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POSSIBILITY OF EARLY COMMENCEMENT OF TAPPING IN RUBBER (*HEVEA BRASILIENSIS*) USING DIFFERENT GENOTYPES AND TAPPING SYSTEMS

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SUMMARY

The feasibility of commencing tapping ('opening') of rubber trees for latex extraction at a lower stem girth (40 and 45 cm) than the currently recommended 50 cm was investigated in three different genotypes. The possibility of combining early opening with low frequency tapping and yield stimulation using Ethrel (LFT + E) was also examined. One of the genotypes tested, RRIC 121, gave a higher dry rubber yield, both per tapping and cumulatively over a given period, when opened at 40 cm than at 50 cm. Of the other two genotypes, one (RRISL 211) showed a clear reduction in yield with early opening, while the other (RRIC 102) did not show a significant yield response. Among the three genotypes tested, RRIC 121 showed the minimum depression in trunk girth increment. Analysis of yield components showed that the response of a given genotype to early opening and LFT + E is determined by the interaction between latex volume per tapping and dry rubber content (DRC), which were negatively correlated. RRIC 121 had a significantly greater DRC, which enabled it to maintain a higher dry rubber yield under early opening and LFT + E despite producing a lower latex volume than both the other genotypes. In contrast, despite producing a substantially greater latex volume than the other two genotypes, RRISL 211 did not produce a higher dry rubber yield because of its lower DRC. The higher DRC was also responsible for the greater response of RRIC 121 to yield stimulation with Ethrel, which reduced the plugging index and increased the initial latex flow rate. Early commencement of tapping in combination with LFT + E is therefore possible in rubber when amenable genotypes are selected, offering the potential of improving the economics of rubber production, especially for smallholders, in West Asia.

INTRODUCTION

Rubber (*Hevea brasiliensis*) is a latex-producing tree belonging to the family Euphorbiaceae. Latex is synthesized in the latex vessels found in the phloem tissue of the rubber tree (Tupy, 1985). Rubber latex is harvested by systematic tapping, which involves periodic cutting of the bark on the trunk in a way which severs latex vessels. The long immature phase of the rubber tree is a major constraint especially to resource-poor smallholder farmers in all rubber-growing countries in Asia such as Sri Lanka, India, Malaysia, Indonesia, Thailand, Myanmar and Vietnam. The period between planting and 'opening' for tapping generally varies from five to seven years. During this gestation period costs accumulate without any returns. Hence, it is important to look at all possible methods to reduce this unproductive period by early

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opening of trees for tapping without any adverse effects on tree girth increment and reductions in long-term yields.

Tree girth forms the best and the most practicable criterion to determine tappability of rubber. The current recommendation is for tapping to commence when the tree reaches a girth of 50 cm at a height of 120 cm from the bud union. If rubber trees could be tapped at smaller girths than practiced currently, it would enable the growers in all rubber-producing countries in Asia to earn an income earlier while reducing the immature cost. However, an inverse relationship exists between extraction of latex and girth increment (Sethuraj, 1981; Obouayeba *et al.*, 2002), because both depend on a common pool of assimilates from photosynthesis. Therefore, earlier commencement of tapping has to be done without causing significant reductions in subsequent girthing, which would in turn reduce rubber yields in the long run. Therefore, the major objective of this study was to determine the influence of early commencement of tapping on rubber yields, yield components, bark characteristics and tree girth increment.

In exploring methods of early opening of rubber trees, the tapping system to be adopted could play a crucial role. In Sri Lanka, the widely adopted exploitation system is the 'half-spiral, alternate-day' ($^1/_2$S d/2) tapping. This means that the tapping cut is made as a spiral covering half the girth of the trunk and that tapping is done once in two days. However, this system has a high tapper requirement, which is a problem in several Asian rubber-producing countries such as Malaysia and Sri Lanka, because of the shortage of skilled tappers and high labour wages. One possible solution to this problem is to tap at a lower frequency (e.g once in three days, d/3). However, low-frequency tapping (LFT) may not extract the maximum possible volume of latex from the tree. To overcome this limitation in LFT, use of yield stimulants such as Ethrel (active ingredient, 2–chloroethylphosphonic acid) in combination with LFT is being investigated in all rubber-growing countries (Nugawela *et al.*, 2000). Therefore, a secondary objective was to investigate the suitability of LFT with stimulants, particularly in trees opened early, with the objective of developing a package of practices aimed at increasing the profit margin of rubber growers, particularly in countries where there is a combination of high tapper wages and a shortage of skilled tappers.

A third factor that has to be considered in developing such a package is the introduction of high-yielding genotypes. The genotype indicates the plant's genetic constitution and determines its inherent ability to grow and produce latex within the environment provided. Hence, with the same management effort a higher performance is always obtained from an improved genotype than from an unimproved, genetically inferior one. When high yielding genotypes are introduced to the industry, to realize their full yield potential, it is important that both genotypes and recommended agronomic practices are adopted correctly. Amongst the various agronomic practices, tapping is one of the most important factors governing productivity. Therefore, in this study, the treatments of early commencement of tapping and different tapping systems were tested on three different genotypes with the objective of determining the genotype(s) which would respond best to early commencement of tapping and LFT with yield stimulation.

Analysis of variations in dry rubber yield in terms of its yield components provides important insights into the physiological basis of yield determination of rubber in response to early commencement. In a yield component analysis, cumulative dry rubber yield per tree (Y) over a given period can be given as:

$$Y = \text{dry rubber yield per tree per tapping} \times \text{number of tappings}$$

The dry rubber yield per tree per tapping (gtt) can be considered as:

$$\text{gtt} = \text{latex volume per tree per tapping} \times \text{dry rubber content}$$

The latex volume per tapping, in turn, is determined by the initial flow rate (IFR) of latex following tapping, length of the tapping cut (LT) and the plugging index (PI), which is an indirect measure of the duration of latex flow following tapping (Jacob *et al.*, 1989; Sethuraj, 1981). These yield components are also influenced by a complex combination of anatomical, physiological, biochemical and environmental parameters (Jacob *et al.*, 1989; Nair, 2000).

Bark characteristics play an important role in determining rubber yield because the latex vessels are located in the bark. Bark thickness (BT) determines the number of latex vessel rings and thereby has a significant influence on latex yield (Gonçalves *et al.*, 2004). Several workers have shown a strong correlation between girth and bark thickness (Gomez, 1982; Huat, 1981). Therefore, commencement of tapping at a lower girth would mean that the capacity of the tree to produce latex could be lower at the time of opening. As the bark is gradually removed over time during the tapping process, the rate of bark consumption (BC) can also determine the responses of trees to early opening. Therefore, the variation in BT and BC was also investigated in relation to early opening. Another possible danger of early commencement of tapping is the premature drying up of the tapping panel, so the incidence of tapping panel dryness (TPD) was also investigated.

