International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 4 No. 1 Sep. 2013, pp. 88-100

http://www.issr-journals.org/ijias/

Effect of opening girth and some latex physiological parameters on yield of Rubber (*Hevea brasiliensis*)

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ABSTRACT: Field experiment was conducted to investigate the possibility of exploiting rubber (*Hevea brasiliensis)* for latex at a lower stem girth (40 and 45 cm) and physiological yield parameters were monitored to establish factors responsible for differences in yield due to opening girths or tapping systems tested. Three different *Hevea* genotypes, i.e. RRISL 211, RRIC 121 and RRIC 102 were exploited at different growth stages, i.e. girth of 40 cm (G_{40}), girth of 45 cm (G_{45}) and girth of 50 cm (G_{50}), using different tapping systems. Significant clonal differences were observed for the initial rate of latex flow (IFR), plugging index (PI), total volume of latex (vol), dry rubber content (DRC) and dry rubber yield when tapping commenced at different opening girths. The overall results of the present study clearly showed that the plugging index was relatively high in trees opened at lower girths, i.e. 40 cm (G_{40}) than in trees opened at higher girths, i.e. G_{45} and G_{50}. Yield differences between trees of the same clone were mainly caused by differences in IFR, while differences between clones were mainly associated with differences in flow time. There is a highly significant positive correlation between PI and DRC irrespective of the tapping systems and opening girths. This study clearly showed that the DRC, PI and IFR vary according to year of tapping, tapping system and opening girth. At the immature phase (especially G_{40} trees during the first year) were probably not mature enough to show normal latex flow relationships. Furthermore, variations in yield determining parameters have to be taken in to account in devising strategies for yield improvement in different clones.

KEYWORDS: Rubber, opening girth, physiological yield parameters, clone, yield.

1 INTRODUCTION

The physiology of *Hevea brasiliensis* is unique. Biosynthesis of latex, the economically important product of the plant, is confined to the latex vessels which exclusively occur in the phloem tissue. Biosynthesis of latex takes place within the latex vessels of the plant using sucrose, i.e. end product of photosynthesis, as the substrate [1]. The volume of latex biosynthesized by a plant depends on the number, diameter and anatomical characters of the latex vessel system and some related physiological and biochemical factors [2]. The physiological aspects that govern the balance between growth and yield are another thrust area of research in rubber. The productivity of a rubber tree is largely determined by genetic and edaphic factors. These genetic differences are expressed through differences in the structure and volume of latex vessels [3]. Latex flow involves a series of physiological changes occurring in the drainage area of the cut. Since latex production is closely correlated with the rate of partitioning of assimilates, water balance and nutritional status of the tree, from a broad point of view, the physiological changes associated with latex flow affects the entire tree [4]. The latex yield is primarily controlled by factors that influence latex production and latex flow. Genetic, environmental and physiological factors are known to influence these two components that determine latex yield [5],[6].The yield determining factors of a rubber tree are identified as, i.e. initial flow rate, plugging index, dry rubber content and length of tapping cut [7]. Previous findings regarding the variability and correlation of these factors with yield reveals that plugging index and total yield are highly correlated among clones. Further, the yield differences between trees of the same clone are mainly due to differences in initial flow rate.

Plugging index is related to many other clonal characters. It is negatively correlated with yield and incidence of dryness and positively correlated with girth, dry rubber content of latex and the magnitude of response to yield stimulation [8]. The girth at opening is of significance in this context and a lower girth is an indication of slower growth and maturity [9]. It is commonly believed that commencement of tapping when *Hevea* trees are too young significantly retards the subsequent growth of the tree. Moreover, it is known to lead to a low yield during the entire tapping cycle of a tree as the girth of the tree is positively correlated with yield [10], [11]. During the juvenile phase of a rubber tree, i.e. up to 4-5 years, food produced by the plant is used primarily for biomass production. Commencement of tapping during this phase may lead to physiological and mechanical problems due to partitioning of assimilates towards latex production [12].

The long immature period between planting to opening for tapping is considered as one of the major constraints in rubber industry when compared with other economic crops. Therefore, early opening would result in revenue being earned earlier and bring forth additional returns. Hence, the main objective of work reported in this paper was to look into the possibility of exploiting *Hevea brasiliensis* for latex at a younger age. Further, the physiological yield determining parameters were monitored to establish factors responsible for differences in yield due to different opening girths or tapping systems tested.

2 Materials and Methods

2.1 Experimental site

The present study was a supplement to a longer experiment to determine the feasibility of early commencement of tapping in three contrasting *Hevea* genotypes. A field experiment was carried out at the Dartonfield Estate of the Rubber Research Institute of Sri Lanka (RRISL), situated in Agalawatta, in the District of Kalutara located in the low country wet zone (WL_1) of Sri Lanka. The Latitude and longitude are 6^o 32’ N and 80^o 09’ E respectively (Survey Department of Sri Lanka, 1988). The climate of this region is characterized by a mean monthly temperature of 22 – 31^{o}C, ample rainfall around the year with no marked dry periods, high ambient humidity (88%), moderate wind and bright sunshine. The soil type belongs to the Agalawatta series, which is silty clay loam in texture and strong brown to yellowish red in colour (Red Yellow Podzolic).

