# PRODUCTIVITY OF RUBBER [*Hevea brasiliensis* (Willd. ex A. de Juss.) Muell. Arg., ] IN RELATION TO CHANGES IN DIFFERENT PHYSIOLOGICAL PARAMETERS IN A DRY SUBHUMID CLIMATIC REGION

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( APPLIED BOTANY )

BY
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(T.R. CHANDRASHEKAR)

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| | | |
|---|---|---|
| $\psi_l$ | = | Leaf water potential (-MPa) |
| $\psi_\pi$ | = | Latex solute potential (-MPa) |
| AN $\psi_l$ | = | Afternoon leaf water potential |
| $C_r$ | = | Rubber content (%, w/v) |
| DRY | = | Dry rubber yield (g $tree^{-1}$ $tap^{-1}$) |
| E | = | Transpiration (m moles $m^{-2}$ $s^{-1}$) |
| F | = | Initial flow rate (ml $min^{-1}$ $cm^{-1}$) |
| FC | = | Field capacity (cm) |
| $g_s$ | = | Stomatal conductance (m moles $m^{-2}$ $s^{-1}$) |
| G | = | Girth of the trees (cm) |
| LY | = | Latex yield (ml) |
| p | = | Plugging index |
| PD $\psi_l$ | = | Pre-dawn leaf water potential (-MPa) |
| $P_{lv}$ | = | Latex vessel pressure potential (MPa) |
| Pretap $P_{lv}$ | = | Pretapping latex vessel pressure potential (MPa) |
| Post-tap $P_{lv}$ | = | Post-tapping latex vessel pressure potential (MPa) |
| PWP | = | Permanent wilting poit (cm) |
| SM | = | Soil moisture (%) |
| $T_{Max}$ | = | Maximum temperature (°C) |
| $T_{Min}$ | = | Minimum temperature (°C) |
| VPD | = | Vapour pressure deficit (KPa) |

# CHAPTER 1

# INTRODUCTION

# 1 INTRODUCTION

Hevea brasiliensis (Willd. ex. Adr. de Juss.) Muell. Arg., the para rubber tree, is the world's major source of natural rubber. Amongst the 10 species of the genus, Hevea, a member of Euphorbiaceae H. brasiliensis is the only one planted commercially. Rubber is obtained by processing the latex collected by repeated, controlled wounding of the bark, known as tapping. The rubber has multifarious uses and there is hardly any segment of life which does not make use of rubber based materials. It is also a vital raw material having immense strategic importance.

The traditional areas of rubber cultivation is limited to the humid tropics within 10° North and South of the equator where the total rainfall, distribution of rainfall and ambient temperatures are congenial for growth of the crop. In India, the traditional rubber growing areas extend upto 13°N, though moderate drought conditions are experienced annually in the northern parts. Altitude-wise, the limit for optimum growth is 450 m MSL.

Most of the natural rubber produced in the country comes from the traditional region. The total production from this region, however, is not sufficient to meet the country's full requirement (Table 1). Further expansion of area under rubber in the region

Table 1. Production, import and consumption of natural rubber in India from 1980-81 to 1988-89 (Metric tonnes).

| Year | Production | Import | Consumption |
|---|---|---|---|
| 1980-81 | 153100 | 9250 | 173630 |
| 1981-82 | 152870 | 42750 | 188420 |
| 1982-83 | 165850 | 33401 | 195545 |
| 1983-84 | 175280 | 35940 | 209480 |
| 1984-85 | 186450 | 37461 | 217510 |
| 1985-86 | 200465 | 41431 | 237440 |
| 1986-87 | 219520 | 45356 | 257305 |
| 1987-88 | 235197 | 53685 | 287480 |
| 1988-89 | 259172 | 59835 | 313830 |

Source: The Rubber Grower's Companion, 1990.

to narrow down the gap between consumption and production is not feasible due to socio-politico-environmental reasons. In order to achieve self sufficiency, it became necessary to explore the possibilities of extending rubber cultivation to other less congenial but potential areas, outside the traditional region (Sethuraj et al., 1989). Therefore, steps were taken in the early 70's and the following regions were identified as marginally suitable for the purpose: the North-East India (22° N to 30° N) including the high elevation areas, the high elevation regions of the Western Ghats (8.5° N to 20° N), certain parts of Madhya Pradesh, Orissa and West Bengal States (19° N to 27° N) and the Konkan region of Western India (13° N to 20° N). It was envisaged to establish rubber plantations successfully by evolving appropriate agrotechnology in these non-traditional regions (Sethuraj et al., 1989).

In pursuance of this, the Rubber Research Institute of India has established several Regional Research Stations in the newly identified areas for raising rubber plantations. One such Station was set up in the North Konkan region at Dapchari in 1981, in the Thane District of Maharashtra State, towards north of Bombay.

The region is characterised by high rainfall, high summer temperatures and prolonged drought. Earlier reports (Chandrashekar, 1983; Sethuraj, 1985) have indicated that the growth of plants in the region supplemented with life-saving irrigation during summer months, was comparable to those of the conventional tract. Successful rubber cultivation in the region depends on identifying clones possessing drought tolerance characteristics and fairly better yield potential and evolving of appropriate agrotechnology.

The production of latex, the commercial product from Hevea, is affected by many factors. Rubber yield is governed by inherent production potential of the tree (relative rates of photosynthesis, partitioning of assimilates and respiration) environmental variations (microclimate within the canopy), leaf area index, meteorological factors, density of planting and plant water relations, which in turn are influenced by soil moisture availability and various other physiological parameters (Sethuraj and Raghavendra, 1987).

The latex being predominantly watery, its flow from the tree presents one of the classical phenomena influenced by plant water relations (Buttery and Boatman, 1976). Clones of Hevea vary in their sensitivity to water stress (Saraswathyamma and Sethuraj, 1975). The latex yields are generally reduced at low moisture levels, prevalent typically in summer months and the pattern of flow gets altered by the soil moisture status (Sethuraj and Raghavendra, 1987). The duration of flow as well as the amount of latex gets reduced during water stress conditions (Sethuraj and Raghavendra, 1984).

In North Konkan, the major environmental constraints limiting crop growth and productivity of rubber are prolonged severe soil moisture deficits and high summer temperatures. The effects of these adverse conditions is now fairly understood (Sethuraj *et al.*, 1989; Bhaskar *et al.*, 1990). Substantial amount of information is available on the effects of drought on yield, yield components and plant moisture status for the traditional region (Gururaja Rao *et al.*, 1988; Devakumar *et al.*, 1988; Vijayakumar *et al.*, 1988). However, such studies, which are vital for generating basic information as well as for devising suitable management practices, are lacking for the non-traditional areas of rubber cultivation. Therefore, the present study was taken up with the following objectives:

1. To study the yield performance in two clones of *Hevea brasiliensis* in the North Konkan region, and

2. To characterise the water relations including stomatal behaviour on seasonal and diurnal bases and to study their interrelationship with yield and its components.

# CHAPTER 2

# REVIEW OF LITERATURE

# 2 REVIEW OF LITERATURE

## 2.1. Generalia and historical

*Hevea brasiliensis* is a fast growing tree with a straight trunk. The bark is usually grey and fairly smooth. It is the tallest species of the genus and in the wild, the trees may grow to over 40 m and live for over 100 years. In plantations they rarely exceed 25 m since growth is reduced by tapping, and they are usually replanted after 25-35 years when yields fall to uneconomic levels (Webster and Paardekooper, 1989). In the estates as well as small holdings, rubber trees are grown as clones of buddings on seedling root stocks or as seedlings. The seedling plantations are raised from the seeds obtained from isolated seed gardens, where selected high yielding clones with other desirable characters are planted in scientific designs so as to maximise cross pollination amongst them (Marattukalam *et al*., 1980).

*Hevea* is indigenous to the tropical rainforests in the Amazon basin at an altitude of below 200 m above sea level near the equator. The region is characterised by monthly mean temperatures of about 29°C with annual rainfall ranging from 1500 mm to 2500 mm. The region has no dry season, but only brief and less wet periods (Webster and Paardekooper, 1989).

Four gifted men played leading roles in the domestication on Hevea brasiliensis. They were Clement Markham of India Office, Joseph Hooker, Director of Kew Gardens, Henry Wickham, Planter, rubber trader and naturalist and Henry Ridley, protege of Hooker and from 1888, Director of Singapore Botanic Gardens (Baulkwill, 1989). Kew Garden played a special role in the domestication of wild plants, for it was here that planting materials of potential value were assembled from abroad, propagated and distributed to other botanical gardens around the world (Baulkwill, 1989).

In India, rubber has been in use from time immemorial (Haridasan and Nair, 1980). In 1810, Roxburgh found that rubber was derived from Ficus elastica grown in Assam and described that in his "Flora Indica". The first suggestion to introduce rubber to the Indian sub-continent was made by Thomas Hancock in 1857. Henry Wickam, the father of the rubber plantation industry in the Far East, was the first to introduce rubber to this part. The first attempt to plant rubber in India was in 1879, when 28 Hevea plants were planted at Nilambur valley of Kerala State. Thereafter rubber cultivation spread to other parts.

In the Indian sub-continent Hevea is mainly grown on the hill slopes in the mid-lands on the western side of the Western ghats and on the foot hills of the Western ghats (Pushpadas and Karthikakuttyamma, 1980). At present extensive cultivation of rubber in India is confined to the Western ghats of the country extending from Kanyakumari district of Tamil Nadu in the south to Coorg district of Karnataka in the north and limited areas in the Andaman and Nicobar islands.

The climatic conditions prevailing in the traditional tract vary from region to region and from year to year, particularly in rainfall (Pushpadas and Karthikakuttyamma, 1980). In fact, the average annual rainfall in the tract varies from about 2000 mm to 4500 mm. Northern parts experience drought period extending from two to five months in a year as the distribution of rainfall is more uneven. However, variation in temperature and humidity is not so marked as that of rainfall.

The main crop from the rubber tree is latex, a hydrosol, where rubber particles are dispersed in an aqueous serum. It is harvested by the process of tapping, a controlled wounding of the bark (Plate 2). During tapping, the latex is collected either in coconut shells or polythene cups. The latex is collected two to three hours after tapping and processed into marketable product. Around 80 per cent of the crop from plantations is in the form of latex. The tree lace and shell scrap (latex which gets dried up on the tapping panel and the collection cups respectively) also form part of the crop and are collected by the tapper just prior to tapping. The latex spilt and/or overflowed on the ground (earth scrap) when gets dried up is also collected as scrap regularly. Normally, 15 to 25 per cent of the total crop constitutes tree lace, sheet scrap and earth scrap, which together are called field coagulum (Thomas et al., 1980).

The yield collected in the form of latex can be processed into preserved latex, latex concentrates, ribbed sheet rubber, crepe rubber and technically specified block rubber. The crop collected as field coagulum can be processed only into crepe or block rubbers. For processing of latex into dry rubber sheets, the latex is diluted and coagulated with acetic acid or formic acid which separates much of the serum to form a coagulum comprising a network of rubber particles with some amount of entrapped serum. The coagulum is washed with water and passed through various machines in order to remove serum and acid and to convert it into various types of marketable rubber (Thomas et al., 1980).

## 2.2. Exploitation of the rubber tree

Rubber is obtained by processing the latex collected by repeated controlled wounding of the bark of the tree known as tapping. The latex flows out when a tapping cut is made on the trunk of the tree mainly because of the very high turgor pressure in the latex vessels (Buttery and Boatman, 1964; Raghavendra et al., 1984). Turgor pressures in the laticifers of Hevea which reach upto 1.5 MPa are among the highest recorded in laticifers of different species (Buttery and Boatman, 1976). The turgor pressure will be maximum during dawn, falls during day and gets rebuilt in the night (Buttery and Boatman, 1967). Decreased turgor pressure during the day has been attributed to the withdrawal of water from the phloem tissues under transpirational stress. The diurnal pressure changes are positively correlated with changes in temperature, leaf water deficit and stomatal opening. However, such variations do not occur in trees without leaves during wintering (Paardekooper, 1989).

## 2.3. Composition of latex

The latex collected by regular tapping consists of the cytoplasm expelled from the latex vessels and is similar to the latex in situ. Apart from water, it contains about 30 to 40 per cent of rubber and about 3 to 5 per cent of other substances (Table 2). The structure and composition of fresh latex has been elucidated by high speed centrifugation (Moir, 1959). Depending on the method followed, 3 to 11 zones can be distinguished. The top fraction consists almost entirely of rubber; the middle zones are made up of the watery phase of the latex, generally called latex serum; the relatively heavy bottom fraction, normally yellowish, viscid and

Table 2. Organic non rubber constituents of tapped latex from <u>Hevea brasiliensis</u>.

| Fresh latex* | | | |
|---|---|---|---|
| Serum 48 | Rubber phase 37 | Bottom frction | Frey-Wysling particles |
| Inositols 1.0-1.5 | Protein 0.5 | Proteins 0.2 | Carotenoids |
| Carbohydrate and proteins 0.5 | Phospholipids 0.6 | Phospholipids, | Plastochromanol |
| Glutathione 0.01 | Tocotrienols (free and | Plastoquinone, | Other lipids |
| Free AA's 0.08 | esterified) 0.09 | Ubiquinol, | |
| Ascorbic acid 0.02 | Sterol and Sterol Esters | Sterols, | |
| Other organic acids | Fats and waxes | Trigoneline 0.07 | |
| Nitrogenous bases 0.04 | | Ergothionine 0.05 | |
| Mononucleotides 0.02 | | | |
| Nucleic acids 0.002 | | | |

*The numbers next to the components indicate their approximate concentrations in g/100 g of latex.

AFter Archer *et al*. (1963).

semi-liquid, consists mainly of the lutoids, while the yellow, lipid containing Frey-Wyssling complexes are normally found at the upper border of the bottom of the fraction (Paardekooper, 1989).

The rubber fraction contains in addition to the rubber hydrocarbon, the proteins and phospholipids associated with rubber particle membranes. The latex serum contains most of the soluble substances normally found in plant cells, such as inositols, carbohydrates, free amino acids, proteins, inorganic anions and metal ions, together with the enzymes and intermediates of various biochemical processes, including rubber biosynthesis. Lutoid serum contains ruptured membranes of lutoids, their liquid content, proteins and other nitrogen compounds as well as metal ions (Buttery and Boatman, 1976).

