WATER RELATIONS, GROWTH AND GAS EXCHANGE IN *Acacia auriculiformis* UNDER EXPERIMENTAL AND NATURAL CONDITIONS

THESIS

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MAY 1997

DECLARATION

I hereby declare that thesis entitled "Water relations, growth and gas exchange in *Acacia auriculiformis* under experimental and natural conditions" is a bonafide record of work done by me under the guidance and supervision of Dr. Jose Kallarackal, Scientist-in-charge, Division of Plant Physiology, Kerala Forest Research Institute, Peechi, Thrissur. The thesis has not previously formed the basis for the award of any degree, diploma, associateship or any other similar title to me.

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Dedicated

to

My Parents

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Abstract

ABSTRACT

Investigations on the water relations and gas exchange of *Acacia auriculiformis* were carried out in natural and controlled environments. The experiments were performed in both seedlings and five year old trees. Different sets of experiments were conducted in *Acacia* plantations, at Kothachira, Palakkad District and in seedlings, at KFRI campus nursery mainly during the summer months. Investigations were also extended to seedlings of *A.mangium*, *A.aulacocarpa* and *A.holocericea*, which are also phyllodinous species with the intention of comparing their physiology with *Acacia auriculiformis*.

Potted seedlings of four species of *Acacia* viz., *A. auriculiformis*, *A. aulacocarpa*, *A. holocericea* and *A. mangium* were used for the study. Measurements of relative water content (RWC), water potential, photosynthetic rate, transpiration, stomatal conductance, water use efficiency etc. of phyllodes were measured diurnally in plants subjected to three stress conditions namely, drought, salinity and flooding.

Normally watered and water-stressed plants showed much difference in their leaf water status. Under drought condition, plants showed very low water potential both at predawn and midday. It gradually decreased as drought days proceeded. A maximum of 12 days drought stress was overcome by all species tested. Wilting started by 10th day in severely stressed plants. The phyllodes became smaller and pale yellow in severely stressed plants. In normally watered plants the predawn water potential was -0.19 MPa and midday water potential was -0.65 MPa. Progressive water stress for 9 days lowered the predawn water potential to -2.3 MPa along with a midday water potential of -3.5 MPa. Water stress for 12 days was the maximum stress bearable by the seedlings. 16 days water stress decreased the predawn water potential to -2.54 MPa and midday water potential to -4.0 MPa. The plants did not show growth in height nor initiated new flushes. Most of the seedlings wilted and dried by 34 days.

Studies in a five year old plantation at Kothachira, where the premonsoon period was taken as stressed and postmonsoon as nonstressed period, revealed that the predawn water potential of phyllodes at the peak of the stressed period decrease to -1.5 MPa. The midday water potential showed a low value of -2.5 MPa in the month of March. Eventhough the litter fall was high during the stressed period, the plants did not wilt, but maintained an evergreen stature. In the litter covered plot, the water potential was slightly higher showing -0.5 MPa and a midday water potential of -1.2 MPa whereas in the open plot it was -1.0 MPa and -2.2 MPa respectively.

Using pressure volume curve method, osmotic potential at the turgor loss point was found to be near -1.39 MPa in the normally watered plants. Osmotic potentials at full saturation and at zero turgor were significantly lower in cyclically stressed seedlings than in nonstressed seedlings. In *A.auriculiformis,* proline levels also were high in the phyllodes of water stressed seedlings which might have contributed to the increase in osmoticum allowing osmotic adjustment.

Response of *A. auriculiformis* phyllodes at various posititions in relation to photosynthesis, transpiration and stomatal conductance were also checked under normal conditions. Phyllodes at positions 4-15 were found to have an average photosynthetic rate of >10 μmol m^{-2} s^{-1} at the peak hours. The stomatal conductance also were higher in these leaves when compared to leaves at positions 16 to 20. At the plantation level net photosynthetic rate was around 7 μmol m^{-2} s^{-1} whereas in the seedlings of *A.auriculiformis,* about 14 μmol m^{-2} s^{-1} was noticed at a photon flux density (PFD) of 1200 μmol m^{-2} s^{-1}. Light saturation curves show that the maximum assimilation rate of 14 μmol m^{-2} s^{-1} occurs at at a PFD of 1000-1200 μmol m^{-2} s^{-1}, in *A.auriculiformis.* In other species like *A.mangium,* the light saturation was found to yeild 13 μmol m^{-2} s^{-1}at a PFD of 1200 μmol m^{-2} s^{-1} and the A_{max} observed in *A.aulacocarpa* was 10 μmol m^{-2} s^{-1} at a PFD of 1200 μmol m^{-2} s^{-1}. In *A.holocericea* a higher $A_{max}$of 23 μmol m^{-2} s^{-1} was found at a PFD of 1600 μmol m^{-2} s^{-1}.