2.2 Planting material

Hevea brasiliensis plants of genotypes RRISL 211, RRIC 121 and RRIC 102 were selected for the experiment and tapping in each of the three clones commenced at different growth stages, i.e. when 60% of trees reached a girth of 40, 45 and 50 cm measured at a height of 120 cm from the union. Data on dry rubber yield and related parameters were gathered during the period from January 2000 to April 2003.

2.3 Experimental treatments and design

The experimental treatment structure was a three-factor-factorial with three rubber genotypes, three opening girths and three tapping treatments as the main effects. For the study, 100 trees of 40 cm girth were selected from each clone and each of the 100 trees were grouped into four with three groups having 30 trees each and the other with 10 trees. Tapping commenced immediately in the first group of all three clones (30 trees of 40 cm girth). Rest of the 30 tree groups of each clone were tapped when 60% of trees reached a girth of 45 and 50 cm at 120 cm from the union. The 10 tree group of each clone remained untapped. Thirty trees selected from each clone for the commencement of tapping at different girths were randomly separated into three sub groups with each sub group having 10 trees. For each sub group, tapping treatments was introduced randomly on a single tree plot design. Ten trees were assigned for each tapping treatment of all three clones. The three tapping treatments were; (i) 1/2S d/2 – high frequency tapping (HFT); (ii) 1/2S d/3 – low frequency tapping without stimulation (LFT); (iii)) 1/2S d/3 plus Ethrel (E) 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 1.6g per tree {2.5 % ET, Ba 1.6 (2.5) 4/y}. Colour bands were painted to differentiate trees in the different groups. The trees were rainguarded and tapped throughout the year according to the tapping systems assigned. A single tapper was employed for tapping throughout the experiment.

2.4 DATA ANALYSIS

Data for each period were analyzed 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>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.

3 RESULTS

3.1 DRY RUBBER YIELD PER TREE PER TAPPING (G TREE $^{-1}$ TAPPING $^{-1}$)

When averaged across all tapping systems, during the first two years after commencement of tapping, yield per tree per tapping (g/t/t) increased with opening girth (Table 1). Yields of G_{40} trees were the lowest and the highest dry rubber yield was given by G_{50} trees in all clones tested. When averaged across all girth classes, low frequency tapping with stimulation recorded higher g/t/t levels and this true for all clones. During the first two years after commencement of tapping g/t/t showed a gradual increase with increasing opening girths. It showed a significant increase when the opening girth increased from 40 cm to 45 cm in all three clones Generally the highest g/t/t was obtained from low frequency tapping with stimulation. This trend was more prominent in trees opened at 50 cm in clone RRIC 121.

Table 1. 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 $^{-1}$)											
Clone	Tapping treatments	1st Year			2nd Year			Tapping treatment mean		Clone mean	
		G_{40}	G_{45}	G_{50}	G_{40}	G_{45}	G_{50}	1st yr	2nd yr	1st yr	2nd yr
RRIC 102	1/2S d/2	5.89	13.35	18.07	8.14	15.24	26.59	12.44^{b}	16.65^{b}	13.81^{c}	18.27^{b}
	1/2S d/3	6.48	11.46	23.73	7.24	16.32	29.49	13.89^{ab}	17.68^{b}		
	1/2S d/3+E	8.25	15.04	22.06	9.85	20.70	30.83	15.12^{a}	20.46^{a}		
RRIC 121	1/2S d/2	13.23	12.26	21.47	20.20	21.45	26.18	15.65^{b}	22.61^{b}	17.23^{b}	28.24^{a}
	1/2S d/3	5.80	14.72	22.11	13.71	25.88	28.55	14.21^{b}	22.72^{b}		
	1/2S d/3+E	9.10	21.65	34.73	24.39	45.49	48.33	21.83^{a}	39.40^{a}		
RRISL 211	1/2S d/2	10.26	21.83	31.57	17.19	25.46	36.15	21.22^{b}	26.27^{b}	23.78^{a}	28.87^{a}
	1/2S d/3	11.52	27.67	31.78	19.59	29.18	34.81	23.66^{ab}	27.86^{ab}		
	1/2S d/3+E	13.85	26.89	38.62	22.07	31.98	43.43	26.46^{a}	32.49^{a}		
Opening girth Mean		9.38^{c}	18.32^{b}	27.13^{a}	15.82^{c}	25.74^{b}	33.82^{a}				

Means of each category with the same letter are not significantly different at P >0.05

3.2 TOTAL DRY RUBBER YIELD PER TREE PER ANNUM

In all clones tested, both the annual mean and the total yield per tree per annum were less in trees opened at 40 cm (G_{40}) and 45 cm (G_{45}) when compared with 50 cm (G_{50}) (Table 2). Furthermore, total dry rubber yield per tree per annum increased with increasing girth in all clones. During first two years after commencement of tapping, the highest dry rubber yield per tree per annum is given by clone RRISL 211. On the other hand, irrespective of the opening girth, clone RRIC 121, performed better under low frequency tapping with stimulation.

