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PHYSIOLOGICAL CONSTRAINTS FOR CULTIVATION OF *HEVEA BRASILIENSIS* IN CERTAIN UNFAVORABLE AGRO-CLIMATIC REGIONS OF INDIA

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Abstract *Increasing the natural rubber (NR) productivity and extending its cultivation to newer areas are the two options to bridge the gap between the demand and supply of NR that is expected to occur in the decades ahead. Adverse agroclimatic conditions often become an obstacle to both these options. Long periods of drought, high and low temperatures, low atmospheric humidity, high intensity of solar radiation and poor soils are some of the most important abiotic factors that restrict the expansion of NR cultivation into hitherto nontraditional regions. India has most of the above stressful agroclimatic conditions and has made NR cultivation successful in some very unfavorable conditions. We review here the recent research in the stress physiology of Hevea brasiliensis focusing on two distinct, but adverse agro-climatic zones, namely the North Konkan and North Eastern regions of the country.*

The North Konkan region experiences drought for about five to six months every year concomitant with high intensities of solar radiation and high temperatures, occasionally going beyond 41^{0}C during the day. In the North East, the winter season lasts for two to three months with the minimum temperature going as low as 5^{0}C at least for brief periods in some nights, but the days can be relatively warmer with abundant sunlight. In both these unfavorable regions, with suitable agro-management polyclonal seedlings of Hevea come up reasonably well and with some added care bud grafted seedlings of high yielding clones also could be grown.

Stress induced inhibition in leaf photosynthesis was a major cause for poor crop growth in both the above regions. High light intensity existing concomitant with an environmental stress aggravated the stress induced inhibitory effects on photosynthesis. Photoinhibition of photosynthesis was evident in the quantum yields for carbon assimilation and Photosystem II activity. The CO_2 saturated rate of photosynthesis and in vivo carboxylation efficiency of the leaf were inhibited during drought and low temperature stresses. High intensity of solar radiation led to an imbalance between the light and dark reactions of photosynthesis in stressed Hevea leaves. This caused increased diversion of photosynthetic electrons for the production of active oxygen species which caused oxidative stress leading to senescence in the stressed leaves exposed to high light intensities. Therefore, partial shading to young plants experiencing stresses like drought and chilling is advisable. The Hevea germplasm pool may be a repository of inherent antioxidant and stress tolerance/avoidance traits which could be used in the crop improvement programs for unfavorable agroclimatic *regions.*

Key words: germplasm; ecological sustainability; environment stress; oxidative stress, photosynthesis; socio-economic development; stress avoidance/ tolerance mechanism.

INTRODUCTION

Hevea brasiliensis is a native forest tree species belonging to the hot and humid tropical Amazon falling within 5^0 latitude on either sides of the equator. Its domestication as a plantation crop is hardly more than a century old. Today, this tree species is commercially cultivated mostly in the South and South East Asian countries where the agroclimatic conditions are suitable for its growth and productivity. An annual rainfall ranging from 2000 to 4,000mm which is well distributed throughout the year, warm and sunny days w temperatures in the range of 21°C to 35°C and atmospheric relative humidity 80% or above are considered to be best for this species. Fairly deep soils (125 cm) with slight to moderate acid pH and a gentle slope are ideal for *Hevea* (Krisnhnakumar, 1993). The climatic requirements for this crop are discussed by Rao and Vijayakumar (1992).

In India, *Hevea* has been traditionally grown mostly in the state of Kerala and to a small extent in certain southern pockets of the state of Tamil Nadu for more than a century. This traditional rubber growing belt in India lies between 8^0 and 12^0 N latitudes between the Arabian sea coast and the Western slopes of the Western Ghats and their foothills. This stretch of land is characterized by fertile soils rich in organic content. This region gets fairly high rainfall from two distinct monsoon seasons.

Today, about 15% of arable land in Kerala is under this crop and expanding rubber cultivation into newer areas in Kerala may not be advisable from our ecological point of view. To meet the growing demand of natural rubber, it has become necessary to produce more rubber by increasing the productivity and extending its cultivation to non-traditional regions outside the state of Kerala. The Konkan region in the West, the Coramandel coast in the East, the Andaman and Nicobar islands in the Bay of Bengal, Northern West Bengal and the North Eastern states have been identified as potential areas for new rubber cultivation in the country (Hajra and Potty, 1986). Experimental plantations have been established in these regions. These non-traditional areas of rubber cultivation in India extends up to 29^0N latitude (Sethuraj *et al.*, 1989).

ENVIRONMENTAL CONSTRAINTS FOR *HEVEA* CULTIVATION

In an elegant study, Rao *et al.* (1993) derived a simple, but useful climatic index based on the temperature and rainfall distribution to assess the hydrothermal suitability of a given geographic zone for the cultivation of *Hevea*. The prospects and limitations of extending rubber cultivation to marginally suitable regions are discussed by Pushparajah (1983).

Unlike the traditional areas, the agroclimatic and pedological factors prevailing in some of the non-traditional areas in India (see Table 1 for a brief summary) can be stressful to *Hevea*. In India, drought and high temperature in the North Konkan and chilling winter in the North East are the two major environmental factors that limit the growth and productivity of *Hevea*.

Summer in the North Konkan can last for six to seven months with practically no rain from January onwards. Summer in this region is characterized by fast depletion of soil moisture, high intensity of solar radiation and temperature and very low atmospheric relative humidity. The fairly warm air (mean maximum temperature 37°C) which can go as high as 41°C (Devakumar *et al.*, 1999) or even beyond that on certain days and low atmospheric relative humidity (40%) lead to high evaporative demand causing atmospheric drought in the North Konkan (Chandrashekar *et al.*, 1990).

