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Physiological Investigations on Factors Influencing Productivity in *Hevea brasiliensis*

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Summary

The Para Rubber tree — Hevea brasiliensis — is the major source of natural rubber. Rubber is obtained by processing the latex collected by wounding the bark of the tree. The flow of latex is an abnormal physiological phenomenon induced by tapping. The yield obtained in a days' tapping thus depends on the volume of latex collected and the rubber content. The cumulative yield over a period of time, however, depends upon the biomass increment and partitioning into economic yield. Studies on major and minor yield components have contributed substantially to characterise high yielders and low yielders and to use such information in plant improvement programmes. Decades of research on exploitation systems have standardised the procedure of latex extraction keeping in view the optimum physiological balance. Chemical methods for enhancing latex flow also have been identified. Physiological investigations are also important in involving early prediction methods for potential yield and stress tolerance.

Introduction

Hevea brasiliensis Is the major commercial source of Natural Rubber. Rubber is obtained by processing the latex, collected by wounding the bark of the tree. Latex is contained in the concentrated rings of laticiferous vessels located in the zone of secondary pholem. In an unexploited tree, there is no movement of latex in the laticiferous system. The latex flows out when a tapping cut is made on the trunk of the tree mainly because of the very high turgour pressure in the latex vessels. Turgour pressures recorded in the laticifers of *Hevea* are among the highest recorded in the laticifers of different species (Sethuraj & Raghavendra, 1987); values as high as 1.5 MPa have been recorded (Buttery & Boatman, 1966). The initial flow of latex is due to elastic contraction of walls after a sudden release of turgour as a result of tapping. After a while, the flow is regulated by capillary forces until the flow ceases as the latex coagulates and plugs the vessels (Boatman, 1966; Milford *et al.*, 1969).

Flow of latex towards the cut end is an abnormal phenomenon induced by tapping. The rate and duration of flow can be altered by changing the system of tapping. Therefore, the physiological factors determining yield in *Hevea brasiliensis* are intimately related to the physiology of latex flow as induced by tapping. The yield of rubber from a tree on every tapping is determined by the volume of latex and percentage of rubber it contains. The volume of latex is determined by the rate and duration of latex flow. There are many internal and external factors which influence the rate and duration of latex flow. The rubber content in latex at a given situation reflects the biosynthetic capacity of the laticiferous vessels.

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The rubber tree being a perennial crop having a commercial life of over 30 years, the factors influencing the cumulative yield include the factors governing growth and partitioning. Sethuraj (1981) has derived a formula depicting the factors governing yield from a day's tapping and subsequently has made a comprehensive analysis of yield components (Sethuraj, 1985; Sethuraj & Raghavendra, 1987).

In the present paper, a review of physiological investigations which have elucidated the mechanisms governing yield and factors influencing them is attempted. All the important steps in the conceptual development are traced though more emphasis is given to the work carried out by the Rubber Research Institute of India in this field.

Yield Components

As already stated, the yield of rubber from a tree is determined by the volume of latex and percentage of rubber it contains. The relationship of yield with the main yield components is presented in the following formula derived by Sethuraj (1981):

$$y = \frac{F.\ l.\ C_r}{p} \qquad ......1$$

Where
- y = Yield of rubber tree^{-1} tap^{-1} (obtained from a tree each time it is tapped)
- F = the average initial flow rate per cm of tapping cut during the first 5 min after tapping
- l = the length of the cut
- p = the plugging index, which is a measure of the extent of latex vessel plugging
- C_r = the rubber content

The yield of rubber per unit land area per year (Y_h) is determined by the average rubber yield per tree per tapping ($\bar{y}$), the number of trees (N) and number of tappings per year (n_t):

$$\text{i.e.}\ \ Y_h = \bar{y}N.\ n_t \qquad ....2$$

Each of the major yield components in the formula 1 is influenced by numerous factors, both internal and external. Analysis of factors influencing the biomass production and its partitioning into rubber should also take into account the effect of tapping and extraction of latex of annual biomass increment. This is important because the girth of the tree is one of the factors influencing yield and it is known that tapping can result in biomass loss which can not fully be accounted for by rubber yield.

The annual biomass produced by a tree subjected to regular tapping (W_a), is substantially low compared to that by an untapped tree (W_m). Marked clonal variation also is reported in this regard. This reduction in biomass is only partially accounted for by the yield of rubber. A proportion (1-k) of the biomass potential that is not realised in a tapped tree and not accounted for by the rubber yield, merits attention. By reducing this proportion, W_a can be increased:

$$W_a = W_m\,(1\text{-}k) \qquad ......3$$

Simmonds (1982) assumed that the loss in biomass in a tree subjected to tapping can be accounted for by rubber and other products removed in latex. Reported data, however, indicate that the loss in biomass in a tapped tree, compared to that in an untapped tree, may vary almost seven times between clones for comparable rubber yields. Calculations based on energy value of rubber and other substances lost in latex can hardly account for the huge loss in biomass when a tree is tapped. It is, therefore, preferable to treat the part of the biomass loss that cannot be accounted for by the rubber yield separately from that accountable for by rubber extracted by tapping.