## 2.4. Physiology of latex production

Production of latex is confined to the latex vessels which occur exclusively in the phloem region. When a tree is tapped for first time the latex obtained is very viscous and flow ceases rapidly. Successive tappings at regular intervals result in increasing yields of more dilute latex, until an equilibrium is reached between rubber extraction and rubber regeneration (Paardekooper, 1989). The sequence of events that follow the opening of the vessel ends by tapping and the mechanism involved have been studied extensively

(Pakianathan, 1966; 1967; Buttery and Boatman, 1970; 1976; Gomez, 1983; Sethuraj, 1985; Sethuraj and Raghavendra, 1987).

The yield of latex from one tapping mainly depends on the initial flow rate of the latex, which in turn depends on the turgor pressure in the latex vessels. After sunrise the turgor pressure normally falls as a result of withdrawal of water under transpirational stress. Therefore, a delay in starting the tapping results in lower yields (Paardekooper, 1989). For this reason tapping is started well before sunrise and is completed as early as possible. Paardekooper (1989) has reported that diurnal variations in yield closely follow the vapour deficit of the air.

Before tapping, latex is contained in the vessels at high hydrostatic pressure, usually between 10 and 15 atmospheres early in the morning. Immediately after tapping, the pressure at the cut ends of the vessels is reduced to ambient pressure and the elastic contraction of the vessel walls under the pressure of the still turgid surrounding cells expel latex at high speed. With help of capillary manometers it has been shown that the turgor pressures of the laticiferous system just below the cut falls considerably and very rapidly during tapping and with the increasing distance from the cut, the pressure declines less and more slowly (Buttery and Boatman, 1967).

The loss of turgor pressure in the vessels disturbs the osmotic equilibrium, creating a suction pressure which causes an inflow of water from the neighbouring cells into the latex vessels, which is called "dilution reaction". This dilution reaction results in decline in the total solids and dry rubber content of latex immediately after tapping, but usually show some recovery before flow ceases and the rubber content is restored to its usual level by synthesis between tappings (Paardekooper, 1989).

A major advance in understanding the mechanism of latex flow resulted from the work of Boatman (1966) and Buttery and Boatman (1966, 1967). Their studies indicated a sort of impediment developing at or within about 1 mm of the cut ends of latex vessels, called plugging, later confirmed by Southorn (1968) by his optical and electron microscope studies of longitudinal sections of latex vessels near the tapping cut. In 1969, Milford et al studied clonal variations in the rate of plugging and proposed that plugging behaviour can be characterised by a "plugging index". It is derived from the ratio between the initial flow rate and the total volume of latex per tapping:

$$p = \frac{\text{Mean initial flow rate during the first five minutes after tapping (ml/min)}}{\text{Total yield volume (ml)}} \times 100$$

The initial flow rate depends on: (a) the number of latex vessels cut; therefore on the length of the cut and the number of vessel rings; and (b) on the pressure in the vessels before tapping. The initial flow rate may vary from less than 1 ml/min to over 5 ml/min depending on clone and length of tapping cut. The plugging index has been shown to be a clonal characteristic. It also varies markedly with season, tapping system and stimulation practice. The index can be as low as 1 for very long flows or over 10 for short flows (Paardekooper, 1989). Many workers have studied the effects of clone, season and tapping system on plugging index and the relation of the latter with other characteristics of latex (Paardekooper and Samosorn, 1967).

Various workers have built up evidence that a major cause of vessel plugging during latex flow is the damage caused to lutoids (Milford et al., 1969). Southorn and Edwin (1968), following upon the microscopic observation of plugs of rubber particles and damaged lutoids near the cut ends of vessels, discovered that the fluid contents of the lutoids caused rapid and complete flocculation of an aqueous suspension of rubber particles thereby indicating that plugging within the vessels is caused by release of B-serum from the ruptured lutoids.

## 2.5. Yield performance under traditional conditions

A good amount of information is available on the yield performance of Hevea under traditional conditions (Marattukalam et al., 1980; Krishnankutty and Srinivasan, 1984; Toms Joseph and Haridasan, 1990). In small scale trials in India, the reported yields range from 900 to 3000 kg $ha^{-1}$ per annum for different clones averaged over the first fifteen years tapping. In Malaysia, the figures range from 1200 to 3000 kg $ha^{-1}$ per annum. In commercial plantings the reported yields vary between 900 to 1500 kg $ha^{-1}$ per annum India, while in Malaysia it varied from 1000 to 2000 kg $ha^{-1}$ per annum during the first fifteen years of tapping.

Of particular interest is the performance of the clones GT 1 and RRIM 600. In India, for the clone RRIM 600, Marattukalam et al. (1980) have reported an yield of 1185 kg $ha^{-1}$ per annum over five years and the corresponding figures in Malaysia are 1386 kg $ha^{-1}$ per annum. From the clone GT 1, the yield obtained from commercial plantations in Malaysia during the first 15 years of tapping was 1615 kg $ha^{-1}$ per annum. In India, it had given an yield of 1337 kg $ha^{-1}$ per annum during the first six years of tapping. Also in another report (Krishnankutty and Sreenivasan, 1984) an yield of 1308 kg $ha^{-1}$ per annum for RRIM 600 and 1326 kg $ha^{-1}$ per annum for GT 1 during the first 10 years of tapping in India has been reported.

## 2.6. Factors affecting yield

The yield of latex in *Hevea* is affected by many factors. The amount of rubber containing tissue per unit volume of bark is one of the important factors determining yield. This, in turn, depends on the number of latex vessel rings, the number of vessels per millimeter of ring and the mean diameter of the vessels. It has been found that the number of latex vessel rings is most important factor and is usually significantly and positively correlated with yield (Webster and Paardekooper, 1989). Two major yield components are initial flow rate and duration of flow. The initial flow rate per unit length of cut is determined by: (a) the amount of latex bearing tissue in the bark, which varies between cultivars and with age of the tree; and (b) the turgor pressure in the vessels which is influenced by the time of day and by tapping system. The duration of flow is determined by the plug formation in the vessels and by the cap formation through coagulation on the tapping cut. It is strongly influenced by cultivar and the tapping system, long cut systems decreasing the plugging and prolonging flow. The plugging of vessels is influenced by differences in stability of the lutoids, which are disrupted by shear and by changes in osmotic pressure caused by dilution reaction (Paardekooper, 1989).

The yield is also determined by the rate of rubber biosynthesis. The balance between latex withdrawal and rubber regeneration is reflected in the dry rubber content of the latex. Between cultivars, an indication of rubber generating efficiency is provided by the difference between total solids _in situ_ in untapped trees and that in tapped trees (Paardekooper, 1989).

In addition to these, yield is also governed by the inherent potential of the tree (relative rates of photosynthesis, partitioning and respiration), environmental variations (microclimate influenced by canopy architechture, leaf area index, meteorological inputs etc.), density of planting, plant water relations which in turn are influenced by soil moisture availability and various other physiological parameters (Sethuraj and Raghavendra, 1987).

## 2.7. Rubber cultivation under marginal rainfall conditions

Many countries including India, are now venturing to grow rubber even in areas with hostile environments. These areas usually pose stress conditions such as prolonged drought, low temperatures in winter, high altitude etc. Large areas of rubber are now grown in localities with a dry season of more than 5 months and total rainfall down to 1500 mm per annum. The effect of marginal rainfall on tree performance is confounded with that of temperature and other environmental factors. In the equatorial regions of rubber cultivation, mean annual temperature is 28°C ± 2°C, and the diurnal variation is about 7°C (Barry and Chorley, 1976). In non-traditional areas the amount of insolation increases because of reduced cloudiness and increased day length. Oldeman and Frere (1982) have reported that because of the higher total annual input of radiation energy, there is a greater potential for dry matter production from photosynthesis in these areas.

In Malaysia, rubber cultivation is being expanded to the northern parts of the country which experiences marginal rainfall conditions with moisture deficits of more than four months in a year. In Thailand, rubber cultivation is being extended to latitudes of around 18° N with a rainfall of 1200-1500 mm (Watson, 1989). In these areas there is a marked dry season of 6 months with severe moisture deficits and temperature margin between 14 and 40°C. Preliminary reports have shown that growth was slower in these areas with trees taking at least one year longer to reach tappable size (Watson, 1989). Saengruksowong et al. (1983) have reported that early latex tests have been promising which must be considered satisfactory under the circumstances. Many more aspects of rubber cultivation under marginal conditions have been discussed in detail by Watson (1989).

In India, steps were taken in the early seventies to explore the possibility of extending rubber cultivation to the non-traditional regions. The following regions were identified as marginally suitable for rubber cultivation: The North East India (22° to 29.5° N) including the high elevation regions; the high elevation regions of the Western Ghats (8.5° to 20° N), certain parts of Madhya Pradesh, Orissa and West Bengal (19° to 27° N), and the Knokan region of Western India (13° to 20° N) (Sethuraj et al., 1989).

## 2.8. Effect of temperature and altitude on Hevea

In the traditional rubber cultivation zones mean annual temperature is about 28°C. As the altitude increases, the temperature decreases by about 0.6°C for every 100 m in height. Normally Hevea cultivation is restricted to below 200 m. In these conditions rubber trees grow most rapidly and the tree require about 6 to 7 years to reach tappable size, and for every rise of 200 m above seal level trees might take 3-6 months longer to reach the tappable size. Therefore, rubber cultivation above 600 m is not advisable (Watson, 1989). Neverthless, it has been reported that in Java many estates laid out in a belt between 600 and 700 m above sea level have proved successful because of good sites with favourable exposure, soils and rainfall. Extensive studies have been carried out in China on the effect of altitude and temperature on Hevea (Huang and Zheng, 1983; Pan, 1983). Dijkman (1951) has reported that some clones performed equally well both at 250 m and 515 m altitudes. The work done in India has also yielded similar results (Anonymous, 1987; 1988).

## 2.9. Yield performance under marginal conditions

Information available on the growth and yield performance of Hevea under marginal rainfall conditions is limited. Most of the reports available are from preliminary studies and conclusive reports are yet to come. In 1983, Pushparajah has reported that at Cox's Bazaar in Bangladesh (23° N) with a monthly mean temperature of about 18°C in December, January and February, it might take 7 years or more to bring up a young plantation compared to about 6 years in Malaysia. Results from a marginal area in Ivory Coast indicated that the growth of GT 1 was reduced when compared to the growth in a wetter area (Watson, 1989). Omont (1982) has noted that the difference in growth between wet and dry areas decreased with increasing age of the trees. In India, Chandrashekar (1983) has reported that the growth of plants with a life-saving irrigation of 15 l/plant/week under North Konkan conditions was almost comparable to that of traditional regions.

Information available on yield performance of Hevea under marginal rainfall conditions is also scanty. In 1983, Pushparajah has reported that a stand of RRIM 600 in the first 18 months of tapping gave a yield of 980 kg $ha^{-1}$, which is comparable to that obtained nearer humid tropics. In trials conducted at Tombokro, a marginal rainfall area in Ivory Coast, irrigated trees gave an yield of 1641 kg $ha^{-1}$ per annum, and unirrigated trees gave an yield of 1614 kg $ha^{-1}$ per annum, by the fifth year of tapping. In the wet areas the expected yield is about 2000 kg $ha^{-1}$ per annum. Watson (1989) while discussing the prospects of rubber cultivation in marginal rainfall conditions concludes:... "It seems probable, however, that use of drought resistant root-stocks and clones, combined with good husbandry, which involves timely establishment of polybagged plants, mulching and protection against wind and sun, could ensure the establishment of productive rubber in all but the very worst circumstances. Once into maturity, any significant area of rubber will exert a beneficial effect on the local microclimate, the trees providing mutual protection against wind damage and sun scorch".

From the Indian sub-continent there are no reports so far on the performance of Hevea under marginal rainfall conditions.

## 2.10. Yield and water relations under marginal conditions

The water cycle is universal in higher plants. About 98 per cent of the water taken up by the plants escapes by transpiration mainly through the leaves. The remaining water is utilised for metabolic purposes including photosynthesis, as a reactant or as a medium and also forms a constituent of the various plant parts including the sap of the xylem and phloem. Thus it plays a vital role in transport of nutrients from the roots, and sugars to the sink organs. In Hevea, the laticiferous tissues in phloem form an additional sink where the sugars are converted to secondary metabolites viz., rubber particles, inositols etc.

As far as annual crops are concerned, there is a plethora of data on water relations. But experiments on tree crops, particularly in *Hevea*, is limited in this regard. In *Hevea*, in addition to the transpirational water loss, there is a secondary and artificial pathway of water loss by way of tapping. Assuming water content in latex to be 65 per cent and that annual production at best can vary from 10 to 15 kg per tree, it can be estimated that around 10-20 litres of water per tree is removed through latex. When compared to the estimated loss of water through transpiration, the water removed through latex by tapping appears to be very much negligible. Neverthless, the more marked the seasonal variations and the dry season, the more distinct are the variations in latex production. The reasons for this astonishing paradox are probably to be found in the colloidal nature of latex and in its flow mechanism.

It is well known that in India, natural rubber production is considerably reduced during summer months when the rainfall is scanty. During the unusual drought season of 1986-87, the yield drop in different clones was in the range of 36 per cent (GT 1) to 61 per cent (Tjir 1), when compared to the favourable wet season yield of 1987 (Vijayakumar *et al.*, 1988).

One of the factors which could influence latex yields during summer or rainy periods is the osmotic potential of C-serum in the latex (Satheesan *et al.*, 1984; Gururaja Rao *et al.*, 1988). It has been reported that in drought tolerant clones osmotic concentrations in C-serum will always be higher compared to drought sensitive clones. This might be due to osmotic adjustment in drought tolerant clones. The ability for osmotic adjustment in these clones can be detected in afternoon leaf water potentials relative to predawn values (Sethuraj, 1985; Gururaja Rao et al., 1986a). The high osmotic concentration of C-serum could sustain the flow of water into the latex so as to allow the flow.

The possible importance of osmotic gradient between B and C-serum was brought out by the experiments conducted at RRII (Satheesan et al., 1982). Clones RRII 102 and RRII 105 kept the fluctuation in the difference in osmotic concentration of B and C-sera at a lower level than that of the clone HP 14 throughout the year. It is suggested that the capacity of the trees to adjust to the osmotic environment in latex may influence their responce to water stress during summer periods.

