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PHOTOSYNTHESIS AND BIOMASS PRODUCTION OF THREE POPULAR *HEVEA BRASILIENSIS* CLONES AS AFFECTED BY WATER STRESS

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Different soil regimes were imposed by watering at 2, 6 and 9 day intervals for two months on six-month-old plants of three *Hevea brasiliensis* clones *viz.,* RRII 105, RRIM 600 and GT 1. To study the recovery, the plants were given normal watering for another two months. The peak carbon dioxide exchange rate (CER) was observed at 9.00 h for control and 8.00 h for stressed plants of all clones. A decrease in values of relative water content (RWC) and chlorophyll content with increase in diffusive resistance was observed under water stress. CER also decreased along with transpiration rate. RWC was found to be the major parameter, which affected the CER. Reduction in dry matter production of the above ground biomass observed was 50 per cent in six days and 84 per cent in nine days due to water stress and the reduction was more for clone RRII 105 (9 days) compared to the other two clones. In another experiment, visual injury like leaf margin drying, shedding of leaves and plant mortality were studied by withholding water for long time. Under severe water stress, highest plant mortality was observed for clone RRII 105 (75%) followed by RRIM 600 (30%) and GT 1 (25%). Recovery after stress was faster for the clone GT 1 and RRIM 600, compared to RRII 105. Clone RRIM 600 acquired more percentage of biomass during the rewatering period after the stress.

Key words: Biomass production, Carbon dioxide exchange rate, *Hevea brasiliensis,* Photosynthesis, Water stress.

INTRODUCTION

Water is an important limiting factor for plant growth and productivity (Hsiao, 1973). Physiological processes affected by water stress include stomatal opening, photosynthesis and respiration etc. (Kramer, 1974). Effects of water deficit on photosynthesis have been interpreted as a consequence of stomatal closing (Boyer, 1976) and also non-stomatal components. The effect of drought on photosynthesis is well documented (Kramer, 1974). Much of it has been attributed to the direct effect of water stress on inhibition of CO_2 fixation.

The cultivation of rubber (*Hevea brasiliensis*) has been extended to non-traditional areas in India, mainly due to the shortage of suitable land in the traditional zone. Potential planting areas were identified in Orissa, Madhya Pradesh, Andhra Pradesh, Karnataka and Maharashtra States. In these non-traditional regions, prolonged dry season cause severe soil moisture deficit accompanied with high temperature. During summer months, dry weather prevails with very high evaporative demand resulting not only in atmospheric drought but also soil drought (Vijayakumar *et al.,* 1988; Mohankrishna *et al.,* 1991; Vijayakumar *et al.,* 1998).

Without irrigation, establishment of

Correspondence: S.K. Dey (E-mail: dey@rubberboard.org.in) rubber is difficult during the long dry season. Heavy loss of plants was observed in many cases. Growth is also inhibited for long period resulting in prolonged immaturity period. There are genotype variations in the effect of water stress on photosynthesis in *Hevea* (Monteny *et al.*, 1985). Clonal variations have also been reported in the survival and growth of young plants under severe moisture stress (RRII, 1990). This experiment was undertaken to study the effect of water stress on photosynthesis and biomass production of three clones included in widely recommended (Category I) clones (Rubber Board, 1992) and to identify suitable clones for early establishment in drought prone areas.

MATERIALS AND METHODS

Pot culture experiments were conducted at Rubber Research Institute of India, Kottayam, Kerala (76° 36'E, 9° 32' N). Brown budded stumps of *Hevea brasiliensis* clones RRII 105, RRIM 600 and GT 1 were planted (one each) in cement pots containing 40 kg soil and were maintained following the recommended package of practices (Rubber Board, 1992). The soil type was oxisol with a field capacity 35 per cent and permanent wilting point of 18 per cent (gravimetric estimations). The plants were subjected to water stress, 160 days after transplanting. The watering schedule was of two (w_1), six (w_2) and nine (w_3) days intervals. A total of 225 plants were maintained in a randomised block design of nine treatments with five replications and five plants per replication. The watering as per the treatments was continued for 60 days during January to March 1992. Thereafter, all the plants were watered at two dry intervals for another 60 days to study the recovery.

In another experiment, plants in 20 pots for each clone were subjected to stress by withholding water till the soil moisture was brought down to 12 per cent to study the variation in plant mortality under extreme water stress. Progressive changes in soil moisture content and plant mortality were monitored.

