Mineral Nutrition, Growth and Nutrient Cycle of Hevea brasiliensis III. The Relationship between Girth and Shoot Dry Weight

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The relationship between trunk girth and the dry weight of the shoot (all above-ground parts of the plant) has been studied on various clones of Hevea brasiliensis, *varying in age from one to thirty-three years. There is a very close correlation between log shoot weight and log girth, and this has enabled calculation of a regression equation which for individual trees of up to 60 cm in girth permits calculation of the shoot mean dry weight to within 15 % of the observed value. The efficiency and use of the equation is discussed.*

In *Hevea* cultivation the trunk girth measurement and the calculated annual girth increment are widely used as parameters of growth, particularly during the period of immaturity. The trunk girth is also the main factor taken into consideration in deciding when to commence tapping and, in view of the ease of measurement, the trunk girth and rate of girthing are used in experimental work to assess the growth performance of new planting materials and the effects of cultural treatments on growth.

It would also be valuable at times to assess experimental and clonal effects upon tree dry weight and rates of increase in dry weight. It is frequently found, for instance, that cultural treatments markedly affect the girth increment in the first few years of tree growth, but that in later years (when there are appreciable differences in girth according to treatment) no treatment effects on girth increment are apparent. Under such circumstances, it may be incorrectly assumed that there are no longer any effects of treatment on growth, but it is probable that the initially larger trees will have grown more than the smaller trees while maintaining a similar girth increment and accordingly weight will be a better indicator of growth than will girth increment. However, it is rarely practicable to fell and weigh trees at intervals in order to determine tree growth and it is evident that a method of estimating tree dry weight based on measurements made on the intact tree would be most useful. CONSTABLE (19[illegible]) related total tree dry weight (lb) and girth (in.) by the regression equation

$$\log \text{weight} = 2.408 \log \text{girth} - 0.355$$

the equation being based on twenty-five sets of observations made on trees uprooted by wind.

In the present paper, data on trunk girth (measured at 60 in. above the union) and shoot dry weight (relating to over five hundred budded trees) have been collated and the relationship between girth and shoot dry weight studied, in order to estimate shoot weight from trunk girth, and to improve the understanding and interpretation of girth measurement. The term 'shoot weight' includes all above-ground parts of the tree (SHORROCKS, 1965).

DETAILS OF THE SAMPLED TREES

Details of the sampled trees are shown in *Table 1*. All trees were growing in rectangular planting systems at densities appropriate to their age and, except for trees in Groups 5, 6, 7 and 8, had received regular fertiliser applications: trees in Groups 5, 6 and 7 were sampled in a manuring experiment of a factorial design (2^4 N,P,K,Mg), trees being drawn evenly from all treatments, and those in Group 8 had

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TABLE 1. DETAILS OF THE GROUPS OF SAMPLED TREES

Group	Clone	Number of trees	Age, years	Girth range[a], cm	Soil series[b]	Notes
1	RRIM 501	44	1, 1½, 2 3 and 4	13—59	Rengam	Groups 1 and 2 situated in same field. Trees sampled on five occasions.
2	RRIM 513	44		12—50		
3	PB 86	24	1½ and 2	6—15	Sungei Buloh	Groups 3 and 4 situated in same field. Group 3 planted as budded stumps, Group 4 as rooted cuttings. Trees sampled on two occasions.
4	PB 86	24		11—21		
5	PB 86	80	4	15—35	Rengam	Groups 5, 6 and 7 situated in same field and sampled on one occasion.
6	GT 1	80		26—40		
7	LCB 1320	77		22—44		
8	RRIM 501, 604, 605, 612, 618, 621	95		52—74	Selangor	Sixteen trees of each clone (except RRIM 621) sampled, eight of which had been tapped for two years and eight not.
9	RRIM 501, 607, 612, 613, 616, 618	36	10	53—87	Related to Malacca	Eleven trees of clone RRIM 501 and five trees of other clones sampled.
10	RRIM 510, Tjir 1	12	1 to 33	12—182	Rengam, Serdang, Sungei Buloh, Malacca	Details given by SHORROCKS (1965)

[a] Girth measured at 60 in. above union: 60 in. above ground level in rooted cuttings.

