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Height-Diameter Relationship of Some Forest Species Exploited for Wood in the Natural Tropical Forest of the Congo Basin

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Abstract

To enrich knowledge on the growth dynamics of commercial forest species in the Congo Basin, a study was conducted in Cameroon, within a community forest in savannah forest transition zone (Zone 1) and within FMU 10 052 in dense semi-deciduous humid forest (Zone 2). It aimed to obtain, in 8 species, the height (H) of the tree from its diameter (D) more accessible: *Entandophragma cylindricum* (Meliacea), *Eribroma oblongum, Sterculia rhinopetala* et *Triplochiton scleroxylon* (Malvaceae); *Erythrophleum suaveolens* et *Piptadeniastrum africanum* (Fabaceae), *Milicia excelsa* (Moraceae) et *Terminalia superba* (Combretaceae). The destructive method was used. After felling and flushing out a tree, the dendrometric parameters were measured and/or calculated. In Zone 1, 6 species including *T. scleroxylon* were calibrated using 30 trees of each. In Zone 2, 45 trees of *E. cylindricum,* 99 of *E. suaveolens* and 82 of *T. scleroxylon* constituted the sample. At the 5% threshold (95% confidence interval), the height-diameter relationship is a linear model. In all species, the height of a tree is predicted by measuring its diameter through linear regression. In Zone 1 regression equation is: H(m) = 28.13 + 19.09 * D(m) for *T. scleroxylon*; H(m) = 12.35 + 30.38 * D(m) for *S. rhinopetala;* H(m) = 23.09 + 26.42 * D(m) for *E. oblongum;* H(m) = 14.86 + 20.92 * D(m) for *P. africanum;* H(m) = 14.98 + 24.78 * D(m) for *T. superba* and H(m) = 1.55 + 32.37 * D(m) for *M. excelsa*. In Zone 2, the relationship is: H(m) = 27.40 + 14.21 * D(m) for *T. scleroxylon*; H(m) = 7.79 + 20.18 * D(m) for *E. cylindricum* and H(m) = 20.08 + 9.74 * D(m) for *E. suaveolens* (probability associated with F < 0.0001). The influence of site parameters (biotic and abiotic) on the height-diameter relationship should be more studied in multilayers forests specifically in the Congo Basin.

Keywords

Relationship, Height, Diameter, Tree, Natural Rainforest

1. Introduction

The height of a tree is one of the basic dendrometric variables in forestry. Several other variables essential to forest management decision-making, such as tree scrolling and volume, stand dominant height and station quality index are derived from tree height, and the projection of stand development over time is based on precise height-diameter functions (Baumeister, 2017; Calama & Montero, 2004). Measuring the height of each tree is a tedious task (Fortin et al., 2009; Maiti et al., 2016). This exercise is even more difficult in natural and complex tropical forests, such as those of the Congo Basin where trees of various ages, species, sizes, vigor classes, crowns and shade tolerance levels coexist, than under uniform planting conditions (Temesgen et al., 2014). Height measurements take longer than more accessible diameter measurements, and visual obstructions, rounded crown shapes, leaning trees, and terrain slopes are additional sources of error for height measurements (Mugasha et al., 2013). Very few studies have examined height-diameter relationships for multispecific natural tropical forests (Mugasha et al., 2013; Temesgen et al., 2014; Tsega et al., 2018). This study lays the foundation for modelling the height-diameter relationship in the forests of the Congo Basin. In these natural tropical forests where logging takes only a few stems of different species per hectare, the height-diameter relationship calibrated from a sample of trees felled in the production forests will make it possible to estimate the height of the trees of a given species. In Cameroon, natural forests are generally mosaics of landscapes ranging from dense evergreen humid forests to forest-savanna transition zones to dense semi-deciduous humid forests (Letouzey, 1985). The study examines, on the one hand, the type of model that applies to the height-diameter relationship for each species, and on the other hand, the influence of the landscape on the model applicable to *Triplochiton scleroxylon* (Malvaceae), a species of very high commercial value in Cameroon (Gorel, 2012; Oumar et al., 2021) encountered at both sampling sites.

