Models to estimate the bunch dry weight in African oil palm (*Elaeis guineensis* Jacq.), American oil palm (*Elaeis oleifera* H.B.K. Cortes) and the interspecific hybrid (*E. oleifera* x *E. guineensis*)

Modelos para estimar el peso seco del racimo en palma africana (*Elaeis guineensis* Jacq.), palma americana (*Elaeis oleifera* H.B.K. Cortes) e híbrido interespecífico (*E. oleifera* x *E. guineensis*)

Ángela P. Contreras B.[1], Gerardo Cayón S.[1, 2], and Germán Corchuelo R.[1]

ABSTRACT

Statistical models were used to estimate the bunch dry weight through indirect nondestructive methods in African oil palm (*Elaeis guineensis*) American oil palm (*Elaeis oleifera*) and the interspecific hybrid (*E. oleifera x E. guineensis*); and compared with the formula proposed by Corley. The studies were conducted at Santa Bárbara and Chaparral-Cuernavaca on the Unipalma plantation, located in the eastern palm region of Colombia. Ten palms were selected for each group and 30 bunches were sampled for six months. Polynomial and exponential statistical models were postulated, with the best being linear without intercept. The results confirm and validate the usefulness of the model formulated to estimate the bunch dry weight of African oil palm (*E. guineensis*), American oil palm (*E. oleifera*) and the interspecific hybrid (OxG); however, it proved more convenient to use the models proposed in this study because they are tailored to the specific environmental conditions of the eastern palm region of Colombia.

Key words: oil palm, plant physiology, growth parameters, statistical models.

RESUMEN

Se determinaron modelos estadísticos para estimar el peso seco del racimo por métodos indirectos no destructivos en palma africana (*Elaeis guineensis*), palma americana (*Elaeis oleifera*) y el híbrido interespecífico (*E. oleifera* x *E. guineensis*) comparándolos con la fórmula propuesta por Corley. Los estudios se realizaron en las Haciendas Santa Bárbara y Chaparral-Cuernavaca de Unipalma, ubicadas en la zona palmera oriental de Colombia. Se escogieron 10 palmas de cada material y se muestrearon 30 racimos durante seis meses. Se postularon modelos estadísticos polinomiales y exponenciales, encontrando que los mejores fueron de tipo lineal sin intercepto. Los resultados confirman y validan la utilidad del modelo para estimar el peso seco del racimo en palma africana (*E. guineensis*), palma americana (*E. oleifera*) y el híbrido interespecífico (OxG) de éstas; sin embargo, es más conveniente utilizar los modelos propuestos en este trabajo porque están ajustados a las condiciones ambientales específicas de la zona oriental palmera colombiana.

Palabras clave: palmas oleaginosas, fisiología de plantas, parámetros de crecimiento, modelos estadísticos.

Introduction

To estimate the productive potential of oil palm, growth analysis is needed, determining the size and activity of the organs called sources (leaves) and demands (bunches). The first analysis of oil palm growth included the use of mathematical functions to describe the dry weight and leaf area and calculate the relative growth rate (RGR), net assimilation rate (NAR) and crop growth rate (CGR); which showed that the growth is exponential and the larger the oil palm, the faster the growth rate (Corley and Tinker, 2009). Goudriaan and Monteith (1990) developed an expolinear equation for growth that describes the transition from the exponential phase to the linear model phase, showing that this could accommodate oil palm growth and yield data, the transition occurring approximately three years after transplant to the field.

The primary data for analysis of growth can be collected from individual plants, or derivatives of whole canopies, although the destructive nature of the technique requires the use of homogeneous groups of plants or plots (Beadle, 1985). Destructive methods cannot be used in perennial crops such as oil palm (Corley and Tinker, 2009) because it has a single growth meristem in the apical region of the trunk where the leaves and inflorescences originate in regular succession (Corley and Gray, 1982), but Hardon *et al.* (1969) and Corley *et al.* (1971) developed nondestructive

Received for publication: 28 March, 2011. Accepted for publication: 2 November, 2011.

