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STUDIES ON WATER USE PHOTOSYNTHESIS AND GROWTH OF EUCALYPTS

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MAIN SYMBOLS AND ABBREVIATIONS

C_p	specific heat of air
D	drainage to the ground water
D	vapour pressure deficit
DIFN	fraction of the sky visible to the sensor
d	zeroplane displacement
E	Evaporation
E_c	chamber transpiration
E_i	Rainfall interception
E_{PET}	Potential evapotranspiration of the area
E_t	transpiration
E_{tcum}	cumulated transpiration
G	soil heat flux
g_a	aerodynamic conductance
g_c	canopy conductance
g_s	stomatal conductance
gbh	girth at breast height
h	hour
ha	hectare
IST	Indian Standard Time
k	von Karman’s constant
k	an extinction coefficient
$\boldsymbol{L}$	leaf area of the conducting surface
l	litre
LAI	leaf area index
m	metre
mm	millimetre
MPa	Megapascals

N	number of observations
n.r.	not recorded
P	precipitation (opanfall)
P_a	annual precipitation
PET	potential evapotranspiration
P_n	net photosynthesis
Q	run off
r_a	aerodynamic resistance
R_n	net radiation
R_{na}	net radiation above canopy
R_{nb}	net radiation beneath increasing accumulation of leaf area
r^2	coefficient of determination
r.h.	relative humidity
S	total solar radiation
s	second
SF	stemflow
T	throughfall
T_a	above canopy temperature
T_g	temperature above ground level
U	mean wind speed
W	watts
W_a	fraction of the year when canopy is wet
WUE	water use efficiency
Z	anemometer reference height
Z_o	roughness length
α	interception fraction
γ	psychrometric constant

Δ	slope of the saturation vapour pressure curve for water
ΔS	change in water content of soil
λ	latent heat of vapourization
ρ	density of air
Ψ	water potential
Ψ_p	pressure potential
Ψ_s	solute potential

ABSTRACT

Eucalypts have been introduced into Kerala as a commercial plantation. To start with *E. globulus* and *E. rostrata* were the species originally introduced in the high ranges of Kerala to meet the fuel needs of the tea and coffee Estates. When the demand for raw materials for paper and rayon pulp increased *E. grandis,* a species suitable for the high ranges and *E. tereticornis* (formerly called as *E. hybrid),* a species for the plains have been raised. The latter two species contribute to the major part of about 30,000 ha in the plantation sector of the Forest Department. The large scale introduction of eucalypts has been attracting criticism from the public by alleging several negative ecological effects including high water consumption. This report presents the results of a detailed investigation on the alleged excessive water consumption by the two eucalypt species planted in Kerala.

Three eucalypt plantations were chosen for intensive monitoring. One of them, *E. tereticornis* plantation at Varavoor is located in an area with relatively high evaporative demand, approximately 3000 mm annual rainfall and 1800 trees ha^{-1}. The second plantation, *E. tereticornis* is situated at Palode, where the rainfall is 2500 mm per annum, but more uniformly distributed. The plantation has a density of 1050 trees ha^{-1}. The third plantation, *E.grandis* is at Muthanga, where the annual rainfall is 1300 mm The plantation exists at 750 m above sea level and contain 1600 trees ha^{-1}.

Since the monsoon period in Kerala lasts for three months, June to August, no field measurement of water consumption was possible. It was also assumed that due to extremely low solar radiation and low vapour pressure deficit, transpiration was negligible during this period. Field measurements were confined to the rest nine months of the year.

Using a scaffold tower in the plantations, microclimate parameters like temperature, relative humidity, wind speed, total solar radiation and net radiation were measured 2 m above the canopy level. The temperature at the ground level was also measured. All measurements were made using electronic sensors connected to a datalogger. Data were collected at 5 seconds interval and averaged hourly. Along with the above microclimate parameters, hourly measurements of the stomata1 conductance were made. In *E. grandis,* the canopy was treated as a two layer structure and appropriate measurements were made in both the layers. In *E. tereticornis,* a single layer model was followed. The data collected thus were applied in the Penman–Monteith equation to get the hourly water loss due to transpiration. The canopy leaf area index was also measured for the above computations. The daily transpiration rates were extrapolated to monthly values. The transpiration loss during the nine months of the year was estimated by totaling the monthly values.

The transpiration loss of water at the three plantations for the 9 months were as follows: Varavoor 1563 mm, Palode 853 mm and Muthanga 1181 mm. The per tree consumption of water ranged between 18 and 44 litres day^{-1} in *E. tereticornis*. In *E. grandis* the per tree consumption was between 13 and 40 litres day^{-1}. In all the three locations, the water potentials were maintained at relatively higher levels even during the non rainy months. This means that the plants were not under water stress during any part of the year. Even the midday water potentials never reached the turgor loss point (–1.75 MPa).

The stornatal control of transpiration in response to increasing atmospheric vapour pressure deficit when examined shows that in *E. tereticornis* apparently the control was not existing at the available soil water content. In *E.grandis*, relatively good control existed with nearly complete closure at values above 4.0 kPa irrespective of the soil water availability.

The relatively high water potentials and the stornatal conductance values throughout the year give indications for abstraction of water from deeper layers of the soil. Since the water tables in these localities occur anywhere within 15 m depth, the eucalypt roots extracting water from the phreatic aquifer cannot be ruled out.

The maximum net photosynthetic rate in both the species was around 20 μmol m^{-2}s^{-1}. In *E. tereticornis*, the water use efficiency was similar during both pre and post monsoon period. In *E. grandis* the water use efficiency was less during the post monsoon period compared to the pre monsoon period. In general, the water use efficiency was better for *E, tereticornis*.

Complete cessation of growth in girth was found during the pre monsoon period in both the species. Extension growth was maintained regardless of the seasons.

1. INTRODUCTION

The genus *Eucalyptus* with about 600 species is mainly found in almost all of the major habitat types in its native Australia. Apart from Australia, a few species are found naturally occuring in Papua New Guinea, Indonesia and the Philippines. The ecological and genetic diversity in the genus is so vast that the eucalypts have been successfully introduced world wide for over 100 years. Because of their multiple advantages, about 40% of all trees raised in plantations in the tropics belong to eucalypts. Some of the reasons for the wide selection of eucalypt as a commercial and social forestry planting material can be summarized as follows.

1. The eucalypts out-perform the native species and other exotics in height and girth increment (This statement cannot be justified in Kerala, where *Acacia auriculiformis* trees have out-performed the eucalypts (Jayaraman and Rajan, 1991).
2. They produce wood for timber, poles, pulp and fuel purposes in a short time.
3. They are relatively easy to cultivate.
4. The eucalypts are not palatable to most grazing animals
5. Eucalypts can tolerate degraded sites and are resistant.
6. When felled, they coppice readily
7. They are a rich source of firewood and provide good charcoal.

8 They are planted for shelter belts, erosion control, land reclamation and drainage.

9. Minor forest products like honey from flowers and eucalypt oil from leaves are available.

In spite of the fact that hardly any other forest tree species qualify for all the merits menticned above, eucalypts have been subjected to severe criticism. This has caused concern to those involved in afforestation programmes. The controversial aspects of eucalypts include the following.

1. The eucalypts consume large quantities of water, depleting the soil and sometimes the aquifer.
2. They deplete the soil nutrients, thereby degrading the site.
3. Their litter do not decompose readily
4. Since the canopy is fairly open, they do not support any wildlife.
5. They do not prevent soil erosion.
6. They provide Competition for other vegetation, especially the ground vegetation because of some allelopathic effects.
7. The species creates lot of social and economic problems like diversion of agricultural land intended for food production for growing eucalypts and consequent reduction of rural employment, diversion of forest products from local markets to industry etc. have been alleged.

During the past decade, a number of studies have been undertaken to investigate the truth contained in most of the controversial aspects mentioned above. For details of such studies, one may refer to Davidson (1985), Poore and Fries (1985) and FA0 (1988). Most recently, the Australian Centre for International Agricultural Research (ACIAR) (1992) has commissioned a scientific statement on the positive and negative aspects of eucalypt planting.

It is to be pointed out that the eucalypt controversy has been a subject of emotional debate in India too. The fears on the deleterious effects of eucalypts in India have been typically expressed by Vandana Shiva et al. (1982) and Vandana Shiva and Bandyopadhyay (1983, 1985). Of the many allegations, the excessive water use of eucalypts has attracted the maximum attention in India (see Calder, 1986, 1992). Several studies on the water relations and water use of eucalypts have been conducted in India (see Dabral, 1970; Rawat et al. 1984, 1985.) However, many of them deal with only seedlings. Stomata1 physiology has been studied using epidermal impressions only. Hence applying the results of these studies to plantations is debatable. An interesting study was commissioned in the state of Karnataka in 1987 on the several aspects of the eucalypt controversy. Several findings from this extensive study can be found in Calder et al. (1992).

The present report is on a study conducted in the state of Kerala. Kerala has nearly 30,000 ha. of eucalypt plantations under two species, namely, *E. tereticornis* and *E. grandis*. The average yield at 10 years for the plantations in Kerala are 72.59 m^3 ha^{-1} for *E. tereticornis* and 137.64 m^3ha^{-1} for *E. grandis* (Jayaraman& Krishnankutty, 1991). *E. tereticornis* is planted in the plains and *E. grandis* in the hills of the State.

The state of Kerala is located in the south western region of India and it experiences an average annual rainfall of 3000 mm. The distribution of the rainfall is not uniform, most of the rains are brought in by the two monsoons operatinp between the months of June and November.

From a detailed analysis of the data on the different species of eucalypt water consumption, Poore and Fries (1985) have concluded that there is no general answer to the question whether eucalypts consume water in excessive quantities. From their review, it is apparent that the hydrological impact of the eucalypts will have to be studied in the different circumstances. Although eucalypt species have been studied in different parts of the world, there are very few comparative studies on their water use in relation to other exotics or indigenous species. One such study is that of Carbon et al. (1982) who compared the water consumption of *E. marginata* with that of *Pinus pineaster*, annual and perennial pastures and native forest using the neutron scattering techniques. They found that the pine forest consumed more water than the others. In a similar study undertaken in Karnataka, India, Harding et al. (1992) have compared the soil moisture regime under plantations of eucalypts, casuarina, Leucaena, degraded natural forest and an agricultural crop (ragi). They did not find any significant difference in the use of water between the tree species, however, ragi consumed only 52-65% of the water consumed by the tree plantations. It should be mentioned that the eucalypt water consumption measured by other methods was much more than that found by soil moisture measurements (Calder et al. 1992).

The present work is a comparative study of the water use of *E. tereticornis* and *E. grandis*, the two main eucalypt species raised on a plantation scale in Kerala. It should be noted that planting of eucalypt as single trees in private gardens, planting rows of trees as windbreaks and avenue trees, and strip-planting of eucalypts in degraded areas are very common in Kerala. The present study does not take into account the water use of such trees because their aerodynamic properties are much different from that of plantations raised on a large scale. Hence no attempt should be made to apply the conclusions in this report to such areas mentioned above. A word of caution is also given against interpreting the results of this study in areas where eucalypts have been mix-planted with other tree species.

The approach made in the present investigation has been to measure the water consumption of *E. tereticornis* and

E.grandis planted at different zones within Kerala. Thus *E. tereticornis* was studied at two localities, namely, Varavoor and Palode. The former locality is characterised by the maximum evaporative demand prevailing in Kerala. The latter locality has more or less uniformly distributed rainfall and the average rainfall is nearly half of the state's average. Due to the extensive type of measurements needed in this project, *E. grandis* could be studied in only one locality, namely, Muthanga in Wyanad District. However, this is the area where *E. grandis* is planted on a major scale. The measurements of various parameters like leaf water potentials, microclimate above the canopy, diurnal stomatal conductance, diurnal rates of net photosynthesis etc. were made on sample days chosen at monthly intervals throughout the year. The monsoon months had to be excluded from measurements because of the continuous rainfall prevailing in almost all places in Kerala. The loss of water due to transpiration was estimated from Penman-Monteith equation using the data collected in, the eucalypt plantations. Since no direct interception measurements were made, the interception values were obtained from canopy and aerodynamic parameters used in existing models.

As already mentioned, water use of eucalypts has to be judged by comparing them with other species in nearby or similar locations. While the work on this project was on, another study on some exotic and indigenous species had been commissioned by the World Bank through their Social Forestry

Programme in the state. The results of this study has been already presented in the form of a report (Kallarackal and Somen, 1992). The report deals with the water use study on *Acacia auriculiformis*, *Anacardium occidentale* and *Tectona grandis*. Since the above study has been conducted in similar spatial and temporal situations as the present one, it is possible to make reliable comparison of the eucalypt water use with other species mentioned above.

2. LAND USE AND WATER BALANCE

In most parts of the world land is basically used for agriculture and forestry. Modern times have seen the conversion of land for recreational purposes also. When land is put to multiple uses, it is important that provided water is for domestic, agricultural and industrial uses. However, the land manager who often meets with the problem of land management for maximum agricultural and timber production is unable to provide enough water for the different uses. Since land management usually involves change in the type of vegetation in a particular locality, the question often arises as to the viability of such a change in meeting the water requirement of that locality.

The change from traditional grasslands to a plantation with exotic species or a change from a native forest to an agricultural crop or selective felling of an evergreen forest, all involve the change in water balance of an area or catchment (McNaughton & Jarvis, 1983). For managing a catchment, it is important to know the type of vegetation which will yield the maximum water to a reservoir throughout the year. A specific example is the conversion of large tracts of land in several countries to plant trees which yield pulp or fuel wood. In a study of the soil moisture regime in South Africa, Stuart-Hill & Tainton (1989) observed that evaporation from a bare soil surface is negligible in comparison with evapotranspiration from vegetated lands. Thus the loss of soil water is mainly due to plant extraction. The above workers have observed that a grass sward is more effective in depleting soil water than the trees. Removal of grass increased the soil moisture regime by 100%, whereas removal of the trees increased the soil moisture by only 20%.

A question with wide implication is whether it is reasonable to manage an area for a single end product. When it is possible to manage an upland for conservation, timber production, recreation and water yield, is it really justifiable to concentrate on just one of the end products. The overall return from an area as a result of multiple use will certainly exceed the return from a single use (McNaughton and Jarvis, 1983). It is therefore essential that we quantify the economic and land-use consequences when contemplating a change. It is here that the scientists should be able to predict the consequences of any land use changes so that the most suitable decision can be made. This study aims at such predictions on the effect of vegetation changes on evapotranspiration.

Before going into the details of the water consumption of trees, it is necessary to get an understanding of the water cycle and how it affects the energy relationships in a forest or plantation. The soil plant atmosphere is a continuum and therefore changes in any of the components will affect the water balance.

When a rainfall event occurs in an area covered with vegetation, some of the water is intercepted by the canopy and it evaporates. The rest, of the water reaches the soil directly or dripping through the foliage (throughfall) or flows down the trunk as stemflow. Of the water that reaches the soil some may be lost as surface runoff, some water is evaporated directly and some infiltrate into the soil. The water that gets infiltrated into the soil moves in different ways. A part of it is retained inthe soil against the force of gravity. It is this water which is mainly used by the vegetation for transpiration. Any surplus water drains downwards to the Water table and then into streams, rivers or underground aquifers. The overall water balance of an area can be expressed in the following equation

$$P = Q + E + \Delta S + D \qquad (1)$$

where P = precipitaton (mostly rainfall in the tropics), Q = runoff, E = evaporation, ΔS = change in water content of the soil and D = drainage to ground water.

To get a clear picture of the water balance of a locality, it is important to quantify all the above parameters. These parameters in brief, represent the hydrology of a catchment and it is important to remember that the vegetation influences the hydrology of a catchment. It should be pointed out at this stage that the water loss from the vegetation (evapotranspiration) forms the most important aspect in this report. The evapotranspiration has three major components viz. (1) Evaporation of intercepted rainfall, (2) transpiration from the canopy and understorey and (3) evaporation from the soil.

In the earlier paragraphs it was mentioned that a part of the rain water which penetrates the soil is retained in the soil. It is this water which is most useful to plants. Plant roots growing in this soil can use most of the water. After their metabolic needs, they incorporate a comparatively small proportion of the water in their tissues, and transpire the rest to the atmosphere.

Transpiration is a physiological process where the water passes from the soil to the air surrounding the leaves along a gradient of water potential. The main resistance in the pathway are the stomata, the opening and closing of which are controlled by variables like light, vapour pressure deficit (D) and soil moisture.

Evaporation is a physical process which depends largely on the radiation reaching the surface. If there is plenty of water in the soil, the evapotranspiration depends on the radiation reaching the ground or surface of the vegetation. it is generally considered to be the same for a vegetated area or a bare surface of water.

However, when water is deficient in the soil, the plants resort to various means of resistance to prevent further loss of water. These include complete or partial shedding of leaves, curling of the lamina, closing of the stomata etc. The soil also forms a hard surface crest preventing any further loss of water due to evaporation. After an evaporation loss of about 12 mm from sandy soils or 20 mm from heavier soils, the hydraulic conductivity of the soil surface falls rapidly causing a marked reduction in evaporation rate (Winter 1974). However, if the tree roots have access to water table, they will be able to use as much water as they want usually regardless of the atmosphere where the shoots are. When the trees lose their leaves or close their stomata, their growth also suffers. In general, the rate of growth of trees is proportional to the amount of water that they use.

With this background on the water balance of trees/catchment it is necessa.ry to present a brief review on the methods used to measure the evapotranspiration. Since several methods have been used by differnt investigators, it is necessary to explain why some of the methods are more applicable in the present situation. They can be broadly divided into the following.

a. Micrometeorological methods

Among these the most important ones are the Eddy correlation technique and the Bowen ratio method. Both these methods require relatively flat and vast areas to perform measurements. Since such areas are a rare feature in Kerala's different agroclimatic zones, we have not adopted them.

b. Water balance methods for catchmenis

These include hydrological methods to measure the water balance of a catchment. Although these methods can provide good information, they do not give much significance to the physiological behaviour of the plants. In this study, since we are more concerned with the vegetational aspect, this method is not followed. This is mainly a hydrologist's method to study the water balance. A large number of studies of this kind have been done around the world (see reviews by Hitbert, 1967; Bosch & Hewlett, 1982).

c. Sap flow methods

In these methods, the water flowing through the trunk of a tree is measured using a heat pulse technique or the more recently known, heat balance method (Dye et al., 1992). The method has shown good reliability with individual trees, but extrapolating these values to the catchment has to be done with extreme caution.

d. Chamber methods

The transpiration is measured using a small porometer chamber clamped to a leaf or enclosing the whole plant in a large chamber and the humidity changes noted. These methods suffer from the artificial conditions created inside the chamber.

e.Tracer methods

Lately tracer methods have gained much acceptance among some investigators (Calder et al., 1986). Deuterium is mainly used as the tracer. The method looks very promising if applicable for a catchment.

f. Penman-Honteith Method

This is probably the most popular and reliable method to stucy the water loss from a stand (Whitehead & Hinckley, 1991). Since this method combines aerodynamic, energy and physiological parameters, the method can be applied to smaller catchments. Although the method involves the measurement of several environmental and physiological parameters and hence considered to be difficult, we think this to be the most reliable method for plantations in Kerala.

In the above paragraphs, we have listed only a few of the most widely used methods for studying water balance. For more details, readers may refer to Sharma (1984), Woodward & Sheehy

3. MATERIALS AND HETHODS

3.1. Site description

Investigations were carried out on two species, namely, *Eucalyptus tereticornis* and *E. grandis*. Two plantations of *E. tereticornis* and one of *E. grandis* were intensively monitored during the study. The site details of the three plantations are presented in Tables 1–3. The geographical locations are marked in Fig. 1. It may be noted that the three plantations are widely separated within the state of Kerala. The *E. tereticornis* plantation at Varavoor is meteorologically influenced by the Palghat gap of the Western Ghats. This area has the maximum evaporative demand (PET = 1663 mm) when compared to other parts of Kerala (Fig.2).

The *E. tereticornis* plantation at Palode received more uniform rainfall when compared to the other two locations. This is probably the only part of Kerala which receives a more or less uniform distribution of rainfall although the cumulative annual rainfall is less than the State's average of 3000 mm.

The *E. grandis* plantation at Muthanga experiences a climate which is more or legs similar to that of the Deccan plateau. However, the rainfall is relatively high and the elevation is nearly 750 m. above mean sea level.

