GIRTH GROWTH OF RUBBER (*HEVEA BRASILIENSIS*) TREES DURING THE IMMATURE PHASE

T. R. Chandrasekhar*, J. Alice, Y. A. Varghese, C. K. Saraswathyamma & K. R. Vijayakumar

Rubber Research Institute of India, Kottayam – 686 009, Kerala State, India

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CHANDRASEKHAR, T. R., ALICE, J., VARGHESE, Y. A., SARASWATHYAMMA, C. K. & VIJAYAKUMAR, K. R. 2005. Girth growth of rubber (*Hevea brasiliensis*) trees during the immature phase. Growth and performance of rubber trees (*Hevea brasiliensis*) during the immature phase were studied in a tropical humid climate. Monthly girth growth of the main stem from 25 clones, between ages three and eight years, was monitored. Monthly girth increments, seasonal and annual absolute and relative girth rates were the analysis parameters. Three seasons, *viz.* S1 (April till July), S2 (August till November) and S3 (December till March) were demarcated for seasonal comparisons. All clones followed a broadly similar pattern of growth. Monthly girth increment varied from 0 to 2 cm month^{-1}. Girth growth began in April/May, peaked in July/August, declined from October and terminated by December. In the subsequent period up to March, no growth was observed. Most of the growth occurred in S1 and S2 with values of 43 and 53% respectively. Based on growth attributes, four groupings of clones were obtained. The results indicated an annual growth period of seven to eight months with an annual mean girth increment of 6.5 cm annum^{-1} and a mean relative increment rate of 2.5 mm cm^{-1} annum^{-1}.

Key words: Para rubber – immature growth – growth rate – growth duration – clonal variation

CHANDRASEKHAR, T. R., ALICE, J., VARGHESE, Y. A., SARASWATHYAMMA, C. K. & VIJAYAKUMAR, K. R. 2005. Pertumbuhan ukur lilit pokok getah (*Hevea brasiliensis*) semasa peringkat belum matang. Pertumbuhan dan prestasi pokok getah (*Hevea brasiliensis*) semasa peringkat belum matang dikaji. Pokok ini tumbuh di kawasan beriklim tropika yang lembap. Pertumbuhan ukur lilit bulanan bagi batang utama 25 klon getah berumur antara tiga tahun hingga lapan tahun direkodkan. Pertambahan ukur lilit bulanan, kadar-kadar ukur lilit mutlak tahunan dan bermusim serta kadar-kadar ukur lilit relatif tahunan dan bermusim merupakan parameter untuk analisis. Tiga musim iaitu S1 (April hingga Julai), S2 (Ogos hingga November) dan S3 (Disember hingga Mac) dipilih untuk perbandingan musim. Semua klon menunjukkan pola pertumbuhan yang agak sama. Pertambahan ukur lilit bulanan berjulat dari 0 cm bulan^{-1} hingga 2 cm bulan^{-1}. Pertumbuhan ukur lilit bermula pada April/Mei mencapai maksimum pada Julai/Ogos, menurun dari Oktober dan berhenti pada Disember. Tiada pertumbuhan diperhatikan selepas itu sehinggalah Mac. Kebanyakan pertumbuhan berlaku semasa S1 dan S2 dengan nilai masing-masing 43% dan 53%. Berdasarkan ciri-ciri pertumbuhan, empat kumpulan klon diperoleh. Keputusan menunjukkan tempoh pertumbuhan tahunan pokok getah sebanyak tujuh bulan hingga lapan bulan dengan purata pertambahan ukur lilit tahunan sebanyak 6.5 cm dan purata kadar pertumbuhan relatif sebanyak 2.5 mm cm^{-1} setahun.

**E-mail: chandratr@rubberboard.org.in*

Introduction

Rubber (*Hevea brasiliensis*) is one of the major industrial crops grown mainly in tropical climates between 12° latitude on either side of the equator. In India, it is largely cultivated in the humid tropical zone between 8° 15' N and 12° 52' N latitudes. Even though the environmental conditions here are comparatively more congenial for growth and productivity of *Hevea*, moderate soil moisture stress is experienced annually. The planting material is routinely propagated by bud grafting high-yielding selections onto seedlings, producing many individuals of a clone. The trees reach a suitable girth for tapping after about seven to eight years. During this period the trunk girth measurements are widely used as attributes of growth. Although growth in *Hevea* can be measured in various parameters, girth or circumference measurement of the main trunk (bole) remains the most important. It is a variable of major interest to planters and is the main factor taken into consideration for evaluating tree growth and attainment of maturity (about 50 cm girth at a height of 150 cm from the bud union) for crop harvesting (called tapping). Girth and girth increment of trees are used in experimental work to assess the growth performance of new planting materials and the effects of cultural treatments on growth (Shorrocks *et al.* 1965, Chandrashekar *et al.* 1998).

Studies on growth are of fundamental importance in understanding the interaction between plant and their environmental conditions (Rose & Charles-Edwards 1981, Hunt 1982). In *Hevea* too, girth increment can be related directly to the accumulation of dry matter. Data relating changes in plant morphology to plant age can be useful in studies dealing with modelling long-term growth. To this end, growth analysis can provide useful insights into the influence of biotic as well as abiotic factors on it.

In *Hevea*, although there is good amount of information on the annual growth patterns, both during immature and mature phases of the trees (Webster & Baulkwill 1989, Sethuraj & Mathew 1992, George & Jacob 2000), reports on growth analysis are scanty. The work of Templeton (1968) was the first major attempt. He studied the biomass accumulation during the immaturity period following destructive sampling. An analysis of immature growth by Chandrashekar *et al.* (1998) and Vijayakumar *et al.* (1998) were the second important efforts. They analysed immature growth of various clones growing in dry sub humid climate where prolonged drought and high summer temperatures exist using trunk girth recordings measured on a monthly basis. However, very little is known about the detailed time-course of the growth of plants in humid tropical conditions (Chandrasekhar *et al.* 2002). The aim of this work was to present an analysis of growth and its performance in *Hevea* trees during their immature phase in humid tropical climatic conditions.

Materials and methods

Study location, field planting and crop management

This study was conducted at the Rubber Research Institute of India at Kottayam (9° 32' N, 76° 36' E, altitude 73 m asl), Kerala State, South India. Two trials were laid out as part of the on-going programme for evaluation of modern clones. The experimental site of the first trial (trial I) was west facing slope (32.5 to 46.6%) and that of the second (trial II) was mostly north facing slope (32.5 to 55.4%) with a small part on a hillock top. The soil is Ustic Kanhaplohumults with a bulk density of 1.25 Mg m^{-3}, permanent wilting point at 19.7% and field capacity at 27.8 %.