MATERIALS AND METHODS

Experimental site

A field experiment was carried out from July 1999 to January 2003 at the Dartonfield Estate in the Rubber Research Institute of Sri Lanka (6°32′N, 80°09′E). It is located in the wet, humid tropical zone of Sri Lanka with an annual rainfall of around 2500 mm, which is well distributed throughout the year with no marked dry periods. The mean air temperature ranged from 22 to 31 °C and ambient relative humidity was around 88 %. The soil belonged to the great group Rhodudults (Panabokke, 1996) and is classified as a Haplic Alisol by FAO/UNESCO and a Typic Hapludult by the USDA (Dassanayake and Hettiarachchi, 1999). It was a silty clay loam in texture and strong brown to yellowish red in colour. The key chemical properties of the top (0–15 cm depth) soil were: pH – 5.11; organic carbon – 1.73 %; total nitrogen – 0.29 %;

available phosphorus – 21 ppm; exchangeable potassium – 26 ppm; exchangeable magnesium – 258 ppm and exchangeable calcium – 216 ppm.

Experimental material

Rubber trees belonging to three genotypes (RRISL 211, RRIC 121 and RRIC 102) that had been planted in 1994 were selected for the experiment. The three genotypes had been planted at a density of 500 trees ha^{-1} with 2.4 m × 8.1 m spacing in several adjacent 0.75 ha blocks of land, which were similar in terms of topography and soil type. There were three blocks for each genotype. RRISL 211 is a recently improved genotype yielding higher than the currently popular RRIC 100 series genotypes and having good post-tapping vigour. RRIC 121 and RRIC 102 are widely grown genotypes in Sri Lanka. For each genotype, 100 trees which had reached a girth of 40 cm at a height of 120 cm from the bud union were selected; trees from all three blocks were selected depending on their girth. The 100 trees were divided randomly in to four groups with three groups having 30 trees each and the fourth having 10 trees. In all genotypes, tapping of trees with a girth of 40 cm commenced in July 1999 in one of the 30-tree groups (G_{40}), chosen at random. In the second and third 30-tree groups, tapping commenced when at least 60 % of trees reached a girth of 45 cm (G_{45}, in August 2000) and 50 cm (G_{50}, in April 2001) at 120 cm from the union. The 10-tree group of each genotype was left untapped.

Experimental treatments and design

The experimental treatment structure was a three-factor factorial with the three genotypes, three opening girths and three tapping treatments as the main effects. The three tapping treatments were: (i) $^1/_2$S d/2 – high frequency tapping (HFT); (ii) $^1/_2$S d/3 – low frequency tapping without stimulation (LFT); and (iii) $^1/_2$S d/3 plus Ethrel application – low frequency tapping with stimulation (LFT+E). Ethrel (2.5 %) was applied to a 2.5 cm band of the stem just below the tapping cut four times per year at a rate of 1.6 g per tree.

Thirty trees selected from each clone for the commencement of tapping at different girths were randomly separated into three subgroups of 10 trees. For each subgroup, one of the tapping treatments was introduced randomly on a single tree plot design. Colour bands were painted to differentiate trees in the different groups. The trees were rain-guarded and tapped throughout the year according to the tapping systems assigned.

Measurements

A single tapper was employed for tapping throughout the experiment. After each tapping, latex was collected into cups attached to the lower end of the tapping panel of individual trees. After latex flow ceased, its volume was measured with a measuring cylinder. The dry rubber content (DRC) was measured by using a Metrolac separately for each treatment after bulking the latex of all 10 trees of a given treatment combination. The Metrolac is an instrument which measures the specific gravity of latex, which is subsequently related to the DRC. In addition to the indirect measurement by the Metrolac, DRC was directly measured by the oven drying method at 3-month intervals. Latex from the 10 trees of each treatment was pooled, and 5 ml of latex was collected into a bottle containing 2–3 drops of the anti-coagulant 10 % ammonia solution. From each bottle, a 1 ml sample of latex was weighed into a Petri dish and 2–3 ml of 5 % acetic acid was added for coagulation. Once coagulation was complete after about 10 min, the sample was made into a thin sheet. After washing the coagulate with distilled water, the sample was oven dried at 60–65 °C for 24 h. Subsequently the dry weight of the coagulate was determined and the DRC was calculated as the ratio between the dry and wet weights of the sample. The IFR was determined monthly by measuring latex volume during the first five minutes after tapping. At the same tapping, the PI was calculated as described by Milford *et al.* (1969), from the IFR (ml min^{-1} during first five minutes after tapping) of a given tapping i and total latex volume per tree (vtt; ml) in the same tapping:

$$PI = (IFR_i/vtt_i) \times 100$$

The dry rubber yields (gtt, see Introduction) were cumulated over three periods: from July 1999 to July 2000 (Period 1 containing data on G_{40} only); from August 2000 to March 2001 (Period 2 containing data on G_{40} and G_{45}); and from April 2001 to January 2003 (Period 3 containing data on G_{40}, G_{45} and G_{50}).

BT and BC were measured in all individual trees at the end of the above-mentioned periods. Thickness of the bark of each tree was measured by using a bark gauge at a height of 150 cm from the highest point of the union. The BC and the LT were measured using a metre tape. Growth of rubber trees was quantified by measuring trunk girth at a height of 150 cm from the bud union at three-month intervals. Incidence of TPD was monitored by visual observation of individual trees also at three-month intervals.

Data analysis

Data for each period were analysed as a three-factor factorial with single trees as replicate plots. Analysis of variance was used to determine the significance or otherwise of the main effects (opening girths, tapping systems and genotypes) and their interactions. Means were separated by standard error of means with appropriate degrees of freedom. When the interaction effects were not significant at $p \leq 0.05$, data for the relevant factors were pooled. Linear correlation analysis was used to determine the strength of relationships between yield and yield components and between the different yield components. Correlation analysis was first performed for the overall data set in which the data for the three factors and the three time periods of comparison were pooled. At the next step, separate correlation analyses were performed for the three genotypes, again pooling the data from the three periods, different opening girths and tapping systems. At the final step, correlations were determined separately for different opening girths using the data for Period 3, which included all opening girths.

