J. Rubb. Res., **11(3)**, 171–186

Static Modelling Approaches to Predict Growth (Girth) of Hevea Brasiliensis *as Tools for Extension Activities in Malaysia*

YAHYA ABD KARIM*#

Rubber (Hevea brasiliensis) is one of the most important agricultural industries in Malaysia. Its production provides the livelihood of large segments of the Malaysian population consisting of smallholders, estate workers and their families. Being a complex agricultural system, a model would help to organise available information or knowledge in order to identify gaps and direct future research in rubber based systems. It may also help in the process of dissemination of the technology to farmers as well as rubber planters. Hence, an attempt is made to develop a model to predict the growth of rubber under different planting densities, climate, clones and management. Validation results show that the model is able to simulate growth (girth) from different range of environment and rubber clones from Malaysia with the modelling efficiency (EF) of 0.87.

Key words: model; dissemination of the technology; predict; growth

The success of introducing technologies to rubber growers depend on how easily these could be adopted by them. As rubber is one of the most important agricultural industries in Malaysia and provides the livelihood of a large segment of the Malaysian population, efforts need to be made to ensure that all available technologies are well disseminated to smallholders through all channels of extension work. Modelling is considered as one of the tools that can be used in education and training[1] as well as in extension activities. This work attempts to explain how the development of a simple static model, outlining the relevant equations and parameters, may be used in this capacity.

Modelling for the simple static model was carried out using SPSS Inc[2]. and Microsoft EXCEL computer software.

The Outline of The Model

A schematic diagram of the model is shown in *Figure 1*.

The following set of assumptions is made before running this static model:

- the planting materials (2-whorl budded plants) are uniform for all experimental sites;

* Rubber Research Institute of Malaysia, Malaysian Rubber Board, P.O. Box 10150, 50908 Kuala Lumpur, Malaysia
\# Corresponding author (e-mail: yahya@lgm.gov.my)

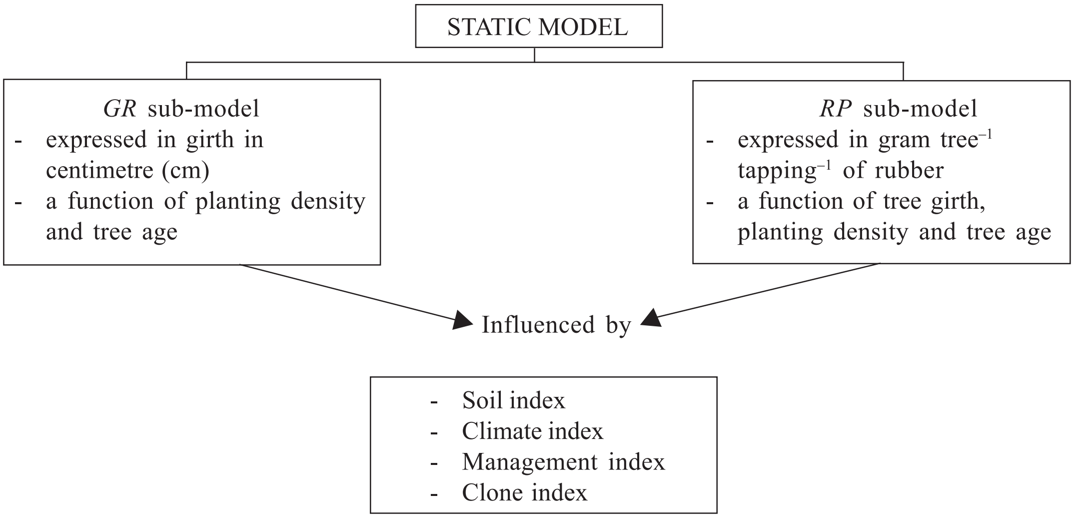

Figure 1. Schematic diagram of the static model.

- optimal management practices (*i.e.* fertiliser, weed control, pest control *etc.*) are applied at all experimental sites
- optimal growth conditions occur at all experimental sites (*i.e.* rainfall, temperature, sunshine *etc.*);
- tapping starts at similar times (*i.e.* 0700hrs) and is carried out on good quality tapping panels.

Description of The Model

Hevea has sometimes been described as a plant able to grow on most soils in the tropics, but its maximum performance and economic viability is restricted due to factors such as clones, climate, management practices and other factors.