The clones used in the trials and their basic details are given in Table 1. Each trial consisted of 13 clones with RRII 105 included in both the trials. Three whorled bud grafted plants raised in polythene baskets (55 × 25 cm, lay flat dimension) for

Table 1 Clones and their basic details

Clone	Parentage	Country of origin
Haiken 1	Primary clone	China
SCATC 88 - 13	RRIM 600 x Pil B84	China
SCATC 93 - 114	TR 31 - 45 x HK 3 - 11	China
RRII 5	Primary clone	India
RRII 105	Tjir 1 x Gl 1	India
RRII 118	Mil 3/2 x Hil 28	India
RRII 208	Mil 3/2 x AVROS 255	India
RRII 300	Tjir 1 x PR 107	India
RRII 308	Gl 1 x PB 6/50	India
PR 255	Tjir 1 x PR 107	Indonesia
PR 261	Tjir 1 x PR 107	Indonesia
PB 217	PB 5/51 x PB 6/9	Malaysia
PB 235	PB 5/51 x PB S/78	Malaysia
PB 255	PB 5/51 x PB 32/36	Malaysia
PB 260	PB 5/51 x PB 49	Malaysia
PB 280	Primary clone	Malaysia
PB 310	PB 5/51 x RRIM 600	Malaysia
PB 311	RRIM 600 x PB 235	Malaysia
PB 312	RRIM 600 x PB 235	Malaysia
PB 314	RRIM 600 x PB 235	Malaysia
RRIM 600	Tjir 1 x PB 86	Malaysia
RRIM 703	RRIM 600 x RRIM 500	Malaysia
KRS 25	Primary clone	Thailand
KRS 128	PB 5/63 x KRS 13	Thailand
KRS 163	PB 6/63 x RRIM 501	Thailand

five months were used for planting. Field planting of the trials was carried out in July and August 1989. The design adopted was randomized complete block design with seven replications in trial I and five replications in trial II. The experimental plots consisted of seven plants in a row in contour planting at a spacing of 3.4 × 6.7 m giving a planting density of 445 plants ha^{-1}. Standard cultural practices such as manuring, weeding, mulching and sun scorch prevention were all part of the agro-management of the crop.

Plant and weather data

Girths of the main stem, measured at monthly intervals from March 1991 till March 1997 (third to eighth year after planting), were the primary data from which growth analysis quantities were derived. Girth measurements were measured from all trees at a fixed height of 1.5 m from the bud union (collar region). Trees under observation were numbered and all recurring girth measurements were made on these trees at the same position marked with paint (renewed every year) and the girth was always measured exactly along the paint mark. Every month, measurements were taken on the first three days and were considered as representing the girth of the trees at the end of the previous month. Meteorological data, i.e. rainfall, minimum and maximum temperatures, and sunshine duration for the respective study periods and the preceding 10 years were collected from the observatory maintained at the station.

Growth analysis parameters

Derivatives of the girth, *viz.* monthly girth increment (absolute girth rate), seasonal and annual absolute and relative girth rates, and their means are the growth analysis attributes. The attribute, relative girth increment rate (R_g), that indicates new girth per unit plant girth per time step was used to study the rate of variations in clones due to seasons and age. It was calculated as $(\ln G2 - \ln G1) \times 10$, where $G1$ and $G2$ are the girth in cm at time $T1$ and $T2$ respectively. The multiplication constant 10 was used to convert the R_g values to mm as the unmultiplied values were very small.

Monthly, seasonal and annual growth trends

Monthly increases in trunk girth were studied. In each trial and clone, girths of trees were used to work out trunk girth averages and monthly increments. To compare growth differences between the clones at different seasons, the 12-month period from April till March was divided into three seasons, i.e. S1, S2 and S3. April till July is the S1 season characterized by adequate soil moisture in the first half of the season and excess soil moisture in the second half, August till November is the S2 season with excess soil moisture in the first half of the season and good to adequate soil moisture in the second half, and December till March is the S3 season which is mostly rainless with low soil moisture. In order to match the growth of clones with the designated seasons, the seasonal growth of each clone was obtained by subtracting the girth value of March with that of July, the value of July with that of November and the value of November with that of subsequent March to represent S1, S2 and S3 seasons respectively. Percentage contribution of the seasons to the annual growth and changes in annual girth increments and the rate as well as the progress of tappability percentage of each clone six years after planting were worked out.

Clustering of clones based on growth parameters

Clustering pattern of the clones was studied by using initial girth, seasonal and annual mean absolute and relative girth rates, mean culmination of absolute growth rate (I_g) absolute girth and percentage tappability of clones up to the end of six years after planting as phenotypic characters in estimating dissimilarity between clones following squared Euclidian distance. Six years after planting was chosen because of maximum variability between the clones in tappability percentages as it is the variable of major interest to planters and is the main factor taken into consideration for evaluating the progress of tree growth and attainment of maturity for crop harvesting. By subjecting the dissimilarity matrix to UPGMA clustering algorithm (Sneath & Sokal 1973) a dendrogram was constructed to depict the grouping structure of clones. A mean distance of 10 was set for truncating clusters of similar growth characteristics.

Statistical analysis

In each trial and clone, girths of plants of all the replications were used to calculate trunk girth averages. Data of plants that became discontinuous due to diseases and wind damages were excluded from analysis. Wherever appropriate, the data were subjected to analysis of variance. Statistical features of trial-wise, year-wise pooled seasonal and clone-wise annual I_g and R_g were calculated. Data analysis and lattice plots of the monthly variations in I_g of the clones were done using R-package (Ihaka & Gentleman 1996).

Results

Weather conditions

The region received an annual rainfall ranging from 2000 to 4000 mm. The rainfall period was from April till November and could be distinguished into two moderate seasons and one major season. The first moderate rainfall season was in April and May. Rains during this season started from pre-monsoon thunderstorm activity that brought relief showers, recharging the soil with adequate soil moisture. This was succeeded in June by the arrival of the south-west monsoon that continued till September, and this was the major season. These rains resulted in excess soil moisture. Occasional periods of monsoon cloud cover extended for 7–10 days, severely restricting the direct-beam solar radiation. Maximum precipitation (about

65% of the total) occurred in this season and a large portion of it was lost as runoff. The October–November period was the second moderate rainfall season that was dominated by post-monsoon north-east rains. It was comparatively weak but brought in good rainfall before withdrawing by mid-November. Thereafter, from December till March, the region did not usually receive rains, resulting in stressful soil moisture deficits. During this season diurnal variation in air temperatures was sporadically punctuated by daily extremes stressful to plant growth.

Monthly mean maximum temperature varied from 28 to 35 °C and that of mean minimum temperature, from 20 to 25 °C. Variation in maximum temperature was not much. Mean maximum temperature in the summer season was around 34 °C but occasionally reached 38 °C. In the remaining months, it was around 31 °C. Mean sunshine duration (SSD) in the summer was around nine hours per day and evaporation was around 5 mm per day. In the monsoon months, mean SSD was 4.4 hours a day while in post monsoon months it was around 5.7 hours a day. Both seasons had similar evaporation values with slightly higher values in the latter season. Maximum humidity was normally 80% reaching 100% during the rainy season.

