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WATER USE OF SELECTED INDIGENOUS AND EXOTIC TREES

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MAIN SYMBOLS AND ABBREVIATIONS

Avg.	Average
c_P	specific heat of air
D	drainage to the ground water
D	vapour pressure deficit
d	zeroplane displacement
dbh	diameter at breast height
E_c	Evaporation
E	chamber transpiration
E_t	transpiration
E_{tcum}	cumulated transpiration
G	soil heat flux
gbh	girth at breast height
h	hour
ha	hectare
I	rainfall interception
IST	Indian Standard Time
K	Karman’s constant
L	leaf area of the conducting surface
l	litre
LAI	leaf area index
mb	millibar
MPa	Megapascals
N	number of observations
n.r.	not recorded
P	precipitation (openfall)

PET	potential evapotranspiration
Pn	net photosynthesis
Q	run off
Rn	net radiation
r^2	coefficient of determination
r_a	aerodynamic resistance
r_c	canopy resistance
r_s	stomatal resistance
r.h.	relative humidity
S	total solar radiation
SF	stemflow
T	throug
Ta	above canopy temperature
Tg	temperature above ground level
u	mean wind speed
W	watts
WUE	water use efficiency
$\boldsymbol{Z}$	anemometer reference height
z_o	roughness length
γ	phychrometric 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

Several exotic species have been used for afforestation in Kerala as a part of the Social Forestry Programme, mainly funded by the World Bank. Among them, the most widely planted species is ***Acacia auriculiformis*** which has met with great success in survival and yield. However, the tree has been the subject of discussion and criticism from some members of the public who have alleged several environmental problems associated with its large scale introduction. Among them, its excessive consumption of water is the most serious one. This report is an attempt to study the water use of ***A. auriculiformis*** by evapotranspiration. To determine how far the evapotranspiration is comparable to other trees, two other species, namely ***Anacardium occidentale*** (cashew) and ***Tectona grandis*** (teak) have been also studied.

Water is lost from a forest stand or plantation by four means (i) Evaporation of the intercepted rainfall, (ii) transpiration from the dry canopy (iii) evapotranspiration from the ground vegetation and (iv) evaporation from the bare soil. Out of these, we have ignored the last two aspects in this study because they are negligible in a well managed plantation. The evapotranspiration from the main canopy was measured by two means, (i) rainfall interception measurements and (ii) transpiration measurements using the Penman-Monteith equation.

To determine the water use of the three species we have selected three pure plantations belonging to the above species in Palghat and Trichur Districts of Kerala. Intensive monitoring of rainfall interception, soil moisture, leaf water potentials, microclimate above the canopy and leaf area index were done in all the three plantations round the year on selected sampling dates. Stomatal resistance and net photosynthesis were also measured simultaneously. All these measurements are difficult in trees, however, using a tall scaffold tower we gained access to the tree canopy.

The major factor which contributes to water loss from a dry canopy is the stomatal resistance (opening and closing of stomata). This, in turn is controlled by the environmental variables and soil water availability. We have established predictive correlations between stomatal resistance and the environmental variables, especially vapour pressure deficit. The analysis of these relations have helped us to know the comparative degree of stomatal response to environmental variables in the three species studied. This indicates that cashew shows less response to vapour pressure deficit when compared to acacia. It has not been possible to understand the exact correlations in teak. However, teak prevents a lot of water loss during dry periods by shedding its leaves.

The water use efficiency of the trees have been also compared. Cashew and acacia are certainly more efficient in their water use when compared to that of teak. At the same time, a cashew tree can consume more than 400 l of water a day during peak summer.

Several observations related to rainfall interception, microclimate, water potentials etc. are presented in this report. A chapter on conclusions and recommendations is also included towards the end.

1. INTRODUCTION

Thanks to funding from the World Bank the social forestry programme has helped to raise a large number of plantations in Kerala. The plantations include both exotic and indigenous species. Some of the major exotic species planted are ***Acacia auriculiformis, Casuarina equisetifolia, Eucalyptus tereticornis, Swietenia macrophylla, Grevillea robusta, Leucaena leucocephala*** etc. Among the indigenous species the most widely planted trees are ***Ailanthus triphysa, Albizia falcataria, Attocarpus heterophyllus, Tectona grandis, Attocarpus hirsutus, Bombax ceiba, Dalbergia latifolia, Emblica officinalis, Gmelina arborea, Pterocarpus marsupium,*** different species of ***Terminalia*** etc. However, it should be remarked that about 70-80% of the total area planted under this scheme are occupied by the exotics (Jayaraman ***et al.,*** 1992). Among them, the most widely introduced tree is ***Acacia auriculiformis*** mainly because of its multiple advantages (Chand Basha, 1987). Regarding the productivity and yield, this tree is doing extremely well in Kerala with a mean annual increment (MAI) of 10-34 m3 ha-1 of commercial volume at 7 years for 2000 trees ha-1 (Jayaraman and Rajan, 1991).

Lately, several environmental groups and farmers have criticised the large scale introduction of several exotic species into Kerala. The criticisms are varied, however, it is interesting to list a few of them.

i. They absorb a large quantity of water from the soil and the ground water table is affected.

ii. Most of them are raised in monocultures and therefore are more prone than mixed forests to the depradations of pests and diseases.

iii. Some of the introduced species are unpalatable to indigenous animals and the pollen of ***Acacia auriculiformis*** are allergic to humans.

iv. Their litter do not decompose easily and they have allelopathic effects preventing any undergrowth.

In the above paragraphs we have pointed out only a few of the many criticisms. It is puzzling to note that many other introduced trees which have formed a part of the horticultural system in the State do not face such severe criticisms. They include trees like rubber ***(Hevea braziliensis)*** cashew ***(Anacardium occidentale)*** and oil palm ***(Elaeis guineensis)*** which have been mainly planted on private holdings.

It is common logic that a species which grows faster consumes more water than a slow growing species. For the past so many years eucalypts have been subjected to a lot of discussions with regard to their ecological effect (see Poore and Fries, 1985; Calder, 1986). A similar type of public uproar has generated against ***Acacia auriculiformis*** which has been planted on a large scale.

The success of social forestry programme depends on the acceptance of a particular tree by the public. Hence it is important to choose a species which is acceptable to the people from the utilization point of view. However, when large scale introductions are done, the species should be ecologically sound. It is from this view point that we have taken up ***Acacia auriculiformis*** for a detailed study with regard to its water use. According to Calder (1986) the only answer to the problem of water use in trees is to make comparative studies on their water use and the mechanisms which control the use of water. The main question that we would like to answer in this project is whether ***Acacia auriculiformis*** trees consume more water than the many native species or other 'accepted' exotics. The main approach to answer this question has been to compare the water use of ***A. auriculiformis*** with that of (i) cashew ***(Anacardium occidentale),*** which is an exotic, but a widely accepted species and (ii) teak ***(Tectona grandis),*** an indigenous species with approx. 76,000 ha (Anon., 1991) under plantation. ***A. auriculiformis*** is a native of Australia and Papua New Guinea, and is a recent introduction into India. ***A. occidentale*** is a native of Central America and northern part of S. America. This was introduced into India, perhaps during the 16th century by the Portuguese (Johnson, 1973). Teak is a native of India.

This project was started with the intention of studying more number of species than dealt with here. But limitations of resources and time have prevented us from covering more number of species. It should be mentioned here that studying the water balance of a catchment planted with one of the above trees is not the aim of this project. More importance is given to the physiological responses of the plant in relation to soil water availability and environmental conditions. However, we are bound to discuss several previous investigations dealing with water balance studies in catchments.

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 use, it is important to see that they provide water for domestic, agricultural and industrial uses. However, the land manager often meets with the problem of land management for maximum agricultural and timber production unable to provide enough water. 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 and 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 percent.

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 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 in the 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

$$P = Q + E + \Delta S + D \tag{1}$$

where, P = precipitation (mostly rainfall in the tropics);

Q = runoff;

E = evaporation;

ΔS = change in water content of the soil;

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 the 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. Thus 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 the 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 necessary to present a brief review on the methods to measure the evapotranspiration. Since several methods have been used by defferent 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 are the Eddy correlation technique and the 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 catchments

These include hydrological methods to measure the water balance of a catchment. Although these methods can provide good information, this does not give much significance to the physiological behaviour of the plants. In this study, since we are more interested in 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 Hibbert, 1967; Bosch and Hewlett, 1982).

c. Penman-Monteith Method

This is probably the most popular and reliable method to study the water loss from a stand (Whitehead and Hinckley, 1991). Since this method combines aero-dynamic, 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.

d. 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 *eta/.*, 1992). The method has shown good reliability with individual trees, but extrapolating these values to the catchment has to be done with extreme caution.

e. 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.

f. Tracer methods

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

In the above paragraphs, we have listed only a few of the most widely used methods in studying water balance. For more details, readers may refer to Sharma (1984), Woodward and Sheehy (1983).

3. MATERIALS AND METHODS

Site description

Detailed measurements were done for three years in three species viz., acacia *(Acacia auriculiformis),* cashew *(Anacardium occidentale)* and teak *(Tectona grandis).* The site details of the three plantations are presented in Tables 1-3. The locations are marked in Fig. 1. It may be noted that all the three plantations are located within a 50 km radius. Topographically, this area is located in that part of Kerala which 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 (See Fig. 2). This part of Kerala has been specifically chosen for our study because it can be reasonably assumed that the water consumption would be maximum here.

Table 1. ***A. auriculiformis*** **- site details**

Sl. No.	Site factors	Description
1.	Forest Division	Palghat Social Forestry Division
2.	Forest Range	Mannarghat
3.	Section	Kothachira
4.	Latitude	10°44'15" to 10°44'30"
5.	Longitude	76°7'45" to 76°8'00"
6.	Altitude	20 m
7.	Annual rainfall	2361 mm (June 1990-May 1991) (Pattambi)
8.	Year of planting	1985-86
9.	Year of coppicing	Not applicable
10.	Rotation number	Not aplicable
11.	Avg. dbh	6.5 cm
12.	Avg. gbh	21 cm
13.	No. of stems/ha	4440
14.	Planting distance	1.5 m x 1.5 m
15.	Avg. tree height	10 m
16.	Leaf area index	3.15
17.	Period of study	June 1990 - May 1991

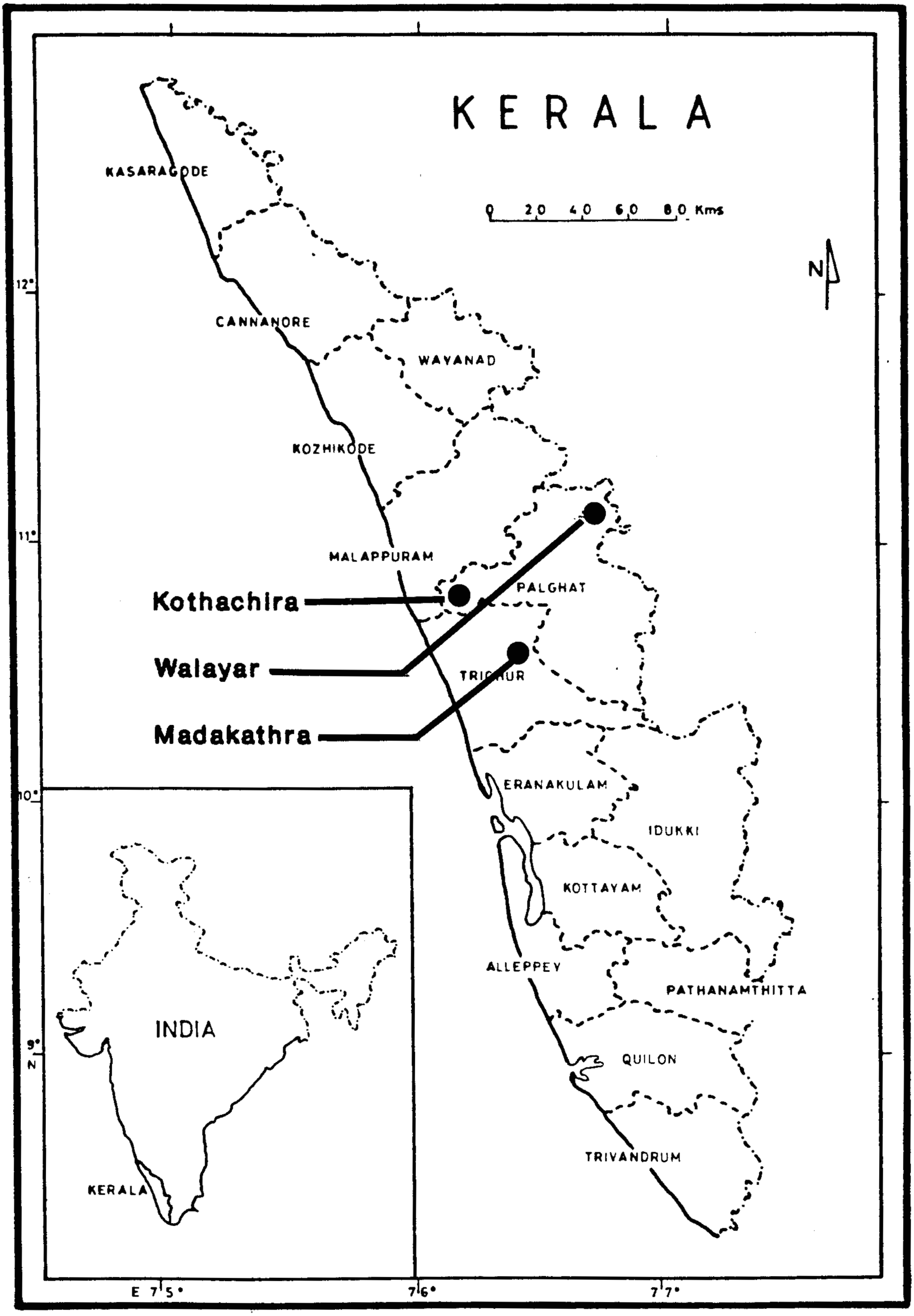


Fig.1. Map showing the study locations

Table 2. ***A. occidentale*** **- site details**

Sl. No.	Site factors	Description
1.	Forest Division	Trichur
2.	Forest Range	Pattikkad
3.	Section	Madakathra (Cashew Res. Stn.)
4.	Latitude	10°32'45" to 10°33'00"
5.	Longitude	76°30' to 76°45'
6.	Altitude	30 m (approx.)
7.	Annual rainfall	3176 mm (Vellanikkara Apr. 91-Mar. 92)
8.	Year of planting	1973
9.	Year of coppicing	Not applicable
10.	Rotation number	First
11.	Avg. dbh	38.5 cm
12.	Avg. gbh	121 cm
13.	No. of stems/ha	169
14.	Planting distance	8 m x 8 m
15.	Avg. tree height	9 m
16.	Leaf area index	2.6
17.	Period of study	April 1991 - March 1992

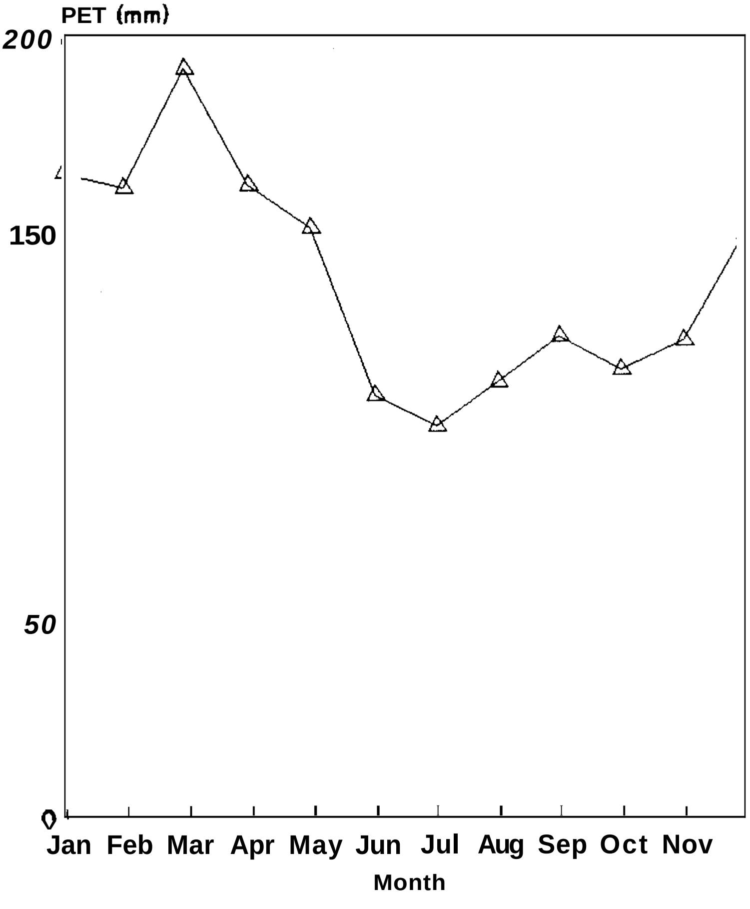


Fig.2. Potential evapotranspiration over

Rainfall interception

Rainfall interception (I) was measured as the difference between openfall (Precipitation) (P) and throughfall (T) plus stemflow (SF).

$$I = P - (T+SF) \qquad (2)$$

The openfall was measured using a conventional type of raingauge located in an open area very near the plantations. In some cases the readings were taken after completion of each event. In others daily measurements were made.

Throughfall was measured by custom-made rainguages kept randomly at different locations within a plantation.

Stem flow was measured using stem collars. The projected crown area was used for stem flow quantifications.

Table *3.Tectona grandis* - site details

Sl. No.	Site factors	Description
1.	Forest Division	Palghat
2.	Forest Range	Walayar
3.	Section	Vattappara
4.	Latitude	$10^{0}50'$ to $10^{0}50'15''$
5.	Longitude	$76^{0}50$ to 76°50'15"
6.	Altitude	180 m
7.	Annual rainfall	1832 mm (1992)
8.	Year of planting	1980
9.	Year of coppicing	Not applicable
10.	Rotation number	Not available
11.	Avg. dbh	14 cm
12.	Avg.gbh	44 cm
13.	No. of stems/ha	800 (present stocking)
14.	Planting distance	2.5 m x 2.5 m
15.	Avg. tree height	8 m
16.	Leaf area index	2.81
17.	Period of study	Jan. 1992 to Dec. 1992

Soil water

Soil water content was measured gravimetrically. The soils were sampled from 2 layers, 0 to 0.3 m and 0.3 - 0.6 m. However, spatial variations were enormous. Hence we discontinued this measurement in the latter part of the work and started depending on the predawn water potentials for getting information on the water availability to the roots.