In this model, the growth of rubber is influenced by different factors, expressed as a Soil Index (*SI*), Climate Index (*CL*), Management Index (*MGg*) and Clone Index for growth (*CIg*), such that the actual growth (GR_{actual}, or girth) is expressed as:

$$GR_{actual} = GR_{max}(SI \times CL \times MGg \times CIg) \quad \dots 1$$

Girth is the main parameter used to determine the growth of rubber and is measured at 160 cm above ground. The maximum girth (GR_{max}) of rubber is a function of tree age and density (trees ha^{-1}) and can be expressed as adapted[3]:

$$GR_{max} = \frac{2.37 \times TAge \times \phi}{22 + TAge + 3.7 \times 10^{-4} \times \left[\frac{TAge^2 \times D}{0.2 + 5 \times D}\right]^{1.35}} \quad \dots 2$$

TABLE 1. SUITABILITY CLASSIFICATION OF SOME COMMON MALAYSIAN SOIL SERIES FOR RUBBER PRODUCTION

Soil class/ (index value)	Properties/ Physical limitations	Comment	Some Malaysian soil series in this class
Class I (1.0)	No limitation Depth - > 200 cm Texture - Sandy clay, Clay loam, Silty Clay loam Gravel and stones (%) - < 15%; pH - 5 - 6 Drainage - well drained; Altitude - < 200 m Nutrient status - high to medium; Slope - < 3%	Soils that have no limitation for rubber cultivation	Munchong, Jeram Prang, Segamat Kuantan, Rengam Jerangau, Yong Peng Bungor
Class II (0.9)	Minor limitation Depth - 150 - 200 cm Texture - Fine sandy clay loam, Loam, Clay Silty clay Gravel and stones (%) - 15 - 20%; pH - 4.5 - 5 Drainage - well drained; Altitude - 200 - 500 m Nutrient status - medium to low; Slope - 3 - 8%	Soils that have one or more minor limitations	Harimau, Senai Batang Merbau, Subang, Kulai
Class III (0.8)	Moderate limitation Depth - 100 - 150 cm Texture - Coarse sandy clay loam, Sandy loam Gravel and stones (%) - 20 - 90%; pH - 4 - 4.5 Drainage - moderately well drained; Altitude - 500 - 600 m Nutrient status - low to very low; Slope - 8 - 20%	Soils that have at least one moderate limitation	Holyrood, Ulu Tiram Pohoi, Tampoi, Lunas Serdang, Kuala Brang
Class IV (0.6)	Serious limitation Depth - > 50 - 100 cm Texture - Loamy sand Gravel and stones (%) - 90%; pH - 6.5 - 7.0 Drainage - Imperfectly drained; Altitude - 600 - 800 m Nutrient status - low to very low; Slope - 20 - 35%	Soils that have more than one serious limitation	Batu Anam, Durian Malacca, Gajah Mati Marang, Kedah, Seremban
Class V (0.4)	Very serious limitation Depth - < 50 cm Texture - Sand, Peat Gravel and stones (%) - > 90%; pH - < 4 or > 7 Drainage - poor, very poor drained; Altitude - > 800 m Nutrient status - low to very low; Slope - > 35%	Soils that have at least one very serious limitation	Selangor, Briah Sungai Buloh, Linau

Source: [7,8]

Where,

TAge = Tree age from time of planting (years)

D = Tree density (number of trees ha^{-1})

Φ = 120 (a constant representing clonal growth performance)

SI, CL, MGg and *CIg* are performance indices varying between 0 to 1.0, based on the Rubber Research Institute of Malaysia's (RRIM) Planting Recommendations[4-6].

GR_{max} refers to optimal conditions, represented in this model by 1.0 for each index (*SI, CL, MG, CIg*).

Soil Index (SI)

The soil index used in this model was based on soil suitability classes for rubber[7] and also on limiting factors for land suitability classifications for rubber, as recommended[8]. The Malaysian soil series have been classified[7,9] into five categories of suitability for rubber-growing as shown in *Table 1*.

Climate Index (CL)

Hevea generally performs best in the tropical lowland climate. Thus, different climatic conditions would be expected to adversely affect growth and production of rubber. In this model, the climate index is a function of sub-indices comprising rainfall *(Ri)*, light (*Li*) and temperature (*Ti*) and expressed as:

The calculation of the climate sub-index is explained below. The value ranges from 0 to 1.0, with 1.0 reflecting the climate that is best for rubber cultivation. Each sub-index equation is derived using statistical software SPSS Inc. SigmaPlot 2001 for Windows and Microsoft EXCEL XP, based in turn on the relationship between relative rubber growth or yield performance against the climate parameters with the highest correlation coefficient (R^2).

Rainfall (Ri)

Rainfall between 1500 to 2500 mm per year is generally considered optimal for rubber cultivation. *Figure 2* shows the overall effect of rainfall on the girth of rubber, indicating that annual rainfall between 1000 to 1100 mm is sufficient for rubber to survive, but above 1200 mm performance is much improved.

In this model, a rainfall index is calculated based on the relationship between *relative* girth and the amount of rainfall. The relative growth rate is calculated based on the girth at that particular rainfall level over the maximum girth of rubber[10].

