Int J Biometeorol (1990) 34:175–180

International Journal of Biometeorology IJB

Influence of soil, plant and meteorological factors on water relations and yield in *Hevea brasiliensis*

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Received January 15, 1990; revised May 21, 1990
Accepted May 31, 1990

Abstract. Influence of factors governing the soil-plant-atmosphere system on components of water relations and yield was studied in two clones of rubber tree, *Hevea brasiliensis*, viz. RRII 105 and RRII 118. Clonal variations were evident in yield and yield components and associated physiological parameters in response to soil moisture status and meteorological factors. Observations made during different seasons indicate variations in yield are attributed to differences in plugging index and initial flow rates. The major yield components and also variations in components of water relations as influenced by meteorological factors. Among the two clones, RRII 105 was found to be fairly drought tolerant compared to RRII 118. RRII 105 was found to respond well to dry weather through higher stomatal resistances, higher leaf water potentials, lowered transpirational water loss and lower relative transpiration ratios, while RRII 118 was susceptible to stress situations.

Key words: *Hevea brasiliensis* – Rubber – Irradiance – Vapour pressure deficit – Water relations – Yield – Yield components

Introduction

Rubber tree (*Hevea brasiliensis*) is indigenous to the tropical rain forest in the Amazon Basin, at an altitude of 200 m above mean sea level and near the equator. This region is characterised by monthly mean temperature between 24° and 28° C, with ample rainfall of annual totals amounting to 1500–2500 mm including some dry spells. In India, *Hevea* is being cultivated on the hill slopes in the midlands, on the western side of the western ghats and on the foothills of the western ghats. A well distributed rainfall was found to favour latex yields. Though the mean annual rainfall in the region is around 3000 mm, its monthly distribution is far from satisfactory (Vijayakumar et al. 1988). Generally, soil moisture deficits are experienced from December to May. During the summer months, dry weather prevails with very high evaporative demand resulting not only in atmospheric drought but also soil drought. Earlier studies indicate that clones may vary in the degree of their drought tolerance (Gururaja Rao et al. 1988a, b; Devakumar et al. 1988). Although the effects of soil drought were studied in relation to yield, the influence of factors governing the soil-plant-atmosphere system on water relations and yield performances under the progressive build-up of soil moisture has received inadequate attention. The present paper deals with the impact of soil, plant and meteorological factors on water relations and yield performance in two clones of *H. brasiliensis* in the traditional rubber-growing tract of India.

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Materials and methods

Experiments were conducted at the Rubber Research Institute of *India Central Experiment Station (CES)*, Chethackal (9°22′ N; 76°50′ E) in clones RRII 105 and RRII 118. These clones were selected based on yield drops during the summer months and the relative drought tolerance, i.e., RRII 105 as being fairly drought tolerant and RRII 118 as susceptible. Observations made during 1987–1988 represent the dry season of 1987 (April–May), the wet season of 1987–1988 (October, December of 1987 and January of 1988) and the dry season of 1988 (February–March). The precipitation and soil moisture levels that occurred during the above periods are shown in Fig. 1. The trees under study were 10 years old and were growing in the same field of which the soil was an oxisol. Both clones were under the same system of tapping. Five uniform trees of representative girth were selected from each clone for experimental purposes. Observations on diurnal changes in components of water relations and meteorological factors were monitored as described in the following paragraph. Detached sun leaves from the periphery of the canopy were sampled for psychrometer and porometer recordings (Devakumar et al. 1988).