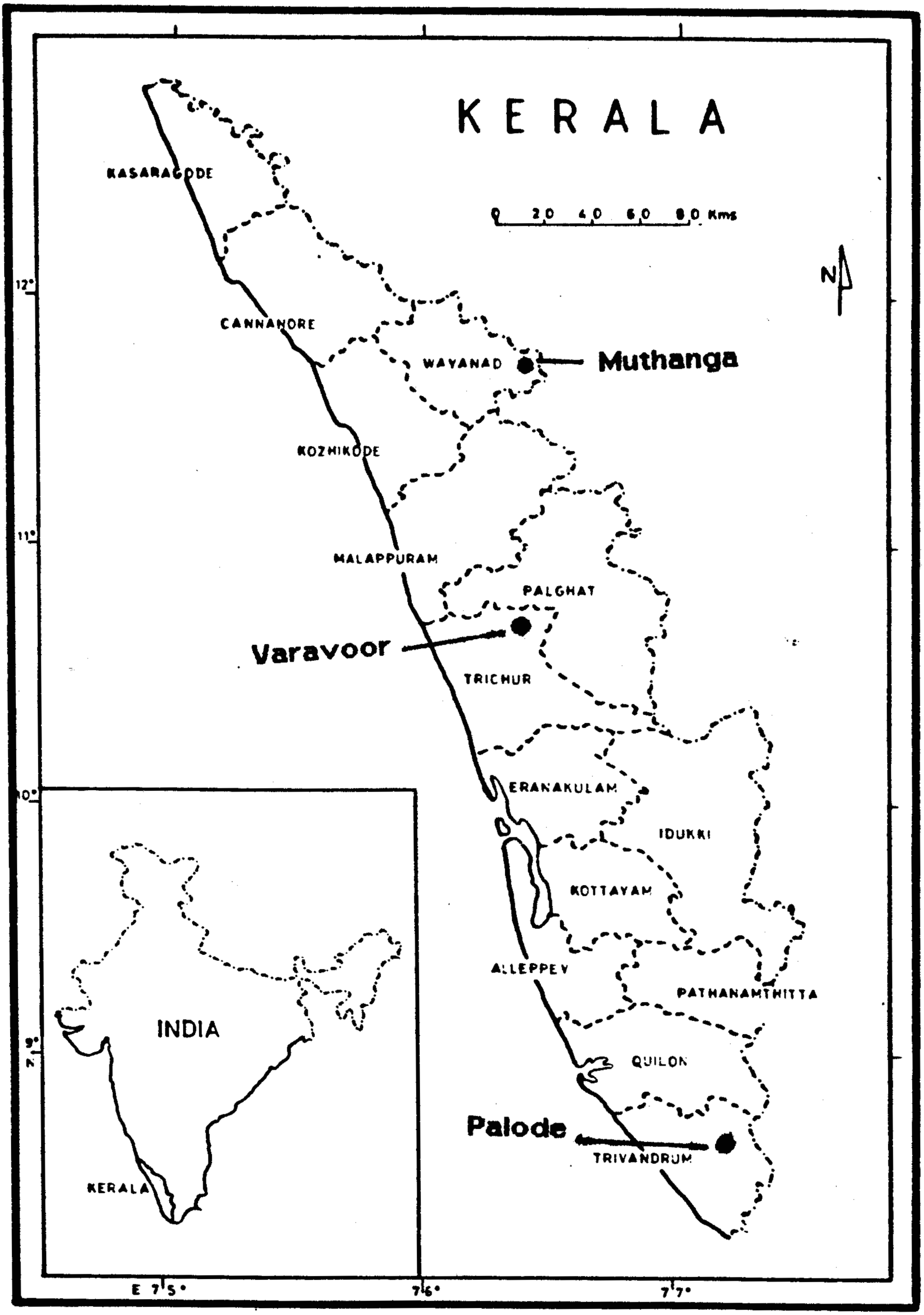

Fig.1. Map of Kerala showing the study locations

Table 1. E. *tereticornis* - *Site* Details

Sl.No.	Site factors		Description
1.	Species	:	*Eucalyptus* ***tereticornis***
2.	Forest Division	:	Trichur
3.	Forest Range	:	Vadakkanchery
4.	Section	:	Varavoor
5.	Latitude	:	10°41'00" to 10^{0} 42'30"
6.	Longitude	:	76^{0} 12'30" to 760 15'00"
7.	Altitude	:	100 m
8.	Annual rainfall	:	2837 mm (1990) - Vadakkancherry
9.	Soil Condition	:	Lateritic
10.	Year of Planting	:	1977
11.	Year of coppicing	:	1987
12.	Rotation number	:	2nd
13.	Average tree diameter	:	9 cm
14.	Number of stems/ha	:	1800 (surviving)
15.	Flanting distance	:	2.5 x 2.5
16.	Average tree height	:	10 m
17.	Leaf area index	:	2.17
18.	Period of study	:	June 1990 - May 1991

Table 2. *E. tereticornis* **- Site Details**

Sl.No.	Site factors		Description
1.	Species	:	Eucalyptus *tereticornis*
2.	Forest Division	:	Trivandrum
3.	Forest Range	:	Palode
4.	Section	:	Bharathannoor
5.	Latitude	:	8^{0}45'00" to 8^{0}45'15"
6.	Longitude	:	76^{0}59'45" to 77^{0} 00'00"
7.	Altitude	:	100 m.
8.	Annual rainfall	:	2465 mm (Aug. 1991-July 1992)
9.	Soil Condition	:	Lateritic
10.	Year of Planting	:	1967 - augmented in 1989
11.	Year of coppicing	:	1988
12.	Rotation number	:	3rd
13.	Average tree diameter	:	0.6 cm
14.	Number of stems/ha	;	1090
15.	Flanting distance	:	3 x 3 m
16.	Average tree height	:	10 m.
17.	Leaf area index	:	0.60
18.	Period of study	:	September 1991 - August 1992

Table 3. *E. grandis* Site Details

S No.	Site factors	Description
1.	Species	*Eucalyptus grandis*
2.	Forest Division	Wyanad
3.	Forest Range	Muthanga
4.	Section	Mavinhalla
5.	Latitude	11°39'to 11040'
6.	Longitude	76°21' 30" to 76°22' 15"
7.	Altitude	770 m
8.	Annual rainfall	1302 mm (1992)
9.	Soil Condition	Forest loam
10.	Year of Planting	1977
11.	Year of coppicing	1989
12.	Rotation number	2
13.	Average. tree diameter	9.9 cm
14.	Number of stems/ha	2500
15.	Planting distance	2 x2m
16.	Average tree height	10 m.
17.	Leaf area index	2.75
18.	Period of study	Feb. 1992 Jan. 93

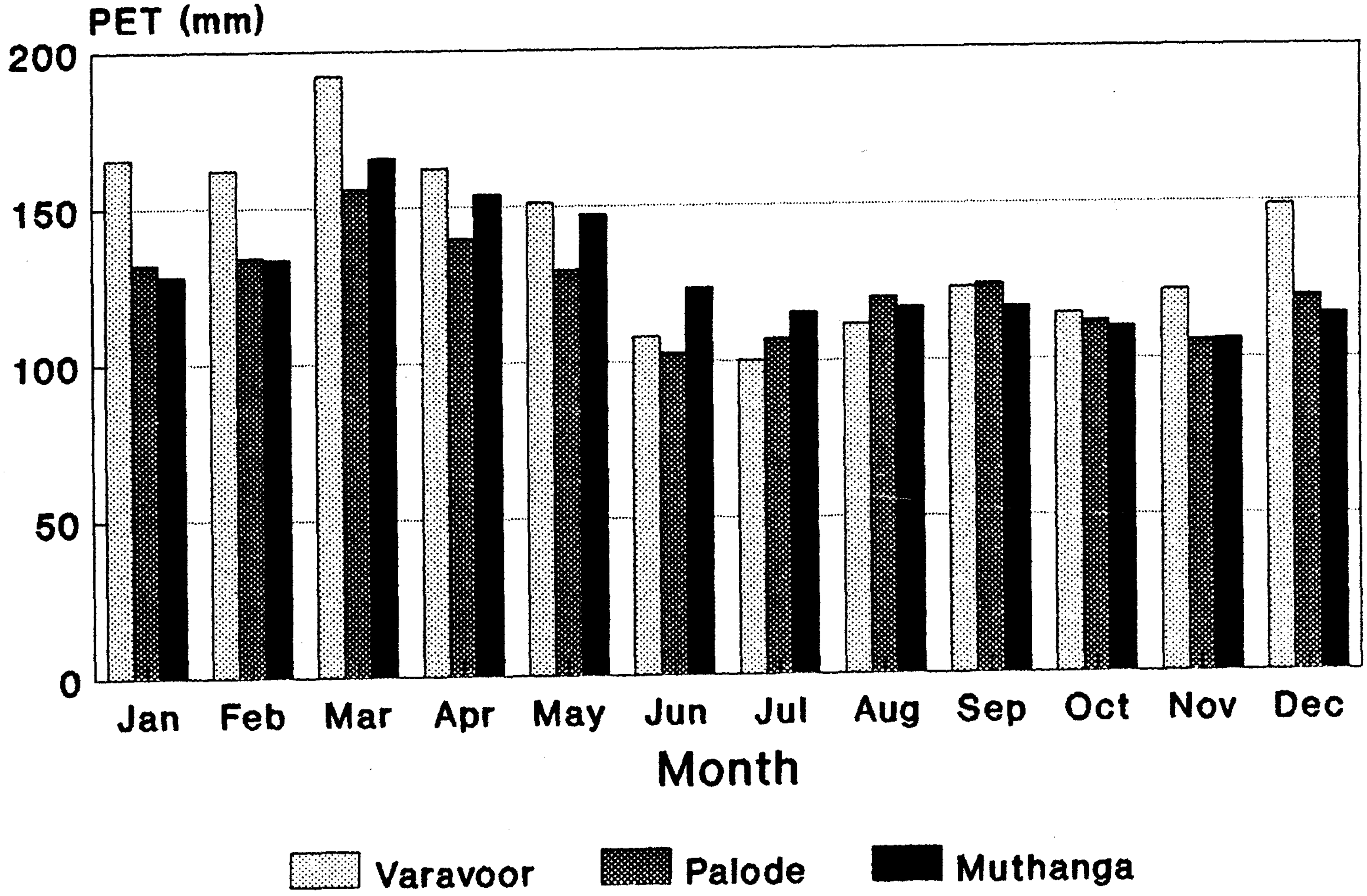

Fig.2. Potential evapotranspiration at the study locations

3.2. Soil water

Soil water content was measured gravimetrically. The soils were sampled from two layers, 0 to 0.3 m and 0.3 to 0.6 m. Since the spatial variations were enormous, this measurement was done only at Varavoor. The predawn water potential values were used for information on the water availability to the roots.

3.3. Water potentials (Ψ)

Predawn and midday water potentials were measured on samples collected from different trees. The sample leaves were enclosed in a polythene bar just before detaching from the plant. All precautions for measurement according to Turner (1988) were taken for the sampling.

A Scholander type pressure chamber (Soil Moisture Equipment Corporation, Ohio, USA) was used for finding the balancing pressure. This balancing pressure was practically taken **as** the water potential as described below (Milburn, 1979).

$$\Psi = \Psi_p + \Psi_s \qquad (2)$$

where,

Ψ = water potential,
Ψ_p □ balancing pressure and
Ψ_s solute potential.

A specific number of leaves were sampled. The number was determined mainly from the extend of variations in the values.

3.4. Weather parameters

The year round weather parameters like the rainfall, maximum and minimum temperatures, relative humidity, wind velocity etc. were collected from weather stations located near the plantations under investigation.

3.5. Microclimate

A 12 m high, steel scaffold tower was installed in the plantations to mount the meteorological equipments through and above the canopy. The meteorological sensors were mounted at least 2 m above the canopy level. The following sensors were used for the data collection.

Temperature and relative humidity - measured using a shielded thermistor (Model 207 temp. and RH probe, Campbell Scientific Inc., Utah, USA).

Wind speed - measured using cup counter anemometer (Model 014A, Met One, Sunnyvale, CA, USA) with a switch closure mechanism.

Net radiation - measured using a net radiometer of the Fritschen type (REBS Inc., Washington, USA).

Shortwave radiation - measured using a pyranometer sensor (Model LI -200S, Licor, Nebraska, USA).

All the above sensors were connected to **a** datalogger (Model 21X or CR10, Campbell Scientific Inc., Utah, USA). Logging was programmed for 5 seconds interval and hourly averages were stored. The stored data were later transfered to a computer for further analysis using the software package PC-208 (Campbell Scientifc Inc., Utah, USA).

3.6. Stomatal conductance (g_S)

A steady state porometer (Model LI-1600, Li-Cor, Nebraska, USA) was used to neasure the stomatal conductance of leaves. The measurements were made at the ambient relative humidity. An average of eight leaf samples from four trees accessible from the scaffold tower were sampled hourly from sunrise to sunset.

The infra-red gas analyser system (LI-6200, Li-Cor, Nebraska, USA) was also simultaneously used for measurement as well as cross-checking the porometer data.

Daily patterns of g_S, were followed on sample days randomly chosen at approximately one month interval over a complete year. Measurements were made on days which were not rainy or completely overcast. However, the measurements had to be completely abandoned for 3 months of the year, starting June because of the heavy down pours and fully overcast skies brought by the South-West Monsoon. The relative humidity (r.h.) was extremely high during this period (>85%)and the frequent rains kept the leaves wet.

Sampling of the leaves were done from the different layers of the canopy. In *E. tereticornis,* porometer measurements were made on the upper and lower sides of the leaves. Since the results showed the presence of stomata only on the abaxial side of the leaf in *E. grandis,* measurements were made only on this side. In the infra-red gas analyser system, appropriate stomatal ratios were fed into the computer console for the two different species. The g_s, in both the instruments were calculated using the inbuilt software provided with the instruments.

3.7. Canopy condcutance (g_c)

The following equation was used to calculate the canopy conductance.

$$g_c = g_s, L \tag{3}$$

where,

L = leaf area index of the conducting surface.

3.8. Aerodynamic conductance (g_a)

The aerodynamic conductance (g_a) was calculated as the reciprocal of aerodynamic resistance (r_a) following the equation of Monteith (1973).

$$r_a = \left\{ \ln \frac{(z - d)}{z_o} \right\}^2 k^2 u^{-1} \tag{4}$$

where,

u = mean wind speed (ms-l)

z = anemometer reference height (m)

d = zero plane displacement - calculated as 0.64 h where, h = crop height (m)

zo = the roughness length (=0.13h)

k = von Karman's constant

3.9. Leaf area index (LAI)

LAI was measured using the principle of light transmittance through the canopy gaps with the help of a commercially available canopy analyser (Model LAI-2000, Li-Cor, Nebraska, USA). This instrument is provided with a fish eye lens to scan the canopy. The value of LAI given by the instrument was usually modified by masking one or two horizontal angles using the C-2000 program. For details of the instrument's functioning, the manufacturer's operational manual may be referred.

The leaf area index was also measured in *E. tereticornis* by destructive sampling. Thirty trees with variable trunk girth were felled in a plantation. The leaves were manually collected from the felled trees. The area of the leaf on each tree was determined from an allometric equation describing the weight/area relation. A linear regression was made between leaf area per tree and its GBH. The LAI of the plantation under observation was later predicted from the GBH measurements of all the trees in the experimental plot.

3.10. Canopy transpiration (E_t)

Canopy transpiration (E_t) was estimated hourly using the Penman-Monteith equation (Monteith, 1973).

$$\lambda E_t = \frac{\Delta (R_n - G) + \rho\, c_p\, D\, g_a}{\Delta + (c_p / \lambda)\ (1 + g_a / g_c)} \qquad (5)$$

where,

E = evapotranspiration rate (mm h^{-1})

λ = latent heat of vaporisation of water (JKg^{-l})

R_n = net radiation (Wm^{-2})

G = soil heat flux (which can be ignored for daily calculations)

ρ = density of air (kgm^{-3})

c_p = the specific heat of air at constant pressure ($JKg^{-2\,0}C$-l)

Δ = the slope of the saturation vapour pressure curve for water ($KPa^{O}C^{-l}$)

D = vapour pressure deficit (KPa)

g_a = aerodynamic conductance (ms-l)

γ = psychrometric constant (kPa°C-l)

g_c = canopy conductance (ms^{-l})

The E_t was calculated assuming **a** single layer model in *E. tereticornis* because not much difference was noticed in the stomatal resistance between the leaves of upper and lower canopy. However, in *E. grandis,* a two layer model was assumed because of its dense nature. The *Rn* for the lower canopy was approximated following Landsberg (1986) using the Beer - Lambert law.

$$\ln (R_{nb} / R_{na}) = -k \sum_{i=1}^{b} L_i \qquad (6)$$

where,

Rna net radiation above the canopy

R_{nb} = net radiation beneath increasing accumulation of leaf area

k = an extinction coefficient (taken here as 0.5)

Li = LAI of the layer

The D is usually taken as the vapour pressure difference between the leaf temperature and the atmosphere. However, in the present study the leaf was assumed to be at the atmospheric temperature for the E_t estimations.

3.11. Net pohotosynthesis *(Pn)*

Leaf net photosynthesis *(Pn)* was measured using a portable infra-red gas analyser (Model LI-6200, Li-Cor, Nebraska, USA) fitted with a one litre chamber. The IRGA was frequently calibrated using known gas mixtures of CO_2. The measurements were recorded on the computer console supplied with the instrument. The *Pn* was calculated in the same console using the software provided by the manufacturer.

3.12. Growth measurements

The growth in the eucalypt trees was followed by monthly measurements of girth at breast height (gbh) using a measuring tape. At least 40-50 trees were measured for this purpose.

4. RESULTS

4.1. *E. tereticornis*

4.1.1. Weather data

The annual weather data collected from stations near Varavoor and Palode are presented in Tables 4 and 5. It may be noted that in both the locations, the wettest months of the year are from June to September. This is due to the high incidence of rainfall brought by the South-West Monsoon. The dry period is from December to March when there is no or scanty rainfall. The temperatures recorded at Varavoor are comparatively higher than the rest of the state. The relative humidity recorded are also much lower than that of Palode. The potential evapotranspiration (PET) values calculated from the data for the past 30 years is shown in Fig.2 (after Rao et al., 1971).

From the point of water availability to the trees, the year may be divided into three periods - the premonsoon period, monsoon period, and post-monsoon period. It is in the premonsoon period that the water is least available to the plants. In the study areas, this is from January to May. During the monsoon period and post-monsoon period the soils in Kerala are mostly under field capacity.

4.1.2. Soil moisture and leaf water potentials

The soil moisture determined gravimetrically at two depths during days when other physiological measurements were made are indicated in Fig.3. Each point in the figure is the mean of three independent determinations. The soil

Table 4. *E. tereticornis* - Weather data for Varavoor during 1990-91

Month	Temperature(°C)			
	Mean max.	Mean min.	Mean max. r.h. (%)	Rainfall (mm)
October	29.4	22.8	90.0	452
November	29.3	22.5	86.5	60
December	30.7	21.4	78.9	0
January	31.0	21.5	75.3	0
February	34.8	20.8	72.4	0
March	36.0	23.7	78.6	0
April	36.7	23.8	81.7	137
May	35.9	23.7	83.2	75
June	31.0	23.3	84.1	879
July	28.5	22.3	95.3	994
August	29.2	22.8	92.8	497
September	31.8	22.9	64.2	116

The rainfall data was collected from a weather station located 5 km away from the study area. All other data were obtained from a weather station 20 km away from the plantation.

Table 5.. E *tereticornis* - Weather data for Palode during 1991-92

Month	Temperature(°C) Mean max.	Mean min.	Mean r.h. (%)	Pan Evaporation (mmd^{-1})	Rainfall (mm)
August	29.5	21.0	02	3.6	226
September	32.4	21.2	76	4.1	34
October	**30.2**	**21.5**	84	2.7	428
November	31.1	21.1	79	3.0	261
December	32.2	19.4	70	3.0	14
January	33.1	18.6	62	4.6	32
February	34.8	21.9	**49**	5.1	0
March	37.0	21.6	66	5.9	0
April	35.8	24.8	71	5.0	119
May	32.6	24.3	80	3.8	462
June	30.2	24.0	86	3.0	479
July	28.9	23.7	85	2.6	410

The above data was collected from a weather station located 3 km. away from the study area. The r.h. recorded is the mean value from two observations taken in the morning and afternoon.

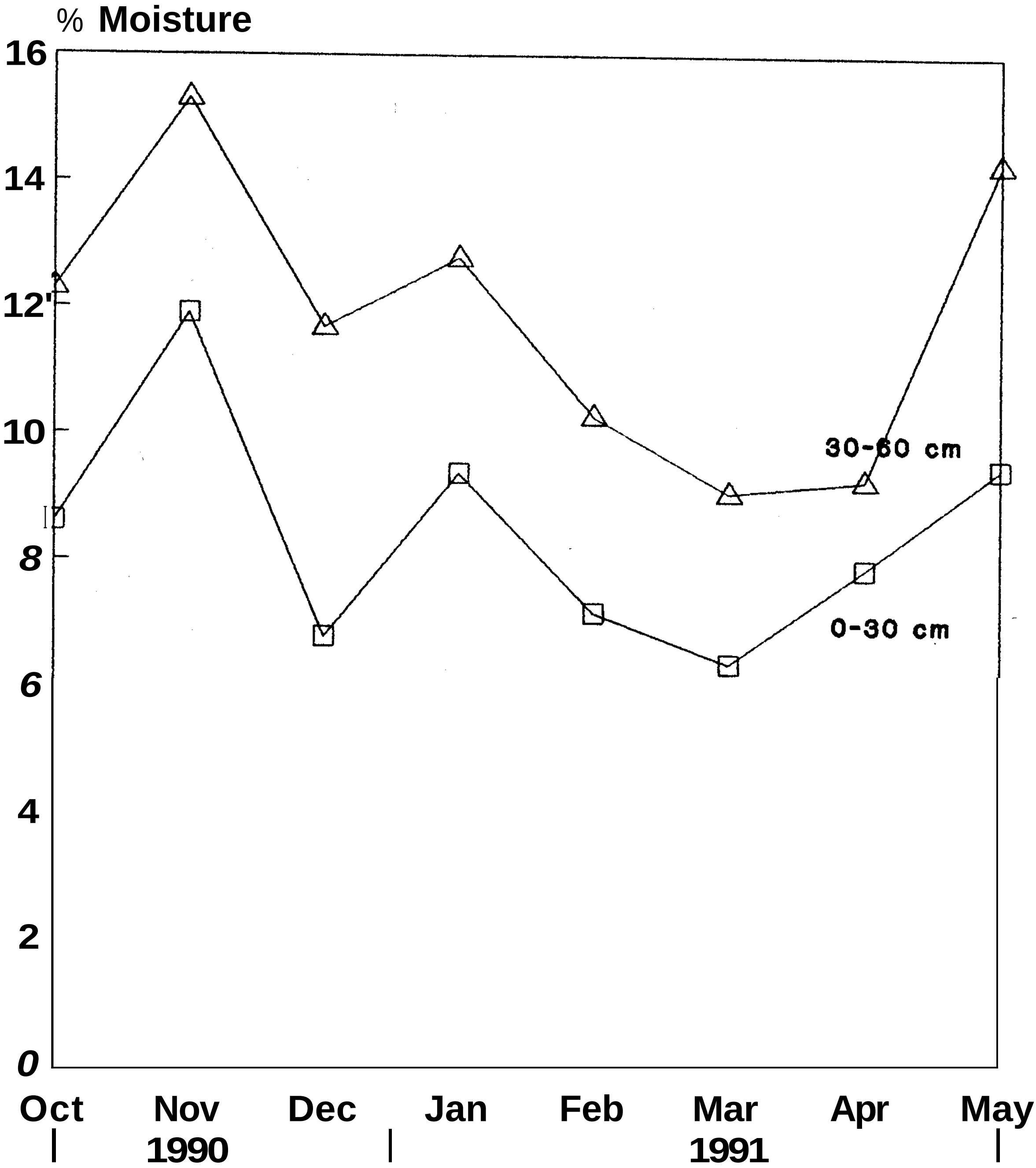

Fig.3. *E. tereticornis* - soil moisture within the plantation (Varavoor) at two depths

moisture content. shows a pattern corresponding to the rainfall and leaf water potentials.

Predawn and midday water potentials measured on days when other physiological measurements were made are shown in Figs. 4a and 4b. Each data point in the above figures is the mean value of at least six independent measurements. The predawn water potentials are indicative of the water availability to the roots. The midday water potentials indicate the maximum tension prevailing in the xylem conducting pathway. Since all the measurements have been made on days with bright sunshine, the values of both predawn and midday values can be reasonably considered as representatives of the minimum water potentials achieved in that month. From Fig.4a and b.it may be noted that the pre-dawn leaf water potentials reach the lowest value of –0.71 MPa in May and the lowest midday values (–1.68 MPa) are reached in March and May. The higher predawn and midday values found in April were probably due to a few summer showers.

At Palode, the minimum predawn value is found in January (–0.34 MPa) and the minimum midday value (–1.40 MPa) is also found in the same month.

