the field is time-consuming and needs more logistical efforts. Thus, in this study, we have focused on evaluating the relationship between height and crown diameter with commonly and less effortlessly measured parameters such as diameter at breast height (DBH) to reduce the inventory costs and time by using these models. Different correlation-regression models for predicting tree height and crown diameter from DBH were developed for *Acacia auriculiformis* species at Char Kukri-Mukri Island in the Bhola district of Bangladesh. To achieve the goal, DBH, total height, and crown diameter of each tree were recorded. Coefficient of determination (R^2) and p-value was used for evaluating the models. The correlation coefficients between DBH and height and between DBH and crown diameter showed positive and significant relationships. The calculated p-value and R^2 value between DBH and height and between DBH and crown diameter in the correlation-regression analysis revealed that linear regression models were best fitted in both cases. The study concluded that the tree height could be estimated by the mean of DBH and vice versa, as well as crown diameter could be estimated by the mean of DBH and vice versa.

Keyword: *Acacia auriculiformis*, tree height, crown diameter, diameter at breast height, plantation

INTRODUCTION

Acacia auriculiformis (Akasmoni) is a fast-growing leguminous tree species and native to the savannas of Papua New Guinea, Northern Australia, and the Islands of the Torres Strait (Hawkins 1987). It has been introduced in several tropical countries such as Malaysia, India, Soloman Islands, Indonesia, Philippines, Nigeria, Tanzania, and Bangladesh for its high adaptive capacity from rich to inferior sites (Kabir 2007). *Acacia auriculiformis* has been introduced in every agro-ecological zone of Bangladesh (Ghani 1990). The maximum height of this tree can be up to 30 m and 60 cm in DBH under certain favorable conditions (Zabala 1990; Hawkins 1987). It prefers to mean annual temperature from 26°C to 30°C, and mean annual rainfall ranges from 1500 mm to 2000 mm (Zabala 1990). It can grow in deep or shallow soils, eroding hillslopes, mining spoil, and highly acid to alkaline soils with pH ranges from 3.0 to 9.5 (Hawkins 1987) and altitudinal range from 0 up to 600 m above sea level (Zabala 1990). With their height, crowns, and diameter at breast height, trees show considerable variation and flexibility (Buba2013). Many forestry activities and processes were related to Diameter at Breast Height (DBH) and crown width.

Therefore, any attempt to improve the accuracy of measuring, predicting, and analyzing these parameters should be considered (Ibrahim and Osman 2014). It is an analysis technique, models, and other statistical tools that can quickly evaluate a more considerable amount of data (Turan 2009). The height-DBH relationship varies between tree species, even within the same forest stand (Mugasha et al. 2013) as well as within the same species with different tree sizes, stand densities, stand ages, compositions, species, and site conditions even over time (Poorter et al. 2006). In some studies, tree bole diameter is well correlated with tree crown diameter, where it can be used for determining the stock and stand density relationships (Ibrahim and Osman 2014). To characterize forest stands, the relationship between tree height and DBH is often used. However, in general, measuring height is more time-consuming than measuring DBH.

Thus, by developing predictive models of height from DBH, measurement costs can be reduced, keeping the accuracy of height at an acceptable level (Mugasha et al. 2013). By using stem DBH relationships with tree height, crown height, and crown length, it is possible to model growth and yield (Peper et al. 2001). As it is easy to measure DBH for the studies in ground-based forest inventory, total height, crown ratio, and crown length could be estimated through stem DBH (Turan 2009). The ability to predict crown diameter from DBH provides an efficient method of obtaining an estimate of crown diameter (Gering and May 1995). Tree volume estimation, their development, and description of stands over time rely heavily on accurate height-diameter functions (Curtis 1967). One of the concerns and challenges of forest management is collecting accurate forest inventory information faster and more efficiently (Iizuka et al. 2017).

Estimating the current growing stock in large *A.auriculiformis* plantations through the traditional inventory system is both uneconomic and time-consuming. To reduce the inventory cost and time, modeling of DBH-height and DBH-crown diameter can be used as a proposed method to overcome higher inventory costs. This study evaluates the tree height- DBH and crown width-DBH relationship by different regression models and finds out the best predicting models for *Acacia auriculiformis* tree plantation.