Water potentials (Ψ)

Mostly predawn and midday water potential measurements were made on samples collected from different trees. The number of leaves sampled each time depended on the similarity of values between measurements. However, a minimum of three samples were always measured. Before midday measurements, the sample leaves were enclosed within a polythene bag before being detached (Turner, 1988).

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).

$$\Psi = \Psi_p + \Psi_s \qquad (3)$$

where, Ψ =water potential;

Ψ_p = the balancing pressure;

Ψ_s = solute potential

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.

Microclimate

A 12 m high, steel scaffold tower was installed in the plantations to mount the micrometeorological equipments through and above the canopy. The measurements were taken at least 2 m above the canopy level.

Temperature - measured using a thermistor (Model 207 temp. and RH probe, Campbell scientific, Inc., Utah, USA). Relative Humidity - measured by an RH sensor (Model 207 temp. and RH probe, Campbell Scientific Inc., Utah, USA). Wind velocity - measured using a Sunnyvale, CA, USA, cup counter anemometer (Model 014 A, Met one) with a switch closure mechanism. Net radiation - measured by a net radiometer of the Fritschen type (REBS Inc., Washington, USA) Solar radiation

- total solar radiation was measured using a pyranometer sensor (LI-200 S, LI-Cor, Nebraska, USA).

All the above sensors were connected to a datalogger (Model 21X; Campbell Scientific Inc., Utah, USA) and the data were logged every 5 seconds and averaged hourly. The stored data were later transferred to a computer for further analysis using the software package PC-208.

Stomatal resistance *(rs)*

A steady state porometer (Model LI-1600, LI-Cor, Nebraska, USA) was used to measure the stomatal resistance of the leaves. An average of eight leaf samples from at least 3-4 trees accessible from the scaffold tower were measured on an hourly basis from sunrise to sunset. Measurements were always made at ambient humidity.

Daily patterns of *rs* were followed on sample days randomly chosen at approximately one month interval over a complete year. Field measurements were done on days which were not rainy or completely overcast. However, the measurements had to be completely abandoned for 3-4 months starting in June and ending in August- September. During these months almost the entire Kerala is lashed by heavy rains brought by the South-west monsoon. The relative humidity has been found to be extremely high (mostly 80%) during this time and the intermittent rains keep the leaves wet most of the time.

The sampling of the leaves were done only from the top canopy layer. Mature leaves well-exposed to solar radiation were taken for this purpose. Measurements were made initially on both the upper and lower leaf surfaces to determine whether to monitor both surfaces. Results showed that only A. *auriculiformis* needed porometer measurements on both surfaces. The *rs* was calculated using the software provided with the instrument.

Canopy resistance *(rc)*

Canopy resistance ***(rc)*** was calculated as follows:

$$rc = rs/L \tag{4}$$

where, *rs* = stornatal resistance (sm-1);

L = leaf area of the conducting surface.

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 leaf gaps. For details of the instrument's functioning, one may refer the manufacturer's operation manual. This instrument had been previously tested for its dependability in a eucalypt plantation where destructive sampling was also made simultaneously.

Aerodynamic resistance *(ra)*

The aerodynamic resistance *(ra)* was estimated using the following equation (Monteith, 1973).

$$r_a = \left\{ \ln \frac{(z-d)}{z_o} \right\} k^{-2} u^{-1} \qquad (5)$$

where, u = mean wind speed (ms-1);

z = anemometer reference height (m);

d = zero plane displacement (m);

zo = roughness length (m);

k = von Karman's constant (0.41).

Net photosynthesis *(Pn)*

Leaf net photosynthesis *(Pn)* was measured with a portable infra red gas analyser (IRGA) (Model LI-6200, Li-Cor, Nebraska, USA) using a one-litre leaf chamber. The leaf chamber has sensors for measuring photosynthetically active radiation (PAR), relative humidity, leaf and chamber temperatures. The IRGA was frequently calibrated against known gas mixtures of CO_2. The measurements were recorded on the data logger supplied with the instrument. The *Pn* was calculated in the datalogger itself using the software provided with it by the manufacturer. The data were later transferred to a computer for further processing.

4. RESULTS

Acacia auriculiformis

Weather data

The annual weather data collected from the weather station maintained by the Rice Research Station, Pattambi is presented in Table 4. This station is approx. 15 km away from the study area. It can be seen that the rainy season caused by the South-west monsoon is from June to September. The dry period is from December to March when there is no rainfall. The temperatures recorded during the dry months are comparatively higher than the rest of Kerala. The relative humidity also shows very low values. Palghat District, where the plantation is located is the district with maximum PET when compared to other districts in Kerala. The PET values reported from an analysis of the data for 30 years is shown in Fig. 2 (data after, Rao *et al.*, 1971).

Table 4. *A. auriculiformis* -Weather data for Kothachira during Oct. 1990 to Sept. 1991

Month	Temperature (°c) (Mean)		Mean r.h.(%)	Rainfall (mm)
	Maximum	Minimum		
October	29.4	22.8	90.0	446
November	29.3	22.5	86.5	97
December	30.7	21.4	78.9	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	84.2	153

The above data was collected from the weather station maintained by the Rice Research Station, Pattambi which is 15 km from the plantation. The r h. was measured at 10.00 h (IST).

Rainfall interception

No extensive measurements were made on the rainfall interception in ***A. auriculiformis.*** However, fine measurements of the openfall, stem flow and throughfall of six events during the South-West Monsoon have been presented in the following Table **5.** It may be commented that the interception rate can be expected to be higher during the rainfall events occurring in other seasons.

Table 5. *A. auriculiformis* - Rainfall interception measurements

Throughfall T (%)	Stem flow SF(%)	Interception I (%)
84.5	7.3	8.2

Soil moisture and leaf water potentials

The soil water content at two depths measured during days when other physiological measurements were made are indicated in Fig. 3(a). Each point in the figure is the mean of 3 independent determinations. It may be seen that the **soil** moisture content shows a pattern very similar to the rainfall and the leaf water potential measurements.

Predawn and midday water potentials measured on days when other physiological measurements were made are shown in Fig. 3(b). Each data point is the mean value of at least six independent measurements. It shows corresponding relation with the soil moisture data. Since the predawn water potentials actually indicate the water availability to the roots of the plant, we take them as more reliable than the soil moisture data. The midday water potentials indicate the maximum tension that is prevailing in the leaf. From the measurements shown in Fig.3(b), *A. auriculiformis* shows high predawn water potentials during October and November. Then there is a gradual decrease in predawn potentials reaching a culmination in the month of March. The corresponding midday values also give a good indication of the water stress to which these trees are subjected during the summer.

It should be pointed out that the water table of this locality in summer (as determined from nearby wells) was 15 m deep. From the water potential measurements it does not seem that the roots of *A. auriculiformis* is in contact with the phreatic aquifer. If it were in contact with the water table, the predawn water potentials would not have shown this much decrease during the summer months. The 4440 stems ha^{-1} in the present experimental plot is also relatively high for a tree like *A. auriculiformis* because the laterally spreading roots might also fail to get

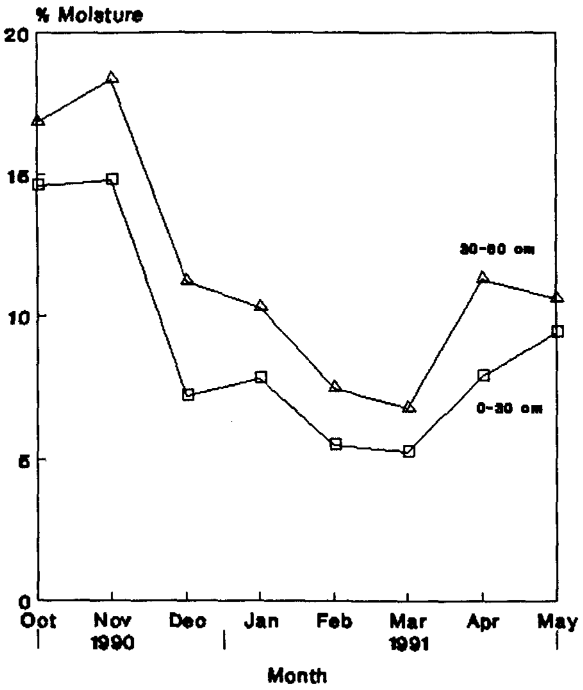


Fig.3(a). *Acacia auriculiformis* - soil moisture within the plantation

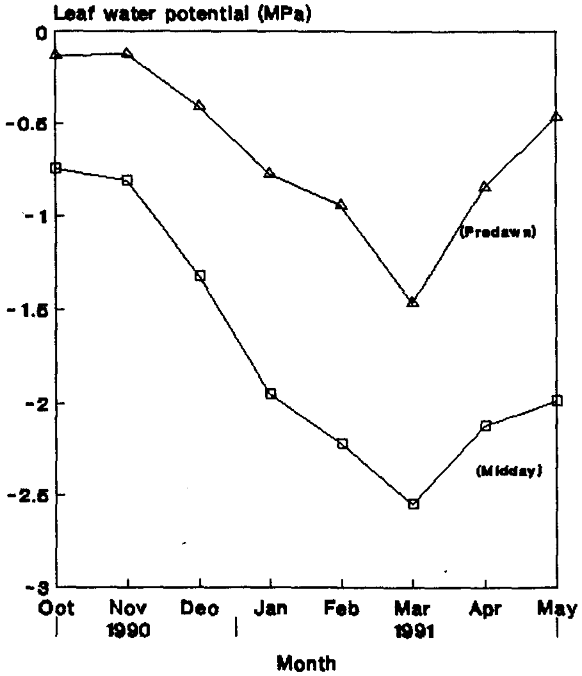


Fig. 3(b) *A. auriculiformis*- Leaf water potential measurements water. In a study on *A. karoo* trees in S. Africa, it was seen that these trees consume water up to a distance of at least 5 m from their stems (Stewart-Hill and Tainton, 1989).

Table 6. *A. auriculiformis* - Microclimate, aerodynamic and canopy resistances and transpiration data on 24-10-90

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	("C)	("C)	(%)	'(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	**24.65**	n.r	**97.4**	**1.24**	n.r	-21	8.9	-	-	
700	**24.83**	n.r	**97.2**	**1.26**	n.r	5	13.3	-	-	
800	**25.89**	n.r	**95.3**	**1.83**	n.r	84	13.1	-	-	
900	**27.52**	n.r	**90.6**	**3.27**	n.r	232	7.4	17	0.352	
1000	29.28	n.r	85.1	5.68	n.r	416	6.6	20	0.592	
1100	29.65	n.r	84.4	6.55	n.r	409	4.6	14	0.786	
1200	29.18	n.r	85.7	5.87	n.r	296	5.9	14	0.612	
1300	29.79	n.r	85.3	6.24	n.r	528	8.4	35	0.549	
1400	31.70	n.r	81.1	9.48	n.r	407	7.6	19	0.768	
1500	27.81	n.r	91.1	3.89	n.r	99	6.5	18	0.297	
1600	27.66	n.r	92.1	3.44	n.r	124	6.1	24	0.259	
1700	26.97	n.r	91.8	3.34	n.r	37	8.4	32	0.156	
1800	26.14	n.r	93.4	2.49	n.r	- 4	7.4	55	0.079	4.45

For details of calculations please refer the text. For symbols and abbreviations refer the list of abbreviations.

Microclimate

The microclimate parameters measured 2 m above the canopy, like atmospheric temperature *(Ta),* relative humidity (rh), vapour pressure deficit *(D)* net radiation *(Rn)* are presented in Tables 6-13. Hourly values have been presented each representing the average of 720 measurements (logging done at 5 s intervals).

Table 7. ***A. auriculiformis*-** **Microclimate, aerodynamic and canopy resistances and transpiration data on 18-11-90**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	23.8	n.r	97.6	.6	n.r	-10	21.0	-	-	
700	23.8	n.r	97.8	5.9	n.r	-2	21.0	-	-	
800	24.2	n.r	97.8	4.5	n.r	51	17.0	85	0.105	
900	25.6	n.r	96.0	6.5	n.r	160	14.8	47	0.264	
1000	29.1	n.r	86.8	13.6	n.r	393	12.8	17	0.838	
1100	31.3	n.r	84.3	19.3	n.r	569	5.5	24	1.375	
1200	31.4	n.r	81.3	16.9	n.r	649	4.4	32	1.159	
1300	31.0	n.r	79.5	17.9	n.r	667	7.5	25	1.250	
1400	33.2	n.r	77.1	23.9	n.r	525	15.7	21	1.119	
1500	34.2	n.r	72.5	29.7	n.r	460	9.1	45	1.135	
1600	32.4	n.r	79.5	25.9	n.r	223	4.9	28	1.441	
1700	30.4	n.r	81.7	16.9	n.r	151	7.1	66	0.518	
1800	29.2	n.r	85.5	14.8	n.r	0	6.5	46	0.530	9.734

Table 8. ***A. auriculiformis*** **- Microclimate aerodynamic and canopy resistances, and transpiration data on 28-12-92**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_{tcum}
(h)	("C)	("C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	22.78	n.r	65.83	9.47	n.r	-68	3.4	-	-	
700	22.32	n.r	66.89	8.92	n.r	-65	3.5	-		
800	22.51	n.r	67.00	9.00	n.r	67	3.7	55	0.371	
900	23.78	n.r	65.05	10.30	n.r	153	3.3	33	0.661	
1000	25.42	n.r	62.03	12.34	n.r	287	3.6	46	0.578	
1100	26.49	n.r	57.43	14.73	n.r	306	4.3	38	0.825	
1200	27.32	n.r	54.23	16.64	n.r	459	3.5	40	0.961	
1300	29.04	n.r	50.12	20.05	n.r	607	2.9	59	0.877	
1400	30.34	n.r	45.78	23.46	n.r	573	3.1	113	0.574	
1500	31.28	n.r	43.41	25.84	n.r	478	3.9	62	0.994	
1600	30.70	n.r	45.60	24.17		228	5.0	74	0.732	
1700	27.61	n.r	53.53	17.18	n.r	90	7.5	59	0.546	
1800	26.75	n.r	56.73	15.21	n.r	7	8.7	194	0.180	7.299

Table 9. ***A. auriculiformis*** **- Microclimate, aerodynamic and canopy resistances and transpiration data on 24-01-91**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	22.5	n.r	68.56	8.8	n.r	-65	6.2	-	-	
700	22.1	n.r	69.03	8.5	n.r	-63	6.7	-	-	
800	23.2	n.r	67.54	9.1	n.r	93	8.8	110	0.207	
900	24.7	n.r	64.86	11.0	n.r	125	7.2	49	0.438	
1000	25.7	n.r	63.16	12.2	n.r	123	6.1	66	0.402	
1100	30.0	n.r	61.33	14.4	n.r	315	4.9	80	0.460	
1200	32.0	n.r	55.84	18.8	n.r	452	4.7	75	0.643	
1300	33.2	n.r	47.30	25.1	n.r	593	3.8	83	0.796	
1400	34.1	n.r	41.67	29.6	n.r	582	4.1	120	0.672	
1500	34.1	n.r	38.67	32.7	n.r	484	5.3	151	0.586	
1600	34.1	n.r	36.61	33.9	n.r	337	4.9	107	0.766	
1700	33.1	n.r	36.89	31.9	n.r	174	4.5	174	0.461	
1800	32.2	n.r	36.18	30.7	n.r	20	4.9	311	0.249	5.68

Table 10. ***A. auriculiformis*** **- Microclimate, aerodynamic and canopy resistances and transpiration data on 21-02-91**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	21.97	n.r	87.90	3.19	n.r	-24.9	13.54	-	-	
700	21.51	n.r	88.30	3.01	n.r	-21.3	15.82	-	-	
800	21.98	n.r	86.40	3.61	n.r	40.3	16.41	-	-	
900	26.59	n.r	61.22	13.51	n.r	177.1	3.70	138	0.258	
1000	28.71	n.r	55.56	17.54	n.r	371.6	3.48	149	0.329	
1100	30.58	n.r	45.88	23.74	n.r	525.5	2.84	160	0.419	
1200	31.54	n.r	40.79	27.44	n.r	626.2	2.59	150	0.515	
1300	32.81	n.r	37.05	31.34	n.r	671.7	2.85	151	0.584	
1400	34.09	n.r	32.92	35.87	n.r	645.8	2.92	206	0.494	
1500	35.09	n.r	29.14	40.07	n.r	569.8	2.96	193	0.573	
1600	35.59	n.r	24.56	43.83	n.r	435.8	3.03	213	0.555	
1700	35.61	n.r	22.15	45.27	n.r	251.5	3.19	293	0.411	
1800	34.83	n.r	21.86	43.55	n.r	51.6	3.39	652	0.177	4.321

Table 11. ***A. auriculiformis*** **- Microclimate, aerodynamic and canopy resistances and transpiration data on 26-03-91**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	26.50	n.r	83.6	5.66	n.r	-48.3	6.15	-	-	
700	25.86	n.r	84.2	5.24	n.r	-45.7	7.38	-	-	
800	28.17	n.r	81.9	6.96	n.r	21.0	10.51	-	-	
900	31.10	n.r	73.8	11.90	n.r	254.7	7.41	143	0.241	
1000	31.87	n.r	66.2	15.97	n.r	317.2	6.03	100	0.419	
1100	34.35	n.r	52.6	25.75	n.r	596.4	4.84	271	0.300	
1200	36.18	n.r	45.0	33.03	n.r	690.0	4.85	208	0.481	
1300	37.58	n.r	37.5	40.52	n.r	733.0	4.23	234	0.514	
1400	38.44	n.r	32.2	46.04	n.r	681.5	4.51	222	0.595	
1500	38.58	n.r	36.1	44.18	n.r	572.8	4.70	168	0.712	
1600	35.03	n.r	54.6	25.56	n.r	396.5	3.73	216	0.335	
1700	33.21	n.r	61.9	19.46	n.r	257.0	3.18	237	0.228	
1800	31.56	n.r	67.7	14.97	n.r	63.9	3.57	238	0.163	3.995

Table 12. ***A. auriculiformis*** **- Microclimate, aerodynamic and canopy resistances and transpiration data on 26-4-1991**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	26.81	n.r	88.0	4.23	n.r	-36.5	14.56	-	-	
700	26.40	n.r	88.3	4.02	n.r	12.5	13.35	-	-	
800	27.07	n.r	84.0	5.74	n.r	68.5	18.08	-	-	
900	29.56	n.r	75.3	10.24	n.r	241.7	9.24	52	0.418	
1000	31.01	n.r	72.5	12.37	n.r	381.0	5.95	55	0.552	
1100	32.22	n.r	67.9	15.47	n.r	525.2	4.83	56	0.709	
1200	33.88	n.r	61.5	20.34	n.r	563.0	5.92	63	0.807	
1300	34.54	n.r	57.7	23.18	n.r	660.2	4.80	75	0.828	
1400	34.77	n.r	55.2	24.85	n.r	615.1	4.03	84	0.789	
1500	34.71	n.r	56.0	24.32	n.r	588.8	4.21	113	0.605	
1600	34.40	n.r	55.9	23.95	n.r	432.6	4.41	88	0.690	
1700	33.26	n.r	59.4	20.74	n.r	239.2	4.14	149	0.365	
1800	32.15	n.r	61.2	18.51	n.r	68.3	4.29	261	0.125	5.888

Table 13. ***A. auriculiformis*** **- Microclimate, aerodynamic and canopy resistances and transpiration data on 28-05-91**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	26.86	n.r	86.2	4.53	n.r	-10.4	14.69	-	-	
700	26.59	n.r	86.7	4.63	n.r	15.6	13.35	-	-	
800	28.45	n.r	84.3	6.19	n.r	157.9	16.97	-	-	
900	30.71	n.r	77.5	9.94	n.r	264.0	15.11	52	0.395	
1000	31.51	n.r	75.3	11.43	n.r	353.9	9.62	45	0.547	
1100	31.48	n.r	74.8	11.64	n.r	394.8	6.04	36	0.682	
1200	32.45	n.r	72.3	13.51	n.r	697.9	4.73	46	0.806	
1300	32.58	n.r	71.0	14.28	n.r	521.3	4.29	42	0.816	
1400	33.00	n.r	69.8	15.17	n.r	600.9	3.99	66	0.645	
1500	32.88	n.r	69.6	15.17	n.r	486.2	4.15	67	0.605	
1600	32.64	n.r	69.8	14.86	n.r	397.9	3.91	84	0.478	
1700	32.11	n.r	70.4	14.16	n.r	210.4	4.54	92	0.383	
1800	31.30	n.r	71.7	12.96	n.r	149.9	3.61	262	0.137	5.494

The highest temperatures were noted in March when it reached nearly **39^0C.** and the lowest relative humidity was observed in February. The *D* values remained highest during February to March. The *Rn* also remained quite high during February to May. It is during these months that the sky remains mostly clear in the study area.

