A·No·14

Journal of Plantation Crops, 2006, 34 (3) : 625-630

Changes in leaf water relations and photosynthetic activity due to drought in mature natural rubber plants grown in North Kerala

Badre Alam[3], Radha Lakshmanan[2], D.B. Nair[1] and James Jacob[1]*

[1]*Division of Plant Physiology, Rubber Research Institute of India, Rubber Board P.O., Kottayam-686009, India.*
[2] *Regional Research Station, Padiyoor, Kerala, India.*
[3]*National Research Centre for Agroforestry, Pahuj Dam, Gwalior Road, Jhansi-284003, U.P.*

Abstract

Hevea brasiliensis (clone RRII 105) plants have been grown in the fields of Regional Research Station, Padiyoor in Northern Kerala (Malabar) with or without irrigation since 2000. During March 2004 and January 2005 we studied the photosynthetic activity in intact leaves of these plants. Padiyoor begins to experience summer conditions once the last rains of the Northeast monsoon are over by December/January and it stretches until June. Rainfed plants showed significant reduction in leaf water potential during summer as early as in January. The drought-imposed reductions in net CO_2 assimilation and photochemical activity and increase in oxidative damage were evident right from the onset of summer (January) which further got aggravated as summer progressed (March). Our results show that drought is a serious environmental stress in Malabar and irrigation fails to fully restore the photosynthetic activity during peak summer.

Key words: Drought, leaf water relations, oxidative stress, photosynthesis, rubber

Introduction

Agroclimatic conditions are not always favourable for natural rubber (NR) cultivation in the traditional track where it is currently grown in the country. The traditional rubber growing region stretches from Kanyakumari district of Tamil Nadu in the South to South Canara district of Karnataka in the North (8°N to 12° N). Natural rubber is mostly grown between these latitudes along the foothills of the Western Ghat which receive fairly high rainfall. Traditionally, drought has not been regarded as a limiting factor for growth and productivity for natural rubber in this part of the country unlike in certain non-traditional regions of natural rubber cultivation like the North Konkan. However, of late, there is an increasing apprehension among rubber growers that drought is gradually becoming a matter of concern in the traditional region. Non-traditional region for rubber cultivation, such as the North-Konkan is characterized by less congenial agroclimatic conditions particularly scanty rainfall, high temperature and high evaporative demand. For example, the annual rainfall in central Kerala and North Konkan regions are about 3000 mm and 2430 mm respectively (Jacob *et al.*, 1999). In addition to having more amount of rainfall, there is better distribution in the traditional region as South-West (June-September) and North-East (October-November) monsoons are generally active in the traditional area unlike in the North-Konkan where the North-East monsoon is practically absent. The other weather parameters that contribute to drought conditions such as number of rain free months, temperature, sunshine hours, solar light intensity, atmospheric humidity etc are less harsh in the traditional zone than in the non-traditional region.

It is generally believed that rubber plantations in the traditional region are free from drought. In the present

---

* For correspondence

study, we investigated this notion in a field trial taken up with a clone RRII 105 which has been grown with or without irrigation since 2000 at Regional Research Station, Padiyoor in the Northern Kerala. Our investigations show that drought prevailing in this part of the traditional rubber growing region can severely impair physiological processes of field grown rubber plants and that watering the plants during summer will not fully restore the physiological function of the trees.

Materials and Methods

The experiment was conducted in a field of Regional Research Station, Padiyoor (11°58′ N, 75° 39′ E, 80 m MSL) located in Northern Kerala (Malabar). A clone of Hevea brasiliensis RRII 105 was used for this study. The year of planting was 2000. The experiment was conducted in two different periods. One of the periods of the experiment was in March 2004 which is considered as peak summer in this area and the other time was in January 2005 which is taken as very early summer. The climatic parameters are given in Table 1.

The plants were grown with or without irrigation and planted in randomized block design (RBD). One set of plants that were grown under rainfed conditions were taken as the drought stressed plants. The other set of plants that were irrigated based on the available soil water depletion and the root depth were considered as irrigated plants (Lakshmanan *et al.*, 2005).