In the North Eastern parts of the country, the winter can be very severe often with the minimum temperatures going below 5°C (Meenattoor *et al.*, 1989). The cool temperature (mean minimum temperature 11°C) and bright solar radiation inhibit growth of *Hevea* in this part of the country. Although there is a reasonably good distribution of rainfall in the North East, it is possible that the plants may suffer from low temperature induced drought during peak winter. But it may be noted that the winter days can be warm (mean maximum temperature 26°C) by early afternoon and the cold spell is largely confined to the night and early morning hours. Strong wind particularly during mid-summer poses a serious threat to this crop in the North East. Both in the North Konkan and the North East, the environmental stress is associated with high intensities of sunlight, much more than what is required to saturate photosynthesis of leaves (Sathik *et al.*, 1998; Devakumar *et al.*, 1998; 1999; unpublished data). Excess light can aggravate the harmful effects of environmental stresses like drought and chilling in *Hevea* leaves (Jacob and Nataraja, 1998; Nair *et al.*, 1999).

It is not only the weather conditions that are stressful in these non-traditional areas. Soils in the non-traditional areas are largely depleted and denuded. For example, the lands available for *Hevea* cultivation in the North East are highly depleted in essential nutrients as well as organic carbon, which makes it necessary to give adequate fertilizers in the early stages of the crop (Krishnakumar and Potty, 1989). These soils have been subjected to the unscientific and primitive practice of shifting cultivation by the native people for centuries, resulting in the loss of its productivity. Similarly, the dry and barren soils of the North Konkan are equally depleted in essential nutrients and very poor in organic matter.

The present review analyses the physiological constraints for growth and productivity of *Hevea* under the severe drought and chilling environments in the North Konkan and the North East regions of India, respectively.

DROUGHT STRESS

The North Konkan region along the Western Coastline of India experiences severe and prolonged soil moisture deficit coupled with very high temperatures and solar radiation and low atmospheric relative humidity for about five to six months every year (Table 1). These environmental conditions are known to inhibit the growth and productivity of *Hevea* (Sethuraj *et al.*, 1989; Chandrashekar *et al.*, 1990; Mohanakrishna *et al.*, 1991), but several studies have shown that with adequate irrigation during the summer months *Hevea* can be successfully cultivated in this region (Sethuraj *et al.*, 1989; Vijayakumar *et al.*, 1998; Devakumar *et al.*, 1998; 1999).

Water deficit during the dry season in this region can be as high as 1070 mm compared to 350 mm in the drought-free traditional region in India (RRII, 1988). Crop growth as estimated from trunk girth is minimum during the rain free summer period in the North Konkan (Chandrashekar *et al.*, 1996). Drought induced soil moisture deficit during peak summer can be so high that the xylem vessels experience negative turgor which shows up as shrinkage of the trunk in the rainfed *Hevea* trees (Chandrashekar *et al.*, 1996; 1998; Devakumar *et al.*, 1998). In the rainfed trees, trunk growth was maximum during the latter part of the monsoon and immediately afterwards (Chandrashekar *et al.*, 1998). Girth increment was minimum in the winter months of November and December (Chandrashekar *et al.*, 1998; Devakumar *et al.*, 1999) which was possibly due to the prevailing low temperature conditions in this region (Annamalainathan *et al.*, 1998).

Girth increment was seen round the year and summer had no adverse effects on tree girthing once adequate irrigation was provided to the trees (Devakumar *et al.*, 1999). This suggested that the prevailing high temperature and low atmospheric relative humidity during summer were not injurious to the trees when water deficit was taken care of. The low atmospheric relative humidity and warmer temperatures favor increased transpirational loss of water resulting in the cooling of the foliage of the irrigated trees during summer. Severe drought caused scorching and photobleaching of chlorophyll in the rainfed trees while the canopy of the irrigated trees remained green and luxuriant.

Adequate irrigation (1 ETc) resulted in good growth and thus reduced the duration of immature period to six years (Vijayakumar *et al.*, 1998). A large percentage of irrigated trees (more than 80%) attained tappable girth by the sixth and seventh year while only a few rainfed trees could attain tappable girth even after nine years of growth (Devakumar *et al.*, 1998; 1999; Vijayakumar *et al.*, 1998, Annamalinathan *et al.*, 1998). Irrigation led to bigger leaf area index resulting in greater solar radiation interception and these trees showed greater and uniform growth in the North Konkan region than in the traditional region (Devakumar *et al.*, 1998; 1999). The total sunshine hours were more in the North Konkan than in the traditional belt. Water, and not the warmer temperatures or the low atmospheric relative humidity, appeared to be the only limiting factor for the cultivation of *Hevea* in this region.

A close analysis shows that the growth and yield of an irrigated plantation of the clone RRIM 600 were better than a rainfed plantation of the same clone in the largely drought-free traditional area (Devakumar *et al.*, 1998). While rainfed trees did not come to tapping even by the ninth year in the North Konkan, with irrigation - despite the high atmospheric temperatures and low atmospheric relative humidity prevailing during summer contributing towards atmospheric drought- it seems that *Hevea* can grow and yield better in the North Konkan than in the traditional regions of India (Devakumar *et al.*, 1998).