RESULTS

Latex volume per tree per tapping

During the two periods which enabled comparison of different opening girths (Periods 2 and 3), the response of mean vtt to early commencement of tapping varied for the three genotypes tested (Table 1). During both periods of comparison, early opening at G_{40} in RRIC 121 gave significantly greater vtt than G_{45} and G_{50}. In contrast, the opposite trend was observed in RRISL 211 with the earlier opened treatments (G_{40} and G_{45}) showing lower vtt than the trees opened at the recommended girth of 50 cm. The response of RRIC 102 to earlier opening differed between the two periods of comparison. During Period 2, vtt did not differ significantly between different opening girths. However, in Period 3, vtt of the earlier opened treatments was lower than that for G_{50}.

The responses of vtt to LFT ($^1/_2$S d/3) also differed between the three genotypes (Table 1). In RRIC 121, vtt under LFT was lower than that for HFT ($^1/_2$S d/2), especially in trees opened at G_{40} during all three periods. However, the vtt of RRIC 121 showed a positive response to LFT + E during all three periods. In particular, during Period 3, trees of RRIC 121 opened at all girths showed substantial increases in vtt under LFT + E when compared to both LFT and HFT. In contrast, in the G_{40} treatment for the other two genotypes, LFT without stimulation did not cause a significant change in vtt relative to HFT. However, with the exception of the G_{40} treatment of RRIC 102 during Period 3, the G_{40} trees of RRIC 102 and RRISL 211 also showed significant increases in vtt under LFT + E as compared to both HFT and LFT. This positive response to LFT + E was also shown in G_{45} and G_{50} trees of the above two genotypes during all periods. When averaged across the different opening girths and tapping treatments, RRISL 211 had significantly greater vtt than the other two genotypes during all three periods. While there was no significant difference between the respective vtt of RRIC 102 and RRIC 121 during Periods 1 and 2, RRIC 102 had a greater vtt during Period 3.

Dry rubber content

Mean DRC varied significantly between different genotypes, opening girths and tapping systems during all periods of comparison (Table 2). As the DRC did not vary significantly with time, only the data for Period 3 are presented. The earlier opened trees of RRIC 121 and RRISL 211 showed significantly greater DRC than the trees opened at the recommended girth of 50 cm. On the other hand, DRC of RRIC 102 did not vary significantly with opening girth. When averaged across opening girths, the DRC of all genotypes showed a similar variation pattern under different tapping systems. In comparison to HFT, LFT without stimulation significantly increased DRC. However, LFT + E caused a significant reduction in DRC which was even lower than

Table 1. Mean latex volume per tree per tapping of selected genotypes of rubber at different opening girths and tapping systems during selected periods after the commencement of tapping (July 1999–January 2003).

		Latex volume (ml tree^{-1} tapping^{-1})							
Period		July 1999–July 2000	August 2000–March 2001			April 2001–January 2003			
Genotype	Tapping system	G_{40}	G_{40}	G_{45}	Mean	G_{40}	G_{45}	G_{50}	Mean
RRIC 102	$^1/_2$S d/2	19	39	47	43	80	64	60	68
	$^1/_2$S d/3	21	40	45	42	75	63	100	80
	$^1/_2$S d/3 + E	29	55	58	57	73	86	110	90
	Mean	23	45	50	47	76	71	90	79
	s.e.	0.8 (18 *d.f.*)	3.6 (45 *d.f.*)		4.4 (45 *d.f.*)		7.6 (72 *d.f.*)		7.6 (72 *d.f.*)
RRIC 121	$^1/_2$S d/2	29	51	37	44	73	47	55	59
	$^1/_2$S d/3	16	35	37	36	56	50	54	54
	$^1/_2$S d/3 + E	26	67	37	52	107	94	93	98
	Mean	24	51	37	44	79	64	67	70
	s.e.	1.2 (18 *d.f.*)	2.9 (45 *d.f.*)		3.5 (45 *d.f.*)		3.5 (72 *d.f.*)		3.5 (72 *d.f.*)
RRISL 211	$^1/_2$S d/2	47	74	109	92	81	81	121	94
	$^1/_2$S d/3	51	77	140	109	87	100	114	100
	$^1/_2$S d/3 + E	64	92	133	113	112	120	152	128
	Mean	54	81	128	104	93	100	129	108
	s.e.	1.7 (18 *d.f.*)	7.5 (45 *d.f.*)		9.1 (45 *d.f.*)		8.8 (72 *d.f.*)		8.8 (72 *d.f.*)

Table 2. Mean dry rubber content (%) of selected genotypes of rubber at different opening girths and tapping systems during a selected period after the commencement of tapping.

Period		Dry rubber content (%) April 2001–January 2003			
Genotype	Tapping system	G_{40}	G_{45}	G_{50}	Mean
RRIC 102	$^{1}/_{2}$S d/2	37.6	36.9	36.4	37.0
	$^{1}/_{2}$S d/3	39.3	37.6	38.9	38.6
	$^{1}/_{2}$S d/3 + E	33.8	34.4	35.5	34.6
	Mean	36.9	36.3	36.9	36.7
	s.e. (8 *d.f.*)		0.65		0.65
RRIC 121	$^{1}/_{2}$S d/2	42.4	43.5	42.8	42.9
	$^{1}/_{2}$S d/3	46.0	46.8	45.4	46.1
	$^{1}/_{2}$S d/3 + E	44.0	43.0	39.9	42.3
	Mean	44.1	44.5	42.7	43.8
	s.e. (8 *d.f.*)		0.26		0.26
RRISL 211	$^{1}/_{2}$S d/2	36.2	34.7	31.9	34.3
	$^{1}/_{2}$S d/3	36.7	36.1	32.5	35.1
	$^{1}/_{2}$S d/3 + E	32.2	31.3	30.6	31.4
	Mean	35.0	34.0	31.6	33.6
	s.e. (8 *d.f.*)		0.46		0.46

that under HFT. Among the genotypes, the DRC was significantly higher in RRIC 121, followed by RRIC 102 and RRISL 211.

Dry rubber yield per tree per tapping

During the two periods which enabled comparison of different opening girths (Periods 2 and 3), the response of mean gtt to early commencement of tapping varied for the three genotypes tested (Table 3). In RRIC 121 and RRIC 102, when averaged across the three tapping systems, opening at a girth of 40 cm gave a significantly higher gtt than opening at 45 and 50 cm. In contrast, gtt of RRISL 211 showed the opposite trend with gtt decreasing with reductions in opening girth during both periods of comparison. When averaged across different opening girths, the response of gtt to LFT and LFT + E, in comparison to HFT, differed significantly for the three genotypes during all three periods of comparison. During two of the three periods, the gtt of RRIC 102 (Periods 1 and 2) and RRIC 121 (Periods 2 and 3) responded positively to LFT + E. However, in RRISL 211, LFT and LFT + E significantly increased gtt relative to HFT only during Period 2. The response of gtt to LFT + E in comparison to HFT was highest in the G_{40} and G_{45} treatments of RRIC 121 during Period 3 (192 % and 127 % respectively).