Some experiments on water relations at the whole plant level have been carried out (Gururaja Rao et al., 1988a; 1988b; Devakumar et al., 1988). The studies indicated the changes in components of water relations like $\Psi$ leaf, latex vessel turgor, latex solute potential, stomatal resistance, transpiration and xylem sap speed in a few clones. The components were studied in association with variations in yield and yield components. The studies indicated higher yields under sufficient soil moisture availability and was associated with decrease in plugging index and enhanced flow rates.

In dry periods a reverse trend was noticed in these two parameters. Gururaja Rao et al. (1988b) have reported that high rates of water loss in susceptible clones was found to be associated with low cuticle thickness and thus more heat absorption.

Based on the components studied several parameters were suggested to be used as screening tools for studying drought tolerance in rubber: estimations of afternoon $\psi$ leaf (Gururaja Rao et al., 1986a), leaf epicuticular waxes and reflectance (Gururaja Rao et al., 1988a), osmotic adjustment and osmotic components (Sethuraj, 1985) and electrolyte leakage from the membranes of the tissues (Rajagopal et al., 1988).

Most of these studies were however, carried out in the traditional rubber growing region. But information relating to these aspects and plant responses to the adverse environmental conditions in non-traditional zones is lacking.

The North Konkan region of Maharashtra is characterised by very high summer temperatures and prolonged drought. Earlier reports (Chandrashekar, 1983; Sethuraj, 1985) indicated that the growth of plants is almost comparable to those of the conventional tract. Rubber cultivation has also been undertaken in other non-traditional areas like Orissa, Madhya Pradesh which experience high summer temperatures and soil drought, North Eastern part of India which experience low temperatures in winter and drought in summer and high elevations (up to 3000 feet above sea level) in Karnataka, Kerala and Meghalaya (Sethuraj et al., 1989). A common feature noticed in all these locations is a prolonged immaturity period (up to 9 years). This can be brought down to normal immaturity period (of about 7 years) by planting stress tolerant clones suitable to these agroclimatic zones. Efforts are also underway to identify clones suitable to these stress prone areas. Clone RRIM 600 was found to grow well in all the above situations (Anonymous, 1987; 1988) but its production capabilities are yet to be ascertained.

# CHAPTER 3

# MATERIALS AND METHODS

# 3 MATERIALS AND METHODS

## 3.1. The study location

The studies were carried out in a plantation located at Parali (Plate 1) under Raigad district of Maharashtra State. The location is about 100 km towards south-east of Bombay. Geographic, weather and soil characteristics of the location are presented in Table 3. Weather details for the study period was collected from the meteorological observatory of the Rubber Research Institute of India's Regional Research Station, located at Dapchari, in the adjacent district, Thane, towards north.

## 3.2. Plant material

The observations were made on two popular clones namely GT 1 (Gondang Tapen 1), a primary clone of Indonesian origin and RRIM 600 (Rubber Research Institute of Malaysia 600), a secondary clone of Malaysian origin. Both are high yielding, category 1 clones and are widely recommended for large scale cultivation. Ten uniform trees of each clone with comparable girth and due for opening were selected to study the behaviour of plants in the first year

Table 3. Geographic, weather and soil characteristics of the study location.

| Particulars | Remarks |
|---|---|
| Geographic characteristics | |
| (i) Longitude | 73.13° E |
| (ii) Latitude | 18.32° N |
| (iii) Altitude | 41.3 m MSL |
| Weather characteristics | |
| (i) Type of climate | Humid with seasonal dry period. |
| (ii) Average annual rainfall | > 2500 mm |
| (iii) Wet period | June - October |
| (iv) Dry period | October - May |
| Soil characteristics | |
| (i) Type of soil | Lateritic clay loam |
| (ii) Terrain | Medium slope |
| (iii) pH | 5.2 - 5.5* |
| (iv) Bulk density | 1.12* |
| (v) Permanent wiling point (-15 bar) | 22 cm* |
| (vi) Field capacity | 35 cm* |

* Average values of three depths viz., 0-30, 30-60, and 60-90.

PLATE 1

GENERAL VIEW OF THE PLANTATION

of opening. The trees were opened for tapping from March, 1989 when they were nine years old. All trees were subjected to ½S, d/2 (half spiral, alternate daily) system of tapping on BO-1 (basal, original 1) panel (Plate 2). During the rainy season, the trees were rainguarded.

### 3.3. Parameters studied

Monthly recordings of soil moisture status, tree girth, bark thickness, length of tapping cut, latex yield, dry rubber yield, rubber content (Cr), initial flow rate (F), plugging index (p), latex vessel pressure potential (Plv), latex solute potential ( $\psi_\pi$ ), leaf water potential ( $\psi$ leaf), transpiration (E) and stomatal conductance ($g_s$) were made from March, 1989 to February, 1990 except for November, 1989 and January, 1990. Apart from these, wintering and reformation period and foliar health during the dry months of March-May was also recorded.

### 3.4. Soil moisture status

The soil moisture content in three depths (0-30, 30-60 and 60-90 cm) in the plantation was determined by gravimetric method. The sampling was done at random in the field irrespective of clones and three replications were taken for each depth. Field capacity (FC) and permanent wilting point (PWP) were found out using pressure

PLATE 2

TAPPING PANEL WITH HALF SPIRAL CUT

plate apparatus (Soil Moisture Equipment Corporation, USA). Bulk density of the soil was determined by the method described by Chopra and Kanwar (1976).

### 3.5 Tree girth, bark thickness and length of tapping cut

Girth of the trees at a height of 150 cm from the bud union, and length of tapping cut were recorded to the nearest mm. Bark thickness was measured using bark gauge at the same height where girth measurements were taken. All the trees were sampled for the above measurements.

### 3.6 Rubber yield and its attributes

Latex yield (ml $tree^{-1}$ $tap^{-1}$) of individual trees for each clone was measured with measuring cylinders.

**Rubber content**: It was measured for each clone separately. Three random latex samples of 10 ml each was drawn separately for each clone after pooling and thoroughly mixing the latex yield from the replicate trees. The samples were taken in aluminium cups for coagulation. After diluting with equal quantity of water, the samples were coagulated using 1 per cent acetic acid. Rubber obtained after coagulation was thoroughly washed and dried in an oven at 60°C to a constant weight and per cent rubber content was estimated.

**Dry rubber yield** was determined as follows:

$$\text{Dry rubber yield per tree} = \frac{\text{Latex yield per tree}}{\text{Per cent rubber content}} \times 100$$

**Initial flow rate and plugging index**: Initial flow rate in ml $min^{-1}$ $cm^{-1}$ of tapping cut during the first five minutes of flow after tapping, was estimated using a stop watch. The stop watch was started when the first drop fell into the measuring cylinder. Four trees were sampled for each clone.

Plugging index was worked out according to Milford et al. (1969) using the equation:

$$p = \frac{\text{Mean flow rate per minute in the first five minutes}}{\text{Total latex volume (ml)}} \times 100$$

Initial flow rate and hence plugging index could not be determined during the extremely dry period due to negligible initial flow of latex.

## 3.7 Latex vessel pressure potential

Latex vessel pressure potential was estimated using disposable manometers comprising No. 49 polythene surgical tubing sealed at one end and fitted with 21 gauge hypodermic syringe needle at the other. The total length of the manometer was 20 cm.

When the manometer is inserted into the latex tissue, the latex forces into the manometer and thus the air present in the manometer gets trapped at the sealed end (Plate 3). The turgor pressure was determined by measuring the length of air column trapped in the manometer inserted into the phloem tissue. The turgor pressure was estimated following the method described by Raghavendra et al. (1984), using the calibration curve of the length of air column in the manometer versus known pressure, prepared by the same authors.

Latex vessel pressure potential was estimated 5 cm below the tapping cut (Plate 3) just before tapping, five minutes after tapping, during initiation of plugging and at dusk. Four trees were sampled for each clone.

### 3.8 Latex solute and leaf water potential

The parameters were recorded using C-52 sample chamber psychrometer (Wescor Inc., Logan, USA) connected to HR 33 T dew point microvoltmeter.

Latex solute potentials were estimated by loading the sample chamber well with the filter paper discs dipped in the latex. Leaf water potentials were determined by placing the circular leaf discs cut using single hole perforator. The loaded and hermetically sealed sample chambers were kept undisturbed for at least 75 minutes

PLATE 3

MEASUREMENT OF LATEX VESSEL TURGOR WITH MANOMETER for leaf samples and 45 minutes for latex samples for vapour and thermal equilibrium before measuring the solute/water potential. The time necessary for equilibriation was found by experience. Water potentials were estimated in dew point depression mode. The microvolt output obtained was converted to water potential values using the conversion factor 0.75 Volts = 1 bar = 0.1 MPa.

Mature healthy sun leaves from the periphery of the canopy were sampled for leaf water potential measurements. Water potentials were measured at pre-dawn and afternoon on each date of observation. The diurnal changes in leaf water potentials was also monitored on three typical days representing wet, moderate stress and severe stress seasons. For the diurnal measurements, the observations were recorded from 6.00 hours at two hourly intervals and ended at 18.00 hours. Three random plants were sampled for measurements.

### 3.9 Transpiration and stomatal conductance

The parameters were recorded using the steady state porometer (Li 1600, Li-Cor instruments, Lincoln, Nebraska, USA). Mature, healthy sun leaves from the periphery of the canopy were sampled for the measurements. The measurements were recorded two times on all the days of observation between 9.30 and 10.30 hours and 12.30 and 13.30 hours, which represent peak conductance periods. Diurnal changes were also monitored on two typical days representing moderate and peak stress periods. The observation timings for diurnal changes were same as that of leaf water potential diurnals. Four trees of each clone were sampled at random for the measurements.

### 3.10 Statistical Analyses

Dry (February-May) and wet (June-December) season data were analysed separately for clonal comparison. Variability of each parameter was worked out and seasonal differences in a parameter within a clone was also tested for significance.

Interrelationships among the various parameters were studied by calculating simple correlation coefficients using the monthly mean values.

# CHAPTER 4

# RESULTS

# 4 RESULTS

## 4.1 Weather characteristics

The climate of North Konkan is dry subhumid with acute summer water deficits (Table 4-5; Fig. 1). The rainfall is almost exclusively confined to the months of June-September and it is of the monomodal and monsoonal type. The rainless period extends from October to the middle of June. Mild winter is experienced from December to February. High summer temperatures (> 37°C) are experienced during April-June period. For most part of the rainless period, the vapour pressure deficits are also high (Table 4).

## 4.2 Soil moisture availability

During rainy months of June-September, the soil moisture was above field capacity in all depths. The soil moisture started declining from October (Table 5) and from February until the onset of monsoon, the soil moisture deficits were experienced. The soil moisture content upto 90 cm depth was at/below wilting point during March-May period. Mean permanent wilting point and field capacity values were 22 cm and 35 cm respectively.

## 4.3 Tree girth, bark thickness, wintering and foliar health

Average girth of the trees and bark thickness of the clones GT 1 and RRIM 600, at opening, are presented in Table 6. The

Table 4. Monthly rainfall, mean minimum and maximum air temperatures and vapour pressure deficients (VPD) recorded at Dapchari during the study period.

| Month | Rainfall (mm) | $T_{Min}$ (°C) | $T_{Max}$ (°C) | VPD (KPa) |
|---|---|---|---|---|
| MAR 1989 | 0.0 | 17.4 | 34.6 | 1.61 |
| APR 1989 | 0.0 | 21.0 | 37.6 | 1.97 |
| MAY 1989 | 0.0 | 23.8 | 37.9 | 1.43 |
| JUN 1989 | 287.8 | 23.4 | 38.5 | 0.61 |
| JUL 1989 | 821.2 | 24.0 | 30.7 | 0.37 |
| AUG 1989 | 604.0 | 23.5 | 28.4 | 0.25 |
| SEP 1989 | 228.8 | 23.0 | 30.7 | 0.41 |
| OCT 1989 | 79.4 | 20.2 | 34.0 | 1.17 |
| NOV 1989 | 0.0 | 18.4 | 34.4 | 1.53 |
| DEC 1989 | 0.0 | 14.2 | 30.9 | 1.17 |
| JAN 1990 | 0.0 | 14.5 | 34.0 | 1.52 |
| FEB 1990 | 0.0 | 14.2 | 32.8 | 1.46 |

Table 5. Volumetric soil moisture content (cm) in the plantation in different months at different depths during the study period.

| Months | Soil depths (cm) | | | |
|---|---|---|---|---|
| | 0-30 | 30-60 | 60-90 | 0-90 |
| MAR 1989 | 6.98 | 7.85 | 8.17 | 22.99 |
| APR 1989 | 6.62 | 6.22 | 7.05 | 19.89 |
| MAY 1989 | 6.63 | 6.20 | 7.16 | 19.99 |
| JUN 1989 | 10.74 | 10.09 | 9.54 | 30.37 |
| JUL 1989 | S | S | S | S |
| AUG 1989 | S | S | S | S |
| SEP 1989 | S | S | S | S |
| OCT 1989 | 10.97 | 13.03 | 13.51 | 37.51 |
| NOV 1989 | +++ | +++ | +++ | +++ |
| DEC 1989 | 8.44 | 9.23 | 9.43 | 27.10 |
| JAN 1990 | +++ | +++ | +++ | +++ |
| FEB 1990 | 7.62 | 8.22 | 9.37 | 25.22 |
| PWP | 7.73 | 7.17 | 6.99 | 21.90 |
| FC | 12.19 | 11.23 | 11.23 | 34.64 |

S: Saturated; +++: not detdermined; PWP: Permanent wilting point;

FC: Field capacity.