MATERIALS AND METHODS

Study area

The study was carried out at Char Kukri-Mukri Island in CharfashionUpazila of Bhola District. Bangladesh Forest Department (BFD) made *A. auriculiformis* plantation under Char Kukri-Mukri Research Station of Bhola District during May 2011. The study area lies between 21°54 and 22°52 north latitudes and between 90°34 and 91°01 east longitudes. This area is part of the delta of the extended Himalayan drainage ecosystem, which forms the lowest landmass. By the combined actions of rivers Meghna, Brahmaputra, and Ganges, the landscape has been developed, low-lying land, estuaries, and islands along the seacoast. Water salinity ranges from 3- 27 ppt in monsoon, but it goes from 10-33 ppt in the dry season (Siddiqi and Khan 1990). The soil of the study area is silt-clay-loam, and soil salinity varies remarkably between the dry seasons and monsoon. Soil salinity ranges from 0.3-4.2 dS/m in December and reaches its peak is as high as nine dS/m from April-May (Hasan 1987). Soil pH varies between 7.5-8.0 and slightly alkaline (Siddiqi and Khan 2000). The annual average temperature of the study area is the highest, 32.7°C, and lowest, 11.6°C, and yearly rainfall is 2360 mm (Bhola District statistics 2011).

Sampling design

The suitable rotation age of *Acacia auriculiformis* is 8 years and 13-15 years for fuelwood and timber, respectively, in Bangladesh (Islam et al. 2013). So, we select 10 years old *Acacia auriculiformis* plantation for our study purpose. For data collection, the random sampling method was used where each tree has the possibility to be selected. After selecting trees randomly, DBH, crown diameter, and total tree height were measured. A total of 252 trees were measured randomly as the sample of the total population. The DBH, tree height, and crown width were taken as independent and dependent variables for data analysis.

Data collection

Data were collected during March 2021 after ten years of planting the Akasmoni tree. All data needed for this study were collected by non-destructive measurements. Four persons were involved in height, DBH, and crown diameter measurements. Height was measured by Haga altimeter according to the formula for measuring tree height with Haga altimeter. Tree diameter at breast height (DBH) was measured by diameter tape (1.3 m from the ground level) with intensive care. The crown diameter 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.

Data analysis

Data were compiled, and Pearson's correlations, as well as these regression models, were investigated using Microsoft Excel and SPSS of version 20. 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 enter method in SPSS of version 20.