Stomatal Resistance *(rs)*

A comparative study of the dorsal and ventral sides of the A. *auriculiformis* phyllode showed the presence of stomata on both surfaces in almost equal frequency (Table 14). It was difficult to distinguish the dorsal and ventral surfaces morphologically. In making *rs* measurements, hence both sides were measured in each phyllode. The *rs* measurements also showed that both sides functioned equally. Hence all values presented here are averages of measurements on dorsal and ventral sides. The values of *rs* are presented in Tables 6 to 13 as canopy resistance (rc)whichhas been arrived at by using the equation,

Table 14. ***A. auriculiforms*** **- Stomatal frequency on the upper and lower sides of the phyllode**

Upper side (No. mm^{-2})	Lower side (No. mm^{-2})	Upper/lower ratio
329 ± 6	388 ± 4	0.85

± s.e. of the mean is indicated. (N = 20)

$$rc = rs/L \quad (6)$$

where,

L = area of the conducting leaf (phyllode) surface.

A consistent pattern of diurnal variations in the *rs* values were found for the trees accessible from the tower erected in the *A. auriculiformis* plantation. Values of *rs* declined sharply at around 09.00 to 11.00 hours and then rose gradually during the day provided the light availability was not limiting. There was again a small decline in *rs* values in the afternoon. Fig.4 shows the diurnal measurements on 18th of November 1990 in the non stress conditions when the soil water availability was good as seen from the leaf water potentials on the same day (see Fig. 3b). The *Rn*, *Ta* and *D* measurements on the same day are presented in the Table 7.

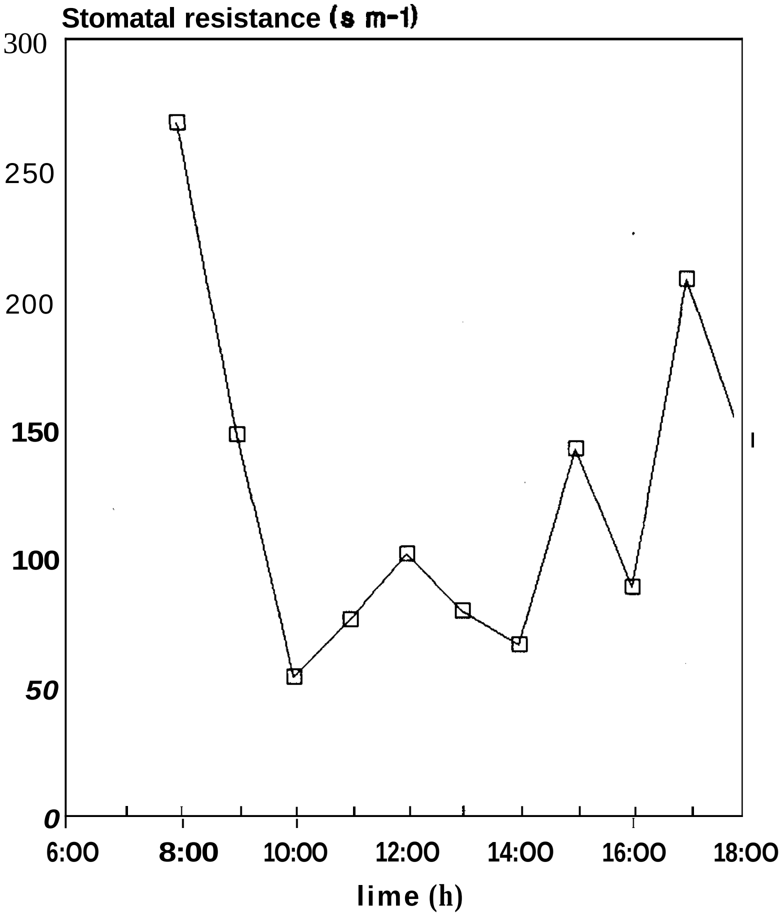


Fig.4. *A. auriculiformis* Diurnal variations in Stomatal resistance on 18.11.90

The diurnal measurements of *rs* during the non-rainy months, that is, from January - March showed high resistance values (see rc values in Table 9 to 11).

The trend seemed to be gradual, for instance, the *rs* values for January showed diurnal variations. However, when the stress became severe in February and March the resistance values remained comparatively higher throughout the day. By examining the water potential measurements and the D measurements it is apparent that both the factors contribute to the stomatal control of transpiration during the summer months. It may be seen that when water is limiting in the soil, i.e., when the water potential of the leaves are low, the *rs* values are very high. This is invariably so even if the *D* shows lower values in the morning with normal light conditions (see Tables 10 and 11 for February and March). However, there is **no** complete stomatal closure even at the lowest water potentials observed.

At increased *D, rs* values of both unstressed and stressed A. *auriculiformis* leaves increased compared to the resistances recorded in more humid air (Fig. 5). The effect of water stress during the summer months was to increase the absolute stomatal resistance of the phyllodes and to increase the sensitivity of the stomata to the air-drying phenomenon. The rate of water loss *(Et)* of water stressed trees was significantly less compared to the rates recorded from unstressed trees (compare *Et* values in Tables 7 and 11).

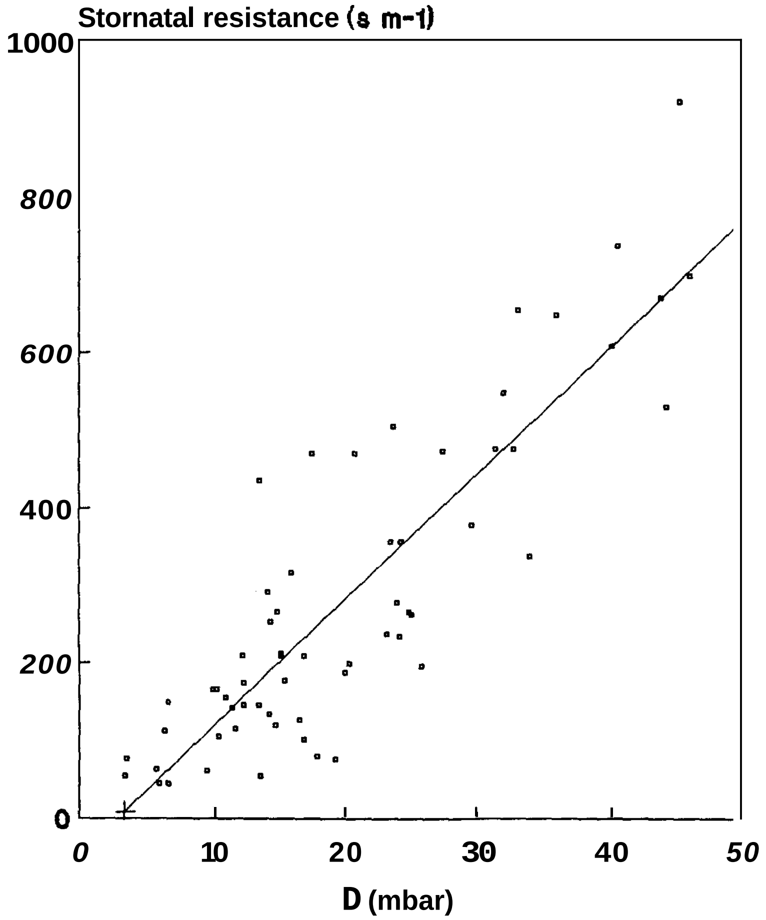


Fig.5. ***A. auriculiformis-*** **Stornatal resistance as a function of**

Fig. 5 shows the relation between stomatal resistance **(*rs*)** plotted against *D* values measured simultaneously. A regression equation of the following form has been fitted to the data.

$$rs = -39.9744 + 16.188D \qquad (7)$$

$(r^2 = 0.76)$

It may be pointed out that large variations in *rs* can occur by the effect of interacting environmental variables. In our present plots we have reduced this by selecting only those *rs* values which have been taken at a net radiation above 100 Wm-2. We have tried a multiple regression procedure combining the several variables except the water potential into one equation.

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

The results showed that the R^2 reaches a value of only 0.78 even in such a case (Table 15). It may be noted that the *D* is the most important factor which controls *rs* in acacia.

Table 15. *A. auriculiformis* - Multiple linear regression analysis on stomatal resistance (*rs*) of the phyllodes

Variable	Coefficient ± S.E.	Partial R^2	P
T_a	5.1192 ± 6.8361	0.0097	>0.05
D	16.2166 ± 1.9330	0.5525	<0.01
R_n	-0.2669 ± 0.0927	0.1269	<0.01
r_a	-7.1071 ± 5.7358	0.0262	<0.05
Constant	-48.1443		

N = 61; $R2 = 0.78$; F = 53.904; P = <0.01

The microclimate conditions in the area deserve special mention. Due to an easterly wind blowing through the Palghat gap of the Western ghats, the *D* values suddenly go to approx. 26 mb. in November. The predawn potentials during this time indicate that the water availability in the soil is not limiting. In such a situation the *rs* values remain quite low even in response to higher *D* values. This can be seen from the Table 7 for November. This is responsible for the extremely high transpiration rate observed in November. Hence the question arises whether *A. auriculiformis* will show low *rs* values at higher *D* values if soil water is available. This deserves more experimental studies.

Leaf area index (LAI)

LAI variations during the year as measured by the light interception method do not show much variations in the values. It has been shown in another study that the maximum litter fall in *A. auriculiformis* occurs in December (Sankaran *et al.*, 1992). It is possible that the new flushings occur almost simultaneously. The average value from a large number of LAI measurements shows the value to be approximately 3.15. We have used this value for the calculation of *rc* using equation *(6).*

The LAI measurements using the canopy analyser is a recent method which needs field calibrations. In *A. auriculiformis* , this calibration has been carried out in the following way. First, an allometric equation was established for the dbh Vs. leaf weight relation by destructive sampling (Jayaraman, *et al.*, 1992). Later another allometric equation was made for the leaf weight Vs. leaf area by actual measurements.

Transpiration

The most widely used form of the combination equation, namely, the Penman-Monteith equation was used to calculate the transpiration from the plantation. This gives a one dimensional description of the interrelationships between the weather and vegetation variables (Monteith, 1973). The equation (9) and the details of the variables used are given.

$$\lambda E = \frac{\Delta (R_n - G) + \rho C_p D/r_a}{\Delta + \gamma (1 + r_c/r_a)} \qquad (9)$$

where,

E = evaporation (mm);

λ = lantent heat of vapourisation (J kg^{-1});

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

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

P = density of air (kg m^{-3})

C_p = specific heat of air (J kg-^{1} ^{0}C^{-1}),

A = slope of the saturation vapour pressure curve for water (mb^{0}C^{-1});

D = vapour pressure deficit (mb);

r_a = aerodynamic resistance (ms^{-1});

γ = psychrometric constant (KPa^{0}C^{-1});

r_c = canopy resistance (sm^{-1}).

The weather data collected above the canopy and the hourly measurements of *rs* formed the basis of applying the above equation in the present circumstance. In our present studies we have taken the atmospheric *D* instead of the leaf-to-air *D* by assuming that the leaf is always at ambient temperature. Computing of the transpiration using all the above parameters was done on an hourly basis. Results are presented in Tables 6 to 13.

From some of the preceeding paragraphs it can be noticed that water loss due to transpiration is the result of interaction of several environmental and physiological variables. While plotting the relationships we usually assume that they work independently. In *A. auriculiformis* one of the most important factor is the water status of the plant as understood by the leaf water potential measurements. The water loss due to transpiration is clearly different in water stressed and unstressed trees.

In the Penman-Monteith equation, the energy factor *(Rn)* may not play an important role in the transpiration value. However, the radiation is an important factor contributing to stomatal opening and closing and hence affect the *rs* values. In the tropics, *Rn* is never limiting except in the rainy season (Table 29).

The *rs* and *D* are again highly correlated factors. Generally, the relation between these two variables can be used for prediction of the stomatal resistance. However, in *A. auriculiformis* **,** although a trend exists, it is further dependant on the soil water availability also.

The *ra* plays only a minor role in tree transpiration. Here, the ***ra*** values are much lower than the *rc* values and approximately in the range of 3-6 sm^{-1}.

It is difficult to predict how far the *Ta* is responsible in controlling the transpiration here. As seen from the Tables 6-13, the *D* also increases along with the temperature. Hence it is difficult to separate the effect of temperature from that of *D.*

One of the interesting observations in this study is the sudden recovery of the stressed plants with the onset of a few summer showers as seen from the Tables 12 and 13 for April and May. The slightest wetting of the soil (the predawn potentials did not appreciate much) induced a low ***rs*** in spite of high *D* values in April.

Photosynthesis *(Pn)*

To understand the instantaneous water use efficiency of the plant, the net photosynthesis and chamber transpiration ***(EC)*** were measured simultaneously. Fig. 6 shows the ***Pn, EC*** and P_n/E_c measured in *A. auriculiformis* **.** Each data point in the figures is the mean value of at least six measurements on different leaves. The water use efficiency (W E) is expressed as the μmol $_2$ assimilated per mmol water consumed. It should be remarked that the W E calculated thus is only an instantaneous one. It has no direct relation with the overall biomass increase in

Table 16. *A. occidentale* - Weather data for Vellanikara during April 1991 to March 1992

Element	April	May	June	July	August	Sept.	October	Nov.	Dec.	Jan.	Feb.	March	Year (cum.)
Max. temp.	35.6	35.1	29.7	29.1	29.0	31.5	30.9	31.5	31.9	32.6	34.5	36.9	-
Min. temp.	24.5	25.5	23.8	22.8	22.7	23.6	23.2	23.0	21.7	20.9	21.8	22.8	-
Rain (mm)	83.8	56.1	993.1	975.6	533.3	61.5	281.7	191.3	0.2	0.0	0.0	0.0	3182.3
R. days	4.0	5.0	28.0	27.0	24.0	7.0	14.0	9.0	0.0	0.0	0.0	0.0	-
RH (%) Max.	83.0	85.0	94.0	94.0	95.0	91.0	90.0	87.0	78.0	69.0	87.0	84.0	-
RH(%) Min.	53.0	55.0	82.0	79.0	78.0	64.0	74.0	63.0	49.0	36.0	42.0	38.0	-
Sunsh. (hr)	8.9	7.5	4.8	2.5	2.8	7.3	4.3	7.1	8.6	9.0	9.2	9.2	-
W. speed km/hr.	4.6	4.4	4.6	4.4	3.4	4.0	3.6	5.9	9.7	4.2	4.1	4.7	-

The above data were collected from the weather station maintained by the Department of Agrometeorology, Kerala Agricultural University. The station is located within a kilometre radius of the study site.

relation to water consumption. However, instantaneous WUE is an indicator of how efficient the leaf is in CO_2 assimilation in relation to transpiration.

From Fig. 6c it is apparent that the WUE is more when the ***rs*** values are higher. This is probably an adaptation with several drought resistant species. Even when partial closure of stomata occurs, CO_2 diffusion takes place normally resulting in higher WUE. In *A. auriculiformis* *rs* values are higher in the morning and late afternoons and also during midday. It is at these times that the WUE values are maximum.

Growth

The growth in girth of the *A. auriculiformis* trees in the plantation was closely followed by measuring the girth at breast height (gbh) of forty trees at monthly intervals. The results are presented in Fig. 7. The averaged values of forty trees chosen in two rows within the plantation show that girth increase occurs in all the months except January to March. Although girth increase occurs in April and May, the slope is certainly less steep when compared to other months of the year.