From an analysis of the pressure volume curve (Fig. 5) for *E. tereticornis,* it may be noted that the water potential at turgor loss point is –1.75 MPa. This means that the *E. tereticornis* trees at both localities do not

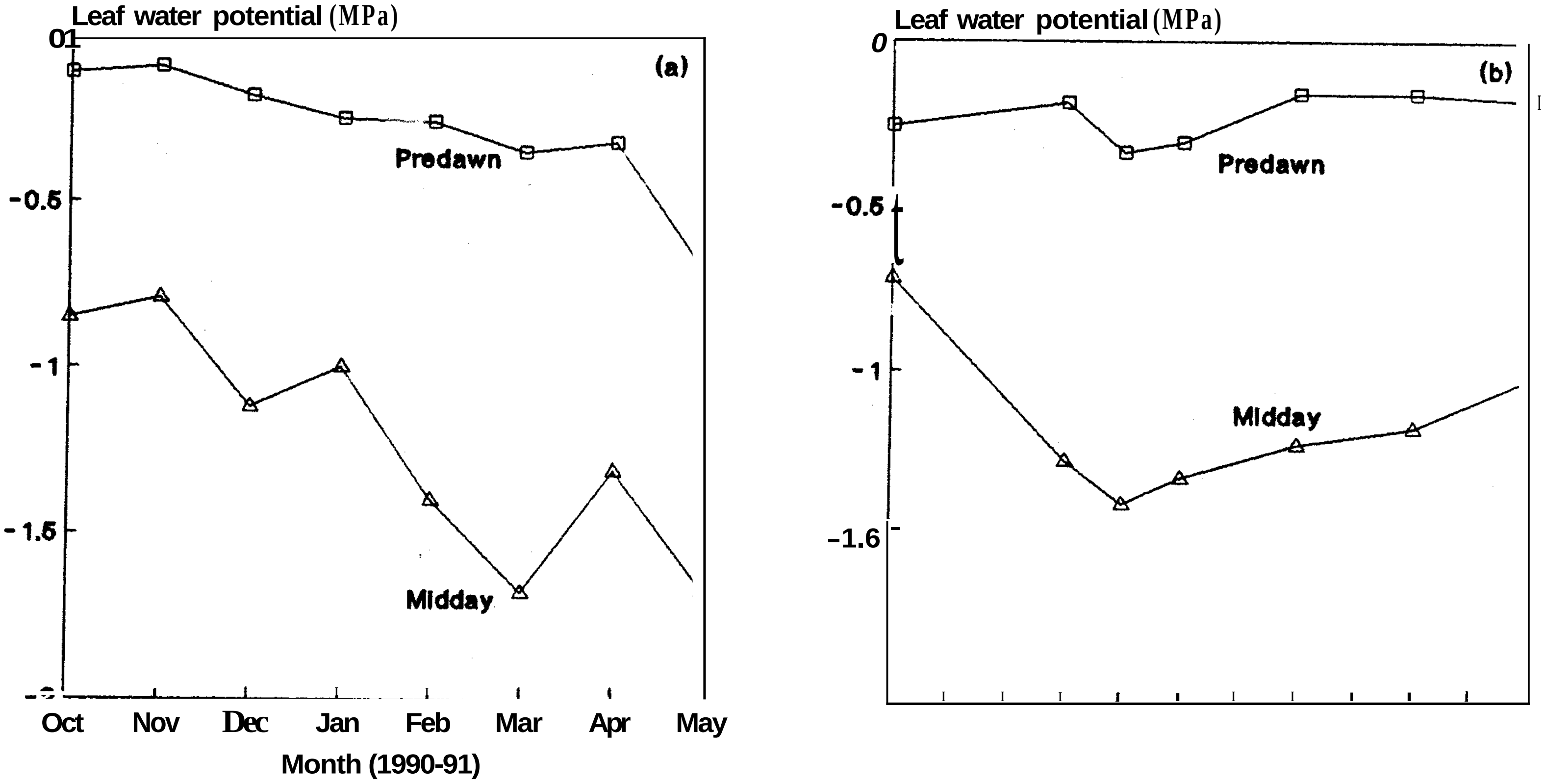

Fig.4. *E tereticornis* - Leaf water potentials - (a) Varavoor (b)

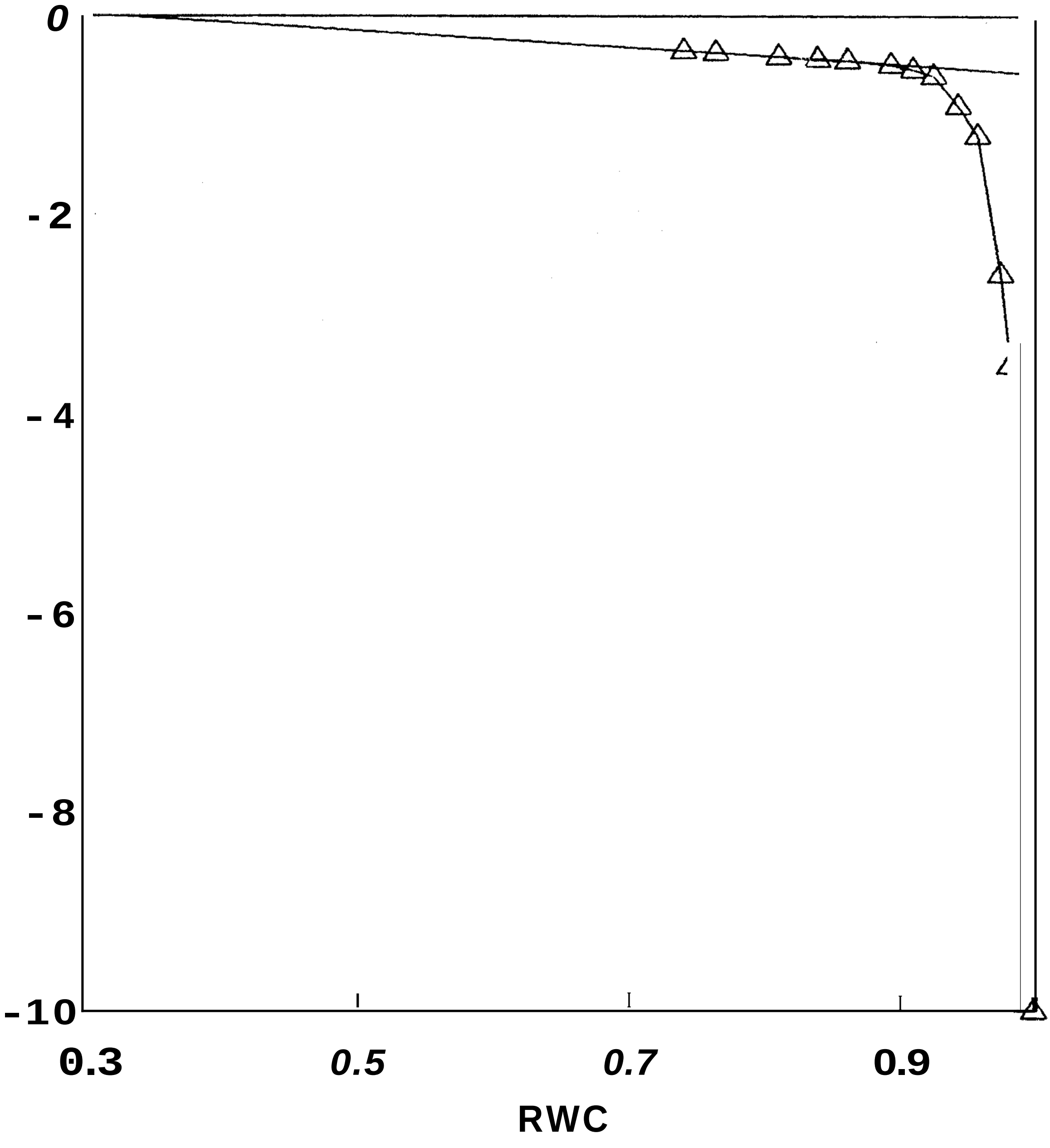

Fig.5. *E. tereticornis* - Pressure volume curve

reach the turgor loss point at any time during the year. As we may see in the later part of this report, this observation has important implications on the stomata1 behaviour of this tree.

Examination of the water potential values on a seasonal basis shows that they are at their highest levels during the post–monsoon period (Sept.-Nov.). During the pre–monsoon period (Dec.-April) both predawn and midday values are lower than the post–monsoon period. However, the values do not reach very low levels as observed in several eucalypt species studied elsewhere. During April and May the trees show slightly higher water potentials, which is due to a few summer showers experienced in these localities.

The water table of both the localities were observed from the nearby wells. During the dry season they remain between 10–15 m deep and during the monsoon and post monsoon period, the levels come within 2–3 m depth because of the possible soil recharge and saturation during the prolonged and heavy monsoon period.

4.1.3. Microclimate

The microclimate parameters measured 2 m above the canopy, like atmospheric temperature (Ta), relative humidity (r.h.), vapour pressure deficit (D) wind speed (u), total solar radiation (S) and net radiation (Rn) are presented in Tables 6 to 13 for Varavoor. Tables 14 to 20 show the

Table 6. *E. tereticornis* (Varavoor) - Hourly microclimate, aerodynanic and stomatal conductances and transpiration data on 9-10-90

Time (h)	T_a (oC)	T_g (oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a (mol $m^{-2}s^{-1}$)	g_s (mmol $m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	23.2	n.r.	100.2		n.r.	-15.73	2.98	1.5	--	--	
700	23.08	n.r.	100.6		n.r.	2.074	2.96	1.5	--	--	
800	24.26	n r.	*99.9*	0.3	n.r.	72.5	2.99	1.5	--	--	
900	**26.63**	n.r.	94.9	0.52	n.r	170.9	2.24	2.0	290	201	
1000	28.47	n.r,	86.9	0.89	n.r.	240.1	1.80	2.5	509	399	
1100	29.6	n.r.	81.5	1.16	n.r.	403.4	1.36	3.3	457	591	
1200	30.3	n.r.	78.4	1.38	n.r.	452	1.24	3.7	625	771	
1300	30.8	n.r.	75.7	1.515	n.r.	578	1.02	4.5	256	.85	
1400	30.8	n.r.	73.7	1.6	n.r.	606	0.79	5.8	406	829	
1500	31	n.r.	73.6	1.62	n.r.	543	0.76	5.8	317	692	
1600	30.6	n.r.	73.8	1.6	n.r.	366.4	0.91	5.0	389	677	
1700	29.4	n.r.	75.3	1.44	n.r.	138	1.13	4,0	247	372	
1800	26.7	n.r.	79.7	1.18	n.r.	33.7	1.58	2.9	247		5.584

Table 7. *E. tereticornis* (Varavoor) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 6-12-90

Time (h)	T_a (°C)	T_g (°C)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a (mol $m^{-2}s^{-1}$)	g_s (mmol $m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	23.41	n.r.	85.8	.39	n.r.	–54.21	.62	3.4	--	--	
700	23.93	n.r.	82.6	.52	n.r.	–49.75	.64	3.7	--	--	
800	24.2	n.r.	82.5	.81	n.r.	9.5	.60	3.7	14	.131	
900	25.6	n.r.	80	.98	n.r,	134	1.52	4.1	267	,289	
1000	27.7	n.r.	74.7	1.3	n.r.	323.8	2.18	5.1	724	.78	
1100	29.4	n.r.	70	1.64	n.r.	465.5	2.14	5.1	508	.866	
1200	29.8	n.r.	68.5	1.72	n.r.	418.8	2.52	5.0	399	,759	
1300	30.1	n.r.	68	1.75	n.r.	488	2.07	5.8	493	,913	
1400	30.7	n.r.	67	1.85	n.r,	541	2.20	6.7	584	1.102	
1500	31.1	n.r.	64.5	2.03	n.r.	433.1	1.96	6.7	353	.829	
1600	31.4	n.r.	61.6	2.2	n.r.	244.6	2.10	6.7	456	,925	
1700	30.3	n.r.	64	1.99	n.r.	71.5	1.82	3.7	15	322	
1800	24.1	n.r.	67.4	1.69	n.r.	–3.7	1.83	3.1	289		7.271

Table 8. *E. tereticornis* (Varavoor) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 16-11-90

Time (h)	T_a (^oC)	T_g (^oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	23.01	n.r.	97.9	,058	n.r	-14.79	.64	2.0	--	--	
700	22.89	n.r.	98	,055	n.r.	-4.64	.64	2.0	--	--	
800	24	n.r.	96.8	.38	n.r.	93.5	.58	1.8	--	--	
900	27.1	n.r.	90	.72	n.r.	270	.90	2.9	497	.380	
1000	29.4	n.r.	82.7	1.11	n.r.	444.5	.73	2.4	447	.574	
1100	29.4	n.r.	80.2	1.19	n.r.	366.8	.71	2.2	522	.561	
1200	30.3	n.r.	77.2	1.38	n.r.	610.9	.76	2.3	506	.800	
1300	30.3	n.r.	76.4	1.43	n.r.	487	.88	2.9	436	.690	
1400	32	n.r.	70.9	1.8	n.r.	625.4	.64	2.0	504	.889	
1500	31.2	n.r.	73.6	1.63	n.r.	367.4	1.14	3.6	366	.600	
1600	28.7	n.r.	82.7	1.06	n.r.	213	1.05	3.4	437	.400	
1700	29.6	n.r.	77.4	1.33	n.r.	203.6	1.24	4.0	264	.395	
1800	28.3	n.r.	79.8	1.15	n.r.	13.8	1.10	3.4	12	.158	5.447

Table 9. ***E tereticornis*** (Varavoor) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data *on* **23-1-91**

Time (h)	T_a (°C)	T_g (°C)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a (mol $m^{-2}s^{-1}$)	g_s (mmol $m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	22.52	n.r.	68.5	.88	n.r	-64.9	1.43	3.2	--	--	
700	22.11	n.r.	69	**.85**	n.r.	-62.94	1.44	3.2	--	--	
800	22.2	n.r.	67	.832	n.r.	-34.02	1.21	3.8	78	0.075	
900	23.7	n.r.	67	.948	n.r.	133.2	0.88	5.1	101	0.137	
1000	26.4	n.r.	59	1.392	n.r.	312	0.67	6.8	166	0.333	
1100	30.5	n.r.	49	2.222	n.r.	482.8	0.68	6.7	215	0.659	
1200	33.4	n.r.	49	3.473	n.r.	569.6	0.46	10.1	235	1.079	
1300	34.6	n.r.	34	3.473	n.r.	598.6	0.57	8.0	183	0.995	
1400	35.5	n.r.	**28**	4.149	n.r.	569.3	0.58	8.0	209	1.138	
1500	35.7	n.r.	28	4.185	n.r.	489.8	0.58	***7.9***	180	0.99	
1600	34.4	n.r.	24	4.177	n.r.	357	0.57	6.0	173	0.922	
1700	35.1	n.r.	29	3.997	n.r.	187.7	0.80	5.7	297	1.146	
1800	31.7	n.r.	31	3.192	n.r.	11.01	1.02	4.5	56	0.234	7.708

Table 10. *E.* **tereticornis** (Varavoor) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 20-2-91

Time (h)	T_a (^oC)	T_g (^oC)	*rh* %	*D* (kPa)	*S* (Wm^{-2})	R_n (Wm^{-2})	*U* (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	21.97	n.r.	87.9	,319	n.r.	-24.92	.653	2.9	--	--	
700	21.51	n.r.	88.3	.301	n.r.	-21.3	.559	2.6	--	--	
800	21.98	n.r.	86.4	.361	n.r.	40.33	.539	2.6	--	--	
900	25.64	n.r.	66.1	1.131	n.r.	157.8	,919	4.5	131	,203	
1000	27.52	n.r.	48.89	1.879	n.r.	386.5	1.67	8.1	149	,409	
1100	29.95	n.r.	41.98	2.465	n.r.	548.3	1.271	5.8	199	.691	
1200	32.15	n.r.	34.43	3.147	n.r.	632.7	1.478	6.7	196	.861	
1300	33.82	n.r.	26.78	3.86	n.r.	650,1	2.177	10.0	142	,800	
1400	35.26	n.r.	21.25	4.494	n.r.	617.6	2.496	13.3	134	,870	
1500	35.71	n,r.	20.93	4.623	n.r.	529.6	2.257	9.9	134	.874	
1600	36.16	n.r.	21.07	4.732	n.r.	388.2	2.025	9.9	55	,394	
1700	35.99	n.r.	21.13	4,683	n.r.	211.4	2.03	9.9	60	,404	
1800	34.93	n.r.	23.28	4.302	n.r.	23.21	1.703	8	52	,310	5.820

Table 11. *E. tereticornis* (Varavoor) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 31-3-91

Time (h)	T_a (^oC)	T_g (^oC)	*rh* %	*D* (kPa)	*S* (Wm^{-2})	R_n (Wm^{-2})	*U* (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	25.03	n.r.	85.8	.451	n.r.	-34.2	.447	2.07	--	--	
700	24.9	n.r.	86.5	.425	n.r.	-27.55	.474	2.179	--	--	
800	25.1	n.r.	06.2	.439	n.r.	-0.50	.466	2.179	--	--	
900	27.4	n,r.	82.4	.652	**n.r.**	104.0	.507	2.4118	164	.139	
1000	30.37	n.r.	74.3	1.117	n.r.	334.7	1.045	5.085	201	.345	
1100	31.96	n.r.	67.95	1.523	n.r.	520.1	**.717**	3.375	352	.690	
1200	33.69	n.r.	55.69	2.320	n.r.	608.9	1.00	4.4778	150	.576	
1300	35.36	n.r.	42.22	3.325	n.r.	**675.5**	1.992	10	141	.714	
1400	37.15	n.r.	33.68	4.203	n.r.	684.5	1.54	6.6333	123	.779	
1500	38.24	n.r.	30.11	4.695	n.r.	637.1	1.709	7.94	110	.773	
1600	30.12	n.r.	33.32	4.489	n.r.	539.8	2.13	9.925	157	.976	
1700	34.22	n.r.	55.03	2.424	n.r.	421.1	2.205	10.075	05	.320	
1800	32.77	n.r.	50.47	2.063	n.r.	186.1	2.244	10.1	80.59	.240	5.561

Table 12. *E.* tereticornis (Varavoor) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 25-4-91

Time (h)	T_a (^oC)	T_g (^oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	26.54	n.r.	82.2	.613	n.r.	-38.21	1.209	5.8571	--	--	
700	25.38	n.r.	79.4	.667	n.r.	-13.96	,552	2.5	--	--	
800	27.53	n.r.	78.1	.811	n.r.	126.7	,679	3.1539	--	--	
900	29.93	n.r.	72.3	1.172	n.r.	315	1.222	5.8143	234	.387	
1000	30.43	n.r.	73	1.174	n.r.	427.7	1.529	6,7833	297	.503	
1100	31.56	n.r.	68.2	1.476	n.r.	554.5	1.697	8.1	198	.476	
1200	32.16	n.r.	63.21	1.766	n.r.	458.2	1.835	8.1	162	.439	
1300	32.47	n.r.	60.46	1.931	n.r.	623.4	2.586	13.5	291	.800	
1400	32.81	n.r.	551.4	2.022	n.r.	649.9	2.281	10.1	286	.826	
1500	33.02	n.r.	55.01	2.265	n.r.	572.5	2.382	10.1	141	.494	
1600	32.8	n.r.	55.36	2.22	n.r.	463.1	2.399	10.1	175	.565	
1700	32.33	n.r.	58.35	2.02	n.r.	254.6	2.089	10.125	146	.411	
1800	31.11	n.r.	65.01	1.583	n.r.	63.81	1.542	10.15	68	.149	5.061

Table 13. *E. tereticornis* (Varavoor) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 21-5-91

Time (h)	T_a (^oC)	T_g (^oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	26.85	n.r.	86.2	.486	n.r.	-10.45	.462	2.2	--	--	
700	26.58	n.r.	86.7	.463	n.r.	15.68	.522	2.4	--	--	
800	27.05	n.r.	77.2	.819	n.r.	136.33	.553	2.6	44	.066	
900	28.46	n.r.	75.7	.943	n.r.	158.8	.594	2.7	99	.147	
1000	29.88	n.r.	74.1	1.093	n.r.	256.8	.751	3.4	186	.295	
1100	30.64	n.r.	72.9	1.195	n.r.	406.1	1.27	5.8	220	.408	
1200	31.98	n.r.	67	1.57	n.r,	658.9	1.581	6.8	202	.539	
1300	33.21	n.r.	62.2	1.928	n.r.	637.1	1.587	b.7	143	.470	
1400	34.69	n.r.	57.51	2.35	n.r.	568.6	1.405	6.7	94	.380	
1500	34.15	n.r.	60.27	2.131	n.r.	493.4	1.773	8.1	188	.586	
1600	33.06	n.r.	63.31	1.858	n.r.	241.5	1.793	8.1	172	.430	
1700	31.91	n.r.	68.15	1.507	n.r.	91.2	11.388	6.8	54	.117	
1800	31.01	n.r.	71.3	1.292	n.r.	9.44	1.079	5.1	19	.0349	3.476

Table 14. *E. tereticronis* (Palode) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 14-7-91

Time (h)	T_a (^oC)	T_g (^oC)	*rh* %	*D* (kPa)	*S* (Wm^{-2})	R_n (Wm^{-2})	*U* (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	24.08	n.r.	86.4	,409	n.r.	-41.1	..	5.9	--	--	
70G	23.98	n.r.	86.6	,401	n.r.	-14.6	..	8.3	251	,035	
800	26.09	n.r.	83.0	.576	n.r.	124	--	5.1	318	,081	
900	27.76	n.r.	77.9	.824	n.r.	304	..	10.2	408	,157	
1000	28.86	n.r.	74.9	,997	n.r.	459	..	10.2	400	,194	
1100	29.66	n.r.	72.5	1.146	n.r.	461	..	10.1	506	,274	
1200	31.03	n.r,	67.7	1.455	n.r.	581	..	8.1	400	.291	
1300	30.4	n.r,	69.67	1.325	n.r.	314	..	13.5	362	.205	
1400	29.51	n.r.	72.5	1.163	n.r.	580	..	20.3	392	.213	
1500	29.58	n.r.	74.1	1.072	n.r.	313	..	13.5	376	,176	
1600	29.79	n.r.	73.4	1.113	n.r.	363	.	13.5	416	.202	
1700	29.18	n.r.	73.7	1.064	n.r.	216	..	13.5	305	,137	
1800	27.71	n.r.	76.5	.872	n.r.	17	..	13.6	247	.085	2.05

Table 15. *E. tereticornis* (Palode) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 1-12.91

Time (h)	T_a (^oC)	T_g (^oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	17.64	..	89.8	.205	-.042	–19.17	.789	3.9	--	--	
700	18.04	..	89.3	.221	17.37	–5.194	.812	3.9	--	--	
800	20.47	20.07	81.2	.466	173.5	91.5	1.087	5.2	120	.0244	
900	24.87	..	70.2	.941	412	260	.948	4.6	312	.1388	
1000	27.36	..	62.91	1.354	625.5	425.7	1.414	6.8	380	.2401	
1100	29.34	..	56.84	1.767	782	551.7	1.279	5.8	321	.281	
1200	29.61	29.5	49.65	2.09	855	616.6	1.918	8.1	313	.2471	
1300	29.14	29.92	49.58	2.108	861	621.9	2.152	10.2	215	.2126	
1400	29.85	30.36	48.1	2.183	788	557	2.559	13.5	254	.2465	
1500	30.26	30.14	45.27	2.357	663.7	460.1	2.135	10.2	226	.2334	
1600	30.24	30.5	46.5	2.303	463.9	298.3	1.985	10.2	226	.2174	
1100	29.15	28.7	48.5	2.082	242.7	119.6	2.528	13.6	144	.1206	
1800	28.04	27.08	56.33	1.662	71.7	–13.81	1.306	5.8	80	.0503	2.0122

Table **16.** *E. tereticornis* (Palode) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 11-1-92

Time (h)	T_a (^oC)	T5 (^oC)	rh %	*D* (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	*U* (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	20 9	19.22	62.42	.928	-.007	-67.04	1.108	5.3	--	--	
700	20.72	18.73	62.28	,922	3.497	-61.17	.695	3.2	--	--	
800	21.09	18.86	61.31	.967	66.85	-14.98	,509	2.4	153	.0498	
900	24.01	22.29	59.15	1.227	359.1.	193.3	,487	2.3	350	.1777	
1000	27.93	26.63	45.39	2.063	581.6	**360.6**	.597	2.7	**389**	.3443	
1100	29.63	29.27	39.25	2.526	782	518.7	.959	4.5	408	.4522	
1200	29.6	30.13	38.44	2.553	891	607	1.729	8.1	416	.4608	
1300	31.16	30.83	35.33	2.933	879	598.3	1.047	5.0	371	.4879	
1400	31.67	31.6	34.5	3.057	856	569	1.188	**5.7**	379	5024	
1500	31.83	32	34.06	3.106	747	472.1	1.489	6.7	318	.4176	
1600	30.99	31.47	34.75	2.931	555.3	322.8	2.446	10.2	289	.3421	
1700	29.78	29.67	36.85	2.646	307.1	146.8	3.478	13.6	174	.1842	
1800	28.76	28.34	38.45	2.432	126.4	13.22	3.245	13.6	127	.1213	3.5403

Table 17, E **tereticornis** (Palode) - Hourly nicroclimate, aerodynamic and stomatal conductances and transpiration data on **19-2-92**