[b] Soil series according to OWEN (1951)

not been manured, being situated on a fertile Selangor series soil (OWEN, 1951).

Trees in Groups 1, 2, 3 and 4 were sampled from different parts of the respective fields on the different occasions in order to minimise variation in inter-tree competition in the remaining population of trees to be subsequently sampled in the same field. Trees in Groups 8 and 9 were sampled at random in different plots of two clone trials; in Group 8 half the trees of each clone had been purposely left untapped for two years before sampling whereas the other trees had been tapped for two years. The trees in Group 10, which were sampled in a number of fields, were selected as being of average growth and can be regarded as typical for the various ages considered (SHORROCKS, 1965).

The method of determining shoot dry weight by the weighing of the entire shoot in the field and by taking samples of different morphological units for drying has been described for Groups 5, 6, 7 and 10 by SHORROCKS (1965), and the same method was employed for all other groups except Group 9: for Group 9 the shoot fresh weight only was determined and shoot dry weight estimated on the basis of 50% moisture content in the fresh shoot, this being the average moisture content of the tapped trees in Group 8.

RESULTS

Shoot dry weight (kg) was found to increase exponentially with increase in girth (cm) for each clone, the relationship between shoot dry weight and girth approximating to the general form,

$$W = aG^b \quad \text{......... (1)}$$

$$\text{or } \log W = \log a + b \log G \quad \text{......... (2)}$$

where W denotes shoot dry weight, G denotes girth and a, b are constants.

When $\log_{10} W\,(Y)$ was plotted against $\log_{10} G\,(X)$, a nearly perfect linear regression was found, thus enabling the relationship between shoot dry weight and girth to be conveniently studied when the data are transformed to their common logarithmic values.

The form of Equation 2 is similar to that proposed for estimating apple tree weight from stem diameter (PEARCE, 1952) and for estimating shoot weight of coffee from stem diameter (DANCER, 1964).

Correlation Between Shoot Dry Weight and Girth

Very close correlations were found between log shoot dry weight and log girth as indicated by the values for the correlation coefficient for each clone shown in *Table 2*: the coefficient approached unity for most clones thus confirming the suitability of the model of Equations 1 and 2. When the correlation coefficients were tested against a population perfect correlation of 0.90 (DAVID, 1938) only one coefficient (serial no. 5) was found to differ significantly.

Comparison of Regression Equations for Different Clones and Derivation of a Single Equation for General Use

The estimation of the constants a and b in Equations 1 and 2 can be approached in two ways: firstly by minimising the errors of estimated W, and secondly by minimising the errors in log W. Owing to the variability of the data it was considered unlikely that the first approach, which is very lengthy, would be greatly superior to the second approach: the second approach has been followed here and the possibly consequent larger errors are accepted.

The regression equations relating log shoot dry weight and log girth are shown in *Table 2*. Whilst it can be seen that the slopes (b) of the equations varied considerably, from 2.18 for PB 86 (serial no. 5) to 3.92 for RRIM 618 (serial no. 12), half of the slopes varied between 2.6 and 3.0. It is to be noted that the slopes were based on varying, and often small, numbers of trees and are thus estimated with different, and often low, degrees of precision. Although significant differences occur between the various slopes most of them (excluding serial no. 5, 12 and 16, which are the extremes) do not differ significantly from the common slope within clones which was found to be 2.871 (*Table 2*).

