J. Rubb. Res., **3(1)**, 53–62

Dynamics of Vegetative Growth of Hevea Brasiliensis *in Determining Tapping Norms*

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A study to determine norms for the tapping of Hevea brasiliensis *was carried out in Côte d'Ivoire. This was aimed at defining age and minimum girth for the panel opening of* Hevea *which takes into account the notion of physiological maturity. The modelled vegetative growth curve is a sigmoid with a change in the gradient at the third phase which is a plausible solution to the problems of this study. Analysis of growth dynamics shows that this point hardly varies, irrespective of the growth class of the clone, and takes place at the sixth year after planting. In addition, several observations on the growth of* Hevea *under different conditions support the proposal of a minimum tapping girth linked with the growth class, thus combining the notion of age and size.*

The criteria currently in force for the tapping of *Hevea* in most African producing countries is to open for tapping when the girth of the tree reaches 50 cm at 1 m from the ground. This norm originates from studies carried out on clones with slow (PR 107) and moderate growth rates (GT 1) for which tapping starts between the sixth and seventh year[1]. Genetic progress has paved the way for the creation of clones with fast growth, *e.g.* PB 235, IRCA 111 *etc.*, with a girth of 50 cm attained between the fourth and fifth year. Hence, these clones are tapped earlier than the group of clones which includes GT 1.

During the tapping of *Hevea*, physiological, mechanical and morphological problems arise especially in clones with fast growth. In fact, after tapping, these clones have a high sensitivity to panel dryness[2] and wind damage. Furthermore, there is pronounced disequilibrium in their trunk, characterised by growth in height, without accompanying radial growth which is rather drastically reduced.

Several arguments contribute to this situation, the main one being that opening at a girth of 50 cm causes some problems, and so the search for additional and more flexible criteria for the initial norm becomes necessary. This research results from the desire to better control the management of energy[3] and hydrocarbons of the tree during vegetative growth dynamics for the determination of norms for the panel opening of *Hevea brasiliensis*. It results from the hypo-thesis that the energy used by the plant in its development is mainly oriented towards vegetative growth in the juvenile phase,

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i.e. to the production of the primary biomass. As a result, no additional effort, especially the secondary activity of rubber production, can be obtained from the tree without disturbing this primary function. The diversion of energy towards latex production, without causing damage to the tree, can only be envisaged when the energy required for growth is reduced.

This paper reports the preliminary results of a study carried out in a Côte d'Ivoire on the contribution of growth dynamics of untapped clones of *Hevea brasiliensis* in determining tapping norms.

MATERIALS AND METHODS

Materials

The study was made using three untapped clones of *Hevea brasiliensis*, namely PB 235, GT 1 and PR 107, which belong to three different classes of vegetative growth. Clones PB 235, GT 1 and PR 107 respectively, represent fast, intermediate and low growth classes.

Methods

Principle of growth modelling. According to Tayeb *et al.*[4], the modelling is a simplified representation of a complex reality and the mathematical formalism is a valuable tool to describe characteristics of the modelised reality. So, modelling is used to translate the experimental results in a mathematical expression, explaining better growth phenomenon.

Criteria of the choice for the growth model. The growth of plants is a continual function, but for every species, there is a maximal value *M*, not reached but approached by the size when, the time is prolonged indefinitely[5]. This function is limited by the *M* value. As growth is an irreversible increase, the function does not decrease[6,7]. As girth is always positive, negative values are discarded in the function. With all these considerations, the family of models to consider are restricted to those that are continuous, without negative, without decreasing and limited function[8]. For this purpose, Debouche[8] and Burillon[9] present two types of growth models taking into account the defined conditions:

- Constant models used for stable growth
- Variable models used in the opposite case.

Hevea brasiliensis *growth model.* The choice of a model is based on the relative stability of growth and the low residual standard deviation. Clone GT 1 girth data have been tested with growth models described by Debouche[8]. The retained model characterises the vegetative growth of *Hevea brasiliensis* clone GT 1. Thus, *it is shown that the vegetative growth of a* rubber tree is best described by the model of Johnson-Schumacher in relation to results of *Table 1*. This model was proposed respectively by Johnson[10] and Schumacher[11].

The analytic expression of the model of growth of Johnson-Schumacher is:

$y = f(x) = Me^{(-b/x-a)}$ where a, b, and M are parameters. Y is girth in cm at 1 m from the ground, x is the time expressed in years.