[1] Department of Agronomy, Faculty of Agronomy, Universidad Nacional de Colombia. Bogota (Colombia).
[2] Corresponding author. dgcayons@unal.edu.co

methods for estimating leaf area and annual production of dry matter. Although nondestructive methods only consider the dry weight of leaves, stems and bunches, these structures constitute over 96% of total dry matter (Corley *et al.*, 1971). Bunch dry weight is a fairly constant fraction of fresh weight (53%), and as such, is routinely used in most studies on oil palm (Corley and Tinker, 2009).

Several nondestructive methods have been developed to estimate leaf area, bunch dry weight and dry matter production of oil palm (Hardon *et al.*, 1969; Corley *et al.*, 1971; Hardon *et al.*, 1972; Awal *et al.*, 2004). They have several advantages over destructive techniques: 1) measurements can be repeated several times on the same oil palms maintaining the minimum required experiment area, whereas with destructive methods, experiment size must be increased for each set of required measurements, 2) nondestructive methods can be used for selection in improvement programs for oil palms without destroying potentially productive oil palms 3) the technique consumes less time and is less laborious than destructive analysis with plants as voluminous as oil palms (Corley, 1976; Chiariello *et al.*, 1989; Norman and Campbell, 1989).

Growth analysis also requires the use of equations to predict the increase in area and dry weight of the plant without the use of destructive sampling, saving plant material by decreasing the area required for the experimental plots. Corley *et al.* (1971) developed the equation D = 0.5275 F to estimate bunch dry weight (D), where F is bunch fresh weight (kg), which has been widely used in oil palm research. However, for more experimental precision, equation constants should be checked and adjusted before applying them in other parts of the world (Mendham, 1971; Hartley, 1988; Henson, 1993).

The aim of the study was to develop, under the conditions of the eastern palm region, statistical models to estimate the bunch dry weight for African oil palm (*E. guineensis*), American oil palm (*E. oleifera*) and the interspecific hybrid (OxG), compared with the formula proposed by Corley *et al.* (1971).

Materials and methods

The study was conducted at two locations in the municipalities of Cumaral (Meta) and Paratebueno (Cundinamarca), under tropical rain forest conditions (Bh-T) at 305 m. The first site was at the La Cabaña farm, located in the Presentando inspection zone, with an average temperature of 27°C, 80% relative humidity, annual rainfall of 3,500 mm and 1,500 to 2,000 h year^{-1} of sunshine. The second site was at the Santa Barbara and Chaparral-Cuernavaca farms on the Unipalma plantation; Santa Barbara is located in the Veracruz inspection zone, with an average temperature of 26°C, relative humidity of 78%, annual rainfall of 2,772 mm and 1,530 h year^{-1} of sunshine; Chaparral-Cuernavaca are located in the municipality of Paratebueno, with an average temperature of 26°C, relative humidity of 78%, annual rainfall of 2,990 mm and 1,530 h year^{-1} of sunshine.

The materials used were: African oil palm (*E. guineensis*) Ténera Unilever Camerún sowed in 1989 on Santa Barbara, Nolí (*E. oleifera*) code 3557, sowed in 1991 on Chaparral-Cuernavaca, and the hybrid (OxG) code 352, sowed in 1991 on La Cabaña 10 palms were chosen and marked per material (with good morphological conditions, length and number of suitable leaves, thick leaflets and a normal dark green color). Bunch sampling was conducted for six months, with a frequency of 8 d for the Ténera material, and 20 d for the Nolí and hybrid materials, for a total of 30 bunches per material. The bunches were harvested at the physiological maturity stage, that is, when the first ripe fruit detached, and were taken to the laboratory for bunch analysis and processed to obtain three bunch weights: 1) actual bunch dry weight (ABDW), 2) calculated bunch dry weight (CBDW) and 3) estimated bunch dry weight (EBDW).