Carbon dioxide exchange rate (CER) and dark respiration (RS) were measured using portable photosynthesis system (LI-6200, Licor, USA) with one litre chamber. Fully mature leaves were used for all measurements. CER measurements were made under sun light above saturation point. For respiration three leaves were covered with dark cloth for 7 to 10 minutes and then clamped into darkened chamber. The steady state of RS was recorded one minute after clamping (Mclaughlin *et al.*, 1990). Diurnal variation of CER was measured (using LI 6200) at an hourly interval from 8.00 to 16.00 h before the irrigation. Leaf area was measured by using the leaf area meter (LI 3000, Licor, USA). Plant height, above ground biomass, leaf area and leaf number and chlorophyll content (Arnon, 1949) were also recorded before and after the treatment and also during the recovery phases. Relative water content (%) in leaf before watering was calculated by the formula suggested by Barrs and Weatherly (1962), as follows:

$$\text{RWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

RESULTS AND DISCUSSION

Soil moisture depletion pattern in the

control pots showed that moisture content remained almost steady throughout the experiment. In the case of w_2, the moisture content decreased from 35 to 21 per cent within six days and in w_3, the decrease was to 18 per cent within nine days. Soil moisture contents of all the pots were raised to field capacity after rewatering.

Carbon dioxide exchange rate (CER) measured during the stress period at two different levels of moisture varied. However, it was steady in the more frequently watered (w_1) plants (Fig. 1). The CER decreased in all the clones under both the higher stress levels. Lower CER was observed in clone RRII 105 on ninth day and it did not recover fully even after watering. The trend was similar in the clone RRIM 600 though the absolute values varied. Recovery of CER in clone GT 1 was complete on watering under moderate stress (w_2). CER was higher in RRIM 600 and RRII 105 than GT 1 under more frequently watered (w_1) condition, which is a clonal character.

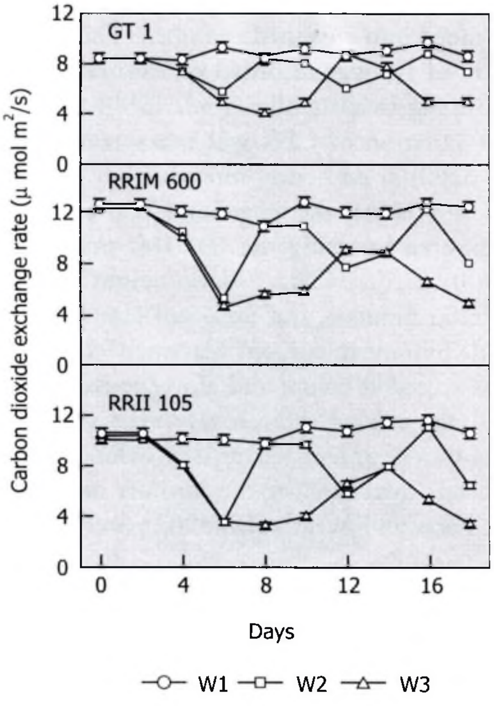

Fig. 1. Effect of irrigation schedule on carbon dioxide exchange rates of young plants of three *H. brasiliensis* clones

Clonal variation in rate of photosynthesis (Samsuddin, 1986; Dey *et al.*, 1995) and its relation to growth and yield of *Hevea* (Samsuddin *et al.*, 1987) has been reported. Water deficit strongly affects photosynthesis and the reduction in gas exchange is due to high canopy resistance or closing of stomata (Monteny *et al.*, 1985). Decrease in photosynthetic rate at low leaf water potential is often attributed to decreased stomatal conductance (Boyer, 1970). Drop in CER and recovery on rewatering was gradual but recovery was not to initial level when water shortage was more drastic (Jacob *et al.*, 1989). Dark respiration (RS) increased nearly two fold in water stressed plants w_2 (3.05) or w_3 (3.43) compared to w_1 (1.63 mol/m²/sec), however, clonal variation was not observed.