Time (h)	T_a (^oC)	T_g (^oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a (mol $m^{-2}s^{-1}$)	g_s (mmol $m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	23.11	22.79	86	.395	-.105	-53.78	2.116	10.7	--	--	
700	22.88	22.44	86	.39	5.35	-48.82	1.764	8.4	--	--	
800	24.14	23.83	82.3	.537	110.3	29.61	1.861	8.3	.319	.0644	
900	26.38	26.52	73.8	,907	320.3	188.3	1.726	8.2	528	.1919	
1000	28.43	28.77	61.7	1.482	550.2	367.5	1.99	10.2	592	.3598	
1100	30.07	30.78	53.87	1.968	735	509.6	2.302	**10.2**	**605**	.4928	
1200	31.76	32.62	47.23	2.478	073	**6i4.9**	2.216	10.2	563	.5843	
1300	32.91	33.42	44.55	2.776	908	636.2	2.064	10.1	475	.5621	
1400	32.76	33.96	48.06	2.583	846	590.6	2.891	13.5	420	.4624	
1500	32.11	33.53	52.95	2.256	770	536.3	4.192	20.3	357	.3407	
1600	30.93	32.01	57.08	1.685	524.7	360.5	4.161	20.3	365	.284	
1700	29.92	30.37	5823	1.765	249.b	158.2	3.256	13.6	296	.2074	
1800	29.25	29.44	59.65	1.632	**120.7**	66.56	2.63	13.6	356	,2195	3.771

Table 18. *E. tereticornis* (Palode) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 21-4-92

Time (h)	T_a (^oC)	T_g (^oC)	*rh* %	*D* (kPa)	*S* (Wm^{-2})	R_n (Wm^{-2})	*U* (ms^{-1})	g_a (mol $m^{-2}s^{-1}$)	g_s (mmol $m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	21.14	24.77	88.8	.38	-.025	-13.96	,903	4.1	--	--	
700	26.92	24.89	88.3	.415	28.11	8.23	1.029	4.6	--	--	
800	28.59	26.98	85.6	.562	190.7	129.9	1.004	4.5	544	.1274	
900	29.33	29.73	79.2	.851	316.2	301.9	2.056	10.2	708	.2598	
1000	30.64	31.15	73.3	1.178	522.9	458.5	2.129	10.2	- 786	.4045	
1100	31.52	32.61	68.57	1.453	..	621.1	1.981	10.1	865	.5604	
1209	32.66	33.17	63.98	1.781	..	656.1	1.964	8.1	773	.606	
1300	32.75	33.29	61.60	1.801	..	656.0	1.842	8.1	641	.592	
1400	33.49	33.84	59.99	2.068	-6999	562.7	2.89	13.5	660	.5677	
1500	32.96	33.43	60.52	1.982	-6999	481.9	3.233	13.5	666	.5376	
1600	32.48	32.96	61.9	1.862	-6999	415	3.275	13.5	695	.5168	
1700	31.96	31.95	62.76	1.767	357.2	228.6	2.711	10.2	725	.4767	
1800	30.78	30.37	65.98	1.512	107.1	48.66	2.481	8.3	382	.2155	4.8644

Table 19. *E tereticornis* (Palode) - Hourly Microclimate, aerodynamic and stomatal conductances and transpiration data on 5-6-92

Time (h)	T_a (^oC)	T_g (^oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a (mol $m^{-2}s^{-1}$)	g_s (mmol $m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	24.39	24.19	85.9	.43	..	-12.09	1.771	8.3	--	--	
700	24.42	24.22	85.8	.435	23.69	-4.611	1.832	8.3	--	--	
800	25.1	25	84.6	.492	211	115.3	2.125	10.4	734	.0849	
900	26.16	26.38	82.5	.597	500.5	323.1	2.506	10.3	798	.1176	
1000	27.33	27.87	78.2	.793	784.9	495.8	2.71	13.7	887	.1743	
1100	28.85	29.84	72.8	1.082	434	245	2.48	10.2	772	.2185	
1200	29.4	30.26	69.92	1.233	432.9	238.5	2.51	10.2	790	.2561	
1300	29.78	30.72	69.07	1.296	500.5	315.8	2.72	13.6	037	.2097	
1400	29.46	30.19	70.5	1.214	256	140.4	3.042	13.6	708	.248 1	
1500	28.42	29.07	75	,969	506.8	355. 8	3.208	13.6	811	.2162	
1600	29.56	31.07	70.8	1.208	125	55.33	3.671	20.4	605	.2289	
1700	29.24	29.6	70.9	1.183	77.5	20.2	3.476	13.6	482	.1858	
1800	28.32	28.33	72.9	1.045	52.95	1.9	3.155	13.6	381	.1317	2.152

Table 20, *E*, tereticornis (Palode) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 25-8-92

Time (h)	T_a (^oC)	T_g (^oC)	*rh* %	*D* (kPa)	*S* (Wm^{-2})	R_n (Wm^{-2})	*U* (ms^{-1})	g_a (mol $m^{-2}s^{-1}$)	g_s (mmol $m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
600	24.39	24.19	85.9	.43	..	-12.09	1.771	8.3	--	--	
700	24.42	24.22	E5.8	.435	23.69	-4.611	1.832	8.3	--	--	
800	25.1	25	04.6	.492	122.6	64.99	2.125	10.4	616	.0762	
900	26.16	26.38	82.5	.597	304.4	210.5	2.508	10.3	94i.	.1294	
1000	27.33	27.87	70.2	.793	485.0	361	2.71	13.7	990	.1876	
1100	28.85	29.84	72.8	1.08	730	554.6	2.48	10.2	971	.2513	
1200	29.4	30.26	69.92	1.233	692.7	521.8	2.51	10.2	1000	.2958	
1300	29.78	30.72	69.07	1.296	696.4	514.1	2.72	13.6	790	.2756	
1400	29.46	30.19	70.5	1.214	524	303.1	3.042	13.6	811	.267	
1500	20.42	29.07	75	.969	506.0	355.0	3.208	13,6	916	.2162	
1600	29.50	31.07	70.0	1.200	561.4	387.8	3.671	20.4	708	.3119	
1700	29.24	29.6	70.92	1.183	387.3	251.1	3.476	13.6	603	.249	
1800	28.32	28.33	72.9	1.045	192.6	100.8	3.155	13.6	637	.1901	2.45

similar type of microclimate measurements made at Palode during one year of intensive monitoring. Hourly values have been presented in the tables, each value representing the average of 720 measurements (logging of data done at 5 seconds interval).

The highest temperature at Varavoor was noted in March when it reached more than 38^{O}C. The lowest r.h. was observed in February. The D values remained relatively high during January to March in both the localities (> 2.0 kP). The wind speed *(u)* showed much higher values during December to February at Varavoor mainly because of a strong easterly wind blowing through the Palghat gap of the Western Ghats. The R_n also remained relatively high during the pre-monsoon period. The measurements of S and R_n made simulataneously at Palode show good correlation (Fig.6).

4.1.4. Stomata1 conductance

A comparative study of the adaxial and abaxial sides of the *E. tereticornis* leaves showed the presence of stomata on both the surfaces in almost equal frequency (Table 21). The leaves were held on the tree in a pendulous manner. However, it is possible to distinguish morphologically between the adaxial and abaxial surfaces of the leaf from the colour and the venation. While making g_s measurements, both the surfaces were measured consecutively and the hourly averages calculated. The g_s measurements showed that both the surfaces functioned identically irrespective of the

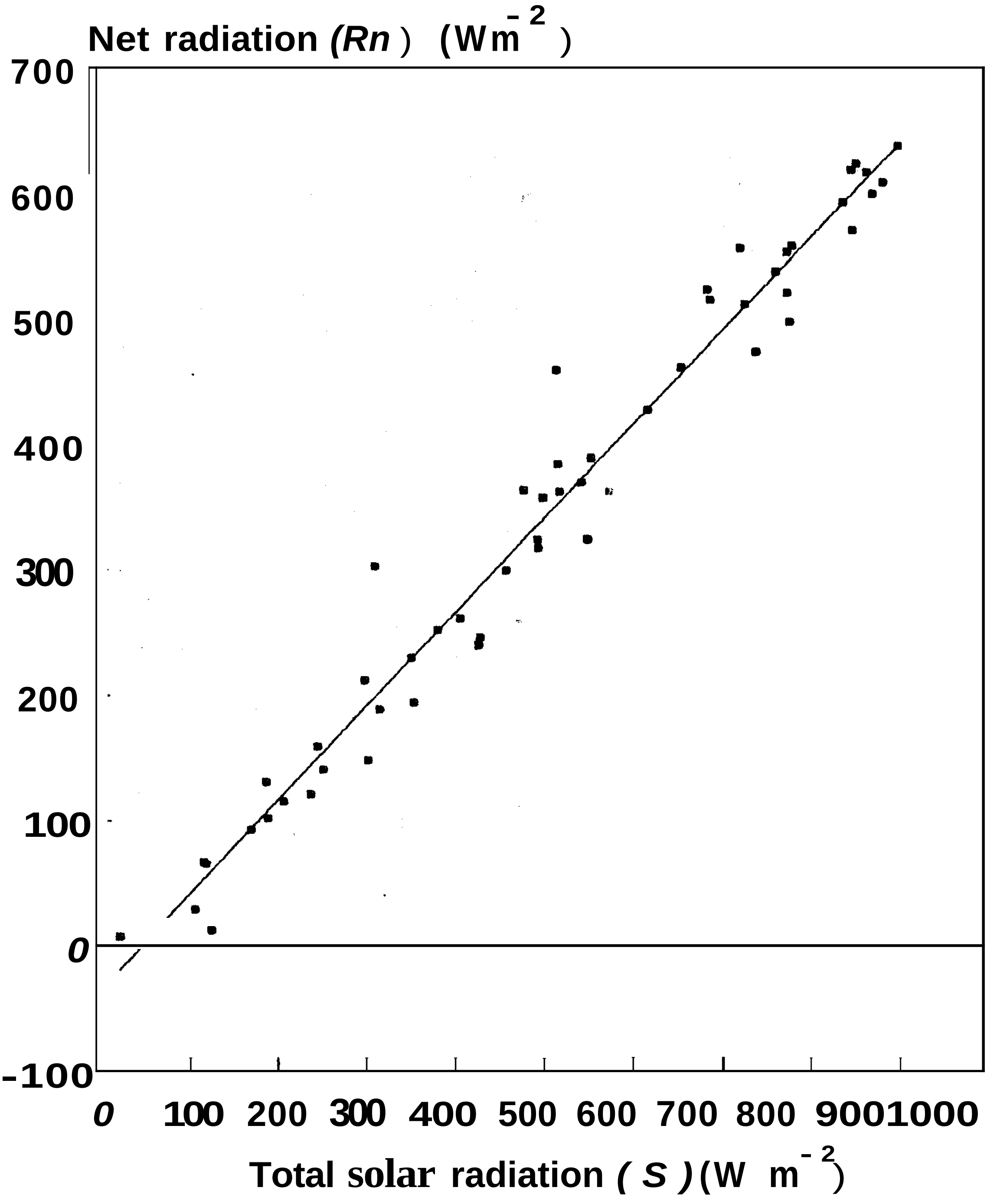

Fig.6. *E. tereticornis* - R_n as a function of S

Table 21. Stomata1 frequency in the leaves of *Eucalyptus*

Species	Adaxial side	Abaxial side
	(No. mm^{-2})	(No. mm^{-2})
E tereticornis	**420 ± 18**	**598 ± 18**
E. grandis	Nil	**284 ± 13**

± S.E. is indicated; N = 10

azimuth angle of the sun. The g_s values are presented in Tables 6 to 20. The canopy conductance (g_c) was calculated from g_s values using the equation.

$$g_c = g_s L \tag{7}$$

where,

L = leaf area index of the conducting surface.

The diurnal variations in g_s values during the post monsoon and the pre-monsoon periods are depicted in Figs. 7a and b. It may be noted that the diurnal variations follow a consistent pattern both in the postmonsoon and dry periods, with higher values in the morning than the afternoon. The seasonal variation was well pronounced at Varavoor when compared to Palode, with higher values of g_s in the postmonsoon period. This is probably because D values reached much higher levels in February at Varavoor compared to that of Palode. At Palode, the diurnal measurements

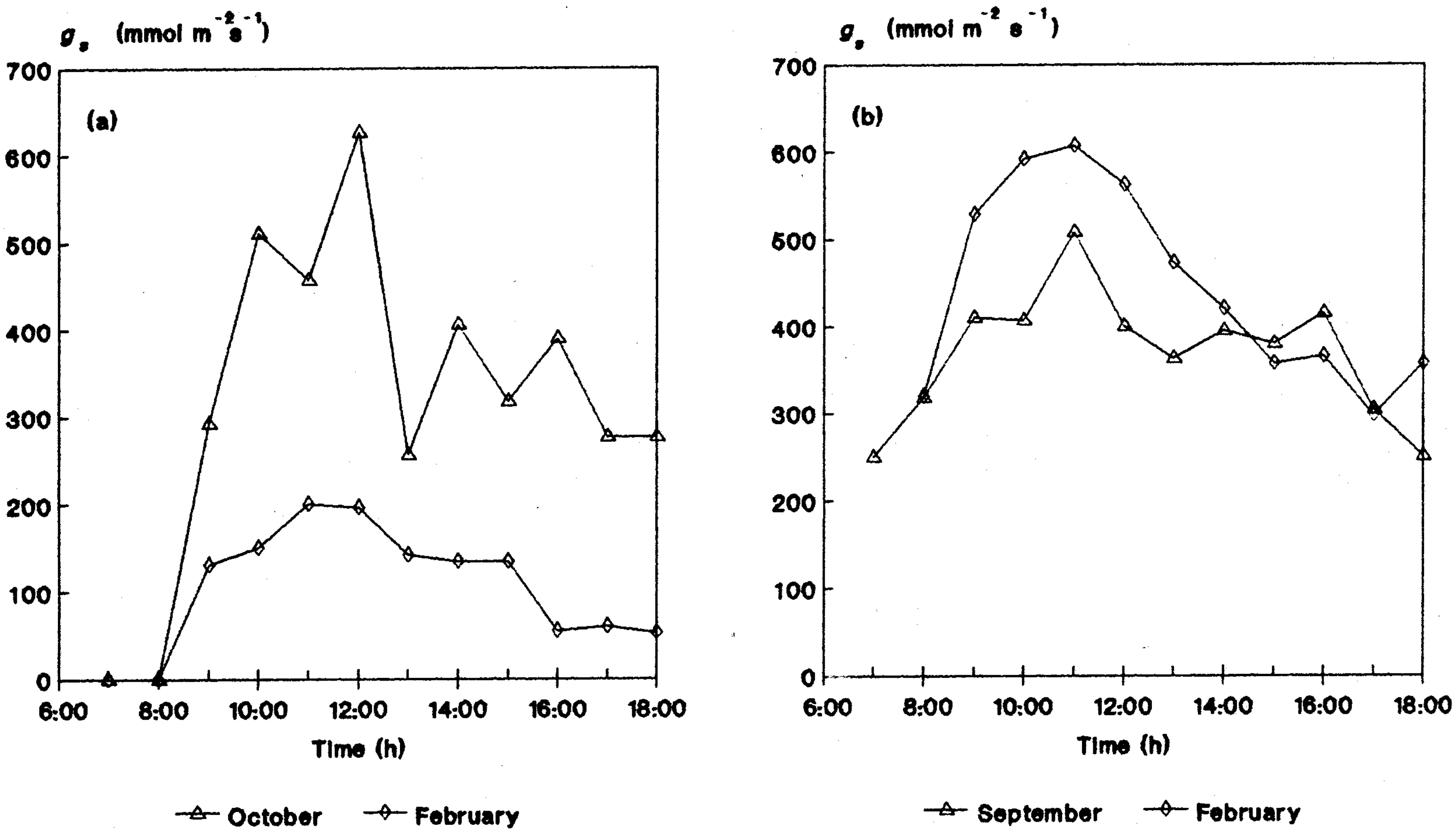

Fig.7. *E. tereticornis* - Diurnal variations in g_s at (a) Varavoor (b) Palode

showed that the g_s values were not significantly different in the two periods.

Fig. 8 shows a scatter plot of the relation between g_s and D measurements. In this graph, all the gs values measured above an R_n value of 100 Wm^{-2} have been used. The correlation between the two factors is poor indicating little stornatal response to atmospheric vapour pressure deficit. In general, in both localities, the relation was similar indicating not much control on the stomatal mechanism by D. The irradiance was certainly important in stornatal functioning, however, the variations were negligible after the light availability became optimum. Since both the plantations in this study are located at low latitudes, light was not a limiting factor except during the monsoon period.

To understand what controls the gs ,a multiple regression analysis of the following form was done using the environmental factors like D, Rn, Ta and

$$g_s = b_0 + b_1 T_a + b_2 R_n + b_3 D + b_4 g_a \qquad (8)$$

However, the correlation coefficient still remained at low level. This probably indicates that, when the roots of *E. tereticornis* have access to water (as indicated by the high predawn water potentials throughout the year), other factors have very little role to play in stomatal functioning. This is unusual when compared to many other

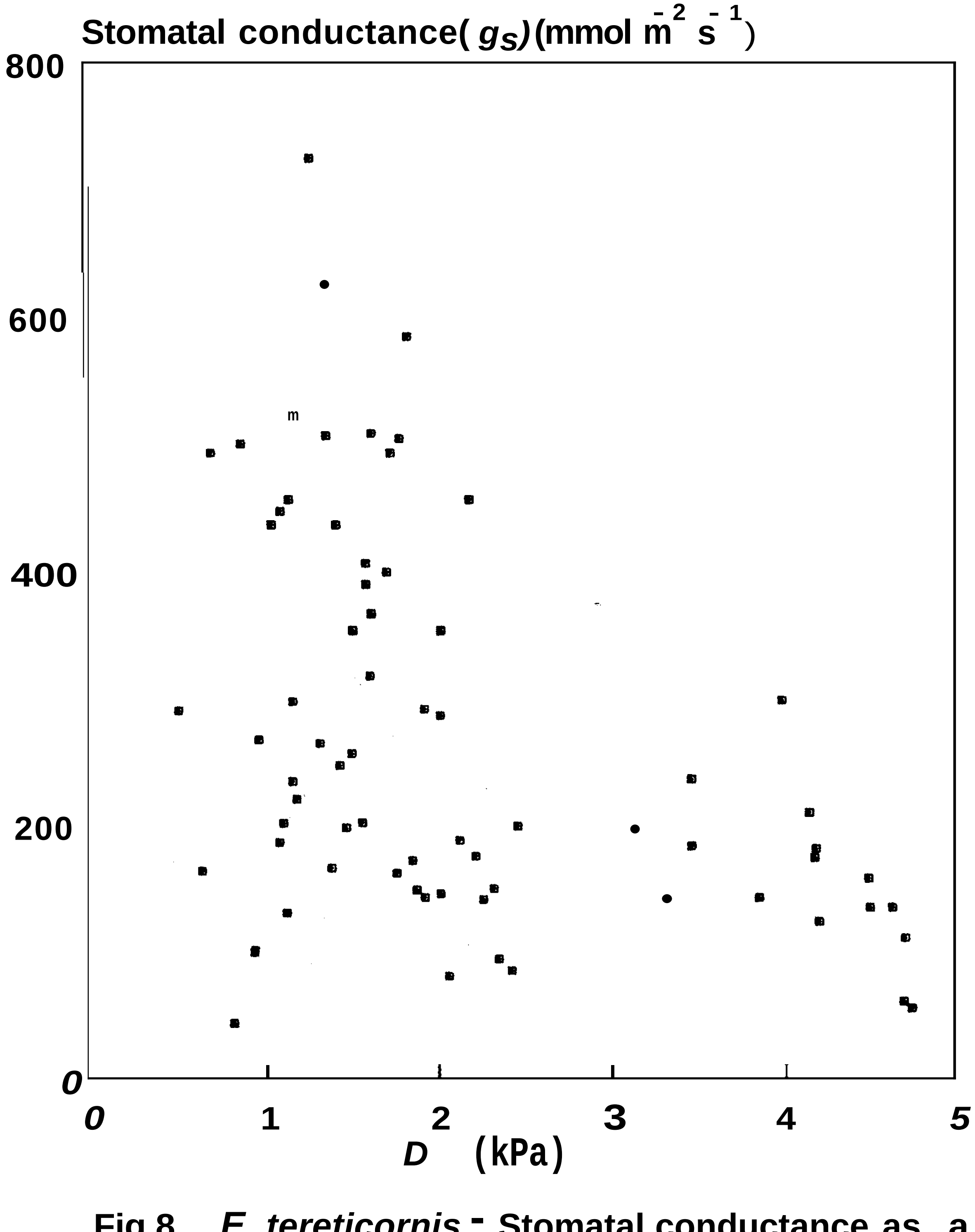

Fig.8. *E. tereticornis* - Stomatal conductance as a function of *D*

plants studied in the literature. In *E. tereticornis* it may be necessary to examine if stomatal control exists in response to D when there is water stress in the soil. The trees in both localities in the present study do not experience extreme stress conditions. Roberts et al. (1992) while studying the *E. tereticornis* in Karnataka have shown that when the midday water potential is around -3.6 MPa, the stomata show almost complete closure. But when the midday potentials were around -2.0 MPa, the stomata functioned normally.

4.1.5. Leaf area index (LAI)

The LAI measurements using the canopy analyser which uses the principle of light interception is a recent method. Hence this was tested against the destructive sampling.

Fig. 9 shows the relation between gbh and leaf area measured in 30 trees using the destructive sampling. It may be seen that the logarithmic values of the two variables show good correlation in a linear fit.

The LAI as measured by the canopy analyser is 2.17 at the Varavoor plantation and 0.60 at Palode. When measurements of the gbh were made to predict the LAI in the above two plantations they agreed reasonably well with the LAI measurements using canopy analyser.

4.1.6. Transpiration

The most widely used form of the combination equation, namely, the Penman-Monteith equation was used to calculate

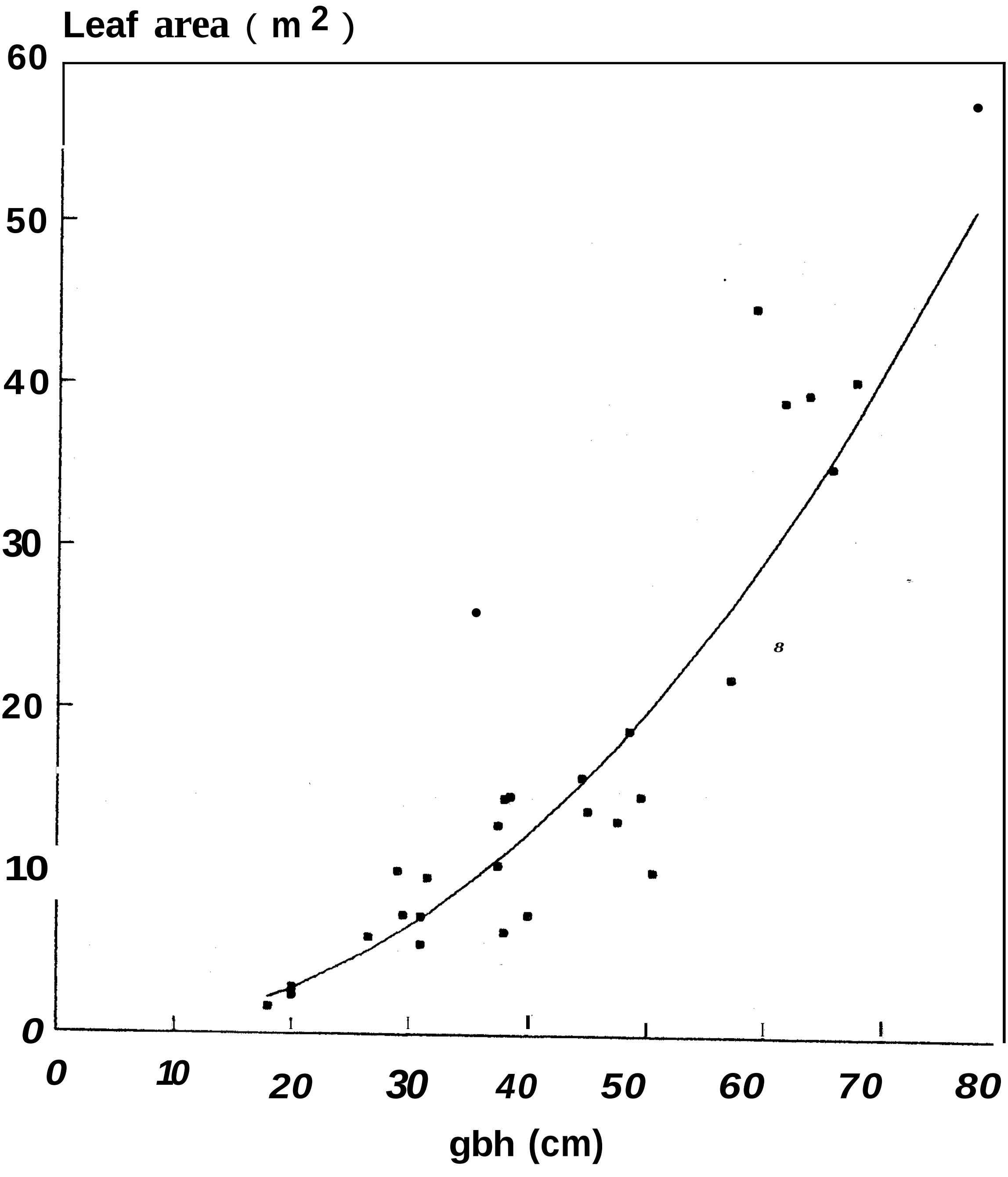

Fig.9. *E. tereticornis* - Leaf area as a function of gbh

the transpiration from the plantation. This gives a one dimensional description of the interrelationships between the weather and vegetation variables (Monteith, 1973).