Monthly growth patterns

Monthly I_g varied from 0 to 2 cm month^{-1} (Figures 1 and 2). In both trials, acceleration phase in I_g started from April and culminated in July in trial I, and in August in trial II. The deceleration phase in trial I was from August, while in trial II it was from September. In the deceleration phase of trial I, there was a small increase in I_g in October and thereafter it declined. In the acceleration phase of trial II, a decline in I_g was observed in July in most of the clones. By December, I_g reached negligible levels in both trials and thereafter till March very little growth was observed. From the fifth year onwards, in January and March, a significant number of trees representing most of the clones showed reduction in girth of about 0.2 to 0.5 cm resulting in negative I_g values. Maximum culmination I_g in trial I was during year 3 and year 4, while in trial II it was during year 4 and year 5 (Table 2). In subsequent years, culmination I_g decreased in all clones.

Seasonal and annual trends

There was considerable variation in seasonal R_g and progressive decline in growth with age (Table 3). During year 3 (Y3) and year 4 (Y4), there was marked difference in growth of clones between trials. In Y3S1, R_g values of the trial I clones were higher but in Y3S2, R_g was the reverse. During Y4S1, there was significant reduction in R_g in both the trials, but was not so in Y4S2. In S3, a little growth was observed during Y3 to Y5, but in later years no growth was recorded. From Y5 onwards, there was progressive decline in seasonal R_g in both trials. There was not much decline in annual I_g from Y3 to Y5 but thereafter steadily declined (Table 4). On the other hand R_g steadily declined right from Y3 in both trials. From Y3 to Y5, most of clones were growing at an I_g of 8 to 10 cm year^{-1}. In both trials most of the growth occurred in S1 and S2 (Table 5). In all the seasons, higher girth group clones had

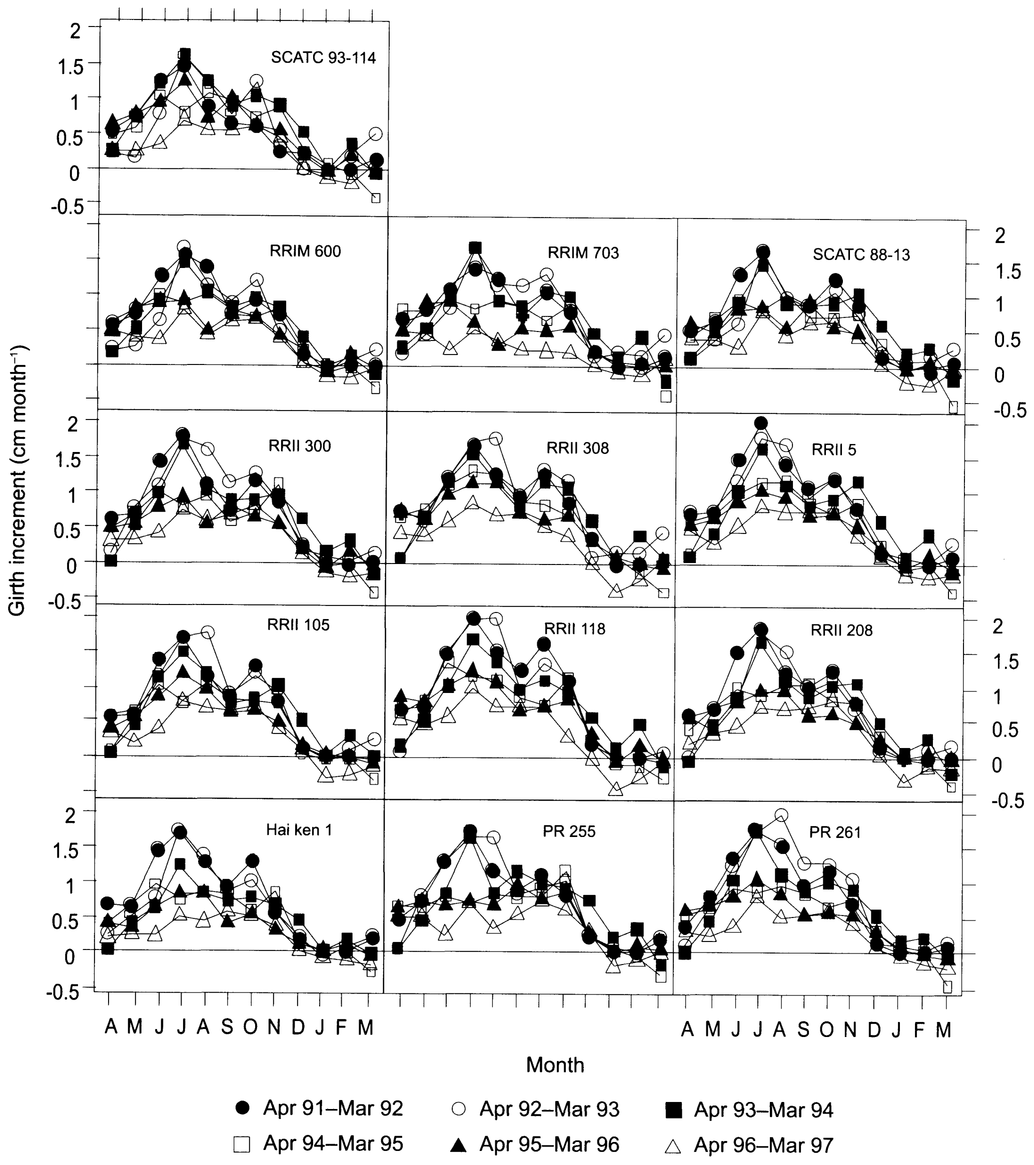


Figure 1 Monthly growth pattern of rubber clones in trial I

higher and lower girth group clones lower I_g and R_g respectively (Table 5). Growth in S1 was higher in trial I than in trial II. On the other hand, in S2 and S3, the trend was reverse. Of the total growth in a year about 42.6% occurred in S1, 51.2% in S2 and 4.7% in S3.