Tapping during the peak summer season is uneconomical and injurious to the trees if they are not irrigated. In the North Konkan the rubber yield during summer months comes to only about 10% of the total yield obtained for the whole year (Chandrashekar *et al.*, 1990) whereas in the drought free non-traditional areas, this proportion comes to about 55-65% (Vijayakumar *et al.*, 1988). Latex yield showed a reduction in the rainfed trees as well as the irrigated trees, but during summer the reduction in latex yield was more in the rainfed than the irrigated trees (unpublished data). Water stress and large water vapor deficit of the air are known to inhibit the free flow of latex (Buttery *et al.*, 1976; Paaradekooper and Sookmark, 1969; Pakianathan *et al.*, 1989). Severe drought decreases rubber yield by reducing the total volume of latex harvested as to chilling stress. Increase in tree girth has been found to be minimum during the winter season (Meenattoor *et al.*, 1991). Growth during the winter period accounted for only about 20% of the total annual growth (Vinod *et al.*, 1996) and this proportion can vary depending on the age of the crop. The mean girth of an eight year old plantation of the clone RRIM 600 increased by 4.8 cm in eight months (from 48.2 cm in February 1987 to 53.0 cm in November 1987), but it could grow only another 0.4 cm in girth in the next three winter months (Sethuraj *et al.*, 1989). This indicates that the rate of girth increment was as high as 0.6 cm per month during the winter-free season and as low as 0.13 cm per month during winter. In the fourth year, the clone RRIM 600 showed about 4.3 cm less girth in the North East than in the traditional region (Sethuraj *et al.*, 1989).

By the eighth year about 70% of the trees of the clone RRIM 600 attained tappable girth in the North East. This increased to 90% and 100% in the next two years (Vinod *et al.*, 1996; Priyadarshan *et al.*, 1998). Several studies show that among the elite clones, RRIM 600 and PB 235 perform better in growth and yield in the cold stress prone North East (Meenattoor *et al.*, 1991; Vinod *et al.*, 1996; Alam *et al.*, 1998).

In the hilly regions of North East India, the Eastern slopes have cooler temperatures for longer periods of the day than the Western slopes and hence poor growth in the former (Saseendran *et al.*, 1993). Low temperature also affected the flowering behavior of *Hevea* clones (Meenattoor *et al.*, 1989). In general, a severe winter prolongs the flowering period beyond April. Severe hail storms, although rarely occur, can sometimes permanently damage the bark tissues and affect the tree growth in this part of the country (Meenaatoor *et al.*, 1995).

The optimum temperature for latex flow is reported to be in the range of 18°C to 24°C (Shuochang and Yagang, 1990). Low temperature prolongs the duration of latex flow as evident from the reduced plugging index which results in more latex yield in the cool winter season than in the non-winter period (Fig. 1). The low temperature induced late dripping sometimes continues for more than 24 hours causing internal stress to the trees. The yield contribution during the entire cool season can be as large as 60% of the total annual rubber yield (Vinod *et al.*, 1996). But indiscriminate tapping during stressful winter season can be injurious to the trees which can even result in tapping panel dryness syndrome (Das *et al.*, 1998 a; b). Leaf fall coincides with the low temperature season. Tapping rest is advised to avoid stress to the plants during this season.

Unlike irrigation during drought, little can be done to ameliorate the harmful effects of chilling stress in the field, particularly in the case of large trees. But shading young plants can help to increase the temperature in the micro habitat during night and early morning and reduce the excess load of solar radiation falling on the leaves during the day. Partial shading during winter months provides a conducive microclimate for young *Hevea* plants and thereby increases the growth substantially in the North East (Fig.4). Covering the seed beds with polythene sheets and keeping budded stumps in polythene sheds increased the temperature in the immediate micro-environment and thus increased the sprouting of seeds and buds. Other than these simple management practices, the survival or otherwise of *Hevea* in cold conditions is largely dependent on the intrinsic cold tolerance characteristics of a clone. Fortunately the severe winter conditions do not prolong for more than a month or so in the North East of India.

indicated by an increase in the plugging index (Devakumar *et al.*, 1988; Rao *et al.*, 1988; see also Fig. 1), but little is known about the stress-induced inhibition in the capacity of rubber biosynthesis by the plants. A much less decrease in rubber yield during summer is also noticed in the traditional area than in the North Konkan because the drought is not as severe as in the North Konkan (Nair *et al.*, 1996).

Clonal variations existed in the degree of tolerance to drought as well as in the response to irrigation. The clone RRIM 600 seems to have better growth as well as yield in the North Konkan region than several other clones (Chandrashekar *et al.*; 1994). The quantity of irrigation needed to sustain a high rubber yield and a physiologically healthy crop seems to be much less in a mature plantation with closed canopy than in an immature one with open canopy. A mature crop of *Hevea* (clone RRIM 600) grown with 1 ETc basin irrigation for ten years could continue to grow and yield well without experiencing any apparent symptoms of stress when the quantity and frequency of irrigation were reduced by one-third in a timely fashion (unpublished data, see also Fig.2, 3). Vijayakumar *et al.* (1998) have shown that only 50% of the estimated crop water requirement for the summer season is the actual irrigation requirement for a mature plantation. This can be partially attributed to the extremely reduced solar radiation interception by the soil surface in the irrigated plantation which has a thick and luxuriant foliage (Devakumar *et al.*, 1998; 1999). Mulching the open soil surface, particularly the basin of young plants will help to reduce the moisture loss from the ground. Rubber plantations with mature canopy reduce the impact of sun on the soil and atmospheric warming and therefore remove less amount of soil water per unit area (Samarappuli and Yogaratnam, 1998). The soil temperature inside an irrigated plantation was several degrees less than a rainfed plantation on summer days. All these help to reduce the surface evaporation as well as the evaporative demand of the micro-habitat within the plantation. It has been speculated that *Hevea* can extract water from deeper layers (Monteny *et al.*, 1985; Chandrashekar *et al.*, 1990). But, the quantity of water extracted by a mature *Hevea* tree is much smaller than that by a Eucalyptus tree of similar age (Jacob, 1999).