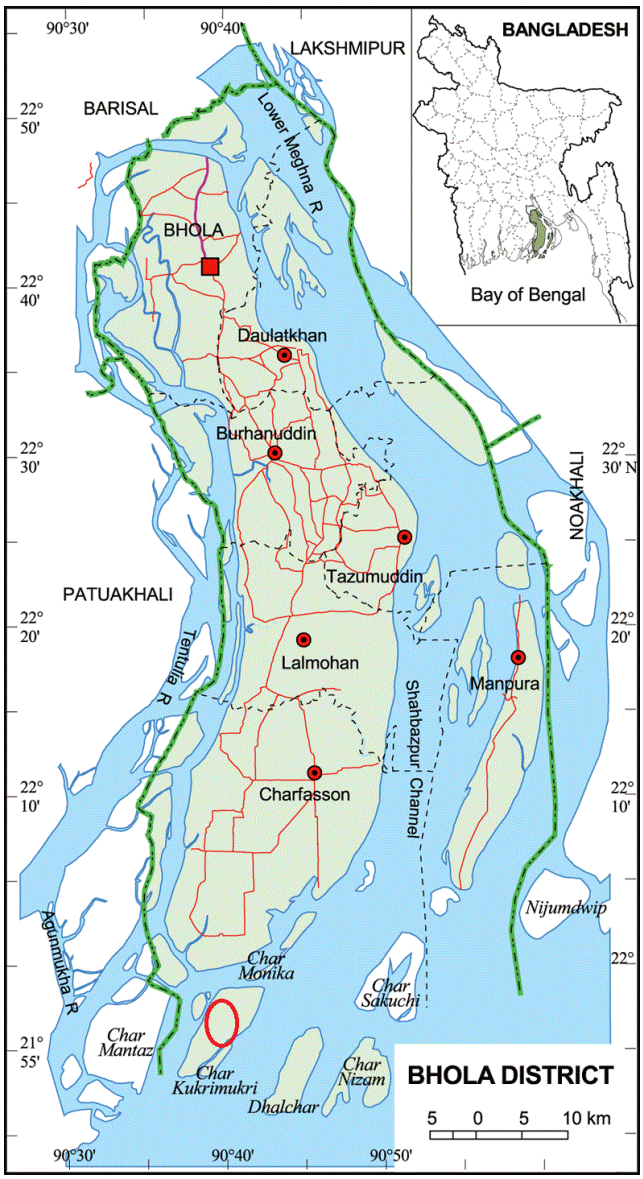

Figure 1. Map of the study area in Char Kukri-Mukri Island, Charfashion Upazila, Bhola District, Bangladesh (Source: Google image)

Table 1. Summary of the data

Measure	Maximum	Minimum	Mean	Std. Deviation	CV value	N	Skewness	Kurtosis
DBH (cm)	22.345	8.294	15.363	3.425	22.293	252	0.221	-0.395
Height (m)	12.200	3.400	8.258	1.501	18.176	252	-0.173	0.290
Crown Diameter (m)	6.564	1.400	4.283	0.952	22.227	252	0.220	-0.249

The summary of the raw data is presented in Table 1. The minimum, maximum, and mean DBH were recorded 8.29cm, 22.34cm, and 15.36cm, respectively, in this study. In contrast, the minimum, maximum, and mean tree heights recorded were 3.40m, 12.20m, and 8.26 m, respectively, in this study. Besides this, the minimum, maximum, and mean crown diameters evaluated were 1.40m, 6.56m, and 4.28m, respectively. The CV value of DBH, height, and crown diameter were 22.29, 18.18, and 22.23, respectively (Table 1). So, the growth rate of height in the *A.auriculiformis* tree is more homogeneous than the growth rate of crown diameter and growth rate of DBH, respectively (Table 1). Deb et al. (2012) found that the mean DBH and mean stem height of *A. auriculiformis* were 26.18 cm and 8.40 m, respectively, in the northeastern region of Bangladesh. Rahman et al. (2018) found DBH, height and crown length of 10 years old *A. auriculiformis* strip plantations in Chattogram district were 19.2cm, 14.86m, and 5.8m, respectively. Deb et al. (2012) also found that Skewness of DBH and stem height was 0.48 m and 0.30 m, respectively, and Kurtosis of DBH and stem height was -0.09 and -0.20, respectively for *A. auriculiformis* plantation in the northeastern region of Bangladesh.

RESULTS AND DISCUSSION

Collected data of DBH, tree height, and crown diameter for ten years old *A. auriculiformis* plantation was analyzed. Different models were developed from the regression statistics where DBH, tree height, and crown diameter were used as both dependent and independent variables. Similarly, the relationship between DBH and height (r = 0.789), the DBH and crown diameter (r = 0.74) showed a positive and strong correlation.

Therefore, it can be concluded that there is a probability of increasing height and crown diameter with the increasing DBH and vice versa. In other words, trees with large DBH were taller and having more expansive canopies. Here, the highest R^2 value was found in linear equation (R^2=0.62) and the lowestR^2 found in exponential equation (R^2 =0.580) between Height and DBH as well as the highest R^2 value was found in linear equation (R^2=0.554) and the lowestR^2 value found in exponential equation (R^2 = 0.52) between crown diameter and DBH. Rahman et al. (2018) also found a positive and significant relationship between height and DBH for *A. auriculiformis* block, strip, and homestead plantation in the Chattogram district of Bangladesh. Arzai and Aliyu (2010) found a very strong linear relationship between DBH and height in *Parkia biglobosa, Khaya senegalensis,* and *Eucalyptus species*, as well as found a strong relationship between DBH and canopy width for *Parkia biglobosa, Khaya senegalensis, Eucalyptus species, Acacia digitate* and *Cassia siamea* species in the savanna zone of Nigeria. Kabir (2007) also found a positive and significant relationship between volume and DBH where height was constant for *A. auriculiformis* plantation in Dhaka Forest Division of Bangladesh.