Leaf water potentials (ψ_{leaf}) and latex osmotic potentials (Latex$_\pi$) were estimated using C-52 sample chamber psychrometer connected to HR 33T dew point microvolt meter (Wescor Inc., Logan,

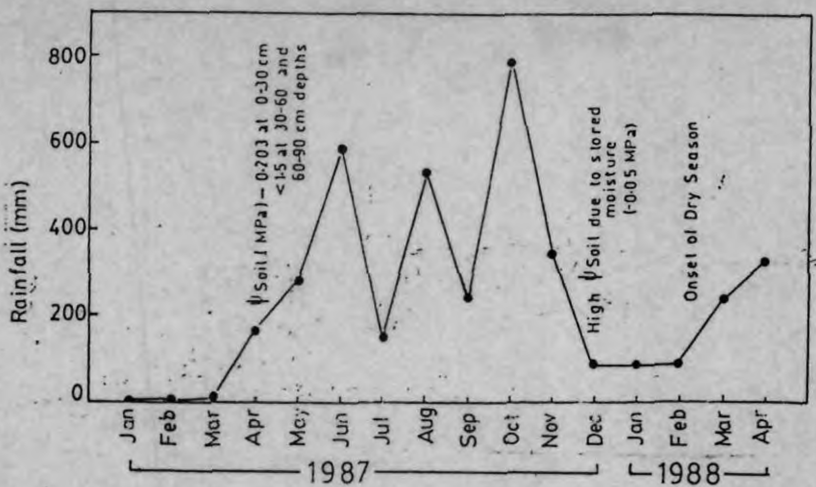

Fig. 1. Rainfall pattern from January, 1987 to April, 1988. During April–May 1987 only the upper soil layer (0–30 cm) had higher water status. Very low soil water potentials below 30 cm (−1.5 MPa) indicate incomplete recharging of the soil

Utah, USA). Leaf discs were used for determining ψ_{leaf} and latex samples taken on filter paper discs were used for estimations of $Latex_{\pi}$. Stomatal resistance (r_s) and transpiration (Tn) rates were estimated using LI-1600 steady state porometer (Li-Cor Instruments, Nebraska, USA). Xylem sap speeds were estimated at 1-h intervals (from dawn to dusk) using Model HP-1 sap flow meter (Hayashi Denkoh, Japan), based on measurements made by heat pulse technique. The sensor and heat probes were installed above the tapping cut into that portion of the cambium tapped by the cut to a depth of 3.5 cm. Latex vessel turgor (P_{lv}) was estimated using disposable minimanometers developed by us comprising No. 48 polythene surgical tubing sealed at one end and fitted with a 21-gauge hypodermic syringe needle at the other (Raghavendra et al. 1984). The total length of the manometer was 20 cm. The length of the air column trapped in the manometer was measured and the turgor pressure was estimated using a calibration curve prepared against known pressures. Turgor pressures were monitored 5 cm below the tapping cut.

Yield (g tree^{-1} tap^{-1}) and yield components including initial flow rate, F (ml cm^{-1} min^{-1}), rubber content, C_r (% w/v) and plugging index were recorded. Plugging index was determined according to Milford et al. (1969) using the equation:

$$p = \frac{\text{Mean flow rate during the first 5 min}}{\text{Total latex yield (ml)}} \times 100.$$

Soil moisture was determined gravimetrically at depths of 0–15, 15–30, 30–60 and 60–90 cm and the values were converted to potential units using characteristic standard curves for soil moisture. Five replications were obtained at each depth. Vapour pressure deficits calculated from the wet and dry bulb temperatures using Assman psychrometer (Ogawa Seiki, Japan) were taken in the open area adjacent to the experimental site and represent that of bulk air. Irradiance was monitored using LI 1800 spectroradiometer with a cosine receptor (Li-Cor Instruments, USA).

Daily transpiration rates were obtained by integrating the hourly recordings of transpiration measured during the day from 0600 to 1800 hours, and by taking the mean value of pre-dawn and dusk transpiration rates as the mean of night transpiration. The daytime sap flow rates were calculated from the cumulative values of 12 hourly radings. The ratio of transpiration to potential evapotranspiration was also calculated. Evapotranspiration rates were estimated according to Penman method (Frere and Popov 1979).