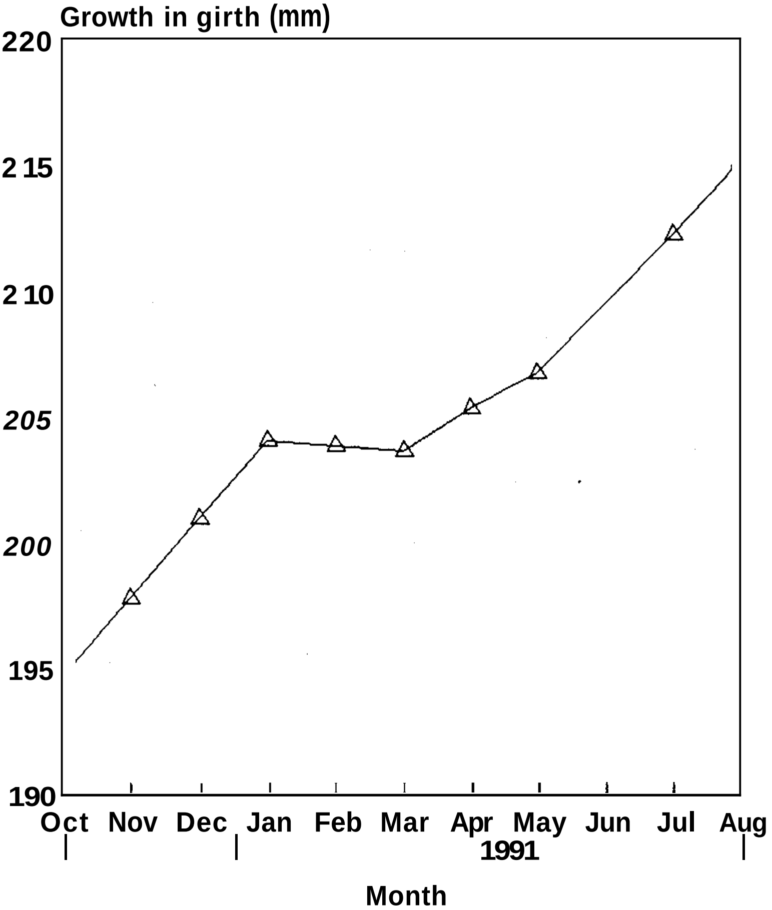


Fig.7. Increase in girth of *A. auriculiformis*

The growth measurements show good correlation with other water stress responses like higher stomatal resistance and lower water potentials. It shows from the results that cambial growth stops during the time of water stress in these trees. 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 stress period. It may be useful to quantify this in relation to water availability in future studies.

Anacardium occidentale (Cashew)

Weather data

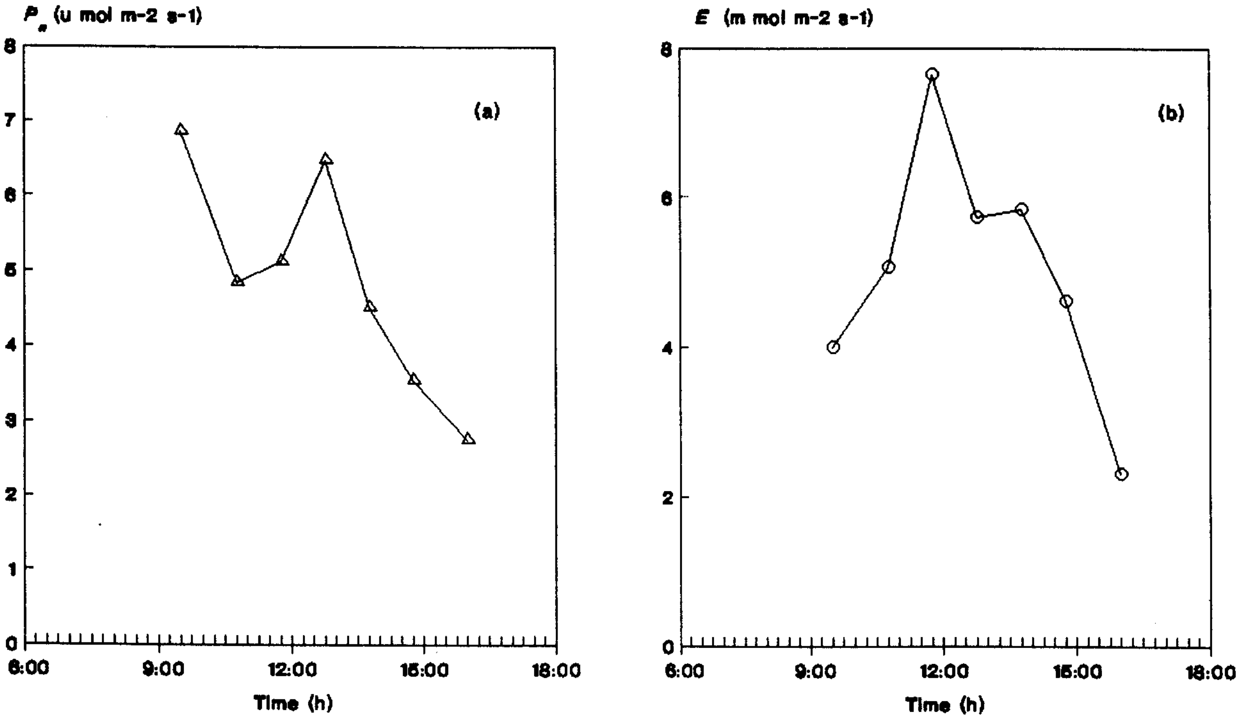
Table 16 shows the annual weather data collected at a weather station within 0.5 km from the cashew plantation monitored for this study. The wettest months of the year are from June to August when 78% of the rain fell in this area. The dry period, from December to March, is characterised by no rainfall. The summer showers mostly falling in April and May contributed 4% of the total. The temperature recordings show March to be the hottest month with the maximum temperature going upto 37^0C. The area although located in Trichur district, has many climatic similarities to the Palghat district where measurements on A. *auriculiformis* and *T grandis* were taken. The PET for the area is more or less similar to the one observed for Palghat (Fig. 2).

Rainfall interception

Rainfall interception was measured for three months lasting the whole period of South-West Monsoon in the experimental plot of cashew. However, stem flow was not separated from the measurements. The result of throughfall measurements on 35-rainy days shows the throughfall to be 79%. The balance of 21% includes intercepted water and the stemflow. If we can reasonably assume the stemflow to be approximately 6%, we can take the interception to be 15% which is nearly twice that of A. *auriculiformis* we have measured in this study.

Soil and leaf water potentials

Fig. 8 shows the predawn and midday water potentials measured on days when other physiological and microclimate parameters were measured. Each data point is the mean value of at least six independent measurements taken from four trees. Since A. *occidentale* gives out a resinous exudation when cut, this created some problems in judging the exact balancing pressure in the pressure chamber measurements. This problem was mostly overcome by scraping off the petiole bark before sealing it in the pressure chamber.



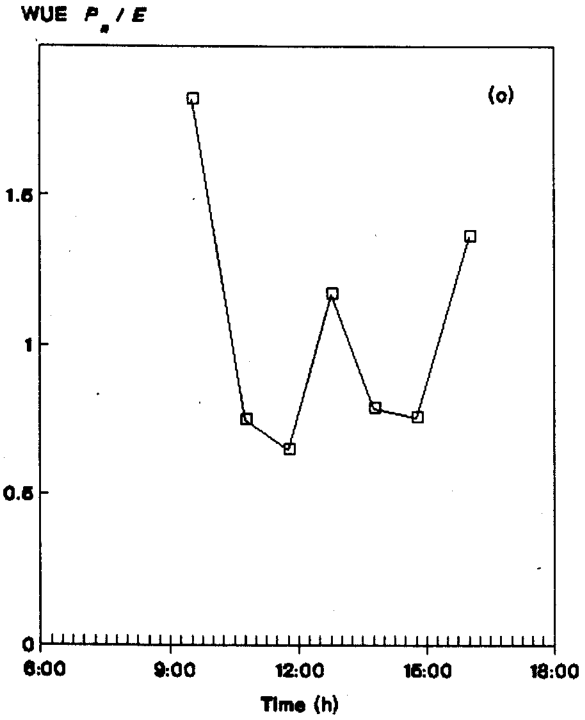


Fig.6. *A. auriculiformis*-

(a) Net photosynthesis

(b) Chamber transpiration

(c) WUE

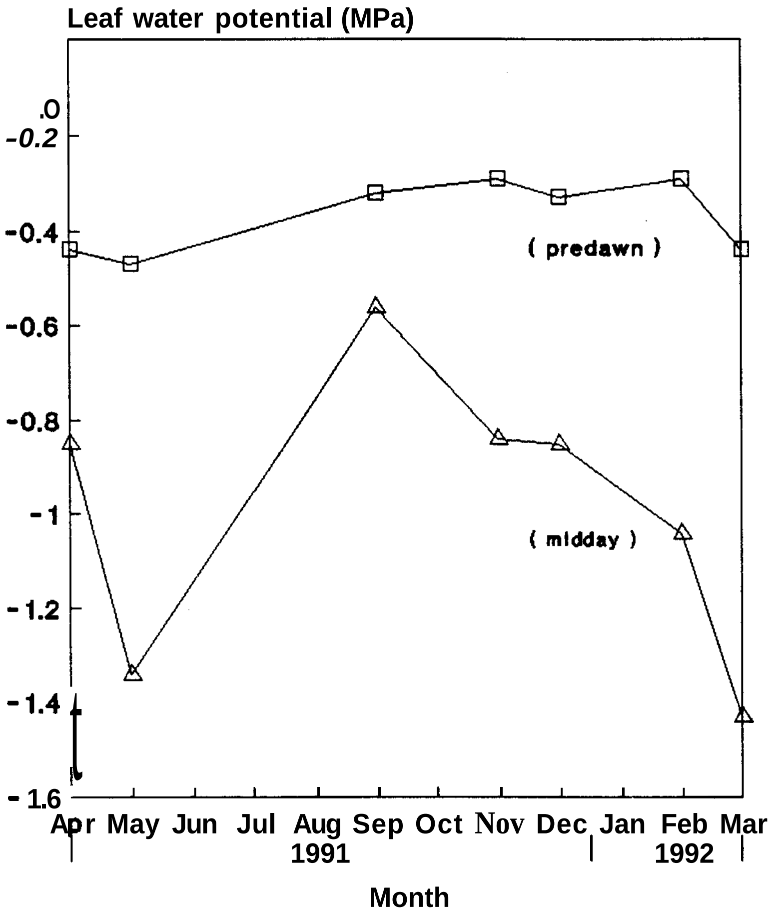


Fig.8. *A. occidentale* - leaf water potentials

From Fig. 8 it is seen that A. *occidentale* shows high predawn water potentials throughout the year. The values are relatively higher than that of A. *auriculiformis.* The water potential reaches the lowest level in March to May. The corresponding midday values show the lowest water potentials attained by this tree in this locality. The relatively high water potentials in summer would indicate that the roots of this plant were in contact with a water source like the phreatic aquifer. Casual observation revealed that the summer water table in this locality was approximately 10-15 m deep. Hence the cashew roots reaching the phreatic level is a possibility which needs further confirmation.

Microclimate

The same meteorological parameters as measured above A. *auriculiformis* canopy were measured here. Apart from these we have measured the total solar radiation above the canopy and the temperature underneath the canopy, 1.5 m. above ground level. All these results are presented in Tables 17-24.

Table 17. *A. occidentale* - Microclimate, aerodynamic and canopy resistances and transpiration data on 23-04-91

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	25.33	n.r	88.5	3.72	n.r	-12.8	9.28	-	-	
700	25.98	n.r	87.2	4.30	n.r	1.3	15.65	-	-	
800	27.27	n.r	85.7	5.19	n.r	73.3	17.00	52	0.160	
900	30.94	n.r	75.0	11.30	n.r	306.0	14.08	47	0.477	
1000	31.14	n.r	72.8	12.31	n.r	313.9	6.69	47	0.567	
1100	32.10	n.r	69.9	14.39	n.r	401.2	5.49	85	0.463	
1200	33.17	n.r	64.6	17.98	n.r	370.2	7.40	93	0.499	
1300	33.83	n.r	62.2	19.89	n.r	381.7	4.82	83	0.602	
1400	33.89	n.r	63.2	19.44	n.r	510.4	3.22	76	0.678	
1500	33.93	n.r	63.6	19.26	n.r	525.6	2.72	98	0.546	
1600	33.62	n.r	63.6	18.93	n.r	450.4	2.80	119	0.444	
1700	32.35	n.r	67.9	15.61	n.r	222.3	2.56	130	0.319	
1800	18.48	n.r	68.9	10.47	n.r	80.9	3.17	257	0.181	4.936

Table 18. *A. occidentale* - Microclimate, aerodynamic and canopy resistances and transpiration data on 14-05-91

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	26.50	n.r	88.6	3.94	n.r	-20.5	18.69	-	-	
700	26.52	n.r	88.9	3.84	n.r	15.9	16.65	-	-	
800	28.96	n.r	84.8	6.13	n.r	142.5	17.20	72	.197	
900	31.14	n.r	78.6	9.71	n.r	274.8	8.97	54	.414	
1000	31.92	n.r	73.0	12.78	n.r	323.4	6.40	60	.509	
1100	32.83	n.r	68.8	15.55	n.r	408.2	7.43	58	.630	
1200	33.83	n.r	63.9	18.99	n.r	402.6	4.49	85	.577	
1300	34.85	n.r	61.1	21.71	n.r	572.7	3.49	84	.699	
1400	34.43	n.r	61.3	21.07	n.r	605.0	2.48	86	.672	
1500	34.17	n.r	61.7	20.59	n.r	352.4	2.65	76	.683	
1600	32.99	n.r	64.4	17.88	n.r	142.5	3.01	80	.531	
1700	32.94	n.r	65.8	17.13	n.r	272.4	3.15	52	.749	
1800	32.26	n.r	65.6	16.59	n.r	71.4	3.31	106	.375	6.036

Table 19. *A. occidentale* - Microclimate, aerodynamic and canopy resistances and transpiration data on 20-09-91

time (h)	T_a (°C)	T_g (°C)	rh (%)	D (mb)	S (Wm^{-2})	R_n (Wm^{-2})	r_a (sm^{-1})	r_c (sm^{-1})	E_t (mm)	E_t cum (mm)
600	22.68	n.r	90.5	2.61	-	-10.8	15.38	-	-	
700	22.70	n.r	90.5	2.62	-	7.3	16.32	-	-	
800	24.54	n.r	89.1	3.37	135.8	103.4	14.15	-	-	
900	27.32	n.r	82.5	6.39	249.1	172.4	11.03	58	0.290	
1000	27.88	n.r	79.0	7.89	373.7	239.6	5.25	61	0.371	
1100	29.24	n.r	72.3	11.28	595.5	364.0	4.52	52	0.617	
1200	29.90	n.r	67.7	13.63	476.5	294.0	4.73	54	0.645	
1300	30.03	n.r	66.6	14.16	490.1	307.8	3.30	68	0.565	
1400	30.14	n.r	65.9	14.56	579.6	368.1	2.73	96	0.443	
1500	29.93	n.r	66.4	14.16	265.1	397.4	2.65	72	0.519	
1600	28.79	n.r	69.4	12.09	209.6	205.1	3.48	84	0.365	
1700	28.36	n.r	70.2	11.51	188.2	120.7	4.99	110	0.258	
1800	27.65	n.r	72.4	10.21	90.3	41.8	5.46	161	0.155	4.231

Table 20. *A. occidentale* - Microclimate, aerodynamic and canopy resistances and transpiration data on 23-11-91

time (h)	T_a (°C)	T_g (°C)	rh (%)	D (mb)	S (Wm^{-2})	R_n (Wm^{-2})	r_a (sm^{-1})	r_c (sm^{-1})	E_t (mm)	E_t cum (mm)
600	23.62	n.r	90.2	2.85	-0.0	-10.5	12.40	-	-	
700	23.55	n.r	90.1	2.88	28.6	10.7	13.40	-	-	
800	25.26	n.r	89.0	3.57	158.3	103.3	11.29	-	-	
900	28.00	n.r	78.7	8.14	370.8	243.9	7.20	74	0.290	
1000	29.95	n.r	68.8	13.19	595.2	437.1	5.68	46	0.676	
1100	30.74	n.r	66.0	15.06	755.0	573.6	4.27	44	0.844	
1200	33.45	n.r	61.3	17.83	860.0	658.5	3.54	57	0.830	
1300	31.80	n.r	9.5	19.01	842.0	641.0	3.32	46	1.021	
1400	32.50	n.r	58.1	20.48	740.0	559.9	4.36	63	0.822	
1500	32.54	n.r	57.7	20.74	517.4	381.1	5.29	69	0.709	
1600	32.34	n.r	58.5	20.09	285.9	198.3	7.38	59	0.648	
1700	30.17	n.r	74.2	11.09	167.8	103.0	4.26	66	0.374	
1800	29.20	n.r	77.4	9.17	78.2	25.5	6.03	100	0.199	6.416

Table 21. ***A. occidentale*** **- Microclimate, aerodynamic and canopy resistances and transpiration data on 23-12-91**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	($\mathrm{Wm^{-2}}$)	($\mathrm{Wm^{-2}}$)	($\mathrm{sm^{-1}}$)	($\mathrm{sm^{-1}}$)	(mm)	(mm)
600	23.71	22.42	86.1	4.08	-0.1	-37.2	9.81	-	-	
700	23.66	21.71	85.9	4.11	5.1	-34.8	6.80	-	-	
800	24.86	23.28	84.3	4.95	103.6	39.9	6.35	121	0.099	
900	26.48	26.09	80.1	6.89	295.3	189.9	3.21	46	0.361	
1000	27.79	27.59	75.8	9.04	495.9	346.6	2.81	48	0.486	
1100	29.20	29.20	70.4	12.01	647.6	463.4	3.04	59	0.548	
1200	30.15	30.41	65.4	14.81	765.0	555.5	2.85	96	0.447	
1300	31.16	31.48	58.8	18.66	797.0	579.8	2.99	75	0.675	
1400	31.99	32.00	54.6	21.58	766.0	553.8	3.28	62	0.880	
1500	32.74	33.26	50.6	24.49	652.9	461.7	3.75	87	0.722	
1600	32.96	32.07	48.1	26.02	479.2	314.6	4.61	71	0.831	
1700	32.64	31.38	47.9	25.64	266.1	140.6	6.11	107	0.535	
1800	31.7	29.89	49.9	23.40	104.2	20.4	7.98	256	0.216	5.804

Table 22. ***A. occidentale*** **- Microclimate, aerodynamic and canopy resistances and transpiration data on 21-01-92**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	($\mathrm{Wm^{-2}}$)	($\mathrm{Wm^{-2}}$)	($\mathrm{sm^{-1}}$)	($\mathrm{sm^{-1}}$)	(mm)	(mm)
600	23.16	22.78	56.86	12.23	-0.0	-70.6	2.23	-	-	
700	22.95	22.65	59.32	11.39	1.6	-51.7	2.27	-	-	
800	23.12	22.88	61.85	10.79	54.7	0.0	2.13	70	0.377	
900	24.04	23.76	61.73	11.46	274.4	148.3	2.57	55	0.504	
1000	25.41	25.20	59.41	13.18	441.8	280.1	2.40	58	0.571	
1100	26.89	27.10	56.57	15.40	668.0	447.3	2.59	50	0.773	
1200	28.28	28.67	51.33	18.70	819.0	560.0	1.92	72	0.696	
1300	29.33	29.74	43.95	22.91	899.0	623.7	1.63	97	0.645	
1400	30.56	30.83	35.82	28.13	864.0	597.2	1.86	101	0.749	
1500	31.28	31.26	30.61	31.68	765.0	522.4	1.77	98	0.853	
1600	31.73	31.29	28.21	33.61	585.7	383.5	1.94	131	0.677	
1700	31.57	30.84	24.87	34.86	364.5	201.5	1.93	118	0.756	
1800	31.32	30.31	22.99	35.24	199.7	65.2	2.44	170	0.528	7.133