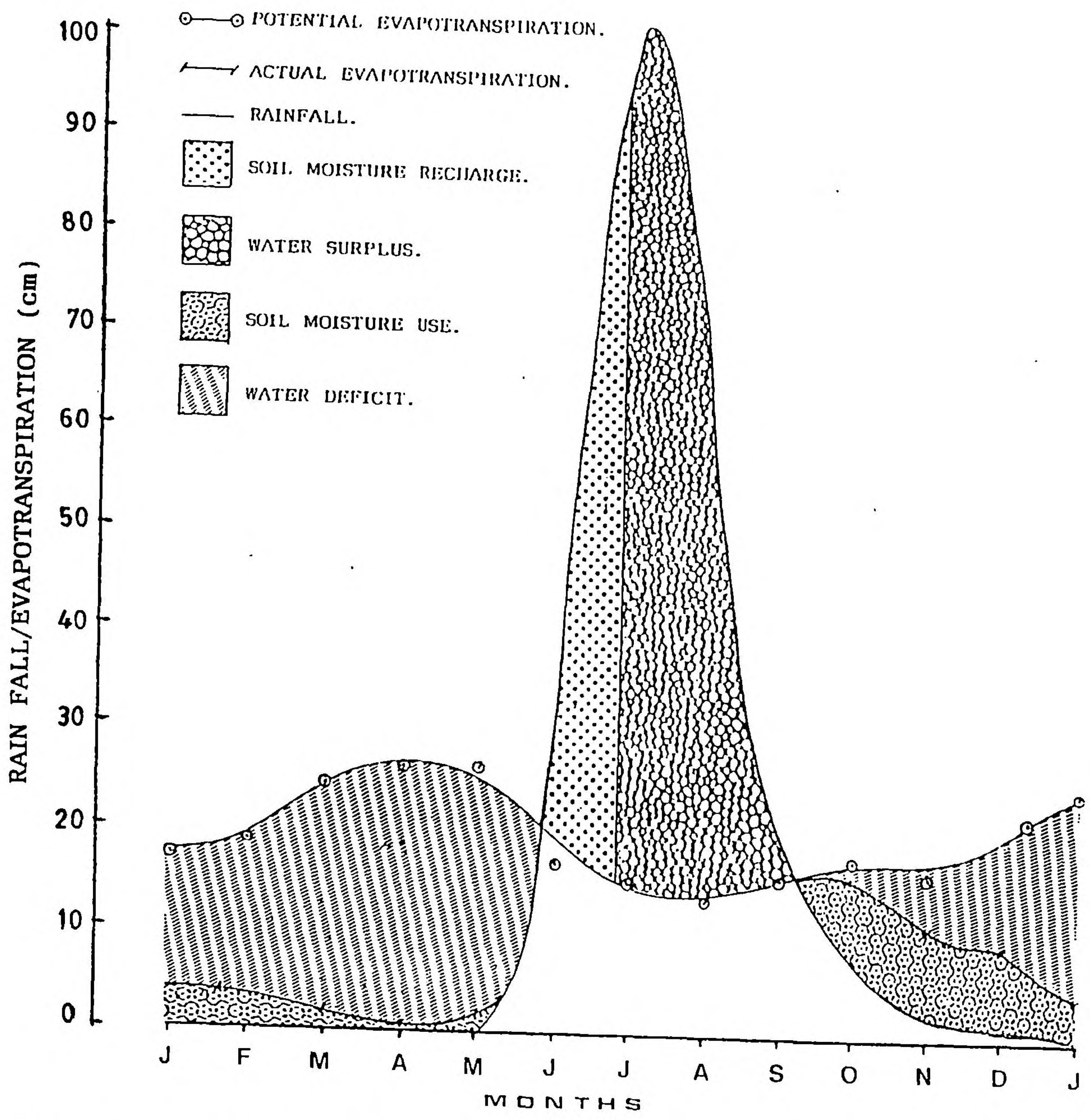


Fig. 1. Generalised climatic water balance of North Konkan region (After Mohankrishna *et al.*, 1991).

Table 6. Girth and bark thickness of experimental trees at opening (March, 1989)

| Clone | Girth (cm) | Bark thickness (mm) |
|---|---|---|
| GT 1 | 49.7<br>(± 1.39) | 7.1<br>(± 0.27) |
| RRIM 600 | 50.1<br>(± 1.19) | 7.3<br>(± 0.26) |
| Significance | ns | ns |

ns: Not significant.

Figures in brackets are standard errors.

differences in girth and bark thickness between the clones were not significant.

Girthing at the end of the study period was slightly better in RRIM 600 (Table 7). Additional girth put up by clones from March 1989 to February 1990 was 3.1 cm in GT 1 and 3.4 cm in RRIM 600. There was a slight decrease in the girth of the trees in May.

It was observed visually that the plants started wintering by the end of December and by the end of January, refoliation was complete. From April onwards severe leaf injury was visible as chlorosis and leaf margin drying. Considerable defoliation was also noticed during this dry period.

Girth was significantly and positively correlated with dry rubber yield, latex yield and PD$\psi_l$ and was negatively correlated with Cr and p in both the clones (Table 11 ). It did not show significant correlation with other parameters.

**4.4 Latex yield**

Latex yield was very low in both the clones in the dry months of February-May (Table 8; Fig. 2). It started increasing with the onset of monsoon and the highest yield was recorded in December. Highest yields were 73.6 and 90.5 ml respectively

Table 7. Girth and bark thickness of trees of clones GT 1 and RRIM 600 at different months during the study period.

| Months | GT 1 | | RRIM 600 | |
|---|---|---|---|---|
| | Girth (cm) | Bark thickness (mm) | Girth (cm) | Bark thickness (mm) |
| MAR 1989 | 49.7 | 7.1 | 50.1 | 7.3 |
| APR 1989 | 49.7 | 7.1 | 50.1 | 7.3 |
| MAY 1989 | 49.6 | - | 49.9 | - |
| JUN 1989 | 50.2 | 7.3 | 50.4 | 7.5 |
| JUL 1989 | 50.8 | - | 51.2 | - |
| AUG 1989 | 51.1 | - | 51.6 | - |
| SEP 1989 | 51.6 | 7.5 | 52.1 | 7.8 |
| OCT 1989 | 52.4 | 7.5 | 52.8 | 7.8 |
| NOV 1989 | - | - | - | - |
| DEC 1989 | 52.8 | - | 53.5 | - |
| JAN 1990 | - | - | - | - |
| FEB 1990 | 52.8 | 7.8 | 53.5 | 8.0 |

Table 8. Yield, yield components and components of water relations in GT 1 and RRIM 600 under North Konkan conditions.

| Parameter | Clone | MAR 1989 | APR 1989 | MAY 1989 | JUN 1989 | JUL 1989 | AUG 1989 | SEP 1989 | OCT 1989 | DEC 1989 | FEB 1990 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Latex yield | GT 1 | 7.2 | 12.5 | 11.3 | 19.2 | 24.9 | 59.5 | 66.4 | 70.8 | 80.7 | 42.7 |
| (ml $tree^{-1}$ $tap^{-1}$) | RRIM 600 | 7.7 | 14.9 | 15.0 | 21.7 | 38.3 | 95.5 | 62.0 | 65.8 | 89.0 | 53.8 |
| Dry rubber yield | GT 1 | 2.79 | 4.58 | 4.0 | 6.66 | 8.68 | 13.33 | 16.67 | 17.57 | 24.53 | 10.03 |
| (g $tree^{-1}$ $tap^{-1}$ | RRIM 600 | 3.28 | 5.54 | 6.10 | 7.45 | 12.46 | 20.44 | 11.72 | 17.51 | 24.03 | 12.91 |
| Rubber content | GT 1 | 38.9 | 36.7 | 35.7 | 34.7 | 34.8 | 22.4 | 20.6 | 24.8 | 30.4 | 23.5 |
| (%, w/v) | RRIM 600 | 42.7 | 37.3 | 40.7 | 34.4 | 32.5 | 21.4 | 18.9 | 26.6 | 27.0 | 24.0 |
| Initial flow rate | GT 1 | --- | --- | 0.020 | 0.056 | 0.054 | 0.047 | 0.056 | 0.057 | 0.043 | 0.045 |
| (ml $cm^{-1}$ $min^{-1}$) | RRIM 600 | --- | --- | 0.038 | 0.078 | 0.088 | 0.059 | 0.061 | 0.049 | 0.061 | 0.073 |
| Plugging index | GT 1 | --- | --- | 9.2 | 6.2 | 4.7 | 2.4 | 2.3 | 1.5 | 1.5 | 2.5 |
| (p) | RRIM 600 | --- | --- | 6.7 | 9.2 | 6.8 | 1.7 | 2.9 | 1.9 | 2.0 | 3.6 |
| Pretapping $P_{lv}$ | GT 1 | 0.73 | 0.62 | 0.46 | 0.92 | 0.84 | 0.82 | 0.83 | 0.83 | 0.70 | 0.64 |
| (MPa) | RRIM 600 | 0.74 | 0.90 | 0.58 | 0.99 | 0.93 | 0.81 | 0.83 | 0.89 | 0.71 | 0.68 |
| Post-tapping $P_{lv}$ | GT 1 | 0.15 | +++ | +++ | 0.40 | 0.15 | 0.11 | 0.10 | 0.08 | 0.08 | +++ |
| (MPa) | RRIM 600 | 0.19 | 0.18 | 0.17 | 0.29 | 0.18 | 0.16 | 0.13 | 0.15 | 0.11 | 0.11 |
| Latex solute potential | GT 1 | 1.18 | 1.20 | 1.20 | 0.58 | 0.55 | 0.41 | 0.39 | 0.51 | 0.73 | 0.73 |
| ( $\psi_{\pi}$, -MPa) | RRIM 600 | 1.02 | 1.00 | 1.02 | 0.55 | 0.57 | 0.41 | 0.46 | 0.48 | 0.73 | 0.78 |
| Predawn $\psi_l$ | GT 1 | 1.75 | 1.86 | 1.70 | 0.90 | 0.63 | 0.70 | 0.67 | 0.87 | 0.88 | 0.88 |
| (-MPa) | RRIM 600 | 1.61 | 1.64 | 1.59 | 0.71 | 0.41 | 0.48 | 0.64 | 0.47 | 0.69 | 0.63 |
| Afternoon $\psi_l$ | GT 1 | 2.15 | 2.15 | 2.06 | 1.15 | 1.28 | 1.39 | 1.33 | 1.62 | 1.82 | 1.82 |
| (-MPa) | RRIM 600 | 1.75 | 1.82 | 1.82 | 0.91 | 0.83 | 1.35 | 1.35 | 1.68 | 1.82 | 1.86 |
| $g_s$: 9.30-10.30 hrs | GT 1 | 61.5 | 36.8 | 16.37 | ** | ** | ** | ** | 169.33 | 96.73 | 45.83 |
| (m moles $m^{-2}$ $s^{-1}$) | RRIM 60 | 139.7 | 86.0 | 70.90 | ** | ** | ** | ** | 209.0 | 39.30 | 46.80 |
| $g_s$: 12.30-13.30 hrs | GT 1 | 23.27 | 18.97 | 13.33 | ** | ** | ** | ** | 142.0 | 29.07 | 11.10 |
| (m moles $m^{-2}$ $s^{-1}$) | RRIM 600 | 77.10 | 73.60 | 43.60 | ** | ** | ** | ** | 292.5 | 73.80 | 34.30 |

--- Not recorded; +++ Trace; ** The values were unrealistically high.

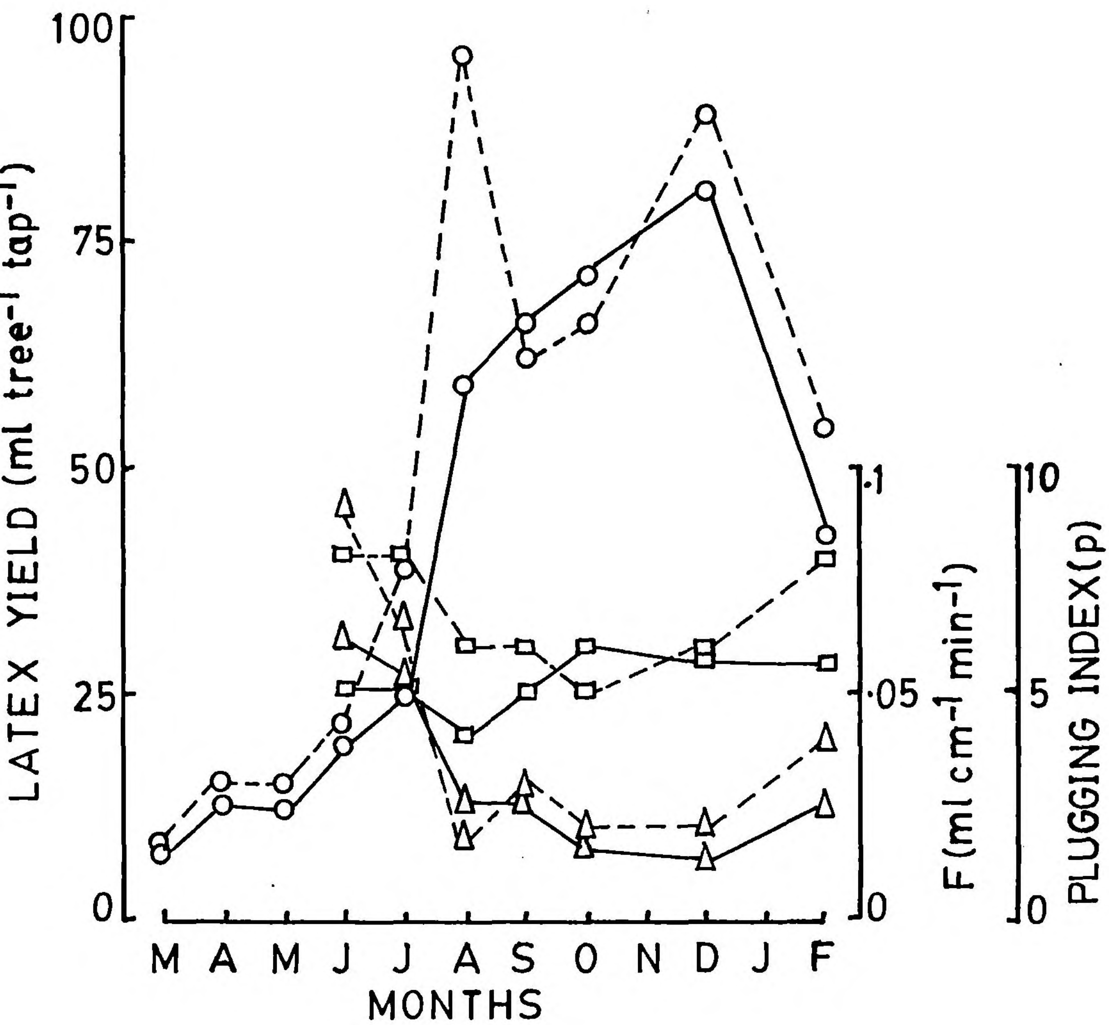


Fig. 2. Seasonal variations in latex yield (o), initial flow rate (□) and plugging index (Δ) in GT 1 (——) and RRIM 600 (---)

in GT 1 and RRIM 600. Lowest yields were recorded in the month of March when the trees were freshly opened for tapping and the yields were 9.1 and 9.7 ml in GT 1 and RRIM 600 respectively.