Table 3. Mean dry rubber yield per tree per tapping of selected genotypes of rubber at different opening girths and tapping systems during selected periods after the commencement of tapping.

		Dry rubber yield per tree per tapping (g tree^{-1} tapping^{-1})							
Period		July 1999–July 2000	August 2000–March 2001			April 2001–January 2003			
Genotype	Tapping system	G_{40}	G_{40}	G_{45}	Mean	G_{40}	G_{45}	G_{50}	Mean
RRIC 102	$^1/_2$S d/2	6.5	6.1	11.3	8.9	24.4	19.6	31.3	25.1
	$^1/_2$S d/3	5.7	22.4	12.2	17.3	41.5	22.0	27.5	30.3
	$^1/_2$S d/3 + E	7.9	25.8	14.8	20.3	27.1	24.6	27.4	26.4
	Mean	6.7	18.1	12.8	15.4	31.0	22.1	28.7	27.3
	s.e.	0.37 (18 *d.f.*)	1.27 (45 *d.f.*)		1.56 (45 *d.f.*)		3.07 (72 *d.f.*)		3.07 (72 *d.f.*)
RRIC 121	$^1/_2$S d/2	13.2	24.9	13.5	19.2	26.1	17.8	26.2	23.3
	$^1/_2$S d/3	5.8	13.5	14.4	14.0	45.2	23.3	25.0	31.2
	$^1/_2$S d/3 + E	9.1	24.3	20.3	22.3	76.1	40.4	42.1	52.9
	Mean	9.4	20.9	16.1	18.5	49.1	27.2	31.1	35.8
	s.e.	0.69 (18 *d.f.*)	1.06 (45 *d.f.*)		1.30 (45 *d.f.*)		2.57 (72 *d.f.*)		2.57 (72 *d.f.*)
RRISL 211	$^1/_2$S d/2	11.0	19.9	24.4	22.1	38.9	23.4	36.2	32.8
	$^1/_2$S d/3	4.1	25.2	29.6	27.4	28.7	38.4	32.4	33.2
	$^1/_2$S d/3 + E	7.8	26.2	28.2	27.2	25.4	39.8	39.6	35.0
	Mean	7.7	23.7	27.4	25.6	31.0	33.9	36.1	33.7
	s.e.	0.64 (18 *d.f.*)	1.41 (45 *d.f.*)		1.81 (45 *d.f.*)		2.97 (72 *d.f.*)		2.97 (72 *d.f.*)

Table 4. Mean cumulative dry rubber yield of selected genotypes of rubber at different opening girths and tapping systems during selected periods after the commencement of tapping.

		Cumulative dry rubber yield (kg tree^{-1})							
Period		July 1999–July 2000	August 2000–March 2001			April 2001–January 2003			
Genotype	Tapping system	G_{40}	G_{40}	G_{45}	Mean	G_{40}	G_{45}	G_{50}	Mean
RRIC 102	$^{1}/_{2}$S d/2	1.09	0.73	1.18	0.96	7.06	5.62	8.93	7.20
	$^{1}/_{2}$S d/3	0.65	1.31	0.77	1.04	8.14	4.28	5.41	5.95
	$^{1}/_{2}$S d/3 + E	0.90	1.37	0.93	1.15	5.41	4.80	5.40	5.20
	Mean	0.88	1.14	0.96	1.05	6.87	4.90	6.58	6.12
	s.e.	0.057 (18 *d.f.*)	0.104 (45 *d.f.*)		0.127 (45 *d.f.*)		0.674 (72 *d.f.*)		0.674 (72 *d.f.*)
RRIC 121	$^{1}/_{2}$S d/2	2.20	2.56	1.42	1.99	7.54	5.10	7.46	6.70
	$^{1}/_{2}$S d/3	0.70	0.84	0.91	0.87	8.87	4.54	4.93	6.11
	$^{1}/_{2}$S d/3 + E	1.04	1.51	1.28	1.39	14.91	7.88	8.30	10.37
	Mean	1.31	1.64	1.20	1.42	10.44	5.84	6.90	7.73
	s.e.	0.109 (18 *d.f.*)	0.084 (45 *d.f.*)		0.103 (45 *d.f.*)		0.535 (72 *d.f.*)		0.535 (72 *d.f.*)
RRISL 211	$^{1}/_{2}$S d/2	1.75	1.84	2.56	2.20	9.00	6.72	10.30	8.68
	$^{1}/_{2}$S d/3	0.75	1.56	1.87	1.71	5.17	7.49	6.38	6.35
	$^{1}/_{2}$S d/3 + E	0.90	1.48	1.78	1.63	4.99	7.76	7.81	6.85
	Mean	1.13	1.63	2.07	1.85	6.39	7.32	8.16	7.29
	s.e.	0.120 (18 *d.f.*)	0.137 (45 *d.f.*)		0.168 (45 *d.f.*)		0.858 (72 *d.f.*)		0.858 (72 *d.f.*)

Number of tapping days and cumulative dry rubber yield

For the three periods of comparison, the number of tapping days for the LFT and LFT + E treatments were 31–36 % fewer than for the corresponding HFT treatment, with the slight variations from the expected 33 % being due to practical difficulties such as public holidays and excessive rain. The three genotypes differed in the responses of cumulative dry rubber yield to earlier opening (Table 4). Dry rubber yield of the G_{40} treatment in RRIC 121 was significantly greater than in G_{45} during Periods 2 and 3 and G_{50} in Period 3. In contrast, the opposite trend was observed in RRISL 211, with the G_{40} treatment having significantly lower yields than the others during both periods. In RRIC 102, early opening at G_{40} did not cause a significant yield reduction as compared to G_{45} (Period 2) and G_{50} (Period 3). The significantly lower yield of the G_{45} treatment in RRIC 102 during Period 3 was the only exception to the above trend. Except in RRIC 102 during Period 2, LFT without stimulation reduced cumulative dry rubber yield relative to that under HFT (Table 4). It was only in RRIC 121 during Period 3 that combining Ethrel stimulation with LFT could compensate for the yield losses due to unstimulated LFT and significantly increase the yield above HFT. The proportional yield gains due to LFT + E during Period 3 were greatest in the G_{40} trees of RRIC 121. There was significant variation between the three genotypes in their mean cumulative dry rubber yield. During all three periods of comparison, mean yield of RRIC 102 was significantly lower than those of RRIC 121 and RRISL 211, which did not show a consistent difference between each other. It should be noted that because gtt values given in Table 3 are means of all tappings during the respective periods, the product between mean gtt and the number of tapping days may not exactly match the total cumulative yield, which has been calculated by cumulating the gtt values of all the tappings within each period.