Table 2. 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})												
Clone	Tapping treatment	1st Year			2nd Year			Tapping Treat mean		Clone Mean		
		G_{40}	G_{45}	G_{50}	G_{40}	G_{45}	G_{50}	1st yr	2nd yr	1st yr	2nd yr
RRIC 102	1/2S d/2	0.98	2.22	3.04	1.40	2.59	4.55	2.08^{a}	2.84^{a}	1.80^{c}	2.39^{b}
	1/2S d/3	0.74	1.31	2.73	0.83	1.84	3.36	1.59^{b}	2.01^{b}		
	1/2S d/3+E	0.94	1.71	2.54	1.13	2.34	3.51	1.73^{b}	2.33^{b}		
RRIC 121	1/2S d/2	2.21	2.03	3.61	3.47	3.65	4.48	2.62^{a}	3.87^{b}	2.25^{b}	3.64^{a}
	1/2S d/3	0.66	1.68	2.54	1.58	2.92	3.25	1.63^{b}	2.59^{c}		
	1/2S d/3+E	1.04	2.47	3.99	2.80	5.14	5.51	2.50^{a}	4.48^{a}		
RRISL 211	1/2S d/2	1.71	3.62	5.30	2.96	4.33	6.18	3.55^{a}	4.49^{a}	3.09^{a}	3.79^{a}
	1/2S d/3	1.31	3.15	3.65	2.25	3.30	3.97	2.71^{b}	3.17^{b}		
	1/2S d/3+E	1.58	3.06	4.44	2.54	3.61	4.95	3.03^{b}	3.70^{b}		
Opening girth mean		1.24^{c}	2.36^{b}	3.54^{a}	2.11^{c}	3.30^{b}	4.42^{a}				

Means of each category with the same letter are not significantly different at P >0.05

3.3 Yield Components of Hevea

3.3.1 Plugging Index (PI)

During the first two years after commencement of tapping, when averaged across tapping systems, plugging index was relatively high in trees opened at G_{40} than in trees opened at G_{45} and G_{50} (Table 3). Among the three clones tested, plugging index was relatively high in RRIC 121 in all girth classes tested. Among the three clones tested, plugging index was relatively high in RRIC 121 in all girth classes tested. When averaged across opening girths even in the second year of tapping, the lowest PI was in stimulated trees while the highest was from un-stimulated trees This was true for all clones and girth classes tested (Table 4).

3.3.2 Initial flow rate (IFR)

During the first two years after commencement of tapping, initial flow rate was lower in trees opened at G_{40} than in trees opened at G_{45} and G_{50} (Table 3). Initial flow rate increased with girth in all clones tested. When averaged across tapping systems, RRISL 211 gave the highest IFR and the lowest was in RRIC 102 (Table 4). During the first two years after commencement of tapping, initial flow rate was lower in trees opened at G_{40} than in trees opened at G_{45} and G_{50}. Initial flow rate increased with girth in all clones tested. When averaged across tapping systems, RRISL 211 gave the highest IFR and the lowest was in RRIC 102. During the first year after commencement of tapping, in all tapping systems and in all clones the initial flow rate increased with increasing opening girths. Furthermore, during the second year after commencement of tapping also, the highest initial flow rate was from trees tapped at G_{50} (Tables 3 and 4).

3.3.3 Dry rubber content (DRC)

During the first two years after commencement of tapping, when averaged across clones, RRIC 121 gave the highest DRC whilst it was lowest in RRISL .Furthermore, DRC decreased with increasing opening girth in RRISL 211. When averaged across the girth classes, a lower DRC was given by stimulated trees than the non-stimulated trees (Tables 3 and 4). During the first two years after commencement of tapping, when averaged across clones, RRIC 121 gave the highest DRC whilst it was lowest in RRISL 211. Furthermore, DRC decreased with increasing opening girth in RRISL 211. When averaged across the girth classes, a lower DRC was given by stimulated trees than the non-stimulated trees. Dry rubber content was relatively high in the second year of tapping than in the first year in all tapping treatments and clones tested. The pattern of variation in DRC across the different opening girths and tapping treatments was different in the three clones and for the two years of tapping (Tables 3 and 4).