TABLE 2. REGRESSION EQUATIONS RELATING LOG SHOOT DRY WEIGHT (Y kg) AND LOG GIRTH (X cm) AND CORRELATION COEFFICIENTS

Serial No.	Group	Clone	Number of trees	Regression equations	Standard Errors		Correlation coefficient
					Slope ±	Intercept on Y axis ±	
1	1	RRIM 501	44	$Y=2.966X-2.891$	0.026	0.044	0.998***
2	2	RRIM 513	44	$Y=2.969X-2.823$	0.030	0.049	0.998***
3	3	PB 86 (buddings)	24	$Y=2.640X-2.433$	0.105	0.108	0.983***
4	4	PB 86 (cuttings)	24	$Y=2.912X-2.729$	0.142	0.165	0.975***
5	5	PB 86	80	$Y=2.178X-1.694$	0.211	0.292	0.760***
6	6	GT 1	80	$Y=2.589X-2.334$	0.130	0.199	0.914***
7	7	LCB 1320	77	$Y=2.635X-2.365$	0.080	0.126	0.968***
8	8	RRIM 501 (tapped)	8	$Y=3.023X-3.049$	0.817	1.422	0.834**
9	8	RRIM 604 (tapped)	8	$Y=3.759X-4.348$	0.634	1.131	0.924***
10	8	RRIM 605 (tapped)	8	$Y=3.011X-2.963$	0.739	1.297	0.856**
11	8	RRIM 612 (tapped)	8	$Y=2.647X-2.390$	0.512	0.932	0.904**
12	8	RRIM 618 (tapped)	8	$Y=3.918X-4.602$	0.441	0.780	0.964***
13	8	RRIM 621 (tapped)	8	$Y=2.313X-1.702$	0.485	0.867	0.890**
14	8	RRIM 501 (untapped)	8	$Y=2.987X-3.031$	0.694	1.232	0.870**
15	8	RRIM 604 (untapped)	8	$Y=2.450X-2.043$	0.348	0.623	0.944***
16	8	RRIM 605 (untapped)	8	$Y=3.861X-4.490$	0.397	0.706	0.969***
17	8	RRIM 612 (untapped)	8	$Y=2.714X-2.528$	0.324	0.589	0.959***
18	8	RRIM 618 (untapped)	8	$Y=2.836X-2.741$	0.617	1.111	0.882**
19	8	RRIM 621 (untapped)	7	$Y=2.766X-2.557$	1.253	2.286	0.703 ($P<0.1$)
20	9	RRIM 501	11	$Y=3.225X-3.286$	0.539	0.958	0.894***
21	9	RRIM 607	5	$Y=2.836X-2.600$	0.580	1.059	0.943*
22	9	RRIM 612	5	$Y=2.970X-2.933$	0.200	0.381	0.994***
23	9	RRIM 613	5	$Y=3.543X-3.806$	0.682	1.229	0.949*
24	9	RRIM 616	5	$Y=3.828X-4.353$	1.080	1.976	0.898*
25	9	RRIM 618	5	$Y=3.341X-3.526$	1.428	2.505	0.803 ($P<0.1$)
26	10	RRIM 501, Tjir 1	12	$Y=2.852X-2.679$	0.122	0.216	0.991***
		All clones	516	$Y=2.7826X-2.5843$	0.015	0.023	0.993***
Regression within serials (passing through overall means of Y and X)			516	$Y=2.8713X-2.7194$	0.027	0.042	0.979***
Regression of mean values of Y (different clones) on mean values of X			26 pairs	$Y=2.7983X-2.6028$	0.055	0.093	0.995***

*$P<0.05$ **$P<0.01$ ***$P<0.001$

There were no indications that some clones had slopes that were consistently higher or lower than others, and the differences in slopes for tapped and untapped trees did not follow any consistent pattern. However, the variation in slope between sites for PB 86 and RRIM 618, which were each represented three times, indicate that a particular clone can exhibit varying slopes depending upon site and cultural practices. Thus whilst there is no clear evidence to indicate that clones (or cultural treatments) should be considered separately when estimating shoot dry weight from girth, it does appear that the use of a single regression equation for all clones under all conditions, as proposed below, may not always be strictly appropriate.

The 26 mean serial values for shoot dry weight and girth follow the regression equation,

$$Y=2.7983X-2.6028 \quad \ldots\ldots\ldots (3)$$

where Y denotes log shoot dry weight (kg) and X denotes log girth (cm).

The regression equation within serials, where a common slope is derived for all clones takes the form,

$$Y=2.8713X-m \quad \ldots\ldots\ldots (4)$$

where m depends on the mean girth and shoot dry weight of the clone concerned.