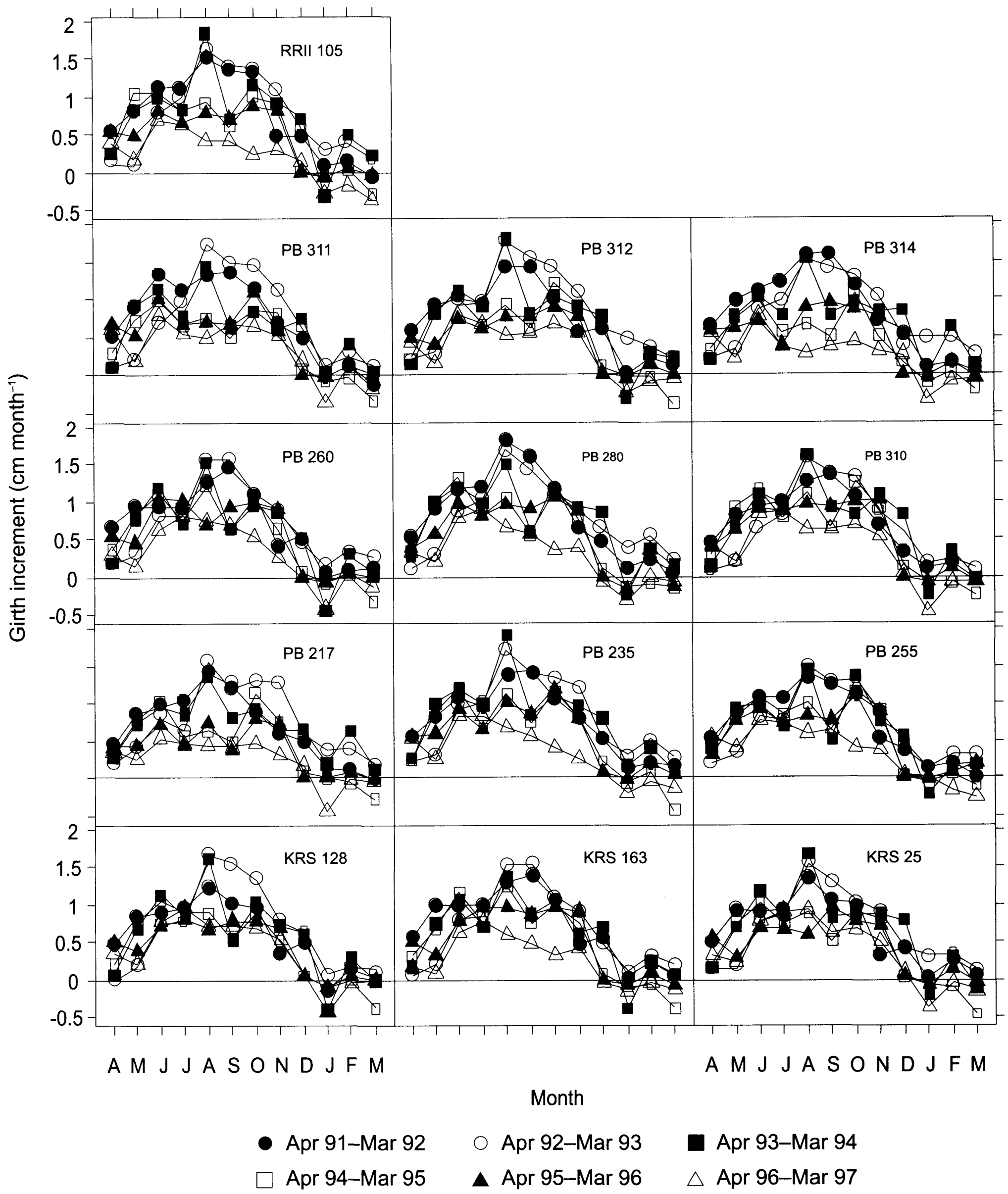


Figure 2 Monthly growth pattern of rubber clones in trial II

Immature growth performance

At the start of the study (Table 5), the largest girth observed in trial I was clone RRII 118 (13.9 cm), followed by RRII 208 and SCATC 93-114 with PR 255 (10.3 cm) as the least vigorous of the clones, while in trial II the largest girth was noted for clone PB 314 (15.0 cm), followed by PB 255 (14.2 cm). KRS 128 was the least vigorous clone. At the end of the study, RRII 118 recorded highest girth (62.2 cm) while Haiken 1 the lowest in trial I. In trial II, highest girth was observed in PB 235 (61.3 cm),

Table 2 Culmination girth increments (I_g, cm) of clones at different years

Trial/ Clone	Years after planting					
	3	4	5	6	7	8
	(91–92)	(92–93)	(93–94)	(94–95)	(95–96)	(96–97)
<u>Trial I</u>						
RRII 118	1.94	1.93	1.63	1.31	1.19	0.96
RRII 308	1.64	1.71	1.49	1.26	1.09	0.80
RRII 5	1.94	1.73	1.59	1.13	1.00	0.77
RRII 208	1.81	1.73	1.59	1.03	0.93	0.81
RRII 105	1.64	1.70	1.44	1.01	1.13	0.77
RRII 300	1.74	1.68	1.61	1.07	0.89	0.77
PR 261	1.67	1.89	1.67	0.90	0.99	0.74
SCATC 93 - 114	1.40	1.52	1.54	1.04	1.19	0.66
PR 255	1.63	1.58	1.56	1.11	0.91	0.69
RRIM 703	1.36	1.61	1.63	0.91	0.90	0.51
SCATC 88 - 13	1.57	1.60	1.41	1.01	0.90	0.77
RRIM 600	1.53	1.62	1.41	0.99	0.90	0.76
Haiken 1	1.63	1.66	1.17	0.91	0.79	0.53
<u>Trial II</u>						
PB 235	1.44	1.70	1.90	1.18	1.20	0.84
PB 280	1.80	1.68	1.50	1.32	1.06	0.90
PB 314	1.60	1.52	1.54	1.08	0.94	0.78
PB 312	1.44	1.78	1.80	1.22	0.90	0.78
PB 255	1.40	1.50	1.46	1.16	1.10	0.78
PB 310	1.36	1.58	1.62	1.26	1.02	0.86
RRII 105	1.50	1.64	1.84	1.04	0.86	0.68
PB 311	1.38	1.72	1.44	0.98	1.10	0.80
KRS 163	1.38	1.54	1.38	1.26	0.98	0.78
PB 260	1.44	1.58	1.52	1.22	1.04	0.80
PB 217	1.40	1.56	1.36	1.14	0.80	0.54
KRS 25	1.36	1.54	1.68	1.04	0.98	0.94
KRS 128	1.26	1.68	1.62	1.06	0.82	0.96

followed by PB 280 and PB 314. KRS 128 recorded lowest girth (50.7 cm). By the sixth year, only RRII 118 in trial I and PB 280, PB 235 and PB 314 in trial II had satisfactory percentage of trees ready for tapping (Table 6). In subsequent years majority of clones in trial II and four clones in trial I attained tappability. At the end of eight years, all clones attained tappability except Haiken 1.

Based on the growth attributes, four groupings of clones were obtained (Figure 3). The clones RRII 118, PB 235, PB 280 and PB 314 with a mean girth of 60.3 cm and 96% tappability formed the first group (Tables 5 and 6). The second group comprising six clones had a mean girth of 56.3 cm and 91.1% tappability while the third group also had six clones with a mean girth of 53.5 cm and 81.5% tappability. The fourth group had nine clones with a mean girth of 50 cm and 56.3% tappability.