Principal characteristics of rubber tree growth. The vegetative growth of *Hevea brasiliensis* is similar to that of most higher plants. It has three growth phases: first, a slow growth phase where the curve has a convex form followed by a very fast or exponential growth near the inflexion point. A second phase follows this somewhat linear phase of slow growth. This second phase which begins with a concave-like curve, is continued by a pratical linear form, defining, in this way, a sigmoïd curve. Our study is focussed on the beginning of the third phase, called 'critical point'. It is at this 'critical point' we think that we would be able to determine the age and corresponding girth. The growth speed V of the model retained is such that:

$$V = f(x) = [Mb \,/\, (x-a)^2]\, e^{(-b/x-a)}$$
$$\text{or}: e^{(-b/x-a)} \,/\, (x-a)^2 = f(x) \,/\, Mb$$

I, A and B are defined as follows:

I (x_1, y_1) is the inflexion point where the maximum growth rate is such that: $x_1 = a + b/2$ and y_1.

A (x_A, y_A) is the point at the end of the first phase of growth (slow) and the beginning of the second (fast) growth phase.

B (x_B, y_B) is the last point of the second phase of growth and the first point of the third (slow) phase of growth.

In other words, V_I, V_A and V_B are the respective growth rates at points I, A and B. Growth being more or less linear in the second phase, the rates V_A and V_B are equal. The points A and B, we are looking for belong to the part of the curve easily assimilated to the right such as $V_A = V_B$[9]. To do this, starting from the fact that point I belongs to a linear phase of fast growth, the linearity of points of the growth curve will be studied in relation to this inflexion point.

RESULTS

Modelling of the Vegetative Growth of *Hevea brasiliensis*

Model of growth. Girth of the clones was measured over ten years *(Table 2)*. The clones were planted with 510 or 555 trees/ha in the rubber zones of the South-east and South-west of Côte d'Ivoire. The girth sizes were measured every year, starting from the end of the second year, in plantations of about 3 ha.

Girth values are constant *(Table 2)* whatever the clone of *Hevea brasiliensis*. This allow

TABLE 1. CONSTANT MODELS

Model	Analytic expression	Values of parameters			Residual error
		M	a	b	
Johnson-Schumacher	$Y = M\, e^{[-b/(x-a)]}$	175.81	–2.23	10.51	1.11
Gaussien	$Y = M\,\{1 - e^{[-((x-a)/b)^2]}\}$	101.86	4.74	4.34	5.62
Mitscherlich	$Y = M\,\{1 - e^{[-(x-a)/b]}\}$	169.61	0.19	17.24	1.78
Gompertz	$Y = M\, e^{\{-\mathrm{Exp}[-(x-a)/b]\}}$	101.86	4.74	4.34	5.62
Logistic	$Y = M/\{1 + e^{[-(x-a)/b]}\}$	93	5.97	2.65	14.52

Y = girth (cm) ; X = age (year) ; M = maximal size of the girth ; a, b = parameters in unity of X.

the use of constant models for this study. Five models have been tested on clones GT 1, PB 235 and PR 107 *(Table 1)*. The analytic expressions obtained for the vegetative growth are *(Figure 1)*:

GT 1: Girth (cm) = 175.81 $e^{[-10\ 51\ /\ (age\ +\ 2\ 23)]}$

PB 235: Girth (cm) = 182.61 $e^{[-8\ 84\ /\ (age\ +\ 1\ 87)]}$

PR 107: Girth (cm) = 185.45 $e^{[-11\ 39\ /\ (age\ +\ 2\ 42)]}$

Characterisation of Growth

The principal components of growth characterisation in *Hevea* are shown in *Table 3*.

Principal Characteristics of Growth

The model of Johnson-Schumacher shows variable characteristics *(Table 3)* of the growth curve, according to the class of growth.