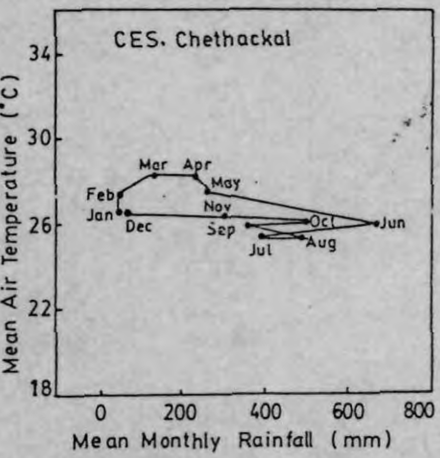

Fig. 2. Climatogram drawn by taking mean monthly rainfall and mean air temperatures (average of 10 years data from Central Experiment Station, Chethackal) in different months

Table 1. Variations in mean ambient temperature, irradiance, vapour pressure deficit and evapotranspiration rates in different seasons

Parameter	1987 Dry season (Apr–May)	1987–1988 Wet season (Oct, Dec, 87; Jan, 88)	1988 Dry season (Feb–March)
Temperature (°C)	36.7	32.4	35.4
Irradiance (W m^{-2})	305.0	241.2	310.5
Vapour pressure deficit (mbar)	34.5	36.4	32.8
Evapotranspiration (mm day^{-1})	5.27	3.97	5.57

Average values of ET_o: (after rounding off to one decimal) dry season, 5.4; wet season, 4.0

Results

Soil water status

Soil water potentials at 0–30 cm depth were −0.2 MPa during April–May 1987. The ψ_{soil} was below the wilting point at 30–90 cm depth (< −1.5 MPa) during the same period. Soil water potentials were very high (−0.05 MPa) during the wet season due to complete recharging of the soil. However, ψ_{soil} values decreased during the dry season of 1988 with the onset of summer. The higher

Table 2. Seasonal variations in yield, yield components and components of water relations in *Hevea* clones RRII 105 and RRII 118

Parameters	RRII 105							RRII 118							C.D.$_{0.05}$		
	Apr	May	Oct	Dec	Jan	Feb	Mar	Apr	May	Oct	Dec	Jan	Feb	Mar	C	M	C × M
Yield and yield components																	
Yield (g tree^{-1} tap^{-1})	46.26	47.68	74.66	96.82	119.48	67.60	43.02	18.62	24.26	41.66	47.60	50.68	46.46	30.06	7.097**	7.097**	10.043**
Initial flow rate (ml cm^{-1} min^{-1})	0.107	0.119	0.1[illegible]	0.129	0.162	0.109	0.109	0.062	0.087	0.102	0.100	0.095	0.094	0.097	0.009**	0.009**	0.013**
Rubber content (%, w/v)	44.20	38.70	36.22	38.82	35.90	38.02	39.26	45.60	38.04	35.42	40.12	39.90	36.06	42.04	2.099**	2.099**	2.969**
Plugging index	3.95	3.58	2.62	2.19	2.02	2.57	4.09	6.59	5.42	3.37	3.46	3.20	2.98	5.37	0.853**	0.853**	NS
Components of water relations	Apr	May	Sep	Oct	Dec	Jan	Mar	Apr	May	Sep	Oct	Dec	Jan	Mar	C	M	C × M
Pre-tapping P_{lv} (MPa)	1.10	1.07	1.10	1.13	1.09	1.11	1.03	0.88	0.82	0.82	1.06	0.98	0.89	0.98	0.097**	NS	NS
Latex solute potential (−MPa)	1.29	1.20	1.21	1.24	1.19	1.21	1.21	1.06	1.05	1.07	1.16	1.01	1.05	1.12	0.074**	0.074**	NS
Pre-dawn ψ_{leaf} (−MPa)	0.16	0.13	0.11	0.11	0.11	0.15	0.12	0.26	0.29	0.21	0.21	0.14	0.17	0.21	0.026**	0.026**	0.038**
Afternoon ψ_{leaf} (−MPa)	1.88	1.82	1.10	1.20	1.30	1.28	1.32	2.42	2.40	1.56	1.48	1.92	1.66	1.65	0.157**	0.157**	NS
Minimum r_s (s cm^{-1})	2.18	2.16	2.60	2.45	2.23	2.10	2.23	1.82	1.84	1.42	1.86	1.26	1.76	1.72	0.505*	NS	NS
Mean r_s (s cm^{-1})	14.62	10.16	11.26	11.30	11.42	10.42	9.48	6.82	8.62	7.62	9.58	8.12	5.78	5.50	0.790**	0.790**	1.118*
Transpiration (mm day^{-1})	0.597	0.552	0.826	1.018	2.136	3.491	0.592	1.08	1.80	1.642	1.922	3.706	4.468	3.016	0.095**	0.095**	0.135**
Transpiration coefficient	0.110	0.108	0.212	0.243	0.544	0.898	0.104	0.242	0.298	0.425	0.457	0.992	1.039	0.673	0.013**	0.013**	0.019*
Cumulative xylem sap speed (cm/12 h)	135.97	121.39	140.27	–	–	158.26	–	72.34	91.57	61.17	–	–	106.84	60.84	NA	NA	NA