Actual bunch dry weight (ABDW)

To calculate ABDW, fresh weight was taken for each bunch and each bunch was threshed separating the stem from the inflorescence elements without separating the fruit, then the fresh weight of the stem was taken and a subsample of the stem was taken and dried in a convection oven at 100°C for 24 h until a constant dry weight was reached. Samples of the inflorescence elements, without separating the fruit, were taken at 5.0 kg in African oil palm and 2.5 kg in Nolí and the hybrid because the latter failed to achieve sufficiently ample inflorescence elements; a subsample was taken from the inflorescence elements of 250 g of normal fruit and another of 200 g of parthenocarpic fruit and dried in an oven until constant dry weight was reached. ABDW was indirectly estimated with the following equation:

$$\text{ABDW} = \frac{\text{bunch fresh weight x bunch subsample dry weight}}{\text{bunch subsample fresh weight}}$$

Calculated bunch dry weight (CBDW)

Each harvested bunch was weighed for fresh weight and the dry weight was calculated (CBDW) with the equation

D = 0.5275 F, formulated by Corley *et al.* (1971), where F equals bunch fresh weight in kg.

Estimated bunch dry weight (EBDW)

With the data for actual (ABDW) and calculated bunch dry weight (CBDW), polynomial models and exponential-polynomial with and without intercept (Tab. 1) were postulated to determine the estimated dry weight (EBDW).

TABLE 1. Postulated statistical models to estimate bunch dry weight ($\hat{y}_i$) for African oil palm (*E. guineensis*), American oil palm (*E. oleifera*) and the hybrid OxG.

Models with intercept	Models without intercept
$\hat{y}_i = b_0 + b_1x_i + b_2x_i^2 + b_3x_i^3$	$\hat{y}_i = b_1x_i + b_2x_i^2 + b_3x_i^3$
$\hat{y}_i = b_0 + b_1x_i + b_2x_i^2$	$\hat{y}_i = b_1x_i + b_2x_i^2$
$\hat{y}_i = b_0 + b_1x_i$	$\hat{y}_i = b_1x_i$
$\hat{y}_i = e^{b_0 + b_1x_i + b_2x_i^2 + b_3x_i^3}$	$\hat{y}_i = e^{b_0 + b_1x_i + b_2x_i^2 + b_3x_i^3}$
$\hat{y}_i = e^{b_0 + b_1x_i + b_2x_i^2}$	$\hat{y}_i = e^{b_1x_i + b_2x_i^2}$
$\hat{y}_i = e^{b_0 + b_1x_i}$	$\hat{y}_i = e^{b_1x_i}$

b_0 = intercept; b_1, b_2, b_3 = estimated parameters; x = bunch fresh weight.

To choose the best model, the study took into account for each: the ability to be applied in the field, its goodness of fit expressed by coefficient of determination (R^2), mean square error (MSE) and the importance of each variable in the model. Correlations were estimated between EBDW, CBDW and ABDW to see association between the model proposed in this paper and the model of Corley *et al.* (1971).

Results and discussion

African oil palm

Statistical models proposed for commercial palm material are presented in Tab. 2. You can see six models with intercept and six without intercept. In models with intercept, the R^2 ranged between 0.90 and 0.91, considered high. The R^2 of cubic models showed no relevance, whereas the R^2 of quadratic models showed relevance and non-relevance, unlike that seen with the linear models which were highly relevant in their coefficients. The MSE ranged between 0.40 and 0.01, the latter being associated with the linear exponential model. From a statistical standpoint, this would be a good model, while the statistical evidence was lower for the cubic model. In previous work (Contreras *et al.*, 1999), it has been reported that statistical models with intercept have relatively low reliability and are not adequate to estimate the dry weight of the African oil palm, contrary to the model proposed by Corley *et al.* (1971) which has intercept.

The proposed intercept models for palm had an R^2 of 0.99, considered outstanding. The SME was low (0.01) for the cubic and quadratic exponential models and highest (0.41) for the simple regression model. The regression coefficients estimated for the cubic models were not relevant, in the quadratic models some coefficients were highly relevant and others were not, whereas in the simple linear models, all were highly relevant.