Initial flow rate and plugging index

Variations of both IFR and PI showed similar patterns between treatments in all periods of comparison. Therefore, only the data for Period 3 are shown in Table 5. Commencement of tapping at a girth of 40 cm did not cause a significant change in IFR and PI in either RRIC 102 or RRIC 121. However in RRISL 211, when compared to the recommended opening girth of 50 cm, opening at lower girths caused significant reductions in IFR and significant increases in PI. LFT without stimulation increased IFR in all three genotypes. However, when LFT was combined with Ethrel stimulation, the higher IFR under LFT could be maintained only in RRIC 121. While LFT without stimulation did not change the PI in any of the genotypes, LFT + E reduced PI in all three genotypes.

Bark characteristics

BT increased with time after the commencement of tapping in all treatment combinations. However, with the exception of RRIC 102 during Period 2, earlier opening did not change BT significantly (data not shown). When averaged across different opening girths, the mean BT in RRIC 121 was significantly reduced under

Table 5. Mean initial flow rate and plugging index of selected genotypes of rubber at different opening girths and tapping systems during a selected period after the commencement of tapping.

		Initial flow rate (ml min^{-1})				Plugging index			
Period		April 2001–January 2003				April 2001–January 2003			
Genotype	Tapping system	G_{40}	G_{45}	G_{50}	Mean	G_{40}	G_{45}	G_{50}	Mean
RRIC 102	$^1/_2$S d/2	1.43	1.38	1.54	1.45	3.91	3.55	3.47	3.64
	$^1/_2$S d/3	1.55	1.34	1.92	1.60	3.23	3.20	3.79	3.41
	$^1/_2$S d/3 + E	1.22	1.22	1.29	1.24	2.15	2.51	2.45	2.37
	Mean	1.40	1.31	1.58	1.43	3.09	3.09	3.23	3.14
	s.e. (72 *d.f.*)		0.102		0.102	0.179			0.179
RRIC 121	$^1/_2$S d/2	2.49	2.19	2.45	2.38	4.86	5.92	5.32	5.37
	$^1/_2$S d/3	2.70	2.46	2.58	2.58	5.76	6.51	5.81	6.03
	$^1/_2$S d/3 + E	2.60	2.55	2.92	2.69	3.46	3.35	6.08	4.30
	Mean	2.60	2.40	2.65	2.55	4.69	5.26	5.74	5.23
	s.e. (72 *d.f.*)		0.133		0.133		0.628		0.628
RRISL 211	$^1/_2$S d/2	1.58	2.19	2.61	2.12	3.42	3.91	3.24	3.52
	$^1/_2$S d/3	2.23	2.52	2.84	2.53	4.11	3.67	2.87	3.55
	$^1/_2$S d/3 + E	1.60	1.91	2.87	2.13	2.75	2.37	2.26	2.46
	Mean	1.80	2.21	2.77	2.26	3.42	3.32	2.79	3.18
	s.e. (72 *d.f.*)		0.157		0.157		0.218		0.218 (72 *d.f.*)

Table 6. Mean bark thickness of the three rubber genotypes under different tapping systems at the end of the period from April 2001 to January 2003.

	Bark thickness (mm)			
Tapping system	RRIC 102	RRIC 121	RRISL 211	Mean
$^1/_2$S d/2	6.2	6.1	6.8	6.4
$^1/_2$S d/3	6.2	6.5	6.6	6.4
$^1/_2$S d/3 + E	6.3	6.6	6.6	6.5
Mean	6.2	6.4	6.7	6.4
s.e. (*d.f.* = 72)	0.14	0.15	0.16	0.09

HFT as compared to LFT with and without stimulation (Table 6). However, no significant variation between tapping systems was observed in the other two genotypes. Overall, RRISL 211 had a greater mean BT than the other two genotypes.

The response of BC to earlier opening varied between Periods 2 and 3. During Period 2, BC was similar for G_{40} and G_{45} in all the genotypes (data not shown). However during Period 3, trees opened earlier in RRISL 211 had significantly greater BC than trees opened at the recommended girth (G_{50}) (Table 7). In contrast, only the G_{45} treatment had greater BC than G_{50} in RRIC 102 and RRIC 121. When averaged across opening girths, in all genotypes, BC was greater under HFT than LFT with and without stimulation. In trees under LFT, yield stimulation increased BC in RRIC

Table 7. Mean bark consumption and length of the tapping cut of selected genotypes of rubber at different opening girths and tapping systems during a selected period after the commencement of tapping.

		Bark consumption (cm)				Length of tapping cut (cm)			
Period		April 2001–January 2003				April 2001–January 2003			
Genotype	Tapping system	G_{40}	G_{45}	G_{50}	Mean	G_{40}	G_{45}	G_{50}	Mean
RRIC 102	$^1/_2$S d/2	24.5	31.4	26.2	27.6	34.7	27.2	31.1	31.0
	$^1/_2$S d/3	20.9	26.3	20.5	22.6	33.0	21.0	32.8	28.9
	$^1/_2$S d/3 + E	21.3	30.2	21.5	24.3	33.5	22.5	31.6	29.2
	Mean	22.3	29.3	22.7	24.8	33.7	23.6	31.8	29.7
	s.e. (72 *d.f.*)		0.43		0.43		0.66		0.66
RRIC 121	$^1/_2$S d/2	20.9	23.7	21.2	21.9	41.2	35.8	34.9	37.3
	$^1/_2$S d/3	16.4	18.1	15.8	16.8	37.5	37.5	33.8	36.3
	$^1/_2$S d/3 + E	16.8	19.0	15.9	17.2	37.0	37.7	32.5	35.7
	Mean	18.1	20.3	17.6	18.6	38.6	37.0	33.7	36.4
	s.e. (72 *d.f.*)		0.37		0.37		0.84		0.84
RRISL 211	$^1/_2$S d/2	26.4	19.7	24.2	23.4	32.3	31.9	31.2	31.8
	$^1/_2$S d/3	16.7	19.0	15.6	17.1	31.2	31.6	29.5	30.8
	$^1/_2$S d/3 + E	18.3	22.7	16.0	19.0	30.5	32.0	15.5	26.0
	Mean	20.5	20.5	18.6	19.9	31.3	31.8	25.4	29.5
	s.e. (72 *d.f.*)		0.52		0.52		0.71		0.71

102 and RRISL 211. Overall, the highest BC was observed in RRIC 102 during both periods of comparison.