Table 3 Seasonal changes in I_g and R_g

Parameter	Years after planting											
	3		4		5		6		7		8	
	Apr 91–Mar 92		Apr 92–Mar 93		Apr 93–Mar 94		Apr 94–Mar 95		Apr 95–Mar 96		Apr 96–Mar 97	
	T I	T II	T I	T II	T I	T II	T I	T II	T I	T II	T I	T II
	S1 (Apr–Jul)											
I_g												
Mean	4.18	3.52	3.29	2.07	3.05	2.96	3.05	2.95	2.91	2.56	1.77	2.09
Minimum	3.00	2.70	1.74	1.30	1.80	2.00	1.10	2.10	1.60	1.60	0.80	1.40
Maximum	5.40	4.60	4.50	3.80	4.70	4.20	5.10	4.00	5.30	3.40	3.50	2.90
CV(%)	11.41	13.88	17.63	20.22	17.51	15.30	19.29	13.60	20.24	17.90	24.91	18.91
R_g												
Mean	2.94	2.33	1.48	0.89	1.01	0.92	0.80	0.73	0.66	0.56	0.36	0.40
Minimum	2.25	1.87	0.80	0.58	0.63	0.56	0.31	0.47	0.39	0.31	0.19	0.27
Maximum	3.88	3.51	2.22	1.43	1.74	1.21	1.12	0.99	0.98	0.80	0.55	0.58
CV(%)	12.11	11.57	17.41	15.30	18.12	16.35	16.15	15.59	17.72	19.02	20.38	19.13
	S2 (Aug–Nov)											
I_g												
Mean	3.92	4.41	4.30	5.32	3.73	4.17	3.34	3.39	2.55	3.38	2.11	2.07
Minimum	1.40	3.00	2.66	4.10	2.10	2.70	2.30	1.80	0.60	2.20	0.80	0.30
Maximum	5.90	5.70	6.30	6.60	5.30	6.10	4.60	4.70	5.00	5.10	3.30	4.00
CV(%)	21.16	16.10	18.93	10.66	15.69	15.93	12.96	16.51	25.60	18.97	28.22	33.33
R_g												
Mean	2.12	2.31	1.65	2.01	1.11	1.17	0.81	0.78	0.54	0.69	0.41	0.39
Minimum	0.80	1.70	1.05	1.30	0.65	0.73	0.57	0.39	0.13	0.43	0.16	0.05
Maximum	2.86	2.95	2.57	2.53	1.52	1.57	1.14	1.07	0.92	0.97	0.65	0.80
CV(%)	17.42	9.98	17.50	13.52	16.39	17.04	11.30	17.57	21.78	17.71	27.91	35.49
	S3 (Dec–Mar)											
I_g												
Mean	0.24	0.76	0.51	1.38	0.83	1.01	-0.17	-0.31	0.25	0.08	-0.40	-0.40
Minimum	-0.20	0.20	0.00	0.60	-0.20	0.00	-0.60	-1.00	-0.30	-0.20	-1.10	-0.90
Maximum	1.30	2.00	2.10	2.60	2.20	2.80	0.20	0.30	0.80	0.60	0.68	0.20
CV(%)	88.96	53.83	71.17	34.73	51.53	62.72	-57.68	-76.64	74.49	208.70	-76.96	-54.31
R_g												
Mean	0.12	0.34	0.18	0.45	0.23	0.26	-0.04	-0.07	0.05	0.02	-0.08	-0.07
Minimum	-0.09	0.09	0.00	0.20	-0.06	0.00	-0.13	-0.23	-0.07	-0.04	-0.18	-0.16
Maximum	0.60	0.89	0.68	0.77	0.51	0.63	0.05	0.06	0.15	0.11	0.14	0.03
CV(%)	88.80	48.48	69.03	28.06	48.24	61.46	-56.14	-79.48	72.51	211.51	-73.94	-54.59

I_g = Girth increment (cm month^{-1}), R_g = relative girth increment (mm cm^{-1} season^{-1})
CV = Coefficient of variation

Table 4 Annual variations in I_g and R_g (mean ± SD) in various clones of *Hevea*