TABLE 2. GIRTH OF CLONES PB 235, GT 1 AND PR 107 (CM)

Clone/Year	2	3	4	5	6	7	8	9	10	11
PB 235	17.5	30.3	41.2	51.1	60.4	65.8	74.0	80.8	85.2	92.9
GT 1	14.9	23.1	33.7	71.9	49.5	56.4	62.0	66.7	74.3	80.1
PR 107	14.0	22.1	31.8	39.6	48.5	54.4	61.2	67.4	73.7	79.5

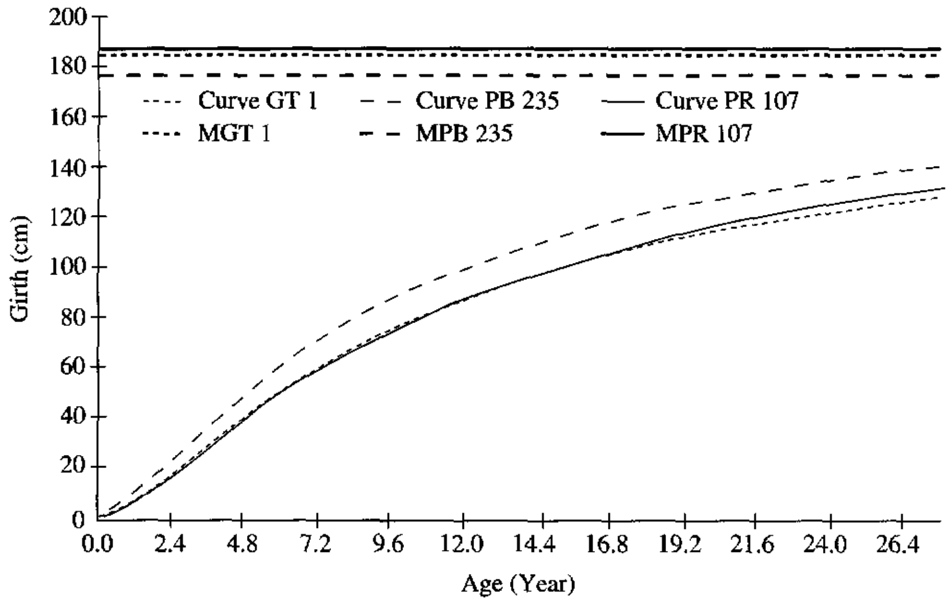

Figure 1. Vegetative growth curve of Hevea brasiliensis *[Johnson-Schumacher Model according to Debouche (1979)]*

Rate of growth. The growth rates of respective clones PB 235, GT 1 and PR 107 are as follows:

$V_{GT1} = f'(x) = [M\,b / (x-a)^2]\, e^{[-b/(x-a)]}$

$e^{(-b/x-a)} / (x-a)^2 = f'(x) / M\,b = => f'(x) = 1708.14\, e^{[-10.51/(age + 2.23)]} / (age + 2.23)^2$

$V_{PB\,235} = f'(x) = [M\,b / (x-a)^2]\, e^{[-b/(x-a)]}$

$e^{(-b/x-a)} / (x-a)^2 = f'(x) / M\,b = => f'(x) = 1614.27\, e^{[-8.84/(age + 1.87)]} / (age + 1.87)^2$

$V_{PR\,107} = f'(x) = [M\,b / (x-a)^2]\, e^{[-b/(x-a)]}$

$e^{(-b/x-a)} / (x-a)^2 = f'(x) / M\,b = => f'(x) = 2114.13\, e^{[-11.39/(age + 2.42)]} / (age + 2.42)^2$

The maximal and average growth rates are obtained by the following expressions:

$V_{average} = 1 / M\,(dy/dx)\,dy = 0.25\,M / b$

$V_{max} = 4\,M / e^2\,b$

Time of growth and maximal growth. The time of growth *(T)* is defined by Debouche[8] as the time needed by the plant to achieve the biggest part of its growth. The maximal growth [$C(T)$], corresponds to the maximal part of the growth contained in the time of growth. Expressions of these parameters of the model are:

$T = M / V_{average} = 4\,b$

$C(T) = 0.779\,M$

Determination of Critical Point (B)

A quasi-linearity *(Figure 2)* is noted between the points of the abscissae contained in intervals: [1.39 ; 5.80], [1.08 ; 5.40] and [1.57 ; 6.20], in clones GT 1, PB 235 and PR 107, respectively. This linearity is confirmed by the coefficient determination r^2, with r^2 = cov $(X, Y)/(\beta_x\beta_y)$, of the linear regression. The value of this coefficient determination is equal to 1 ($r^2 \sim 1$). It means that the vegetative growth of *Hevea brasiliensis*, during this period, have a linear form *(Figure 3)*. Therefore, it is concluded that the minimal growth rate of this second phase is reached when X_A = 1.39 and X_B = 5.8 with 7.74 cm/year, X_A = 1.08 and X_B = 5.4 with 9.25 cm/year and X_A = 1.57 and X_B = 6.20 with 7.57 cm/year for clones GT 1, PB 235 and PR 107, respectively.