If Equation 4 is passed through the overall mean levels of log W and log G the following equation is derived,

$$Y=2.8713X-2.7194 \quad \ldots\ldots\ldots (5)$$

The slopes of Equations 3 and 5 do not differ significantly and it is appropriate to consider the regression equation fitting all 516 trees involved, which takes the form,

$$Y=2.7826X-2.5843 \quad \ldots\ldots\ldots (6)$$

or

$$W=0.002604G^{2 \cdot 7826} \quad \ldots\ldots\ldots (7)$$

Equation 6, which is very similar to Equations 3 and 5, is considered the most appropriate regression equation for estimating shoot dry weights of all clones from their girths, as it is implicit in the calculation of Equation 6 that all trees belong to the same population. The slope of Equation 6 only differs significantly from the few extreme values (serial no. 5, 12 and 16) and from the slopes of 2.97 which have extremely low standard errors (serial no. 1 and 2).

Efficiency of the Regression Equation 6, Y=2.7826X−2.5843, for Estimating Shoot Dry Weights

In order to facilitate comparison between observed and estimated shoot dry weights the trees were grouped in girth classes at intervals of 5 cm (*Table 3*). The shoot dry weights for all trees in a given group were estimated using regression Equation 6: the mean estimated shoot dry weight of a given group was then compared with the observed mean shoot dry weight (*Figure 1*). The difference between these means did not indicate any particular bias in estimation; the difference between the means for trees with girths up to 70 cm was less than 7%, except for one girth class where a value of 11.3% was obtained which is high owing to the presence of one abnormal tree (of clone RRIM 513) in a group of six trees.

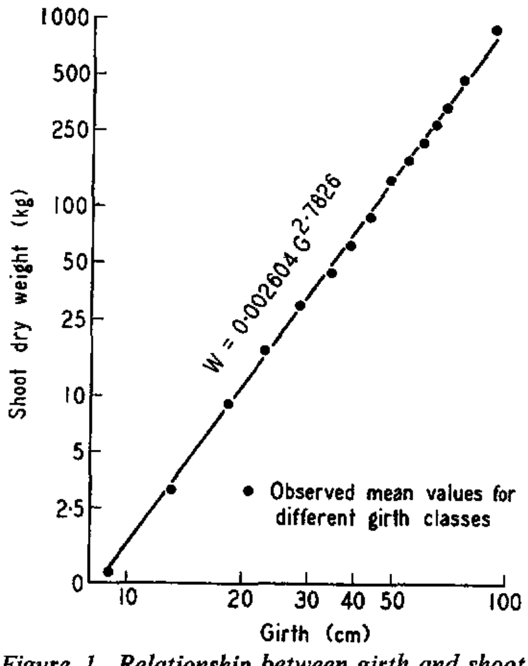

Figure 1. Relationship between girth and shoot dry weight (Equation 6), showing the observed mean values for the different girth classes.

TABLE 3. TEST ON THE EFFICIENCY OF THE REGRESSION EQUATION $Y=2.7826X-2.5843$

Girth classes, cm	No. of trees	Girth (geometric mean), cm	Observed weight (geometric mean), kg	Estimated weight (geometric mean), kg	Weight bias		Estimated tree variation	
					kg	% estimated weight	Variance (kg sq. units)	C.V.%
Below 6	1	5.60	0.48	0.31				
6—11	12	9.04	1.18	1.19	−0.01	−0.9	0.02	12
11—16	44	13.16	3.15	3.39	−0.24	−7.0	0.28	16
16—21	36[a]	18.54	8.96	8.79	0.17	1.9	1.97	16
21—26	64	23.41	17.47	16.84	0.63	3.7	4.94	13
26—31	39	28.54	30.12	29.20	0.92	3.1	23.57	17
31—36	80	33.86	44.53	46.99	−2.46	−5.2	35.26	13
36—41	64	38.27	63.60	66.12	−2.52	−3.8	54.88	11
41—46	22	42.69	88.04	89.58	−1.54	−1.7	66.45	9
46—51	6[b]	48.34	140.9	126.6	14.31	11.3	457.6	17
51—56	17[a]	53.93	169.0	171.6	−2.64	−1.5	291.8	10
56—61	59	58.43	215.3	214.6	0.66	0.3	970.7	15
61—66	33	63.27	268.6	267.9	0.68	0.2	3979	24
66—71	22	67.87	329.9	325.5	4.36	1.3	4191	20
71—81	8	74.03	471.1	414.5	56.63	13.7	17615	32
81 and above	6[c]	92.68	837.3	774.6	62.66	8.1	23982	20

[a] One tree omitted owing to high discrepancy between observed and estimated weights.
[b] This group contains one tree of clone RRIM 513, with extremely large observed weight resulting in high bias and error.
[c] One untapped tree (girth 182 cm, clone Tjir 1) omitted.