Simple linear, quadratic and simple exponential models would be adequate to estimate bunch dry weight but, since

TABLE 2. Estimate statistical models for bunch dry weight ($\hat{y}_i$) of African oil palm (*E. guineensis*).

Model	R^2	SME	b_0	b_1	b_2	b_3
$\hat{y}_i = b_0 + b_1x_i + b_2x_i^2 + b_3x_i^3$	0.91	0.40	-7.91 NS	2.52 NS	-0.16 NS	0.004 NS
$\hat{y}_i = b_0 + b_1x_i + b_2x_i^2$	0.90	0.40	-1.56 NS	0.77 *	-0.01 NS	
$\hat{y}_i = b_0 + b_1x_i$	0.90	0.38	-1.89 *	0.65 **		
$\hat{y}_i = e^{b_0 + b_1x_i + b_2x_i^2 + b_3x_i^3}$	0.90	0.10	-1.09 NS	0.51 NS	-0.03 NS	0.001 NS
$\hat{y}_i = e^{b_0 + b_1x_i + b_2x_i^2}$	0.90	0.10	-0.16 NS	0.25 **	-0.01 **	
$\hat{y}_i = e^{b_0 + b_1x_i}$	0.88	0.01	0.59 **	0.25 **		
$\hat{y}_i = b_1x_i + b_2x_i^2 + b_3x_i^3$	0.99	0.40		0.40 NS	0.02 NS	0.001 NS
$\hat{y}_i = b_1x_i + b_2x_i^2$	0.99	0.39		0.50 **	0.01 NS	
$\hat{y}_i = b_1x_i$	0.99	0.41		0.58 **		
$\hat{y}_i = e^{b_0 + b_1x_i + b_2x_i^2 + b_3x_i^3}$	0.99	0.01		0.22 **	-0.003 NS	-0.001 NS
$\hat{y}_i = e^{b_1x_i + b_2x_i^2}$	0.99	0.01		0.22 **	-0.01 **	
$\hat{y}_i = e^{b_1x_i}$	0.99	0.04		0.16 **		

b_0 = intercept; b_1, b_2, b_3 = estimated parameters; x = bunch fresh weight; MSE = mean square error

** Significance 1%; * Significance 5%; NS, not significant.

the idea is to use the simplest and most economical and practical one, we chose the simple regression model EBDW = 0.582 x (R^2 = 0.99 and SME = 0.41). To determine if this model would be a good estimate for bunch dry weight, we estimated values for BDW and CBDW, and correlated each with the ABDW values. The results are presented in Tab. 3 where one can see a positive correlation, highly significant and equal for both models.

TABLE 3. Correlation coefficients of simple linear (*r*) for the actual bunch dry weight (ABDW) with calculated bunch dry weight (CBDW) and estimated bunch dry weight (EBDW) in African oil palm (*E. guineensis*).

Model	*r*	
$\hat{y}_i = b_1 x_i$	CBDW	EBDW
PSR	0.95 **	0.95 **

** Significance 1%.

Based on this, it is more convenient to use the estimated model in this paper, as adjusted especially for Colombian conditions with reference to the traditional model originally developed by Corley *et al.* (1971).

American oil palm

Statistical models for estimating the dry weight of the American oil palm "Nolí" bunch are presented in Tab. 4. The R^2 for models with intercept varied between 0.83 and 0.89 and the SME between 0.30 and 0.01. The R^2 for the cubic and quadratic models showed no relevance, while for the simple linear models some did and others did not, therefore the model with the highest apparent prediction is the simple linear ($\hat{y}_i = b_0 + b_1 x_i$). The models for the Nolí oil palm without intercept also showed high R^2 (≥ 0.89) and SME varied between 0.28 and 0.01; the R^2 for the cubic models showed relevance and non-relevance, and in the quadratic models, some R^2 showed relevance and others not. From a statistical standpoint, the best models are simple linear and simple linear exponential, of which, because of its simplicity and ease of implementation in the field, the selected model is EBDW = 0.575 x (R^2 = 0.98 and CME = 0.04).