Net CO_2 assimilation rate (A) and chlorophyll a fluorescence were simultaneously measured on intact mature leaves of plants using a Portable Photosynthesis System (LI-6400, Licor, U.S.A.) attached with a leaf chamber fluorometer (LCF- 6400-40, Licor, U.S.A.) following the techniques of Genty *et al.*, (1989) and Schreiber *et al.*, (1998). All these photosynthetic measurements were made at a leaf temperature of 30 ± 0.4 °C and leaf-air VPD of around 2.0kPa at a constant CO2 concentration of 360 μ mol mol^{-1} using a CO_2 injector (LI-6400-01, Li-COR, U.S.A.) between 8.30 AM and 11.30 AM IST. The ambient CO2 concentration was 360 μ mol mol^{-1}. Light intensities were 500 μ mol mol^{-2} s^{-1} obtained from the LED sources attached with the LCF.

Table 1. Climatic parameters during the experimental periods in Padiyoor, North Kerala where the study was conducted. The figures are the monthly mean.

Parameters	Early summer	Peak summer
Temperature (maximum), °C	34.1	36.9
Temperature (minimum), °C	19.4	22.6
RH (%) forenoon	93.5	91.3
RH (%) afternoon	74.7	58
Evaporation (mm)	3.5	5.7
Sun shine hour	7.8	8.5

Diurnal (pre-dawn, mid-day and late afternoon) variation in the maximum potential photochemical efficiency defined as the ratio of variable to maximum fluorescence emitted by chlorophyll (Fv/Fm) was estimated after dark adaptation of leaves for 20 minutes. Maximal fluorescence under light exposure (Fm′) was obtained by imposing a 1s saturating flash to the leaf in order to reduce all the PSII reaction centers after attaining a steady state fluorescence (Ft). Minimal fluorescence immediately after light exposure (Fo′) was determined by imposing dark while a far-red light was simultaneously switched on to oxidize PSII rapidly by drawing electrons from PSII to PSI. Effective PS quantum yield (Φ_{PSII}) and the other associated chlorophyll fluorescence parameters were also measured. The excess photosynthetic electrons across PSII (J*) i.e. the electrons diverted to processes not linked to photosynthetic C metabolism were also calculated (Jacob and Karaba, 2000; Alam and Jacob, 2002; Alam *et al.*, 2005). Measurements were made on intact attached leaves in a well-exposed branch after cutting the branch from the tree. The cut-end of the branch was immediately immersed in a bucket of water and about 15 cm from the cut-end was again cut under the water following the standard methods (Devakumar *et al.*, 2002).

Diurnal patterns of leaf water potential (Ψ_L) were estimated from the leaf discs (6mm diameter) obtained by a single-hole paper punch using Dew point Microvolt Meter (WESCOR, U.S.A.) with C-52 chamber (WESCOR, U.S.A.) following the standard technique

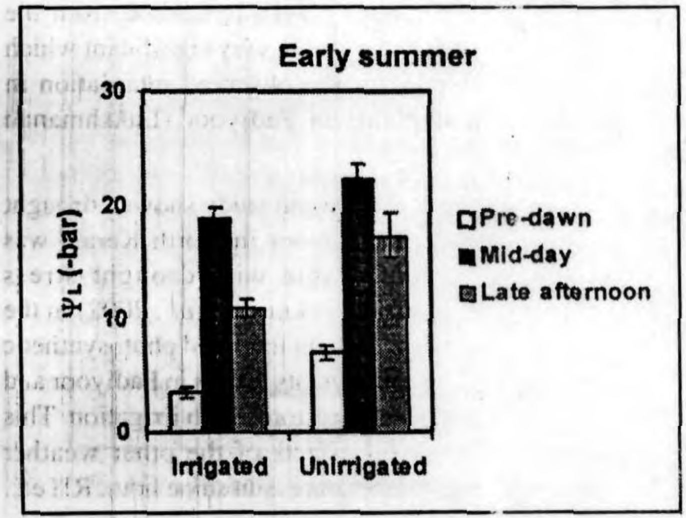
After the measurements of photosynthetic activity, the contents of chlorophyll (Chl) and malondialdehyde (MDA) in the leaves were estimated according to the methods of Arnon (1949) and Heath and Parker (1968), respectively. The ratio of MDA to chlorophyll was taken as an index of oxidative damage (Alam and Jacob, 2002).