DISCUSSION

The vegetative growth of clone is similar to that of most superior plants. It presents three

TABLE 3. PARAMETERS, GROWTH RATE AND GROWTH TIME OF CLONES PB 235, GT 1 AND PR 107

Clone	a	B	M	V_{max}	V_{aver}	$I\,(x_I\,;\,y_I)$	T	$C(T)$
PB 235	–1.87	8.84	182.61	11.18	5.16	(2.55) (24.71)	39.24	142.25
GT 1	–2.23	10.5	175.81	9.06	4.18	(3.02) (23.75)	42.00	136.96
PR 107	–2.42	11.4	185.45	8.81	4.07	(3.28) (25.10)	45.60	144.47

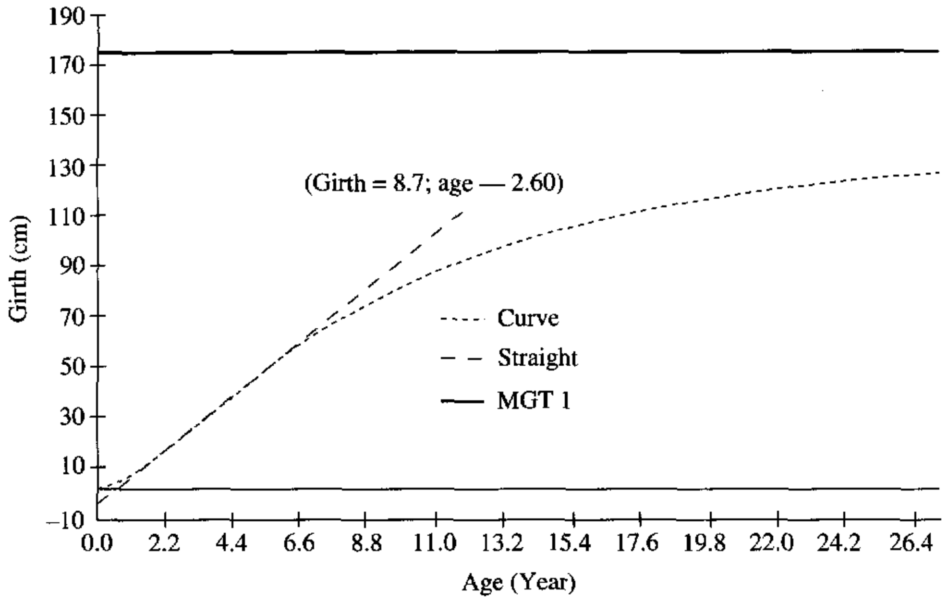

Figure 2a. Linearity of the second phase of growth of clone GT 1.

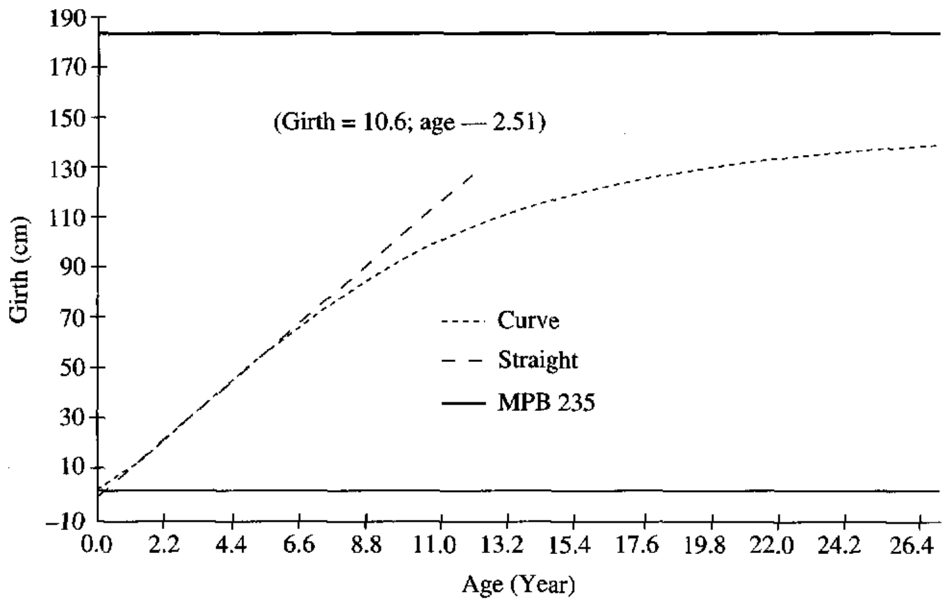

Figure 2b. Linearity of the second phase of growth of clone PB 235.