Correlations between estimated dry weight (EBDW) and calculated dry weight (CBDW) with the actual dry weight (ABDW) are expressed in Tab. 5, showing that the correlation coefficients (*r*) were highly significant ($P \leq 0.01$) but higher in the ABDW-EBDW association (0.91). This indicates that although both models are reliable for estimating the dry weight of American oil palm bunches, the simple regression model selected in this study (EBDW = 0.575 x) is more suitable for being adapted to the Colombian palm region.

TABLE 5. Correlation coefficients (*r*) of simple linear for actual bunch dry weight (ABDW) with calculated bunch dry weight (CBDW) and estimated bunch dry weight (EBDW) in American oil palm (*E. oleifera*).

Model	*r*	
$\hat{y}_i = b_1 x_i$	CBDW	EBDW
PSR	0.88 **	0.91 **

** Significance 1%.

Hybrid (OxG)

The estimations of the 12 models proposed for the hybrid material (Tab. 6) show that the R^2 of models with intercept

TABLE 4. Estimate statistical models for bunch dry weight of ($\hat{y}_i$) American oil palm (*E. oleifera*).

Model	R^2	SME	b_0	b_1	b_2	b_3
$\hat{y}_i = b_0 + b_1 x_i + b_2 x_i^2 + b_3 x_i^3$	0.86	0.27	-5.95 NS	3.51 NS	-0.48 NS	0.025 NS
$\hat{y}_i = b_0 + b_1 x_i + b_2 x_i^2$	0.85	0.27	2.41 NS	-0.27 NS	0.07 NS	
$\hat{y}_i = b_0 + b_1 x_i$	0.83	0.30	-0.93 *	0.70 **		
$\hat{y}_i = e^{b_0 + b_1 x_i + b_2 x_i^2 + b_3 x_i^3}$	0.83	0.01	-1.64 NS	0.98 NS	-0.12 NS	0.005 NS
$\hat{y}_i = e^{b_0 + b_1 x_i + b_2 x_i^2}$	0.89	0.01	0.20 NS	0.15 NS	0.001 NS	
$\hat{y}_i = e^{b_0 + b_1 x_i}$	0.89	0.01	0.15 NS	0.17 **		
$\hat{y}_i = b_1 x_i + b_2 x_i^2 + b_3 x_i^3$	0.89	0.27		0.87 **	-0.11 NS	0.008 NS
$\hat{y}_i = b_1 x_i + b_2 x_i^2$	0.99	0.28		0.40 **	0.02 **	
$\hat{y}_i = b_1 x_i$	0.98	0.04		0.58 **		
$\hat{y}_i = e^{b_0 + b_1 x_i + b_2 x_i^2 + b_3 x_i^3}$	0.99	0.01		0.26 **	-0.02 NS	0.008 NS
$\hat{y}_i = e^{b_1 x_i + b_2 x_i^2}$	0.99	0.01		0.21 **	-0.002 NS	
$\hat{y}_i = e^{b_1 x_i}$	0.99	0.01		0.19 **		

b_0 = intercept; b_1, b_2, b_3 = estimated parameters; x = bunch fresh weight; MSE = mean square error.

** Significance 1%; * Significance 5%; NS, not significant.

TABLE 6. Statistical models to estimate bunch dry weight of the ($\hat{y}_i$) hybrid (OxG).