All the measurements were made in six to ten replications in five different trees. Standard errors were estimated. Independent t-test was done to find out the significance of the means.

Results and Discussion

Drought resulted in significant reductions in the leaf water potential (Ψ_L) which was evident right from the onset of summer (Fig. 1). As summer advanced the reduction in Ψ_L was more pronounced. Irrigation resulted in maintaining better Ψ_L, but, even with irrigation, there was reduction in Ψ_L as summer season progressed. The reduction in Ψ_L was maximum at mid-day. The above results suggest that the prevailing atmospheric conditions such as high temperature and low relative humidity (RH) increased the evaporative demand of the atmosphere to such an extent that watering the trees was not adequate enough to prevent reduction in the Ψ_L even in the irrigated trees.

Drought-induced reduction in Ψ_L had a direct impact on the photosynthetic and transpiration rates of the leaf. Irrigation certainly helped to maintain better CO_2 assimilation (A) and transpiration (E) rates both during early and peak summer seasons (Fig. 2). However, even in irrigated plants A and E showed appreciable reductions as drought and summer progressed. The extent of reductions in A and E as summer season progressed was clearly more in the rainfed than the irrigated trees. It can be inferred from this observation that irrigation alone was not capable of restoring the photosynthetic function during peak summer. Several studies have shown that high light and high temperature that occurred concomitantly with drought stress proved to be more detrimental to the photosynthetic apparatus than any stress alone in natural rubber plants (Nair *et al.*, 1998; Jacob *et al.*, 1999; Alam *et al.*, 2005) as observed in several other species (Valladares and Pearcy, 1997; Cornic and Fresneau, 2002). It may be noted that during the experimental period there was practically no rainfall and the maximum air temperatures were 34.1 °C and 36.9 °C in January 2005 and March 2004; respectively, whereas, the minimum air temperatures in these two months were 19.4 °C and 22.6 °C, respectively. Sun shine hours, evaporation and afternoon RH in the two periods were also suggestive of atmospheric dryness (Table 1). Thus, it can be concluded that in addition to water deficit stress the other prevalent weather conditions were also stressful to rubber plants in North Kerala.



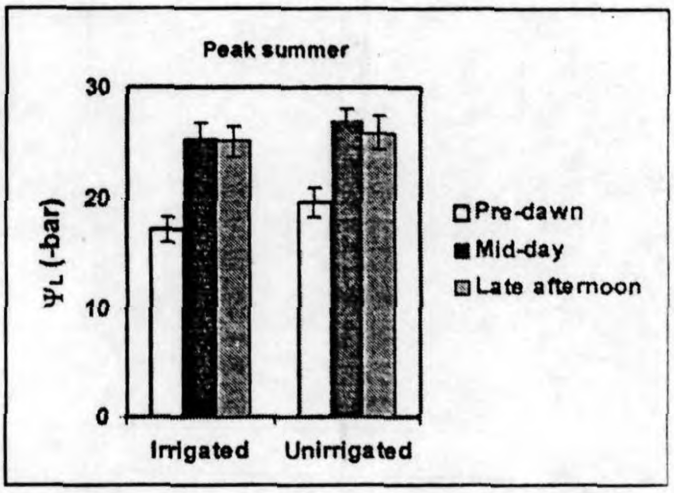


Fig.1. Diurnal pattern of leaf water potential (ΨL) of Hevea brasiliensis as influenced by drought in a field of North-Kerala and the effects of irrigation. *significant at $p<0.05$.

Measurements on the maximum potential quantum yield of PSII (dark adapted Fv/Fm) also indicated significant reductions due to drought which could be considerably improved when the plants were irrigated (Fig. 2). The inhibitions in dark adapted Fv/Fm were maximum during mid-day similar to the reduction in Ψ_L. The drought-induced inhibition in dark adapted Fv/Fm showed appreciable improvement when the leaves were allowed to "relax" in complete darkness inside the laboratory. This observation confirms the additional stress imposed by light on the photosynthetic machinery that was already experiencing water deficit stress.