The microclimate data collected above the canopy and the hourly measurements of g_s formed the basis of applying the above equation in the present circumstance. In our present study we have taken the atmospheric D instead of the leaf to air D by assuming that the leaf is always at the ambient temperature. Computing the transpiration using the above parameters was done on an hourly interval. Results are presented in Tables 6 to 20.

From the above tables and from Fig. 10 it may be seen that the water loss due to transpiration varies diurnally as well as seasonally. This is due to the interaction of several environmental factors like R_n D, g_a etc. and physiological factors, mainly, the g_s and the water potential of the plant. In the Penman-Monteith equation, the energy factor R_n, may not play an important role in determing transpiration value. However, solar radiation is a prerequisite for stomata1 opening and hence affects g_s values.

In most plants, g_s and D are found to be highly correlated variables. But here these two variables are not so correlated. Hence it can be reasonably concluded that transpiration proceeds in accordance with the atmospheric

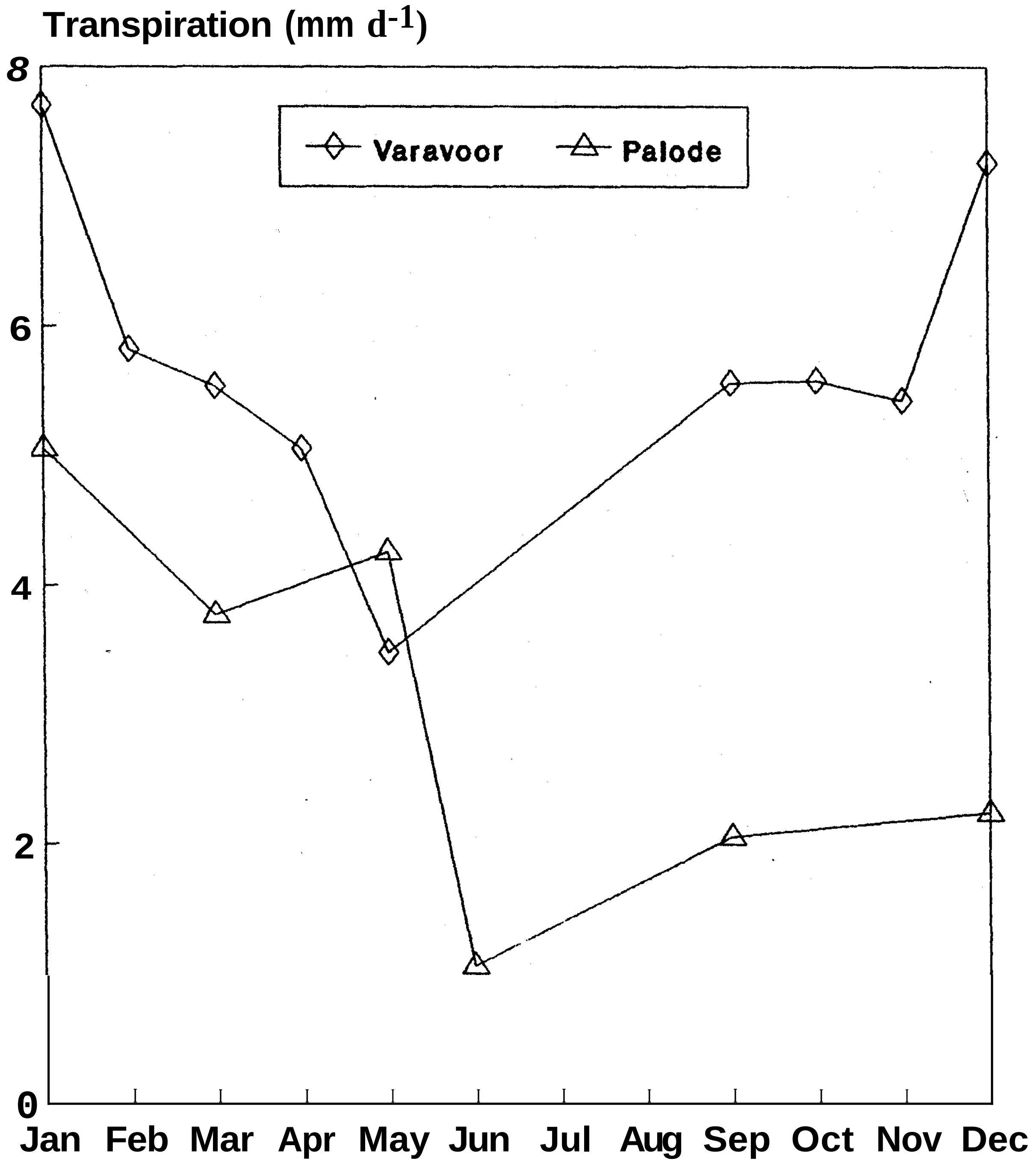

Fig.10. *E. tereticornis* Seasonal variations in daily transpiration rate

vapour pressure deficit in the absence of any remarkable physiological control on stornatal opening. As the g_s does not show any response to D, any increase in the vapour pressure deficit contributes to increased transpiration at least upto a threshold value.

4.1.7. Rainfall interception *(Ei)*

The amount of water lost by interception of rainfall has been estimated from a model requiring minimal data (Calder and Newson, 1979, 1980; Calder, 1992b).

$$E_i = f\,(P_a \alpha - w_a E_{pet}) \qquad (9)$$

where,

f = the fraction of the catchment area under canopy coverage.

P_a = the anual precipitation

α = the interception fraction (taken as 0.4)

w_a = the fraction of the year when canopy is wet (taken as 0.000122 P_a)

E_{PET} = Potential evapotranspiration of the area.

In the above equation, f was measured using the canopy analyser which gives the fraction of sky visible to the sensor (DIFN). f is calculated as (1-DIFN).

Using the above equation the values obtained for Varavoor and Muthanga are given in Table 22. It may be

Table 22. *E. tereticornis* & *E. grandis* - **Rainfall interception estimated from equation (9)**

Station	f	P_a(mm)		W_a	E_{PET}(mm)	E_i(mm)	E_i as % P_a
Varavoor (*E.* tereticornis)	0.68	2837	0.4	0.35	1663	381	13.4
Palode (*E.* tereticornis)	0.35	2465	0.4	0.30	1484	189	7.7
Muthanga (*E.*	0.86	1302	0.4	0.16	1534	230	18.3

noted that 13.4%, 7.7% and 18.3% of the rainfall are intercepted in the three localities respectively. The differences in interception are mainly due to variations in LAI .

4.1.8. Net photosynthesis (P_n) and water use efficiency (WUE)

Fig. **11** shows the P_n, E_c and WUE(Pn/Ec) measured simultaneously in *E. tereticornis* at Palode. For the sake of brevity, only the sample day measurements made on a post monsoon day and a day during the premonsoon period have been graphed. Each data point in the figures is the mean value of at least six measurements on different leaves from different trees. - The WUE is expressed as the µmol CO_2 assimilated per mmol H_20 transpired on a unit leaf area basis.

The diurnal variations in Pn indicate that the photosynthesis is more efficient during the morning, and there is a gradual decrease in the rate during the afternoon (Fig. lla.).

If we assume the sample days measurement as indicative of the post monsoon (August) and premonsoon (February) periods, it may be noted that the P_n and E_c are not significantly different in the above periods. Hence the calculation of the WUE also does not show much variations between the two seasons. This is unlike in *E grandis* reported here. From the Fig. llc it means- that the WUE

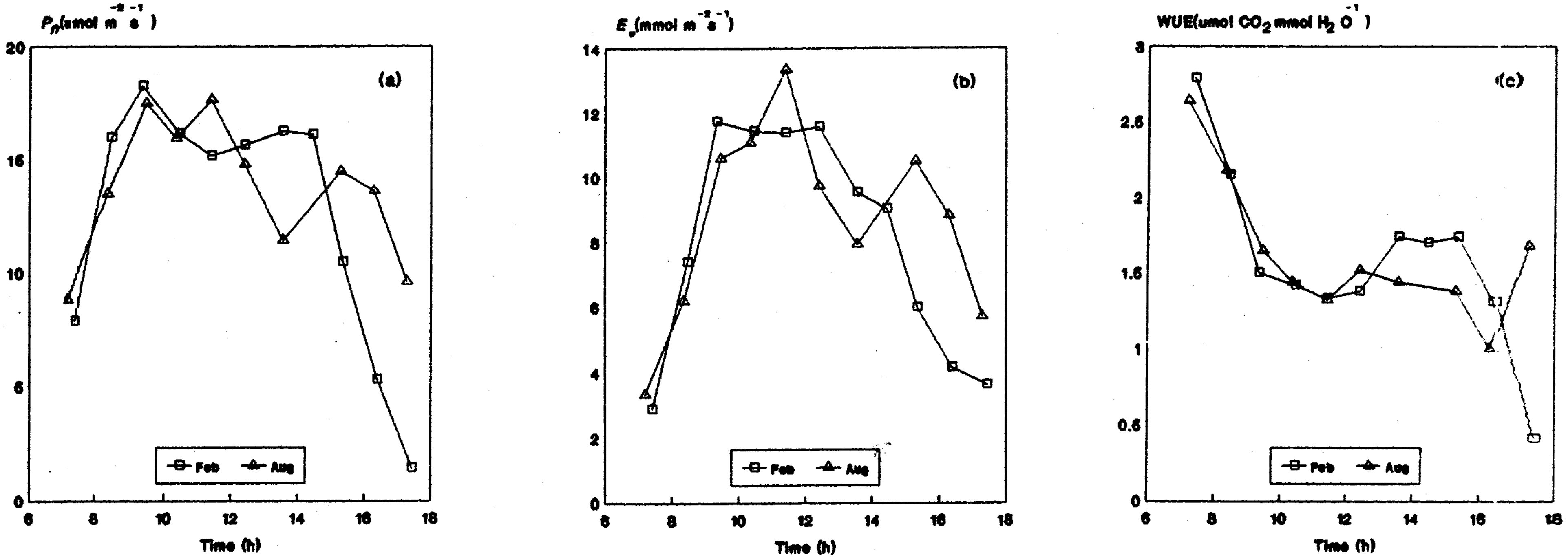

Fig.11. *E. tereticornis* - Diurnal changes in P_n E_c *and WUE*

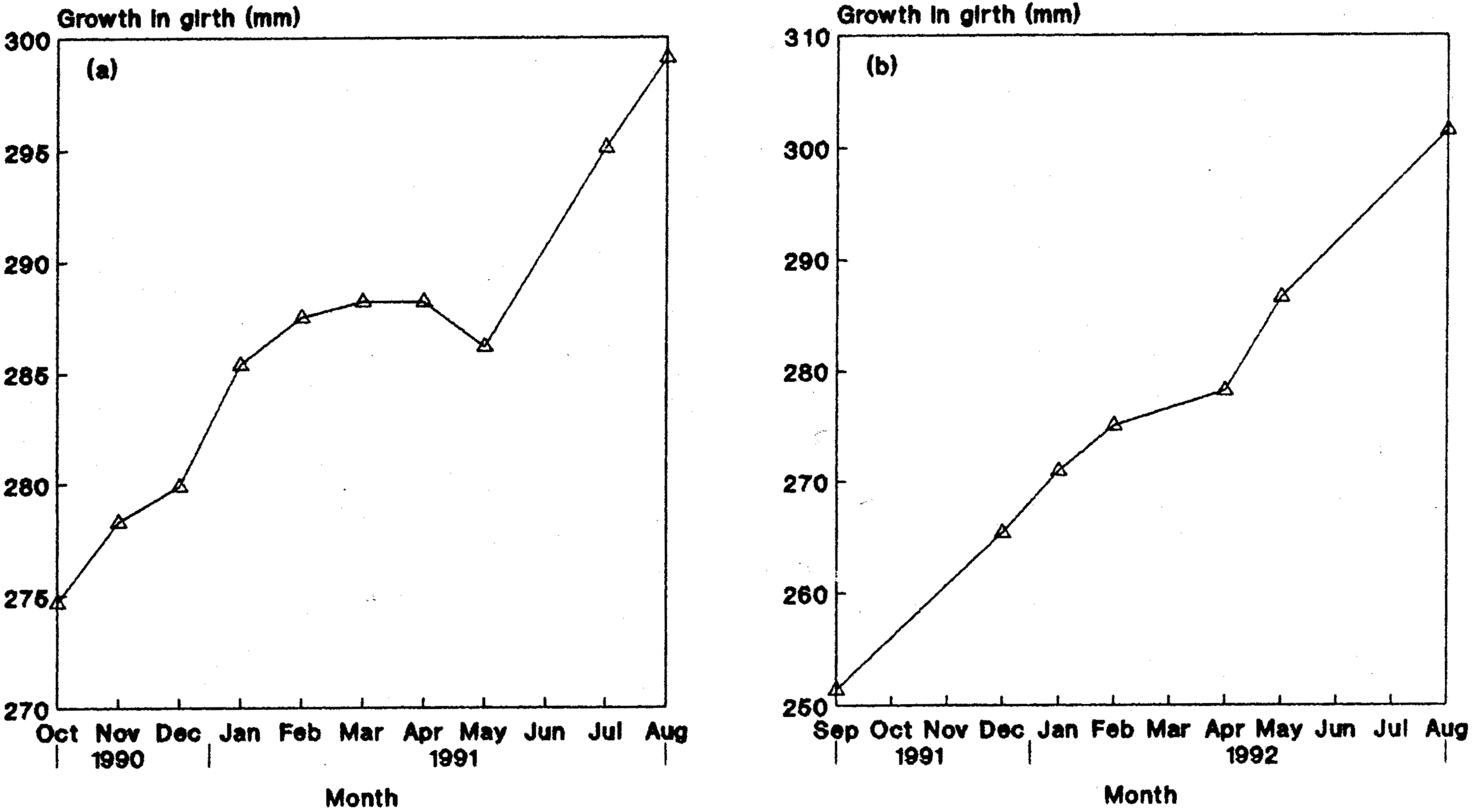

Fig.12. *E. tereticornis* - Increase in girth at (a) Varavoor and (b) Palode

values in *E. tereticornis* ranges between 1.5 and 3.0 µmol CO_2 mmol H_2O^{-1}.

4.1.9. Growth

The growth in girth of 40 trees followed at monthly intervals is depicted in Fig. 12 a & b. The averaged values show that the increase in girth during the pre-monsoon months is minimal. This, however, does not mean that extension growth is affected during the pre monsoon months. As a matter of fact we have observed the production of new leaves during the pre-monsoon period.

4.2. *E grandis*

4.2.1. Weather data

The annual rainfall data collected from a station located 2 km. from the plantation is presented in Table 23. It may be noted that the wettest months of the year are from June to September which is due to the rainfall brought by the South-west monsoon. The dry period is from December to March when there is no or scanty rainfall. The PET values calculated for Mysore from the data collected for 30 years have been shown in Fig. 2 (after Rao et al., 1971). This is because no such data is available for Wyanad. However, the climatic similarity of Wyanad with that of Mysore is well recognised.

4.2.2. Leaf water potentials

Fig. 13 shows the predawn and midday water potentials

Table 23. *E. grandis (Muthanga)* - Rainfall data for Muthanga during the study period (1992-93)

Month	Rainfall(mm)
February	Nil
March	Nil
April	73
May	172
June	411
July	220
August	203
September	140
October	83
November	Nil
December	Nil
January	Nil

The above data was collected from a station located 2 km. away from the study area. The number of rainy days with > 10 mm rainfall was 45 days.

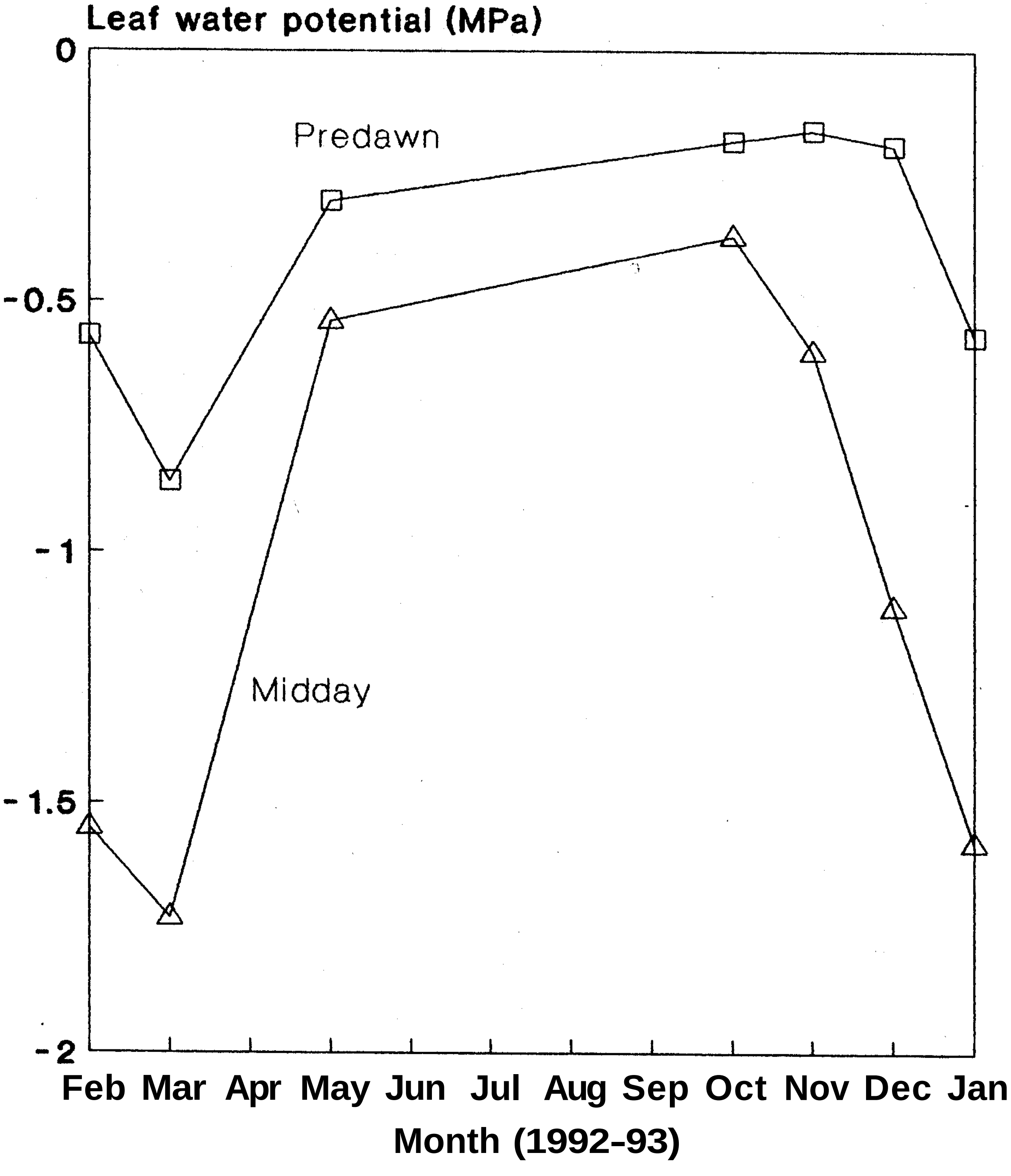

Fig.13. *E. grandis* - Seasonal changes in leaf water potentials

in *E. grandis* when other physiological and microclimate parameters were measured. Each data point is the mean value of at least six independent measurements taken from at least four trees.

From Fig. 13, it may be noted that *E grandis* shows relatively high predawn water potentials throughout the year. The values certainly indicate that *E grandis* is subjected to slightly more stress than the *E. tereticornis* studied at the two localities. This is due to the lower rainfall experienced by the *E. grandis* site when compared to the other two. In *E. grandis* the predawn water potentials reach the lowest levels towards the end of the dry period. The corresponding midday values also show a similar trend. However, the midday values also never reach levels less than –2.0 MPa. Although a p-v-curve analysis of *E. grandis* has not been done in the present study it can be reasonably assumed that the water potential at turgor loss point to be around –2.0 MPa, which means that the water potentials in *E. grandis* never reach the turgor loss levels.

4.2.3. Microclimate

The same micrometeorological parameters as measured above the *E. tereticornis* canopy level were measured here also. The results are presented in Tables 24 to 29.