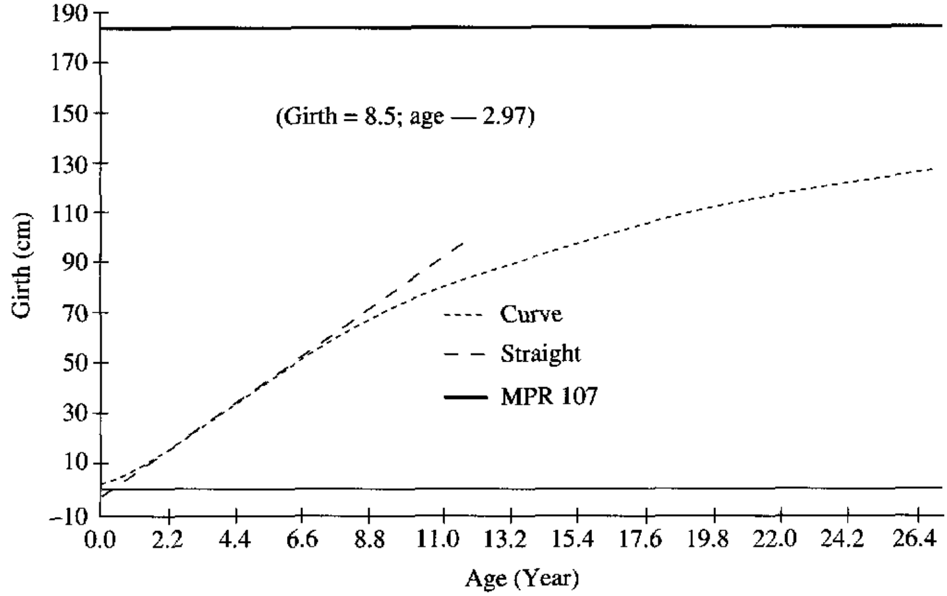

Figure 2c. Linearity of the second phase of growth of the clone PR 107.

phases of growth : a slow growth phase (with a convex tendency), followed by a very fast or exponential growth phase, containing the point of inflection. To this more linear phase followed a second slow growth phase with a concave tendency and is continued by a practically linear form, defining a sigmoïd curve.

The vegetative growth of clones PB 235, GT 1 and PR 107 is characterised by a high push during a short period; 2 to 3.5 years, with a maximum increase at the end of this period. It is followed by a negative slow growth covering a greater part of the plant's life. The point of inflexion is in the lower half of the growth curve, conferring on it a dissymetric left slope[8,9]. This left dissymetric slope, which is very strong, seems to constitute a characteristic that will lead to the definition of a maturity criteria. In fact every thing happens as if the plant puts up, within a short time, the essentials of structures giving it force and maturity.

This study shows further that the growth of the same species of *Hevea brasiliensis* is well described by the same model of growth (*Table 2* and *3*). The particularities observed are rather clonal, such that the three classes of growth produce a family of three superimposed curves (*Figure 1*). This will present a particular interest where some phenomena can be produced at the same time regardless of the clone, apart from the size of plants which will be in line with the growth class of clones. The analyses of the dynamics of growth shows that one can reasonably determine a favourable moment for the tapping of *Hevea* without great damage to its physiological state. This will correspond with the growth curve at the point beginning the third phase of growth. This point which we term 'critical point' really exists and is evidenced by the examination of the growth rate table of the three clones studied, under the conditions in Côte d'Ivoire, which present a somehow critical point too. This point is effectively apparent from the