2. Material and Methods

2.1. Study Site

The study was carried out respectively in the dense semi-deciduous humid forest and in the forest-savanna transition zone. In dense semi-deciduous forest, data were collected in the Annual Cutting Plot (ACP 1-3) during operation in 2015 of the Forest Management Unit (FMU) 10,052, concession 1058 located in the

Eastern region, Kadey Division, Ndélélé Subdivision. In the forest-savannah transition zone, they were collected in the ACP under harvesting in 2011 in the Community Forest (CF) of the Coopérative des Paysans de la Lekié (COPAL) located in the Centre Region, Lekié Division, Batchenga Subdivision. FMU 10 052 is located between north latitudes 3˚44'28" and 4˚06'54" and east longitudes 14˚27'24" and 14˚48'44". The COPAL CF is located between the north latitudes 4˚29'16" and 4˚29'33' and the east longitudes 11˚47'74" and 11˚61'25" (**Figure 1**). The climate in both sites is of the humid Equatorial type with four seasons including two rainy seasons (one small, from March to June and one large, from September to November), and two dry seasons (one long, from December to February and one small, from July to August). During the year, the mean temperature varies between 20 and 24˚C in both sites, with an average rainfall of 1600 mm in the Eastern region (SFIL, 2012) and 1550 mm for the Central region (Amougou, 2011).

According to Letouzey (1985), FMU 10,052 belongs to the dense semi-deciduous rainforest of Meliaceae, Sterculiaceae/Malvaceae and Ulmaceae characterized mainly by the abundance of species of the genera *Cola*, *Sterculia* and *Celtis*. The most representative commercial species are *Triplochiton scleroxylon* (Malvaceae), *Erythropheum suaveolens, Piptadeniastrum africanum*, *Terminalia superba*,

