J. Rubb. Res., 1(3), 190-198

Effects of Atmospheric and Soil Drought on Growth and Development of Hevea brasiliensis

A.S. DEVAKUMAR*, M.B. MOHAMED SATHIK*, JAMES JACOB*,#, K. ANNAMALAINATHAN*, P. GAWAI PRAKASH** AND K.R. VIJAYAKUMAR*

A field study was conducted in the severely drought prone North Konkan region on the West coast of India where rubber plants (clone RRIM 600) had been grown with and without summer irrigation since 1987. After nine years, trees grown with irrigation had a 32% increase in leaf area index and nearly twice as much sunlight interception by their canopy as the rainfed trees. This led to 52% more shoot biomass per tree in the irrigated treatment. Irrigated trees had thicker bark and most of that was present as soft bark. At the end of the seventh and eighth year, 78% and 97% of the irrigated trees were ready for tapping respectively, suggesting fast and uniform growth of the trees. The rainfed trees however did not reach tapping stage even after nine years of growth, indicating that water was the most important and the only limiting factor in this region.

In the traditional rubber growing region of India where there is no severe drought stress, the rainfed trees of the same clone attained tappable girth after nine years. Yield was significantly high in the irrigated trees grown in the North Konkan area compared to the traditional region. Thus, the results indicate that, with irrigation during summer, rubber cultivation is possible and there is faster and more uniform growth, and a higher latex yield in the non-traditional North Konkan region.

The global demand for natural rubber is likely to increase in the years to come[1]. To bridge the gap between the demand and supply of natural rubber, cultivation is being extended to non-traditional areas in some of the rubber growing countries like India, China and Vietnam. The climatic conditions in these regions however may not be very viable for rubber cultivation. Drought is probably the single largest factor limiting agricultural productivity in general and it is the most important factor that restricts the expansion of cultivation of *Hevea brasiliensis* to newer areas in several rubber growing countries. It is being cultivated on an experimental basis, in Dapchari, situated in the North Konkan region of Maharastra, India, and the climatic conditions there are characterised by long dry periods, high temperatures and low atmospheric humidity for almost half of the year[2]. Kottayam, on the other hand is situated in the drought-free, traditional rubber growing region of the

* Rubber Research Institute of India, Plant Physiology Division, Kottayam 686 009, Kerala, India
E-mail: rrii-kotm@x400nicgw.nic.in
** Rubber Research Institute of India, Regional Research Station, Dapchari 410 610, Maharastra, India
# Corresponding author

country. The rainfall distribution in Dapchari is seasonal with almost no rainfall between November and May[2], and the cumulative annual rainfall is about 2430 mm (*Figures 1A, 1B* and *1C*). The daily sunshine hour is longer than in Kottayam. The normal daytime temperatures range between 38°C–41°C in summer with occasional days getting as hot as 47°C, but in Kottayam the maximum temperature seldom crosses 35°C (*Figures 1* and *2*). Relative humidity is very low in Dapchari compared to Kottayam (*Figure 2*). These environmental conditions result in large evapo-transpirative demand and coupled with the poor rainfall distribution, lead to both soil and atmospheric drought in Dapchari during summer.

Thus, in Dapchari, the annual environmental conditions are extremely severe for at least four months during the dry season. The objective of the present study was to assess the technical feasibility of establishing a successful rubber plantation in Dapchari by providing summer irrigation (the extreme environmental conditions in this area demand irrigation). Tree growth and productivity of irrigated and rainfed rubber in this region are also compared with Kottayam which is free of any significant drought stress.