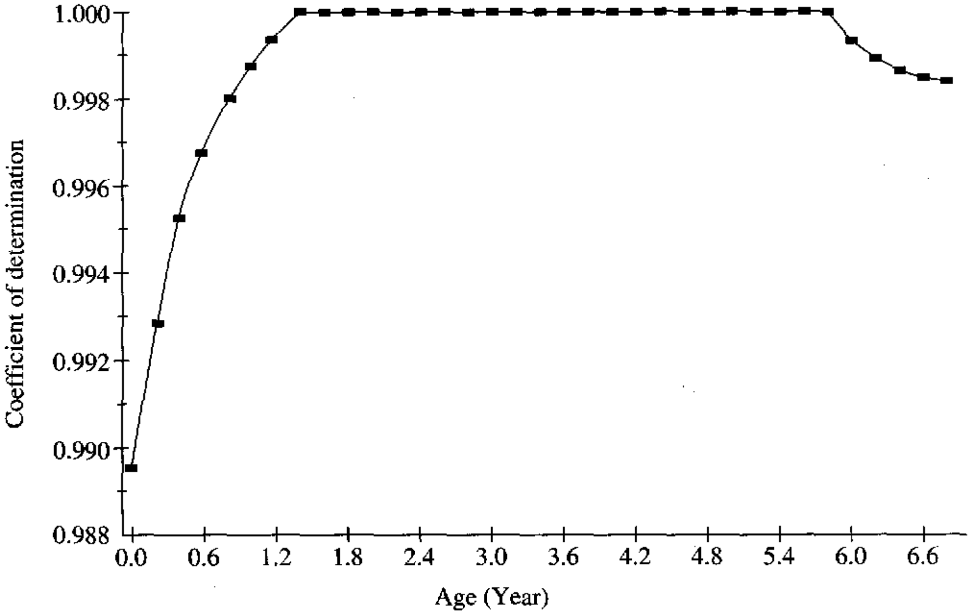

Figure 3a. Coefficient of determination of the linear regression of the growth of Hevea brasiliensis *clone GT 1.*

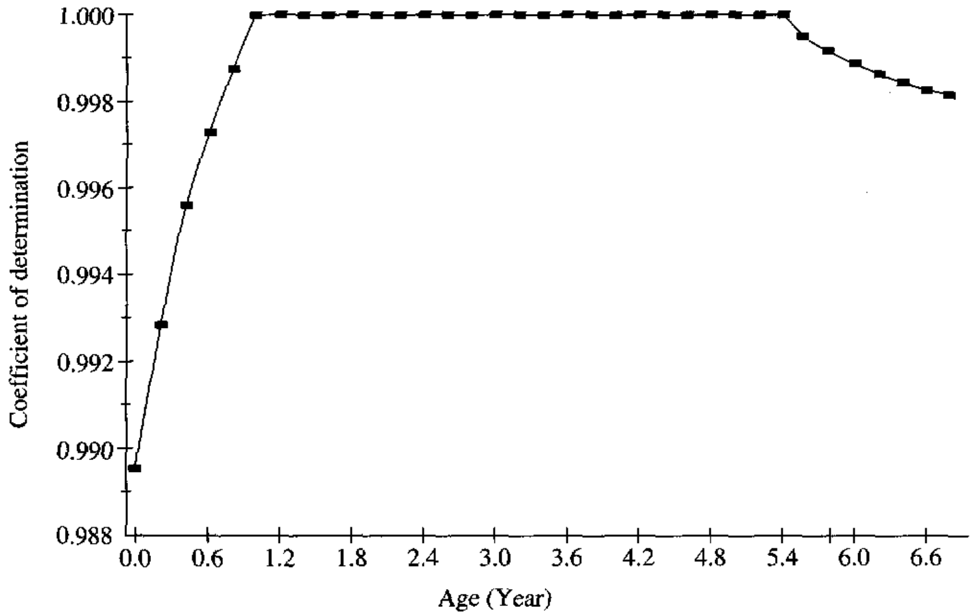

Figure 3b. Coefficient of determination of the linear regression of the growth of Hevea brasiliensis *clone PB 235.*