Table 23. *A. occidentale* - Microclimate, aerodynamic and canopy resistances and transpiration data on 24-02-92

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	22.08	20.65	88.9	2.94	-0.0	-20.6	11.45	-	-	
700	22.47	20.93	87.8	3.32	4.5	-20.2	7.88	-	-	
800	23.51	22.25	85.8	4.14	102.2	46.1	6.41	-	-	
900	26.38	25.43	78.4	7.54	306.6	200.6	6.62	61	0.300	
1000	28.89	28.17	66.6	13.28	534.5	382.3	6.45	56	0.571	
1100	29.96	30.43	58.5	17.59	733.0	535.7	3.85	60	0.753	
1200	31.42	32.47	52.5	21.86	863.0	636.2	2.74	84	0.711	
1300	33.01	34.01	45.5	27.45	920.0	677.7	2.95	86	0.856	
1400	34.29	35.02	36.1	34.53	888.0	645.8	2.92	128	0.736	
1500	35.02	35.41	32.4	38.06	781.0	551.0	2.77	106	0.932	
1600	32.79	32.84	45.9	27.35	605.0	411.9	2.33	97	0.732	
1700	30.68	30.66	55.0	19.85	379.6	249.6	2.58	79	0.625	
1800	30.02	29.70	55.4	18.92	179.3	86.4	3.23	115	0.403	6.626

Table 24. *A. occidentale* - Microclimate, aerodynamic and canopy resistances and transpiration data on 13-03-92

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	22.57	21.39	89.7	2.8	-0.1	-15.2	10.44	-	-	
700	22.18	21.05	89.9	2.7	9.1	-9.9	8.73	-	-	
800	23.12	21.72	89.1	3.0	136.2	71.7	13.65	-	-	
900	26.16	24.56	83.1	5.8	368.5	225.6	11.21	-	-	
1000	29.14	28.63	45.2	22.3	615.9	384.8	3.71	65	0.826	
1100	31.70	31.94	28.2	33.6	805.0	534.3	3.17	103	0.849	
1200	34.03	34.54	15.2	45.2	924.0	619.9	2.57	120	0.991	
1300	35.98	36.58	9.8	53.5	965.0	652.8	2.19	166	0.867	
1400	36.70	37.17	9.1	56.1	927.0	624.3	1.96	185	0.817	
1500	37.05	37.34	8.9	57.3	806.0	531.3	1.94	176	0.866	
1600	37.06	37.04	9.0	57.2	627.0	391.0	2.03	144	1.028	
1700	36.89	36.46	9.1	56.6	381.1	201.6	2.19	169	0.858	
1800	35.56	34.55	18.2	48.4	145.7	16.4	3.14	226	0.537	7.649

The highest temperatures in this locality were observed in March when they reached more than $37^{O}C$ above the tree canopy. The ground temperature in the days recorded in this study showed nearly $1^{0}C$ less than the above canopy values in the forenoon. However the afternoon values were more or less identical.

The r.h. values recorded in this locality are noteworthy. In March the r.h. values showed extremely low values. It is questionable, how far these values are near to the absolute values because most of the humidity sensors available commercially show noisy responses below 20% r.h. The *D* also shows relatively higher values during March. The *Rn* values are also quite high during the months of December to March.

Fig. 9 shows a plot of the *Rn* against S measured above the A. *occidentale* canopy. The two parameters measured above the cashew canopy show good correlation when fitted by the following equation.

$$Rn = -43.00 + 0.76\,S \qquad (10)$$

$r^2 = 0.98$

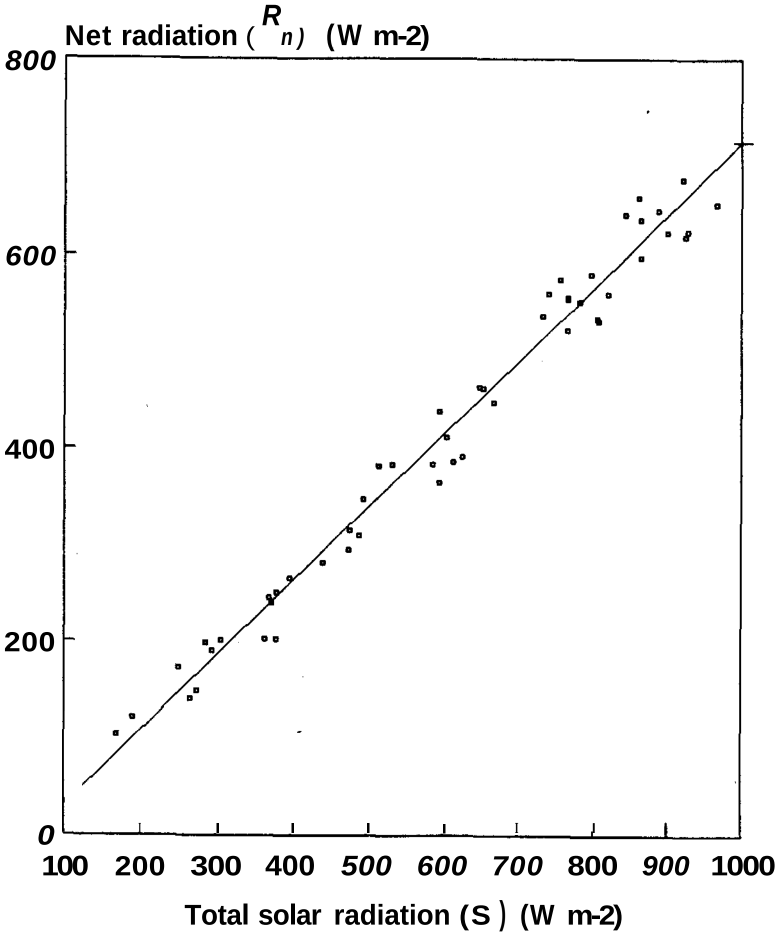


Fig-9. *A. occidentale* - R_n as a function of

Since *Rn* is more difficult to measure because of the requirement of more sophisticated sensors, the above relation has potential predictive value in situations where only solar radiations are available. This can be also used to compare the *Rn* values in other types of vegetation.

Stomatal Resistance *(rs)*

Microscopic examination of the A. *occidentale* leaf showed that stomata were present only on the abaxial side. Hence only the abaxial side was subjected to porometer measurements. The hourly measurements done on the leaves accessible from the scaffold tower is presented in Tables 17-24 as *rc* arrived at by using equation (6). The canopy of A. *occidentale* was peculiar in having more than 90% of the leaves fully exposed to the incoming direct radiations.

A more or less consistent pattern of diurnal variations in rs was shown from the porometer measurements. ***rs*** values declined sharply from 09.00 h to 11.00 h after which it rose up slightly at 12.00 h. Then again the ***rs*** values declined for some time. A typical diurnal measurement made on the trees on 23.12.1991 is presented in Fig. 10. The pattern shows a partial midday closure of the stomata at around noon. The same pattern could be noticed even when the trees were under water stress during March (Table 24).

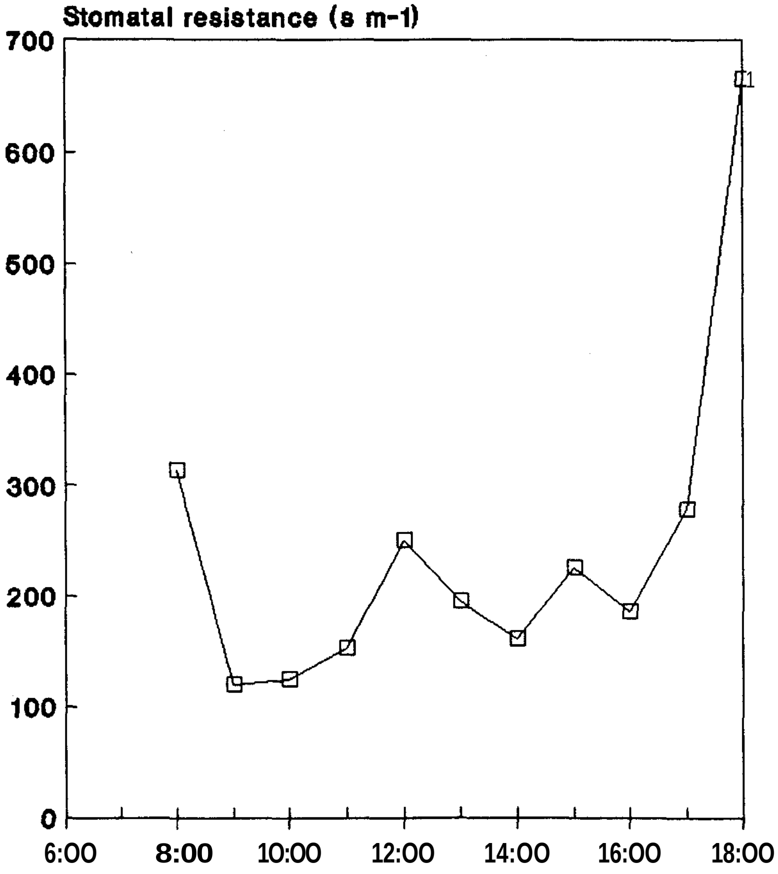


Fig.10. *A. occidentale* - **Diurnal variations in stomatal resistance on 23.12.91**

The seasonal variations in *rs* are also quite pronounced. The daily *rs* values were uniform from September to February and then they shot up abruptly in March. The sudden decrease in April and May is due to the summer showers which increased the water potentials.

However, even at extremely high *D* values in March, the *rs* values were not as high as that of A. *auriculiformis.* This probably indicates the less efficient stomatal closure in cashew when compared to A. *auriculiformis* in response to *D.*

To test the influence of various microclimate parameters on *rs,* we have used a multiple linear regression model as in equation (7). The results of this analysis are presented in Table 25. It shows that *D* is very closely correlated with the *rs.*

Table 25. *A. occidentale* - Multiple linear regression analysis on stomatal resistances (rs) of leaves

Variable		Partial R^2	P
T_a	2.9883 ± 2.9886	0.01	> 0.05
D	5.4209 ± 0.7147	0.46	< 0.01
R_n	-0.0839 ± 0.0378	0.69	<0.05
r_a	-2.1257 ± 2.4064	0.01	>0.05
Constant	51.4192		

N = **72; R2** = **0.71;** F = **45.469;** P = **<0.01.**

Fig. 11 shows the ***rs*** values plotted against the ***D*** values measured simultaneously. An equation of the following form has been fitted to the data.

$$rs = 94.5312 + 5.7501\, D \tag{11}$$

$r^2 = 0.71$

If all the field measurements are taken into account the correlation coefficient reduces slightly. Hence we have taken only those *rs* measurements when the net radiations were more than 100 Wm^{-2}. In cashew, the correlation is quite significant irrespective of the fact that the trees were stressed or unstressed. However, the slope of the regression curve is much less steeper when compared to A. *auriculiformis* showing that the response is slower.

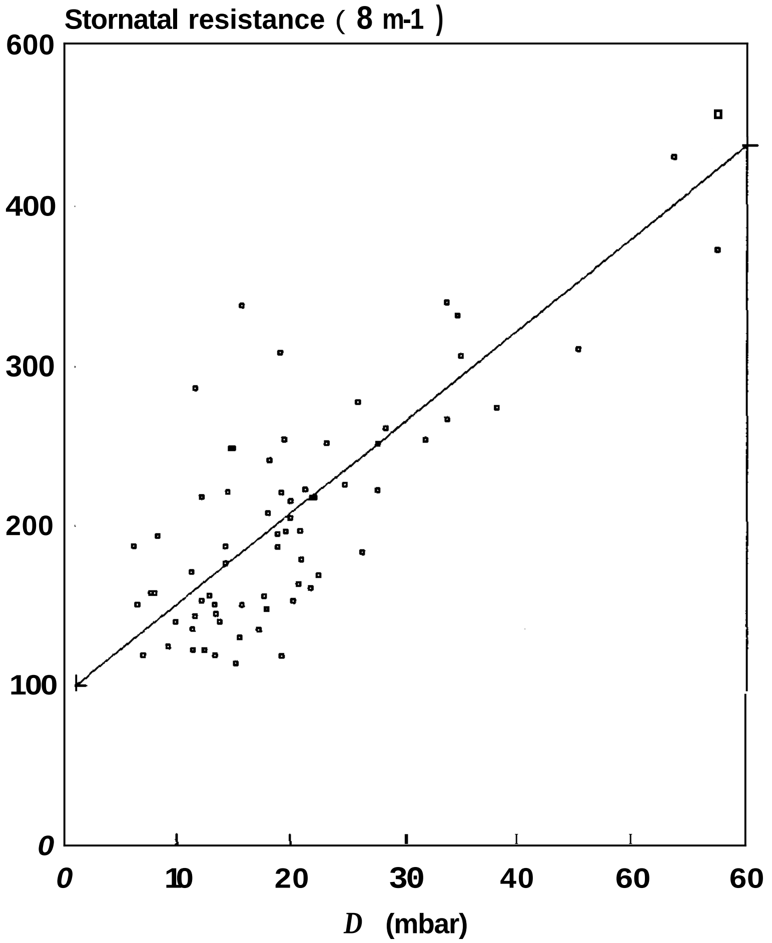


Fig.11. *A. occidentale* - Stomatal resistance as a function of *D*

Leaf area index

The LAI measurements were made throughout the year which do not show much variations. The average value from a large number of measurements was taken as 2.6. This value has been used in the calculation of *rc* using equation (6).

Transpiration *(Et)*

As in A. *auriculiformis,* the Penman-Monteith equation was used in the calculation of transpiration in cashew. The hourly calculation of *Et* using the above equation is presented in Tables 17-24.

In the Penman-Monteith equation, the *Rn* may not play an important role in the transpiration value compared to *D.* However, the *rs* is greatly controlled by the *Rn.* The *Rn* is usually not a limiting factor in the tropics (see Tables 17-24).

The *ra* plays only a minor part in the transpiration calculation using the Penman-Monteith equation. It may be noticed from Tables 17 to 24 that *ra* values reach their lowest levels in January, approximately 1.5 s m^{-1} This is due to an easterly wind blowing through the Palghat gap of Western Ghats.

Photosynthesis (*Pn)*

The net photosynthesis ***(Pn),*** the chamber transpiration ***(EC)*** and the WUE ***(Pn/Ec)*** are depicted in Fig. 12a, b, c. Each data point depicted in the graphs are the mean values of at least six measurements. The measurement was made in cashew trees on 24.02.1992. It may be seen that the *Pn* rates are in general much higher for cashew when compared to Acacia. The WUE as depicted in the figure shows that the overall WUE is slightly better for cashew when compared to acacia.

Growth

As in A. *auriculiformis,* the growth in girth was not followed in cashew because the plantation was a mature one. New leaf production in the mature plant occurred mainly in the month of December. This happened soon after all the old leaves had fallen off from the trees.

Tectona grandis (Teak)

Weather data

The annual weather data collected during the study period from a station located within 5 km. from the study area is presented in Table 26. As in other cases, the wettest months of the year are from June to September. This location has comparatively less rainfall. The dry period is from December to March when there is no rainfall. Apart from rainfall, it has not been possible to obtain the other weather parameters for the area. The PET values reported for Palghat District (see Fig. 2) should be applicable to this study area also.

Table 26. *T: grandis* - Rainfall data for the year 1992

Month	Rainfall (mm)
January	0
February	0
March	0
April	53 (2)
May	44 (2)
June	470 (17)
July	390 (15)
August	335 (15)
September	187 (9)
October	77 (3)
November	276 (6)
December	0
Total	1032

The above data was collected from the Kerala Forest School, Walayar which is approx. 5 km. away from the study area. The number of rainy days (>10.0 mm) are indicated in parenthesis.

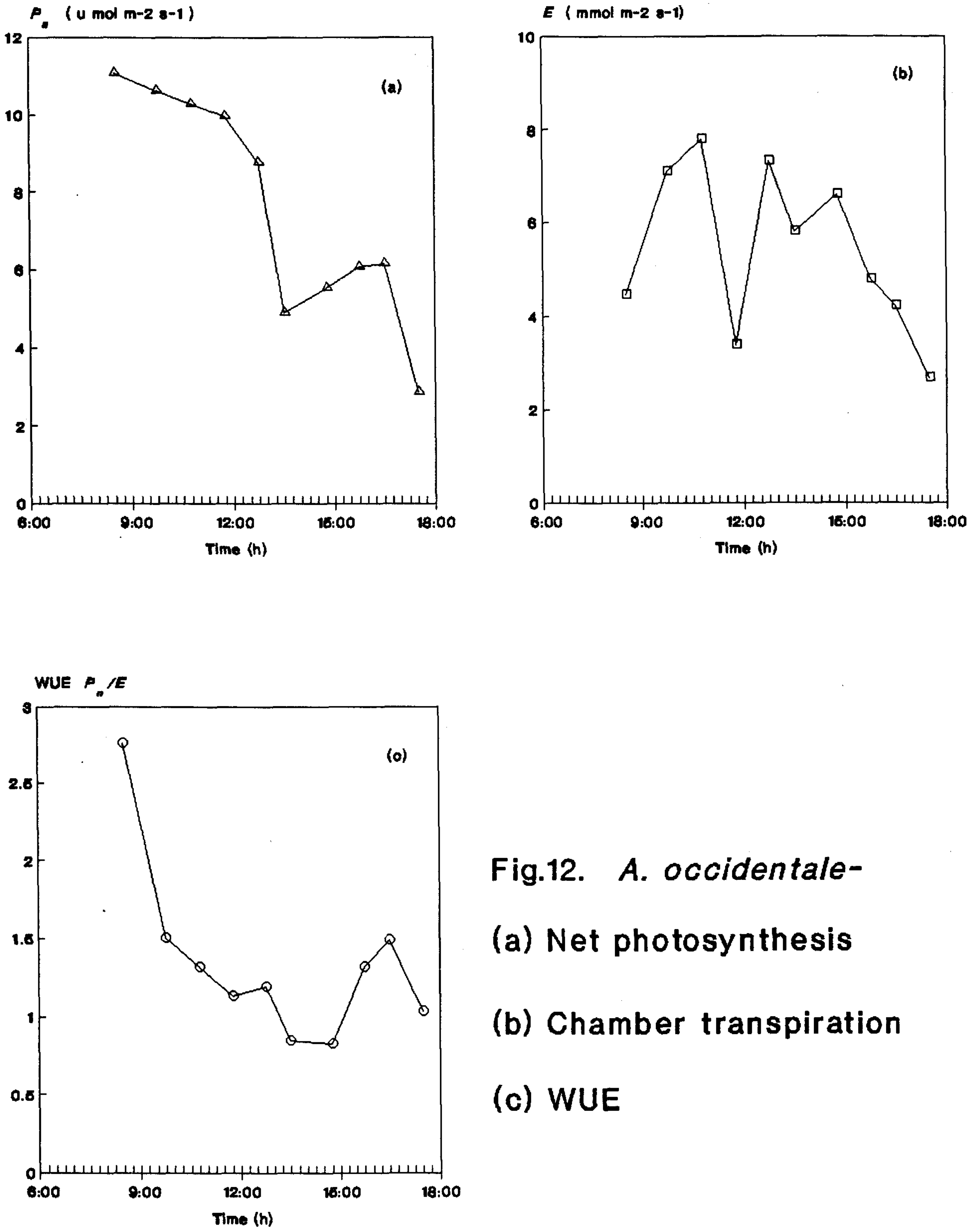


Fig.12. *A. occidentale-*

(a) Net photosynthesis

(b) Chamber transpiration

(c) WUE

Leaf water potentials

Predawn and midday water potentials measured on days when other physiological measurements were taken are shown in Table 27. The predawn water potentials have remained quite high during the measurement period. It should be remembered that *T: grandis* trees shed its leaves before the dry period begins as indicated previously. This is the reason that we are not able to make the measurements during the dry period. From the measurements shown in Table 27, the midday water potentials do not indicate much differences. The values we have obtained are very similar to the values shown for teak in Nigeria (Whitehead et al., 1981). From the values it is apparent that the plant is not under stress during any time of the year when it is bearing leaf.