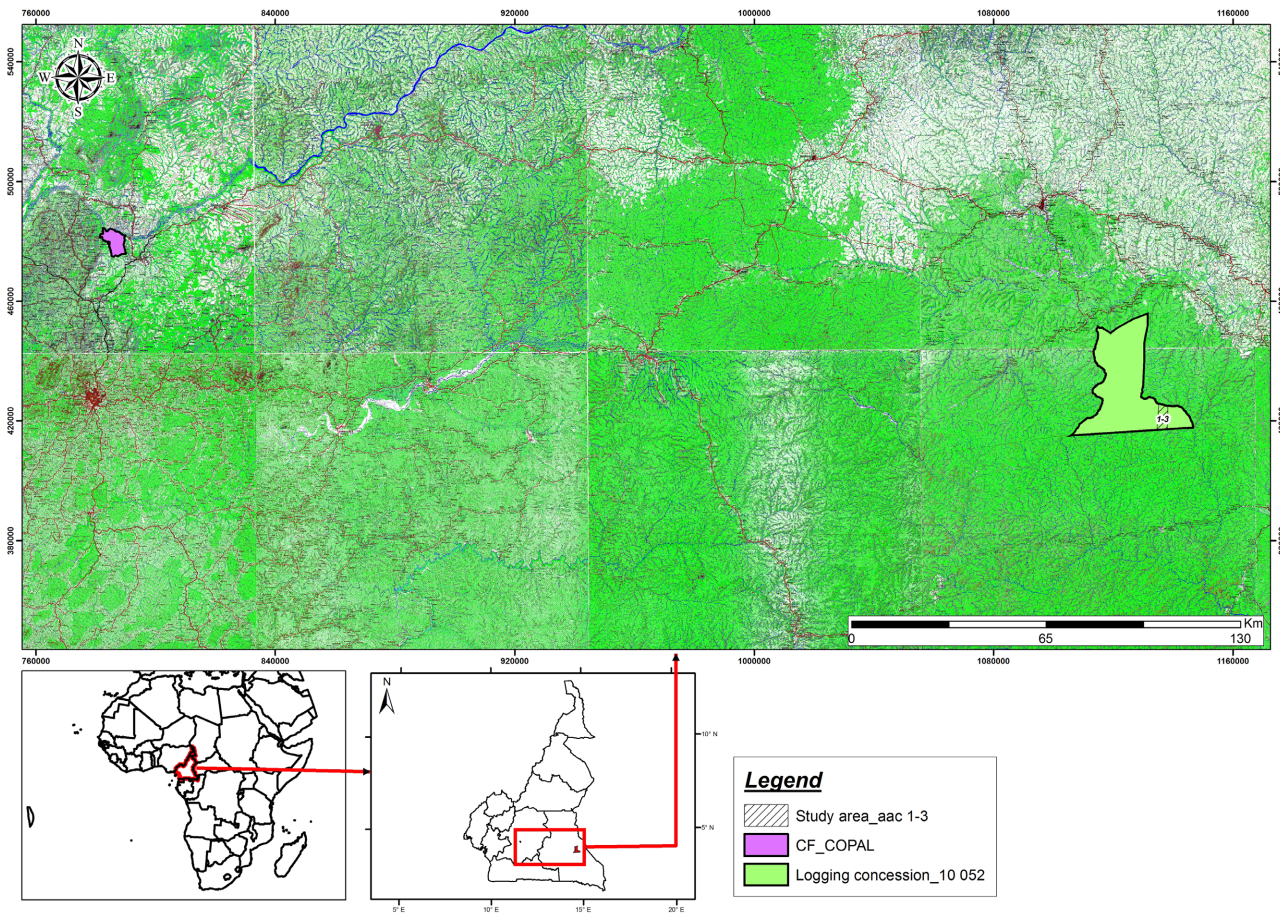

Figure 1. Localisation of the FC-COPAL and FMU 10,052.

Mansonia altissima, *Entandophrama cylindricum, Desbordesia glaucescens,* etc. (SFIL, 2012). The COPAL CF belongs to the forest savannah transition zone, with the most common species: *Triplochiton scleroxylon, Lophira alata, Terminalia superba, Lovoa trichilioides, Milicia excelsa, Eribloma oblongum* and *Ricinodendron heudolotii* (Letouzey, 1985; FC COPAL, 2007). Soils of the two zones are ferralitic with some differences (Jones et al., 2013).

2.2. Methods

Species selection depended on economic importance, resource availability (SFIL and COPAL order book), and species exploited during the study periods. A total of 8 species, belonging to 8 genera and 5 families were sampled. From May to July 2011, *Triplochyton scleroxylon*, *Eribroma oblongum* and *Sterculia rhinopetala* (Malvaceae), *Milicia excelsa* (Moraceae), *Piptadeniastrum africanum* (Fabaceae), and *Terminalia superba* (Combretaceae) were sampled from the forest-savannah transition zone (Zone 1). From September to November 2015, *T. scleroxylon, Entandophragma cylindricum* (Meliaceae) and *Erythrophleum suaveolens* (Fabaceaa) were sampled in FMU 10,052 (Zone 2). *E. cylindricum*, *E. suaveolen* and *T. scleroxylon* are among the thirty-five most exploited species in the Congo Basin (Pérez et al., 2005).

In Zone 1, 30 individuals were calibrated for each of the selected species: *Triplochyton Sleroxylon*, *Eribroma oblongum, Milicia excelsa, Piptadeniastrum africanum, Sterculia rhinopetala* and *Terminalia superba.* In Zone 2, the sample consisted of 82 individuals of *T. Scleroxylon*, 45 individuals of *Entandophragma cylindricum* and 99 individuals of *Erythrophleum suaveolens.*

The destructive method was used. Felling teams were followed in each AHC under operation. After felling and flushing out a tree, dendrometric measurements are made: height of the stump, diameters big-end and small-end, length of the log, length of the abutment, length of the crown. The total height of the shaft is calculated by adding the height of the stump, the length of the abutment, the length of the log and the length of the crown (**Figure 2**). Collected data were analyzed using Excel and Xlstat Software (**Table 1**).

3. Results

3.1. Height-Diameter Relationship in Forest-Savannah Transition Zone

By *T. scleroxylon* the height-diameter relation follows a linear model which results in the equation: H (m) = 28.13 + 19.09 * D(m) with the determination coefficient of R^2 = 0.84. This is a positive and very strong correlation. In this equation, the confidence interval of the means is: H = 47.54 ± 4.46 and D = 1.00 ± 0.21. The parameter D has a fairly narrow confidence interval compared to that of parameter H, that is fairly wide, similarly, the constant of the model (28.13) is quite wide. The model indicates that within the range of variation of variable D given by the calibration, each time D increases by 1 m, H increases by 19 m. The

Figure 2. Dendrometric measurements.