The results from the regression analyses by the SigmaPlot software shows that the

$$CL = f\,(\text{Rainfall } (Ri) \times \text{Light Index } (Li) \times \text{Temperature Index } (Ti)) \quad \ldots 3$$

Where f is the function of *Ri, Li* and *Ti*

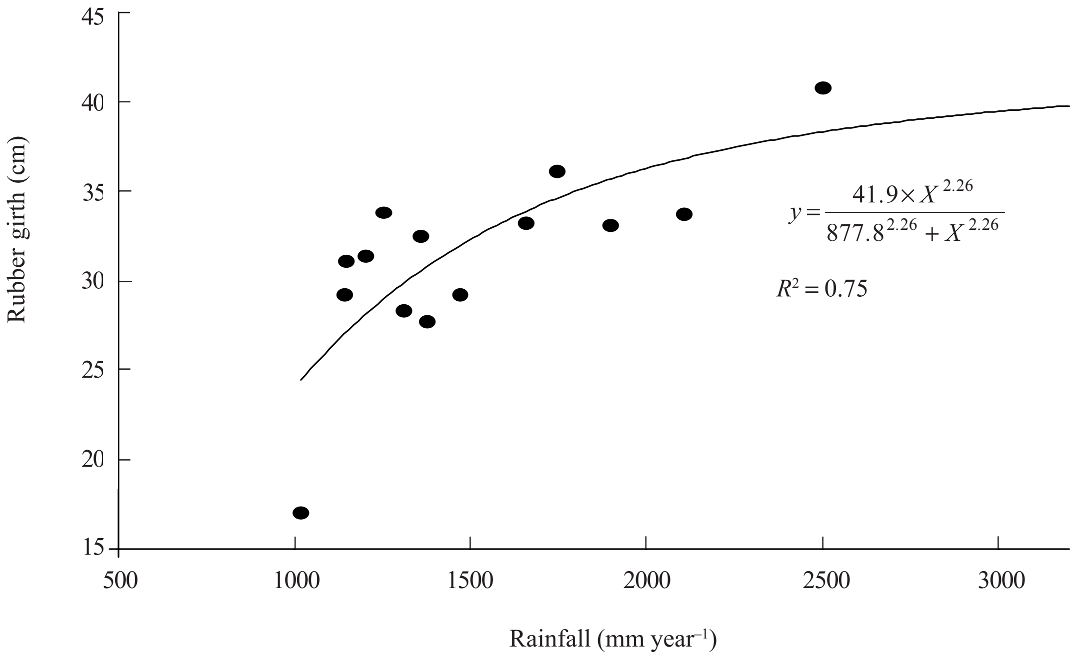

Figure 2. The effect of the rainfall on the actual girth (cm) of clone GT 1 after four years of planting.

equation below is best fit with the highest R^2 (0.75) and written as follows:

$$Ri = \frac{1.037 \times R^{2.26}}{898.2^{2.26} + R^{2.26}} \qquad \ldots 4$$

R = Rainfall in mm year^{-1}

The *Rainfall* (*Ri*) index is in between the range of 0 to 1.

Light Index (Li)

In this model the *Li* is calculated based on results[11], where the average monthly sunshine (*SS*) (direct radiation) hours data was plotted against the *relative* yield of rubber (*Figure 3*). The relative yield of rubber here is based on the yield of rubber for a particular quantity of sunshine, divided by the maximum yield of rubber.

The *Li* is expressed as follows:

$$Li = \frac{1.018 \times SS^{2.13}}{52.78^{2.13} + SS^{2.13}} \qquad \ldots 5$$

$$R^2 = 0.62$$

The relationship between the average monthly sunshine hours and the yield of rubber for GT 1 shows that longer sunshine hours are positively correlated with the yield of rubber (*Figure 3*).

The *Li* will give a value of 0 or 1 to reflect the optimum amount sunshine that is adequate for growth of rubber.

Temperature Index (Ti)

Based on data for the GT 1 clone[11], the relationship between the yield of rubber and