MATERIALS AND METHODS

Location

The study was carried out at the Regional Research Station of the Rubber Research Institute of India located at Dapchari in Maharastra state, India. This station is situated in the North Konkan (Western coast line of India) region 20° 04' N, 72° 04' E, 48 m MSL with a plain topography. The soil is classified as an oxisol, with pH 6.3, bulk density 1.4 mg m^{-3}, field capacity 30% and permanent wilting point 17%. The annual rainfall averaged for the last ten years is 2430 mm. Most of the rainfall occurs between June and September and the rest of the year is dry (*Figures 1B* and *1C*). As a typical semi-arid subtropic, solar radiation received in this region is very high[2]. Atmospheric relative humidity in this region ranges from 26%–100% (at 7.40 a.m.) and 10%–100% (at 2.40 p.m.). During summer, high solar radiation associated with high temperature and low relative humidity (*Figures 1D, 1E* and *2C, 2D*) results in high vapour pressure deficit between the leaf and the surrounding atmosphere, and this subsequently increases the evapo-transpirative demand of the atmosphere. Thus, rubber trees in this region are subjected to prolonged periods of both soil and atmospheric drought stress during summer.

Planting Material

Five hundred uniform polybag plants of clone RRIM 600 were maintained in the nursery in large polybags for one year prior to planting just before the onset of the monsoon during 1987, at a spacing of 4.9 m × 4.9 m. Immediately after clearing the area for planting, cover crop was established using a leguminous creeper *Pueraria phaseoloides*. After establishment of the plants in the field, the plant basin was mulched using dry leaves, grass cuttings and cover crops. 12:12:12 NPK mixture at 250 kg/ha was applied till the plants attained the tappable growth and 10:10:10 NPK mixture at 900 g/tree thereafter. Fertiliser application was done in two split doses, (April–May and September–October) during both immature and mature phases. These cultural practices were done as per the standard package of practices given by Rubber Research Institute of India[3].

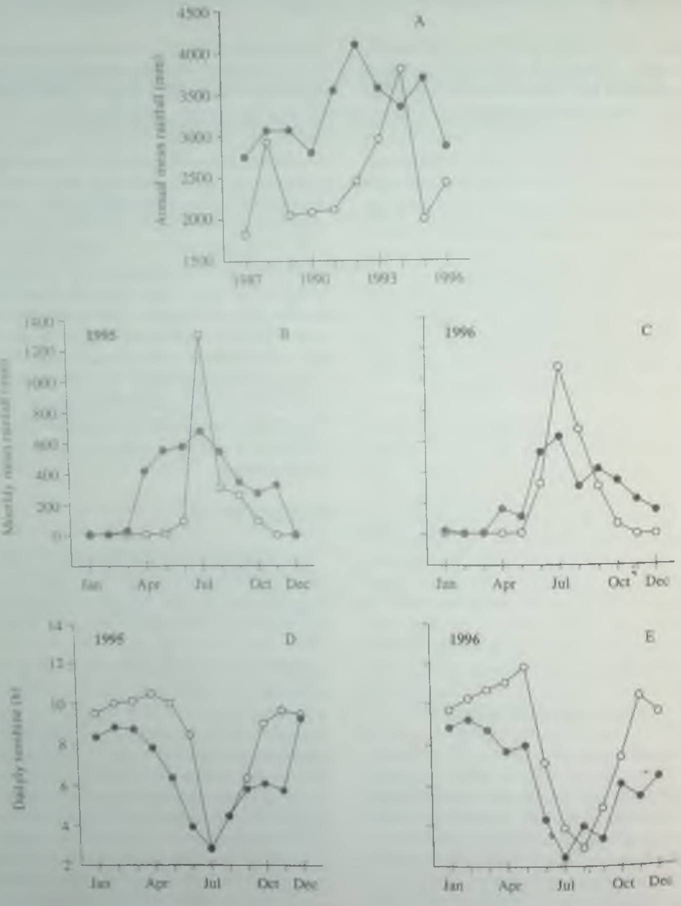

Figure 1. Annual mean rainfall (1987–1996, A), monthly mean rainfall (1995, B; 1996, C) and sunshine hours (1995, D; 1996, E) at Dapchari (○) and Kottayam (●).