** Significant at 1% level; * Significant at 5% level
NS, not significant; NA, not analysed; C, clone; M, month; C × M, clone × month

water potentials in the surface layers during the dry season of 1987 were found to be due to the light showers received prior to the observations.

Meteorological factors

The climatogram of mean monthly air temperatures versus mean monthly precipitation (Fig. 2) indicates that the rubber trees experienced soil moisture stress from December/January to May. Though the total annual rainfall was around 2700 mm, its uneven distribution during different months resulted in soil moisture stress during the above period. During the dry months, increases in radiation and temperature as well as vapour pressure deficit (VPD) were observed with time. The seasonal variations in these parameters and values of evapotranspiration, ET_0, were clearly indicated between dry and wet months. The ET_0 values were around 5.4 mm day^{-1} in most of the dry season and 4.0 mm day^{-1} in the wet season (Table 1).

Plant factors

Yield and yield components. Maximum rubber yields were obtained under conditions of adequate soil moisture availability (−0.05 MPa, wet season) in both clones (Table 2). However, the absolute yields were higher in RRII 105 compared to RRII 118. Lowered yields in the summer months in both clones indicate that availability of soil moisture is one of the important factors influencing latex yields through its effect on plant-water relations.

Among the yield components, initial flow rate of latex was found to be high during wet months, while plugging index and rubber content of latex were low during the wet months in both clones. All the major yield components showed significant variations with time in both the clones; the interactions between season and clone were also significant in relation to yield, initial flow rate and rubber content (Table 2).

Components of water relations. Most of the components of water relations were studied during April, May, September, October and December, 1987 and January and March, 1988. Observations during February, 1988 could not be recorded due to wintering (defoliation) of trees.

Pre-tapping latex vessel turgor was found to be high during wet months (Table 2). There was significant clonal variation in P_{lv}, although the variation between months was not significant. RRII 105 was found to maintain better latex vessel turgor than RRII 118. Latex solute potentials were also found to be lower in RRII 105 compared to RRII 118. Latex$_\pi$ was found to be low in dry months in both the clones.

Pre-dawn leaf water potentials differed significantly between clones and seasons. RRII 105 was found to possess very high pre-dawn as well as afternoon leaf water potentials. Results indicate that maximum ψ_{leaf} and xylem sap speeds were noticed after the restoration of complete soil moisture status, i.e. from June onwards and decreased again with the onset of dry season in 1988. RRII 105 was found to maintain higher stomatal resistances than RRII 118 in all the seasons. There was no appreciable variation in minimum stomatal resistance between the clones. The computed daily transpiration rates were higher in wet months, and were lower in clone RRII 105 than RRII 118. The variation of transpiration rate between months and clones was highly significant. The mean transpiration ratio (Tn/PET) ranged from 0.104 to 0.544 in clone RRII 105 and from 0.242 to 1.039 in RRII 118. Again, clonal and seasonal variations of this parameter were highly significant. The cumulative xylem sap speeds were markedly higher in both the clones during wet months. Observations could not be carried out during some months due to technical limitations.