Table 27. *T. grandis* - Leaf water potentials in teak (MPa)

Date	Predawan (MPa)	Midday (MPa)
15.05.92	-0.21	-0.72
29.10.92	-0.26	-0.76
21.11.92	-0.16	-0.69
01.12.92	-0.15	-0.88

Each value indicated is the mean of 3 to 6 measurements made in the field. The standard errors are negligible.

Microclimate

The various microclimate parameters measured above and within the canopy are presented in Tables 28-31. Hourly values, each representing the mean of 720 measurements are shown.

It should be pointed out that the microclimate parameters were measured in teak plantation only in the leafy stage. Hence only four tables are presented showing the microclimatic conditions from May to December. From these tables the maximum temperatures *(Ta)* are found in May. The temperatures below the canopy *(Tg)* is usually 1^{o}C lower than the above canopy ***(Ta)*** values in the morning. However, in the afternoon *Tg* values are higher when compared to the *Ta* values. This observation is similar to the data in cashew already presented.

Fig. 13 shows the relation between S and *Rn* measured above the teak canopy during the different months. They show good correlation so that prediction of *Rn* is possible from S measurements. A regression equation of the following form has been fitted to the data which shows an $r^2 = 0.98$.

$$Rn = -48.4338 + 0.7887\,S$$

Table 28. *T. grandis* **Microclimate, aerodynamic and canopy resistances and transpiration data on 15-05-92**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
600	23.24	22.94	88.9	3.16	0.1	-13.5	8.70	-	-	
700	23.51	23.37	88.9	3.23	87.1	50.0	3.48	-	-	
800	25.10	24.95	86.6	4.30	268.3	179.6	3.72	75	0.087	
900	26.92	26.76	79.1	7.42	480.1	343.7	1.63	99	0.164	
1000	27.39	27.68	77.9	8.08	455.6	341.5	1.38	87	0.206	
1100	29.15	30.04	71.9	11.37	767.0	582.6	1.27	93	0.281	
1200	30.32	31.64	67.2	14.17	878.0	651.8	1.26	108	0.311	
1300	31.23	32.81	61.6	17.46	950.0	691.3	1.15	107	0.395	
1400	31.98	33.86	59.1	19.40	917.0	647.8	1.18	136	0.354	
1500	32.53	34.24	57.5	20.78	818.0	554.3	1.20	159	0.328	
1600	32.14	33.23	58.7	19.78	646.1	414.8	1.12	218	0.233	
1700	30.02	30.13	65.4	14.73	178.7	105.3	1.16	278	0.137	
1800	28.84	28.72	68.5	12.47	74.3	31.2	1.29	739	0.044	2.546

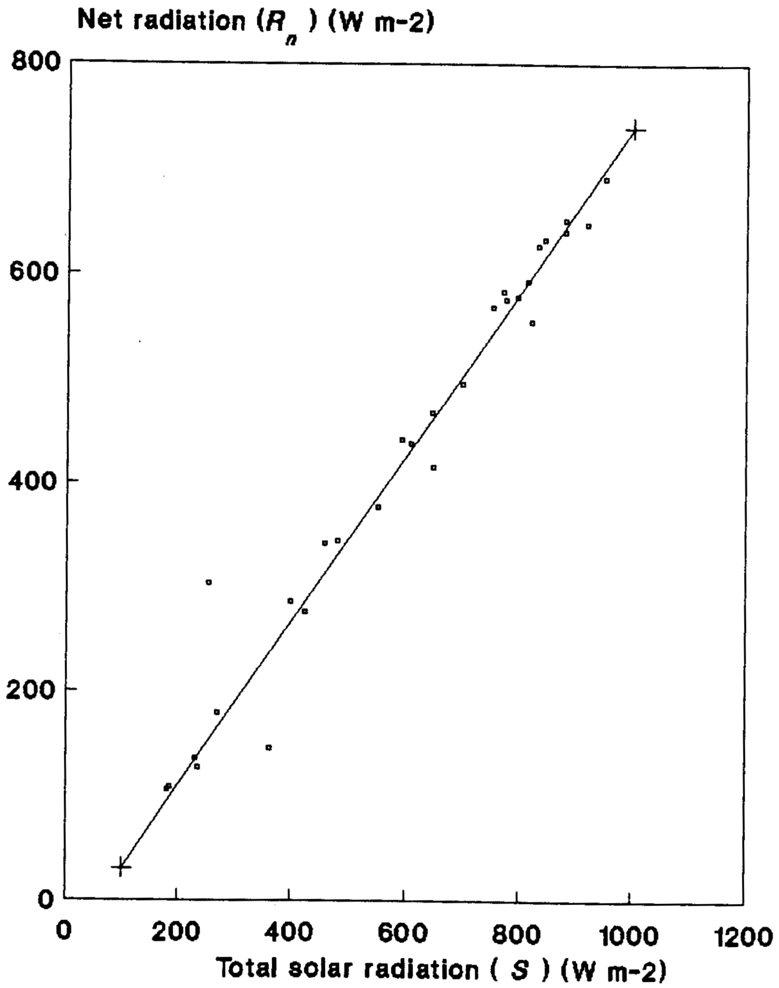


Fig.13. *T. grandis* - R_n as a function of S

It is interesting to note that the slope of the curve plotted for the above canopy measurements in cashew is very similar (cf. Fig. 9).

Stomatal resistance *(rs)*

Sample measurements on the abaxial and adaxial sides of the teak leaves showed extremely high resistance on the adaxial surface. From this we concluded that stomata were present only on the abaxial side of the leaf. It was difficult to count the stomata in teak leaves by the usual method of taking epidermal impressions. All the *rs* measurements presented here are those made on the abaxial surface only. The result of measurements during various days of the year are presented in Tables 28, 30 and 31 as *rc* values. The ***rs*** values can be arrived at by multiplying the *rc* values by the LAI (2.81 in teak).

A more or less consistent pattern of diurnal variations in ***rs*** values were found in teak. The ***rs*** values declined sharply at around 09.00 hrs. and they rose gradually from 14.00 hrs. onwards (Fig. 14). The *D* and *Rn* measurements taken simultaneously are also presented. There was no indication of a midday stomatal closure.

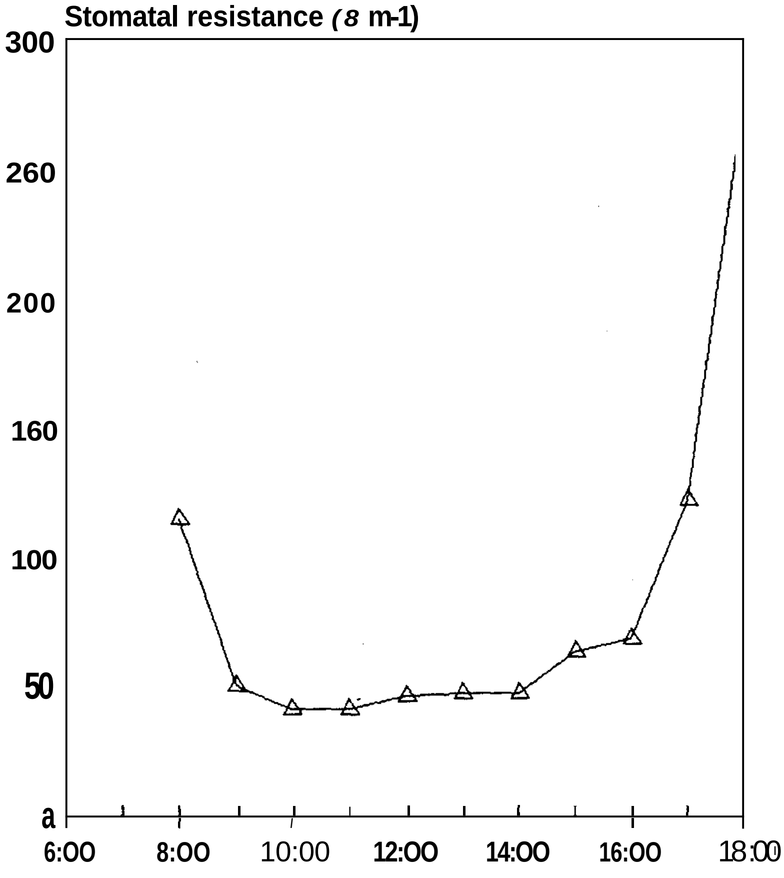


Fig.14. ***T. grandis*** **- Diurnal variations in stomatal resistance on 29.10.92**

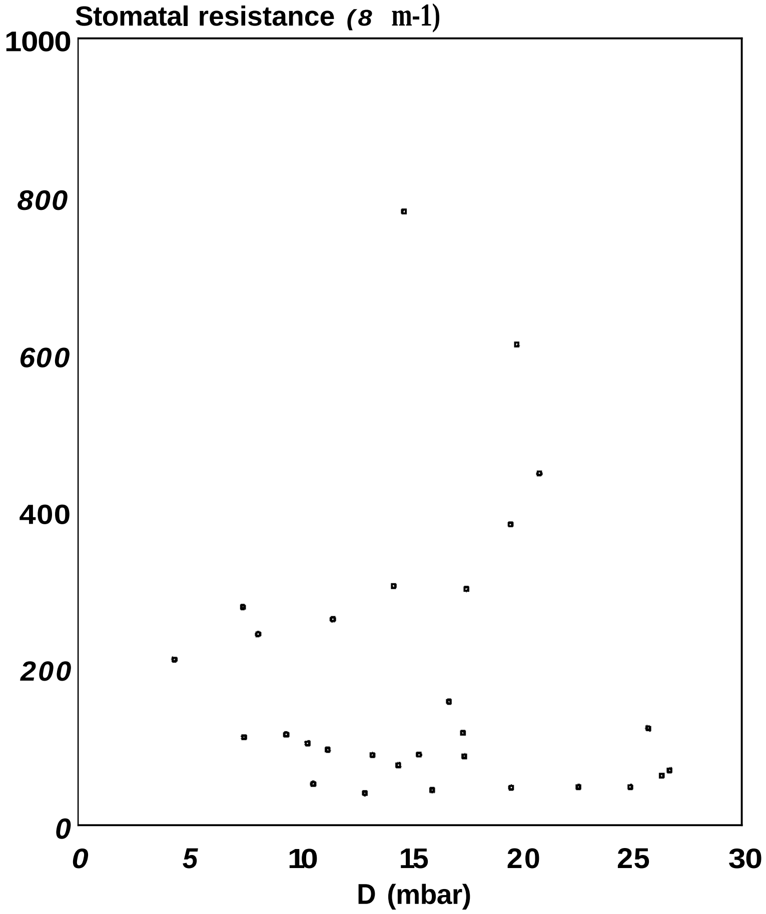


Fig. 16. *T grandis*- Stomatal resistance as a function of *D*

Fig. 15 shows a scatterplot of the relation between D and ***rs.*** This probably indicates that several factors are interacting to control the ***rs*** values in teak. This has been tested using a multiple linear regression model of the form described in equation (7). The result of this analysis shows that *Ta,* D and *Rn* are tied up with *rs* as shown in Table 32. It has also not been possible to measure the *rs* at higher values of *D* which occurs in the dry season when the teak trees are in the leafless state. Whitehead et al. (1981) have shown a better relation between ***rs*** and which they measured in Nigeria. However, their data have been taken from two days measurements separated by a gap of only seven days. Hence the interacting factors would have been more uniform in their location.

Table 29. ***T. grandis*** **- Microclimate data above the canopy for 3 days in June at Walayar (19.6.92 to 22.6.92)**

time	T_a	T_g	rh	D	S	R_n	u	Rain
(h)	(°C)	(°C)	(%)	(mbar)	(Wm^{-2})	(Wm^{-2})	($m\ s^{-1}$)	(mmh^{-1})
1800	24.71	24.18	87.1	4.02	19.2	8.9	6.9	0
1900	24.50	24.15	87.5	3.85	4.9	-3.8	6.1	0
2000	24.20	23.87	88.6	3.45	0.0	-4.7	5.3	2.286
2100	24.19	23.89	89.0	3.32	0.1	-3.7	5.0	3.302
2200	24.10	23.84	89.1	3.27	0.0	-2.5	5.1	0
2300	24.31	24.03	89.2	3.29	0.0	-3.1	4.8	0.762
0	24.63	24.23	88.8	3.46	0.0	-7.4	4.7	0
100	24.78	24.22	87.8	3.80	0.0	-6.1	4.5	1.524
200	24.52	24.11	87.8	3.74	0.0	-11.2	6.1	3.302
300	24.58	24.22	88.2	3.64	0.0	-11.1	6.1	0.254
400	24.61	24.24	88.2	3.65	0.0	-7.9	6.0	0
500	24.63	24.17	87.7	3.81	0.0	-9.9	5.6	0
600	24.58	24.12	87.7	3.79	0.0	-6.3	4.6	0
700	24.96	24.34	86.9	4.14	4.5	-2.5	4.8	0
800	25.20	24.52	85.8	4.54	41.0	26.2	5.0	0.254
900	25.17	24.75	86.6	4.29	95.5	69.6	4.8	0
1000	25.89	25.48	85.7	4.77	157.9	114.1	5.8	0
1100	26.94	26.45	83.4	5.90	186.0	139.0	6.5	0
1200	27.48	27.21	81.4	6.83	313.0	233.7	7.1	0
1300	25.14	24.87	84.1	5.18	211.0	162.3	7.8	6.604
1400	23.89	23.61	87.5	3.69	119.9	93.2	6.4	2.032
1500	23.87	23.57	87.9	3.58	110.7	85.6	7.3	8.380
1600	24.09	23.99	88.5	3.45	197.3	150.4	6.2	1.270
1700	24.54	24.36	88.3	3.60	89.7	68.0	6.4	3.556
1800	24.44	24.21	88.4	3.57	13.5	7.2	6.1	2.540
1900	24.29	23.99	88.0	3.65	2.1	-2.1	6.1	0.254
2000	24.49	24.12	88.2	3.62	0.0	-3.0	5.1	5.080
2100	24.49	24.18	88.6	3.51	0.0	-4.8	5.6	3.810
2200	24.80	24.45	88.4	3.63	0.0	-6.5	4.5	0
2300	23.58	23.24	87.3	3.70	0.0	-7.0	6.5	3.048
0	23.44	23.06	88.1	3.44	0.0	-9.6	5.5	0.254
100	23.83	23.44	88.3	3.45	0.0	-4.6	4.4	0
200	24.36	23.96	88.3	3.57	0.0	-6.1	5.4	2.032
300	24.80	24.35	88.1	3.74	0.0	-9.3	4.9	0.762
400	24.91	24.39	87.8	3.86	0.0	-5.8	4.2	1.524

Table 29 continued

Table 29 continued

time	T_a	T_g	rh	D	S	R_n	u	Rain
(h)	(°C)	(°C)	(%)	(mbar)	(Wm^{-2})	(Wm^{-2})	(m s^{-1})	(mmh^{-1})
500	24.68	24.26	87.9	3.76	0.1	-3.6	5.3	9.400
600	23.77	23.50	88.5	3.37	0.1	-2.8	4.7	2.286
700	23.68	23.41	88.8	3.27	3.2	0.7	4.6	1.016
800	23.63	23.39	88.9	3.24	9.3	6.2	4.8	1.016
900	23.65	23.50	88.8	3.27	64.2	51.4	5.0	0.762
1000	24.35	24.08	88.3	3.56	41.2	31.5	4.2	0.254
1100	24.78	24.54	87.7	3.83	111.9	86.8	4.1	1.016
1200	26.10	25.62	86.2	4.68	207.0	158.5	5.6	0.508
1300	26.71	26.30	85.1	5.23	455.4	346.5	6.1	1.270
1400	25.49	25.11	86.6	4.39	172.8	133.9	5.9	6.350
1500	25.32	25.03	86.8	4.28	222.9	170.5	6.4	5.588
1600	24.75	24.37	87.2	4.00	114.6	89.4	5.9	4.318
1700	25.40	24.98	87.1	4.18	128.3	96.9	4.8	0
1800	25.93	25.20	86.3	4.59	34.6	22.8	5.0	0.508
1900	24.38	23.91	87.9	3.69	3.7	.0	5.2	6.096
2000	24.02	23.65	88.4	3.46	0.0	-3.2	4.2	0.762
2100	23.97	23.58	88.2	3.51	0.0	-3.2	5.3	2.794
2200	23.68	23.32	88.3	3.43	0.0	-2.1	4.6	0
2300	23.67	23.34	88.6	3.32	0.0	-2.1	3.9	1.016
0	23.89	23.54	88.7	3.36	0.0	-2.1	3.9	0.254
100	23.97	23.62	88.6	3.39	0.0	-2.3	3.9	0
200	24.05	23.66	88.3	3.50	0.0	-2.6	4.9	2.540
300	24.19	23.81	88.2	3.56	0.0	-2.6	5.0	2.540
400	24.36	23.93	87.9	3.68	0.1	-2.2	4.3	1.778
500	24.69	24.18	87.6	3.87	0.0	-3.7	5.6	0
600	24.55	24.06	87.6	3.82	0.2	-5.4	5.4	1.778
700	24.63	24.06	87.5	3.87	9.8	1.6	4.4	1.778
800	23.61	22.99	86.6	3.91	42.6	30.9	5.7	1.524
900	23.24	23.02	88.2	3.35	126.9	101.4	5.6	0
1000	23.57	23.37	88.2	3.42	125.7	100.3	5.2	0.254
1100	23.89	23.58	87.8	3.61	94.5	74.4	4.6	0.254
1200	24.27	24.19	87.9	3.66	224.1	175.4	4.8	1.270
1300	24.62	24.46	87.8	3.76	168.0	132.0	4.4	4.826
1400	25.20	25.08	87.7	3.95	210.7	167.9	4.4	1.778
1500	25.41	25.01	87.2	4.14	92.1	73.1	4.3	5.080
1600	25.43	24.97	87.2	4.16	64.7	50.8	4.0	3.048
1700	25.01	24.60	87.2	4.05	101.4	76.4	4.3	0.254