LOW TEMPERATURE STRESS

Plants native to warm tropics can suffer from chilling injury when exposed to low temperatures during winter (Long *et al.*, 1994). *Hevea* is not an exception (Sethuraj *et al.*, 1989). In parts of sub-Himalayan North East India, the low temperature during winter can reach as low as 5^{0}C in January (Meenattoor *et al*, 1989) which can cause cold injury if it persisted (Jiang, 1984). The low temperature hours are largely confined to the nights and early mornings. But the days can be warmer with temperature reaching above 26^{0}C with high sun light intensity (Table 1) by early afternoon. The prevalence of high light intensity during low temperature conditions can aggravate the stress injuries due to the latter (Oquist *et al.*, 1987). Chilling conditions set in by December and the coldest month is usually January. The weather warms up by February. Thus the severe chilling stress period is largely restricted to about a month or so. During the other seasons of the year, congenial conditions exist here favoring the growth of *Hevea*. Some clones can come up here as good as in the traditional areas (Sethuraj *et al.*, 1989). In areas where the monthly mean temperature is only 20°C or less through out the year, the growth of *Hevea* is severely inhibited (Jiang, 1988).

Young rubber plants are more vulnerable to chilling injury than mature trees. Young sprouted buds succumb to chilling stress very easily (RRII, 1988), but clonal variations exist in tolerance

ENVIRONMENTAL STRESS AND PHOTOSYNTHESIS BY *Hevea* LEAVES

Photosynthesis is one of the first physiological processes and is inhibited when plants are exposed to abiotic stresses such as drought and chilling temperatures (Baker, 1996). During the stress-free seasons, the light saturated rates of photosynthetic CO_2 assimilation by leaves (A) ranged from 13 to 16 $\mu molm^{-2}s^{-1}$ in the North Konkan and the North East which was comparable with the stress-free traditional regions (Vijayakumar *et al.*, 1998; see also Table 2 and Fig. 5). In trees experiencing severe drought stress in the North Konkan and chilling stress in the North East, A_{sat} was close to zero or at times, even on the negative side indicating respiratory loss of assimilated carbon (Sathik *et al.*, 1998, see also Table 2 and Fig.5). As the winter day got warmer in the afternoon, A_{sat} became positive in the North East, but remained highly negative in the drought hit North Konkan due to the worsening dry conditions in the summer afternoons (Sathik *et al.*, 1998). The optimum temperature for photosynthesis in *Hevea* ranged from 27 to 33°C and there was very severe inhibition in photosynthesis at temperatures below 10°C and above 40°C (Zongdao and Xuequin, 1983).

High light intensity inhibited photosynthesis in the drought and cold stressed *Hevea* leaves. Leaf photosynthesis rates were higher when measured at sub-saturating than saturating light intensities in the cold stressed (Fig. 5) and drought stressed (Devakumar *et al.*, 1999) *Hevea* leaves. Therefore, it appears that the shaded leaves in the canopy contribute to the total carbon balance of the plantation more than the exposed leaves during stressful environmental conditions (Devakumar *et al.*, 1999). Shading young *Hevea* plants experiencing a severe abiotic stress is therefore highly advisable.

Drought and cold stress inhibited the quantum yield for CO_2assimilation (as indicated by the reduced initial slope of the photosynthetic light response curve) as well as the efficiency of PS II activity (as studied from chlorophyll fluorescence measurements) (Jacob *et al.*, unpublished data; see also Table 2). This indicates that the light use efficiency was severely affected in the stressed leaves of *Hevea*. Severe drought (Table 2) and cold stresses (unpublished data) decreased the *in vivo* efficiency of the carboxylase enzyme and the CO_2 saturated rate of photosynthesis (AmaxCi) in the mature leaves of *Hevea*. Repeated and prolonged exposure to low temperature, particularly concomitant with high sun light intensity can damage the photosynthetic machinery as a result of oxidative stress and trigger senescence of the leaves (McKersie and Lesham, 1994).

ENVIRONMENTAL STRESS AND OXIDATIVE DAMAGE

Whether it is the drought in the North Konkan or the chilling condition in the North East, the abiotic stress is always associated with a high intensity of solar radiation (Table 1) which is more than what is required to saturate leaf photosynthesis in the stressed *Hevea* leaves (Devakumar *et al.*, 1998; Jacob *et al.*, and unpublished). In unstressed plants, leaf photosynthesis saturated at a photosynthetic active radiation (PAR) of about 1000$\mu mole\ m^{-2}s^{-1}$ (Nataraja and Jacob, 1999), but in stressed plants this will be substantially lower and high light can in fact inhibit photosynthesis (Table 2, Fig. 5). The stress seasons receive high intensities of solar radiation and long sunshine hours both in North Konkan and North East (Devakumar *et al.*, 1999; Dey *et al.*, 1999; see also Table 1).

Environmental stresses inhibit the biochemistry of photosynthetic CO_2 assimilation by *Hevea* leaves, which is the reason for the small light requirement for photosynthesis in stressed leaves. In nature, the drought and cold stresses come concomitant with high PAR intensity in India which is in excess for use in leaf photosynthesis. When the photosynthetic biochemistry is inhibited and the leaves continue to receive PAR more than what is required to sustain the reduced rates of photosynthesis, there will be an imbalance between the photochemical and biochemical reactions of photosynthesis. This results in the over-energization of the thylakoid membranes which results in the diversion of more photoelectron for the production of various active oxygen species (AOS) such as super oxide, hydrogen peroxide and singlet oxygen (Jacob and Nataraja, 1998; Jacob *et al.*, 1999). These AOS can react with almost all types of biomolecules in an active cell resulting in oxidative damage leading to the breakdown of the cellular constituents and the eventual death of the cell (Long *et al.*, 1994). Production of AOS and thus oxidative stress are increased at high PAR due to the increased absorption of the light energy by the chlorophyll pigments.