Discussion

In a survey conducted during March, 1987, we noticed that soil moisture was below the wilting point (< −1.5 MPa) at depths of up to 60 cm. It was also observed that even to 60–90 cm depth, the water availability was very low. Severe water deficits were experienced by rubber plantations due to unusual drought resulting from unusual rainfall pattern with very low precipitation during October–November, 1986 and almost total absence of rain in December, 1986 to March, 1987 (Vijayakumar et al. 1988). Even the scanty rains received were only partially effective (Fig. 1); it was evident from the afternoon leaf water potentials that the trees were experiencing severe drought.

In *H. brasiliensis*, low rubber yield in summer and wintering is thought to be due to soil moisture stress (Chua 1970). Separate quantification of effects on clones RRII 105 and RRII 118 would be possible only with irrigation experiments. Although the pre-tapping latex vessel turgor (P_{lv}) was not very low in April–May, 1987 (dry season) and February-March, 1988, the initial flow rate of latex (F) was very low. Significantly higher rubber content (C_r) and subsequently higher viscosity of latex might have resulted in low F values (Buttery and Boatman 1976). Clonal variations in latex yields in RRII 105 and RRII 118 in the summer months was associated with differences in latex vessel turgor, initial flow rate, rubber content and plugging index. It is evident from Fig. 3 that maintenance of higher latex vessel turgor in RRII 105 results in better latex flow. Absence of seasonal variation in P_{lv} can be ascribed to osmotic adjustment in the latex (Raghavendra et al. 1984). In RRII 105, higher turgor in all the months is associated with lowered Latex$_\pi$.

The present study indicates that agro-meteorological factors play an important role in soil- and plant-water relations and water relations of laticifers (latex vessel system) through regulation of stomatal opening. We observed progressive atmospheric demand during dry periods, which might have resulted in increased resistance. Maintenance of higher plant water status in RRII 105 is associated with higher stomatal resistance. Earlier stu-

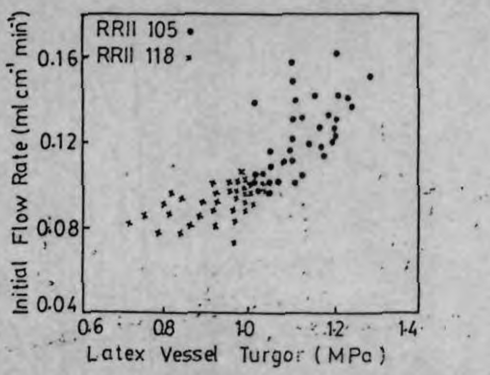

Fig. 3. Relationship between latex vessel turgor and initial flow rate of latex in RRII 105 and RRII 118 (observations taken from different seasons)