Opening girth had significant effects on the LT in all genotypes during Period 3 (Table 7). With the exception of G_{45} in RRIC 102, LT was greater in trees opened earlier than in trees opened at the recommended girth. During Period 2, only RRIC 121 showed a similar trend with the LT of G_{40} being significantly greater than that of G_{45} (data not shown). When averaged across opening girths, the mean LT for the different tapping systems varied for the three genotypes. In RRIC 102, the mean LT under HFT was significantly greater than under LFT and LFT + E. On the other hand, in RRISL 211, trees under both HFT and LFT without stimulation had greater LT than under LFT +E. In contrast to both the above genotypes, the LT of RRIC 121 was similar for all the tapping systems studied.

Influence of early commencement of tapping on tree girth increment and tapping panel dryness

The variation of tree girth during the experimental period at different opening girths is shown in Figure 1 for each of the three genotypes tested. In RRIC 102, girth increment of tapped trees, averaged across the tapping treatments, showed a decreasing trend with time at all opening girths compared to the untapped control (Figure 1a). Consequently, girth depression due to tapping increased throughout the experimental period. This depression in girthing was less in G_{45} and G_{50} trees than in G_{40} trees. Among the three genotypes, RRIC 121 showed the lowest depression in

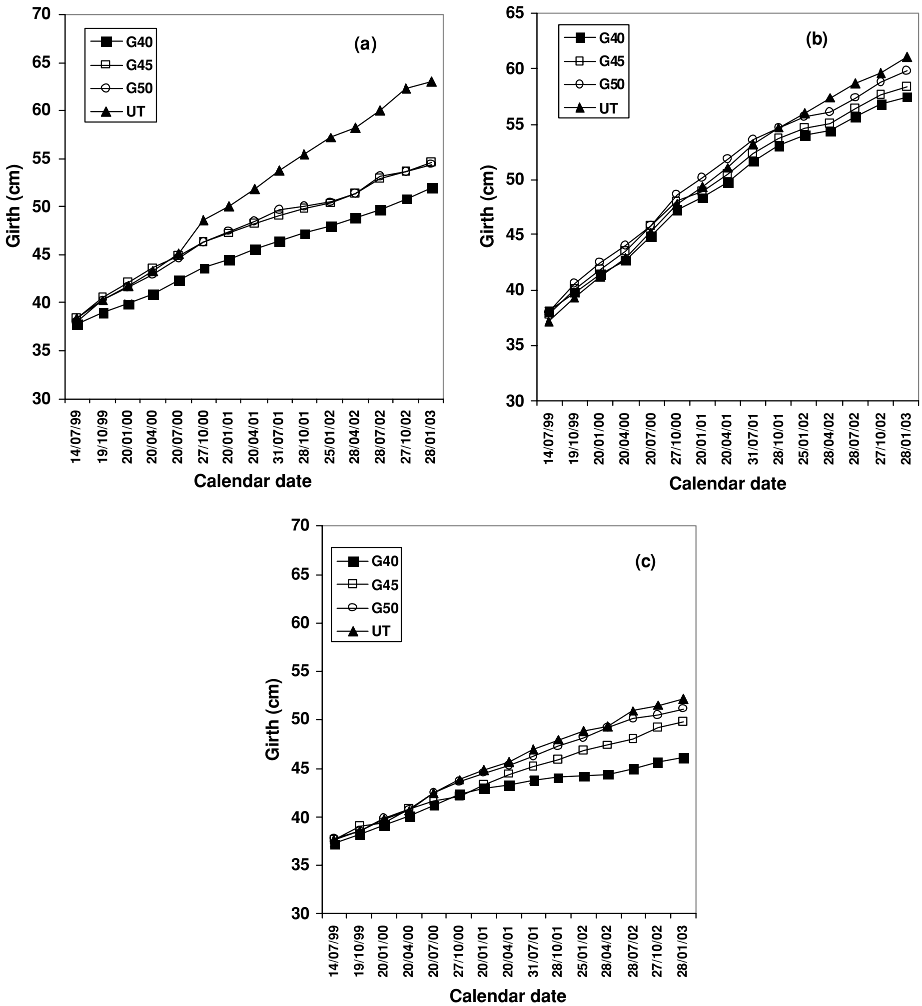

Figure 1. Variation of tree girth (at 150 cm above the bud union) of (a) RRIC 102, (b) RRIC 121 and (c) RRISL 211 during the experimental period at different opening girths. UT:untapped trees; G40, G45 and G50: opened at 40, 45 and 50 cm girth at 120 cm above the bud union.

girthing due to tapping (Figure 1b). Here also, there was a gradual increase in girth depression with decreasing opening girth. However, at a given opening girth, the girth depression was least in RRIC 121 in comparison to the other two genotypes. Among the genotypes tested, RRISL 211 had the lowest rate of girthing in the untapped treatment (Figure 1c). In RRISL 211 also, earlier commencement of tapping at 40 and 45 cm caused substantial girth depressions, which were greater than in RRIC 121, but less than in RRIC 102. However, the exact causes of the commencement of girth depression in the G_{50} trees of RRIC 102 (Figure 1a) even before the commencement of tapping in April 2001 are not known.

Table 8. Linear correlation coefficients between cumulative dry rubber yield, yield components and bark characteristics for the overall data set and for the three genotypes separately.

	Linear correlation coefficient (r^2) with cumulative dry rubber yield per tree			
Variable	Overall	RRIC 102	RRIC 121	RRISL 211
Cumulative latex volume per tree	0.85***	0.91***	0.91***	0.96***
Latex volume per tree per tapping	0.53***	0.70**	0.84***	0.45*
Dry rubber content	0.18^{ns}	0.51*	0.26^{ns}	0.12^{ns}
Dry rubber yield per tree per tapping	0.86***	0.83***	0.92***	0.78***
Number of tapping days	0.80***	0.88***	0.69**	0.89***
Initial flow rate	0.31*	0.30^{ns}	0.57*	-0.02^{ns}
Plugging index	-0.07^{ns}	-0.19^{ns}	-0.15^{ns}	-0.19^{ns}
Bark consumption	0.01^{ns}	0.21^{ns}	-0.23^{ns}	0.40^{ns}
Bark thickness	0.79***	0.80***	0.75***	0.89***
Length of tapping cut	0.26*	0.28^{ns}	0.42^{ns}	0.22^{ns}
Number of data points in the correlation	54	18	18	18

ns: non-significant at $p = 0.05$; *: significant at $p < 0.05$; **: significant at $p < 0.01$; ***: significant at $p < 0.001$. Means of 10 replicate trees in each genotype × opening girth × tapping system treatment combination were used in the correlations. Means were calculated separately for the three periods of comparison.