It is a common observation that leaves of the *Hevea* trees exposed to direct sun light turn yellow and necrotic faster than the shaded leaves during severe winter and drought seasons. Laboratory studies have shown that even moderate light intensities can enhance the injurious effects of water deficit and high temperature stresses in *Hevea* leaves (Nair *et al.*, 1999). In a *Hevea* plant suffering from drought or cold stress, the signs of oxidative stress are evident not only in the leaves exposed to direct sun, but also in other tissues such as the bark and latex (Das *et al.*, 1998a; Alam *et al.*, 1998; unpublished data).

Crop improvement program for the agro-climatically stressful areas into which *Hevea* is expected to be introduced needs to take into account the inherent antioxidant capacity of the clones apart from the well known drought tolerance and avoidance mechanisms such as better root system, avoiding interception of excess solar radiation through leaf movement, reduced leaf area, mutual shading or deposition of epicuticular wax, osmoregulation, etc. Among the modern elite clones, RRIM 600 appears to perform better in both the drought-prone North Konkan and the low temperature stress-prone North East of India. Such clones will be an ideal candidate for a comprehensive investigation into the mechanisms of abiotic stress tolerance which can be vital in our future crop improvement programs. Polyclonal trees and wild germplasm lines are a rich repository of useful stress tolerance traits which are yet to be exploited thoroughly. While expertise in highly specialized areas like molecular cloning, biotechnology and physiology is extremely important, an integrated and interdisciplinary approach to the biology of the whole plant is the need of the hour to achieve tangible results in our crop improvement programs for abiotic stress tolerance in *Hevea*.

SOCIO-ECONOMIC AND ECOLOGICAL DIMENSIONS OF CULTIVATION OF NATURAL RUBBER IN MARGINAL AREAS

Apart from India, in several other natural rubber growing countries attempts are being made to expand rubber cultivation in to stressful agroclimatic areas. For example, denuded waste lands in Thailand, low temperature and drought prone coastal and high altitude regions in Vietnam, low temperature prone areas in China, forest fringes that are fast turning into deserts in Nigeria, laterite soils denuded due to shifting cultivation in Cameroon etc (personal communication). Such regions have one or more of these general characteristics, namely, poor soil fertility and crop productivity, inadequate tree cover, deforestation, desertification, soil erosion, lack of water for human consumption and irrigation, poverty, malnutrition, etc.

In general, agro-climatically marginal areas are home for some of the poorest indigenous people throughout the world. The situation is not different in several natural rubber growing countries mentioned above. Cultivating natural rubber in such areas helps to improve the earnings and thus the standard of living of these poor people. In addition, natural rubber cultivation, over time improves the fertility status of the soil through litter recycling etc and helps to restore degraded ecosystems (Jacob, 2000). While trying to expand natural rubber cultivation into agro climatically marginal areas, it will not be prudent to expect maximum productivity in the first cycle of the plantation. The approach should be more focused to reclaim the degraded soils by providing a permanent tree cover with a rubber plantation for 25-30 years. Polyclonal seedlings may suite these areas better than elite high yielding clones which are propagated through bud grafting and may prove to be more difficult to be cultivated there than polyclonal seedlings. The focus should be more on the socio- economic development and the ecological sustainability (Swaminathan, 1996) than on increasing the natural rubber production *per se*, while planning strategies to expand its cultivation to agro climatically marginal areas. Expanding natural rubber cultivation and developing natural rubber based forestry systems for marginal areas will help greatly to meet the dual objectives of restoring the health of these fragile ecosystems and the poor native people inhabiting there. Given the remarkable adaptability of *Hevea brasiliensis* to a wide range of agro-climatic conditions, there is a clear possibility of using its cultivation for the sustainable and integrated development of agroclimatically marginal areas.

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Table 1. A summary of the major agro-climatic and soil characteristics of traditional, North Konkan and North East regions of India at a glance. The North Konkan and North East are the two major nontraditional areas in India into which cultivation of rubber is being extended.

Parameters	Traditional	N - Konkan	North - East
[1] Longitude	74°5 - 77° 30 E	72°. 04' E	90 - 93° E
[1] Latitude	8° 15-12° 5 N	20°. 04' N	22° - 29.5° N
[1] Altitude (m MSL)	20 - 840	48	30 - 1100
[1,3,5] Annual rainfall (mm)	3000	2430	2024
Monsoon months - South West	June - Sep	June - Sep	June - Sep
Monsoon months - North East	Oct - Nov	Nil	Nil
[1] Number of rainfree months/year	1 or 2	6 - 7	Nil
[1] Duration of drought	March, April	Jan. - May	Nil
[1,2] Summer mean max. temp. (^{0}C)	33	37	31
[1,2] Summer mean min. temp. (^{0}C)	25	23.5	21
[1,2] Winter mean max. temp.(^{0}C)	31.5	31.5	26
[1,2] Winter mean min. temp.(^{0}C)	22	15.5	11
[1,3] Total annual sunshine hours.	2210	2911	2221 (1993)
[1,3] Mean sunshine hours/day, summer	9.5	10.4	6.7 (1993)
[1,3] Mean sunshine hours/day, winter	8.5	9.0	7.5 (1993)
[2,3] Max Photosynthetic Active Radiation (μ mole m^{-2} sec^{-1}) summer	1500 - 1800	1600-1800	1500 - 2000
[1,4] Max Photosynthetic Active Radiation (μ mole m^{-2} sec^{-1}) winter	1200 - 1500	1100-1400	1500 - 1800
[1,5] Midday mean RH (%) (summer)	67	39.5	56
[1,5] Midday mean RH (%) (winter)	62	36	49
[1,5] Evaporation (mm) (summer)	5.4	7.4	NA
[1] Evaporation (mm) (winter)	3.5	4.5	NA
[6] Number of storms/ year	Nil	Nil	At least once in summer
Number of hailstorms/ year	Nil	Nil	Once in 10 years
[7] Soil Type	Ultisol	Oxisol	Sandy clay loam
[7] Soil pH	4 - 6.5	6.3	4 - 5
[1] Topography	Gentle slope to hilly terrain	Plain to gentle slope	Plain to very hilly terrain
[5,7] Field capacity (%)	16 - 32	30.5	22 - 24
[5,7] Permanent wilting point (%)	6.5 - 24	17	10 - 11