Table 3. Mean plugging index (PI), Mean initial flow rate (IFR) and Dry rubber content (DRC) of selected genotypes of rubber at different opening girths during selected periods after the commencement of tapping

Clone	Opening girth	Mean PI		Mean IFR (ml min^{-1})		Mean DRC	
		1^{st} year	2^{nd} year	1^{st} year	2^{nd} year	1^{st} year	2^{nd} year
RRIC 102	G_{40}	3.509^{a}	3.720^{a}	0.853^{c}	1.140^{c}	33.745^{b}	36.589^{a}
	G_{45}	3.246^{a}	3.264^{b}	1.726^{a}	1.401^{b}	34.100^{b}	36.021^{a}
	G_{50}	3.342^{a}	3.125^{b}	1.488^{b}	1.675^{a}	35.551^{a}	36.942^{a}
RRIC 121	G_{40}	4.926^{b}	4.473^{c}	1.178^{b}	1.527^{c}	43.420^{b}	41.099^{b}
	G_{45}	5.741^{a}	5.721^{a}	2.693^{a}	2.276^{b}	44.465^{a}	42.263^{a}
	G_{50}	4.849^{b}	5.123^{b}	2.747^{a}	2.549^{a}	31.648^{c}	42.238^{b}
RRISL 211	G_{40}	3.192^{a}	4.379^{a}	1.713^{c}	2.046^{b}	32.379^{a}	35.922^{a}
	G_{45}	3.002^{a}	2.970^{b}	3.323^{a}	2.452^{a}	31.234^{b}	33.501^{b}
	G_{50}	3.050^{a}	2.520^{c}	2.916^{b}	2.626^{a}	31.648^{b}	31.098^{c}

Means of each category with the same letter are not significantly different at P >0.05

Table 4. Mean plugging index (PI), Mean initial flow rate (IFR) and Dry rubber content (DRC) of selected genotypes of rubber on different tapping systems during selected periods after the commencement of tapping

Clone	Opening girth	Mean PI		Mean IFR (ml min^{-1})		Mean DRC	
		1^{st} year	2^{nd} year	1^{st} year	2^{nd} year	1^{st} year	2^{nd} year
RRIC 102	$1/_2S$ d/2	3.446^{a}	3.683^{a}	1.297^{b}	1.456^{a}	34.022^{b}	37.068^{a}
	$1/_2S$ d/3	3.831^{a}	3.837^{a}	1.519^{a}	1.535^{a}	36.168^{a}	38.262^{a}
	$1/_2S$ d/3+E	2.820^{b}	2.594^{b}	1.252^{b}	1.225^{b}	33.206^{b}	34.222^{b}
RRIC 121	$1/_2S$ d/2	5.349^{b}	5.205^{b}	2.143^{a}	1.914^{b}	39.165^{b}	41.328^{b}
	$1/_2S$ d/3	5.796^{a}	5.735^{a}	2.119^{a}	2.107^{b}	41.361^{a}	45.929^{a}
	$1/_2S$ d/3+E	4.370^{c}	4.397^{c}	2.356^{a}	2.331^{a}	39.008^{b}	40.546^{c}
RRISL 211	$1/_2S$ d/2	3.181^{a}	3.661^{a}	2.426^{b}	2.229^{b}	31.762^{b}	33.369^{b}
	$1/_2S$ d/3	3.286^{a}	3.528^{a}	2.900^{a}	2.533^{a}	33.432^{a}	36.103^{a}
	$1/_2S$ d/3+E	2.777^{b}	2.680^{b}	2.626^{ab}	2.363^{ab}	30.068^{c}	31.049^{c}

Means of each category with the same letter are not significantly different at P >0.05

3.4 CORRELATION ANALYSIS FOR YIELD AND YIELD COMPONENTS

3.4.1 CORRELATION ANALYSIS FOR THE OVERALL DATA SET

When correlation analysis was performed on yield and yield components for the overall data set (i.e. clones, opening girths and tapping treatments pooled together) during the first and second years after commencement of tapping, yield showed a highly significant ($P < 0.001$) positive correlation with latex volume (Table 5). Yield also had a highly significant positive correlation ($P< 0.001$) with the initial flow rate. Furthermore, plugging index had a highly significant negative correlation with yield. However, strength of relationships of all these components showed reductions during the second year. Dry rubber content had a significant negative correlation with yield in the first year. The correlations between initial flow rate and latex volume and between DRC and PI were highly significantly ($P < 0.001$) positive while highly significant negative correlations were shown between DRC and latex volume and between PI and latex volume. During the first year, PI and IFR did not have a significant correlation, but in the second year there was a significant positive correlation (Table 6).