Table 30. ***T. grandis*** **Microclimate, aerodynamic and canopy resistances and transpiration data on 29-10-92**

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
800	25.38	23.31	71.20	9.32	183.0	107.2	2.36	41.4	0.352	
900	26.61	25.05	69.89	10.50	397.9	285.9	2.42	18.2	0.583	
1000	27.96	27.27	66.11	12.79	591.1	441.3	2.21	14.5	0.847	
1100	29.05	28.77	60.51	15.88	749.0	567.6	1.76	15.3	1.251	
1200	30.12	30.04	54.45	19.47	831.0	627.1	1.98	16.8	1.467	
1300	30.93	30.83	49.66	22.53	842.0	633.2	1.92	17.1	1.802	
1400	31.55	31.38	46.43	24.83	772.0	575.5	2.05	17.0	1.998	
1500	31.92	31.36	44.55	26.25	644.9	467.0	2.05	22.8	1.837	
1600	32.04	29.98	44.15	26.62	451.6	303.5	2.30	24.7	1.704	
1700	31.55	28.10	44.65	25.66	234.8	126.3	2.81	43.5	1.064	
1800	30.03	25.34	46.71	22.70	53.7	-11.59	3.64	96.5	0.487	13.4

Leaf area index (LAI)

The mean value of LAI taken from a number of measurements using the light interception method shows it to be 2.81. This value has been used in the calculation of ***rc*** using equation (6).

Transpiration *(Et)*

As in the other two species studied, the Penman-Monteith equation was used to calculate the transpiration in teak. The results of the hourly calculation of transpiration made during several days of the year are presented in Tables 28, 30 and 31.

The most striking feature in this study is the extremely high transpiration shown by teak in the measurement taken on a day in October (see Table 30). The cumulative value for the day reaches as high as 13.4 mm which looks incredible when compared to the other two species studied. The hourly values sometimes go as high as approx. 2 mm. The high transpiration is mainly due to the extremely low values measured during the day.

Table 31. *T. grandis* Microclimate, aerodynamic and canopy resistances and transpiration data on 30-11-92 to 1-12-92

time	T_a	T_g	rh	D	S	R_n	r_a	r_c	E_t	E_t cum
(h)	(°C)	(°C)	(%)	(mb)	(Wm^{-2})	(Wm^{-2})	(sm^{-1})	(sm^{-1})	(mm)	(mm)
1500	29.18	29.47	57.1	17.34	607.1	436.6	1.61	30.96	0.991	
1600	29.12	28.52	57.2	17.26	422.2	276.3	1.67	41.28	0.803	
1700	28.82	27.56	58.0	16.64	229.3	135.4	2.16	55.52	0.579	
1800	27.94	26.18	59.5	15.25	57.4	-5.7	2.49	73.31	0.414	
1900	26.25	23.58	65.0	11.94	0.5	-43.7	2.78	-	-	
2000	25.59	23.04	67.0	10.80	0.1	-27.0	2.65	-	-	
2100	25.63	23.01	67.8	10.56	0.0	-34.2	2.62	-	-	
2200	25.21	22.52	69.1	9.89	0.1	-44.7	2.42	-	-	
2300	24.56	22.43	71.9	8.67	0.3	-44.4	2.34	-	-	
0	24.92	22.70	70.4	9.33	0.3	-45.2	2.18	-	-	
100	25.12	23.13	70.2	9.50	0.3	-37.6	1.87	-	-	
200	24.50	23.17	74.5	7.83	0.3	-41.4	1.73	-	-	
300	24.05	22.99	75.8	7.24	0.3	-24.1	1.99	-	-	
400	23.60	22.61	76.7	6.79	0.3	-20.9	2.02	-	-	
500	23.05	22.17	79.1	5.89	0.1	-44.0	1.82	-	-	
600	22.93	22.15	80.5	5.44	0.0	-40.6	1.80	-	-	
700	22.91	22.15	81.3	5.23	10.6	-33.5	1.78	-	-	
800	23.48	22.89	80.3	5.70	129.0	26.3	1.53	53.74	0.203	
900	24.68	24.39	76.1	7.45	360.5	145.2	1.30	39.50	0.352	
1000	25.99	26.01	69.4	10.27	550.5	376.5	1.38	36.65	0.516	
1100	26.67	27.07	68.1	11.15	695.7	495.2	1.50	33.77	0.579	
1200	27.62	28.42	64.3	13.17	877.0	639.8	1.43	31.42	0.745	
1300	28.09	28.81	62.2	14.34	811.0	592.8	1.45	27.01	0.899	
1400	28.33	29.12	60.3	15.29	793.0	578.3	1.33	31.28	0.908	6.993

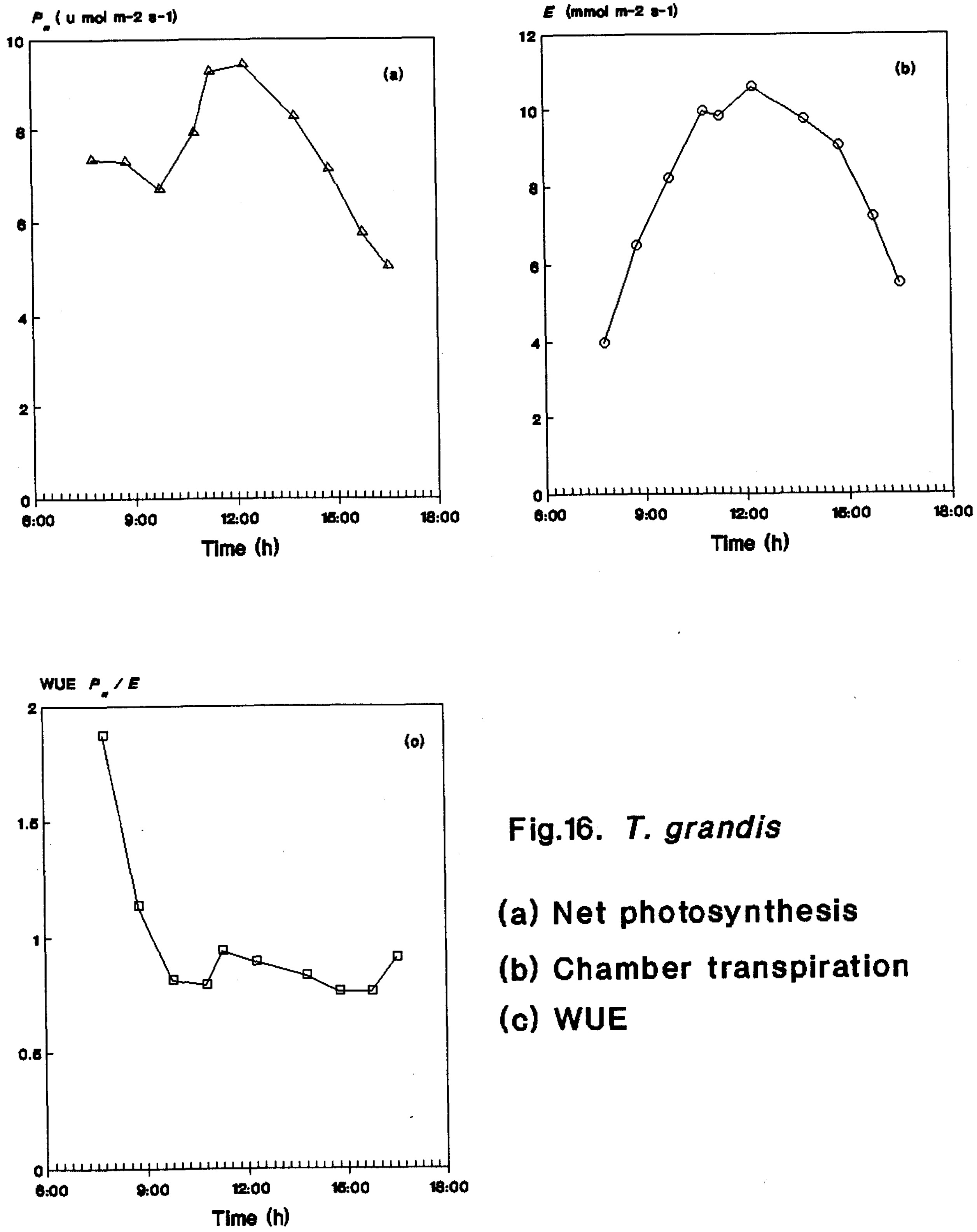


Fig.16. *T. grandis*

(a) Net photosynthesis

(b) Chamber transpiration

(c) WUE

Table 32. ***T. grandis*** **- Multiple linear regression analysis on stomatal resistances (r_s) of leaves**

Variable	Coefficient ± S.E	Partial R^2	P
T_a	162.0299 ± 17.2474	0.78	<0.01
D	-53.3234 ± 6.3357	0.74	<0.01
R_n	-0.4626 ± 0.0983	0.47	<0.01
Constant	-3488.7884		

$N = 28; R^2 = 0.76; F = 29.964; P = <0.01$

Photosynthesis *(Pn)*

The diurnal variations in *Pn, EC* and the WUE *(Pn/Ec)* are depicted in Fig. 16. Each data point depicted in the graphs is the mean of six measurements made hourly on different leaves. The measurements were made on teak trees on 30-1-92. When compared to acacia and cashew, the water use efficiency in teak is lower.

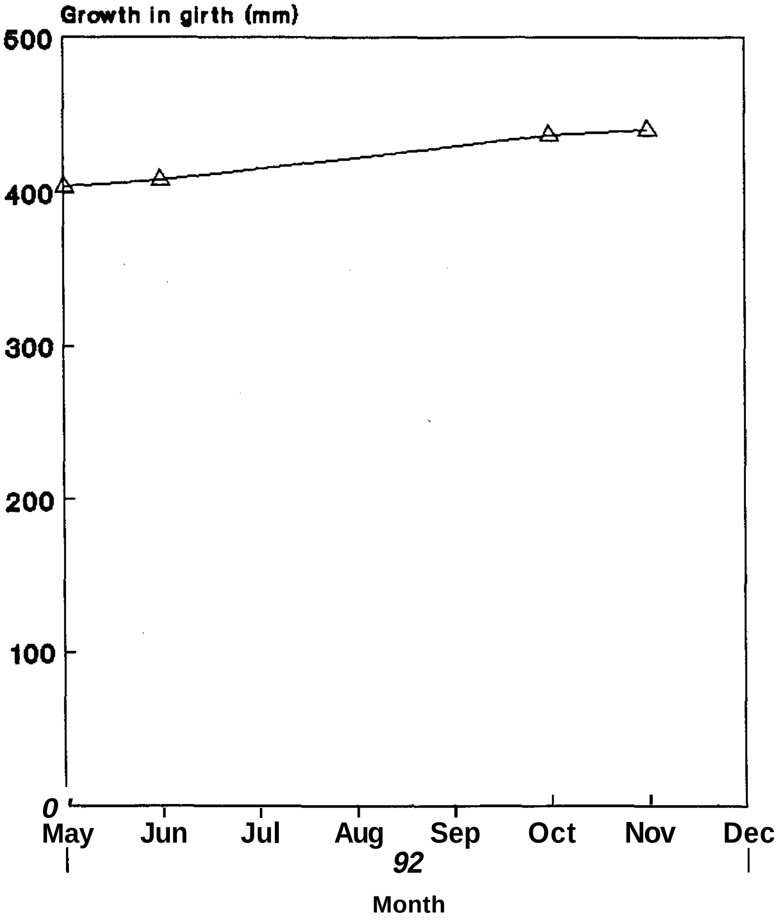


Fig.17. Increase in girth of *T. grandis*

Growth

The growth in girth of 40 trees in the teak plantation was followed during the study period. The results are presented in Fig. 17. It shows that growth was normal showing no water stress effects on growth. It has not been possible to present the growth measurements during the leafless stage in teak. It is reasonable to assume that there will be no growth during the leafless period.

It has been observed that the leaf fall and flushing of new leaves in teak is strictly not related to water stress. For example flushing of new leaves usually occur in March-April when the trees are still under soil water stress. Similarly, the leaf abscission which occurs in November-December does not coincide with water stress in the soil.

5. DISCUSSION

In the preceeding pages, we have presented several observations related to the water consumption of three tree species which are important in plantation forestry of Kerala State. There are twelve agroclimatic zones for this small state of India. The plots intensively monitored for this study comes under zone 8-Palghat except for the cashew plantation which comes under zone 7-High lands. However, the evaporative demand for all the three localities are basically the same. The rainfall in the three localities also range between 2000 and 3000 mm annually. The dry period in all the three localities is from January to March when there is no rainfall. It would have been certainly ideal to compare the water use of all the three species in adjacent plantations. However, the possibility of getting such a suitable location is rather remote.

Water status of the trees

The enormous spatial variations met within a plantation made us to discontinue the soil water measurements by gravimetric methods. This may be due to the variation in physical properties of the soil. However, the water potential measurements taken at predawn and midday indicate the water availability to the trees. A comparison of the water potential measurements in the three species shows that A. *auriculiformis* trees are under maximum stress with predawn water potentials as low as -1.47 MPa and midday values as low as -2.6 MPa. It is worth noting that cashew trees under maximum stress shows a predawn potential of only - 0.47 MPa at the same time. It is difficult to compare the water potentials in teak with the other two species. Teak trees do not bear any leaf during the summer period. The water potential measurements made in teak in Nigeria in January shows predawn values similar to our values and midday values nearly -1.3 MPa. (Whitehead et ***al.,*** 1981).

Thus it is seen that A. *auriculiformis* has the lowest water potentials which is lower than several other tropical species studied (Robichaux et *al.,* 1984). The deciduous nature of teak need not be caused by the water regime in the soil. In this study, the leaf shedding started in December when the predawn water potential was only -0.15 MPa. However the values of D shows sudden increases in December. The water potentials in cashew is interesting because the plant is able to maintain relatively higher potentials in the dry period. It should be remembered that this is done not even at the cost of stomatal conductance. As seen from the ***rs*** measurements in cashew, the stomatal closure is only partial in the dry period. This means that the cashew trees have some other mechanism which helps to keep the water potentials high, thus keeping the leaf turgid. The low water potentials shown by A. *auriculiformis* during the dry period have some ecological significance. It has been found that the response of the stomata to D increases when the leaf water potentials decrease. From the results of *rs* measurements, it looks that the *rs,* D and water potentials are highly intercorrelated in A. *auriculiformis.*

From the water potential measurements, it does not seem that the roots of A. *auriculiformis* or *T grandis* was in touch with the water table during the dry period. The roots of teak does not seem to travel deeper than 60 cm in the soil (Alexander et *al.,* 1981). However, the roots of cashew trees seemed to extract water from deeper layers of the soil in the present study area. It should be mentioned here that the summer water table in all the three localities studied was 10-15 m deep.

Microclimate

The microclimate parameters have been mainly measured to apply their values in the Penman-Monteith equation. However, they are of great significance in the present work because of two reasons: 1. Microclimate measurements are very few in the tropics. 2. It is probably for the first time that they are being measured above some plantations in Kerala.

The temperature measured above and below the canopy did not indicate much difference during the forenoon, however, in the afternoon, the temperature below the canopy was a unit higher than the above canopy values. This is very similar to the measurements made in some of the temperate forests (Roberts ***etal.,*** 1984). However, measurements in an Amazonian terra firme rain forest show differences of about 5 units between the upper and lower canopy (Roberts ***et al.,*** 1990). This is probably due to the several layers of canopy present in the rain forest. The variation in microclimate parameters above and below the canopy has significant influence on the stomatal functioning of the upper and lower canopy leaves. Apart from the temperature, other microclimate variables have not been measured underneath the canopy in this study.

Relations have been plotted for the S and *Rn* using the measurements made above the canopy in teak and cashew during the various months of the year. Good linear relations exist between the two variables and the differences in the slope of the curve is not significant above the two types of canopies. From these measurements, the value of ***Rn*** can be reasonably predicted from S measurements.

Since *Rn* is used in the Penman-Monteith equation and difficult to be measured in most cases, S can be conveniently used to predict the *Rn* values.

Stomatal response to environment

The stomatal frequency in the three species studied shows that stomata are present on both sides of the phyllode in A. *auriculiformis* only. In cashew and teak, stomata are present only on the abaxial side. Thus from the LAI measurements it appears that A. *auriculiformis* has a conducting leaf surface nearly 2.5 times that of cashew and teak in the plantations studied here.

The diurnal pattern of ***rs*** in all the three species shows a lot of similarities. During forenoon, the ***rs*** values gradually decrease towards the noon. In the afternoon the resistance tends to increase towards the evening. We have noticed a partial midday closure of stomata in all species except in *T grandis.* Medina (1983) have commented that midday stomatal closure is widespread in tropical trees. Whitehead et ***al.,*** (1981) have not observed midday stomatal closure in teak trees they studied in Nigeria. From these observations it is probably clear that the light availability is the most important factor controlling the stomatal resistance in all the plants studied, with possible interaction from other factors. However, it is generally found that light is not quantitatively related to stomatal resistance after an optimum level. Hence the predictive value associated with this parameter is low as seen from the several regression analyses done.