Sources: 1. Agro- Meteorology Data, RRII; 2. Sethuraj *et al.*, (1989); 3. Devakumar *et al.*, (1998); 4. Mohankrishna *et al.*, (1991); 5. Chandrashekar *et al.*, (1990); 6. Meenatoor *et al.*, (1995) and 7. Krishnakumar (1993).

Table 2. Leaf photosynthesis of mature Hevea plants grown in the drought-prone North Konkan and stress-free traditional regions.

Parameters	Traditional (stress-free)	North Konkan	
		Drought season (Irrigated)	Drought season (non-irrigated)
A_{sat} (μ mole m^{-2} s^{-1})	10-14	12	0
A (PFD=250 μmole m^{-2} s^{-1}) (μ mole m^{-2} s^{-1})	-	7	3
Apparent QY for CO_2 assi. (mol CO_2 per mole photon)	0.04-0.06	0.026	0.008
A (maxCi) (μ mole m^{-2} s^{-1})	20-25	23	10
Carboxylation Efficiency (mol CO_2 m^{-2} s^{-1} /ppm)	0.062-0.077	.064	0.029
Dark adapted Fv/Fm			
PS II QY at low PFD (μ mol m^{-2} s^{-1})	0.80	0.79	0.41
	0.78	0.78	0.38
PSII QY at high PFD (μ mole m^{-2} s^{-1})			
Rate of e^- transport to processes other than C reduction	0.38	0.32	0.16
(μ mole m^{-2} s^{-1})	10	12	36

Sources: Jacob *et al* (1999); Nataraja and Jacob (1999).

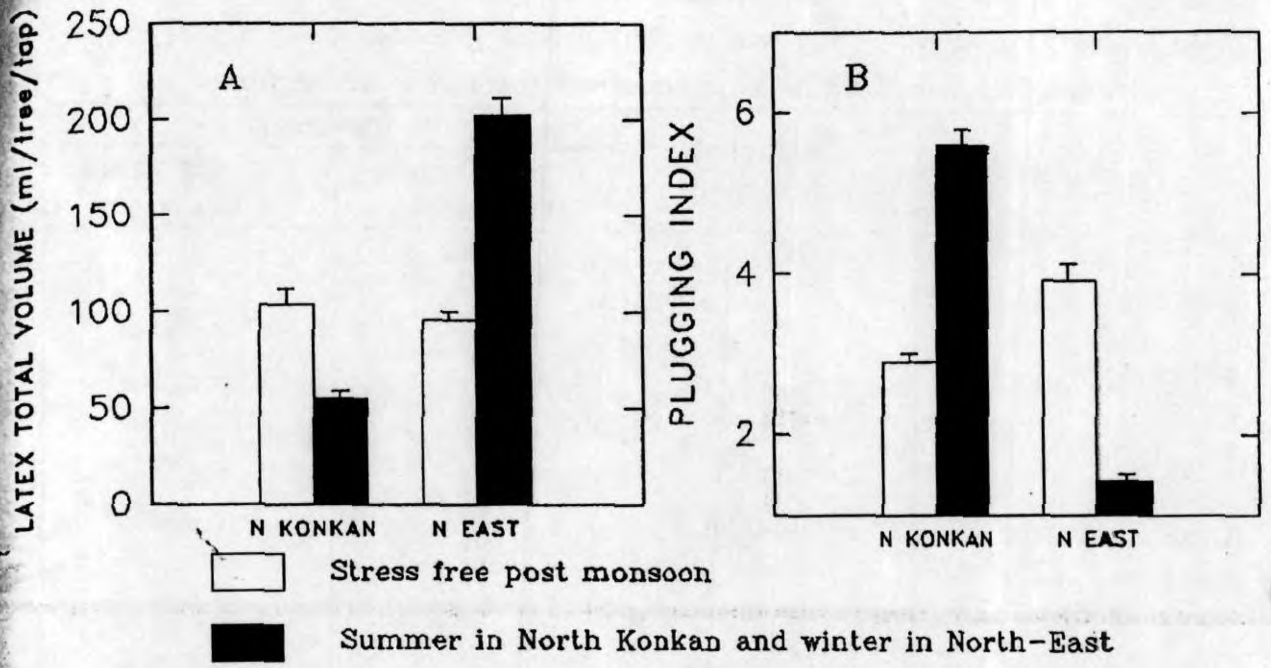

Fig. 1. Effect of severe summer and chilling winter on total volume of latex harvested per tree/tap (A) and plugging index (B).

(The trees in North Konkan received 0.5 Etc irrigation during summer.)