Table 5. Correlation coefficients between yield and yield components for the overall data set

Overall	Yield vs Vol	Yield vs IFL	Yield vs PI	Yield vs DRC
1st year	0.80***	0.62***	-0.32***	-0.31***
2nd year	0.53***	0.32***	-0.24***	-0.11ns

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*
Vol: latex volume; IFR: initial flow rate; PI: plugging index; DRC: dry rubber content

Table 6. Inter- relationships between yield components

Overall	DRC vs PI	DRC vs IFR	DRC vs VOL	PI vs VOL	PI vs IFR	IFR vs VOL
1st year	0.52***	-0.13*	-0.49***	-0.49***	0.06 ns	0.64***
2nd year	0.60***	0.27***	-0.38***	-0.57***	0.26***	0.42***

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

3.4.2 Correlation analysis for different opening girths

When correlation analysis was done for yield and yield components for different opening girths during first year after commencement of tapping, latex volume had a highly significant positive correlation with dry rubber yield in all girth classes. Anyhow, the correlation was stronger in G_{40} trees and it reduced with increasing girth. Also, the strength of the relationship had reduced during the second year of tapping in all girth classes (Table 7). The Initial flow rate (IFR) was also significantly correlated to yield in all girth classes, but the strength of the correlation had reduced during the second year. The correlation between yield and plugging index (PI) was negative and significant for all girth classes and the intensity of the relationship appear same during the two years tested. The dry rubber content (DRC) showed a significant negative correlation with yield with increasing girth (Table 7). During the first year in G_{40} trees, DRC and IFR did not have a significant correlation (Table 8). However, in the second year, significant positive correlations were observed in both G_{40} and G_{45} trees. Furthermore, G_{50} trees showed an appreciable, but non-significant correlation during both first and second years of tapping. The DRC and latex volume had significant negative correlations during the first two years in all girth classes. The correlation between PI and latex volume, during second year was significant for $G_{40.}$ Furthermore, G_{45} and G_{50} trees showed significant correlations during both years. During the first two years after commencement of tapping, IFR had significant positive correlations with latex volume irrespective of opening girths (Table 8).

Table 7. Correlation coefficients between yield and yield components for different opening girths

Opening girths	Yield vs Vol	Yield vs IFR	Yield vs PI	Yield vs DRC
G_{40} trees 1st year	0.90***	0.44***	0.003 ns	-0.18 ns
2nd year	0.45***	0.31*	-0.27*	-0.12 ns
G_{45} trees 1st year	0.75***	0.53***	-0.39**	-0.35**
2nd year	0.44***	0.23*	-0.26*	0.25 ns
G_{50} trees 1st year	0.64***	0.53***	-0.34*	-0.36**
2nd year	0.48***	0.26*	-0.33*	-0.24*

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

Table 8. Inter- relationships between yield components for different opening girths

Opening girth	DRC vs PI	DRC vs IFR	DRC vs Vol	PI vs Vol	PI vs IFR	IFR vs Vol
G_{40} 1st year	0.30**	-0.18 ns	-0.31**	-0.08 ns	0.21*	0.56***
2nd year	0.56***	0.38**	-0.35**	-0.55***	0.24*	0.36**
G_{45} 1st year	0.67***	0.11 ns	-0.49***	-0.61***	0.12 ns	0.53***
2nd year	0.60***	0.38**	-0.31**	-0.57***	0.47***	0.30**
G_{50} 1st year	0.50***	-0.17 ns	-0.59***	-0.53***	0.14 ns	0.58***
2nd year	0.63***	0.18 ns	-0.42***	-0.69***	0.10 ns	0.53***

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

3.4.3 Correlation analysis for different tapping systems

When correlation analysis was done for yield and yield components separately for different tapping systems, during first and second years after commencement of tapping, yield had a highly significant ($P < 0.001$) positive correlation with latex volume (Table 9). It was broadly similar to the pattern showed in the overall correlation analysis (Table 5). Inter-relationships between yield components for different tapping systems (Table 10) were broadly similar to the pattern showed in the overall correlation analysis (Table 6).

Table 9. Correlation coefficients between yield and yield components for different tapping systems

Tapping systems	Yield vs Vol	Yield vs IFL	Yield vs PI	Yield vs DRC
$1/_2$S d/2 1st year	0.78***	0.57***	-0.24*	-0.28*
2nd year	0.42***	0.28*	-0.29*	-0.14 ns
$1/_2$S d/3 1st year	0.80***	0.68***	-0.36**	-0.34*
2nd year	0.49***	0.15 ns	-0.18 ns	-0.14 ns
$1/_2$S d/3+E 1st year	0.80***	0.63***	-0.17 ns	-0.28*
2nd year	0.52***	0.53***	0.06 ns	0.07 ns

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

Table 10. Inter-relationships between yield components for different tapping systems

Tapping systems	DRC vs PI	DRC vs IF	DRC vs Vol	PI vs Vol	PI vs IF	IF vs Vol
$1/_2$S d/2 1st year	0.55***	-0.09 ns	-0.49***	-0.47***	0.05 ns	0.60***
2nd year	0.54***	0.09 ns	-0.38**	-0.56***	0.17 ns	0.54***
$1/_2$S d/3 1st year	0.56***	-0.21 ns	-0.51***	-0.57***	-0.08 ns	0.76***
2nd year	0.69***	0.33*	-0.41***	-0.57***	0.34*	0.35**
$1/_2$S d/3+E1st year	0.44***	-0.10 ns	-0.43***	-0.34**	0.23*	0.62***
2nd year	0.49***	0.32*	-0.24*	-0.44***	0.31*	0.48***

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

3.4.4 CORRELATION ANALYSIS FOR DIFFERENT CLONES

When correlation analysis was done for yield and yield components of different clones during the first and second years after commencement of tapping, yields of RRIC 121 and RRIC 102 had highly significant ($P < 0.001$) and positive correlations with latex volume (Table 11). In clone RRISL 211, DRC showed a significant negative correlation with yield during the first two years of tapping. Furthermore, strength of the relationship between latex volume and yield was reduced considerably during the second year in clones RRIC 102 and RRISL 211.