Model	R^2	SME	b_0	b_1	b_2	b_3
$\hat{y}_i = b_0 + b_1x_i + b_2x_i^2 + b_3x_i^3$	0.84	0.21	-9.89 NS	3.80 NS	-0.33 NS	0.010 NS
$\hat{y}_i = b_0 + b_1x_i + b_2x_i^2$	0.83	0.21	-3.11 *	1.34 **	-0.05 *	
$\hat{y}_i = b_0 + b_1x_i$	0.80	0.24	0.03 NS	0.56 **		
$\hat{y}_i = e^{b_0+b_1x_i+b_2x_i^2+b_3x_i^3}$	0.87	0.61	-3.13 *	1.29 **	-0.12 *	0.003 NS
$\hat{y}_i = e^{b_0+b_1x_i+b_2x_i^2}$	0.85	0.01	-0.72 *	0.42 **	-0.02 **	
$\hat{y}_i = e^{b_0+b_1x_i}$	0.77	0.02	0.45 **	0.13 **		
$\hat{y}_i = b_1x_i + b_2x_i^2 + b_3x_i^3$	0.99	0.22		0.27 NS	0.07 NS	-0.004 NS
$\hat{y}_i = b_1x_i + b_2x_i^2$	0.99	0.24		0.60 **	0.003 *	
$\hat{y}_i = b_1x_i$	0.99	0.23		0.57 **		
$\hat{y}_i = e^{b_0+b_1x_i+b_2x_i^2+b_3x_i^3}$	0.99	0.01		0.18 **	0.01 NS	-0.001 NS
$\hat{y}_i = e^{b_1x_i+b_2x_i^2}$	0.99	0.01		0.25 **	-0.01 **	
$\hat{y}_i = e^{b_1x_i}$	0.99	0.02		0.19 **		

MSE = mean square error; ** Significance 1%; * Significance 5%; NS, not significant.

was generally low (between 0.61 and 0.01), some of the R^2 for the cubic models showed high relevance (**) and others did not. The simple linear and quadratic models showed significant (*) and highly significant (**) coefficients, of which quadratic, quadratic exponential and simple linear exponential had the better statistical behaviors. From the practical viewpoint for use in the field, the exponential simple linear model would be best.

The models for the hybrid without intercept exhibited high R^2 (≥ 0.988) and SME ranged between 0.239 and 0.010, the R^2 for cubic models was highly relevant and not relevant, whereas in the quadratic models R^2 was relevant and highly relevant. From a statistical standpoint, the best models are simple linear and simple linear exponential, of which, and from the practical point of view of field application due to simplicity and ease of calculation and economy, the selected model is EBDW = 0.567 x (R^2 = 0.988 and MSE = 0.231).

The degree of association between EBDW and the previous model are seen in Tab. 7, showing that the correlation coefficients (*r*) were similar and highly significant ($P \leq 0.01$), so we conclude that both models are reliable for estimating bunch dry weight in the hybrid OxG.

TABLE 7. Correlation coefficients (*r*) of simple linear for actual bunch dry weight (ABDW) with calculated bunch dry weight (CBDW) and estimated bunch dry weight (EBDW) in the hybrid (OxG).

Model	*r*	
$\hat{y}_i = b_1x_i$	CBDW	EBDW
PSR	0.895 **	0.895 **

** Significance 1%.

It is inferred that the correlation coefficient of the two models regarding the observed values is the same and highly significant, therefore, the proposed model in this paper is similar to that proposed by Corley *et al.* (1971) but more suitable as it was adjusted to Colombian tropical conditions.

General model

Finally, a general model was estimated for the three studied materials, with the same statistical tests described above for each material. Since models without intercept were the best for the three materials, a model that uses bunch fresh weight (x) was postulated, finding that the best model is EBDW = 0.557 x which provides an R^2 of 0.989 and SME of 0.323. To determine the degree of association, correlation analysis was performed between the estimated values of bunch weight (EBDW) and calculated values of bunch weight (CBDW) with the actual values (ABDW), presented in Tab. 8. The general model has a greater association of the variables than the models of each of the materials separately and also a greater association than the model proposed by Corley *et al.* (1971); confirming that this is a reliable model to estimate the bunch dry weight of African oil palm, American oil palm and the hybrid (OxG).

TABLE 8. Correlation coefficients (*r*) of simple linear for actual bunch dry weight (ABDW) with calculated bunch dry weight (CBDW) and estimated bunch dry weight (EBDW) in the general model for the three studied materials.