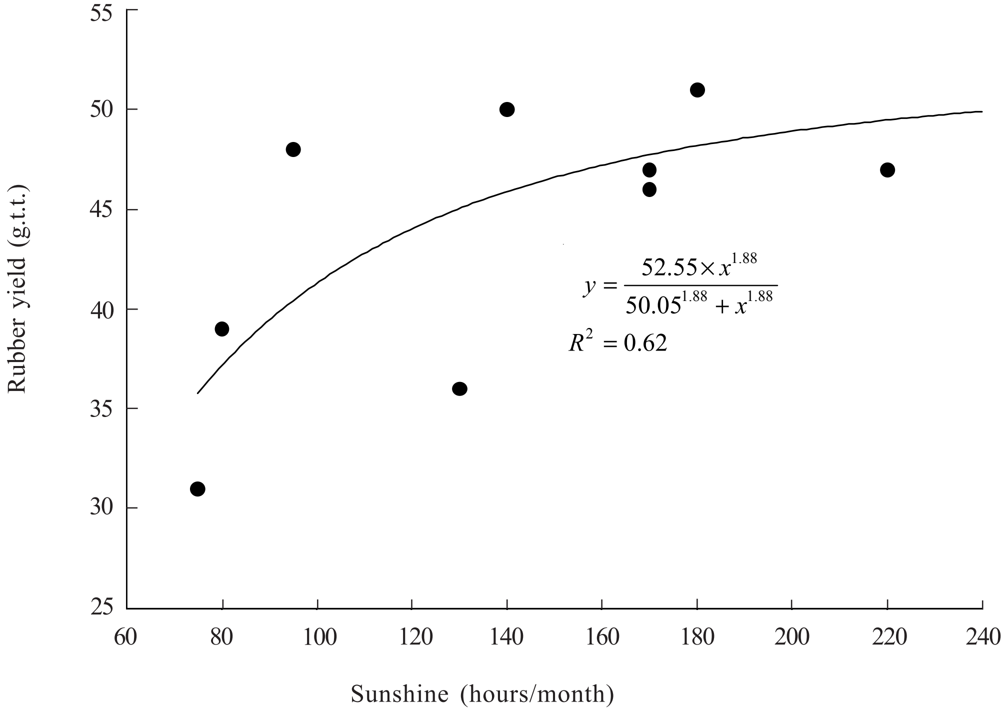

Figure 3. The relationship between sunshine received on GT1 rubber yield (g.t.t. - gram tree^{-1} tapping^{-1}) of the clone[11].

the monthly mean temperature (°C) shows an increase in between 24°C–28°C, followed by a decline at or above 30°C (*Figure 4*).

The relative yield is calculated based on the yield of the particular month divided by the highest yield of rubber and the equations that best fit (R^2 = 0.89) is as follows:

$$T_i = -0.0154Tcc + 0.8864T - 11.797(24°C < T < 28°C) \quad \ldots 6$$
$$R^2 = 0.89$$

Where T values between 24°C–28°C are assumed good for rubber plantations.

Since there is no data to relate the effect of temperature directly to growth (girth), it was assumed that the temperature index (*Ti*) for growth is similar to that for rubber production (*Equation 6*). This assumption seems valid as the yield of rubber is positively related to the girth of rubber trees[12,13].

Clone Index (CIg)

Girth of rubber is affected by tapping at different girth sizes between tapped and untapped[14]. Girth increment of a tapped tree is 58.7% (0.587) less than the girth increment of untapped rubber tree[15].

If tapping is started when the tree is too young and slender, subsequent growth and girth will be poor and the relationship is written as:

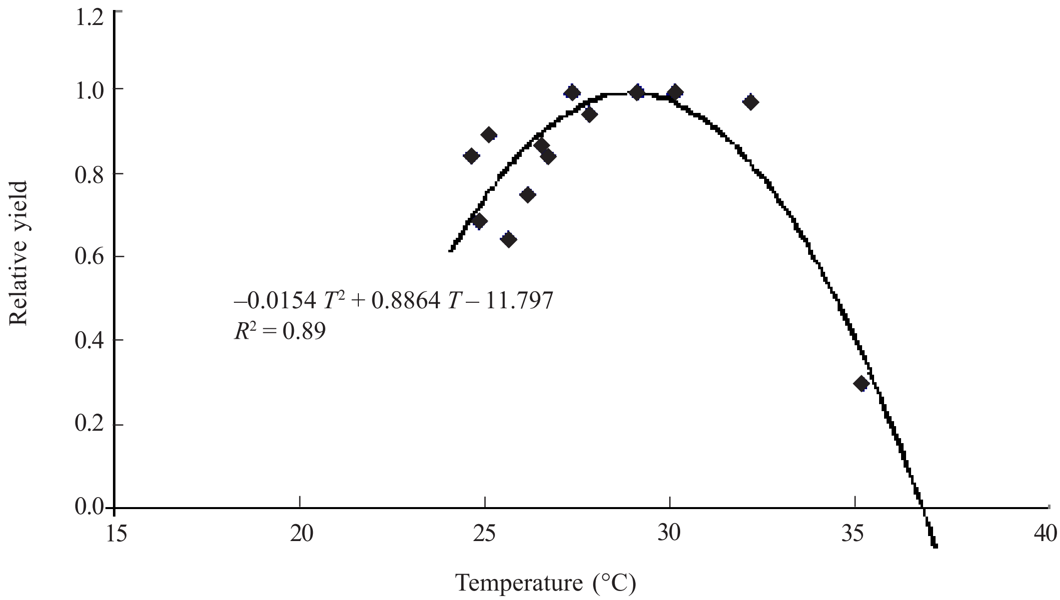

Figure 4. The relative yield of rubber against temperature.