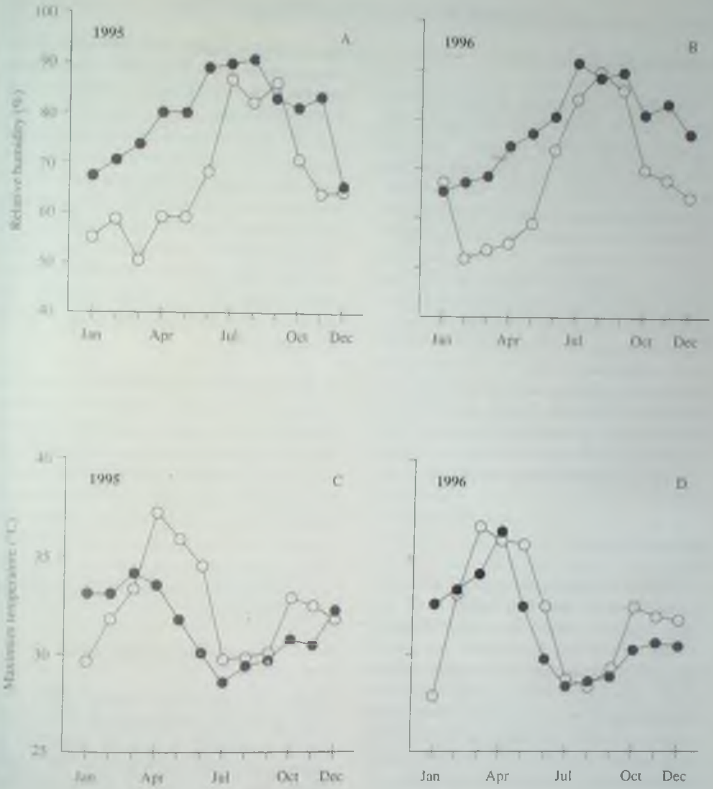

Figure 2. Monthly means of relative humidity (1995, A; 1996, B) and maximum temperature (1995, C; 1996, D) at Dapchari (○) and Kottayam (●).

Irrigation Schedule

Quantity and frequency of irrigation was worked out at different growth stages based on the modified Penman equation[4-5] that took into account the growing conditions and past ten years of weather records for the region. The basis on which irrigation quantity and the schedules were worked out is described in detail by Vijayakumar *et al*[6]. During the initial two years of planting (summer of 1987 and 1988), uniform life-saving irrigation was given for all the 500 plants throughout the dry season. From the summer of 1989 onwards, 250 plants were maintained under rainfed condition without any irrigation, while another 250 trees were given irrigation. Details of the quantity and frequency of irrigation given at different stages of growth are given in *Table 1*. Basin irrigation was given throughout the experiment period.

Measurements

All the measurements recorded here were made during the summer of 1996 on 15 trees each, selected randomly from the irrigated and rainfed plantations. Trunk girth was used to compute standing shoot dry biomass[7]. Photon flux density (PFD) was measured simultaneously inside the plantation and in the open field at mid-day under bright sunlight using a Ceptometer (Analytical Development Company, UK) with an 80 cm integrating line sensor, and light interception by the canopy was computed. Leaf area index (LAI) was determined with a Plant Canopy Analyzer (LAI-2000, Li-Cor, Inc., USA) in remote mode using two units. One unit was dedicated to automatically record the light above the canopy continuously at 15 s intervals, and the other unit was manually operated to record observations under the canopy. These measurements were made either during dawn or in the dusk to avoid bright sunlight. A 4 cm^2 bark plug was carefully cut and removed using a chisel. After measuring the total thickness of the bark, the soft bark portion was separated carefully to retain only the hard bark and the thickness was recorded. Subtracting the hard bark thickness from the total thickness, the soft bark thickness was obtained. All the bark thickness measurements were made using a screw gauge which is more accurate and separated bark easier measured when compared to a bark gauge.