Table 1. Statistical analysis of dendrometric measures.

Species / Statistical Analysis	Descriptive Statistics		Variance	Parameters of the regression: y = b + ax	
	H (m)	D(m)	F value	b: constant	a: director coefficient
Zone 1: transition forest savanah					
Triplochiton slceroxylon	47.54 ± 4.46	1.00 ± 0.21	144.4***	28.13	19.09
Sterculia rhinopetala	35.90 ± 5.87	0.77 ± 0.17	128.8***	12.35	30.38
Eribroma oblongum	47.27 ± 4.40	0.91 ± 0.15	128.7***	23.09	26.42
Piptadeniastrum africanum	43.06 ± 6.87	1.34 ± 0.25	42.5***	14.86	20.92
Terminalia superba	35.20 ± 4.56	0.82 ± 1.52	60.4***	14.98	24.78
Milicia excelsa (Moraceae)	53.87 ± 6.16	0.99 ± 0.16	78.4***	21.55	32.37
Zone 2: dense humid semidecidous forest					
T. slceroxylon	43.29 ± 6.75	1.12 ± 0.24	26.26***	27.40	14.21
Entandophragma cylindricum	41.24 ± 8.36	1.16 ± 0.28	38.90***	17.79	20.18
Erythrophleum suaveolens	35.38 ± 4.72	0.95 ± 0.16	12.67***	26.08	9.74

model is verified at 83%, 17% due to effects other than the explanatory variables (H and D) that vary simultaneously. At the 5% threshold, the confidence interval for observations is 95%, the regression model is linear, and the scatter plots are not distended (Figure 3(a)).

For *S. rhinopetala*, the height-diameter relationship also follows a linear model that results in the equation: H (m) = 12.35 + 30.38*D(m) with $R^2 = 0.82$. The confidence interval of the means is: H = 35.90 ± 5.87 and D = 0.77 ± 0.17. Parameter D has a narrow confidence interval compared to parameter H, the constant of the model (12.35) is quite wide. The model indicates that within the range of variation of the variable D given by the calibration, each time D increases by 1 m, H increases by 30 m. The correlation is positive and very strong (R > 0.8). The model is 82% verified, 18% of which is due to effects other than the explanatory variables (H and D) that vary simultaneously. At the 5% threshold, the confidence interval for observations is 95%, the height-diameter model is linear, and the point clouds are not distended (Figure 3(b)).

For *E. oblongum,* this is also a linear model whose equation is: H (m) = 23.09 + 26.42 * D(m) with $R^2 = 0.83$. The confidence interval of the means is: H = 47.27 ± 4.40 and D = 0.91 ± 0.15. Parameters D and H have narrow intervals, that of the model constant (47.27) is quite wide. The model indicates that within the range of variation of variable D given by the calibration, each time D increases by 1 m, H increases by 26 m. The correlation is positive and very strong (R > 0.8). The model is 83% verified, with 17% due to effects other than the explanatory variables (H and D) that vary simultaneously. At the 5% threshold, the confidence interval for observations is 95%, the regression model is linear and the scatter plots are not distended (Figure 3(c)).

For *P. africanum*, the height-diameter relationship also follows a linear model whose equation is: H (m) = 14.86 + 20.92 * D(m) with $R^2 = 0.603$. The confidence interval of the means is: H = 43.06 ± 6.87; D = 1.35 ± 0.25 m. Parameter D has a narrow confidence interval with respect to H which has a wide interval. The constant of the model (14.56) is quite wide. The model indicates that within