$CIg = GR_{actual} \times site\ index \times (1.0 - 0.587)$ if tree is tapped before it reaches 45 cm girth (< 45 cm).

where CIg = the clone index for the growth model

For the trees that remain untapped either before or after the girth has reached 45 cm, the girth is calculated as;

$$CIg = GR_{actual} \times site\ index \times (1.0/0.587) \quad \ldots 7$$

TABLE 2. EXAMPLES OF *CIg SITE* INDICES FOR DIFFERENT CLONES BASED ON RRIM PLANTING RECOMMENDATIONS[4,6]

	Site Index (*site*)				
Clone	GT 1	PR 261	PB 260	RRIM 600	PR 255
Resistance to pink disease	0.8	1.0	0.6	0.6	0.6
Resistance to *Oidium*	0.8	0.6	0.8	0.8	0.6
Resistance to *Colletotrichum*	0.8	0.8	0.6	0.6	1.0
Resistance to *Corynespora*	0.8	0.8	0.8	0.8	0.8
Resistance to *Phytopthora*	0.6	0.6	0.8	0.6	0.6

The *site index* (*Table 2*) is based on incidence of *Phytophthora, Corynespora, Colletotrichum, Oidium* and *Pink diseases* (*Cortisium salmonicolor*) in Malaysia.

If the trees are tapped after the girth has reached > 45 cm, then $CIg = 1.0 \times site\ index$.

Management Index (MGg)

Rubber trees are grown under a wide range of management conditions either as monocrop or in mixture with other crops. During the immature period, it is important to establish conditions that favour the growth of rubber. Leguminous cover crops are often established due to their capability to provide N_2 from nitrogen fixation and to provide a clean, weed-free surface in the strip-planted areas. If no understorey crops are established, weed growth will compete for available growth resources such as nutrients, water and space. It is important to include the effect of ground cover as this may affect growth and production of rubber in a positive or negative way.

It was reported that rubber trees planted with leguminous cover crops treatment could be tapped 11 months earlier than when crops were left weedy with natural grasses[16]. Maximum (or optimal) management inputs are given both to immature and mature crops, including the establishment of leguminous cover crops and complete weeding in the planting row up to the width of the canopy.

In this model the Management Index (MG_g) is calculated as a function of Ground Cover Index (*Gci*) and fertiliser effect (Fef_g) and is written as:

$$MG_g = f(Gci) \times Fef_g \qquad \text{... 8}$$

Ground Cover (Gci)

Ground cover index is calculated using the following formula[17]:

$$Gci = 0.50*exp\ (\%L/1.445) \times (1 - 0.4(\%Weed\ control\ (WC)) \qquad \text{... 9}$$

Gci is a function of the % light fraction (*L*) of ambient at ground level and the % of weed control (*WC*). *L* is the percentage of light penetrating the rubber tree canopy covered area as well as planting strip that is occupied by other crops (*i.e.* natural weeds *etc*). *WC* defines the percentage of weeds (*i.e. Imperata* grass species, *etc*.) controlled (*i.e.* 40%) leaving the remainder weedy (60%). Percentages are expressed as 0.6 for 60% or 0.4 for 40%.

Fertiliser Effect (Fef_g)

Fertiliser experiments carried out[18] show that the girth rate of unfertilised rubber trees was 12% lower on average compared with fertilised plots. Therefore in this model, *Fef* is defined as:

$$Fef_g = 1 - fg \qquad \text{... 10}$$

where f_g = 0 if the trees receive optimal fertiliser

f_g = 0.12 if the trees are unfertilised

Model Validation

The accuracy of a certain model can be evaluated through validation processes. Validation is better understood as a process that results in an explicit statement about the behaviour of a model[19]. To determine the accuracy of the developed static model for predicting the growth of rubber, simulated values from the model were compared to the experimental data based from for Malaysian conditions (RRIM, 1980;1998), data from the RRIM Planting Recommendations[4,5,6,20]. Validation also will be extended to other widely planted rubber clones (*e.g.* RRIM 901, PR 255, PR 261, PB 260 and RRIM 600) in Malaysia.

This validation process is important as it gives an indicator whether the developed model demonstrates an ability to simulate growth as well as rubber production in a wide range of clones. If the output of the model corresponds well with the experimental data, then the model is an adequate representation of a rubber tree system. If not, then it will provide some basis for improvement of the developed model. The validation processes is carried out by using a set of statistical analyses[21] formulated to evaluate the performance or accuracy of the developed model. The mathematical expressions that describe the analyses are presented as in *Table 3*.