The latex yield was significantly higher for the clones RRIM 600 both in dry and wet season (Table 10). The differences in latex yield between the seasons within a clone were also significant in both the clones.

Correlation of latex yield with other parameters (Table 11) indicate high and positive correlation with dry rubber yield and high negative correlation with rubber content and p in both the clones. Predawn $\psi_l$ and $\psi_\pi$ were negatively correlated with latex yield and the correlation was significant only in GT 1. It did not correlate significantly with other parameters.

### 4.5 Dry rubber yield

Dry rubber yield obtained in different months are presented in Table 9. The yield trend (Fig. 3) was similar to that of latex yield. Lowest yields were observed in the month of March and the highest in December.

Seasonal differences in the clonal behaviour of the parameter are given in Table 10. Rubber yield was significantly higher for RRIM 600, only in the dry season. Within a clone, the seasonal differences were highly significant in both the clones.

Table 9. Monthly dry rubber yield (g $tree^{-1}$ $tap^{-1}$) from clones GT 1 and RRIM 600 under North Konkan conditions in the first year of tapping.

| Months | Clones | |
|---|---|---|
| | GT 1 | RRIM 600 |
| MAR 1989 | 2.79 | 3.28 |
| APR 1989 | 4.58 | 5.54 |
| MAY 1989 | 4.05 | 6.10 |
| JUN 1989 | 6.65 | 7.45 |
| JUL 1989 | 8.68 | 12.46 |
| AUG 1989 | 13.33 | 20.44 |
| SEPT 1989 | 13.67 | 11.72 |
| OCT 1989 | 17.57 | 17.51 |
| NOV 1989 | +++ | +++ |
| DEC 1989 | 24.53 | 24.03 |
| JAN 1990 | +++ | +++ |
| FEB 1990 | 10.03 | 12.91 |
| Mean | 10.59 | 12.14 |
| SE | ±2.05 | ±2.05 |

+++: Not determined.

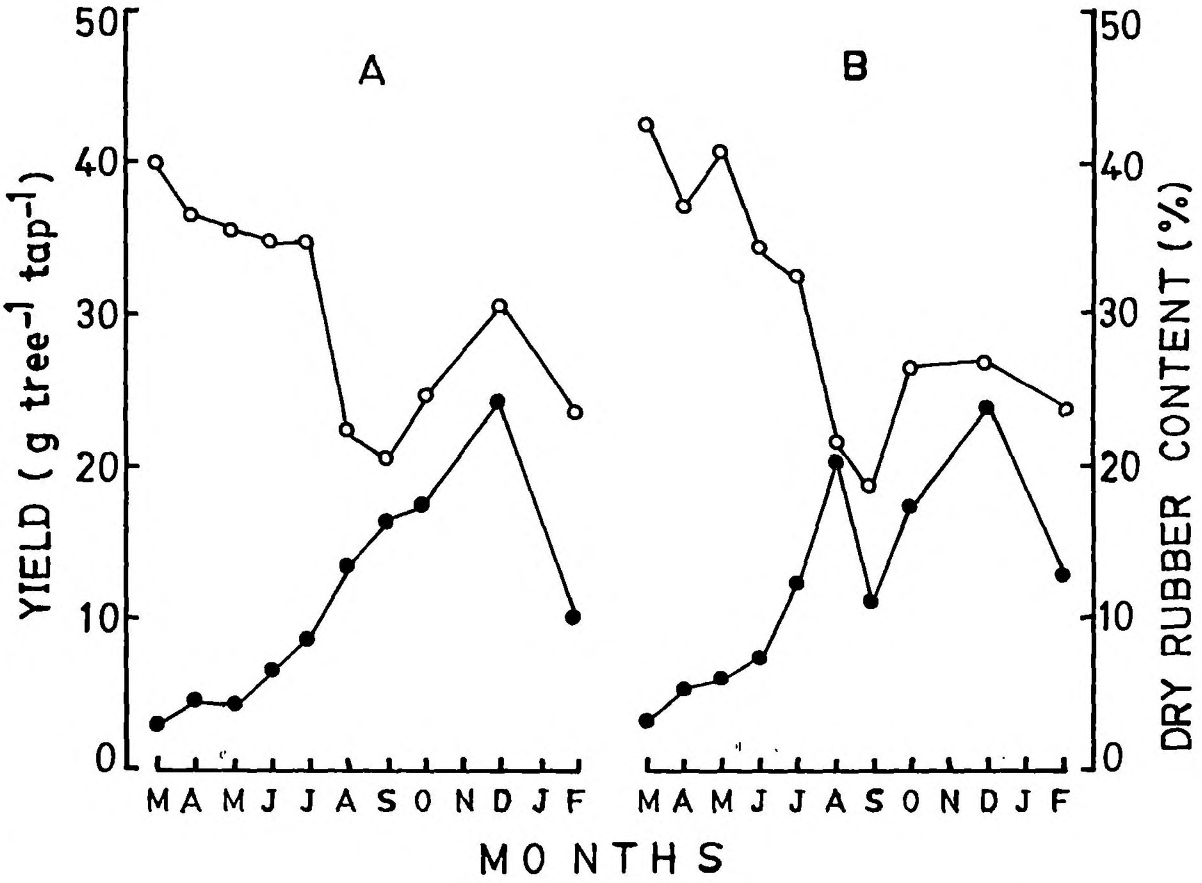


Fig. 3. Seasonal variations in dry rubber yield (●) and dry rubber content (o) in GT 1 (A) and RRIM 600 (B) under North Konkan conditions.

Table 10. Yield, yield components and a few components of plant moisture status in clones GT 1 and RRIM 600 in dry and wet seasons.

| Parameter | Clone | Dry season means | $C.D_{0,05}$ (C.V.,%) | Wet season means | $C.D_{0.05}$ (C.V.,%) |
|---|---|---|---|---|---|
| Latex yield | GT 1 | 18.41 | 3.38* | 53.61 | 7.59* |
| (ml $tree^{-1}$ $tap^{-1}$) | RRIM 600 | 22.87 | (13.7) | 62.04 | (12.6) |
| Dry rubber yield | GT 1 | 5.36 | 0.957** | 14.07 | ns |
| (g $tree^{-1}$ $tap^{-1}$) | RRIM 600 | 6.96 | (26.0) | 15.60 | (24.0) |
| Rubber content | GT 1 | 33.71 | 1.73* | 27.93 | 0.956* |
| ($C_r$, %, w/v) | RRIM 600 | 36.14 | (5.5) | 26.81 | (5.0) |
| Initial flow rate | GT 1 | +++ | --- | 0.049 | 0.0075** |
| (F, ml $cm^{-1}$ $min^{-1}$) | RRIM 600 | +++ | --- | 0.065 | (19.0) |
| Plugging index (p) | GT 1 | +++ | --- | 3.16 | 0.682* |
| | RRIM 600 | +++ | --- | 4.07 | (26.8) |
| Pretapping latex | GT 1 | 0.605 | 0.101* | 0.809 | 0.042* |
| turgor ($P_{lv}$, MPa) | RRIM 600 | 0.715 | (17.0) | 0.863 | (7.2) |
| Post-tapping latex | GT 1 | 0.051 | 0.048** | 0.169 | ns |
| turgor ($P_{lv}$, MPa) | RRIM 600 | 0.183 | (42.6) | 0.169 | (33.7) |
| Latex solute potential | GT 1 | 1.076 | 0.116* | 0.528 | ns |
| ($\psi_\pi$, -MPa) | RRIM 600 | 0.955 | (13.0) | 0.528 | (4.0) |
| Predawn leaf water | GT 1 | 1.55 | 0.084* | 0.77 | 0.063* |
| potential ($\psi_l$, -MPa) | RRIM 600 | 1.37 | (6.4) | 0.57 | (13.5) |
| Afternoon leaf water | GT 1 | 2.045 | 0.173* | 1.43 | ns |
| potential ($\psi_l$, -MPa) | RRIM 600 | 1.814 | (10.0) | 1.32 | (12.2) |
| Stomatal conductance | GT 1 | 38.51 | 9.95** | @ | --- |
| (9.30-10.30) | RRIM 600 | 77.24 | (23.4) | @ | --- |
| Afternoon $g_s$ | GT 1 | 17.96 | 7.13** | @ | --- |
| (12.30-13.30) | RRIM 600 | 56.35 | (26.16) | @ | --- |

+++: Not recorded due to very low latex yield; *$P < 0.05$; **$P < 0.01$;
ns: Not significant; @: The values recorded were unrealistically high due to very high relative humidity.
Note: Differences between seasons within a clone for all the parameters were highly significant ($P < 0.01$) except for post tapping $p_{lv}$ in clone RRIM 600 which was not significant.

Table 11. Interrelationships among yield, components of yield and plant moisture status and soil moisture in clones GT 1 and RRIM 600.

| Parameter | Clone | LY | $C_r$ | F | Pretap $P_{lv}$ | Post-tap $P_{lv}$ | $\psi_\pi$ | P | PD$\psi_l$ | AN$\psi_l$ | G | SM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dry rubber yield | GT 1 | 0.9710*** | -0.6507* | 0.3961 | 0.3021 | -0.1028 | 0.6279 | -0.8524** | 0.6545* | 0.3179 | 0.8403** | 0.5364 |
| (DRY) | RRIM 600 | 0.9590*** | -0.7342* | 0.1130 | -0.0329 | -0.5440 | 0.6124 | -0.8166* | 0.7319* | -0.0066 | 0.7996** | 0.5734 |
| Latex yield | GT 1 | | -0.8000** | 0.4321 | 0.3255 | -0.1514 | 0.6972* | -0.9192** | 0.6909* | 0.3476 | 0.8628** | 0.6297* |
| (LY) | RRIM 600 | | -0.8628** | 0.0778 | -0.0462 | -0.5835 | 0.6848* | -0.9073** | 0.7391* | -0.0026 | 0.7905** | 0.6675* |
| Rubber content | GT 1 | | | -0.4231 | -0.2914 | 0.2085 | -0.7486* | 0.7446* | -0.6997* | -0.4356 | -0.7367* | -0.6828* |
| ($C_r$) | RRIM 600 | | | -0.2357 | -0.1055 | 0.5314 | -0.7814** | 0.7846* | -0.7963** | -0.1313 | -0.7772** | -0.7376* |
| Initial flow rate | GT 1 | | | | 0.9420*** | 0.5733 | 0.7932** | -0.5939 | 0.7318* | 0.7439* | 0.4279 | 0.7589* |
| (F) | RRIM 600 | | | | 0.5223 | 0.2432 | 0.4230 | 0.3601 | 0.5885 | 0.7217* | 0.2029 | 0.3248 |
| Pretapping $P_{lv}$ | GT 1 | | | | | 0.7433* | 0.7758** | -0.4275 | 0.6842* | 0.8226** | 0.2108 | 0.7824** |
| Pretap $P_{lv}$) | RRIM 600 | | | | | 0.5644 | 0.5284 | 0.2292 | 0.3734 | 0.7049* | -0.1469 | 0.4754 |
| Post-tapping $P_{lv}$ | GT 1 | | | | | | 0.3614 | 0.1741 | 0.3086 | 0.6468* | -0.2151 | 0.3044 |
| (post-tap $P_{lv}$) | RRIM 600 | | | | | | -0.0041 | 0.7939* | -0.1909 | 0.5800 | -0.7113* | -0.0804 |
| Latex solute potential | GT 1 | | | | | | | -0.6873 | 0.9635*** | 0.8915*** | 0.5478 | 0.9320*** |
| ($\psi_\pi$) | RRIM 600 | | | | | | | -0.3403 | 0.9070*** | 0.6233 | 0.4597 | 0.9595*** |
| Plugging index | GT 1 | | | | | | | | -0.7320* | -0.1475 | -0.8853** | -0.5677 |
| (p) | RRIM 600 | | | | | | | | -0.3944 | 0.5243 | -0.7518* | -0.4325 |
| Predawn | GT 1 | | | | | | | | | 0.8542** | 0.6835* | 0.8420** |
| (PD $\psi_l$) | RRIM 600 | | | | | | | | | 0.5230 | 0.6942* | 0.8338** |
| Afternoon | GT 1 | | | | | | | | | | 0.2456 | 0.8180** |
| (AN $\psi_l$) | RRIM 600 | | | | | | | | | | -0.2074 | 0.5855 |
| Girth | GT 1 | | | | | | | | | | | 0.4186 |
| (G) | RRIM 600 | | | | | | | | | | | 0.3879 |

N: 10; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

Relationship of rubber yield with other parameters are given in Table 11. It was significantly and negatively correlated with Cr and p and significantly and positively correlated with PD $\psi_l$ and tree girth.

**4.6 Rubber content**

Rubber content was highest in the month of March, when the trees were opened first (Table 8; Fig. 3). The rubber content decreased steadily with tapping progression and the lowest values were observed in the month of September.

As regards seasonal differences, the Cr was significantly higher in RRIM 600 during the dry season, and in GT 1 during the wet season (Table 10). Seasonal differences within a clone were highly significant.

The parameter was significantly and positively correlated to $\psi_\pi$, p, and PD $\psi_l$ and was negatively correlated with latex yield and dry rubber yield in both the clones (Table 11).

**4.7 Initial flow rate**

During the peak of the dry season, F could not be determined due to very low latex yield. The initial flow rate varied from 0.02 ml $min^{-1}$ $cm^{-1}$ in the dry season to 0.08 ml $min^{-1}$ $cm^{-1}$ in the wet season (Table 8; Fig. 2). Clonal differences were significant, being higher in RRIM 600 (Table 10).