Diurnal changes in vapour pressure deficit (VPD), ambient mean temperature and irradiance at hourly intervals on the days of observation are presented in Fig. 2. Temperature, VPD and light intensity continued to increase till 12.00 to 13.00 h and declined thereafter. Comparison of diurnal changes of CER was made between plants under more frequent watering (w_1) and stressed plants (w_3) (Fig. 3). Peak photosynthetic rate was recorded around 9.00 h in all the three clones in more frequently watered (w_1) plants whereas under stress it was at 8.00 h. Under stress, the clone RRII 105 recorded the lowest CER while RRIM 600 showed a slow and steady decrease. The

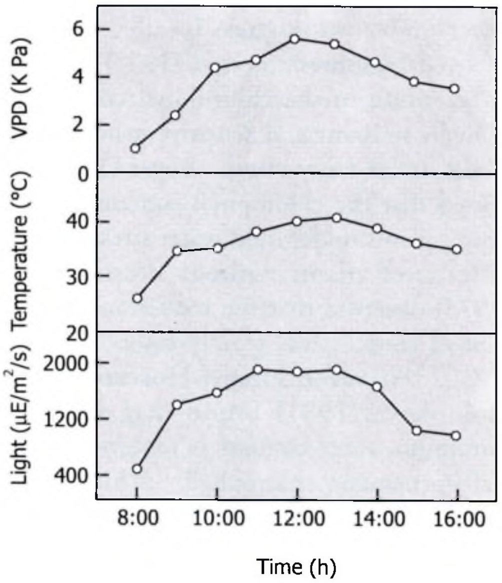

Fig. 2. Change in light intensity, temperature and vapour pressure deficit (VPD) during the day

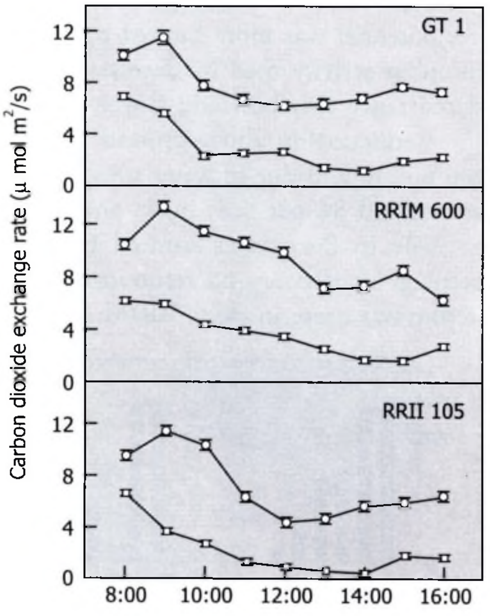

Fig. 3. Effect of water stress on carbon dioxide exchange rates of three *H. brasiliensis* clones at different times of the day

clone GT 1 maintained better CER under stress compared to RRII 105. CER decreased in all the clones under stress but in RRII 105 it was found to be faster and was close to zero at 14.00 h. Such decreases in CER during water stress were also reported in other plants like orange (Yelenosky *et al.*, 1986).

Reduction in transpiration (Tr) rate was observed in stressed plants of all the clones and the peak Tr was observed at 10.00 h for clone RRII 105, 12.00 h for RRIM 600 and 14.00 h for GT 1 for plants under treatment w_1. The mean Tr of the day for the plants was lower in both w_1 and w_3 for clone RRII 105 than for other clones. Similar trend was reported by Devakumar *et al.* (1988).

The water use efficiency (WUE) at single leaf level or ratio of carbon assimilation to water loss in transpiration under stress condition is shown in Fig. 4. The WUE decreased during midday in stressed plants for all the clones. The WUE value reached the lowest point near zero in the clone RRII 105. However, it was comparatively better in the other two clones. Increased WUE un-

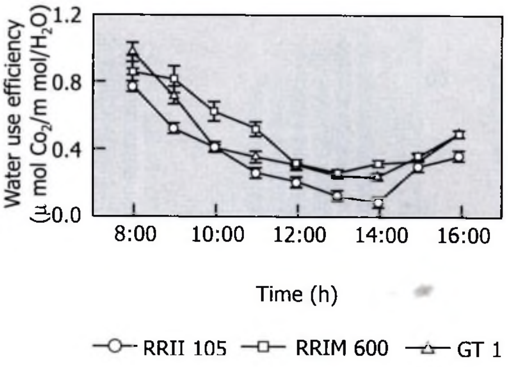

Fig. 4. Day time changes in water use efficiency of young plants of three clones of *H. brasiliensis* subject to severe water stress (W_3)

der stress conditions enables the plants to maintain relatively higher levels of energy consumption via net CO_2 uptake at reduced Tr (Steur *et al.*, 1988; Mohankrishna *et al.*, 1991). The mean diurnal WUE (mmol CO_2/mmol H_2O) was lowest in clone RRII 105 (0.34) during stress conditions (w_3) followed by GT 1 (0.48) and RRIM 600 (0.50) (Fig. 4). Mean stomatal resistance (sec/cm) of the day under stress (w_3) was the highest in clone RRII 105 (19.8) followed by clones GT 1 (10.5) and RRIM 600 (11.0). High resistance indicates the closing of stomata to check the transpiration and ultimately reducing the carbon dioxide exchange rate.