The total biomass realised in a tree subjected to regular tapping (W_a), can be partitioned to shoot and root biomass (W_g) and annual yield of rubber (Y):

$$W_a = W_g + 2.5\,Y \qquad ....4$$

The factor 2.5 accounts for the high calorific value of rubber.

The relationship among the annual biomass increment of the untapped tree (W_m), the biomass increment of a tapped tree (accounting for also the biomass of rubber) (W_a) and the actual biomass (shoot + root) increment of a tapped tree (W_g) can be expressed by the following formulae:

$$W_a = W_g + 2.5\,Y \qquad ....5$$

$$W_a = W_m(1-k) \qquad ....6$$

$$W_g = [W_m(1-k)] - 2.5\,Y \qquad ....7$$

Some of the assimilates produced in an untapped tree are utilised for rubber biosynthesis in the laticiferous system. When a tree is tapped, a part of latex thus synthesised is extracted. It is believed that the loss of latex by tapping triggers its re-synthesis. The ratio of rubber yield per tree per year (Y), to the total biomass per tree per year (inclusive of rubber extracted) (W_a), is defined as harvest index (c). In calculating the harvest index, only the rubber extracted is considered and the high calorific value of rubber (2.5 times that of carbohydrate) is accounted:

$$c = \frac{2.5\,Y}{W_a} \qquad ....8$$

A peculiar situation in *Hevea* is that the yield of latex from a tree is determined by not only the inherent factors and the environment but also by the exploitation methods adopted. The sink volume can be altered by changing the exploitation systems. The value of 'c' is thus regulated by the quantity of the rubber (Y) extracted, unlike in other crops where basically the inherent factors influencing 'c' determine the yield.

Marked clonal variation with respect to all the major yield components have been reported (Saraswathy Amma & Sethduraj, 1975). These components are also influenced by exploitation methods and environmental parameters (Sethuraj, 1977).

Sub-components of Major Yield Components

Of the four major components in the formula, the factors influencing 1 (related to girth of the tree) have already been discussed. All the other three components also are influenced by the exploitation systems and clonal characters. Some of the important sub-components of these major components are listed. This list is only indicative and not complete. Many biochemical components such as carbohydrates, enzymes of carbohydrate metabolism and rubber biosynthesis (invertase to polymerase) may exert their influence on one of the major components directly or through the sub-components listed.

Sub-components of Major Components

Initial Flow Rate (F)

* Number of latex vessel rings
* Diameter and other anatomical characters of latex vessels
* Turgor pressure at the time of tapping

Plugging Index (P)

* Rubber particle stability as determined by the composition of the protecting film (lipoprotein) of rubber particles
* Lutoid particle stability and the composition of lutoid membrane
* Flocculation potential of lutoid serum
* Antagonising effect of C-serum on lutoid serum activity
* Dilution reaction on tapping
* Mineral composition of latex
* Drainage area

Rubber Content (C_r)

* Rubber biosynthetic capacity
* Level of exploitation

Internal Factors Influencing Initial Rate of Flow

Turgor pressure at the time of tapping

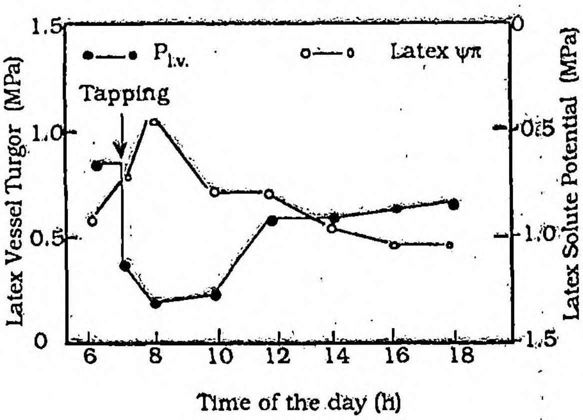

Fig. 1. Semi-diurnal changes in latex vessel turgor and latex solute potential in clone RRII 118 (After Gururaja Rao *et al.*, 1988).

influences the initial rate of flow (Sethuraj, 1977). The turgor pressure is influenced, besides by environmental factors, by the osmotic potential of the latex serum (Fig. 1) (Gururaja Rao, *et al.*, 1988).

Plugging Index — All the sub-components listed have been found to influence plugging index to varying degrees. Clonal/seasonal variation in plugging index could be ascribed to some of these sub-components (Table 1). Besides internal factors, the exploitation techniques as well as environmental parameters also influence plugging index, mediated through one or more of these sub-components (Tables 2, 3).

Rubber Content — It is well known that the rubber content in latex is negatively correlated with the intensity of exploitation. Though it is assumed that the rubber content, in any given situation, reflects the biosynthetic capacity, experimental validation is lacking.

Girth Increment of Trees Under Tapping — Distinct clonal variation in factor 'k' has been observed (Sethuraj, 1985). The influence of exploitation systems on this factor has also been established (Table 4).