The highest temperatures in this locality were observed in March when they reached more than 32°C above the tree

Table 24, *E. grandis* (Muthanga) - Hourly microclimate, aerodynamic and stomatal conductances and Transpiration data *on* 13-2-92

Time (h)	T_a (^oC)	T_g (^oC)	*rh* %	*D* (kPa)	*S* (Wm^{-2})	R_n (Wm^{-2})	*U* (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
a. Upper canopy											
600	16.21	15.34	91.1	.164	0	-14	.76	3	--	--	
700	15.93	15.26	91.1	.161	1	-7	1.01	5	--	--	
800	17.00	15.97	89.5	.205	91	31	1.17	5	197	.0419	
900	20.25	20.25	81.9	.436	315	168	1.08	5	270	.1368	
1000	23.33	23.33	69.96	.863	535	323	1.10	5	392	.3657	
1100	24.76	24.56	61.8	1.198	729	481	1.62	8	209	.4173	
1200	26.48	26.63	49.66	1.742	663	451	1.85	8	151	.3234	
1300	27.25	27-49	40.61	2.15	693	470	2.29	11	120	.3124	
1400	28.37	28.46	36.43	2.457	728	483	2.16	11	78	*.2396*	
1500	28.83	28.25	34.52	2.597	560	352	1.60	7	*64*	.2050	
1600	28.94	28.12	33.29	2.663	477	272	1.85	**6**	76	*.2387*	
1700	28.03	26.97	**46.48**	2.039	264	142	1,74	**8**	72	.1670	
1800	26.24	25.41	56.31	1.49	133	43	2.06	11	54	.0900	2.539
lower canopy											
600	16.21	15.34	91.1	,164	-078	-14	.76	3	--	--	
700	15.93	15.26	91.1	.161	1	-7	1.01	5	--	--	
800	17.00	15.97	89.5	,205	91	i2	1.17	5	19	.0207	
900	20.25	20.25	81.9	**.436**	315	65	1.08	5	27	.0634	
1000	23.33	23.33	69.96	**.863**	535	125	1.10	5	39	.1735	
1100	24.76	24.56	61.8	1.198	729	187	1.62	8	28	.1911	
1200	26.45	26.63	49.66	1.742	663	176	1.85	8	15	.1485	
1300	27.25	27.49	40.61	2.15	693	183	2.29	11	12	.1459	
1400	20.37	28.46	36.43	2.457	728	108	2.16	11	7	.1104	
1500	28.83	20.25	34.52	2.597	560	137	1.60	8	**6**	.0950	
1600	28.94	28.12	33.29	2.663	477	106	1.85	8	7	.1138	
1700	28.03	26.97	**46.48**	2.039	264	55	1.74	8	7	.0808	
1800	26.24	25.41	56.31	1.49	133	16	2.06	11	**5**	.0441	1.186

Table 25, *E.* **grandis**(Muthanga) - Hourly microclimate, aerodynamic and stomata1 conductances and transpiration data on 12-3-92

Time (h)	T_a (°C)	T_g (°C)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a (mol $m^{-2}s^{-1}$)	g_s (mmol $m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
a. Upper canopy											
600	18.27	17.74	89.8	.214	0	-24	1.17	5	--	--	
700	17.58	16.86	90.4	.193	9	-18	1.21	6	--	--	
800	18.43	16.98	89.8	.217	147	24	0.63	3	--	--	
900	23.17	19.36	74.5	.745	404	176	0.60	2	192	.1674	
1000	25.87	23.25	55.67	1.479	646	357	.85	4	213	.3680	
1100	27.89	27.04	42.56	2.173	844	529	1.170	5	48	.1515	
1200	30.08	30.44	25.74	3.168	955	616	1.91	8	27	.1160	
1300	30.73	32.05	15.16	3.755	991	648	2.80	14	21	.1008	
1400	31.91	33.1	10.91	4.216	940	598	2.43	10	25	.1362	
1500	32.72	33.31	10.32	4.441	848	528	2.12	10	25	.1429	
1600	31.9	31.63	30.l	3.34	609	367	1.97	10	36	.1519	
1700	29.88	29.29	38.79	2.582	334	192	2.40	10	50	.1518	
1800	25.43	28.03	43.09	i.208	130	86	2.06	11	8	.0213	1.51
b. Lower canopy											
600	18.27	17.74	89.8	.214	0	-24	1.17	5	-	.0005	
700	17.58	16.86	90.4	.193	9	-18	1.21	6	-	.0005	
800	18.43	16.98	89.13	.217	147	24	.63	3	-	.0007	
900	23.17	19.36	14.5	.745	404	68	.60	2	8	.0376	
1000	25.07	23.25	55.67	1.479	646	139	.85	4	8	.0745	
1100	27.89	27.04	42.56	2.173	044	206	1.17	5	5	.0686	
1200	30.08	30.44	25.74	3.168	955	240	1.91	8	2	.0468	
1300	30.73	32.05	15.16	3.755	991	252	2.80	14	1	.0240	
1400	31.91	33.1	10.91	4.216	940	233	2.43	10	1	.0279	
1500	32.72	33.31	10.32	4.441	848	206	2.12	10	1	.0511	
1600	31.9	31.63	30.1	3.34	609	143	1.97	10	4	.0780	
1700	29.88	29.29	38.79	2.582	334	75	2.40	10	4	.0626	
1800	28.43	28.03	43.09	2.208	130	33	2.06	11	1	.0213	.494

Table 26. *E. grandis* (Muthanga) - Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 14-5-92

Time (h)	T_a (^oC)	T_g (^oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
a. Upper canopy											
600	20.23	19.92	90.6	.223	0	-5.533	.54	2	--	--	
700	20.39	20.03	90.6	.226	25	9.91	.51	2	--	--	
800	21.06	20.81	90.4	.241	95	59.05	.48	2	--	--	
900	22.49	22.05	89.6	.285	243	162.1	.57	3	--	.0017	
1000	25.76	24.44	81.8	.614	0	387.5	.85	4	257	.2569	
1100	28.04	26.75	71.4	1.085	0	616.9	1.24	6	293	.4607	
1200	28.76	27.49	63.43	1.446	0	514.3	1.01	4	439	.6676	
1300	30.6	28.29	53.95	2.025	0	634.7	.86	4	421	.5650	
1400	30.7	27.98	55.08	1.985	0	273.8	.76	3	638	.8347	
1500	30.89	29.97	52.18	2.135	605	447.6	1.36	7	212	.5211	
1600	30.96	29.51	53.12	2.103	559	397.4	1.11	5	147	.3776	
1700	29.63	27.6	63.36	1.527	269	178.7	1.18	6	127	.2207	
1800	28.87	26.58	66.84	1.322	113	47.32	.88	4	100	.1359	4.342
b. Lower canopy											
600	20.23	19.92	90.6	.223	0	-5.533	.54	2	--	--	
700	20.39	20.03	90.6	.226	25	9.91	.51	2	--	--	
800	21.06	20.81	90.4	.241	95	59.05	.48	2	--	--	
900	22.49	22.05	89.6	.285	243	63.21	.57	3	--	.0011	
1000	25.76	24.44	81.8	.614	0	151.1	.85	4	51	.1707	
1100	28.04	26.75	71.4	1.085	0	240.6	1.24	6	40	.2486	
1200	28.76	27.49	63.43	1.446	0	200.5	1.01	4	22	.1875	
1300	30.6	28.29	53.95	2.025	0	247.5	.86	4	15	.1907	
1400	30.7	27.98	55.08	1.985	0	145.7	.76	3	12	.1440	
1500	30.89	29.27	52.18	2.135	605	174.5	1.36	7	5	.0702	
1600	30.96	29.51	53.12	2.103	559	154.9	1.11	5	28	.3087	
1700	29.63	27.6	63.36	1.527	269	69.69	1.18	6	5	.0467	
1800	28.87	26.58	66.84	1.322	113	18.45	.88	4	0	.0004	1.368

Table 27. ***E.* grandis** (Muthanga) - Hourly microclimate, aerodynamic and stomatal conductances and **transpiration data** on 28-10-92

Time (h)	T_a (^oC)	T_g (^oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
a. Upper canopy											
600	18.13	18.01	89	.228	-.03	−6.453	.452	2	--	--	
700	16.22	18.01	89	.23	11.49	3.307	.452	2	--	--	
800	18.68	18.65	88.9	.24	61.38	43.89	.49	2	--	--	
900	19.79	19.59	88.5	.265	159.5	116.4	.504	2	--	--	
1000	21.56	21.13	85.7	.37	250.4	178.4	.564	2	810	.2349	
1100	22.25	21.47	80.8	.514	183.3	126.6	.623	3	657	.238	
1200	22.52	21.58	79.7	.554	170.8	118.5	.646	3	637	.245 1	
1300	22.14	21.23	80	.533	212.6	150.4	.504	2	784	.2624	
1400	23.78	22.28	75.7	.719	369.6	282.4	.519	2	805	.4144	
1500	25.89	24.45	72.4	.925	313.5	174.6	.693	3	544	.3659	
1600	26.2	25.11	70.1	1.015	325	135.6	.862	4	292	.2724	
1700	24.78	23.9	71.8	.883	119	35.51	.74	3	190	.1494	
1800	23.27	22.37	78.5	.617	53	−10.78	1.076	5	159	.0904	
b. Lower canopy											
600	18.13	18.01	89	,228	-.03	−6.453	.452	2	--	--	
700	18.22	18.01	89	.23	11.49	3.307	,452	2	--	--	
800	18.68	18.65	88.9	.24	61.38	43.89	.49	2	--	--	
900	19.79	19.59	88.5	.265	159.5	116.4	.504	2	--	--	
1000	21.56	21.13	85.7	.37	250.4	69.42	.564	2	611	.1024	
1100	22.25	21.47	80.8	,514	183.3	49.37	.623	3	755	.1439	
1200	22.52	21.58	79.7	.554	170.8	46.21	.646	3	639	.1383	
1300	22.14	21.23	80	.533	212.6	58.51	,504	2	536	.1185	
1400	23.78	22.28	75.7	,719	369.6	110.1	.519	2	505	.1671	
1500	25.89	24.45	72.4	.925	313.5	68.09	,693	3	300	.1341	
1600	26.2	25.11	70.1	1.015	325	52.88	,862	4	162	.0868	
1700	24.78	23.9	71.8	,883	119.5	13.84	.74	3	247	.1004	
1800	23.27	22.37	78.5	.617	53.89	−4.204	1,076	5	311	.0876	1.079

Table 28. *E, grandis* (Muthanga) - Hourly microclimate, aerodynanic and stomatal conductances and transpiration data on 31-12-92

Time (h)	T_a (^oC)	T_g (^oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a ($mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
a. Upper canopy											
600	12.37	11.61	90.2	.141	-	-21	.46	2	--	--	
700	11.76	11.16	90.3	.133	1	-20	.48	2	--	--	
800	11.9	10.83	90.4	.134	39	2	.46	2	--	--	
900	14.17	13.95	89.9	.163	144	43	.73	3	510	.0712	
1000	18.45	17.37	82.7	.382	598	250	.91	4	599	.2424	
1100	21.78	20.3	63.52	.956	811	487	1.30	5	540	.5491	
120G	24.49	23.64	48.02	1.606	313	624	2.02	11	439	.7646	
1300	26.61	25.63	37.44	2.181	944	683	1.88	8	256	.6578	
1400	27.42	26.38	35.86	2.344	630	689	1.96	8	290	.7753	
1500	28.29	26.52	35.72	2.472	770	526	.97	4	205	.5837	
1600	28.1	25.55	36.62	2.41	613	405	.87	4	301	.6932	
1700	26.67	24.25	40.35	2.089	355	80	.72	3	192	.3484	
1800	23.54	21.9	50.12	1.459	72	44	.69	3	27	.0409	4.727
b. Lower canopy											
600	12.37	11.61	90.2	.141	-	-21	.46	2	--	--	
700	11.76	11.1	90.3	.133	1	-20	.48	2	--	--	
800	11.9	10.83	90.4	.134	39	2	.46	2	--	--	
900	14.17	13.95	89.9	.163	144	16	.73	3	29	.0237	
1000	18.45	17.37	82.7	.382	598	97	.91	4	35	.0756	
1100	21.78	20.3	63.52	.956	811	190	1.30	6	31	.1684	
1200	24.49	23.64	48.02	1.608	931	243	2.02	11	29	.3428	
1300	26.61	25.63	37.44	2.181	944	266	1.88	8	29	.3534	
1400	27.42	26.38	35.86	2.344	630	268	1.96	8	23	.3037	
1500	28.29	26.52	35.72	2.472	710	205	.97	4	7	.1071	
1600	28.1	25.55	36.62	2.41	613	158	.87	4	9	.1263	
1700	26.67	24.25	40.35	2.089	355	31	.72	3	2	.0273	
1800	23.54	21.9	50.12	1.459	72	44	.69	3	7	.0572	1.585

Table 29, *E.* grandis (Muthanga) – Hourly microclimate, aerodynamic and stomatal conductances and transpiration data on 31-1-93

Time (h)	T_a (^oC)	T_g (^oC)	rh %	D (kPa)	S (Wm^{-2})	R_n (Wm^{-2})	U (ms^{-1})	g_a (mol $m^{-2}s^{-1}$)	g_s (mmol $m^{-2}s^{-1}$)	E_t (mmh^{-1})	E_t (mmd^{-1})
a. Upper canopy											
600	14.56	14.24	73.8	.435	-	-66	.52	2	--	--	
700	13.67	13.18	75.9	.378	1	'-64	.46	2	--	--	
800	15.05	14.45	69.26	.533	31	-43	.76	3	150	.0728	
900	18.2	17.91	55.38	.938	200	9	1.14	5	166	.1524	
1000	21.28	20.81	45.24	1.388	558	254	1.65	9	286	.4112	
1100	23.06	22.72	40.21	1.687	791	579	1.72	8	327	.6156	
1200	24.48	24.54	36.14	1.962	931	702	1.71	8	294	.6692	
1300	25.69	25.83	31.67	2.256	1010	763	1.67	8	204	.5712	
1400	26.76	26.31	30.77	2.434	964	729	1.52	7	212	.6296	
1500	26.96	26.4	31.06	2.453	871	639	1.49	7	161	.4883	
1600	27.42	26.7	23.75	2.787	286	215	1.18	6	132	.3922	
1700	26.2	25.64	27.2	2.477	139	50	1.09	5	119	.2941	
1800	24.62	24.22	32.12	2.104	50	-31	1.06	5	77	.1631	4.459
b. Lower canopy											
600	14.56	14.24	73.8	.435	-	-66	.52	2	--	--	
700	13.67	13.18	75.9	.378	1	-64	.46	2	--	--	
800	15.05	14.45	69.26	.533	31	-17	.76	3	6	.0187	
900	16.2	17.91	55.38	.938	200	3	1.14	5	7	.0349	
1000	21.28	20.81	45.24	1.388	558	99	1.65	9	18	.1388	
1100	23.06	22.72	40.21	1.687	791	226	1.72	8	5	.0564	
1200	24.48	24.54	36.14	1.962	931	273	1.71	8	11	.1296	
1300	25.69	25.03	31.67	2.256	1010	297	1.67	8	17	.2244	
1400	26.76	26.31	30.77	2.434	964	284	1.52	7	13	.1937	
1500	26.96	26.4	31.06	2.453	871	249	1.49	7	14	.2051	
1600	27.42	26.7	23.75	2.787	286	83	1.18	6	10	.1557	
1700	26.2	25.64	27.2	2.477	139	19	1.09	5	3	.0452	
1800	24.62	24.22	32.12	2.104	50	-12	1.06	5		.0056	1.208

canopy. When compared to the two plantations of *E. tereticornis,* this location is cooler because of the higher geographic elevation. The ground temperature recorded showed nearly $2^{O}C$ lower temperatures than the above canopy temperatures in the morning. However, towards the noon and afternoon, this gap was narrowed, and sometimes the ground temperatures slightly crossed the above canopy temperature.

The r.h. values recorded in this locality are noteworthy. In March, the r.h. value decreased from 90% in the morning to nearly 10% in the afternoon (see Table 25). The D also showed relatively higher values in March. The R_n is also quite high during the dry period.

Fig. 14 shows a plot of the R_n against S measured above the *E. grandis* canopy. The two variables show good linear correlation when fitted by the following equation.

$$R_n = -44.06 + 0.72\,S \qquad (10)$$

$$r^2 = 0.94$$

Since R_n is a difficult parameter to be measured because of the requirement of more sophisticated sensors, the above relation can be used for predicting R_n where S data is available above the *E. grandis* canopy.

4.2.4. Stomatal conductance (g_s)

Microscopic examination of the *E. grandis* leaf showed that the stomata were present only on the abaxial side. This is unlike *E. tereticornis* where the stomatal frequency is more or less equal on both leaf surfaces.

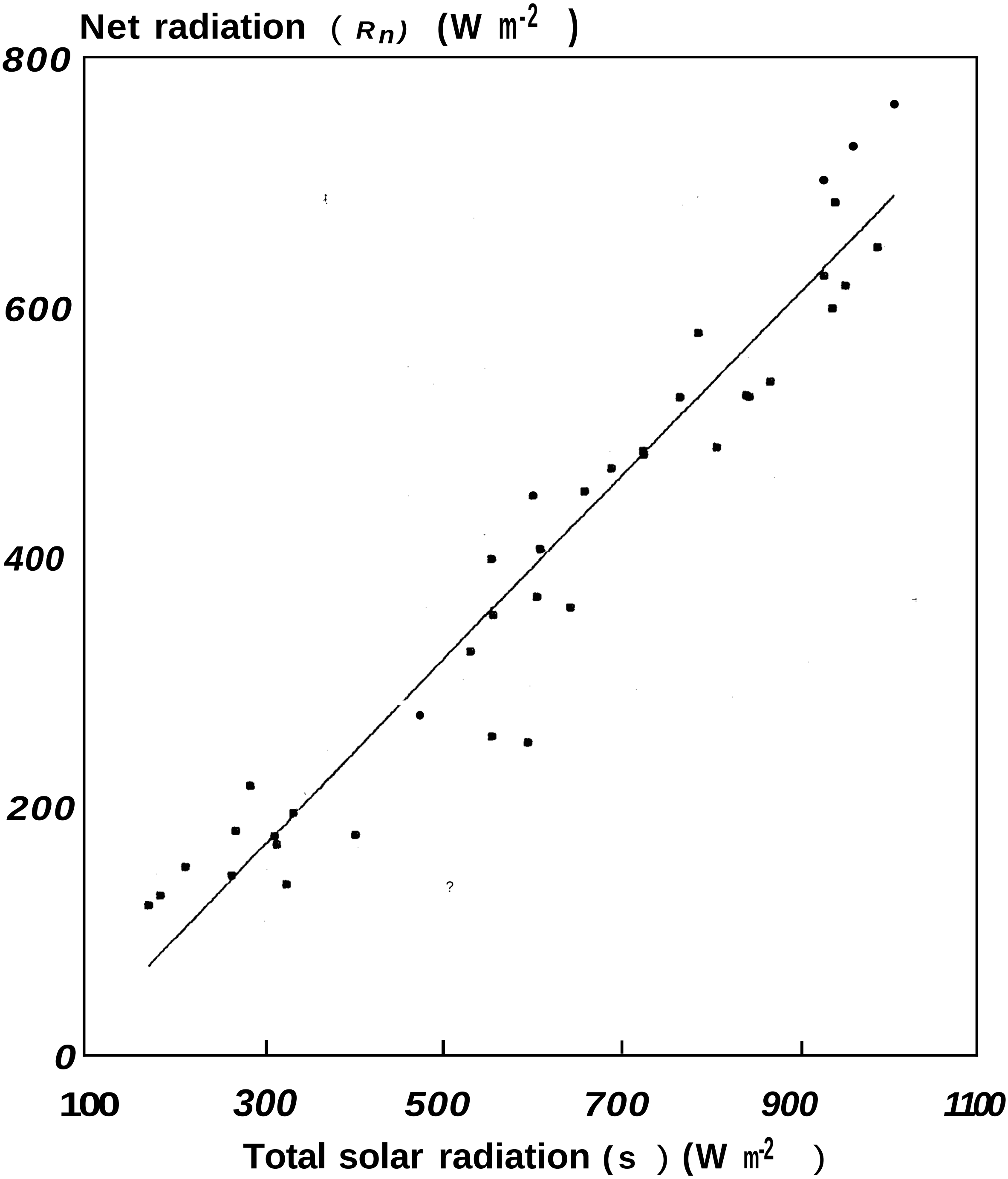

Fig.14. *E.grandis* - *Rn* as a function of *S*

Measurements with the porometer also confirmed this. Hence only the abaxial side was subjected to porometer measurements later. The hourly measurements done on leaves accessible from the scaffold tower is presented in Tables 24 to 29 . The LAI in *E grandis* was much higher than that of *E. tereticornis.* Hence a two layer model of transpiration was followed. From observations it was fround that nearly 70% of the top layer was receiving full sunlight and hence treated as a separate layer from the lower 30%, The measurements made in both the layers are presented in Tables 24 to 29.

A more or less consistent pattern of diurnal variations in g_s was found in porometer measurements (Fig. 15a & b). In *E. grandis,* the morning measurements showed high g_s values and in the afternoon the values decreased. Since the plants did not appear to be under water stress, the trend was the same during the dry period also. The trend was the same in both the upper and lower canopies. The g_s values in the postmonsoon period reached more than 800 mmol $m^{-2}s^{-1}$

To test the influence of various microclimate parameters on g_s, a multiple linear regression model as depicted in equation (8) was tested using T_a, g_a, R_n and D against *gs*. It showed that g_s was mostly controlled by D and the other variables had only minor or non-significant role in controlling g_s.

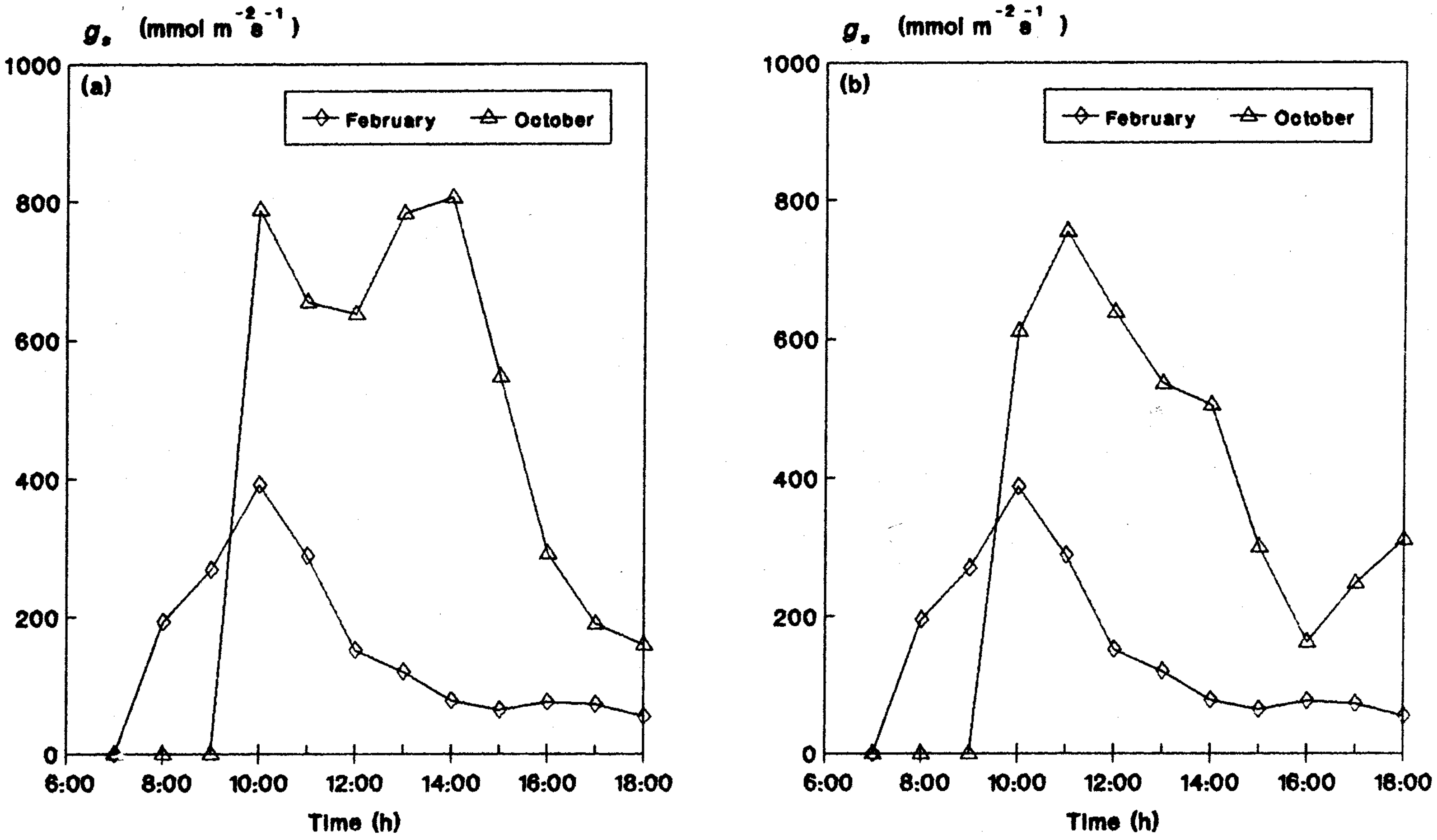

Fig.15. *E. grandis* - Diurnal variations in g_s - (a) upper canopy
(b) lower canopy

Fig. 16 shows the relation between g_s vs. D values measured simultaneously. An equation of the following form has been fitted to the data.

$$\log g_s = 6.7504 - 0.08065\, D \qquad (11)$$

$$r^2 = 0.65$$

This indicates that *E. grandis* is provided with a reasonably good stomatal control of water loss in response to atmospheric water vapour deficit irrespective of the presence of sufficient water in the soil. It should be pointed out that such a control mechanism is relatively poor in *E. tereticornis.*

4.2.5. Leaf area index

The LAI measured by the .canopy analyser gives an average value of 2.75 which is more than the value shown by *E. tereticornis* plantations at the other two locations. In working out the g_s for the upper layer of the canopy, an LAI value of 1.85 was used whereas for the lower canopy layer a value of 0.8 was used.