The quantity of water lost by a tree was computed from the xylem sap flow measurements. Xylem sap speed was measured based on the heat pulse chase technique using a sap flow meter (HP-1, Hayashidenko, Japan). From the xylem sap speed, the volume of water lost was computed using the active xylem area present in the total cross sectional area of the trunk. Measurements recorded on rainfed and irrigated trees were statistically compared using independent *t* test.

RESULTS AND DISCUSSION

There was a substantial increase (32%) in the LAI of irrigated trees compared to unirrigated trees (*Figure 3A*). Due to the high LAI the amount of sunlight intercepted by the irrigated trees was twice that of the rainfed trees (*Figure 3B*). The observed large LAI and high light interception resulted in an increase of trunk girth and shoot biomass by 24% and 52% in the irrigated and rainfed trees, respectively (*Figures 3D* and *3E*). Such an interactive relationship has been shown in other tree species[9-11]

TABLE 1. DETAILS OF THE IRRIGATION SCHEDULE FOLLOWED AT DIFFERENT GROWTH STAGES

Year	Quantity of irrigation (l/plant/irrigation)	Frequency and time of the year
1987 and 1988	150.0	November to February: Once in 10 days; March to May: Once in 7 days.
1989 to 1993	212.0	November to February: Once in 10 days; March to May: Once in 7 days.
1994 onwards	422.5	January: Once in 3 days; February: Thrice in 7 days; March to May: Once in 2 days.

The quantity of irrigation was equal to an evapotranspiration coefficient of one crop.

There was significantly thicker bark in the irrigated trees than in the unirrigated trees (*Figures 3F* and *3G*). The ratio of the thickness of the soft bark to that of the total bark was higher in the irrigated trees than in the rainfed trees. The quantity of water lost by rainfed trees was less, compared to irrigated trees (*Figure 3G*).

It is envisaged that the irrigated trees of clone RRIM 600 could come to tapping by the end of the seventh year unlike in the traditional regions where tappable girth is attained only after nine years. Thus, the immaturity period can be reduced by about two years in the North Konkan with summer irrigation. This is in agreement with earlier findings[6]. Irrigation also resulted in a higher number of trees than could be tapped in the first year (78%) and within one-and-a-half-years all the irrigated trees were tapped. Such findings are uncommon in the traditional regions. This is an indication of uniform growth that the trees could attain when provided with summer irrigation. Similarly, the LAI and shoot dry weight were higher in the irrigated trees grown in the North Konkan region than in the traditional regions (*Table 2*). For example, nine-year-old trees of clone RRIM 600 grown with irrigation in the North Konkan region had 25% higher LAI and 23% more trunk girth than the trees grown in the traditional regions. Additionally, the shoot dry biomass of the irrigated trees in the area is higher than in the traditional region. In the case of rubber yield, irrigation also generated higher yield than the rainfed trees by 55%, 45% and 43% during the first, second and third year of tapping, respectively[8].

The large LAI which gave a large photosynthesising source and high rates of photosynthesis per unit leaf area are achievable in plants grown in the North Konkan region if there is adequate irrigation during summer, because water is the major, and possibly the only environmental constraint for growth in this area[6,12].

We further show that increased growth was because the North Konkan region has, on an annual basis, relatively warmer temperatures and has more sunshine hours than the traditional areas (*Figures 1D, 1E* and *2C, 2D*)