Clone	N	Years after planting											
		3		4		5		6		7		8	
		Apr 91–Mar 92		Apr 92–Mar 93		Apr 93–Mar 94		Apr 94–Mar 95		Apr 95–Mar 96		Apr 96–Mar 97	
		I_g	R_g	I_g	R_g	I_g	R_g	I_g	R_g	I_g	R_g	I_g	R_g
Trial I													
RRII 118	49	10.2 ± 1.39	5.54 ± 0.58	9.6 ± 1.06	3.40 ± 0.48	8.5 ± 1.09	2.26 ± 0.28	8.4 ± 1.54	1.80 ± 0.24	6.5 ± 1.59	1.19 ± 0.23	5.1 ± 1.51	0.86 ± 0.20
RRII 308	47	8.4 ± 1.81	5.54 ± 0.96	8.7 ± 1.61	3.65 ± 0.65	8.6 ± 1.20	2.68 ± 0.50	7.7 ± 1.24	1.89 ± 0.25	6.2 ± 1.36	1.28 ± 0.22	4.6 ± 1.17	0.87 ± 0.18
RRII 5	47	9.0 ± 1.64	5.57 ± 0.92	8.7 ± 1.53	3.47 ± 0.63	8.0 ± 1.22	2.36 ± 0.30	7.8 ± 1.51	1.88 ± 0.37	5.5 ± 1.39	1.14 ± 0.25	4.8 ± 1.26	0.89 ± 0.22
RRII 208	49	8.9 ± 1.22	5.29 ± 0.62	7.7 ± 1.33	3.06 ± 0.61	7.5 ± 1.02	2.29 ± 0.37	7.0 ± 1.09	1.74 ± 0.24	5.0 ± 1.49	1.07 ± 0.28	4.4 ± 0.87	0.87 ± 0.19
RRII 105	48	8.3 ± 1.49	5.23 ± 0.70	8.1 ± 1.28	3.39 ± 0.54	7.7 ± 0.95	2.39 ± 0.30	6.7 ± 0.87	1.71 ± 0.20	5.5 ± 1.20	1.21 ± 0.24	4.4 ± 1.14	0.87 ± 0.22
RRII 300	49	8.5 ± 1.11	5.37 ± 0.54	8.8 ± 1.14	3.59 ± 0.49	7.6 ± 1.07	2.32 ± 0.37	6.6 ± 1.30	1.66 ± 0.28	4.8 ± 1.42	1.04 ± 0.27	4.3 ± 1.38	0.85 ± 0.25
PR 261	49	8.2 ± 1.30	5.53 ± 0.66	9.2 ± 0.90	3.92 ± 0.56	7.6 ± 1.09	2.37 ± 0.37	6.4 ± 1.03	1.62 ± 0.22	5.1 ± 1.25	1.12 ± 0.22	3.6 ± 1.27	0.71 ± 0.21
SCATC 93 - 114	46	6.3 ± 1.32	3.97 ± 0.68	6.2 ± 1.60	2.80 ± 0.56	8.9 ± 1.09	3.05 ± 0.45	6.8 ± 1.14	1.82 ± 0.29	5.9 ± 1.16	1.33 ± 0.23	3.7 ± 1.16	0.76 ± 0.22
PR 255	47	7.9 ± 1.68	5.73 ± 0.97	8.3 ± 1.06	3.83 ± 0.74	7.7 ± 1.37	2.58 ± 0.55	6.6 ± 1.39	1.78 ± 0.38	5.5 ± 1.22	1.26 ± 0.23	4.2 ± 0.85	0.88 ± 0.18
RRIM 703	47	7.8 ± 1.59	4.97 ± 1.09	7.4 ± 1.37	3.16 ± 0.59	8.4 ± 1.52	2.70 ± 0.53	7.1 ± 1.47	1.80 ± 0.31	4.4 ± 1.17	0.97 ± 0.22	2.6 ± 0.76	0.53 ± 0.18
SCATC 88 - 13	49	8.1 ± 1.28	5.10 ± 0.74	6.6 ± 1.44	2.85 ± 0.71	7.7 ± 1.22	2.50 ± 0.35	6.5 ± 1.28	1.71 ± 0.28	4.7 ± 1.09	1.08 ± 0.20	4.0 ± 1.10	0.84 ± 0.22
RRIM 600	49	7.7 ± 1.36	4.71 ± 0.71	6.4 ± 1.32	2.72 ± 0.49	7.3 ± 1.02	2.42 ± 0.45	6.6 ± 1.09	1.76 ± 0.28	5.0 ± 1.12	1.17 ± 0.26	4.0 ± 1.28	0.84 ± 0.28
Haiken 1	45	8.2 ± 0.98	5.07 ± 0.57	7.0 ± 1.33	2.90 ± 0.52	5.4 ± 1.27	1.81 ± 0.44	5.6 ± 1.27	1.57 ± 0.34	3.7 ± 0.87	0.90 ± 0.21	2.8 ± 0.87	0.64 ± 0.19
Pooled	621	8.3 ± 1.64	5.20 ± 0.88	7.9 ± 1.69	3.29 ± 0.70	7.8 ± 1.41	2.44 ± 0.49	6.9 ± 1.43	1.75 ± 0.30	5.2 ± 1.45	1.14 ± 0.26	4.1 ± 1.34	0.80 ± 0.24
Trial II													
PB 235	35	9.1 ± 1.34	5.04 ± 0.52	9.2 ± 1.19	3.38 ± 0.41	10.1 ± 1.02	2.74 ± 0.37	7.6 ± 1.02	1.67 ± 0.22	6.2 ± 1.57	1.17 ± 0.30	5.2 ± 1.17	0.88 ± 0.19
PB 280	33	10.0 ± 1.13	5.44 ± 0.51	8.5 ± 1.14	3.05 ± 0.43	9.4 ± 1.06	2.56 ± 0.32	7.8 ± 1.65	1.71 ± 0.33	6.2 ± 2.03	1.16 ± 0.34	4.4 ± 1.57	0.76 ± 0.22
PB 314	35	9.9 ± 1.53	5.06 ± 0.45	8.8 ± 1.20	3.06 ± 0.36	8.8 ± 1.20	2.34 ± 0.34	6.2 ± 1.69	1.36 ± 0.31	5.1 ± 1.43	0.98 ± 0.21	3.9 ± 1.23	0.70 ± 0.21
PB 312	31	8.5 ± 1.64	5.11 ± 0.54	9.3 ± 1.64	3.63 ± 0.42	8.9 ± 1.35	2.57 ± 0.42	7.1 ± 1.45	1.65 ± 0.33	5.4 ± 1.63	1.12 ± 0.38	5.2 ± 1.49	0.95 ± 0.26
PB 255	34	8.5 ± 1.50	4.73 ± 0.86	7.8 ± 1.60	2.95 ± 0.46	8.3 ± 1.39	2.41 ± 0.37	7.3 ± 1.37	1.72 ± 0.31	6.2 ± 1.55	1.26 ± 0.32	5.2 ± 1.19	0.94 ± 0.19
PB 310	33	8.2 ± 1.10	4.80 ± 0.41	7.7 ± 1.73	3.07 ± 0.62	8.2 ± 0.91	2.51 ± 0.35	7.6 ± 1.46	1.84 ± 0.31	6.2 ± 1.38	1.29 ± 0.26	5.0 ± 1.51	0.92 ± 0.22
RRII 105	34	9.0 ± 1.81	5.26 ± 0.51	8.2 ± 1.13	3.23 ± 0.56	8.7 ± 0.96	2.57 ± 0.40	7.2 ± 1.12	1.72 ± 0.30	5.2 ± 1.02	1.09 ± 0.22	4.0 ± 1.23	0.76 ± 0.25
PB 311	35	9.0 ± 1.16	5.15 ± 0.45	8.4 ± 1.07	3.19 ± 0.39	7.8 ± 0.87	2.26 ± 0.26	6.1 ± 0.94	1.46 ± 0.22	5.6 ± 1.18	1.17 ± 0.20	4.8 ± 0.97	0.92 ± 0.16
KRS 163	34	8.6 ± 1.30	4.99 ± 0.54	7.9 ± 1.53	3.04 ± 0.42	7.6 ± 1.15	2.29 ± 0.36	7.1 ± 1.26	1.74 ± 0.30	5.8 ± 1.04	1.22 ± 0.21	4.4 ± 1.18	0.82 ± 0.18
PB 260	35	8.5 ± 1.33	5.16 ± 0.55	7.9 ± 1.42	3.20 ± 0.39	7.7 ± 1.62	2.36 ± 0.51	6.9 ± 1.30	1.74 ± 0.31	6.1 ± 1.14	1.31 ± 0.22	4.3 ± 1.38	0.83 ± 0.27
PB 217	33	8.3 ± 1.72	4.75 ± 0.65	8.1 ± 1.22	3.15 ± 0.45	8.3 ± 1.35	2.47 ± 0.50	6.4 ± 1.26	1.54 ± 0.30	4.2 ± 1.43	0.90 ± 0.31	3.5 ± 1.29	0.69 ± 0.24
KRS 25	34	7.4 ± 1.47	4.84 ± 0.66	7.7 ± 1.56	3.36 ± 0.52	8.5 ± 1.48	2.75 ± 0.43	6.1 ± 1.17	1.60 ± 0.30	4.9 ± 0.88	1.12 ± 0.21	5.3 ± 1.08	1.09 ± 0.23
KRS 128	35	7.4 ± 1.28	4.79 ± 0.69	7.9 ± 1.03	3.44 ± 0.43	7.5 ± 1.22	2.45 ± 0.41	6.0 ± 1.07	1.61 ± 0.31	5.1 ± 1.28	1.18 ± 0.27	4.8 ± 1.07	1.00 ± 0.22
Pooled	441	8.6 ± 1.59	5.01 ± 0.60	8.2 ± 1.44	3.21 ± 0.49	8.4 ± 1.40	2.48 ± 0.42	6.9 ± 1.43	1.65 ± 0.32	5.5 ± 1.49	1.15 ± 0.29	4.6 ± 1.37	0.87 ± 0.25