The regression models are presented in Table 2. Here, the highest R^2 value found in linear regression analysis (R^2=0.62) with a p-value is .000*** between DBH and height is best fitted. On the other hand, the highest R^2 value found in linear regression analysis (R^2=0.55) with a p-value is .000*** between DBH and crown diameter is best fitted. Deb et al. (2012) found that all intercepts, regression coefficients, R^2 value, and p-value were significant in all models for estimating stem biomass of *A. auriculiformis* in the northeastern region of Bangladesh. Rahman et al. (2018) found R^2 value (0.92), R^2 value (0.92), and R^2 value (0.93) in regression line for *A. auriculiformis* strip, block, and homestead plantation, respectively, in Chattogram district of Bangladesh. Kabir (2007) found an R^2 value (0.95) in *A. auriculiformis* height vs. DBH linear regression model in Dhaka Forest Division of Bangladesh. Rahman et al. (2018) also found p-value (0.00225*), p-value (0.0024*), and p-value (0.0008*) in regression line for *A. auriculiformis* block, strip, and homestead plantation, respectively, in the Chattogram district of Bangladesh. Buba (2013) stated that one could use the prediction model to estimate the others by measuring either the DBH or the crown diameter. Acharya (2006) points out that the crown ratio can be calculated from stem DBH unless the crown ratio is defined differently.

In conclusion, a positive and moderate correlation was found between DBH and tree height as well as between DBH and crown diameter of *Acacia auriculiformis* trees in Char Kukri-Mukri Island, Bhola. The equations developed in this research will provide a method for predicting DBH or tree height and DBH or crown diameter depending on the data and the model used. This study concludes that it is easy to predict the tree height and canopy diameter from DBH as it is easy to measure for ground-based inventory and stand structure determination. The models developed by this study were based on data collected from Char Kukri-Mukri Island at Bhola district in Bangladesh. It should be used cautiously outside this area as plants show plasticity due to climatic and soil variability. With a greater variety of site and stand conditions, future research is needed in addition to a greater variety of tree sizes and ages.