Table 11. Correlation coefficients between yield and yield components for different clones

Clones	Yield vs Vol	Yield vs IFR	Yield vs PI	Yield vsDRC
RRIC 102 1st year	0.98***	0.32*	-0.40***	0.10 ns
2nd year	0.81***	0.29*	-0.38**	-0.04 ns
RRIC 121 1st year	0.93***	0.79***	-0.15 ns	-0.38**
2nd year	0.91***	0.47***	-0.44***	-0.14 ns
RRISL 211 1st year	0.71***	0.48***	-0.55***	-0.33*
2nd year	0.29*	0.22*	-0.25*	-0.26*

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001*

Table 12. Inter-relationships between yield components for different clones.

Clones	DRC vs PI	DRC vs IFR	DRC vs Vol	PI vs Vol	PI vs IFR	IFR vs Vol
RRIC 102 1st year	0.18 ns	0.11 ns	0.06 ns	-0.47***	0.32*	0.32*
2nd year	0.23*	0.35**	0.01 ns	-0.57***	0.07 ns	0.31*
RRIC 121 1st year	0.21*	-0.29*	-0.41***	-0.20 ns	0.04 ns	0.70***
2nd year	0.32*	0.12 ns	-0.14 ns	-0.59***	0.07 ns	0.50***
RRISL 211 1st year	0.26*	-0.15 ns	-0.35**	-0.71***	-0.35**	0.75***
2nd year	0.25*	-0.01 ns	-0.18 ns	-0.55***	-0.13 ns	0.72***

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

3.4.5 FURTHER CORRELATION ANALYSIS FOR DIFFERENT OPENING GIRTHS

When further correlation analysis was done for yield and yield components for different opening girths (clones pooled) under different tapping systems during the first two years after commencement of tapping, yield and latex volume had highly significant positive correlations at all opening girths and tapping systems during the first year. Correlations of DRC, PI and IFR with yield varied according to year of tapping, tapping system and opening girth (Tables 13, 14 & 15).

Table 13. Correlation coefficients for trees opened at 40 cm (G_{40}) under different tapping systems

Tapping systems	Yield vs Vol	Yield vs IFR	Yield vs PI	Yield vs DRC
1/2S d/2 1st year	0.87***	0.04 ns	0.30 ns	0.44*
2nd year	0.65**	0.68***	-0.21 ns	0.03 ns
1/2S d/3 1st year	0.94***	0.81***	0.28 ns	-0.53*
2nd year	0.37 ns	0.12 ns	-0.20 ns	-0.22 ns
1/2S d/3+E 1st year	0.92***	0.67***	0.47*	-0.28 ns
2nd year	0.27 ns	0.53*	0.36 ns	0.33 ns

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

Table 14. Correlation coefficients for trees opened at 45 cm (G_{45}) under different tapping systems

Tapping systems	Yield vs Vol	Yield vs IFL	Yield vs PI	Yield vs DRC
1/2S d/2 1st year	0.64***	0.51*	-0.29 ns	0.36*
2nd year	0.15 ns	0.09 ns	-0.28 ns	-0.08 ns
1/2S d/3 1st year	0.75***	0.67***	-0.50*	-0.32 ns
2nd year	0.26 ns	0.04 ns	-0.16 ns	-0.07 ns
1/2S d/3+E 1st year	0.75***	0.53**	-0.16 ns	-0.30 ns
2nd year	0.34 ns	0.75***	0.47*	0.63**

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

Table 15. Correlation coefficients for trees opened at 50 cm (G_{50}) under different tapping systems

Tapping systems	Yield vs Vol	Yield vs IFL	Yield vs PI	Yield vs DRC
1/2S d/2 1st year	0.69***	0.54**	-0.27 ns	-0.43*
2nd year	0.30 ns	0.28 ns	-0.35 ns	-0.08 ns
1/2S d/3 1st year	0.55**	0.41*	-0.30 ns	-0.59 ns
2nd year	0.55*	0.09 ns	-0.34 ns	-0.26 ns
1/2S d/3+E 1st year	0.61**	0.68***	0.05 ns	-0.28 ns
2nd year	0.31 ns	0.37*	0.18 ns	-0.24 ns

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

Correlations between DRC and PI and between IFR and latex volume were consistent in G_{45} and G_{50} trees. However, G_{40} trees did not show significant correlations during the first year. During first two years after commencement of tapping, DRC versus IFR did not show consistent correlations in all opening girths and tapping systems (Tables 16, 17 and 18). In all girth classes, irrespective of the tapping systems, DRC versus latex volume showed consistent negative relationships. Further, PI versus latex volume had consistent negative relationship in trees opened at G_{45} and $G_{50.}$ In contrast, G_{40} trees did not show such a relationship during the first year. There was no consistent relationship between PI and IFR, irrespective of the opening girths and tapping systems (Tables 16, 17 & 18).