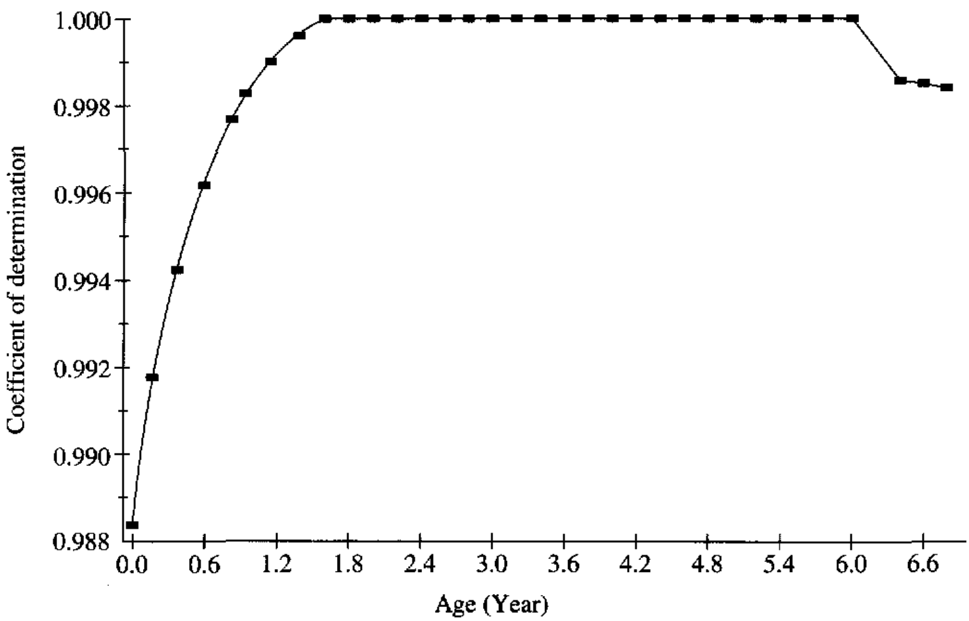

Figure 3c. Coefficient of determination of the linear regression of the growth of Hevea brasiliensis *clone PR 107.*

6th year after planting. Until confirmation is given by further studies, we think that this point will indicate a great phenological and or physiological phenomenon, and physiological maturity. This will signify that *Hevea brasiliensis*, irrespective of its clone and the growth class of the clone, reaches maturity at the same time, that is 6 years after planting.

The maturity as defined is reached at an age where it corresponds to a time when the plant would have put forth the essentials of the requirement to ensure the production of rubber. However, the maturity alone cannot permit the determination of the tapping period of *Hevea*. In fact plants can, at the supposed age of maturity, remain stunted due to slow growth caused by various reasons. They cannot be tapped because tapping them at a girth inferior to 40 cm reduces drastically the annual girth growth and is likely to affect future yield levels. The notion of maturity must therefore be coupled with that of minimal size in tapping.

CONCLUSION

This study of the dynamics of vegetative growth of *Hevea brasiliensis* shows a growth curve which can be described as a dissymetric sigmoid, very strong on the left. It consists of particularities which distinguish clone classes whose growth are illustrated by a family of curves. The analysis of the growth rate led to the definition of a 'critical point' which is the starting point of the third phase of growth; this critical point is determined where it corresponds with an important stage of the plant's development – the physiological maturity. At the end of this analysis, we can conclude that the phase of rapid growth begins between 1.08 years and 1.60 years and ends between 5.4 years and 6.2 years inclusive. In other words, the fast growth of clones studied begins around 11 months after planting and ends at the age of 6 years Furthermore, this phenomenon occurs practically at the same age, irrespective of the growth class of the clones This maturity becomes effective 6 years after planting The definition of this criteria should not be a condition *sine qua non* for the tapping of rubber since some delay in growth is observed, such that the plant can be stunted even while having the supposed age of maturity This implies that henceforth the notion of age should be imperatively coupled with that of minimum girth size for the tapping of rubber These results confirm the current norm for moderate and slow growth clones (GT 1, PR 107, *etc*) while in case of clones with fast growth such as PB 235, IRCA 111, *etc* , a similar adaptation is necessary

The results reported here will lead further studies involving a great number of clones It will also be possible to conduct an anatomical structures study of the bark of *Hevea* Such studies should lead to a better use of genetic improvements

ACKNOWLEDGEMENT

The authors wish to thank Dr Logon Theophile, researcher at the Mathematical Research Institute (IRMA) and Krappe Emmanuel, student at the University of Cocody, for their mathematical contribution The valuable assistance of Sylla Soualiho and Dr Koffi K Edmond (CNRA/ Bimbresso) for the translation, and Barro Bouraima and Amani Kouadio (CNRA/ Bimbresso) for their computing assistance, is also appreciated

Date of receipt July 1999
Date of acceptance January 2000

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