RRIC 102 had the largest number of trees with TPD, followed by RRISL 211. It is notable that TPD was observed only in the trees that were opened early (G_{40} and G_{45}). While in RRIC 102, TPD was observed under all tapping systems, in RRISL 211 it was found only under HFT and LFT+E. In contrast to the above two genotypes, RRIC 121 did not show any dry trees under any opening girths or tapping treatments.

Correlations between yield, yield components and bark characteristics

When correlation analysis was performed between cumulative dry rubber yield (Y), yield components, bark characteristics and the number of tapping days for the overall data set (i.e. periods of comparison, opening girths, tapping systems and genotypes pooled together), Y showed highly significant ($p < 0.0001$) positive correlations (Table 8) with gtt, the number of tapping days (tdays), cumulative latex volume (cvol), vtt and BT. In addition, IFR showed a significant ($p < 0.05$) positive correlation with Y. Interestingly, PI, DRC, BC and LT did not show significant ($p = 0.05$) correlations with Y. Most of the highly significant positive correlations that were present in the overall data set were also observed when correlations were performed separately for the three genotypes (Table 8) and for the three opening girths (Table 9). However, a positive correlation between Y and IFR was present only for RRIC 121. While there was no significant correlation between Y and DRC in the overall data set, a positive ($p < 0.05$) correlation existed in RRIC 102.

When correlation analysis was done separately for the three opening girths, using data from Period 3 (Table 9), significant positive correlations with Y were shown for cvol, gtt, IFR, vtt and BT at all three opening girths. In addition, Y was negatively correlated with PI only for G_{45} and positively correlated with BC and tdays only

Table 9. Linear correlation coefficients between cumulative dry rubber yield, yield components and bark characteristics for the overall data set and for the three opening girths separately for the period between April 2001 and January 2003.

	Linear correlation coefficient (r^2) with cumulative dry rubber yield per tree			
Variable	Overall	G_{40}	G_{45}	G_{50}
Cumulative latex volume per tree	0.63***	0.58***	0.83***	0.68***
Latex volume per tree per tapping	0.58***	0.65**	0.81***	0.45***
Dry rubber content	0.00^{ns}	0.30*	-0.25^{ns}	-0.42*
Dry rubber yield per tree per tapping	0.89***	0.90***	0.91***	0.85***
Number of tapping days	0.10^{ns}	0.00^{ns}	-0.07^{ns}	0.46***
Initial flow rate	0.53***	0.62***	0.60***	0.47***
Plugging index	-0.01^{ns}	0.22*	-0.34**	-0.04^{ns}
Bark consumption	-0.09^{ns}	-0.09^{ns}	-0.24*	0.31**
Bark thickness	0.29***	0.29**	0.33**	0.33**
Length of tapping cut	0.23***	0.32**	0.30**	0.01^{ns}
Number of data points in the correlation	270	90	90	90

ns: non-significant at $p = 0.05$; *: significant at $p < 0.05$; **: significant at $p < 0.01$; ***: significant at $p < 0.001$. Individual replicate values in each genotype × opening girth × tapping system treatment combination during April 2001–January 2003 period were used in the correlations.

for G_{50}. Y was positively correlated with LT in the overall data set for Period 3 and separately for G_{40} and G_{45}.

In the overall data set for all periods, several notable correlations were observed among yield components and between yield components and bark characteristics. For example, gtt was positively correlated with IFR ($r^2 = 0.47$***), vtt (0.67***), BT (0.75***) and tdays (0.41**). IFR had positive correlations with vtt (0.55***) and BT (0.50***), but a negative correlation with BC (−0.59***). PI showed a positive correlation with DRC (0.73***) but a negative correlation with vtt (−0.57***). Accordingly, vtt was positively correlated with IFR (0.55***) and BT (0.70***), but negatively correlated with PI (−0.57***) and DRC (−0.46***). In addition, BC showed a positive correlation with the number of tapping days (0.32*).

DISCUSSION

Response to early commencement of tapping

The main issue investigated was whether it was feasible to commence tapping of a rubber tree at a lower girth than the currently recommended 50 cm. The secondary, but no less important, question was whether the response to early opening varied for different genotypes and tapping systems. Our results clearly showed that earlier commencement of tapping without a significant depression in subsequent girthing is possible in RRIC 121 when LFT is employed (Figure 1b). This particular genotype gave a higher dry rubber yield, both on a per tapping basis (Table 3) and on a cumulative basis (Table 4), when opened at a girth of 40 cm under LFT, either with or without yield stimulation. Although opening at 40 cm girth in RRIC 102 also gave a yield which was comparable to that obtained when opened at 50 cm, there was a significant depression in subsequent girthing in this genotype. Therefore, early commencement of tapping cannot be recommended for this particular genotype as the resulting girth depression could ultimately reduce yields in the long run.

Hence, our results demonstrate that it is possible to reduce the immature period of rubber and allow an earlier income to the growers, especially smallholders, throughout Asia if specific genotypes, which are suitable for earlier opening, are identified. In fact, work at the Rubber Research Institute, Malaysia had shown in the 1970s that opening at a girth of 45 cm was more profitable to the grower (Ng *et al.*, 1972). An economic analysis conducted on the data obtained within the relatively short duration of the present study showed the same result. In agreement with our results, Obouayeba *et al.* (2002) also showed that optimum opening girth for some of the rubber genotypes grown in the Ivory Coast was 40–45 cm.

The relative 'tolerance' of RRIC 121 to early opening was further confirmed by smaller reductions in girth increment due to tapping (Figure 1b) and the absence of TPD. In view of the close relationship that exists between girth and yield (Gomez, 1982; Narayanan and Ho, 1970), the smaller reductions in per tapping yield in RRIC121 were probably because it was able to maintain an adequate rate of girthing despite earlier opening. An adequate rate of stem girth increment meant less impeded development of latex vessels thus enabling a smaller reduction in per tapping yield. Incomplete development of latex vessels in the earlier opened trees was one of the probable reasons why RRISL 211 responded negatively to earlier commencement of tapping (Table 4).

Response to low frequency tapping

It was clear that early opening should be combined with LFT to obtain a higher dry rubber yield, both per tapping and cumulatively, in RRIC 121. While LFT of earlier opened trees (G_{40}) increased yields in both RRIC 121 and RRIC 102 (Tables 3 and 4), only RRIC 121 could increase its yields further when LFT was combined with yield stimulation. The key cause of these positive responses in RRIC 121 is probably its higher DRC when compared to the other two genotypes. An analysis of genotypic variation in yield components and bark characteristics along with their correlations with yield is needed to elucidate the physiological basis of the response of different genotypes to different opening girths and tapping systems.