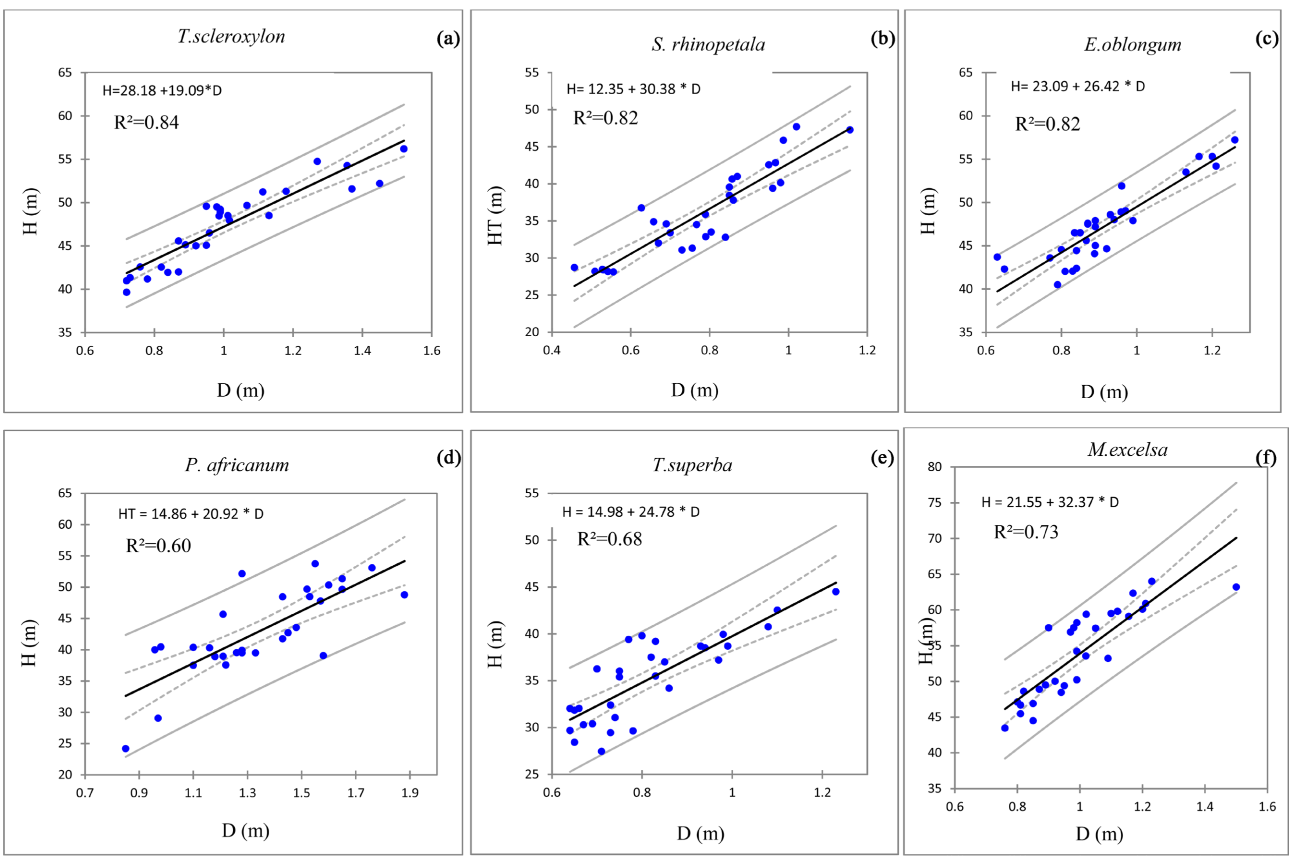

Figure 3. Heigh-Diameter relationship in the forest-savannah transition zone.

the range of variation of the variable D given by the calibration, each time D increases by 1 m, H increases by 21 m. The correlation is positive and strong (0.5< R < 0.8). The model is 60% verified, 40% of which is due to effects other than the explanatory variables (H and D) that vary simultaneously. At the 5% threshold, the confidence interval for observations is 95%, the regression is linear and the scatter plots are quite distended (**Figure 3(d)**).

For *T. superba*, the model is linear according to the equation: H (m) = 14.98 ± 24.78 * D(m) with R^2 = 0.68. The confidence interval of the means is: H = 35.20 ± 4.56 and D = 0.82 ± 1.52. The parameter H has a narrow confidence interval compared to that of D which is wide. The constant of the model (14.98) is quite wide. The model indicates that within the range of variation of the variable D given by calibration, each time D increases by 1 m, H increases by 24 m. The correlation is positive and strong (R^2 > 0.6). The model is verified at 68%, 32% being due to effects other than the explanatory variables (H and D), which vary simultaneously. At the 5% threshold, the confidence interval for observations is 95%, the regression is linear and the scatter plots are slightly distended (**Figure 3(e)**).