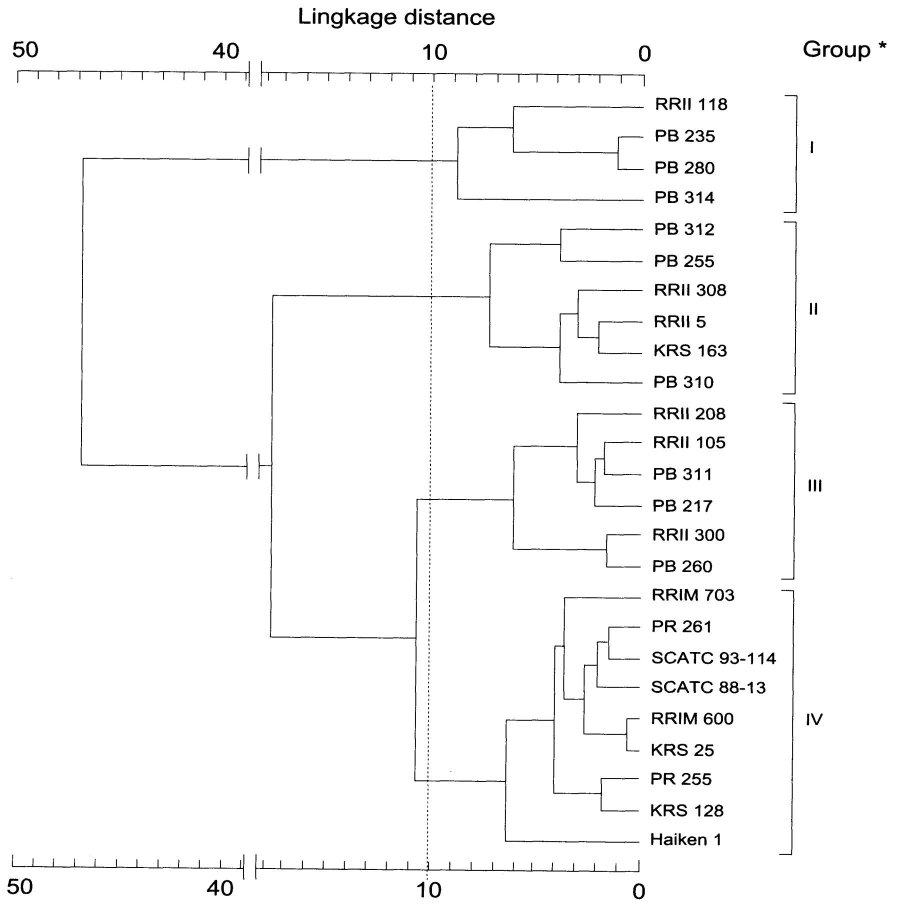
I_g = Girth increment (cm month^{-1}), R_g = Relative girth increment rate (mm cm^{-1} season^{-1})

Table 5 Variations in absolute girth (cm) in March 1991 and 1997, seasonal and annual mean girth increment rates ($\bar{I}_g$) and relative increment rates ($\bar{R}_g$) in various clones of *Hevea*

Clone	Girth	S1 (Apr–Jul)		S2 (Aug–Nov)		S3 (Dec–Mar)		Annual		Girth
	March 91	$\bar{I}_g$	$\bar{R}_g$	$\bar{I}_g$	$\bar{R}_g$	$\bar{I}_g$	$\bar{R}_g$	$\bar{I}_g$	$\bar{R}_g$	March 97
Trial I										
RRII 118	13.89	3.71	1.24	4.00	1.17	0.18	0.057	7.89	2.46	62.2
RRII 308	11.52	3.33	1.28	3.65	1.21	0.31	0.112	7.28	2.60	56.2
RRII 5	12.21	3.32	1.29	3.57	1.14	0.22	0.077	7.11	2.51	56.0
RRII 208	12.93	2.97	1.15	3.52	1.12	0.13	0.050	6.63	2.32	53.6
RRII 105	12.09	3.00	1.20	3.42	1.15	0.14	0.056	6.56	2.41	52.8
RRII 300	11.98	3.05	1.23	3.38	1.11	0.22	0.078	6.64	2.41	52.6
PR 261	11.23	3.00	1.25	3.41	1.20	0.17	0.064	6.58	2.51	51.3
SCATC 93 - 114	12.88	2.95	1.18	2.98	0.98	0.26	0.101	6.19	2.27	50.7
PR 255	10.31	2.92	1.29	3.37	1.20	0.34	0.119	6.62	2.61	50.6
RRIM 703	12.21	2.99	1.17	2.94	1.03	0.35	0.122	6.28	2.33	50.0
SCATC 88 - 13	12.33	2.83	1.15	3.15	1.09	0.20	0.080	6.19	2.32	50.0
RRIM 600	12.86	2.96	1.16	3.03	1.03	0.10	0.041	6.09	2.23	49.9
Haiken 1	12.61	2.52	1.07	2.79	0.99	0.11	0.048	5.42	2.11	45.4
Mean	12.24	3.04	1.21	3.32	1.11	0.21	0.077	6.58	2.39	52.4
SE	0.52	0.11	0.05	0.12	0.04	0.07	0.020	0.21	0.07	1.4
Trial II										
PB 235	13.98	2.92	0.96	4.13	1.24	0.64	0.208	7.70	2.41	61.3
PB 280	13.90	3.00	1.01	3.97	1.20	0.53	0.180	7.50	2.39	60.2
PB 314	14.98	2.66	0.90	3.67	1.11	0.65	0.198	6.98	2.21	57.6
PB 312	12.81	2.65	0.98	3.98	1.28	0.50	0.187	7.13	2.44	57.5
PB 255	14.23	2.82	0.97	3.79	1.17	0.39	0.139	7.00	2.27	57.3
PB 310	13.27	2.67	0.95	4.04	1.30	0.30	0.124	7.01	2.37	56.1
RRII 105	12.88	2.64	0.97	3.77	1.25	0.34	0.137	6.75	2.35	55.0
PB 311	13.39	2.74	0.99	3.69	1.19	0.39	0.134	6.82	2.32	55.0
KRS 163	13.40	2.58	0.95	3.78	1.21	0.33	0.139	6.69	2.29	54.8
PB 260	12.52	2.73	1.02	3.78	1.25	0.26	0.120	6.76	2.39	53.9
PB 217	13.64	2.42	0.89	3.42	1.13	0.56	0.191	6.39	2.20	52.6
KRS 25	11.83	2.58	1.04	3.66	1.27	0.33	0.153	6.57	2.46	51.7
KRS 128	11.99	2.58	1.01	3.58	1.26	0.22	0.107	6.38	2.38	50.7
Mean	13.29	2.69	0.97	3.79	1.22	0.42	0.155	6.90	2.35	55.7
SE	0.79	0.01	0.05	0.17	0.01	0.11	0.004	0.26	0.08	1.9