Where,

Pi = predicted values
Oi = observed values
n = number of samples
σi = mean of the observed data

The lower limit for the maximum error, root mean square error and coefficient of determination (ME, RMSE and CD) is zero, while the maximum value for the modelling efficiency (EF) is one. Both EF and coefficient residual mass (CRM) can become negative. If EF is less than zero, the model-predicted

TABLE 3. MATHEMATICAL EXPRESSIONS OF THE STATISTICAL ANALYSES USED FOR MODEL VALIDATION[21]

Criterion	Calculation formula	Range
Maximum error (ME)	$Max\,\lvert Pi - Oi \rvert \Big\vert_{i=1}^{n}$	≥ 0
Root mean square error (RMSE)	$\left[\sum_{i=1}^{n}\left(\frac{Pi - Oi^2}{n}\right)\right]^{0.5} \cdot \frac{100}{\sigma}$	≥ 0
Coefficient of determination (CD)	$\frac{\sum_{i=1}^{n}(Oi-\sigma)^2}{\sum_{i=1}^{n}(Pi-\sigma)^2}$	≥ 0
Modelling efficiency (EF)	$\frac{\left(\sum_{n=1}^{n}(Oi-\sigma)^2 - \sum_{n=1}^{n}(Pi-\sigma)^2\right)}{\sum_{n=1}^{n}(Oi-\sigma)}$	≤ 1
Coefficient of residual mass (CRM)	$\frac{\left(\sum_{n=1}^{n}Oi - \sum_{n=1}^{n}Pi\right)}{\sum_{n=1}^{n}Oi}$	≤ 1

values are worse than the observed mean. The CD is a measure of proportion of the total variance of observed data explained by the predicted data.

As the main criterion used to determine the growth of rubber is the development of tree girth, the comparison of observed *versus* simulated girth is shown in *Figure 5* below. The graph shows that the model is able to simulate the girth of rubber with a good correlation ($R^2 = 0.92$) for a range of different clones.

Taking individual clones, it is possible to examine how different management practices affect the accuracy of model prediction. *Figure 6* shows observed and simulated values of clone RRIM 901, planted under different land use sectors (estate and smallholder).

This demonstrates that the model is able to simulate the girth of rubber under different land use sectors with a reliable correlation coefficient ($R^2 = 0.99$). The ability of the model to predict the growth of this clone on different soil classes (class I and class II) also showed a good relationship ($R^2 = 0.99$) between observed and simulated values (*Figure 7*).

As above, the statistical criteria[21] were used to evaluate the modelling efficiency for growth (girth) for a range of clones, land use sectors and soil classes. The results are given in *Table 4*.

The coefficient of determination (CD) from this analysis is used to express the ratio of the scatter of simulated and observed values. Statistically, the lower limit for CD is 0 while the value closer to 1 is a good value. Negative values for EF mean that modelling variability is greater than experimental variability[24]. Negative (< 0) values of modelling efficiency (EF) indicate that the mean of the observed values is a better estimate than that derived from simulations. A positive (> 0) coefficient of residual mass (CRM) values indicates a tendency to underestimate the observed values, while negative ones indicate a tendency to overestimate[21]. In this case the CRM is -0.05, indicating that this model overestimates the growth of the rubber.

DISCUSSION

From the above statistical analyses and validation results, the simulated results appear to fit well with the experimental data, with modelling efficiencies of 0.87 for a range of clones and environments (*Table 4*). However, there is a tendency for the model to

TABLE 4. OVERALL STATISTICAL ANALYSIS FOR OBSERVED *VERSUS* SIMULATED GROWTH (GIRTH) FOR A DIFFERENT RANGE OF CLONES

Parameters	Value
Number of observations or data sets (n)	157
Maximum Error (ME)	8.0
Root Mean Square Error (RMSE)	15.5
Coefficient of Determination (CD)	1.94
Modelling Efficiency (EF)	0.87
Coefficient of Residual Mass (CRM)	–0.05
Correlation coefficient (R^2)	0.92