General model	*r*	
$\hat{y}_i = b_1x_i$	CBDW	EBDW
PSR	0.95 **	0.96 **

** Significance 1%.

The results of this study confirm the importance and validation of the model formulated by Corley *et al.* (1971) to estimate the bunch dry weight in African oil palm (*E. guineensis*), American oil palm (*E. oleifera*) and the interspecific hybrid (OxG). However, the models proposed in this work present a viable option because they comply with statistical parameters and are adjusted to Colombian tropical conditions, therefore providing data that are more consistent with the Colombian environmental reality. Similarly, for a good estimate of bunch dry weight, it would be better to use the general model due to the higher degree of association with the actual values of bunch dry weight.

Literature cited

Awal, M.A., I. Wan, J. Endan, and M. Haniff. 2004. Determination of specific leaf area and leaf area-leaf mass relationship in an oil palm plantation. Asian J. Plant Sci. 3(3), 264-268.

Beadle, C.L. 1985. Plant growth analysis. pp. 20-25. In: Coombs, J., D.O. Hall, S.P. Long, and M.O. Seurlock (eds.). Techniques in bioproductivity and photosynthesis. Pergamon Press, Oxford, UK.

Contreras, A.P., G. Corchuelo, O. Martínez, and G. Cayón. 1999. Estimación del área y del peso seco foliar en *Elaeis guineensis*, *Elaeis oleifera* y el híbrido interespecífico *E. guineensis* x *E. oleifera*. Agron. Colomb. 16(1-3), 24-29.

Corley, R.H.V., J.J. Hardon, and G.Y. Tan. 1971. Analysis of growth of the oil palm (*Elaeis guineensis* Jacq.) I. Estimation of growth parameters and application in breeding. Euphytica 20, 307-315.

Corley, R.H.V. 1976. Photosynthesis and productivity. pp. 55-76. In: Corley, R.H.V., J.J. Hardon, and B.J. Wood (eds.). Oil palm research. Elsevier, Amsterdam, The Netherlands.

Corley, R.H.V. and B.S. Gray. 1982. Growth and morphology. pp. 7-21. In: Corley, R.V.H., J.J. Hardon, B.J. Wood (eds.). Oil palm researches. Elseiver, Amsterdam, The Netherlands.

Corley, R.H.V. and P.B. Tinker. 2009. La palma de aceite. 4th ed. Fedepalma, Bogota.

Chiariello, N.R., H.A. Mooney, and K. Williams. 1989. Growth, carbon allocation and cost of plant tissues. pp. 327-366. In: Pearcy, R.W., J.R. Ehleringer, H.A. Mooney, and P. Runde (eds.). Plant physiological ecology: field methods and instrumentation. Chapman and Hall, London.

Goudriaan, J. and J.L. Monteith. 1990. A mathematic function for growth based on light interception and leaf area expansion. Ann. Bot. 66, 695-701.

Hardon, J.J., C.N. Williams, and I. Watson. 1969. Leaf area and yield in the oil palm in Malaya. Expl. Agric. 5, 25-32.

Hardon, J.J., R.H.V. Corley, and S.C. Ool. 1972. Analysis of growth in oil palm. II. Estimation of genetic variances of growth parameters and yield of fruit bunches. Euphytica 21, 257-264.

Hartley, C.W.S. 1988. The oil palm. Longmans Green. New York, NY.

Henson, I.E. 1993. Assessing frond dry matter production and leaf area development in young palms. pp. 473-478. In: Proceedings 1991 PORIM Institute Palm Oil Research Conference Agriculture, Palm Oil Research Institute of Malaysia. Kuala Lumpur.

Mendham, N.J. 1971. Note on leaf area measurement in oil palms. Papua New Guinea Agric. J. 22, 230-231.

Norman, J.M. and S.G. Campbell. 1989. Canopy structure. pp. 301-326. In: Pearcy, R.W., J.R. Ehleringer, H.A. Mooney,and P.W. Rundel (eds.). Plant physiological ecology: field methods and instrumentation. Chapman and Hall, London.