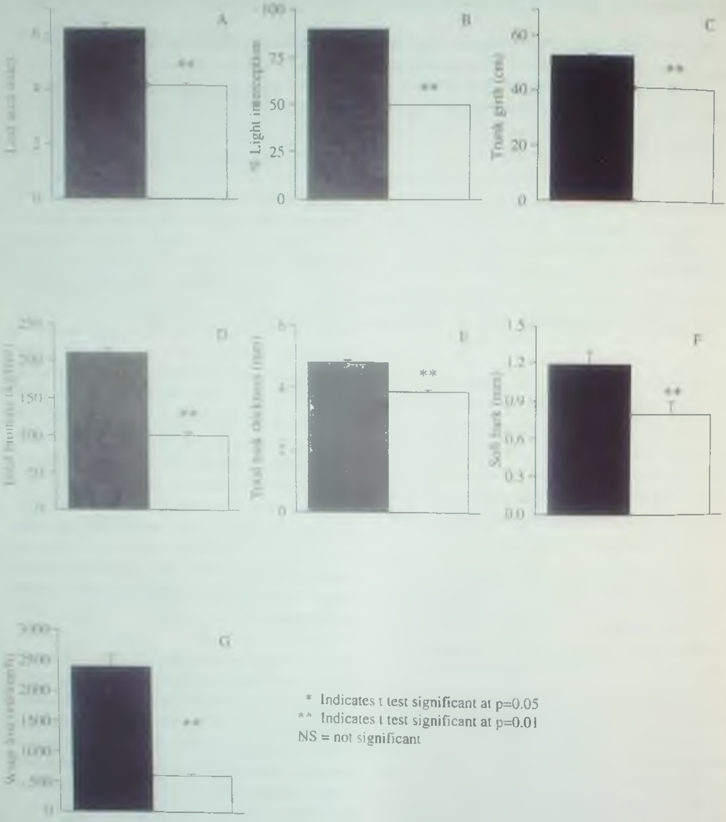

Figure 3. Growth attributes of nine-year-old Hevea brasiliensis *trees grown under irrigated (■) and rainfed (□) conditions in the North Konkan region. Each bar is an average of 15 observations (except for root biomass for which n=4); ± SE shown.*

TABLE 2. COMPARISON OF GROWTH AND YIELD OF IRRIGATED TREES IN THE DROUGHT PRONE NORTH KONKAN (RRS, DAPCHARI) AND STRESS FREE REGION OF INDIA (KOTTAYAM)

Parameter	Dapchari	Kottayam
LAI	6.28	5.02
Girth (cm)	58.02	52.24
Biomass (kg/tree)	211	157
Yield (kg/ha)		
1st year	1058	681
2nd year	1683	1164
3rd year	1624	1137

LAI, girth and biomass given are for nine year old trees for both the sites (n=15). Yield is from traditional regions[8].

which would lead to enhanced photosynthetic productivity in a tropical species like *Hevea*, provided water is not a limiting factor. The trial also illustrates that overcoming the limitations of water through irrigation could increase photosynthetic productivity and eventually plant growth, since the North Konkan region has warmer temperatures and longer sunshine hours than the other rainfed regions.

The high temperature and low relative humidity prevailing in the North Konkan region increase the evaporative demand of the atmosphere[2]. This will create an atmospheric drought stress on the plant. Soil and atmospheric drought lead to poor carbon assimilation, ultimately affecting the growth. On the other hand, if water is not a limiting factor as in the case with the irrigated trees, (*Figure 3G*) the biomass production will not be affected. Increased water loss from the irrigated trees is not only due to the large atmospheric demand but is also due to the large canopy size (*Figure 3A*). A positive correlation has been shown to exist between the total canopy water loss and biomass production[9,10]. Total biomass increased as the quantity of water lost by the plant increased. Thus, our results show that the environmental conditions (long sunshine hours, warmer temperatures and dry air) prevailing in the drought prone North Konkan region are favourable for rubber cultivation, provided the trees are irrigated in summer.

The economic feasibility of irrigating large plantations depend on the availability of water, labour and the price of natural rubber. Considering the expected increase in the global demand for natural rubber, expanding the cultivation of *Hevea* with irrigation to dry and marginal regions in countries like India and Vietnam may be a viable proposition. Further, it has been shown that *Hevea* plantations improve the physical, chemical and biological properties of the marginal soils thus helping to reclaim denuded lands which will be an added advantage from an environmental standpoint.