Compared with control plants, the RWC and chlorophyll content were lower in stressed plants (Fig. 5). Total chlorophyll per unit weight was highest in RRII 105 (w_1) but per cent reduction was more in the stressed plants. RWC was lowest in the w_2 and w_3 treatments. Among the clones RRIM 600 showed higher RWC value. Chlorophyll content showed a remarkable decrease in clone RRII 105 than the other two clones. The chlorophyll content was lower under water stress in all the clones analysed. Kulshreshtha *et al.* (1987) reported no variation in the chlorophyll content in drought resistant and sensitive genotypes of wheat under water stress. Boyer (1976) reported that the chlorophyll content of sunflower plants under mild water stress did not differ from plants without stress. Hsiao (1973) observed that the reduction of chlorophyll content was mainly associated with RWC. However, Haspel-Horvatovic and Holubkova (1981) found that a certain minimum water content is required in the leaf to maintain chlorophyll. A high correlation (r=0.0667*) was observed between chlorophyll content and RWC in the present studies. Similar correlation was also reported in tomato (Castrillo and Calcagno, 1989) under water stress. Photosynthesis at low water potential was more limited by loss of chloroplast activity than by decreased diffusive resistance (Mathew and Boyer, 1984).

Reduction in above ground biomass (from bud union) due to water stress was 50 per cent and 84 per cent in w_2 and w_3 respectively in the clones studied (Fig. 6). Percentage of recovery on resuming normal watering was more in clone RRIM 600 and

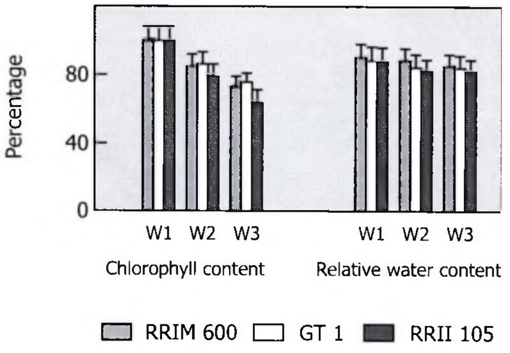

Fig. 5. Effect of water stress on chlorophyll and relative water contents of different *H. brasiliensis* clones expressed as percentage of control plants

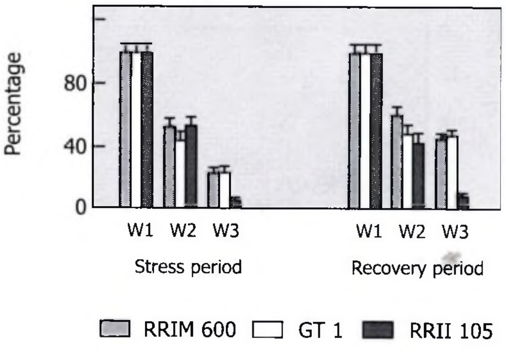

Fig. 6. Above ground biomass of different *H. brasiliensis* clones expressed as percentage of control in water stress and recovery phases

GT 1 than in RRII 105. Difference in dry matter production in *Hevea* due to difference in the availability of water under water stress was reported by Haridas (1980). Faster recovery growth was noticed in clone RRIM 600 than in the other two clones. Decrease of CER under unirrigated condition has been reported earlier (Mohankrishna *et al.*, 1991; Vijayakumar *et al.*, 1988). Total leaf area and leaf number were also less under water stress, and the reduction was more under w_3 treatment. The leaf number reduction was 7 per cent and 11 per cent in w_2 and w_3 treatments respectively. The percentage reduction in leaf area per plant is presented in Fig. 7. In general, leaf area reduced to 17 per cent and 27 per cent in treatments w_2 and w_3 respectively. The reduction in leaf area per plant was higher in the clone RRII 105 than RRIM 600 and GT 1. During normal watering at recovery stage, it was observed that the clone RRIM 600 and GT 1 required more leaf are area than RRII 105. Clonal variation was observed in plant height and the reduction due to water stress was more in RRII 105 than the other two clones (Fig. 8). Recovery in plant height on rewatering was also less in clone RRII 105.