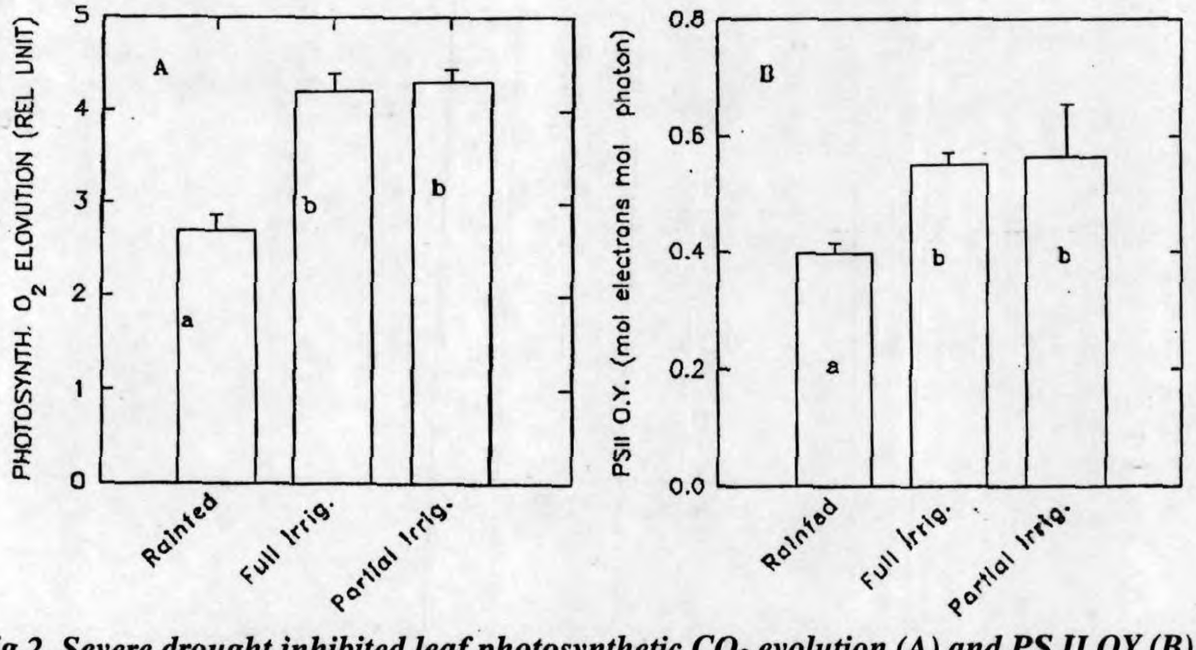

Fig.2. Severe drought inhibited leaf photosynthetic CO_2 evolution (A) and PS II QY (B).

There was no difference between fully and partially irrigated trees (See also Fig. 3).

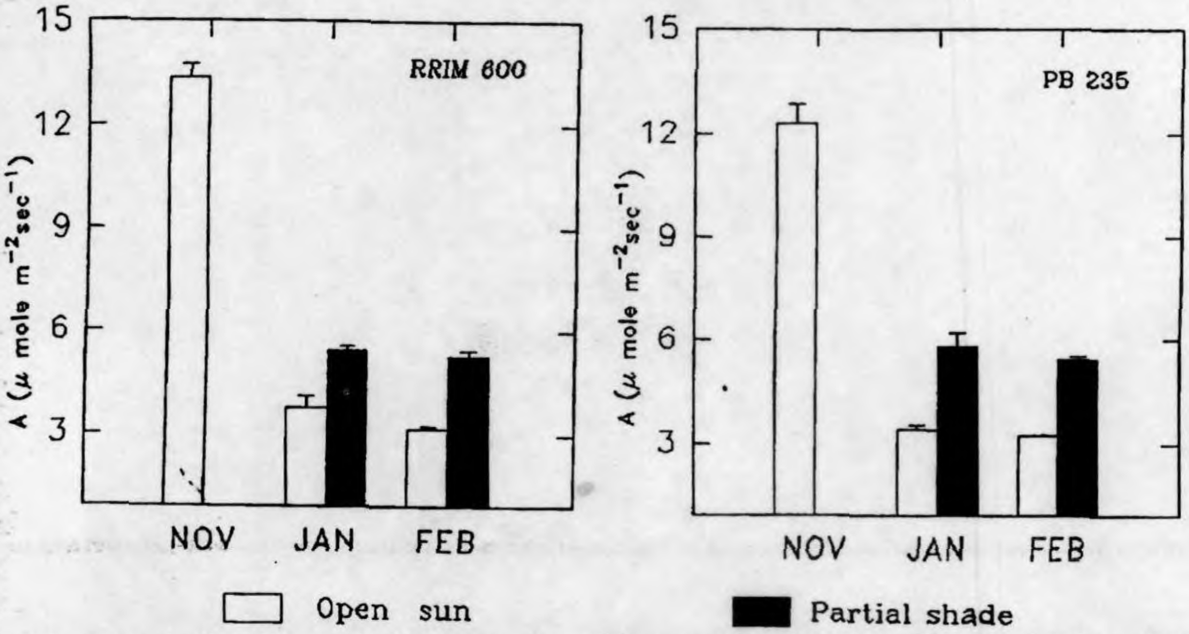

Fig.5. Photosynthetic CO_2 assimilation rates of leaves (A) of young Hevea plants grown in the open sun or partial shade during winter in the North East