By *M. excelsa*, the relationship follows a linear model whose equation is: H (m) = 21.55 + 32.37 * D(m) with R^2 = 0.74. The confidence interval of the means is H = 53.87 ± 6.16 and D = 0.99 ± 0.16. Parameter D has a narrow confidence interval compared to H, which has a wide interval. The model constant (21.55) is quite wide. The model indicates that within the range of variation of variable D given by calibration, each time D increases by 1 m, H increases by 32 m. The correlation is positive and very strong (R > 0.8). The model is checked at 73%, 27% being due to effects other than the explanatory variables (H and D), which vary simultaneously. At the 5% threshold, the confidence interval for observations is 95%, the regression is linear, and the scatter plots are slightly distended (**Figure 3(f)**).

The probability associated with F (Fisher's test) for all species sampled is in this case less than 0.0001 (**Table 1**). This means that for a given species, we take the risk of getting 0.01% wrong when predicting the height of an individual. This explanatory variable is highly significant for all 6 species in the forest-savanna transition zone.

3.2. Height-Diameter Relationship in Dense Humid Semi-Deciduous Forest

By *T. scleroxylon*, the linear model equation obtained is H (m) = 27.40 + 14.21 * D(m) with R^2 = 0.25. The means confidence interval is H = 43.29 ± 6.75 and D = 111.78 + 23.62. The parameter H has a fairly narrow confidence interval compared to D whose confidence interval is wide. The constant of the model (27.40) is quite wide. The model indicates that within the range of variation of variable D given by observations, each time D increases by 1 m, H increases by 14 m. The linear correlation is positive but weak (R^2 < 0.5). The model is 97% verified, 3% being due to effects other than the explanatory variables (H and D) that vary simultaneously. At the 5% threshold, the confidence interval for observations is 95%. The regression is linear and only the values 0.5 < D < 1.5 m deviate from the scatter plot (Figure 4(c)).

By *E. cylindricum*, the relationship is linear according to the equation: H (m) = 17.79 + 20.18 * D(m) with $R^2 = 0.47$. The confidence interval of the means is H = 41.24 ± 8.37 and D = 116.19 + 28.57. The parameter H has a narrow confidence interval compared to that of D which is quite wide. The constant of the model is quite wide (17.79) and the model indicates that within the limits of the range of variation of the variable D given by the observations, each time D increases by 1 m, H increases by 20 m. The linear correlation is positive and average ($R^2 \leq 0.5$). The model is 93% verified, 7% being due to effects other than the explanatory variables (H and D) that vary simultaneously. At the 5% threshold, the confidence interval for observations is 95%, the regression is linear, and the 0.5 ≤ D < 1.5 m deviates from the scatter plot (Figure 4(a)).

For *E. suaveolens,* the relationship is linear according to the relation: H (m) = 20.08 + 9.74 * D(m) with $R^2 = 0.12$. The confidence interval of the means is H = 35.38 ± 4.72 and D = 95.39 + 16.49. The parameter H has a narrow confidence interval compared to that of D which is quite wide. The constant of the model (20.08) is quite wide. The model indicates that within the range of variation of the variable D given by calibration, each time D increases by 1 m, H increases by 9 m. The linear correlation is positive and very weak ($R^2 = 0.11$). The model is