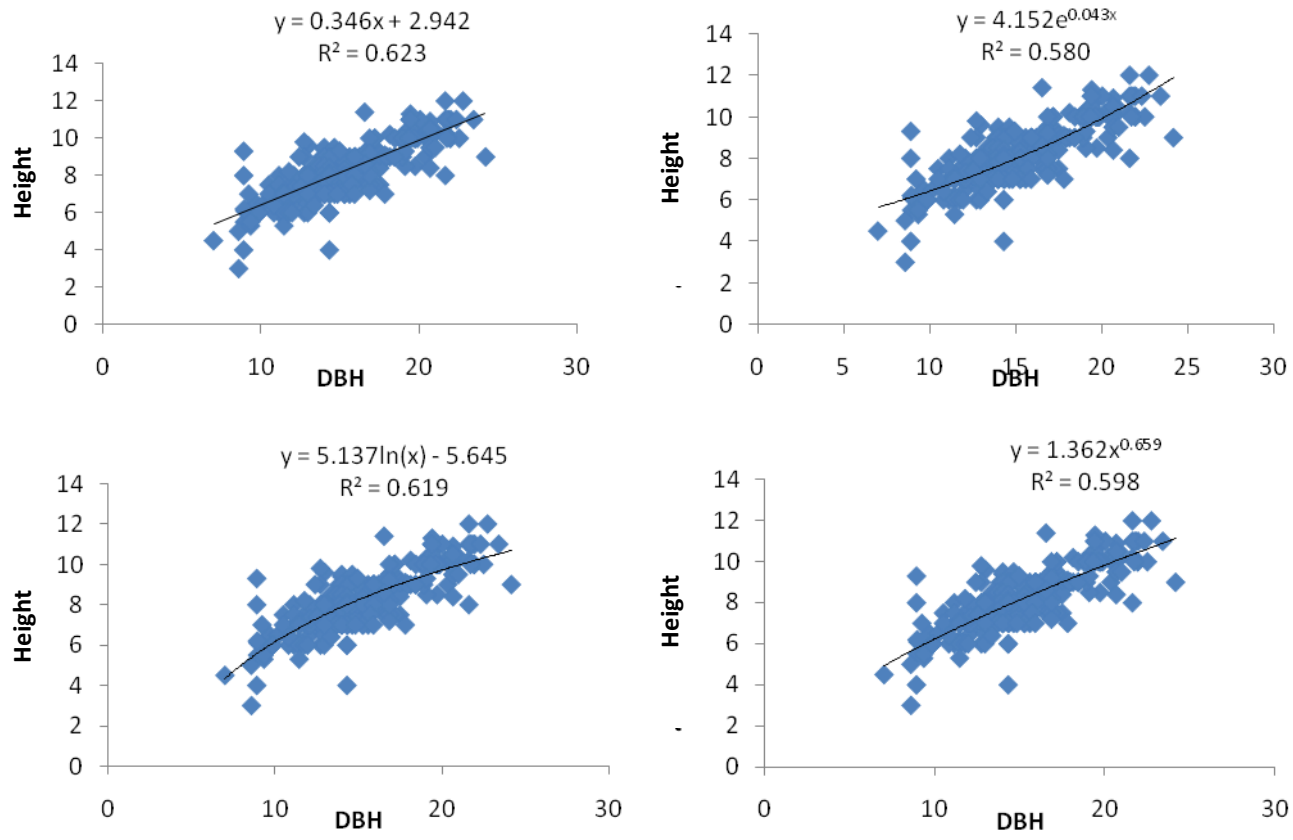

Figure 2. Relationship between Diameter at Breast Height (DBH) and Height

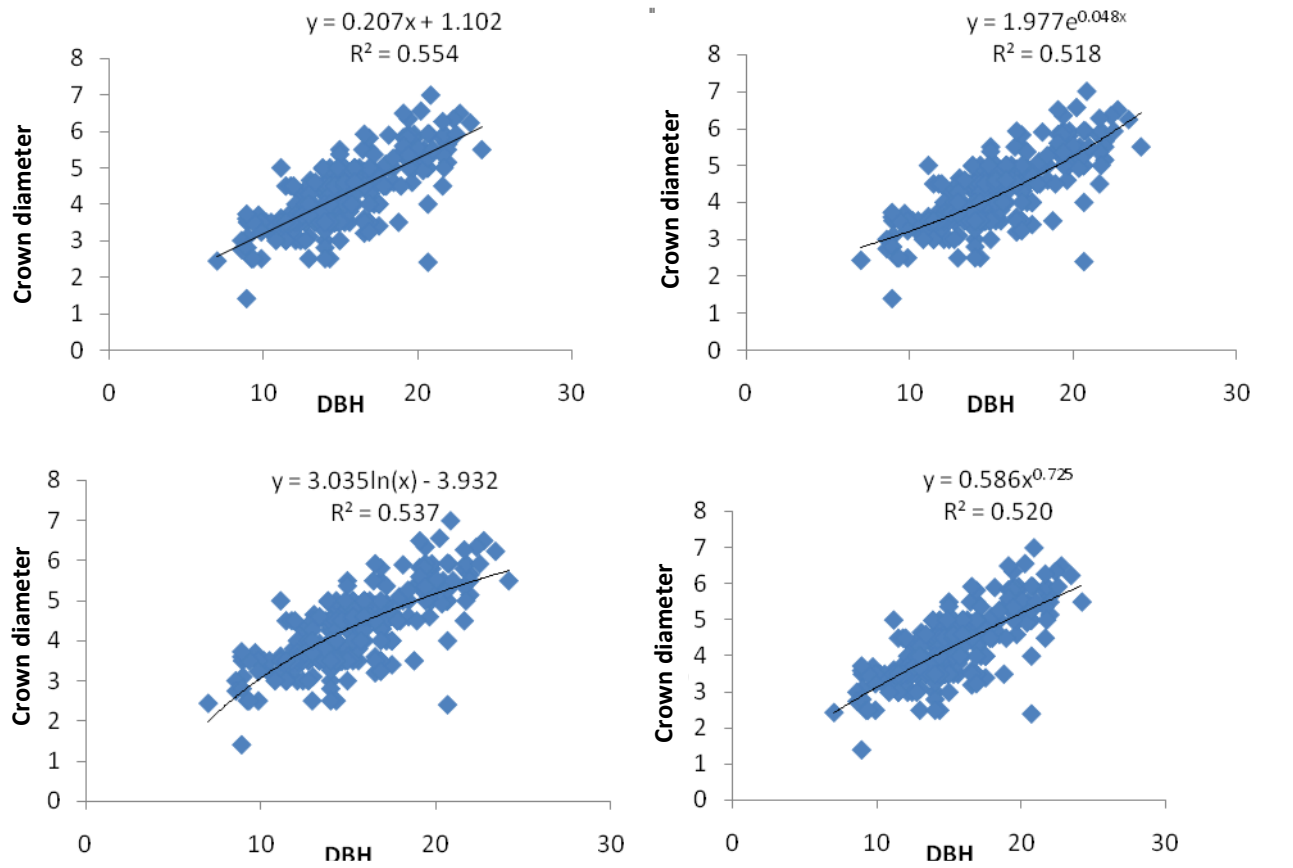

Figure 3. Relationship between Diameter at Breast Height (DBH) and Crown Diameter (CD)

Table 2. F-values, Regression prediction model, coefficient of determination (R^2), mean square error (MSE), standard error of coefficient (SEC), standard error of intercept (SEI), and p-value of the analysis of variance of the different tree variables

Model	Prediction model	R^2	MSE	SEC	SEI	F-value	P-value
Linear	DBH=0.486+1.801 (Height)	0.623	4.439	0.743	0.089	413.643	0.000***
	Height= 2.943+0.346 (DBH)	0.623	0.852	0.268	0.017	413.643	0 .000***
	DBH=3.897+2.677 (Crown Diameter)	0.554	5.253	0.666	0.152	310.767	0 .000***
	Crown Diameter=1.103+0.207 (DBH)	0.554	0.406	0.185	0.012	310.767	0.000***
Exponential	DBH = 5.530 e $^{0.121 \text{ (Height)}}$	0.620	0.020	0.277	0.006	407.329	0.000***