The PSII quantum yield (Φ_{PSII}) also showed similar trend as that of A and dark adapted Fv/Fm (Fig. 3). The rate of photosynthetic electron flow to processes other than CO_2 assimilation (J*) was more in the rainfed plants than irrigated plants during peak summer (Fig. 3). In early summer, there was no significant difference in J* between the irrigated and unirrigated plants. It is interesting to note that as summer advanced, J* showed a progressive reduction in both the irrigated and unirrigated plants. This was because of the increased inhibition in PSII activity as summer advanced which could not be fully avoided even with irrigation. Diversion of more photosynthetic electron

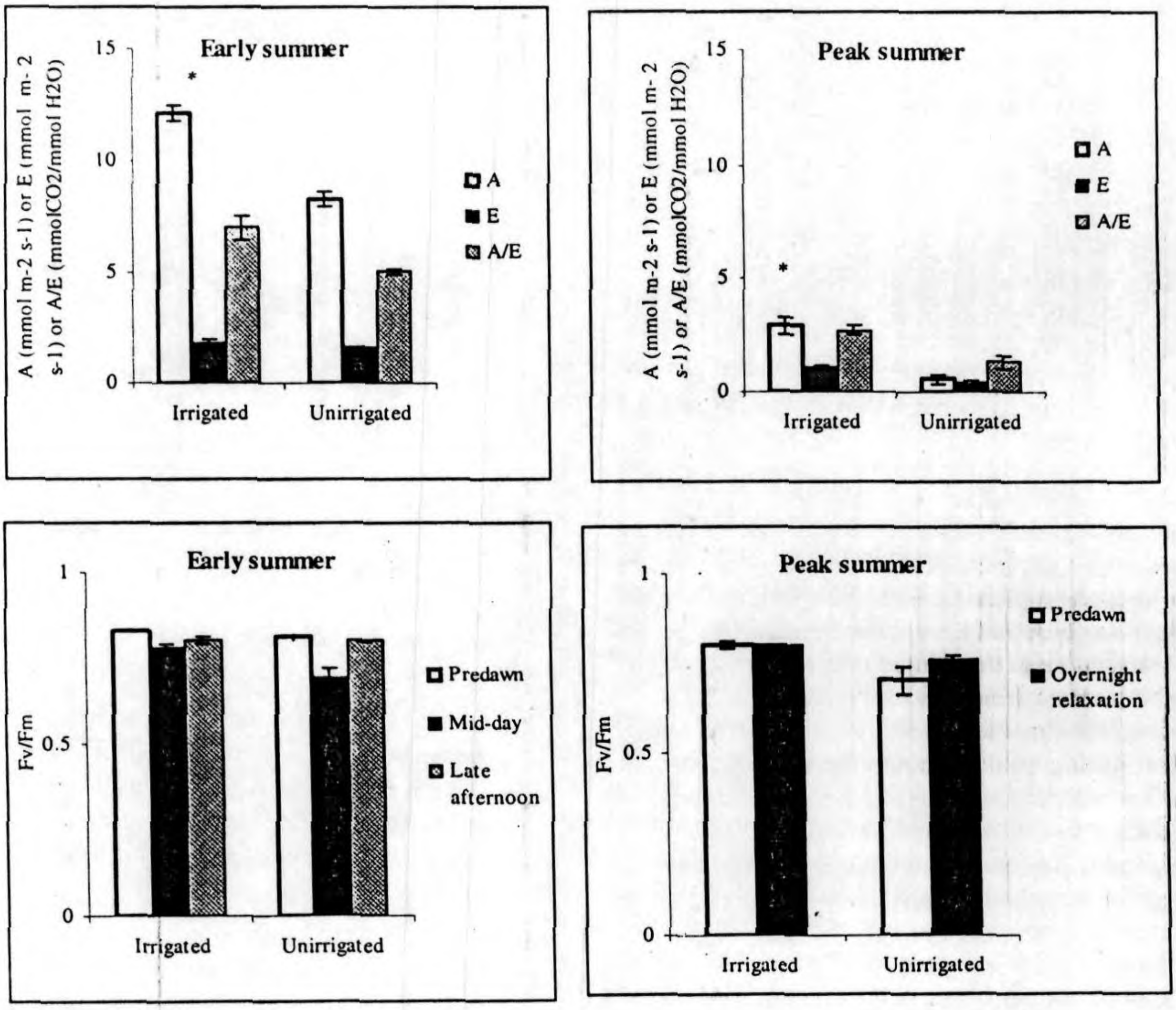


Fig.2. Changes in drought-induced photosynthetic activities in the leaves of Hevea brasilienis grown in a field of North-Kerala. * significant at $p<0.05$.