In both the clones, correlation of F with pretap $P_{lv}$ was significant and positive (Table 11). With $\psi_{\pi}$ and PD $\psi_{l}$, the correlation was significant only in GT 1. Hwever, a reverse trend was noticed with AN $\psi_{l}$, where F was found to be significantly correlated only in RRIM 600.

**4.8 Plugging index**

In general, the plugging indices were higher in dry months compared to wet months (Table 8; Fig. 2). In most of the months, clone GT 1 had comparatively lower plugging indices.

The plugging index exhibited highly significant and negative correlations with latex yield, rubber yield and significant and positive correlation with Cr in both the clones (Table 11). It was significantly associated with pretap $P_{lv}$ in RRIM 600, but in GT 1 it was not. On the other hand, p was significantly and negatively correlated with PD $\psi_{l}$ in GT 1 but in RRIM 600 it was not.

**4.9 Latex vessel pressure potential**

Of the two clones, GT 1 and RRIM 600, the latter maintained better $P_{lv}$ in all the months (Table 8; Fig. 4). Lowest values were observed in the month of May and highest were noticed with the onset of monsoon; it was high in all the rainy months. Recoupment of $P_{lv}$ in GT 1 by evening was evident only in wet months. In RRIM 600, the recoupment in $P_{lv}$ was better in all the months, eventhough full recovery was not noticed in any month. RRIM 600 had a significantly higher value of $P_{lv}$ as compared to GT 1 (Table 11).

Correlation of the parameter with others (Table 11) indicate significant and positive correlations with $\psi_{\pi}$, Posttap $P_{lv}$, F and PD $\psi_l$ in GT 1 and in RRIM 600, it had significant and positive correlations with F and AN $\psi_l$ only.

**4.10 Latex solute potential**

Monthly variations in $\psi_{\pi}$ are presented in Table 8 and Figure 4. RRIM 600 maintained better $\psi_{\pi}$ in all the months. The differences were significantly higher in RRIM 600 in the dry season only (Table 10).

Latex solute potential had significant correlation with latex yield, Cr, PD $\psi_l$ and soil moisture (Table 11).

**4.11 Leaf water potential**

Monthly variations in predawn and afternoon leaf water

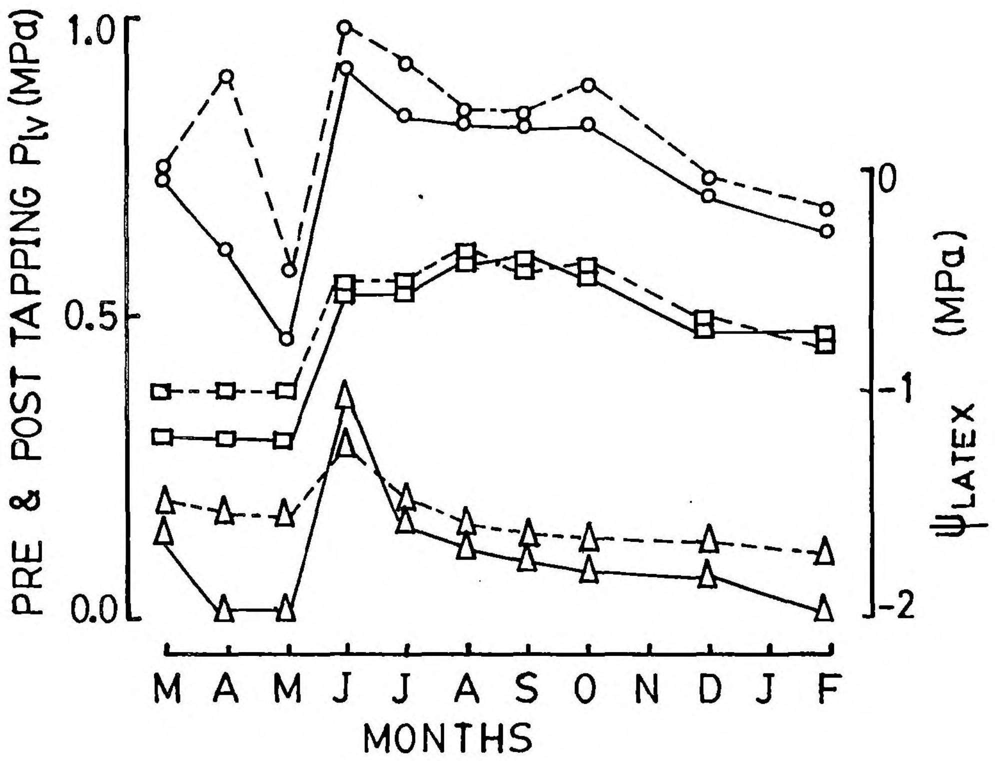


Fig. 4. Seasonal variations in pre-tapping $P_{lv}$ (o), $\psi_{\pi}$ (□) and post-tapping $P_{lv}$ in GT 1 (——) and RRIM 600 (– – –).

potentials are presented in Table 8 and Figure 5. RRIM 600 had a comparatively better $\psi_l$ in the dry months. In the extreme dry period of March-May, the PD $\psi_l$ values declined to -1.5 to -1.8 MPa. An immediate recovery in their values was noticed with the onset of monsoon and the higher values were maintained till September-October. The AN $\psi_l$ was below -2.0 MPa during the peak dry period. With the onset of monsoon it increased to around -1.0 MPa. Afterwards there was a gradual decline upto December. In February, 1990 the AN $\psi_l$ increased to around -1.5 MPa. RRIM 600 had higher AN $\psi_l$ in all the months.

The differences in PD $\psi_l$ due to clones were significant, RRIM 600 having higher values in both the seasons (Table 10). However, AN $\psi_l$ was significantly higher in RRIM 600 in dry season only.

The diurnal changes in $\psi_l$ were similar in the morning hours during wet and moderate stress periods in both the clones (Table 12; Fig. 6). However, under severe stress $\psi_l$ values during the morning hours were significantly lower compared to the values in wet and moderate stress period. Afternoon $\psi_l$ values were also comparatively low during the severe stress period. The drop in mid-day and AN $\psi_l$ during mild stress and severe stress periods were almost similar. The $\psi_l$ values started rising after 14.00 hrs. both during wet and mild stress periods. However, this trend was not noticed

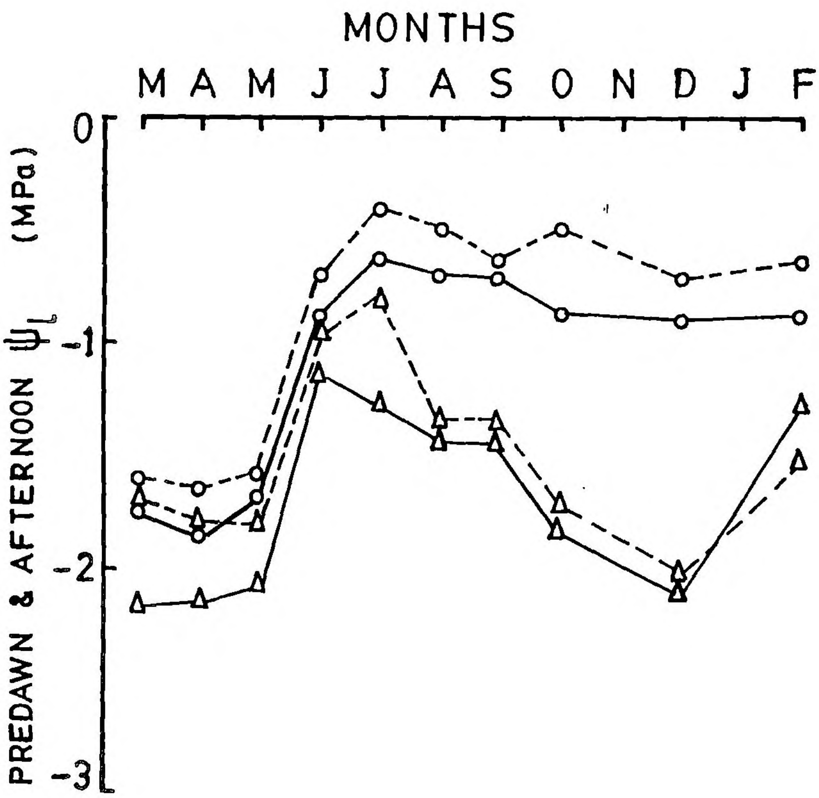


Fig. 5. Seasonal changes IN PREDAWN (o) and afternoon (Δ) leaf water potential ($\psi_l$) in GT 1 (——) and RRIM 600 (– – –).

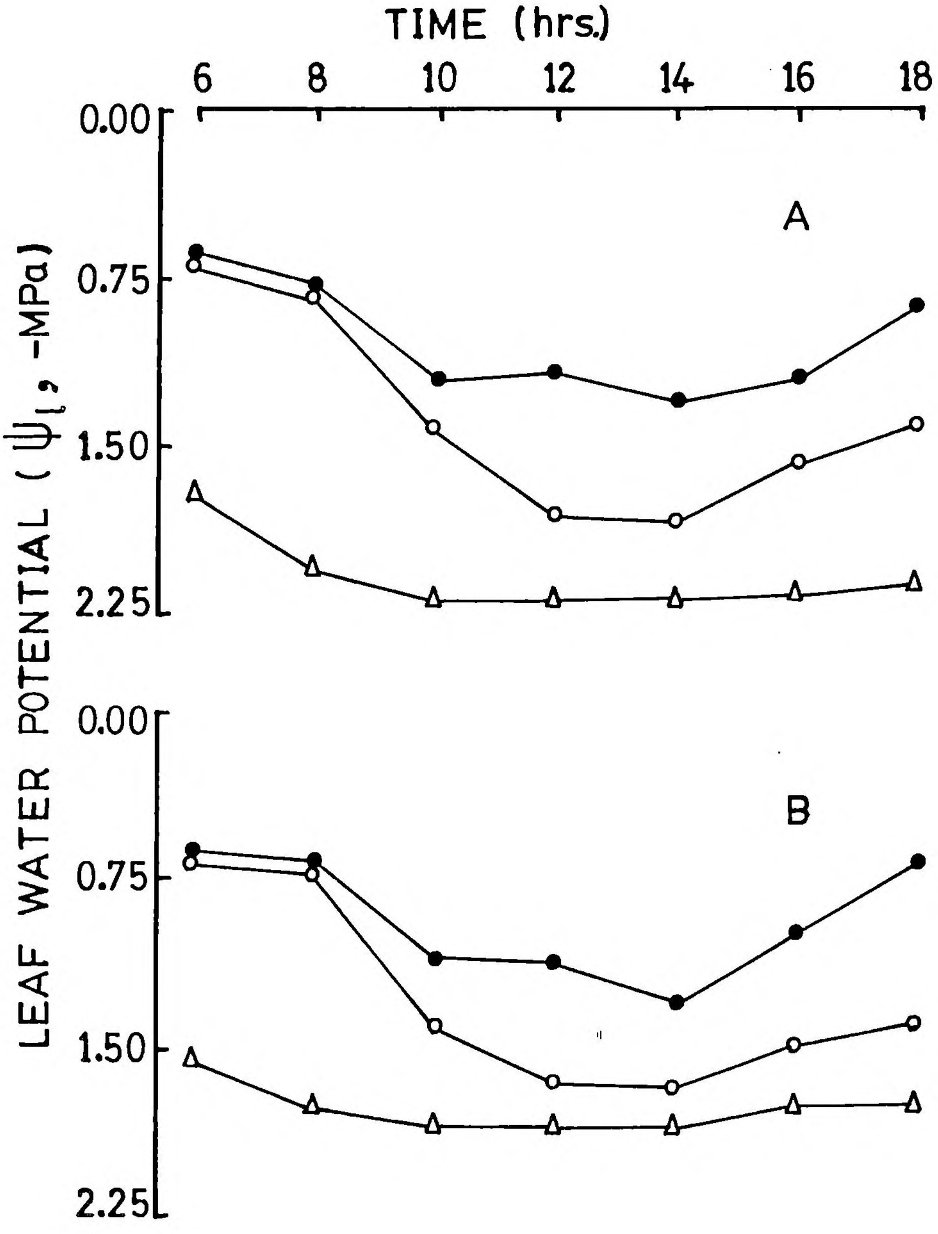


Fig. 6. Diurnal variations in leaf water potential in wet (●, September), moderate dry (o, October) and Extreme dry (Δ, May) months in GT 1 (A) and RRIM 600 (B).

Table 12. Diurnal variation in leaf water potential, transpiration and stomatal conductance during typical days of severe dry (16.05.1989) and moderate dry (28.10.1989) periods.

| Parameter | Date | Clone | Time (hours) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 06.00 | 08.00 | 10.00 | 12.00 | 14.00 | 16.00 | 18.00 |
| Leaf water potential | 16.05.1989 | GT 1 | 1.70 | 2.040 | 2.170 | 2.170 | 2.150 | 2.130 | 2.080 |
| ( $\psi_l$ , - MPa) | | RRIM 600 | 1.59 | 1.730 | 1.840 | 1.820 | 1.820 | 1.730 | 1.750 |
| | 28.10.89 | GT 1 | 0.68 | 0.800 | 1.400 | 1.820 | 1.840 | 1.530 | 1.370 |
| | | RRIM 600 | 0.66 | 0.650 | 1.400 | 1.640 | 1.680 | 1.460 | 1.370 |
| | 16.05.1089 | GT 1 | 0.00 | 0.319 | 0.346 | 0.507 | 0.434 | 0.281 | 0.116 |
| | | RRIM 600 | 0.00 | 0.695 | 1.239 | 1.123 | 0.838 | 0.619 | 0.185 |
| Transpiration | 28.10.1989 | GT 1 | 0.00 | 1.467 | 0.849 | 0.455 | 0.269 | 0.397 | 0.137 |
| (E, m moles $m^{-2}$ $s^{-1}$) | | RRIM 600 | 0.00 | 1.779 | 1.668 | 1.310 | 1.263 | 0.386 | 0.154 |
| | 16.05.1989 | GT I | 0.00 | 26.87 | 13.330 | 11.10 | 6.280 | 9.310 | 4.190 |
| | | RRIM 600 | 0.00 | 27.40 | 40.87 | 28.96 | 21.93 | 9.900 | 5.00 |
| Stomtal conductance | | | | | | | | | |
| ($g_s$, m moles $m^{-2}$ $s^{-1}$) | 28.10.1989 | GT 1 | 0.0 | 231.0 | 358.0 | 14.37 | 11.96 | 9.500 | 8.600 |
| | | RRIM 600 | 0.0 | 266.0 | 43.37 | 36.50 | 30.26 | 19.80 | 11.40 |

during severe stress even upto 18.00 hrs. when the recordings were stopped. The pattern of diurnal changes in $\psi_l$ in all the months were comparable for both the clones.