Analysis of yield components

Analysis of yield components showed that the primary determinant of dry rubber yield, both per tapping and cumulative, was the latex volume rather than the DRC (Tables 8 and 9). Tupy (1985) and Nair (2000) have also shown strong correlations between rubber yield and latex volume. Therefore, obtaining a greater latex volume per tapping is the key to obtaining a greater dry rubber yield per tapping. This was true for both the genotype which responded positively to early commencement of tapping (RRIC 121) and for the genotype which responded negatively (RRISL 211

(Table 1). The significant positive correlation between vtt and BT ($r^2 = 0.70^{***}$) shows that genotypes that have thicker bark produce a greater latex volume.

However, the response of dry rubber yield to different opening girths and tapping systems is determined by the interplay between latex volume and DRC. The negative correlation between vtt and DRC ($r^2 = -0.46^{***}$) in the overall data set indicates that there exists an upper threshold to yield increase in rubber through measures to increase the extracted latex volume. This is understandable because synthesis of latex and its rubber content requires assimilates produced by photosynthesis (Samsuddin and Impens, 1978). The rates of supply of assimilates and their utilization for biosynthesis of rubber could be limiting with increasing latex volume, thus leading to the observed negative relationship. Sonquhan *et al.* (1990) have also indicated that such a negative relationship is possible. Therefore, in the present study, the greater DRC of RRIC 121 enabled it to maintain a higher dry rubber yield (Tables 3 and 4) under early opening and LFT + E despite producing a lower latex volume than either of the other genotypes (Table 1). In contrast, despite producing a substantially greater latex volume than the other two genotypes, RRISL 211 was unable to give a higher dry rubber yield because of its lower DRC.

BT and its response to early opening and different tapping systems also played a significant role in determining the yield response to the study treatments. Thicker bark probably contains a greater number of latex vessels, which would allow a greater latex IFR. A greater IFR would, in turn, increase vtt and thereby the dry rubber yield. This is confirmed by the significant positive correlations between BT and IFR ($r^2 = 0.50^{***}$) and between IFR and vtt ($r^2 = 0.55^{***}$).

In addition to the influence of BT through IFR, latex volume was also partly determined by the PI, operating through the DRC; vtt would be greater under treatments such as LFT + E which induce less plugging of latex vessels (Tables 1 and 5). This is shown, in the present experiment, by the negative correlation between vtt and PI ($r^2 = -0.57^{***}$). Moreover, genotypes with a lower DRC and treatments such as LFT + E which induce lower DRC (Table 2), would also have less plugging of vessels (and thereby higher latex volumes), as shown by the positive correlation between PI and DRC ($r^2 = 0.73^{***}$) and negative correlations between vtt and DRC and PI. These results agreed with the findings of Waidyanatha and Pathiratne (1971). Milford *et al.* (1969) concluded that PI is a genetically determined constant for a given genotype. This was only partially supported by results of the present study, as PI varied significantly with opening girth and tapping treatments (Table 5). However, there was also clear genotypic variation in PI, which could be related to the DRC (Table 2). For example, RRIC 121, which had a higher PI than the other two genotypes, had a significantly greater DRC. Therefore, by initiating greater plugging, the DRC has an antagonistic effect on the latex volume extracted. Our results showed that this influence of DRC on PI is a general phenomenon which was present across different genotypes, opening girths and tapping treatments.

The interactive functioning of the different yield components discussed above also explains why RRIC 121 was more responsive than the other two genotypes to yield stimulation under low frequency tapping. The effect of the stimulant Ethrel is to prolong the period of latex flow after a bark incision by delaying the plugging of latex vessels (Abraham, 1977). As the latex flow of RRIC 121 is clearly curtailed earlier by its inherently higher DRC, the yield stimulant was more effective in this genotype than in the others where the plugging of latex vessels did not occur as quickly as in RRIC 121.

Among the bark characteristics studied, BT had the highest influence on yield because it was a direct indicator of the status of development of latex-producing tissue. This agreed with the results of Gonçalves *et al.* (2004) who also observed significant correlations between yield and BT and the number of latex vessel rings. The ability of RRIC 121 to maintain its stem girth increment despite early commencement of tapping (Figure 1a) also contributed to its capacity to respond positively to early opening at G_{40}. Greater stem girth of the G_{40} trees of RRIC 121 as compared to the G_{40} trees of the other two genotypes probably allowed RRIC 121 to have a greater BT and thereby produce a higher yield. In addition to BT, dry rubber yield showed a positive correlation with LT (Table 9). This was because a greater number of latex vessels would be opened for extraction with a longer tapping cut. This is in agreement with the conclusions of Sethuraj and George (1980) and Paardekooper (1989).

Implications of results of the present study for rubber production in West Asia

The present study has demonstrated that it is possible to commence tapping of rubber at a lower girth (40 cm) than the currently recommended 50 cm, provided genotypes which are amenable to early commencement of tapping are identified. This has important implications for the economics of rubber growers, especially smallholders, who occupy the greater share of the rubber-growing land area in all the rubber-producing countries in Asia. For example, 64 % of the rubber cultivated area of Sri Lanka is occupied by smallholders for whom early commencement of tapping would mean an earlier income after investment in new planting. Genotypes such as RRIC 121, which are able to sustain its yields despite earlier opening, would be ideal for these smallholders. Similar to earlier commencement of tapping, LFT + E could also improve the economics of rubber production in West Asia. Here again, our results showed that yields of only some genotypes such as RRIC 121 are able to respond positively to LFT + E. However, because LFT reduces the tapping cost of the grower in comparison to HFT (data not shown), adoption of LFT + E may be economically more profitable even in genotypes which do not show substantial yield increases in response to LFT. Therefore, LFT + E can be recommended to growers, especially to those who are currently on marginal profit or break-even levels, irrespective of the opening girth adopted.

Results of the present study carry an important message to rubber breeders as well. It is clear that the newly developed genotype RRISL 211 does not respond positively to new management options such as early commencement of tapping or LFT + E, which are likely to be adopted in the future. Thus, during the process of breeding new genotypes, it is imperative that rubber breeders screen their progeny for positive responses to these new management options. Clonal screening under the traditional methods of management is unlikely to yield genotypes which are well suited to the modern rubber industry.

The significant positive response of the genotype RRIC 121 to early opening and stimulated LFT came about because of its inherently greater DRC. In order to explain the greater DRC of RRIC 121, the process of photosynthesis, which provides the primary assimilates for biosynthesis of rubber, should be studied. This work is reported in the second paper of this series (Gunasekara *et al.*, 2007).

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