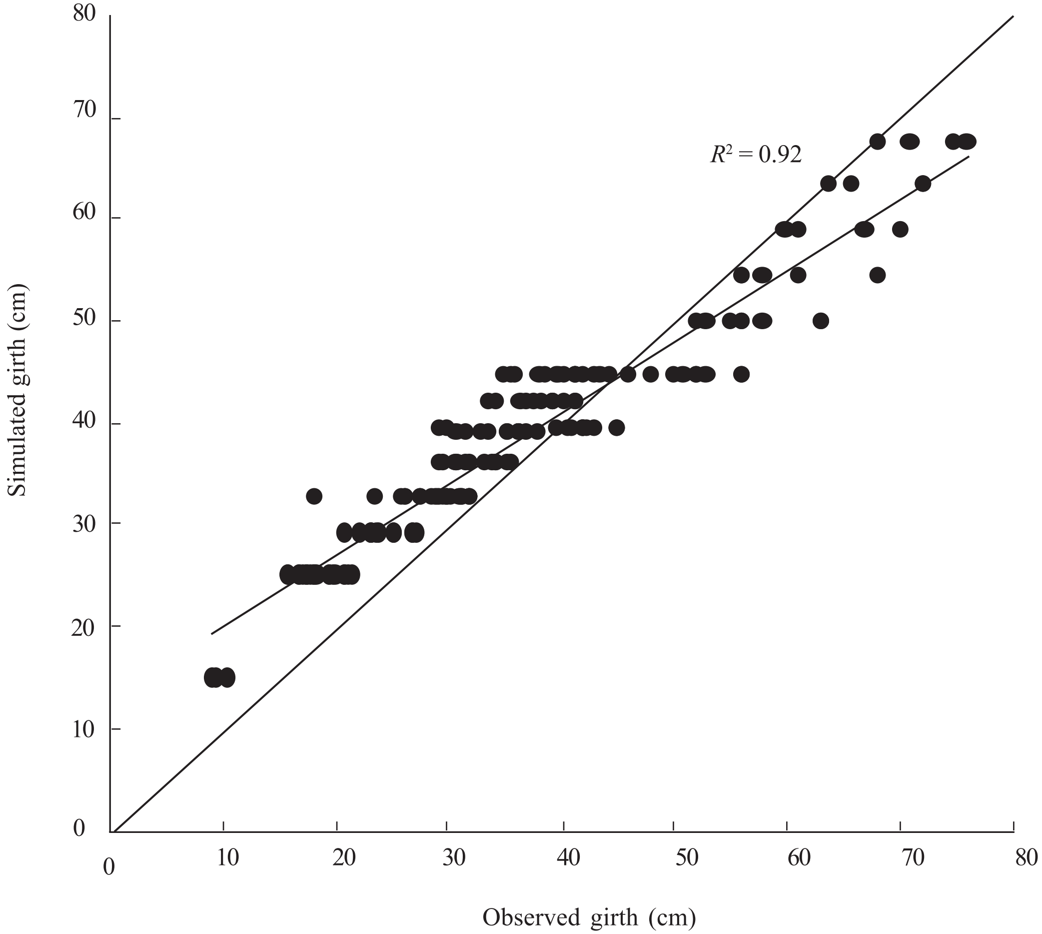

Figure 5. Observed vs simulated rubber growth (girth) for a range clones, land use sectors and soil types.
Clones: RRIM 901, PR 255, PR 261, PB 260 and RRIM 600

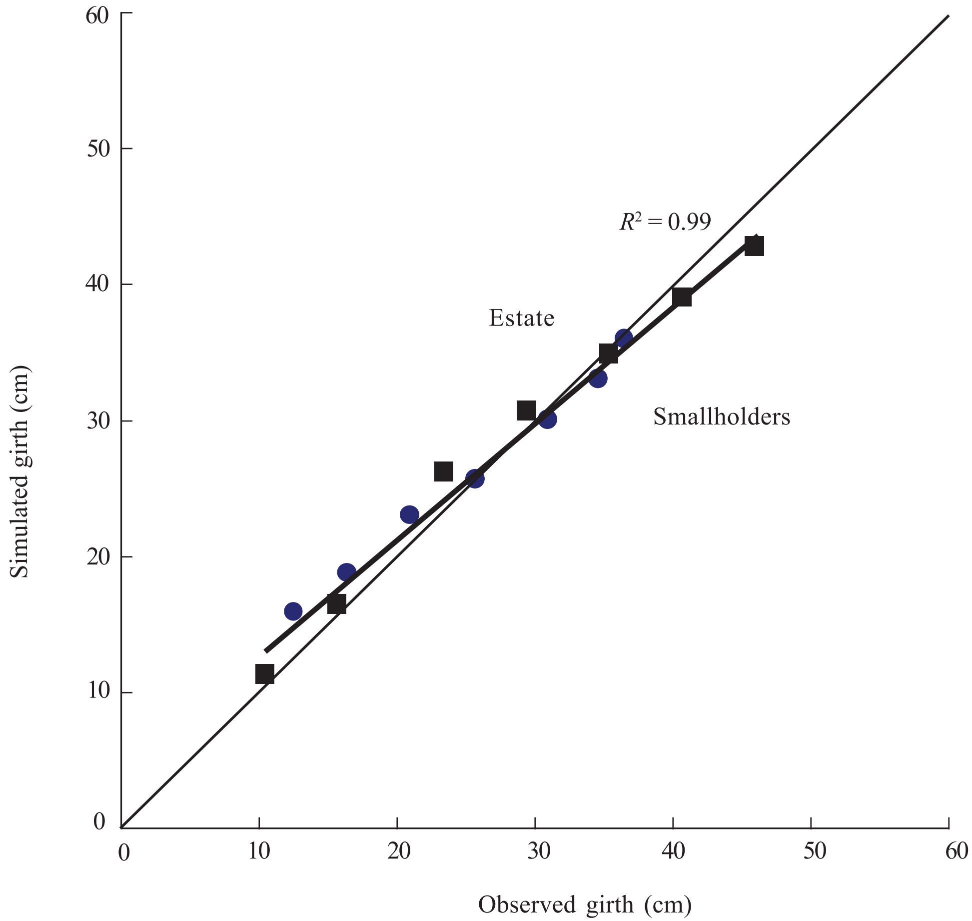

Figure 6. Observed vs simulated girth for RRIM 901 during immaturity period in different land use sectors (■ - estate and • - smallholders)[18,22,23].