Effect of Environmental Factors on Yield —The influence of soil moisture stress on yield could be related to different sub-components of yield. It was also observed that in clones susceptible to drought, irrigation results in modification of these sub-compo-

Table 1. Seasonal variations in plugging index and neutral lipid content of rubber phase in Tjir 1 and Gl 1

Clone	December		January		February		March	
	PI	TG/100g	PI	TG/100g	PI	TG/100g	PI	TG/100g
Tjir 1	8.2	20.70	12.8	15.68	13.2	11.84	11.1	20.[illegible]
Gl 1	5.5	19.87	6.1	21.01	6.2	20.50	5.5	20.[illegible]

Table 2. Initial flow rate and plugging index of Tjir 1 and PB 86

Length of cut	Tjir 1: Initial flow rate ml/min	Tjir 1: Initial flow rate ml/min/cm cut	Tjir 1: Plugging index	Tjir 1: Total latex yield per tapping (ml)	Tjir 1: Total latex yield per cycle of 12 days (litres)	PB 86: Initial flow rate ml/min	PB 86: Initial flow rate ml/min/cm cut	PB 86: Plugging index	PB 86: Total latex yield per tapping (ml)	PB 86: Total latex yield per cycle of 12 days (litres)
S/1	4.6	0.08	3.1	160	0.48	5.8	0.09	2.8	205	0.60
2/3 S	3.8	0.09	4.1	103	0.46	4.2	0.10	3.2	133	0.56
S/2	3.2	0.10	4.1	81	0.49	3.5	0.11	3.4	102	0.61
S/3	2.3	0.11	4.6	57	0.50	2.4	0.11	4.3	58	0.49
S/4	2.0	0.13	5.6	39	0.47	2.0	0.13	4.6	46	0.55

Table 3. Relationship between plugging index, rate of flow, yield and soil moisture content

Clone	Soil moisture content-20			Soil moisture content - 100		
	Plugging index	Rate of flow	Yield in cc	Plugging index	Rate of flow	Yield in cc
PB 6/9	5.97	28.98	88.00	2.65	32.45	227.37
PB 5/139	7.32	23.86	52.25	3.63	18.76	94.22
PB 5/60	3.77	26.33	115.25	3.99	30.94	162.87
PB 86	6.75	22.82	56.75	3.34	25.94	116.75
BD 10	6.20	18.62	58.50	4.16	21.64	99.81
LCB 1320	8.75	27.52	56.00	4.67	28.18	134.87
Tjir 1	15.95	19.39	21.50	3.99	34.60	176.37
G1 1	4.27	15.58	56.25	4.44	20.68	77.36
AVROS 255	7.15	19.21	60.12	3.91	21.29	122.68

Table 4 Biomass production (t $ha^{-1} Y^{-1}$), harvest index and factor 'k' in relation to exploitation system during 1983-84

Exploitation systems	Biomass production	Harvest index	Factor 'k'
No tapping	49.9	—	—
1/2 S d/1 6d/7	20.8	0.28	0.425
1/2 S d/2 6d/7	25.9	0.15	0.387
1/2 S d/3 6d/7	27.5	0.14	0.362
1/2 S d/7	29.0	0.06	0.383
1/4 S d/1 6d/7 ET 5%	20.4	0.28	0.430
1/4 S d/2 6d/7 ET 5%	23.1	0.19	0.426
1/4 S d/3 6d/7 ET 5%	24.8	0.14	0.425
1/4 S d/7 ET 5%	31.2	0.06	0.333
C. D. (P = 0.05)	12.5	0.12	0.092

nents in favour of higher yield (Table 5).

Effect of Stimulation —Use of 2-Chloroethyl phosphonic acid to stimulate latex flow has become a commercial practice in rubber plantations. The application of this chemical significantly reduces the plugging index resulting in longer duration of flow.

Table 5. Variation in yield, plugging index and soil moisture as affected by irrigation during the period of drought (February-March)

Treatment	Soil moisture (%)	Plugging index	Yield
Non-irrigated	20	7.53	51.45
Irrigated	100	4.30	83.00

Extension of drainage area as a result of stimulant application is reported by Sethuraj *et al.* (1975). The stimulant effect has also been related with a better lutoid stability (Ribaillier, 1970). However, the exact action of ethylene, released from 2-Chloroethyl phosphonic acid, at sub-cellular level to delay the process of plugging is still not very clear.

Physiological investigations in relation to productivity in *Hevea* have generated information which have been successfully utilised in parent selection by the breeders. The basis of clonal variation in regard to stress tolerance has been revealed. Clonal variation in response to exploitation systems also could be explained on the basis of physiological variations. Efforts are underway to make use of the variability of yield components at physiological and biochemical levels for early prediction of yield and stress tolerance. Though contribution of physiologist in elucidating the mechanism governing productivity has been impressive, the potential of this knowledge in plant improvement programmes is still to be exploited fully.

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