away from CO_2 assimilation appears to have induced oxidative damage to the leaf. The ratio of MDA to Chlorophyll, an index of oxidative damage resulting from impaired photosynthetic photochemistry (Alam and Jacob, 2002) was significantly more in the unirrigated plants during peak summer, but the difference was not significant during early summer (Fig. 4).

Drought-induced inhibition in photosynthetic rate in Padiyoor located in North-Kerala were comparable to those obtained at Dapchari (72°.04′ E, 20°.04′ N) which is situated in the extremely drought prone North-Konkan region (Devakumar *et al.*, 2002). However, the severity of water deficit and other weather parameters such as temperature, RH, sun shine hours, evaporation etc. were considerably more harsh in Dapchari than in Padiyoor. Nevertheless, the harmful effects o e physiology of the rubber plants as studied from the photosynthetic physiology were very significant which could be responsible for the observed retardation in growth of rainfed plants in Padiyoor (Lakshmanan *et al.*, 2005).

In conclusion, the present study showed drought stress experiencing in Padiyoor in North Kerala was physiologically comparable with drought stress occurring in Dapchari (Devakumar *et al.*, 2002) in the North-Konkan region. Drought inhibited photosynthetic performance of the rubber plants grown in Padiyoor and the same could not be fully restored with irrigation. This underlines the stressful effects of the other weather parameters such as temperature, sun shine hour, RH etc.