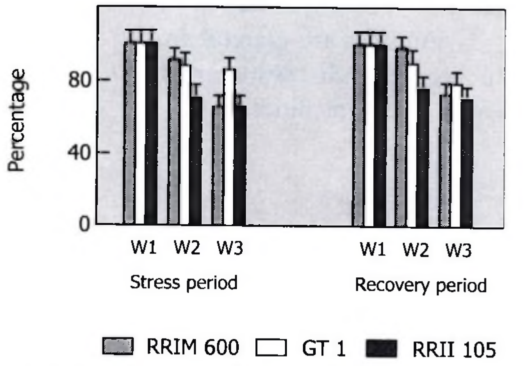

Fig. 7. Leaf area per plant of *H. brasiliensis* clones expressed as percentage of control at the end of water stress and recovery phases

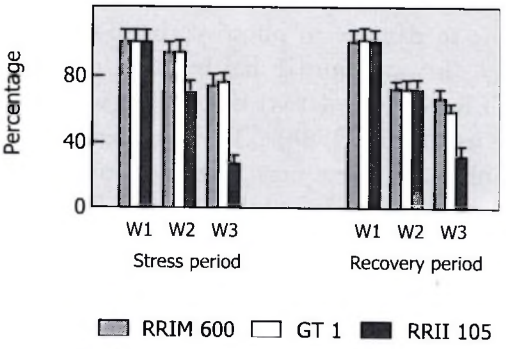

Fig. 8. Plant height of *H. brasiliensis* clones expressed as percentage

Plant mortality

Visual injury like leaf margin drying was noticed at 16-18 per cent of soil moisture in all the clones subject to stress by withholding water. Shedding of leaves was observed for the clone RRIM 600 (2%) but not in RRII 105. Plant mortality was 75 per cent in RRII 105, 30 per cent in RRIM 600 and 25 per cent in GT 1. Oozing of latex was observed from near the budded area in all clones indicating bark injury. The extent of injury was more in RRII 105 (3%) followed by RRIM 600 (2%) and less in GT 1 (0.5%). The information on the changes due to extreme water stress may be useful for understanding the symptoms that develop in these clones in stress prone area.

Though the present experiment was carried out in pots on 160 day old plants and the observation was only for four months, the results show that the growth reduction due to water stress cannot be recovered even after sufficient rewatering for a period equal to that of the period of stress. Among these clones, RRIM 600 and GT 1 are more tolerant to water stress than RRII 105. Recovery in CER after rewatering of the stressed plant was not up to the optimal level in clone RRII 105, which may be due to damage to photosynthetic machinery. It was reported that in Eucalyptus, the CER recovered two days after watering (Kirschbaum, 1988). The high light along with water stress may have induced inhibition of leaf photosynthetic rate. Repeated and prolonged exposure to abiotic stresses may make the repair mechanisms inadequate. This causes irreversible damage to the photosynthetic machinery leading to senescence and poor dry matter production (Long *et al.*, 1994).

Results of the path coefficient analysis of CER with other parameters revealed that RWC affects the CER more than diffusive resistance or chlorophyll content (Table 1). It appears that a minimum leaf water content is required to continue the carbon exchange. Higher osmoticum in combination with higher temperature causes severe membrane damage in leaf discs of *H. brasiliensis* (Nair *et al.*, 1995). Low latex solute potential also affects the CER under stress conditions (Vijayakumar *et al.*, 1998).

Table 1. **Direct (diagonal) and indirect efforts of physiological parameters on carbon-dioxide exchange rate**

	RS	RWC	Chl	r
RS	-0.532	-0.244	0.019	-0.757*
RWC	0.222	0.585*	-0.016	0.791*
Chl	0.429	0.390	-0.024	0.795

RS : Diffusive resistance
RWC : Relative water content
Chl : Chlorophyll content

* $P \leq 0.05$; $R^2 = 0.846$ Residual = 0.392; n = 9

Effects of recovery of *H. brasiliensis* plants from water stress on carbon gain and water loss from the leaves by transpiration deserves further attention. Faster recovery from water stress may be of importance for plant total carbon gain. If the recovery is rapid (as in GT 1), the plants can make maximum use of water, when it later becomes available. The clone GT 1, however, shows CER even after complete recovery and the dry matter production is lower due to overall reduction in photosynthesis. The tolerance of this clone to water stress may have a relationship to its late wintering character. The clone RRIM 600 with high values of RWC was able to maintain a high CO_2 assimilation rate during stress period. This probably is a adaptive physiological trait, resulting in high water use efficiency. The clone RRIM 600 thus may be more suitable for water stress situations. In general, it is evident from these studies that RRIM 600 and GT 1 are more moisture stress tolerant clones than RRII 105.

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