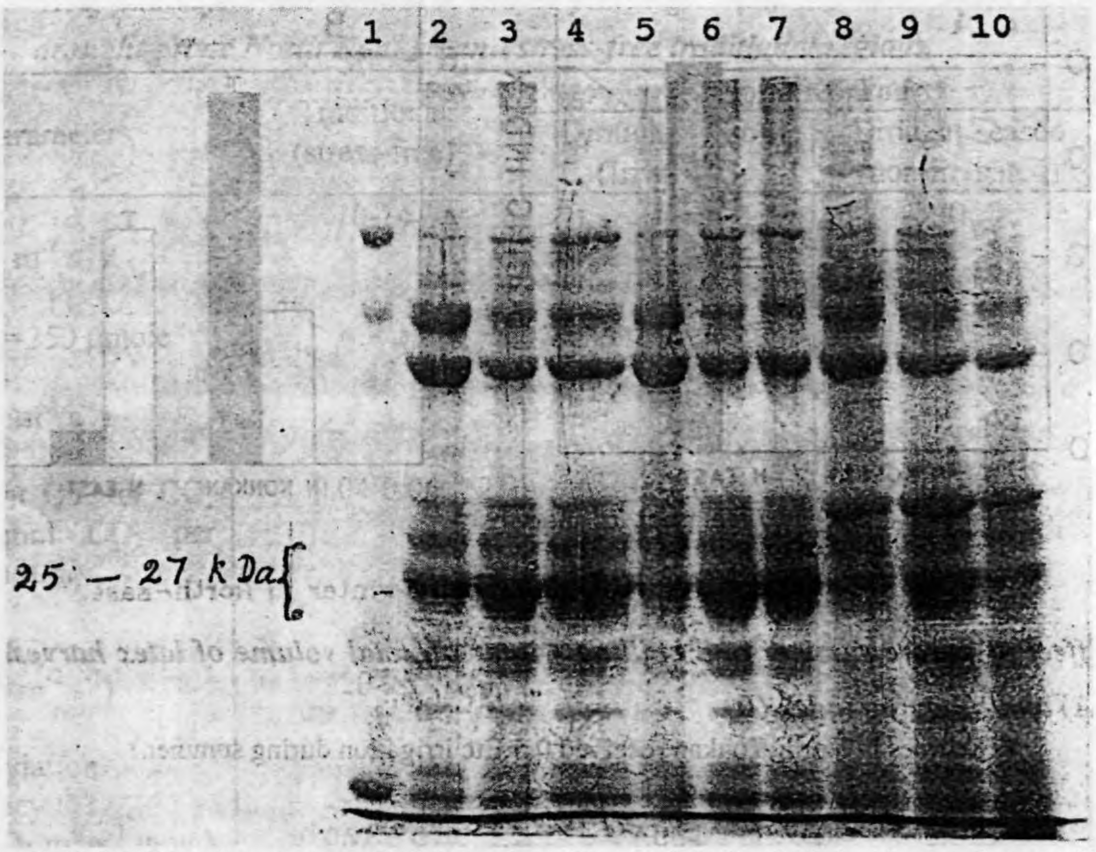

Fig. 3. SDS-PAGE of proteins of chloroplast (lanes 2,3,4), thylakoid membrane (5,6,7) and stromal fractions (8,9,10) from rainfed (2,5,8), 1.0 Etc irrigation (3, 6, 9) and partially irrigated (4, 7, 10) trees in North Konkan. The partial irrigation was only 1/3 of 1.0 Etc treatment. The results show that partial irrigation did not affect the protein of photosynthetic apparatus.

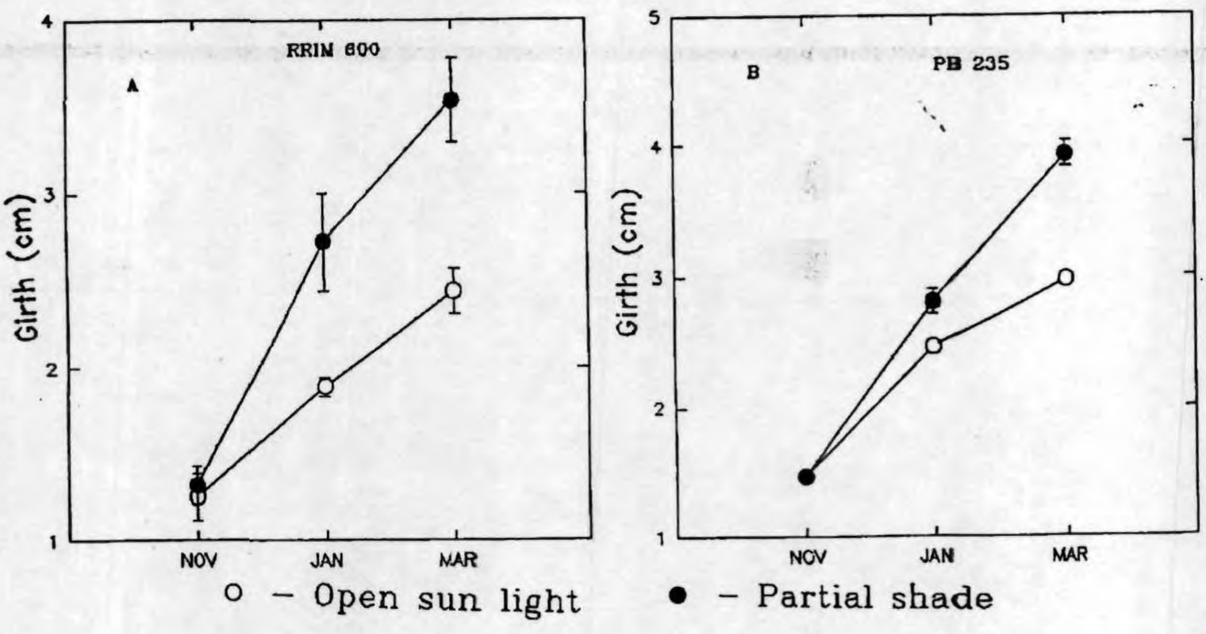

Fig. 4. Girth increment of young Hevea plants grown in the open sunlight or partial shade during winter in the North East.