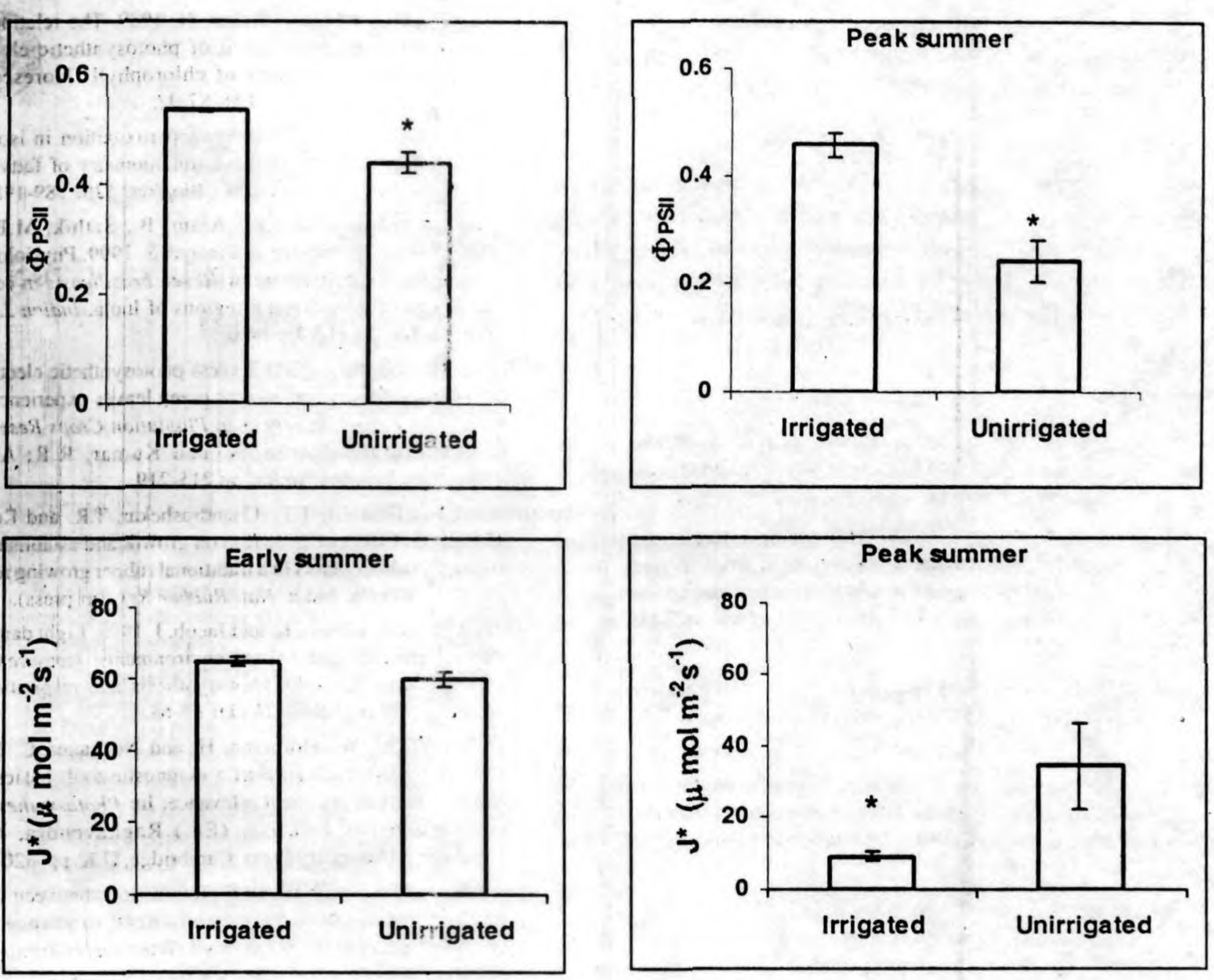


Fig. 3. Effective quantum yield of PSII (FPSII) and excess photosynthetic electrons(J*) diverted away from CO2 assimilation in the leaves of Hevea brasiliensis as influenced by drought in the field conditions of North-Kerala and the effects of irrigation. * significant at $p<0.05$.

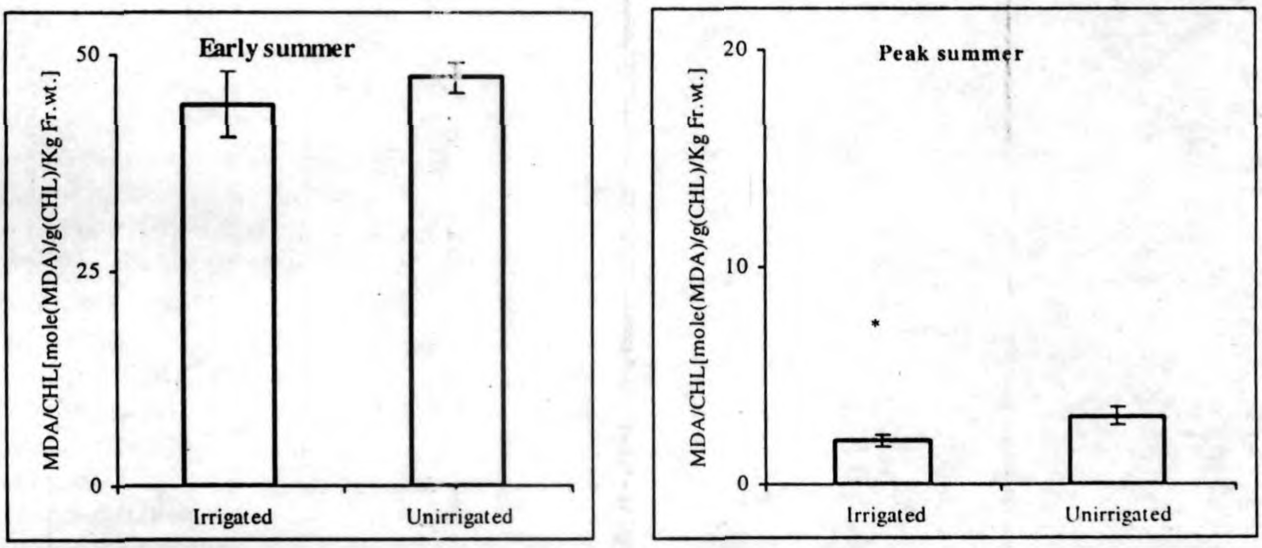


Fig.4 Drought-induced oxidative damage in the leaves of Hevea brasiliensis grown in a field of North-Kerala. * significant at $p<0.05$.