The parameter was highly and positively correlated with Cr and $\psi_\pi$ in both the clones (Table 11). The correlation with latex yield was significant and negative. In clone GT 1, the correlations were significant with pretap $P_{lv}$, F, p and AN $\psi_l$. In RRIM 600, the AN $\psi_l$ was significantly correlated with pretap $P_{lv}$ and F only.

**4.12 Stomatal conductance and transpiration**

Monthly changes in $g_s$ and E are presented in Table 8 and Figure 7. The diurnal changes in the parameters are given in Table 10 and Figure 8.

Lower $g_s$ and E were observed from March to May and from December to February. During most of the observations, RRIM 600 maintained higher $g_s$ and E when compared to GT 1.

The diurnal pattern of $g_s$ and E indicate maximum stomatal opening at 8.00 hrs. In RRIM 600, the $g_s$ during forenoon hrs was higher than that of GT 1. Severe inhibition of $g_s$ and E were observed throughout the day in May. Clone RRIM 600 had higher $g_s$ and E rates during both days of diurnal observations.

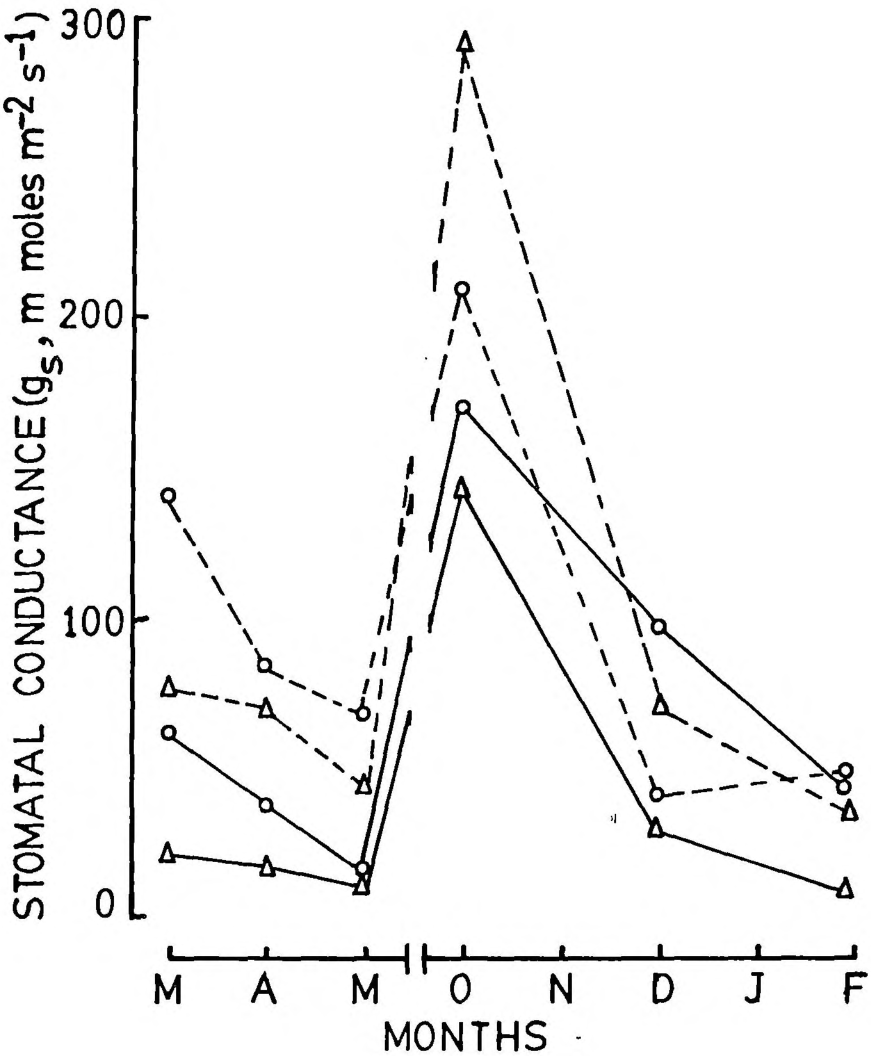


Fig. 7. Seasonal variations in stomatal conductance during 9.30 - 10.30 hrs (o) and 12.30 - 13.30 hrs (Δ) in GT 1 (——) and RRIM 600 (---).

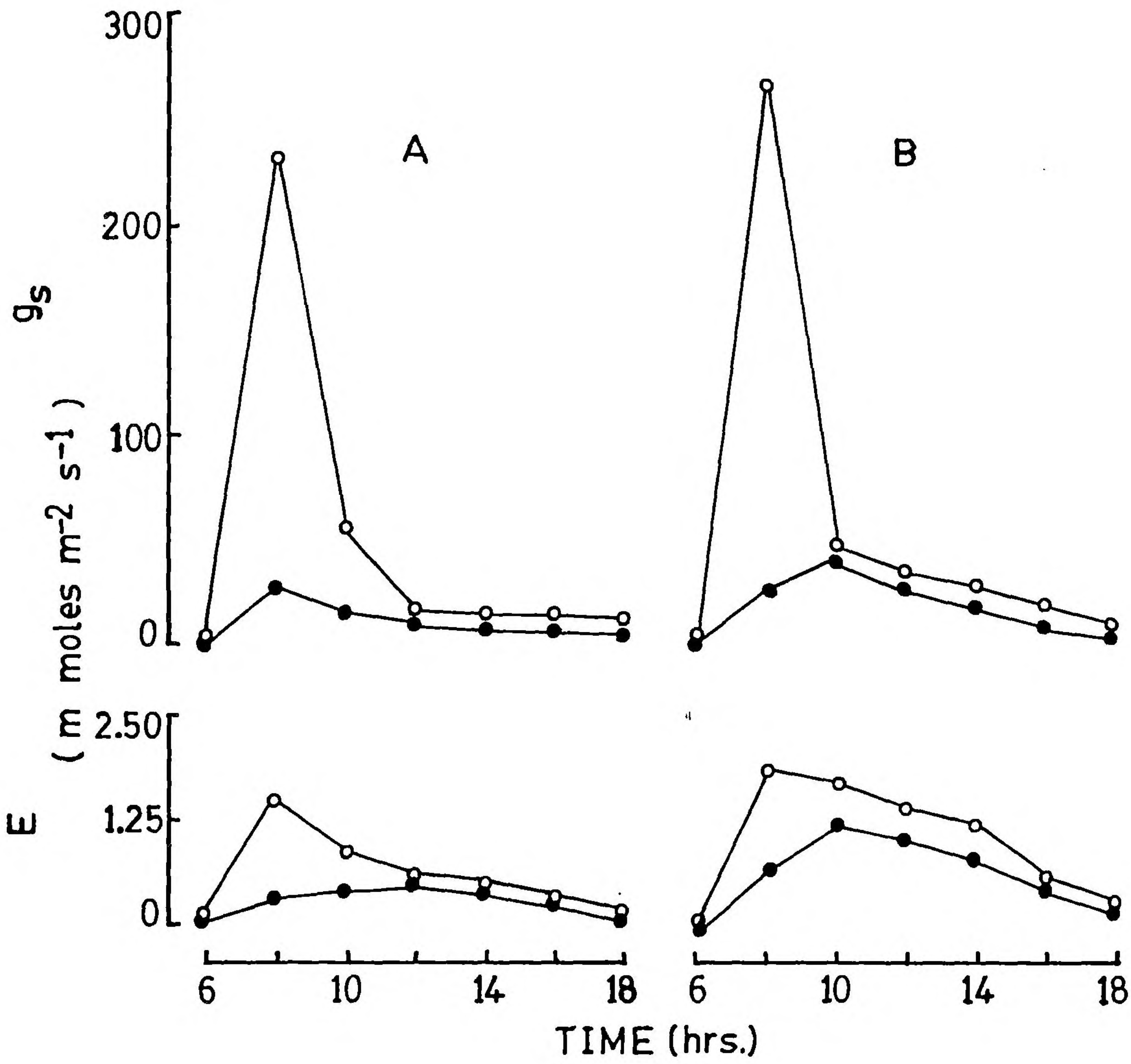


Fig. 8. Diurnal changes in stomatal conductance ($g_s$) and transpiration (E) during moderate dry (o, October) and severe dry (●, May) in GT 1 (A) and RRIM 600 (B).

### 4.13 Variability of the parameters

Variability and other statistical features of the parameters are presented in Table 13 and Figure 9. Among the parameters studied, variability was high in latex yield, DRY, p and PD $\psi_l$ and was low in pretapping $P_{lv}$. In RRIM 600, variability in most of the parameters was comparatively low.

Table 13. Variability and other statistics on yield and yield components and a few components of plant moisture status in clones GT 1 and RRIM 600 under North Konkan conditions.

| Parameter | Clone | Mean | SD | CV (%) | Highest | Lowest | Range |
|---|---|---|---|---|---|---|---|
| Latex yield | GT 1 | 39.52 | ±27.90 | 70.6 | 80.7 | 7.2 | 73.5 |
| | RRIM 600 | 46.37 | ±31.70 | 68.4 | 95.5 | 7.7 | 87.8 |
| Dry rubber yield | GT 1 | 10.59 | ±6.83 | 64.5 | 24.53 | 2.79 | 21.74 |
| | RRIM 600 | 12.14 | ±6.84 | 56.3 | 24.03 | 3.28 | 20.75 |
| Rubber content | GT 1 | 30.25 | ±6.8 | 22.5 | 38.9 | 20.6 | 18.30 |
| | RRIM 600 | 30.55 | ±8.2 | 26.8 | 42.7 | 18.9 | 23.80 |
| Initial flow rate | GT 1 | 0.047 | ±0.012 | 26.2 | 0.057 | 0.02 | 0.037 |
| | RRIM 600 | 0.063 | ±0.016 | 25.4 | 0.088 | 0.04 | 0.048 |
| Plugging index | GT 1 | 3.8 | ±2.7 | 71.7 | 9.2 | 1.5 | 7.7 |
| | RRIM 600 | 4.4 | ±2.8 | 64.4 | 9.2 | 1.7 | 7.5 |
| Pretapping $P_{lv}$ | GT 1 | 0.739 | ±0.137 | 18.6 | 0.92 | 0.46 | 0.46 |
| | RRIM 600 | 0.806 | ±0.127 | 15.8 | 0.99 | 0.58 | 0.41 |
| Post-tapping $P_{lv}$ | GT 1 | 0.107 | ±0.118 | 110.3 | 0.40 | 0.0 | 0.40 |
| | RRIM 600 | 0.167 | ±0.052 | 31.1 | 0.29 | 0.11 | 0.18 |
| Latex solute potential | GT 1 | -0.75 | ±0.330 | 43.6 | -0.39 | -1.18 | -0.79 |
| | RRIM 600 | -0.70 | ±0.243 | 34.7 | -0.41 | -1.00 | -0.59 |
| Predawn $\psi_{leaf}$ | GT 1 | -1.08 | ±0.485 | 44.8 | -0.63 | -1.86 | -1.23 |
| | RRIM 600 | -0.887 | ±0.511 | 57.6 | -0.41 | -1.64 | -1.23 |
| Afternoon $\psi_{leaf}$ | GT 1 | -1.68 | ±0.38 | 22.4 | -1.15 | -2.15 | -1.00 |
| | RRIM 600 | -1.52 | ±0.39 | 25.7 | -0.83 | -1.86 | -1.03 |

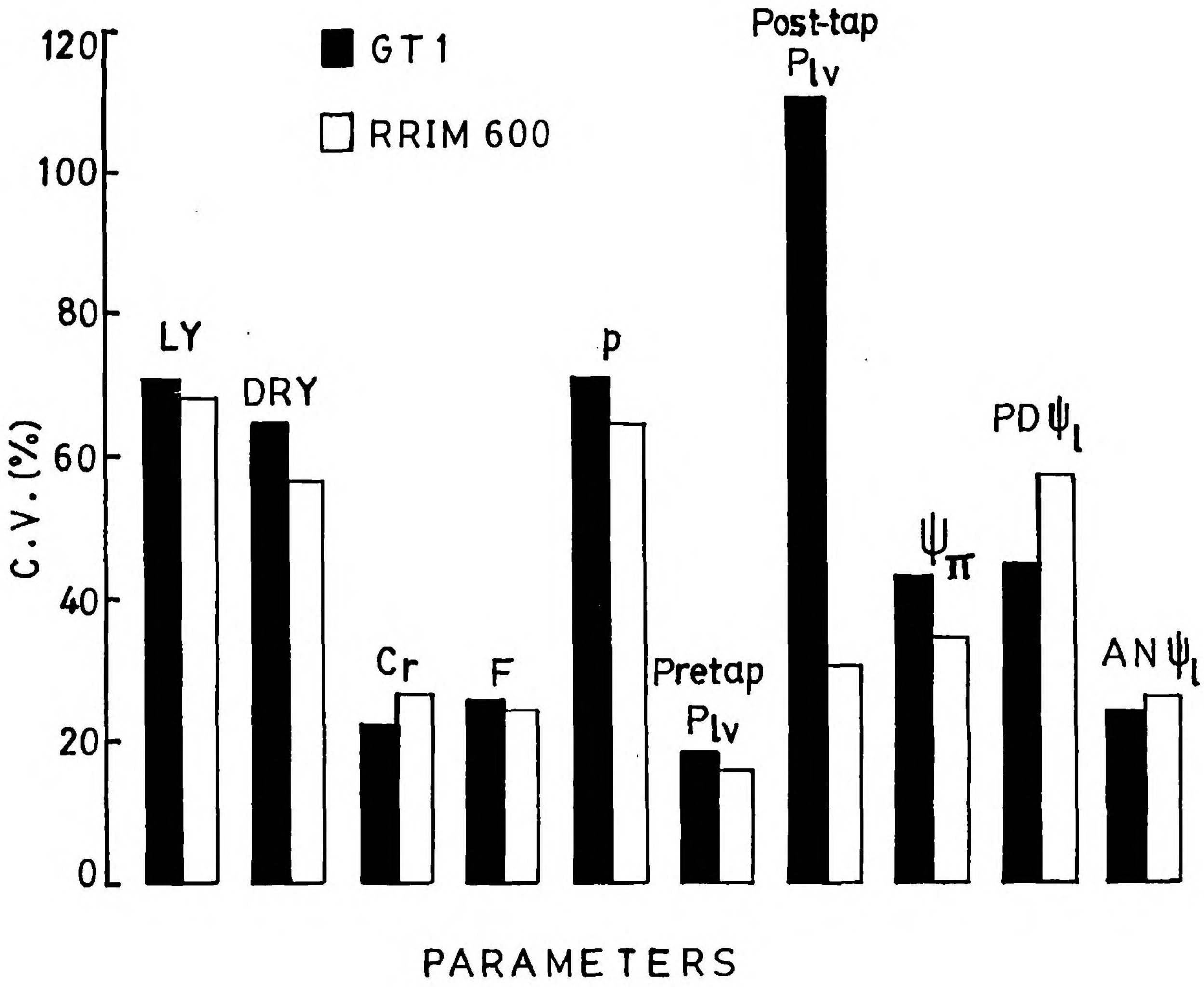


Fig. 9. Variability among yield, yield components and a few components of water relations in GT 1 and RRIM 600 under North Konkan conditions.