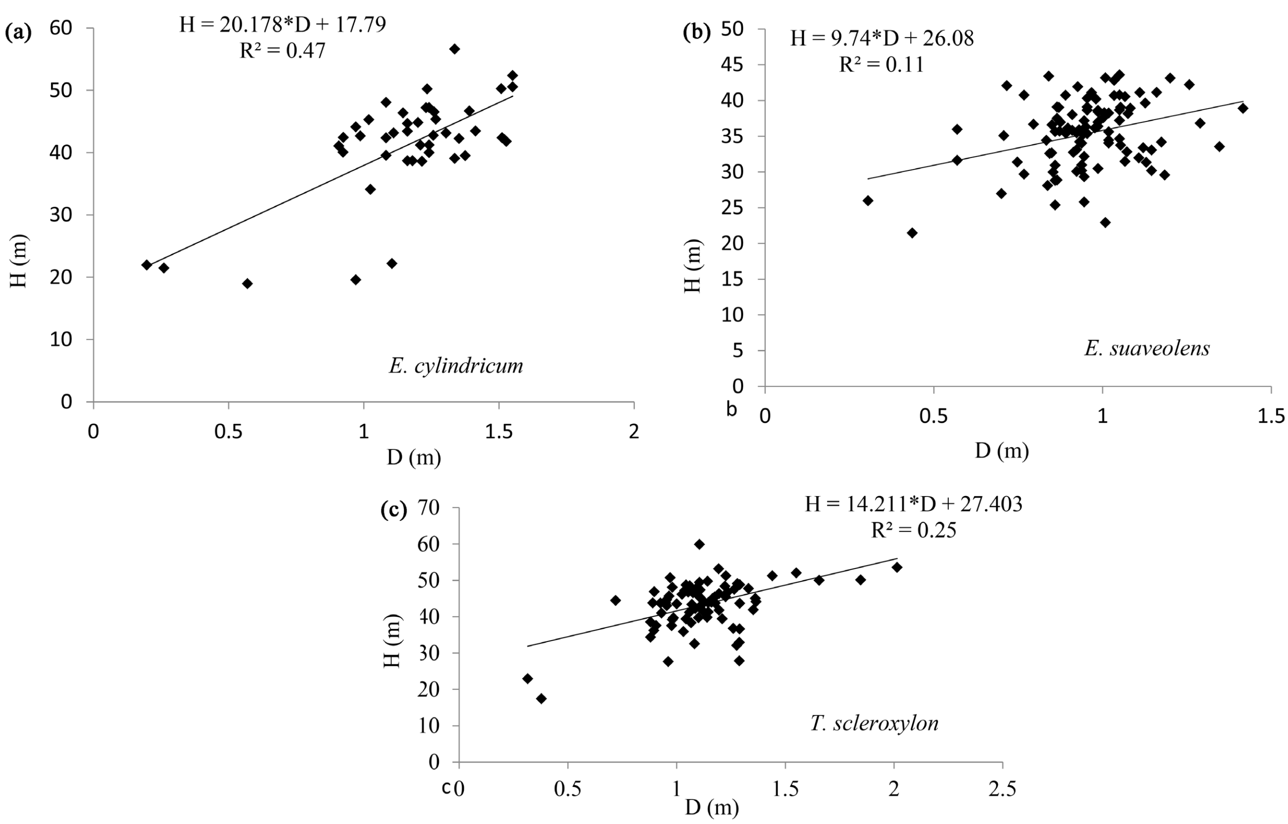

Figure 4. Heigh-Diameter relationship in the dense humid semidecidous forest.

98% verified, 2% being due to effects other than the explanatory variables (H and D) that vary simultaneously. At the 5% threshold, the confidence interval for observations is 95%, the regression is linear but the D < 0.5 m deviates from the scatter plot (**Figure 4(b)**).

The probability associated with F for all three species (*E. cylindricum, E. suaveolens* and *T. scleroxylon*) is less than 0.0001 (**Table 1**). This means that for a given species, we take the risk of getting 0.01% wrong when predicting the height of an individual. This explanatory variable is highly significant for all 3 (three) species in the semi-deciduous dense humid forest area.

4. Discussion

Both in forest-savanna transition zones and in dense semi-deciduous humid forest areas, the height-diameter relationship follows a linear model for all the 8 (eight) species studied. These results corroborate those of various authors who have worked on the height-diameter relationship either in monospecific, monostrate forest plantations (Fortin et al., 2009; Sharma & Zhang, 2004; Robinson & Wykoff, 2011; Huang et al., 1992; Sharma & Parton, 2007; Trincado et al., 2007; Kebede & Soromessa, 2018; Santiago-García et al., 2020; Baumeister, 2017; Sharma & Breidenbach, 2015) or in multi-stratum and multi-species natural forest (Mugasha et al., 2013; Temesgen et al., 2014; Tsega et al., 2018). However, the determination coefficient is high ($R^2 > 0.6$) in the forest-savanna transition zone and low ($R^2 > 0.5$) in the dense humid semideciduous forest, but the probability associated with the Fisher test for the 8 (eight) species in both sites is less than 0.0001 and therefore highly significant. This means that by predicting the total height of an individual of one of these species using the linear model associated with it, one takes the risk of getting 0.01% wrong. Therefore, the proposed model for each of these 8 (eight) species can be used to predict the total height of each individual in its population from the accessible diameter measurement.