	Height = 4.153 e $^{0.044 \text{ (DBH)}}$	0.580	0.016	0.153	0.002	345.486	0.000***
	DBH = 7.016 e $^{0.177 \text{ (Crown Diameter)}}$	0.537	0.025	0.320	0.010	290.281	0.000***
	Crown Diameter = 1.978 e $^{0.049 \text{ (DBH)}}$	0.518	0.026	0.092	0.003	269.064	0.000***
Logarithmic	DBH= 13.313 ln (Height) – 12.508	0.580	4.947	1.506	0.716	345.486	0.000***
	Height = 5.137 ln (DBH) - 645	0.620	0.861	0.691	0.255	407.329	0.000***
	DBH= 10.660 ln(Crown Diameter) + 0.129	0.518	5.675	0.941	0.650	269.064	0.000***
	Crown Diameter= 3.036 ln(DBH) – 3.932	0.537	0.422	0.484	0.178	290.281	0.000***
Power	DBH = 2.237 (Height) $^{0.908}$	0.599	0.021	0.221	0.047	373.058	0.000***
	Height = 1.362 (DBH) $^{0.659}$	0.599	0.015	0.126	0.034	373.058	0.000***
	DBH = 5.374 (Crown Diameter) $^{0.717}$	0.520	0.026	0.339	0.044	270.926	0.000***
	Crown Diameter = 0.586 (DBH) $^{0.725}$	0.520	0.026	0.070	0.044	270.926	0.000***

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