Table 16. Inter-relationships between yield components for trees opened at 40 cm (G_{40}) under different tapping systems

Tapping system	DRC vs PI	DRvs IFR	DRC vs Vol	PI vs Vol	PI vs IFR	IFR vs Vol
1/2S d/2 1st year	0.16 ns	-0.29 ns	0.24 ns	0.24 ns	-0.10 ns	0.26 ns
2nd year	0.46*	0.08 ns	-0.44*	-0.68***	0.20 ns	0.39*
1/2S d/3 1st year	0.33 ns	-0.37*	-0.61*	0.18 ns	0.33 ns	0.84***
2nd year	0.55*	0.22 ns	-0.20 ns	-0.62**	0.07 ns	0.54*
1/2S d/3+E 1st year	0.30 ns	0.04 ns	-0.37*	0.39*	0.66***	0.73***
2nd year	0.41*	0.58*	-0.20 ns	-0.35 ns	0.45*	0.30 ns

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

Table 17. Inter-relationships between yield components for trees opened at 45 cm (G_{45}) under different tapping systems

Tapping system	DRC vs PI	DRC vs IFR	DRC vs Vol	PI vs Vol	PI vs IFR	IFR vs Vol
1/2S d/2 1st year	0.68***	0.13 ns	-0.48*	-0.62**	0.03 ns	0.63**
2nd year	0.63**	0.06 ns	-0.39*	-0.45*	0.29 ns	0.55*
1/2S d/3 1st year	0.66***	0.10 ns	-0.46*	-0.65***	-0.08 ns	0.71***
2nd year	0.68***	0.50*	-0.46*	-0.61**	0.65**	0.08 ns
1/2S d/3+E 1st year	0.63**	0.03 ns	-0.46*	-0.49*	0.33 ns	0.41*
2nd year	0.50*	0.46*	-0.09 ns	-0.12 ns	0.57*	0.33*

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

Table 18. Inter-relationships between yield components for trees opened at 50 cm (G_{50}) under different tapping systems

Tapping system	DRC vs PI	DRC vs IFR	DRC vs Vol	PI vs Vol	PI vs IFR	IFR vs Vol
1/2S d/2 1st year	0.60**	-0.12 ns	-0.66***	-0.52*	0.28 ns	0.51*
2nd year	0.43*	0.13 ns	-0.23 ns	-0.74***	-0.14 ns	0.68***
1/2S d/3 1st year	0.61**	-0.23 ns	-0.59**	-0.66***	0.01 ns	0.65***
2nd year	0.81***	0.22 ns	-0.58**	-0.73***	0.25 ns	0.39*
1/2S d/3+E 1st year	0.41*	-0.14 ns	-0.48*	-0.36*	0.35 ns	0.61**
2nd year	0.55**	0.13 ns	-0.36*	-0.51*	0.28 ns	0.58**

*ns, non-significant at P = 0.05; *significant at P = 0.05; **significant at P = 0.01; ***significant at P = 0.001.*

4 Discussion

In this study, significant clonal differences were observed for the initial rate of latex flow, plugging index, total volume of latex, dry rubber content and dry rubber yield when tapping commenced at different opening girths. The overall results of the present study, clearly showed that plugging index was relatively high in trees opened at lower girths, i.e. 40 cm (G_{40}) than in trees opened at higher girths, i.e. G_{45} and G_{50}. Further it was lower in stimulated trees than in un-stimulated trees in all girth classes and clones tested (Tables 3 and 4). Anyhow, [13] had reported that the plugging index was relatively constant within a clone. An analysis of variance of the data of the present study also showed that the trees of a given clone varied more in initial flow rate than in plugging index. A clone with a low plugging index is expected to give a higher latex yield [14] and PI can also be reduced by the application of yield stimulants [15].

It is clear that stimulants delay the plugging of latex vessels and prolong the latex flow resulting in a higher dry rubber yield. Therefore, yield increases through stimulation were mainly due to increases in latex volume and reduction in PI. Among the clones tested, PI was relatively high in clone RRIC 121 (Table 4). Among the girth classes tested, the yield per tree per tapping of clone RRIC 121 responded positively to yield stimulation and it was associated with a lowering of the PI. In contrast, in RRIC 102 lowering of PI did not result in an increase of yield per tree per tapping. [13], [16] showed that a clone with a high PI on $1/_2$S d/2 tapping will respond better to stimulation than one with a low PI. Results obtained from this study confirmed the above observations.