Knowing that both sites are under the influence of the same climatic and soil parameters (Amougou, 2011; SFIL, 2012; Jones et al., 2013), the difference in R^2 value between the two landscapes could be explained by sampling (Colas, 2020) or soil parameters (Fortin et al., 2009). Regarding sampling: in forest-savannah transition zone, the observations concerned individuals of (Minimum Exploitability Diameter) D ≥ MED ≥ 0.6 m in this case D > 0.6 m except in *S. rhinopetala* with some individuals of D ≤ 0.6 m; in semi-deciduous forest areas the sample had in addition to individuals of D ≥ MED< ≥0.6 m, some young D < MED individuals. However, a more in-depth study of the influence of site parameters (biotic and abiotic) on the height-diameter relationship such as that conducted by (Sharma & Parton, 2007; Trincado et al., 2007; Fortin et al., 2009; Yang & Huang, 2014) would better explain this difference.

In semi-deciduous dense humid forest, R^2 alone cannot justify the linear regression of the height-diameter relationship, adding statistical analysis could better justify the model (Colas, 2016, 2020). Indeed, the descriptive statistics of this regression indicate for the 3 (three) species that: 1) at the 5% threshold, the confidence interval of the observations is 95% and 2) the probability associated with F is less than 0.0001 covering the highly significant explanatory variable and thus allowing to accept the adjustment of the model. This means that for a given species, we take the risk of being wrong by 0.01% when predicting the height of an individual from its diameter alone despite a low coefficient of determination ($R^2 < 0.5$).

5. Conclusion

Several variables to forest management decision-making, such as tree scrolling and volume, stand dominant height and station quality index are derived from tree height, and the projection of stand development over time is based on precise height-diameter functions. Measuring the height of each tree is a tedious exercise that is even more difficult in natural and complex tropical forests than under uniform planting conditions. Height measurements take longer than more accessible diameter measurements. To obtain the total height of a tree from the measurement of the accessible diameter, this study laid the foundation for modelling the height-diameter relationship in the forests of the Congo Basin by investigating the type of model that applies to the height-diameter relationship for six (6) commercial species: encountered in the forest-savannah transition zone and the dense humid semi deciduous forest in Cameroon.

A total of 8 species, belonging to 8 genera and 5 families were sampled: *Triplochyton scleroxylon*, *Eribroma oblongum* and *Sterculia rhinopetala* (Malvaceae), *Milicia excelsa* (Moraceae), *Piptadeniastrum africanum* and *Erythrophleum suaveolens* (Fabaceae), *Terminalia superba* (Combretaceae), and *Entandophragma cylindricum* (Meliaceae) were sampled. The destructive method was used. Felling teams were followed in each site under operation. After felling and flushing out a tree, dendrometric measurements were made and collected data were analyzed using Excel and Xlstat Software. Both in the forest-savanna transition zone and in the dense semi-deciduous humid forest area, the height-diameter relationship follows a linear model for all the 8 (eight) species studied. However, the determination coefficient is high ($R^2 > 0.6$) in the forest-savanna transition zone and low ($R^2 > 0.5$) in the dense humid semideciduous forest, but the probability associated with the Fisher test for the 8 (eight) species in both sites is less than 0.0001 and therefore highly significant. This means that by predicting the total height of an individual of one of these species using the linear model associated with it, one takes the risk of getting 0.01% wrong. Therefore, the proposed model for each of these 8 (eight) species can be used to predict the total height of each individual in its population from the accessible diameter measurement. However, a more in-depth study of the influence of site parameters (biotic and abiotic) on the height-diameter relationship would better explain this difference obtained in both sites.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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