In order to obtain an assessment of the accuracy of estimating the shoot dry weight of individual trees from their girth, the variance for each girth group was calculated from the mean squared difference between the observed and estimated weights: the coefficient of variation of the accuracy was calculated on the basis of the estimated weights. For trees with girths up to 60 cm the mean coefficient of variation (c.v.) was 13.5%, varying between 9% and 17%, and for trees with girths greater than 60 cm the mean value for c.v. was much higher, being 24%. It is suggested that the error involved in estimating the weight of individual trees be taken as 15% for trees up to 60 cm girth, and that for trees of greater girth the regression Equation 6 be used with caution: when estimating the mean weight of a group of n trees the error involved would be $\frac{15}{\sqrt{n}}$ %

If two groups of trees from two plots, or a single group of trees on two occasions, are to be compared it is necessary to have an estimate of the girth difference at which it is possible to distinguish significantly between estimated shoot dry weights.

For n trees the distinguishable girth difference ($\triangle G$) at significance level when the girth of the trees approximately equals G can be calculated from the following equation,

$$\triangle G = \frac{2\sqrt{2}CG}{b\sqrt{n}} \qquad \text{......... (8)*}$$

where C denotes the proportional accuracy of the estimated shoot dry weight (or c.v. expressed as a proportion) and b denotes the constant of Equation 6 for slope.

If $C=0.15$ and $b=2.783$

$$\text{then } n = 0.02324 \left(\frac{G}{\triangle G}\right)^2 \qquad \text{......... (9)}$$

$$\text{or } \triangle G = \frac{(0.1524)}{\sqrt{n}} G \qquad \text{......... (10)}$$

Equation 10 shows that on a single tree basis, for trees of girth below 60 cm, the minimum girth difference at which estimated weights could be established as significantly different ($P<0.05$) must be 15%. If tree-to-tree variations are considered, two plots each containing 36 trees can be shown to exhibit significant difference in estimated mean weights if the plots differ in mean girth by 2.54% or more; likewise significant weight increment in a similar given plot between two occasions can only be demonstrated if the girth increment is 2.54% or more. As an example, analysis can distinguish significantly between mean tree weights for plots with mean girths differing by 0.5 or 1.5 cm at girth levels of 20 and 60 cm respectively.

CONCLUSIONS

There is a very close correlation between log shoot weight and log girth, and this has enabled calculation of a regression equation which for individual trees of up to 60 cm in girth permits calculation of the shoot mean dry weight to within 15% of the observed value.

In experimental work, using individual tree data, a 15% difference in tree girth must exist before the shoot dry weight difference can be established as significant at $P<0.05$, but when comparing plots of, say, 36 trees, the difference in mean girth between the plots need only be 2.5% to establish significant weight differences.

The particular regression equation used in the above calculations may not be appropriate for all classes and cultural conditions, but the additional errors in estimated dry weight, over

* *Derivation of Equation 8*

Variance of mean shoot weight of n trees $= \frac{\sigma^2}{n}$, therefore significant difference between two means each of n trees (denoted below as $\triangle W$)

$$= \frac{t\sqrt{2}\sigma}{\sqrt{n}}$$

As $\sigma = CW$ and $t=$ approx. 2, $\quad \triangle W = \frac{2\sqrt{2}CW}{\sqrt{n}}$

Differentiating equation 6 $\quad \frac{\triangle W}{W} = \frac{b\triangle G}{G}$

Eliminating $\triangle W$, $\quad \triangle G = \frac{2\sqrt{2}CG}{b\sqrt{n}}$

those resulting from the use of alternative equations for particular conditions and data, are likely to be small.

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