Thus, from a physiological perspective, the notion that drought might not be a major stress factor in a traditional region like North-Kerala can not be fully justified.

Acknowledgement

Authors acknowledge the help extended by Smt.Visalakshi Ammal, Technical Officer and Smt. Sheela P.Simon, Senior Scientific Assistant of the Plant Physiology Division, Rubber Research Institute of India, Kottayam for the biochemical studies related to this work.

References

Alam, B. and Jacob, J. 2002. Overproduction of photosynthetic electrons is associated with chilling injury in green leaves. *Photosynth.* **40(1)** : 91-95.

Alam, B., Nair, D.B. and Jacob, J. 2005. Low temperature stress modifies the photochemical efficiency of a tropical tree species *Hevea brasiliensis*: Effects of varying concentrations of CO_2 and photon flux density. *Photosynth.* **43(2):** 247-252.

Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts. Polyphenol oxidases in *Beta vulgaris*. *Plant Physiol.* **24:** 1-5.

Cornic, G. and Fresneau, C. 2002. Photosynthetic carbon reduction and carbon oxidation cycles are the main electron sinks for photosystem II activity during a mild drought. *Ann. Bot.* **89** : 887-894

Devakumar, A.S., Sathik, M.B.M., Sreelatha, S., Thapaliyal, A.P. and Jacob, J. 2002. Photosynthesis in mature trees of *Hevea brasiliensis* experiencing drought and cold stresses concomitant with high light in the field. *Indian J. Nat. Rubber Res.* **15 (1) :** 1-13.

Genty, B., Briantais, J.M. and Baker, N. 1989. The relationship between the quantum yield of photosynthetic electron transport and quenching of chlorophyll fluorescence. *Biochim. Biophys. Acta.* **990**: 87-92.

Heath, R.L. and Parker, L. 1968. Photoperoxidation in isolated chloroplasts. I. Kinetics and stoichiometry of fatty acid peroxidation. *Arch. Biochem. Biophys.* **125:** 189-198.

Jacob, J., Annamalainathan, K., Alam, B., Sathik, M.B.M., Thapaliyal, A.P. and Devakumar, A.S. 1999. Physiological constraints for cultivation of *Hevea brasiliensis* in certain unfavourable agroclimatic regions of India. *Indian J. Nat. Rubber Res.* **12 (1&2):** 1-16.

Jacob, J. and Karaba, K.N. 2000. Excess photosynthetic electrons- a matter of life and death for green leaves experiencing a stress. In: *Recent Advances in Plantation Crops Research.* (Eds.) Muraleedharan, N. and Kumar, R.R; Allied Publishers Limited, India, pp.215-219.

Lakshmanan, R., Edathill, T.T., Chandrashekar, T.R. and Reghu, C.P. 2005. Effect of irrigation on growth and establishment of young rubber plants in a traditional rubber growing [illegible]on in North-Kerala, India. *Nat. Rubber Res.* (in press).

Nair, D.B., Annamalainathan, K. and Jacob, J. 1998. Light damages cell membranes under stress environments: measurements on membrane stability, photosynthesis and respiration in *Hevea*. *J. Plant. Biol.* **26 (1):** 65-68.

Schreiber, U., Bilger, W., Hormann, H. and Neubauer, C. 1998. Chlorophyll fluorescence as a diagnostic tool: basics and some aspects of practical relevance. In: *Photosynthesis: A comprehensive Treatise*, (Ed.) Raghavendra, A.S., Cambridge University Press, Cambridge, U.K, pp. 320-336.

Valladares, F. and Pearcy, R.W. 1997. Interactions between water stress, sun-shade acclimation, heat tolerance and photoinhibition in the sclerophyll *Heteromeles arbutifolia*. *Plant Cell and Environ.* **20**: 25-36.