# CHAPTER 5

# DISCUSSION AND CONCLUSIONS

# 5 DISCUSSION

## 5.1 Weather and soil moisture characteristics

The location is typical of North Konkan region. The climate of the region is of dry subhumid type with a prolonged rainless period of 7 to 8 months (Table 4; Fig. 1). The rainfall is mono-modal and monsoonal type. The annual rainfall is high (>2500 mm) but restricted to a period of four to five months when it normally exceeds the plant needs followed by a long and dry spell extending from October to May. The continuous rainless period in the region results in water deficits of around 1700 mm (Anonymous, 1988). Temperatures are also high during the summer months coupled with high vapour pressure deficits (Table 4). Thus, although the total rainfall would be apparently sufficient to meet the annual requirement of the crop, the pattern of rainfall does not prove to be optimal for rubber.

In contrast, the traditional rubber growing zone receives both South-West as well as North-East monsoon from June to September and October to December respectively. In addition, the region also receives thunder-showers during March-May. Thus the duration of soil moisture deficits experienced in the traditional region is much less (Sethuraj et al., 1989). Further, the summer temperatures and vapour pressure deficits are also not high (<34°C and <1.3 KPa respectively).

From the soil moisture profiles presented in Table 5, it is clear that soil moisture declined steadily from February to until the onset of monsoon in June. The soil moisture content upto 90 cm depth was at/below permanent wilting point during March-May and thus the plants were exposed to the combined effect of high temperature and atmospheric and soil moisture stress.

**5.2 Yield and its variations**

A decline in the latex and dry rubber yield during the dry period was associated with high rubber content, high p, low $\psi_{\pi}$ and $\psi_{l}$ (Tables 8-9; Fig. 2-4) which in turn was apparently due to low soil moisture content (Table 5). Similar observations have been reported earlier for the traditional region (Devakumar et al., 1988). Drastic reduction in yield in the summer months (Table 9; Figs. 2-3) was probably due to low levels of soil moisture and high VPD (Tables 4-5). The total yield obtained in these months was only 11 per cent of that obtained during the rest of the period. The mean monthly yield in summer months was 28 per cent for GT 1 and 32 per cent for RRIM 600, when compared to their respective yields in rest of the months. However, in the traditional region, even in a year of severe drought, the mean monthly yield obtained in the dry months was as much as 64 per cent for GT 1 and 54 per cent for RRIM 600 of their respective yields in the wet months (Vijayakumar et al., 1988). The monthly changes in yield (Table 9) were comparable with that of the traditional region.

Higher mean monthly yield of clone RRIM 600 in summer months was due to the higher latex output and dry rubber content (Tables 8-9; Figs. 2-3). In the wet months though the dry rubber yield differences between the clones were not significant, the latex yield was significantly higher in RRIM 600 (Table 11). In terms of per cent decline, GT 1 was found to be more drought tolerant than RRIM 600 in the traditional region (Vijayakumar et al., 1988). However, when compared to the clones like Tjir 1 and RRII 118, both GT 1 and RRIM 600 are drought tolerant in terms of yield. This could be one of the reasons for the absence of marked difference in the summer yield of these two clones in the North Konkan. But, if the seasonal differences in yield of these two clones in the region is considered and when compared to the first year yield in the traditional region (Toms Joseph and Haridasan, 1990) GT 1 is found to be more susceptible than RRIM 600.

Estimated first year yield $ha^{-1}$ of the clones (from 300 trees in a stand of 400 trees $ha^{-1}$) made from the monthly yield recordings, indicate an yield of 550 kg for GT 1 and 622 kg for RRIM 600 (Table 14). For the traditional region, Toms Joseph and Haridasan (1990) have reported an yield of 672 kg $ha^{-1}$ for

Table 14. Anticipated mean monthly rubber yield (kg) per hectare in clones GT 1 and RRIM 600 in different months under North Konkan conditions in the opening year.

| Months | Clones | |
|---|---|---|
| | GT 1 | RRIM 600 |
| January | 58.5 | 70.2 |
| February | 39.1 | 50.3 |
| March | 10.9 | 12.8 |
| April | 17.9 | 21.6 |
| May | 15.8 | 23.8 |
| June | 25.9 | 29.0 |
| July | 33.9 | 48.6 |
| August | 52.0 | 79.7 |
| September | 53.3 | 45.7 |
| October | 68.5 | 68.3 |
| November | 78.0 | 78.0 |
| December | 95.7 | 93.7 |
| Total | 549.5 | 621.7 |

Assumptions:

1. Stand per hectare: Assumed maximum stand $ha^{-1}$ being 400 trees $ha^{-1}$. Assumed percentage of trees attaining tappability in the opening year being 75. 2. Tapping system: S/2, d/2, 100 per cent. 3. Average tapping days per month: 13 days. 4. Rainguarding: Tapping with rain guarding during rainy months. 5. Stimulation: No stimulation.

GT 1 and 681 kg $ha^{-1}$ for RRIM 600 in the first year of tapping. When compared to these figures, the reduction in the yield of clones is marginal in the North Konkan region.

The difference in estimated first year yield between the two clones in the North Konkan region was found to be not significant. Very low yields were recorded in the months of March-May (Tables 8-9; Figs. 2-3). The per tap yield obtained in these months was found to be not economical. Therefore, tapping rest may have to be given and it may have to be continued until the onset of South-West monsoon in mid-June. After deducting the yield obtained in summer months, the first year yield $ha^{-1}$ works out be 493 kg for GT 1 and 549 kg for RRIM 600.

The monthly rainfall distribution and yield pattern show that tapping with rainguarding will be an obligatory requirement in the North Konkan region.

**5.3 Physiological behaviour**

High p in summer months was associated with significant decrease in pretap $P_{lv}$ and high Cr (Table 8; Figs. 2-4). The mean estimated water potential of the bark ($\psi$bark) in summer months was -0.47 MPa for GT 1 and -0.24 MPa for RRIM 600. These values suggest that roots were drawing water from the lower depths than studied, with RRIM 600 having deeper roots than GT 1. This could possibly explain the higher $P_{lv}$ in RRIM 600 than GT 1. Monteny et al (1985) have also reported similar indirect evidence for water absorption by Hevea brasiliensis from the deeper layers of soil.

The post-tapping $P_{lv}$ did not show any seasonal difference in RRIM 600. In GT 1, the drop in post-tapping $P_{lv}$ was significant in April and May (Fig. 4) and it was negligible. Figure 4 indicates a regaining of post-tapping $P_{lv}$ soon after the receipt of rainfall. However, this was not accompanied by concomittant decrease in p, though considerable increase in F was observed. These findings are in agreement with the earlier report for the traditional region (Anonymous, 1988). The present data also suggests that the effect of drought on latex yield may be mostly indirect by way of increased plugging resulting in low yield. Eventhough, the pretapping $P_{lv}$ was high in both the clones in June (Fig. 4), highest yield was recorded in December when the pretapping $P_{lv}$ had only a minor effect on seasonal changes in latex out put, though positive $P_{lv}$ is an obligatory requirement for latex flow. However, within a season, the $P_{lv}$ at the time of tapping would have significant effect on the latex out put. Paardekooper and Sookmark (1969) have reported an yield loss of upto 30 per cent by tapping in afternoon hours when compared to the night tapping. Thus, as discussed earlier (Devakumar et al., 1988; Vijayakumar et al., 1988) drought induced biochemical changes in latex properties are important and more studies are needed in this direction.

The higher yield observed in RRIM 600 during summer months was associated with higher plant moisture status as indicated by higher $P_{lv}$, $\psi$ bark, predawn and afternoon $\psi_l$. Stomatal conductance and E rates were also higher in the clone (Tables 8-10; Figs. 7-8).

Earlier studies (Devakumar et al., 1988) have shown that maintenance of higher plant water potential in summer months is one of the factors associated with drought tolerance. Higher stomatal resistance and sap flow rate were found in RRII 105 when compared to RRII 118 in which yield depression was more. However, the present study shows that in RRIM 600 higher $\psi_l$ is maintained in spite of higher $g_s$ and E rates (Figs. 7-8). In the present case, induction of deeper and probably denser roots might be responsible for the higher plant moisture status.

The monthly changes in p are comparable to that of the traditional region (Table 8; Fig. 2). The immediate recovery in pretap $P_{lv}$ is similar to the observations reported earlier (Anonymous, 1988). The pretapping $P_{lv}$ recorded in June (Fig. 4) was very high compared to other months. Also, there was sudden increase in $\psi_\pi$ in the same month. This needs further investigations. The pretapping $P_{lv}$ during the rainy months could not be completely accounted for by the $\psi_\pi$ alone. Building up of root pressure might be one of the reasons for this. The very high $\psi_\pi$ observed in rainy months needs to studies further. The incomplete recovery of predawn $\psi_l$ in June, unlike the traditional region (Anonymous, 1988) might be due to the damage caused to the root system in the preceeding dry period and higher VPD in the months. Higher afternoon $\psi_l$ in June might be due to the reduction in leaf area that was caused by the preceeding extreme drought. The higher AN $\psi_l$ noticed in February can be attributed to post wintering effect, physiological immaturity and lower $g_s$ of the leaves (Table 8; Fig. 7).

Devakumar et al. (1988) have reported the absence of difference in stomatal resistance during morning hours when wet and dry seasons are compared. The present study on diurnal changes in $\psi_l$ shows that $\psi_l$ in the morning hours is comparable during wet and moderate stress periods (Table 12; Fig. 5). However, during severe stress there was a significant reduction in $\psi_l$ and $g_s$ and the values were very low (Table 12; Fig. 7). Wet season observations of $g_s$ using steady state porometer were unrealistically high (exceeding 1000 m moles $m^{-2}$ $s^{-1}$). One of the reasons for obtaining such high values could be the very high relative humidity. Such problems with porometer recordings have been reported earlier (Garnier and Berger, 1987). In three-year old unirrigated plants of RRII 105 grown in this region, no net photosynthesis could be observed under extreme drought conditions in April (unpublished). The low values of $g_s$ in summer months as observed in the present study could probably account for this.

The interrelationships of yield and the influencing attributes (Table 11) indicate that soil moisture status, girth of the trees, leaf water and latex solute potentials are the important factors controlling dry rubber yield through latex output. The analysis suggests that the effect of soil moisture is more evident when latex yield is considered than DRY and that observations on PD $\psi_l$ might be a good indicator of drought tolerance in Hevea. Some components of yield and plant moisture status did not show significant linear correlation with yield. They might be having non-linear relationships. Further analyses are needed to quantify the interrelationships among the various factors.

The correlations also suggests that soil moisture status may influence most of the components of yield and plant moisture status. Correlation between PD $\psi_l$ and soil moisture indicate that yield of rubber in the North Konkan region can be considerably improved by irrigation, the quantitative effects and viability of which need to be worked out.

## SUMMARY

The total production from the traditional rubber growing tract in India is not sufficient to meet the country's full requirement. Expansion of rubber cultivation to other potential areas could be a viable alternative towards increased productivity of rubber and in this direction the possible cultivation of rubber in North Konkan belt has been seriously considered. However, information on yield and associated physiological characteristics of the crop under this agroclimatic conditions is lacking. The present study was taken up to elucidate on these aspects.

The study was carried out in a plantation at Parali in the Raigad District of Maharashtra State. Observations were made on two popular clones viz., GT 1 and RRIM 600 planted in 1980. Monthly recordings of soil moisture content, yield and its components and plant moisture status were recorded in newly opened trees from March, 1989 to February, 1990.

The latex and dry rubber yields were low during dry months and high during wet months. However, rubber yields were best under mild stress period. The extreme soil and atmospheric moisture deficits in the summer months resulted in very low yield and plant moisture status. The per tap dry rubber yields in summer months were very low. The total yield obtained in these months was only 11 per cent of that obtained during the rest of the period. The difference in responses of the clones studied as measured from various parameters were significant in most of the cases.

The clone RRIM 600 yielded better than GT 1, and was more tolerant to drought. The higher yield observed in RRIM 600 was associated with high plant moisture status as indicated by high latex vessel pressure potential and predawn and afternoon leaf water potentials. Stomatal conductance and E rates were also higher in the clone. However, there was not much difference between the clones in the pattern of diurnal changes in leaf water potential, transpiration and stomatal conductance. The estimated first year yield per hectare was 550 kg for GT 1 and 622 kg for RRIM 600.

The correlation analysis revealed that soil moisture status, girth of the trees, leaf water potentials and latex solute potentials were the important factors controlling dry rubber yield through latex yield. The study revealed that reasonable rubber yields can be obtained in dry subhumid climatic regions in spite of drought in the summer months.

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