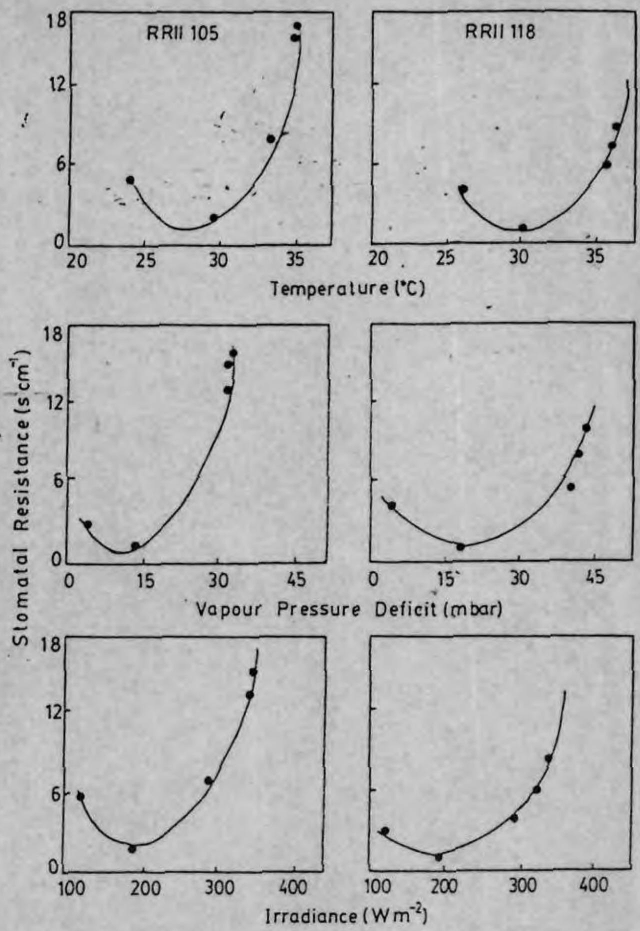

Fig. 4. Stomatal resistance in *Hevea* clones RRII 105 and RRII 118 during the dry season plotted against radiation, temperature and VPD. Each point is the mean of 5 observations calculated from measurements taken between 0900 and 1400 hours

dies indicate that stomatal resistance below 3 s cm^{-1} is indicative of fully open stomata. The process of stomatal closure was initiated at r_s values around 5 s cm^{-1} and complete closure occurred at resistance values greater than 15 s cm^{-1}. This was reflected by highly negligible rates of CO_2 uptake at higher r_s values (Satheesan et al. 1984).

In most of our experiments, initiation of stomatal closure in RRII 105 and RRII 118 occurred at irradiance of around 275 W m^{-2}, ambient temperature of 33° C and VPD of 28 mbar; the upper limit of these factors was 300 W m^{-2}, 35° C and 35 mbar, respectively (Fig. 4). The high stomatal resistances in RRII 105 compared to RRII 118 (Table 2) indicate that the stomata of RRII 105 are more sensitive to meteorological factors than those of RRII 118.

Absence of seasonal and clonal variation in minimum stomatal resistance, i.e., the peak hours of stomatal opening, suggests that these clones do not behave differently at the time of maximum photosynthesis. However, variations in stomatal resistance (at times other than peak hours of photosynthesis) might play a vital role in plant-water relations, thereby maintaining better plant-water status in RRII 105, resulting in higher latex output.

As reported earlier (Devakumar et al. 1988), the transpiration coefficient can be used as a tool to quantify soil moisture availability, as in tree crops such quantifications are often difficult using soil moisture data alone. Our observations indicate that transpiration rates were higher in RRII 118 compared to RRII 105, even though the sap flow rates in the latter were higher, despite changes of leaf water potential. This indicates a lower root resistance which may be due to either higher root density or better root permeability to water. Maintenance of higher stomatal resistance in this clone might be an adaptive feature, and is another factor contributing to the high plant water status in RRII 105, which results in higher latex yields due to higher latex vessel turgor. The lower latex solute potentials during dry months also contribute towards the turgor maintenance. We also observed that transpiration rates were higher in the afternoon hours when the VPD is high, even though the maximum stomatal opening was seen in the morning.

It should be mentioned here that the additive effect of environmental variables is more than an individual effect, i.e. radiation causes an increase in temperature, which in turn affects VPD and indirectly influences stomatal regulation. Variations in these meteorological parameters, viz., irradiance, temperature and VPD, exceeding the limits indicated, might result in stress in *Hevea*. The lowered transpirational rates in the dry season can be ascribed to higher stomatal resistance which in turn resulted from high leaf temperatures and associated meteorological factors.

In conclusion, it can be stated that low latex solute potentials and sufficient available water to maintain higher P_{lv} are the conditions required for good flow of latex. The meteorological parameters, irradiance, ambient temperature and VPD, play an important role in maintenance of plant water status through their effects on stomatal resistance and transpiration, thereby influencing latex vessel turgor and latex outputs. Further studies are in progress to assess the direct and indirect effects of these meteorological factors on latex yields in *Hevea*.

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