Very few studies are available on the stomatal functioning of A. *auriculiformis.* Srinivasan ***et al.,*** (1990) have compared 15 species of *Acacia* with regard to their growth characteristics and certain physiological features during the early stages. They have concluded that A. *auriculiformis* shows the highest ***rs*** values and least transpiration. However, this is based on measurements taken at the noon, probably assuming that the peak values in all species are attained at noon. It can be noted from the detailed studies of a number of *Acacia* species that all of them need not have peak stomatal conductance at midday. Several of them peak during the later morning hours and in some of them a second peak in stomatal conductance can be found in the afternoon (Ullmann, 1985,1989). A. *auriculiformis,* studied presently also shows a morning peak of conductance (= lower ***rs*** values) with another small peak in the afternoon. This is in contrast with the native Australian Acacia species in spring (water available) (Schulze et ***al.,*** 1982; Ullmann ***et al.,*** 1985). The two Acacia species measured in Portugal also showed a similar trend (Lange et ***al.,*** 1987). Tunstall and Connor (1975) have also shown a similar trend in A. *harpophylla* growing in semiarid conditions. This character of A. *auriculiformis* may be reflecting a poorer adaptation to drought because the more drought resistant species show a peak in the morning, only under water stress. This is probably because A. *auriculiformis* is basically a tropical species naturally occurring in Papua New Guinea and tropical parts of Australia.

From a multiple linear regression analysis model it has been shown that the stomatal resistance in A. *auriculiformis* is significantly tied to two environmental variables, namely ***D*** and ***Rn.*** Although this relationship is strong, the relationship between ***rs*** and water potential should be examined to see if there is a stomatal response to bulk leaf water status. It seems complete stomatal closure did not happen even at water potential a low as -2.6 Mpa recorded here. In fact, the loss of turgor in these trees occurred at around -2.0 MPa, as measured from p-v curve analysis (results not presented here). This observation is very similar to that of A. koa, in which, apart from the above two environmental variables, temperature was also related to ***rs*** values (Hansen, 1986).

To our knowledge there is no previous report on the water use of A. *auriculiformis.* However, brigalow (A. *harpophylla)* has been the subject of a hydrological study by Tunstall and Connor (1981). They have shown the maximum and minimum rates of evapotranspiration over monthly intervals as 3.3 and 0.046 mmd-1 respectively. The plants also developed extremely low water potentials (as low as -6.8 MPa). Both these are much lower than what we have measured in A. *auriculiformis.* It should be remembered that brigalow occurs in the semi-arid regions of Australia.

When compared to A. *auriculiformis,* cashew trees also show a stomatal conductance with a morning peak. The small peak shown in the afternoon in A. *auriculiformis* does not occur in cashew. There is apparently a partial midday closure of stomata as seen in many other tropical species (Medina, 1983). It is also noteworthy that the ***rs*** values (lower level) were maintained almost at a uniform level by the cashew leaves throughout the year except in the month of March. However, in A. *auriculiformis* this was not so. In the latter, the ***rs*** values started increasing gradually as the dry period progressed.

As the multiple linear regression model suggests, the ***rs*** values in cashew are significantly correlated to environmental variables such as D and ***Rn.*** Of these, the most important correlation is between *D* and ***rs*** which helps to predict the ***rs*** from D measurements.

The most interesting observation in A. *occidentale* is the maintenance of relatively high water potentials even during the dry period. In this work, it has not been possible to examine the rooting depth of the cashew plants. From the high water potentials maintained by the plant during the dry season, it seems that the roots have penetrated into much deeper layers than we imagine. Some of the previous investigations have reported deep penetration of the roots of cashew. Tsakiris and Northwood (1967) have traced the roots of a 4 **1/2** year old cashew tree to 5 m depth and was still descending. The same authors have observed a 7.30 m spread for the lateral root system of a &year old tree. From these studies and the high water potentials shown in our work, it is certain that cashew plants explore a wide range of soil profile. The possibility of the roots reaching the phreatic level of the soil cannot be rejected. In fact, Ohler (1979) has identified the ability of cashew roots to reach the phreatic level as a character determining the success of a cashew plantation. Dagg and Taplay (1967), by constructing a water balance for differently spaced cashew trees have commented that the lateral spread of the roots is the most important factor to adapt-the trees to the dry environment. In a detailed excavation study of the vertical and lateral spread of the roots in a mature cashew plantation, Khader (1986) have reported the presence of fine roots upto a depth of 9.5 m. However, 90% of the fine roots were observed upto a depth of 6 m. Wahid *et al.* (1989), who studied the distribution pattern of active roots in cashew observed that most of the (mineral) absorbing roots were confined to the top layer of the soil. It is doubtful if the same criteria can be applied for water absorption. The rooting depth and spread of cashew tree needs further studies in different environments.

Roots of several *Acacia* species have been also traced to depths of 6 to 12 m, but often the roots are not evenly distributed (New, 1984). In *A. meamsii,* 75% of the root volume was in the uppermost 0.7 m of soil (Hosegood, 1963). There is no recorded observations on the rooting depth or spread of *A. auriculiformis* trees. From our records of the predawn water potentials, the roots do not seem to explore much deep into the soil.

The ***rs*** measurements in teak have been done only for 3 months compared to the eight months measurements in the other two plants. This is mainly because the trees are in a leafless state for nearly 4 months of the year. Then the newly flushed leaves take a month to achieve maturity. Soon after the leaves mature, the rainy season started in the study area making it difficult to make any stomatal resistance measurements. By December, the leaves started showing signs of senescence and abscission.

From the ***rs*** measurements done in teak, it is clear that they show a lot of similarities to some measurements done in Nigeria by Whitehead ***et al.,*** (1981) during dry season. They have also shown good correlation of rs with irradiance and D. However, the wet season measurements of *T grandis* by Grace ***et al.,*** (1982) have shown very low resistance values. From the multiple linear regression analysis we have done, it has been shown that ***Ta,*** *D* and ***Rn*** show good correlation with ***rs.*** When taken out independently, they showed very little correlation with ***rs.*** Whitehead ***et al.*** (1981) have also shown a relatively poor correlation between the variables when taken independently.

The transpiration measurements show extremely high values in teak when there is no water stress. For example, it came to as high as 13.4 mmd^{-1} for a day in October. This is consistent with the extremely high conductance measured by Grace ***et al.*** (1982) also. However, when the measurements were done in December, this value fell down to nearly half, although there was no appreciable reduction in soil water content. The reduction could have been probably due to leaf senescence which had started by the end of November. The ***rs*** values had shown an increase at this time when compared to the October values. It may be noted that the ***D*** values decreased in December.

Transpiration

A comparative account of the monthly transpiration in the three species studied has been presented in Table 33. From the mean values shown, it is seen that probably all the trees transpire nearly equal quantities. However the mean values have very little significance in this study. We feel the most important aspect to look is the water consumption during the dry period, especially from December to March in this study area. It can be noticed that cashew trees consume more water during this period compared to other two species. Teak trees are adapted to the dry period, with all the leaves shed at this time reducing transpiration to almost zero. *A. auriculiformis* trees are also well adapted to drought conditions, which although not by reduction of the transpiring surface, but by partially closing their stomata. It should be remembered that this partial closure is not at the cost of WUE. It has been shown that $C0_2$ diffusion takes place normally in these trees even when stomata are closed partially. This character probably accounts for the fast growth of A. *auriculiformis* when compared to the other species. In this way it has some superiority over teak which sheds its leaves at the expense of growth. The high transpiration rates shown by cashew trees in the dry period is probably a favourable adaptation for a horticultural crop for introduction to semi-arid environments. However, if the roots of these plants are extracting water from the phreatic aquifer, the tree will certainly have some implications on the water availability of an area or catchment. It may be argued that in the present study the cashew plantation chosen was a fully mature one and the A. *auriculiformis* was a fairly young plantation. When A. *auriculiformis* attains full maturity, its roots may also possibly reach deeper layers of soil. However, as planned at present, the A. *auriculiformis* are meant for felling at a fairly young stage (within 10 years) for fuel wood purposes. Hence the danger of their roots extracting the phreatic zone do not exist at present. The per tree consumption of water by cashew trees when the canopy is dry is also incredibly high showing an average value of 361 litres a day. Although this is not important when we consider the water consumption of a stand/plantation, nevertheless this shows the capacity of a single tree in absorbing the water from the soil. In fact cashew trees showed the use of 452 litres d^{-1} tree-'of water during a day of measurement in March.

Table 33. Daily water use by *A. auriculiformis, A. occidentale* and *T: grandis*

Month	*A. auriculiformis*		A. occidentale		*T. grandis*	
	(mm^{-1})	(ld^{-1} tree^{-1})	(mm^{-1})	(ld^{-1} tree^{-1})	(mm^{-1})	(ld^{-1} tree^{-1})
January	5.68	14.2	7.13	421.9	NR	NR
February	4.32	10.8	6.63	392.3	NR	NR
March	3.99	10.0	7.65	–452.6	NR	NR
April	5.89	14.7	4.94	292.3	NR	NR
May	5.49	13.7	6.04	357.4	2.55	15.93
June	NR	NR	NR	NR	NR	NR
August	NR	NR	NR	NR	NR	NR
September	NR	NR	4.23	250.3	NR	NR
October	4.45	11.1	NR	NR	13.40	83.75
November	9.73	24.3	6.42	379.9	NR	NR
December	7.30	18.3	5.80	343.2	6.99	43.69
Mean	5.85±1.63	14.6±2.7	6.11±0.97	361.2±57.3	7.64±13.56	47.8±84.8

Mean ± S.E is indicated. The ld-1 tree-' (litre per day per tree) has been calculated from mmd^{-1} values by dividing the latter by the number of trees per hectare.

Rainfall Interception

In the above account we have dealt with only the water loss from a dry canopy due to transpiration. A few months of the year in the study area are wet because of the monsoon rains. During this period, although there are occasional non-rainy periods, the *Rn* are extremely low because of the overcast sky. The *Rn* values are <100 Wm^{-2} as seen from the Table 29. Accompanying this low radiations are the comparatively lower temperature, low D etc. which can contribute to high ***rs*** values. This probably means that water consumption by transpiration is a negligible factor during the rainy season. However, evaporation of the intercepted rain water from the wet canopy is a major factor. Our present measurements on the rainfall interception in A. *auriculiformis* and cashew show that nearly 8% of the rainfall is intercepted by the canopy in the former and 15% by the latter.

In teak, although we have not made any measurement, Dabral and Subha Rao (1968) have shown that 21% of the rainfall is intercepted by the teak canopy in a study conducted at Dehra Dun, India. We should expect the interception value to be much lower than this in our study area because (i) the PET is much higher in Dehra Dun when compared to our study area, and (ii) the rainy season is more prolonged in the study area because of the operation of two monsoons giving rise to low D values.

Annual Evapotranspiration

Since the main purpose of this study is to compare the water use of several species, we feel it is important to work out the annual evapotranspiration for stands of these species. For a most ideal figure for annual evapotranspiration it is important to make daily measurements on both wet and dry canopy. However, this is a practical impossibility especially with regard to making stomatal resistance measurements. Hence we have used the following assumptions to reach a more or less realistic figure. Since the same yardstick is used for all the three species, the values are certainly relative, although not absolute.

1. Transpiration from the dry canopy occurs only during the day time.
2. Transpiration is negligible during the three months (June to August) of intense monsoon rains. However, evaporation of the intercepted water will be the major form of water loss.
3. Evaporation from the bare soil and transpiration from the ground vegetation (if any) are negligible (Landsberg, 1984).
4. The daily transpiration calculated for different days of a month can be used to extrapolate the monthly transpiration.

Using the above assumptions we have presented the annual evapotranspiration, which includes transpiration from the dry canopy and evaporation from the wet canopy in Table 34.

Table 34. Annual evapotranspiration (mm) from the canopy of *A. auriculiformis, A. occidentale* and *T grandis*

Month	*A. auriculiformis*	*A. occidentale*	*T. grandis*
January	176 (D)	221 (D)	Nil
February	121 (D)	186 (D)	Nil
March	123 (D)	237 (D)	Nil
April	153 (D) 11 (W)	148 (D) 13 (W)	71 (D) 11 (W)
May	143 (D) 6 (W)	187 (D) 8 (W)	74 (D) 9 (W)
June	72 (W)	149 (W)	99 (W)
July	82 (W)	146 (W)	82 (W)
August	67 (D) 40 (W)	30 (D) 79 (W)	7 (D) 70 (W)
September	102 (D) 13 (W)	97 (D) 9 (W)	201 (D) 39 (W)
October	112 (D) 37 (W)	102 (D) 42 (W)	375 (D) 16 (W)
November	292 (D) 8 (W)	135 (D) 29 (W)	168 (D) 58 (W)
December	226 (D)	180 (D)	217 (D)
Total	1784 (D + W)	1998 (D + W)	1497 (D + W)

D = dry canopy; W = wet canopy.

The figures for dry canopy have been arrived at by extrapolation of the daily data to monthly intervals. The number of rainy days (rainfall 10 mm) have been taken into account in this calculation. The evaporation from the wet canopy have been derived from the interception percentage of each species from the monthly rainfall data. The interception value for teak was taken as 21% (Dabral and Subha Rao, 1968).

It shows that the evapotranspiration is maximum for the cashew plantation with a figure of approx. 2000 mm. A. *auriculiformis* ranks second with an annual figure of nearly 1800 mm and teak consumed least showing approx. 1500 mm. Although these figures are approximations, nevertheless they give a comparative account of the water consumption. The same yardstick has been used in the calculation for all the three species. The high value shown by cashew is due to both high transpiration rates during the summer months and high interception during the rainy season. If we take the water consumption of the three species during the dry period, that is, from December to March, the values are 646 mm, 824 mm and 217 mm for acacia, cashew and teak respectively. The low values shown by teak is due to the leafless state of this plant during a major part of the dry period.

Water Use Efficiency

The WUE of the three species studied also deserve some comments. A species which grows fast will certainly consume more water. From a comparative study it can be noticed that A. *auriculiformis* uses water most efficiently. This is because even when partial stomatal closure occurs, the Co_2 diffusion seems to occur normally, thus the photosynthesis is not seriously affected. Thus A. *auriculiformis* is comparatively economical in its water use during the stress period. Contrary to this, cashew trees seem to have more wide-spread roots which mines deeper soils not accessible to other crops. Hence they do not suffer from droughted conditions. The stomatal behaviour of the cashew leaves under artificial stress needs to be examined further. The WUE in teak is lower when compared to cashew or A. *auriculiformis.* Because of its leafless state in the stress period it has not been possible to look at its WUE in that period.

As a conclusion to this discussion, it may be remarked that the transpiration values reported here may slightly overestimate the real values because we have done our measurements on fully exposed leaves at the top layer of the canopy. The values reported here could have been more realistic if a multilayer model had been accepted. However, this will involve more cumbersome measurements including microclimate parameters and porometer measurements at different levels in the canopy. This was not possible because of the vastness of the work undertaken in this project. However, the values reported here can be considered to be the maximum possible water consumption by a species if all its leaves are fully exposed to the sun. From a general survey of the canopy it can be found that it is only in A. *auriculiformis* a sizeable percentage of the canopy do not receive full sunlight. In cashew and teak examined here, most of the leaves are well exposed to the full sunlight because of their peculiar canopy structure. Therefore the future studies should aim at refining the present data as well as developing predictive models for different agro-climatic zones.

CONCLUSIONS AND RECOMMENDATIONS

From the preceeding discussion it is evident that indiscriminate speculation concerning the water use of an exotic species like *A. auriculiformis* is misleading. Cashew trees use more water than the former on an individual as well as stand basis. Indeed, teak stand uses much less water than the two other species studied.

The relatively high consumption of water by cashew trees is mainly due to the following reasons.

1. Their roots are probably mining deeper into the soil, probably reaching the phreatic aquifer.
2. Because of the above reason they maintain relatively higher water potentials in summer which in turn gives more turgidity to the leaves.
3. The stomatal response to atmospheric vapour pressure deficit is less when compared to that of *Acacia auriculiformis.*
4. The interception loss is nearly 15% which is twice that of *Acacia.* This mav be due to the higher leaf angles in cashew.

In spite of all the above, the water use efficiency (WUE) is maximum in cashew when compared to the other two species.

Acacia auriculiformis is characterised by the following.

1. The low water potentials shown during the summer probably indicates their inability to go into deeper soils.
2. The response of their stomata to atmospheric vapour pressure deficit is better than that of cashew with partial closure during drought period. However, if sufficient water is available in the soil during times of high vapour pressure deficit, the stomatal behaviour is not known.
3. The WUE is relatively good because in spite of the partial stomatal closure, $C0_2$ diffusion seems to occur normally, thereby the photosynthesis is not adversely affected.

Teak, T. *grandis* has the following characteristics.

1. Due to the leafless nature in the dry period, a lot of water loss is prevented.
2. The response of the stomata to closure not only depends on vapour pressure deficit, but to net radiation and temperature also.
3. The WUE is relatively poor like many other slow growing species.

Based on some of the above conclusions we may be able to give the following recommendations.

1. Afforestation by *Acacia auriculiformis* of land previously occupied by teak will certainly increase the annual evapotranspiration. However, in certain wastelands it should be considered as a priority species because of its excellent abilities to survive under dry conditions giving higher yields at the same time. This includes planting them on waste lands, roadsides and other strip lands. Since the A. *auriculiformis* roots do not seem to extract the water table in summer, they are in no way a danger to the localwater resources. However, if water is made available to them round the year, their water consumption can go higher up. Hence it is not advisable to use them for afforestation near a reservoir. Their comparatively low percentage of interception loss at the same time, suits them for a catchment where slow surface runoff is desired without much soil erosion.

2. Cashew, *Anacardium occidentale,* although an exotic species, has been naturalised in Kerala since the 16th century. It is probably for the first time that we are quantifying its water use. It shows that cashew is in no way more economical than *A. auriculiformis* in its water consumption. The indications are that the cashew tree is extracting water from the phreatic aquifer in summer months by its deep roots. Hence in certain critical areas where water scarcity is a problem in summer months, this tree should be planted with caution. Cashew is well known among the public for its drought hardiness. The water consumption by an individual tree as worked out in this study looks incredible. If that is the case, planting them near any water source should be done with caution.

3. Teak, *Tectonagrandis,* is an ideal tree with regard to water conservation. Its leafless nature during the dry period helps to conserve the soil moisture during the most critical part of the year. More studies are required to know its stomatal responses to environment. A complete water balance study including hydrological, micrometeorological and physiological parameters is called for in this species which is the most important timber tree of India.

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