The initial flow rate was also associated with yield differences observed with different tapping systems at G_{40} but to a lesser extent to that of PI (Tables 3 and 4). It has been reported that the relative importance of initial flow rate as a factor determining the yield is less than that of PI [17], [18]. However, in this study, the high yield per tree per tapping of clones RRIC 121 and RRISL 211 with stimulation was linked to an increased initial flow rate as well (Table 4). Nevertheless, in the case of RRIC 102, even in the second year of tapping, stimulation did not increase IFR.

Besides clonal characteristics, age of the tree also influenced the DRC in their latticifers [19]. Results of this study showed that the DRC was relatively high in the second year of tapping than in the first year in all clones and tapping systems tested irrespective of the opening girth (Tables 3.7 and 3.8). The DRC was relatively low in stimulated trees than in non-stimulated trees as reported by [20]. Since, stimulated trees have given a higher g/t/t, DRC may not be a significant factor in determining g/t/t. However, RRIC 121 was capable of maintaining higher values of DRC over the other two clones even with stimulation (Table 4).

In order to interpret the variation in yield, it is necessary to understand the inter-relationships that exist between yield and yield components. In this study, it is apparent that irrespective of the opening girth, latex volume showed a highly significant positive correlation with dry rubber yield (Table 5). Especially in G_{40} trees during the first year, the most important factor influencing the yield was latex volume with the other factors being of secondary importance. But in the second year, other yield components were also important in determining yield. This principle was common for all opening girths and clones tested (Tables 13, 14 and 15).

Overall correlation analysis clearly showed that the initial flow rate was positively correlated with the total yield. Similarly the plugging index and DRC were negatively correlated with yield (Table 5). In agreement with the previous findings regarding the variability of these factors, the correlation between IFR and total yield was particularly high within clones (Table 11) while the correlation between PI and yield was higher between clones. Yield differences between trees of the same clone were mainly caused by differences in IFR, while differences between clones were mainly associated with differences in flow time. There is a highly significant positive correlation between PI and DRC irrespective of the tapping systems and opening girths (Tables 8 and 10). In agreement with these findings, [13] also found that PI was highly correlated with DRC. This suggests that a higher DRC, therefore a higher latex viscosity, causes an earlier plugging of the latex vessels.

During the first year, PI did not have a significant positive correlation with IFR (Table 6). This may be due to the fact that PI and IFR behaved independently during the first year after commencement of tapping. However, in the second year, PI versus IFR had a significant positive correlation. During the first year, in G_{40} and G_{45} trees, IFR was mainly determined by the number of latex vessels and size of the latex vessels and not by the DRC. This could have been responsible for the absence of a significant correlation between DRC and IFR. But, in the second year, with age the number of latex vessels and size of the vessels increase. Hence, restriction for IFR may be reduced resulting in a significant positive correlation between DRC and IFR. Similarly G_{50} trees (higher girth trees) have more latex vessel rings and a greater size of the latex vessels. Thus, there would not be any limitations for IFR. This may the cause for the absence of a significant correlation in G_{50} (Table 8).

Furthermore, during the study period, initial flow rate showed a significant positive correlation with latex volume irrespective of opening girths. Therefore, latex volume may be determined by the IFR. Yield versus IFR also had a significant positive correlation for all opening girths. This reveals that, when the IFR increases, the latex volume also increases and finally it increases the yield. This study clearly showed that the DRC, PI and IFR vary according to year of tapping, tapping system and opening girth. At the immature phase (lower girth trees) physiological functions may not occur properly. Therefore, lower girth trees (especially G_{40} trees during the first year) were probably not mature enough to show normal latex flow relationships.

5 CONCLUSION

The study clearly revealed that the variations in latex yield either due to different girths at opening or tapping systems were controlled by the yield-determining latex parameters such the initial flow rate, plugging index and dry rubber content. There are significant clonal variations in these parameters and these variations have to be taken in to account in devising strategies for yield improvement in different clones. Accordingly, to improve latex yield in RRISL 211, the dry rubber content has to be improved. In contrast, to improve latex yield in RRIC 102, total latex volume has to be improved by greater initial flow rate and/or lower plugging index. RRIC 121 showed relatively less yield variation, both within and between years, in comparison to the other two clones, irrespective of the opening girths and tapping systems. This character of yield stability in the face of fluctuating environmental conditions is highly useful in some growing environments. Though this study has demonstrated the possibility of exploiting some new *Hevea* clones at a younger age, such knowledge when confirmed and extended could be beneficial not only in the exploitation of *Hevea* but also possibly in its breeding for crop improvement.

ACKNOWLEDGMENT

Financial support from the National Science Foundation of Sri Lanka for this as part of the first author's PhD research project is acknowledged. The authors are grateful to the management of the Rubber Research Institute of Sri Lanka for granting permission to conduct studies at their reserves.

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