Table 6 Proportion of rubber trees attaining tappable girth

Clone	Total no. of trees	Years after planting					
		6		7		8	
		Number	Percent	Number	Percent	Number	Percent
Trial I							
RRII 118	49	31	63.3	45	91.8	48	98.0
RRII 308	47	11	23.4	32	68.1	40	85.1
RRII 5	47	10	21.3	32	68.1	41	87.2
RRII 208	49	6	12.2	26	53.1	41	83.7
RRII 300	49	4	8.2	24	49.0	35	71.4
RRIM 703	47	3	6.4	17	36.2	28	59.6
SCATC 93 - 114	46	2	4.3	14	30.4	27	58.7
RRII 105	48	2	4.2	15	31.3	41	85.4
PR 261	49	2	4.1	19	38.8	31	63.3
RRIM 600	49	1	2.0	8	16.3	30	61.2
SCATC 88 - 13	49	1	2.0	13	26.5	27	55.1
PR 255	47	0	0.0	16	34.0	28	59.6
Haiken 1	45	0	0.0	1	2.2	7	15.6
Total	621	73	11.8	262	42.2	424	68.3
Trial II							
PB 280	33	19	57.6	31	93.9	32	97.0
PB 235	35	20	57.1	31	88.6	35	100.0
PB 314	35	18	51.4	28	80.0	31	88.6
PB 255	34	10	29.4	27	79.4	30	88.2
RRII 105	34	9	26.5	20	58.8	32	94.1
PB 312	31	8	25.8	20	64.5	31	100.0
KRS 163	34	7	20.6	22	64.7	30	88.2
PB 310	33	6	18.2	22	66.7	32	97.0
PB 217	33	5	15.2	19	57.6	25	75.8
PB 311	35	5	14.3	23	65.7	30	85.7
PB 260	35	3	8.6	20	57.1	29	82.9
KRS 25	34	1	2.9	9	26.5	24	70.6
KRS 128	35	0	0.0	6	17.1	22	62.9
Total	441	111	25.2	278	63.0	383	86.8



* Group designation is based on mean girth and tappability percentage at the end of study period.

Figure 3 UPGMA cluster pattern of the clones based on the growth attributes

Discussion

The study location is in the centre of the traditional rubber-growing zone in India. Rainfall pattern is fairly well distributed. Initial growth observed for the clones in April may not be due to the activity of cambium but largely due to the rehydration of tissues resulting in complete restoration of turgor that was lost during the preceding stress period. Appreciable increase in girth observed for all clones in the following month, indicated that there had been no severe damage to the photosynthetic machinery in the preceding stress period. Rapid increase in growth from May onwards was probably brought about by the decrease in the direct beam solar radiation and increase in diffuse radiation. Maximum growth of all clones observed in July/August was due to continuous accumulation of biomass occurring in spurts covering a variable number of days because of periodical changes in light and other environmental factors.

The rate of growth declined progressively in all seasons. This trend was in agreement with earlier reports (Templeton 1968, Chandrashekar *et al.* 1994, 1998). Seasonal differences observed in growth rate between the trials could be due to differential capture of radiation by the sites of the two trials. In the dry season, growth of all clones was reduced substantially. A small amount of growth observed could be easily related with the pre-monsoon showers. In March 1995 and 1996, there was reduction in girth in most of the clones due to the stress conditions.

It is well known that temperature and water availability are the two most important constraints for growth and yield of plants. When ambient temperatures are above optimum, substrates that could be used for growth are increasingly lost through excessive respiration (Hellmers & Warrington 1982). In the present study, the observed shrinkage of tree stems in January and March could be due to soil moisture stress conditions. This type of stem shrinkage resulting from drought has been confirmed for many species of angiosperms and gymnosperms of the temperate and the tropics (Kozlowski 1971, 1972). In the initial years of observation reduction in girth was negligible. Therefore, it can be presumed that increased leaf area has also contributed to the reduction in girth during summer months. During the monsoon season, even though most part of many days was cloudy with low sunshine hours, girth increase was good, indicating that the plants have received adequate photosynthetically-active radiation. It appears that *Hevea* prefers conditions of low light intensity for good growth.

In spite of no apparent limiting factors from October till December, the growth of plants started decreasing and in November it stopped completely. It is difficult to determine which environmental factor or factors that might have played a role in the decline. One of the possible reasons could be the deciduous nature of *Hevea* trees. The trees shed leaves (wintering) annually during autumn with the onset of cooler conditions, the biochemical signalling for which must set in much earlier. This signalling may have led to decreased photosynthetic activity in leaves, resulting in the progressive decline in terminal growth, leading to complete cessation of growth by December.

Peak growth in trial I occurred when the sun was in the northern horizons while in trial II it was observed when the sun was in the southern horizons. Though it is difficult to explain, possible reason could be differential capture of radiation by the sites of the two trials. The experimental site of trial I is west facing slope and that of the second is mostly north facing slope with a small part on a hillock top. It is well known that slope and aspect create variability in radiation climate mainly due to the exposure of the sites to different time periods of direct sunlight and shade at any given season, resulting in seasonal as well as spatial variability in the radiation regimes (Rosenberg 1974, Lee 1978). This could have been the reason for the shifts in peak growth periods of the two trials.

From the growth curves, it is clear that in the tropical humid conditions, active growth period of *Hevea* trees is about seven to eight months from April till November with three months of grand period of growth from July till September. Based on the clustering patterns, group I clones can be termed as high, group II as above average, group III as average and group IV as below average vigour clones. In general, it could be said that the clones originated from China, Thailand and

Indonesia were of poor vigour, while those of Malaysia and India were of high vigour.

The main focus of the paper is to provide information on three important aspects of growth of *Hevea* trees, namely, absolute girth rate, relative girth rate, growth period and their age-related annual trends. Under ambient conditions of the tropical humid climate experienced in the traditional rubber-growing region in India, annual growth period of the trees was about seven to eight months with an annual I_g of 6.5 cm year^{-1} and R_g of 2.5 mm cm^{-1} year^{-1}. Of late, a major stress in *Hevea* improvement is on breeding latex timber clones that are superior in both latex as well as timber production. In this direction, group I clones appear to be promising.

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