4.2.6. Transpiration (E_t)

As in *E. tereticornis* the Penman–Monteith equation was used in the calculation of transpiration in *E. grandis*. The hourly values of calculated using the above equation is presented in Tables 24 to 29. It may be noted that the water loss due to transpiration from the lower canopy is

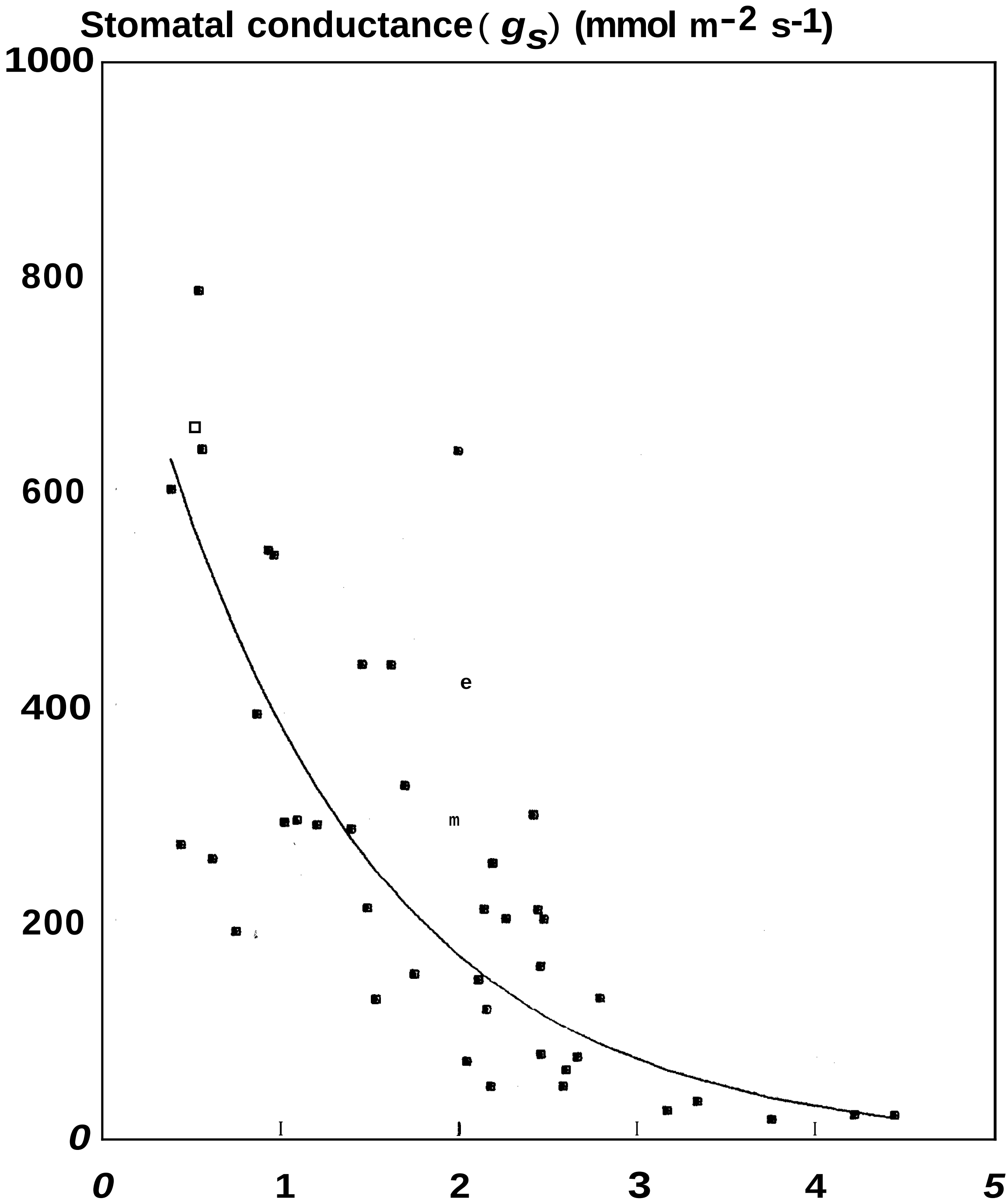

Fig.16. *E. grandis* - Stomatal conductance as function of *D*

much less than that of the upper canopy. The seasonal variations in daily transpiration rate from the upper and lower layers of the canopy are depicted in the Fig. 17. It may be noted that the transpiration loss is comparatively low in February and March in spite of the high atmospheric demand as indicated by the higher values of *D*. This is because of the partial stomata1 closure as shown by the low g_S values. On the contrary, in October, the g_S values are extremely high (Fig. 15a & b). In spite of this, transpiration rates are low mainly because of the low atmospheric demand created by the monsoon showers.

4.2.7. Rainfall interception

The rainfall interception *(Ei)* as estimated from equation (9) is depicted in Table 22.

4.2.8. Net Photosynthesis *(Pn)* and Water use efficiency (WUE)

To understand the instantaneous WUE in the different seasons, the *Pn* and *Ec* were measured simultaneously. Fig. 18a, b & c shows *Pn*, *Ec* and WUE *(Pn/Ec)* measured in *E. grandis* during the postmonsoon and dry periods. Each data point in the figures is the mean value of at least six measurements on different leaves from different trees. The WUE is expressed as the mmol CO_2 assimilated per mmol H_20 consumed. It should be mentioned that the WUE calculated thus is only an instantaneous one. It has no direct

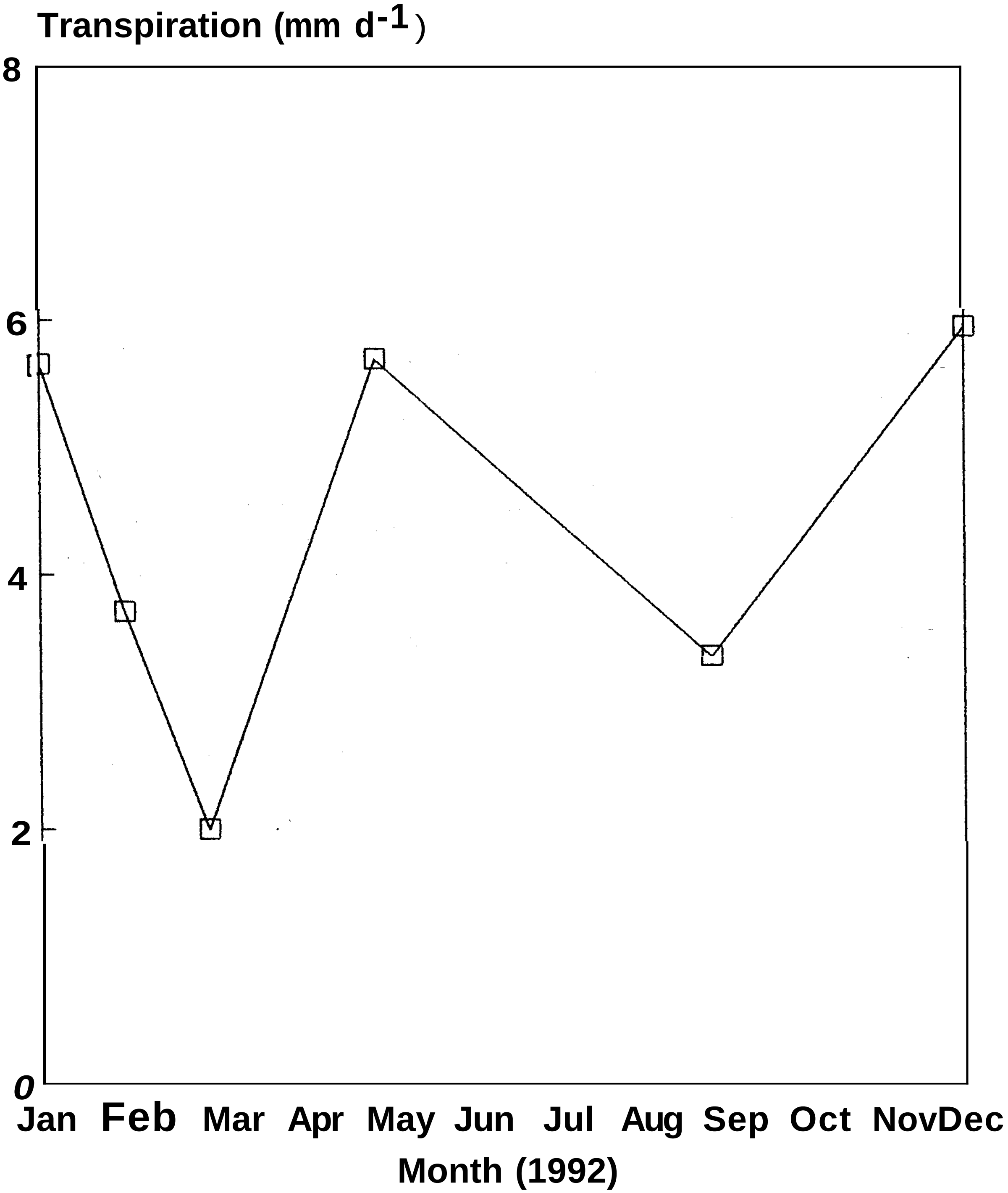

Fig.17. *E. grandis* Seasonal variations in daily transpiration rate

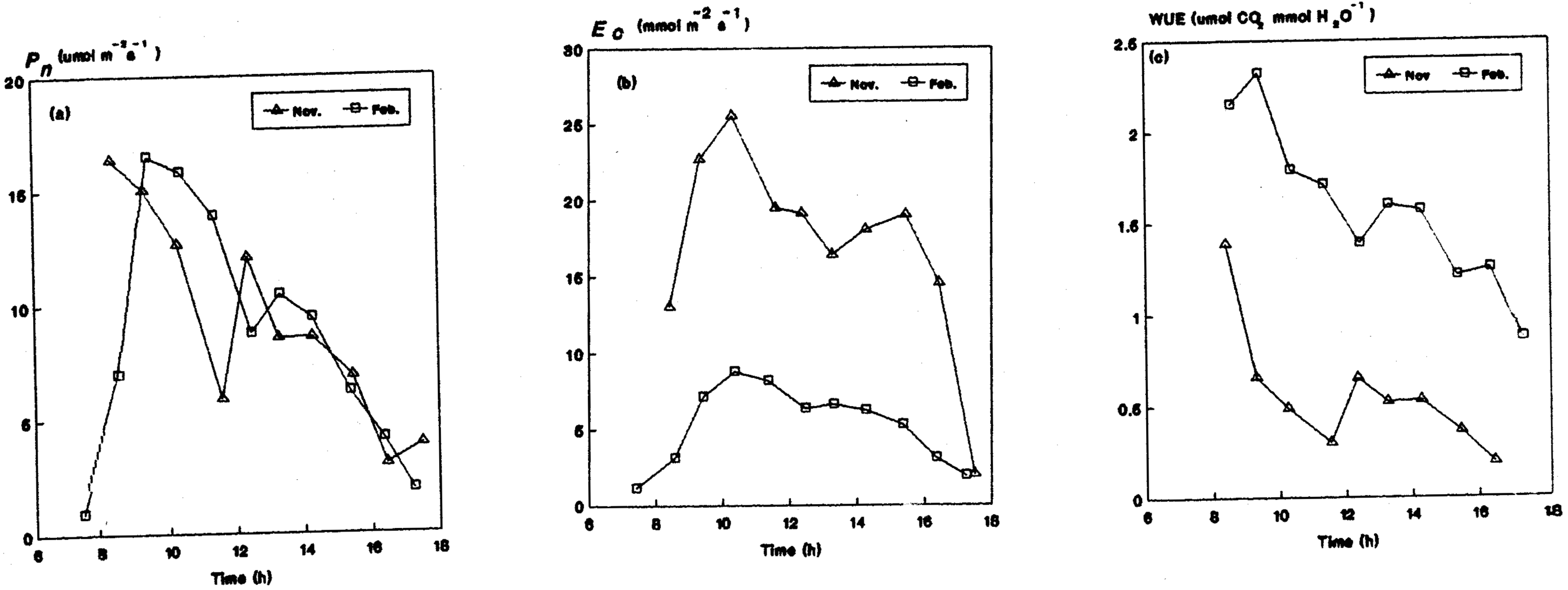

Fig.18. *E. grandis* - Diurnal variations in P_n E_c and WUE

relation with the overall biomass increase in relation to water consumption. However, instantaneous WUE is an indicator of how efficient the leaf is in $C0_2$ assimilation in relation to transpiration. The diurnal variations in *Pn* indicate that the photosynthesis is more efficient during the morning and decreases in rate in the afternoon.

The figures indicate that the P_n during the postmonsoon and dry periods are more or less similar. However, the *Ec* values indicate that the transpiration is much less during the dry period uhen compared to postmonsoon period. Thus when the WUE is calculated, it is found that *E. grandis* is more efficient in its water use during the dry period when compared to the postmonsoon. When the WUE during the two periods is compared, it shows that the values in post-monsoon period ranges between zero and one mmol CO_2 mmol H_2O^{-1} whereas in the dry period the values are between one and 2.5 umol CO_2 mmol H_20^{-1}. It should be mentioned here that the measurements in both the periods were done on clear days when the sky was not overcast.

4.2.9. Growth

The growth in girth of the *E. grandis* trees in the plantation was closely followed by measuring the gbh of forty trees at monthly intervals. The results are presented in Fig. 19. The averaged values of forty,trees show that girth increase occurs in all the months except February to April.

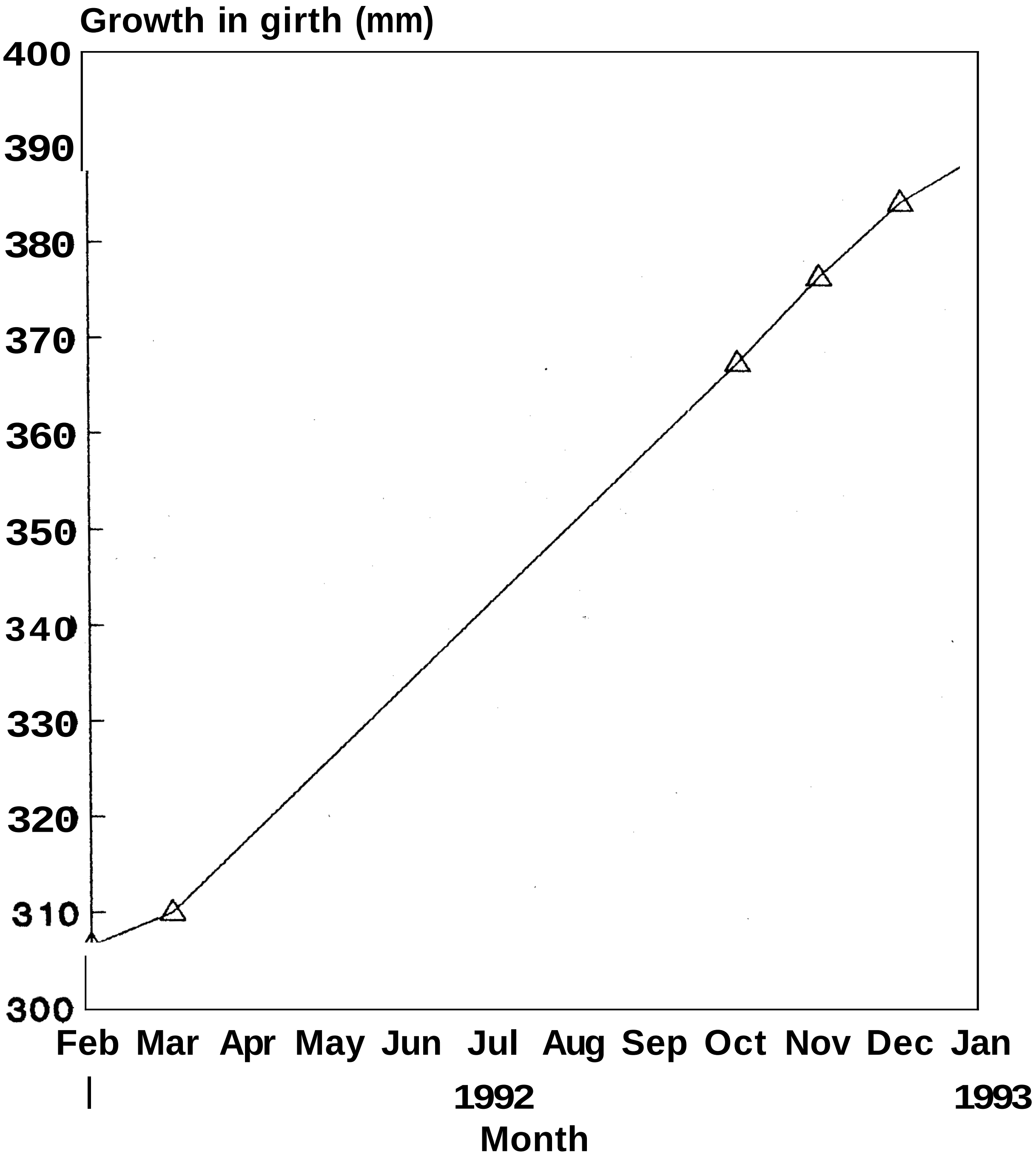

Fig. 19. *E. grandis* - Increase in girth (Muthanga)

The growth measurements show good correlation with other parameters like P_n and E_t. It seems that. the cambial growth ceases during the above period. However, this does not mean that the extension growth is affected by water stress. Our casual observations indicate the existence of extension growth even during the dry period. It may be useful to quantify this in relation to water availability in future studies.

5. DISCUSSION

The water use of the two species of eucalypts planted in Kerala has been studied in three agroclimatically different locations. *E. tereticornis,* generally planted in the plains of the State and occupying lorger area (approximately 20,000 ha) than *E. grandis* (approx. 10,000 ha) has been studied in two locations. Indeed, the study would have been more useful if eucalypt plantations in all the agroclimatic zones of Kerala had been covered. However, the locations have been chosen with the intention of applying the results of this study to other locations also. Thus, one of the locations of *E. tereticornis* (Varavoor) has been chosen in an area where the evaporative demand is among the highest in Kerala. This is due to this area getting subjected to the effects of Palghat gap, which is a gap in the Western Ghats range of mountains. At the same time the annual rainfall is typical of Kerala (nearly 3000 mm per annum) with the two monsoons giving most of the rainfall. There is a clear cut dry period starting from December to March. The second *E. tereticornis* plantation studied at Palode represents an area in Kerala where the rainfall is more uniformly distributed and the mean annual rainfall is less than 2000 mm (it should be pointed out that during the study period, the rainfall was higher than normal). The spacing and rotation of the plantation also deserve mention. The Varavoor plantation had 1800 stems ha^{-1} whereas at Palode the density was only 1090 stems ha^{-1}. The Varavoor plantation was in the second rotation, while the Palode one was in the third rotation. The average girth of the trees in both plantations were similar.

The *E. grandis* plantation (Muthanga) was chosen in an area (Wyanad) which has the majority of *E. grandis* plantations in Kerala. The elevation is high and temperatures are low when compared to other parts of Kerala. The other major *E. grandis* growing areas in the state are Munnar and Peermedu which have much higher rainfall than Wyanad. The evaporative demand in Wyanad is also higher than Munnar or Peermedu.

The LAI of the three plantations under investigation also varied. The *E. tereticornis* plantation at Palode had the lowest LAI when compared to the other two. This is because this plantation had the least number of stems ha^{-1} by following a 3 x-3 m spacing. The LAI as measured by the canopy analyser and the destructive sampling method shows good agreement. The present investigation has also helped to develop a reliable method for predicting the LAI from girth measurements of *E. tereticornis* trees.

5.1. Water status of the trees

Measurements of the soil water content upto 1 m depth have been made in several studies dealing with water use of trees. However, in the present study it has been found inadequate because the roots seemed to penetrate much deeper. This is the reason for discontinuing the soil moisture measurements in plantations other than at Varavoor. The predawn water potential can indicate the soil water potential accessed by the roots (Crombie et al., 1988).

A look at the water potential measurements in the two species shows that both the species are not under water stress during any part of the year. This is apparent from the high predawn water potentials shown by the trees in all the locations. Even in the dry period, the predawn water potentials did not come down to less than –0.7 MPa. The midday water potentials also indicate the relatively high water status of the plants. In *E. tereticornis* the minimum midday water potential reached was –1.68 MPa in March. Considering the turgor loss point in this species which is at –1.75 MPa, it seems that the turgor loss point is never reached in both the localities of *E. tereticornis.* If we assume a similar turgor loss point for *E. grandis,* it seems that this species also never reaches this point here. It must be mentioned that the water potentials observed in this study are among the highest reported for eucalypt species in the unirrigated condition.

The range in water potential values in all the three plantations throw light on the water holding capacity of the soils in these locations. As can be noticed from the wells dug at most places in Kerala, the soil reaches field capacity during the heavy and continuous showers experienced during the two monsoons lasting 3-4 months. Hence water availability is not a problem for the eucalypt plantations in Kerala. As the water potentials indicate, it is possible that the eucalypt roots are penetrating much deep into the soil. This point will be further discussed below in appropriate places in some of the following paragraphs.

It is informative to compare the water potentials of certain other trees studied in similar locations. The data on several tree species studied in Kerala show that of the species studied, only *A. auriculiformis* shows lower predawn and midday water potentials compared to other tree species including eucalypts (Kallarackal and Somen, 1992). The relatively high water potentials are characteristic of several tropical trees (Robichaux et al., 1984). Roberts et al., (1992) have reported midday water potentials as low as –3.6 MPa in *E. tereticornis* growing in the neighbouring state of Karnataka where the annual rainfall especially in this particular location was approx. 800 mm only.

The water tables in the study localities of Kerala are between 10 to 15 m deep. The high water potentials shown by the eucalypt species can lead us to a conclusion that their roots are in touch with the water table. However, before reaching such a conclusion it may be necessary to undertake a root excavation study or calculating the soil water balance.

5.2 Microclimate

Very few measurements are available on the microclimate parameters in forests or forest plantations in Kerala. The temperatures measured above and below the canopy did not show differences of more than 2°C. This variation was more apparent during the months immediately following the monsoons. The variations were less during the summer months. Usually the differences were negligible in the forenoon, whereas afternoon values generally indicated a difference with more temperature at the ground level. This is similar to the measurements made in plantations of other trees in Kerala (Kallarackal & Somen, 1992) and also some temperate forests (Roberts et al., 1984). However, measurements in the Amazonian rain forests have shown differences of aobut 5 units between the upper and lower canopy (Roberts et al., 1990). In the present study it may be also noted that the variations in the above canopy and ground level temperatures were similar in both *E. grandis* and *E. tereticornis* although the former had a much higher LAI than the latter at Palode.