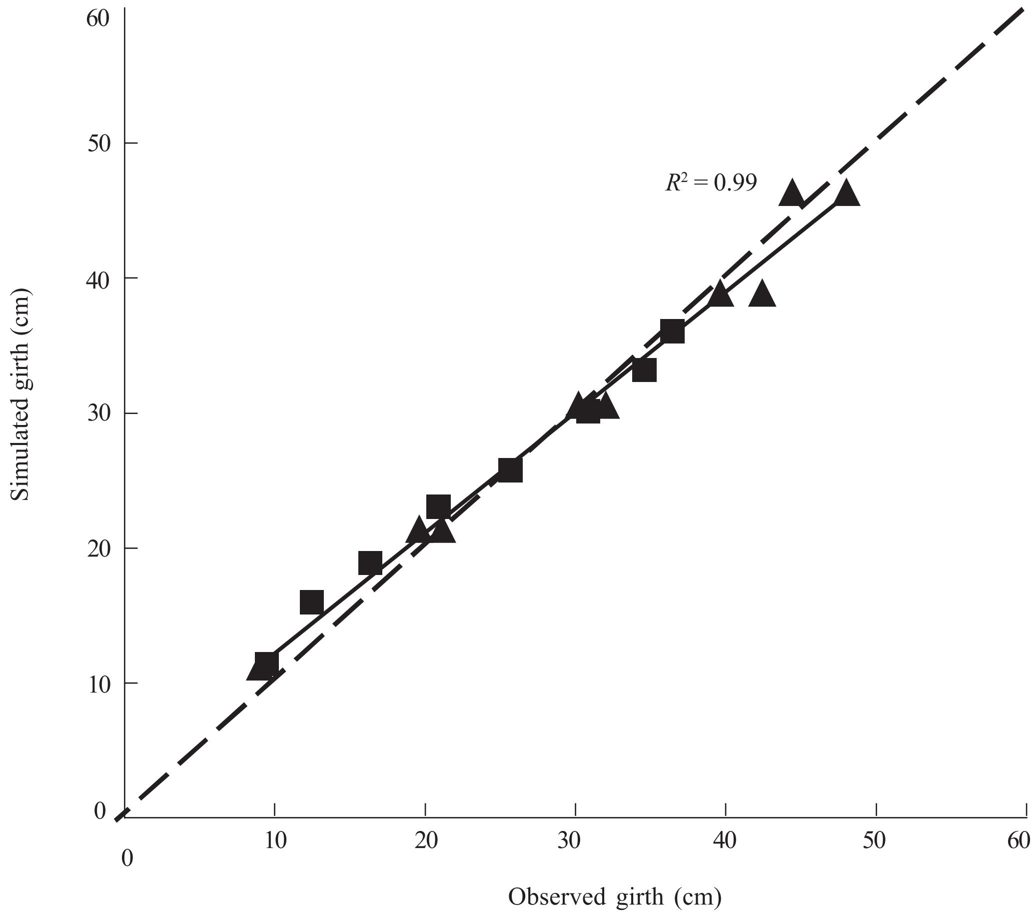

Figure 7. Observed vs simulated growth for rubber during immaturity period of clone RRIM 901 on class I (▲) and class II soils (■)[18,22,23].

overestimate the growth and the reason could be linked to many factors such as the selection of planting material, weather conditions and agro-management factors. The successful establishment of nursery stock in the field depends on the type and quality of planting materials. The type of material, *e.g.* stock derived from 2-whorl polybag budding, 2-whorl budded plants, green budding, brown budding *etc*., will determine the performance of each type according to environmental conditions such as climate, soils and management.

As this model assumed that the planting stock was uniform for every experimental site, the use of different types of planting stocks, with different periods in the nursery, could be a reason for overestimation.

Successful establishment of nursery stock is also related to weather conditions. Even though conventional recommendations dictate that rubber planting is carried out during the wet season. Dry periods occurring after planting may cause casualties depending on the type of planting stock or planting materials used. Any replacement then depends on the availability of planting materials.

Hence, the growth of rubber in the field does not tend to be uniform due to different planting dates, consequently resulting in lower than expected girthing rates. The longer the time taken for replacement, the more the girth of the trees varies, giving low average girth measurements. Since this model assumes uniform growth conditions, the simulation results will tend to overestimate growth, especially in the early stages.

CONCLUSION

Despite the fact that this model includes only a limited number of parameters related to climate, soil, clone and management, it is able to simulate with a good efficiency (EF) of 0.87 growth (girth) of rubber.

Even though this is a simple static model, it has advantages such as:

- ability to simulate growth and production for a range of different rubber clones;
- ease of construction, as few input parameters are involved;
- the facility to make improvements or adjustments, as the relationships between parameters are relatively few;
- use as a starting point for beginners and as a step to using and understanding more complex models;
- use as an extension tool for end users (smallholders), as it is easy to understand.

Date of receipt: May 2007
Date of acceptance: March 2008

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