ACKNOWLEDGEMENT

The authors thank Dr P.J. George for providing the Ceptometer used for light measurements. We also thank the several field staff at the Dapchari Regional Station for their technical assistance in the field.

Date of receipt: March 1998
Date of acceptance: August 1998

REFERENCES

1. SMITH, H.P. AND BURGER, K. (1992) The Outlook for Natural Rubber Production and Consumption, *Natural Rubber* (*Sethuraj, M.R. and Mathew, N.M. eds.*) p.26–49. Amsterdam: Elsevier Science.

2. MOHANA KRISHNA, T., BHASKER, C.V.S., SANJEEVA RAO, P., CHANDRASHAKER, T.R., SETHURAJ, M.R. AND VIJAYAKUMAR, K.R. (1991) Effect of Irrigation on Physiological Performance of Immature Plants of *Hevea brasiliensis* in North Konkan. *Indian J. nat. Rubb. Res.*, 4, 36–45.

3. ANONYMOUS (1997) *Rubber and its Cultivation*. Kottayam: Rubber Board, 3–28.

4. RAO, K.N., GEORGE, C.J. AND RAMASHASTRY, K.S. (1971) Potential Evapotranspiration over India. *India Meteorol. Dept. Scientific Rep.*, **136**, 17.

5. VIJAYAKUMAR, K.R., GURURAJA RAO, G., SANJEEVA RAO, P., DEVAKUMAR, A.S., RAJAGOPAL, R., GEORGE, M.J. AND SETHURAJ, M.R. (1988) Physiology of Drought Tolerance of *Hevea*. *Compte-Randu du Colloque Exploitation Physiologic et Amelioration de l'Hevea, Paris, France*, 269–281.

6. VIJAYAKUMAR, K.R., DEY, S.K., CHANDARSHAKER, T.R., DEVAKUMAR, A.S., MOHANAKRISHNA, T., SANJEEVA RAO, P. AND SETHURAJ, M.R. (1998) Irrigation Requirement of Rubber Trees (*Hevea brasiliensis*) in the Subhumid Tropics. *Agril. Water Manager*, **35**, 245–259.

7. SHORROCKS, V.M., TEMPLETON, J.K. AND IYER, G.C. (1965) Mineral Nutrition, Growth and Nutrient Cycle of *Hevea brasiliensis* III. The Relationship between Girth and Shoot Dry Weight. *J. Rubb. Res. Inst. Malaya*, **19**, 85–92

8. TOMS JOSEPH AND HARIDAS, V. (1990) Evaluation of Planting Materials under Commercial Planting — Third Report. *Rubber Board Bulletin*, **26**, 12–19.

9. BEADLE, C.L. AND TURNBULL, C.R.A. (1991) Comparative Growth Rates of Eucalyptus in Native Forest and in Plantation Monoculture, *Growth and Water Use of Forest Plantations*. (*Calder, I.R., Hall, R.L. and Adlard, P.G., eds*), p 318–331. New York: John Wiley and Sons.

10. SANDS, P.J. (1996) Modelling Canopy Production. III. Canopy Light Utilization Efficiency and Its Sensitivity to Physiological and Environmental Variables. *Aust. J. Plant Physiol.*, **23**, 103–114.

11. WANG, Y.P., JARVIS, P.G. AND TAYLOR, C.M.A. (1991) PAR Absorption and Its Relation to Above Ground Dry Matter Production of Sitka Spruce. *J. Appl Ecol.*, **28**, 547–560.

12. CHANDRASHAKER, T.R., VIJAYAKUMAR, K.R., GEORGE, M.J. AND SETHURAJ, M.R. (1994) Response of Few *Hevea* Clones to Partial Irrigation During Immature Growth in a Dry Subhumid Climatic Region. *Indian J. nat. Rubber Res.*, **7(2)**, 114–119.