Radiation measurements show that S and R_n are not limiting factors in the study localities. It has been shown that they limit photosynthesis or transpiration only during the monsoon period in Kerala (Kallarackal & Somen, 1992). Good correlation exists between S and R_n above the eucalypt canopy. The slope of the curve is very similar to the ones shown for cashew and teak (Kallarackal & Somen, 1992). From measurements taken over cashew, teak and eucalypts it is found that R_n is always lower by a factor of about 0.75 than S.

5.3. Stomatal responses to environment

In the two species of eucalypts studied, only *E. tereticornis* had stomata on both sides of the leaves. In *E. grandis* stomata were present only on the abaxial side. In *E. tereticornis,* the stomatal frequency was slightly more on the abaxial side than the adaxial side. However, in *E. grandis,* apart from having stomata on the abaxial side only, their frequency was also much less than that of *E. tereticornis.* This fact could have implications on the lower water utilization by *E. grandis* found in this study. Presence of stomata only on one side of the leaf and their lower frequency can reduce the stomatal conductance for water vapour.

The diurnal pattern of g_s in the two species shows some differences. In *E tereticornis,* the *gs* values were nearly uniform throughout the day in the post-monsoon period (Kallarackal, 1992) although a trend of lower g_s was apparent in the dry period. The measurements in Karnataka have also shown that the diurnal variations are less in *E. tereticornis* when compared to *E. camaldulensis* (Roberts et al., 1992). In *E. grandis* the g_s was high in the morning, decreasing in the afternoon. A midday closure of stomata is not apparent in both the species.

The seasonal changes in g_s also deserve some comments here. In *E tereticornis,* the seasonal changes in g_s was not very apparent when compared to *E. grandis.* The g_s values were much higher during the post-monsoon period in *E. grandis* when compared to the summer period. In Karnataka, seasonal changes in the g_s values of *E. tereticornis* have been shown to be great, especially when the leaf water potentials were in the range of –3.0 to –3.6 MPa (Roberts et al., 1992). In the present study, the trees were not under any severe water stress throughout the year. Hence, in the absence of any stornatal control, it is not surprising that *E. tereticornis* do not show much seasonal variations in g_s

Very few studies are available on the effect of environmental variables on stomatal functioning in *E. tereticornis* . From the multiple regression analysis of the different environmental variables against g_s it is found that including ***D,*** none of the variables are strongly correlated with g_s. The R_n is certainly important in controlling g_s, however, after reaching an optimum level, ***Rn*** does not seem to have a positive correlation. In a large number of plants g_s has been shown to be well correlated with D (Lange et al., 1971; Schulze et al., 1972; Calder, 1978; Roberts, 1978). It is possible that in the absence of any soil water stress (as is seen from the present study), the increasing vapour pressure deficit of the atmosphere has no remarkable influence on the stomatal mechanism in . *E. tereticornis.* However, in *E. grandis,* a reasonably good correlation has been found to exist between

g_s and *D*. It seems that below a vapour pressure deficit of 2.0 kPa, the stomata of *E. grandis* responds exponentially, but above 2.0 kPa, gs decreases at a slow rate. It is interesting to note that the g_s vs *D* relation in *E. grandis* studied in S. Africa is linear (Dye, 1987). The *E.grandis* trees in the present study were also not experiencing any severe stress. Thus it may be concluded that *E. grandis* stomata almost close when the atmospheric vapour pressure deficit increases to 4.0 kPa. This, in fact, is a desirable character in an afforestation programme where both water conservation and biomass productivity are desired.

Colquhoun et al , (1984) have conducted detailed investigations on the relation between g_s and *D* in six widely occuring eucalypt species in Western Australia. They found that in *E. marginata* and *E. calophylla* there was no correlation between g_s and *D* in which case they are similar to the *E. tereticornis* in the present study. Three other species, namely, *E. maculata*, *E. resinifera* and *E. saligna* showed some stomatal regulation based on *D*. *E. wandoo* showed stomatal control and also developed lower xylem pressure potentials. In *E. globulus* studied in Portugal, Pereira et al. (1986, 1987) have found correlation between g_s and *D*, however, the correlation depended on the leaf water potential variations also. Thus from the above account it seems that the stomatal conductance in eucalypt varies much in different species depending on the variations in vapour pressure deficit as well as leaf water potential.

What is most important to look for in water use studies of eucalypts is how a particular species behaves in a given environment. Thus in the eucalypt species now studied in Kerala, it seems that *E tereticornis* does not have any stomatal control in response to changes in vapour pressure deficit of the atmosphere. On the other hand, *E. grandis* trees have shown good stomatal control in response to increasing atmospheric vapour pressure deficit (>2.0 kPa). The question that could be raised in this finding is whether *E. tereticornis* trees have any stomatal control when the soil water stress increases. From the work done in Karnataka (Roberts, et al., 1992), it seems that they do have a stomatal control at lower water potentials. However, this is not applicable in Kerala where the chance of *E. tereticornis* reaching water potential much lower than that reported in the present study is rather remote because of much higher rainfall and the soils reaching the field capacity during the monsoon period. If eucalypt species studied at present are compared to trees of other genera in Kerala, it can be seen that *Acacia auriculiformis* and *Anacardium occidentale* show good stomatal regulation in response to atmospheric *D* (Kallarackal & Somen, 1992). Of this *A. occidentale* is more similar to *E. grandis* in having a reasonably good stomatal regulation in response to *D*. However, *Tectona grandis,* the most widely planted tree species in Kerala did not show any stomatal control at lower levels of *D* (Kallarackal & Somen,

5.4. Transpiration

From Table 30, it is apparent that the *E. tereticornis* plantation at Varavoor shows much more transpiration loss when compared to Palode. The reason for this difference can be ascribed to the following factors

1. Planting distance
2. LAI differences
3. Microclimate

The plantation at Varavoor with an LAI which is four times that of the Palode plantation, must have created a greater demand for soil moisture reserves. It is also surprising to note that the annual transpiration at Palode is nearly two-thirds of the transpiration at Varavoor in spite of the low LAI and nearly half the number of stems ha-1.

The only explanation that can be given is the possible rooting depth and root system ramification at Palode because it was in its third rotation cycle compared to the second cycle at Varavoor. The comparatively higher predawn and midday leaf water potentials at Palode is an important evidence for this. The differences in D between the two sites is also apparent. Varavoor experienced much higher D in summer when compared to Palode.

The lower annual transpiration shown by *E. grandis* is interesting. In spite of the higher number of stems ha^{-1} and a larger LAI, this species uses much less water than

Table 30, Monthly estimates of water loss (mm month-1) from eucalypt plantations by transpiration (E_t) extrapolated from daily measurements during premonsoon and postmonsoon period.

Month	*E. tereticornis* Varavoor	*E. tereticornis* Palode	*E. grandis* Muthanga
September	168	62	101
October	173	63	104
November	163	61	145
December	225	62	196
January	239	110	176
February	163	106	104
March	172	134	62
April	152	146	116
May	108	109	177
Total	1563	853	1181
Annual Rainfall	2837	2465	1302
Et as % of rainfall	55%	34%	91%
E_i as % of rainfall	13.4	7.7	18.3

E.tereticornis at Varavoor. There can be several reasons for this. Although the LA1 is higher, stomata are present only on one side of the leaf and their frequency is lesser when compared to *E. teretieornis.* Apart from this *E. grandis* shows excellent stomatal regulation in response to increasing atmospheric vapour pressure deficit.

A number of studies are available on the transpiration in several eucalypt species. Using deuterium tracer the transpiration in *E. tereticornis* and *E. camaldulensis* at three different sites in the nearby State of Karnataka has been studied (Calder et al. 1992a). Soil moisture depletion measurements at the same sites using the neutron probe were made by Harding et al. (1992). Both these studies have shown that the total water use of the eucalypts is equal to or only slightly less than the rainfall. In the former study, sometimes the water use was found even greater than the rainfall. The rainfall in these localities were between 500 and 1000 mm.

Greenwood and Beresford (1979) investigated the transpiration rates in different eucalypt species growing on sites with differing rainfall regimes ranging from 420 mm to 850 mm per annum. They found that *E. globulus* transpired at the highest rate in the site with 850 mm rainfall. *E. caladocalyx* transpired highest at the site with 500 mm rainfall, and *E. wandoo* transpired highest at the site with 420 mm rainfall.

Sharma (1984) has reported the evapotranspiration from a eucalypt community with different species in an area with 1031 mm annual rainfall in Western Australia. The above community lost 923 mm annually by evapotranspiration. Samraj and his colleagues (ICAR, 1987) have estimated that afforesting a watershed with *E. globulus* in Nilgiris, India will reduce the water yield by 17% than when it is maintained as grassland.

Greenwood et al., (1985) by studying an upslope in Western Australia have reported evapotranspiration ranging from 1600 mm to 2700 mm in *E. maculata, E. globulus, E. caldocalyx, E. wandoo* and *E. leucoxylon.* The area had an annual rainfall of 680 mm. This means that the evapotranspiration exceeded the annual rainfall by a factor of four. Excavation studies at this site revealed that the roots of the eucalypts had penetrated to a depth of 6 m and the water table was only 5 m deep. Evaporation rates of the above magnitude cannot be supported by solar radiation alone, but also by advection of heat from the air mass moving above the forest (Calder, 1985). Dye (1987) conducted a study on the *E. grandis* at Eastern Transvaal in S. Africa. Transpiration estimation using the Penman-Monteith equation showed a daily rate of 2.4 mm to 8.9 mm.

From the above account of eucalypt water use it is apparent that the different species behave differently. Even the same species can show different behaviour depending on the rainfall and other climatic or edaphic conditions.

This further strengthen the necessity to study the eucalypt water use in different geographical and climatic zones.

The transpiration figures shown in the present study indicate that in *E. tereticornis,* the water loss in the non-rainy months by this process is only half or less than half of the annual rainfall. The water loss by transpiration during the monsoon period of three months need not be taken seriously because the weather data in most localities indicate that transpiration would be limited by the sunlight availability. In *E. grandis* however, the percentage of water lost by transpiration is nearly equal to or only slightly less than the rainfall. This apparently high water use of *E. grandis* can probably be due to the low rainfall experienced by this locality when compared to the two localities of *E. tereticornis.* When *E. tereticornis* of Varavoor is compared to *E. grandis,* the former transpires much more than the latter. In a closely monitored study on a *Pinus radiata* catchment in New Zealand, 50% of the annual rainfall was seen to be lost by transpiration (Whitehead and Kelliher, 1991).

When the difference in the transpiration figures of *E. tereticornis* at Varavoor and Palode are compared, it becomes apparent that spacing of the plantation has an important role to play. The number of trees per hectare at Palode is nearly half of that at Varavoor. At the same time, the per tree consumption of water on a volumetric basis shows that it is nearly in the same range in both the localities. Hence, the spacing and its consequent effect on reduction of leaf area index is probably responsible for the less consumption of water at palode. Adlard et al. (1992) in a study on the spacing in eucalypt plantation have shown that a spacing of 3.75 x 3 m, or 888 stems ha-1 gives a similar total yield at the rotation age of 8 years when compared to closer spacing. If water can be conserved without much reduction in yield, wider spacing in plantations should gain more popularity. Stoneman and Schofield (1989), in a study in Western Australia have proposed thinning *E. marginata* plantation to increase the water yield. In a detailed hydrological study conducted at Nilgiris, southern India, Samraj and his colleagues (ICAR, 1987) have also suggested wider spacing for higher water yield. However, Calder (1992b) believes that thinning need not reduce the water use in water limited conditions. The present study shows that water is not a limiting factor for sites in Kerala. Hence thinning or planting at lesser density can probably help to conserve water.

The transpiration loss in *E grandis* plantation is of some concern in a comparatively low rainfall area like the present one. It should be remembered that spacing in this plantation is as close as that of the *E. tereticornis* plantation at Varavoor. Hence, the possibility of using wider spacing is to be looked into.

An important aspect to be discussed is the rooting depth and the availability of water to the roots to sustain the present rate of transpiration. Because of the prolonged monsoon rains in Kerala, it should be assumed that the soil in most parts of Kerala reaches the field capacity soon after the monsoon period. This is unlike the neighbouring state of Karnataka, where it need not reach field capacity due to low and sometimes deficient rainfall (Harding et al., 1992). The field capacity in the laterite soils in areas close to the present locations have been shown to be around 0.25 m^3 m^{-3} of soil (Das et al., 1976). If the wilting point is considered to be 0.12 m^3 m^{-3}, then the available water is approximately 130 mm for a rooting depth of 1 m. This means that for supporting a transpiration of more than 1500 mm (as in E. *tereticornis* at Varavoor), a rooting depth of 12 m is required if we assume no rainfall input during the post monsoon and premonsoon period. The rainfall during this period is usually less than 200 mm in the study locations. This means that the roots of *E. tereticornis* at Varavoor could probably be extracting water from the phreatic aquifer which is found anywhere within 15 m in most parts of Kerala.

As seen from the results, *E. tereticornis* at Palode transpires 853 mm during the post–monsoon and pre–monsoon periods. If the same criterion for soil water availability is applied here, it requires a rooting depth of 6.5 m to support this much transpiration loss. Thus it may be reasonably assumed that when planting density is reduced, the rooting depth is also reduced if we assume the lateral rather than the vertical spread of the root system. Similarly in the *E. grandis* plantation studied here, it requires 9 m rooting depth to support the transpiration estimated in the present study. The water table at Muthanga is found to be 10-15 m deep.

The rooting depth of eucalypts mentioned above is similar to those reported in different excavation studies done in Australia (Carbon et al., 1982). Several studies done in Australia have shown that the roots get access to the phreatic aquifer (Greenwood and Beresford, 1979;. Greenwood et al., 1985). It should be remembered that although the above-ground coppices in the present study are 3-4 years old, their root system is 15-20 years old because they are in the second or third rotation. Hence the possibility of their roots penetrating into much deeper layers of the soil cannot he ruled out. Samraj et al., (ICAR, 1987) have also discovered that during the first rotation the roots of *E. globulus* do not extract water from the water table. But during subsequent rotations they reach the water table.

5.5. Water loss by means other than transpiration

As pointed out in the second section of this report water is lost from a forested area or plantation by several means other than transpiration. They include rainfall interception loss, surface runoff, evapotranspiration from the ground vegetation, evaporation from the bare ground and drainage of soil.

Although the present study did not envisage the direct measurement of any of the above parameters except transpiration, it will be of interest to discuss these parameters in the light of investigations done elsewhere.

Rainfall interception as estimated from models shows that it is 13% and 8% in *E tereticornis* plantations at Varavoor and Palode respectively. The value of 13% is close to the interception values determined elsewhere for this species (George 1978). Since *E. tereticornis* trees have pendant leaves, the interception percentage is low when compared to some other species. Since measurements of interception at high rainfall areas like the ones in the present study are rare, it is difficult to make comparisons. In a study on a 5 year old *E tereticornis* plantation in West Bengal, India, Banerjee (1972) has measured the interception to be 23% of the rainfall in an area with average annual rainfall of 1000 mm. However, the percentage of interception was <12% in *E. tereticornis* at Dehra Dun where the annual rainfall is 2000 mm (George, 1978). Measurements in Karnataka in *E.camaldulensis* have shown the interception to be 4% and 12% in an area with annual rainfall of 993 mm and 423 respectively (Hall et al., 1992). Thus from these studies, it is apparent that no definite value can be fixed for interception. The lower interception value shown by the Palode plantation is due to the lower canopy coverage. Calder (1992b) has opined that interception values cannot be lowered remarkably by thinning because it would increase the canopy ventilation, resulting in increased evaporation. However, interception estimated at Palode from the model definitely suggests a remarkably lower interception figure (7.7%) in the present study. Direct measurements are probably required to confirm this.

Interception estimates in the *E. grandis* plantation studied here gives a figure of 18% of the annual rainfall of 1300 mm. When compared to *E. tereticornis* plantations, the LAI was higher in *E. grandis*. The figure of 18% is certainly within the limits of interception shown by several species of eucalypts (see review by Poore and Fries, 1985). It should be pointed out that the leaf angle in *E. grandis* is much less vertical than *E. tereticornis* which would increase the interception.

The interception in eucalypt species may be compared to certain other species studied in similar areas of Kerala. Thus in *Acacia auriculiformis,* the interception is 8% of the annual rainfall of 2360 mm (Kallarackal and Somen, 1992). Similarly cashew trees, *(Anacardium occidentale)* intercepted 15% of the annual rainfall of 3175 mm.

Surface runoff during and soon after the rainfall events is also an important factor to be considered in water balance. In the eucalypt planted sites in Kerala, most of which are on the slopes of hills, this could be an important factor. Detailed runoff studies made on a watershed in the highlands of Kerala (CWRDM 1991) have shown the runoff coefficient (runoff/rainfall) as high as 0.9. An average runoff coefficient of 0.4 can be derived from the above work. It may be reasonable to use this figure in the two *E tereticornis* sites studied. However, the *E. grandis* site was more or less flat, hence the runoff loss could be minimal.

The transpiration and evaporation from ground vegetation and bare soil can be also substantial in Kerala. Most eucalypt plantations in Kerala have a good undergrowth of weeds including *Eupatorium* and *Lantana*. Grass is widely prevalent in *E. grandis* plantations. Although most of these undergrowth are seen to dry out during the dry period, their water consumption during the post monsoon period could be subtantial. Very few studies are avaiable on this form of water loss from eucalyt plantations. Water balance studies on a *Pinus radiata* catchment in New Zealand (Whitehead and Kelliher, 1991) have shown the evaporation from the understorey and the soil to be 7% of the rainfall, the annual rainfall being 1400 mm. The eucalpyt canopy in the present two sites of *E. tereticornis* was fairly open. This would mean that the above type of loss from these plantations could be more than that reported for *Pinus radiata* cited above.

Thus, it is clear from the above discussion, that other factors, apart from transpiration and interception are important in working out the water balance of the plantations. However, the present project deals with the question of the "excessive water use" of the eucalypts. Since the approach to answering this question is the comparative water use of eucalypts and other native or exotic trees, water loss by transpiration certainly forms the most important component.

6. CONCLUSIONS AND RECOMMENDATIONS

From the results of investigations on the water use of the two species of eucalypts planted in Kerala, the following conclusions can be drawn.

6.1. Transpiration during the post and pre-monsoon periods from an *E. tereticornis* plantation with 1800 stems ha^{-1} shows that 55% of the rainfall is lost by this process. At the same time, when the tree density is 1090 stems ha-1, only 34% of the rainfall is transpired. When the transpiration figures are converted to depth equivalents, the figures are 1563 mm and 853 mm respectively for the above two plantations. In volumetric equivalents, the trees in the plantations consumed between 19-43 1 $tree^{-1}$ day-1 and 18-44 1 tree-1 day-1 respectively. This means that the per tree consumption of water was nearly the same irrespective of the planting distance.

6.2. Transpiration from a *E. grandis* plantation with a density of 1600 stems ha-1 shows that 91% of the rainfall is transpired during the post and pre-monsoon periods. In depth equivalents this is 1181 mm and in volumetric equivalents this is 13-40 1.$tree^{-1}$ day^{-1}.

6.3. Both the species in all the three localities maintain relatively high leaf water potentials when compared to eucalypts studied elsewhere. This means that the eucalypts in Kerala, in general, are not under severe water stress during any part of the year. The midday water potentials never reached levels less than the turgor loss point (–1.75 MPa) indicating no complete stomatal closure due to loss of turgidity.

6.4. Stomatal conductance measurements in *E. tereticornis* and *E. grandis* indicate diurnal and seasonal variations. The Conductance was relatively higher during the forenoon. Seasonally, the conductance was higher in both species during the post–monsoon period. However, at nc time during the year, complete stomatal closure was observed provided the light was not 1imiting.

6.5. The stomatal control of transpiration in response to atmospheric vapour pressure deficit was examined in both species. *E. tereticornis* did not show any apparent control even at relatively high vapour pressure deficit under the available soil water. In *E. grandis,* although no complete closure seemed to exist the response to atmospheric vapour pressure deficit was clearly visible. Hence **it** may be concluded that *grandis* has better stomatal control mechanisms when compared to *E. tereticornis.*

6.6. The relatively high water potentials and the high stornatal conductance shown by the two species indicate abstraction of soil water by deep penetrating roots.

To support a transpiration loss of 1563 mm (the figure shown by *E. tereticornis* at Varavoor), it requires rooting depth of approximately 12 m if we assume the water holding capacity of the soil is 0.25 m^3m^{-3} and the wilting point is at 0.12 m^3m^{-3}. This assumption requires that there is no extra input of rainfall during the post and pre-monsoon periods. This probably gives an indirect indication that the roots are in contact with the water table because the water table at Varavoor was found at 9 m depth. Excavation studies will be required to confirm this.

6.7. The maximum net photosynthetic rate in both the species was around 20 $\mu mol\ m^{-2}s^{-1}$ The water use efficiency of *E. tereticornis* during post and pre-monsoon period were similar. However, in *E. grandis,* the water use efficiency was less during post monsoon compared to the pre-monsoon period. In general, the water use efficiency was better for *E. tereticornis.*

6.8. After following the growth in girth of the two eucalypt species on a monthly interval, it was found that during the pre-monsoon period there was complete cessation of growth in girth. However, extension growth was observed regardless of the seasons.

Based on the above conclusions, the following suggestions are made.

In a place like Kerala where the soils reach field capacity during the monsoon period, the water availability to the roots is not limiting provided the roots are able to penetrate deeper. This is certainly indicated in the present study. Even during the dry period, the eucalypt trees do not show any wate.: stress symptoms, indirectly indicating the deep penetration of roots. From the water table depth in many localities, which occur within 15 m, it seems that the eucalypt could be easily extracting the water table. Indeed, an excavation study of the root system in eucalypt plantations at different locations is highly desirable.

If the roots are extracting from the water table, are they really dangerous to the water resources? It is not the first time that it is known that the eucalypts extract from the water table. Several investigations in Australia have shown this to be true. Studies have also shown that eucalypts can considerably reduce the stream flow. This means that if catchments supplying reservoirs are planted with eucalypts, they can certainly reduce the water availability. Moreover, in an year with deficient or delayed rainfall, the possiblity of the water table going down at a faster rate cannot be ruled out.

The high water use of eucalypts in an area with rich soil water availability and high vapour pressure deficit is not at all surprising. As the present study has shown, *E. tereticornis*, which is widely planted in the state, has little stomatal control of water loss when soil water is not limiting.

The water use of *E. tereticornis* at Palode shows that when the trees are widely spaced, that is 1090 stems ha^{-1}, the water consumption by transpiration reduces considerably. Although the per tree consumption remains the same, the reduced number of trees per hectare can conserve the water to a great extent. In such a situation, it can be reasonably assumed that the roots of trees need not penetrate deeper as in a denser plantation. Instead, they could be seeking water available from the locality by lateral spread of roots.

Some of the recent studies in Karnataka have shown that 888 stems ha-1 can give a similar yield of wood as a denser plantation. Moreover, when plants are widely spaced, the interception losses can also be minimised. Although, more open canopy will result in increased ventilation, and therefore increased evaporation, the net gain of water will certainly be more than in a denser plantation. It can be argued that the *E. tereticornis* when planted at higher density is consuming only 55% of the annual rainfall. It is certainly a high consumption when the water lost by runoff is also accounted, the runoff figure being more than 40% of the rainfall. The figure could be much higher in many eucalypt planted areas, where the land is degraded due to loss of much top soil.

The water consumption by *E. grandis* is also quite high. However, the stomatal control of water loss by these trees is comparatively better than *E. tereticornis.* The water loss by transpiration is certainly high when worked as a percentage (91%) of the rainfall. However, the runoff in the study areas in Wyanad should be considered minimal because of the flat terrain. If the planting distance of the *E. grandis* is increased from the present spacing in order to contain only 888 trees ha^{-1}, it may be possible to conserve water without affecting the phreatic aquifer.

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