The diurnal pattern of photosynthesis showed two peaks, one in the morning by 0900 hours and another at 1400 hours in the afternoon. Comparative studies on the photosynthetic rate of seedlings under water stressed conditions show that photosynthetic rate decreases as the drought stress progresses. After 9 days, the plants loose their capacity to photosynthesise. Only after rewatering, the plant can recover photosynthesis to the normal rate. Other species like *A.mangium*, *A.aulacocarpa* and *A.holocericea* also reduced their photosynthetic rate by 5th day to <2 μmol m^{-2} s^{-1}, but *A.auriculiformis* was able to photosynthesise at a higher rate for about 9 days under drought stress. Plants of *A.auriculiformis* subjected to drought stress for various days followed by one day watering also showed that, more than 8 day drought stress reduces the photosynthetic rate to a level of 2 μmol m^{-2} s^{-1} or less.

Stomatal conductance (g_s) measured diurnally in *A. auriculiformis* showed gradual increase from 1000 hours onwards and reached minimum by 1700 hours. By 1200 hours, there was a reduction in stomatal conductance for about two hours and it again gradually increased by 1500 hours and then decreased.

Transpiration from the trees at the leaf level and canopy level in plantations for stressed and nonstressed period was estimated. At a leaf level, instantaneous transpiration measured using infrared gas analyser showed diurnal values ranging between 4 to 8 mmol m^{-2} s^{-1}. At the canopy level, estimations using Penman - Monteith model during stressed period showed lesser values of 10 mm day^{-1} while nonstressed period showed slightly higher values viz. 14.3 mm day^{-1}. An average of 5.85 mm day^{-1} including stressed period can be expected from a five year old plantation. It has been estimated that the average water consumption of a single tree, amounts to 14.6 litres per day when the planting density is 4440 trees ha^{-1}.

Seedlings grown under normal conditions showed a peak transpiration rate of 12 mmol m^{-2} s^{-1} at 1100 hours. Drought stress reduced transpiration rate to 2 mmol m^{-2} s^{-1}

by 9th day. Phyllodes of *A.auriculiformis* showed partial closure of the stomatal aperture so as to reduce stomatal conductance and transpiration. It has been noticed that all species of acacias studied presently can adjust their transpiration rates followed by drought stress. Seedlings showed an initial increase in transpiration rate, but by 3rd day onwards their transpiration was limited to less than 4 mmol m^{-2} s^{-1} In this way *A.auriculiformis* transpires at the rate of 4 mmol m^{-2} s^{-1} up to the 10 day during peak hours where as *A.holocericea* at a rate of 2 mmol m^{-2} s^{-1} by 5th day onwards. In the normally watered plants, the maximum transpiration rate noticed during peak hours differed. *A.auriculiformis* showed 10 μmol m^{-2} s^{-1} whereas *A.aulacocarpa*, *A.holocericea* and *A.mangium* showed 6, 18, and 12 mmol m^{-2} s^{-1} respectively. In this way, *A.aulacocarpa* can be considered to have the lowest transpiration rate per unit leaf area during peak hours.

The instantaneous water use efficiency (WUE) of trees of *A.auriculiformis* was found to vary between 0.5 to 2.0. Normally watered seedlings showed a WUE of 0.5 to 1.5 whereas drought stressed plants showed an increase in WUE from 1.5 to 3.0 up to 10 days thereafter decreased to less than 1.0. In *A.mangium*, drought stress did not hinder WUE for 5 days, but the WUE at 1200 hours to 1600 hours was seen reduced very much. Diurnal measurements of WUE on seedlings of *A.auriculiformis* subjected to different water stress cycles shows that the WUE is maintained at a minimum of 0.5 up to 8 day stress cycles. In all cases, the depression in WUE was observed by 1100 hours and WUE was high during 0900 to 1000 hours. The afternoon WUE was seen to be affected more, by drought stress.

In *Acacia auriculiformis*, salinity stress (100 mol m^{-3}) resulted in a predawn water potential value of -0.4 MPa , and a midday water potential of -1.4 MPa by 9 days. Salinity stress at higher concentration (200 mol m^{-3}) reduced the predawn water potential to -0.5 MPa and the midday water potential to -2.9 MPa within a period of 9 days. Salinity stressed plants (100 mol m^{-3}), showed slightly more photosynthetic rate, for the first 5 days following treatment. A higher dose of NaCl did not favour photosynthesis. Better photosynthetic rates of 8-11 μmol m^{-2} s^{-1} were noticed for 5 days in *A.mangium* but declined afterwards. The higher dose (200 mol m^{-3} NaCl) showed some abnormal values on 5th day giving a maximum photosynthetic rate of 15 μmol m^{-2} s^{-1} during 1400 hours. Lower rates of salinity stress was found to maintain normal photosynthetic rate similar to that of control plants in *A.aulacocarpa* and *A.holocericea*, but slightly higher rates in *A.mangium*.

In *A.auriculiformis* salanity stress (100 mol m^{-3}) initially increased transpiration rate to 14 mmol m^{-2} s^{-1} at 1300 hours showing a distortion in the stomatal closure mechanism. The higher concentration of 200 mol m^{-3} of sodium chloride, also resulted in an increase in transpiration rate to 8 mmol m^{-2} s^{-1} in the first day, which then decreased to 4 mmol m^{-2} s^{-1} from the third day onwards. Towards the end of 9th day, salinity stress of higher concentration decreased transpiration rate to 2 mmol m^{-2} s^{-1}. Salinity stress in lower and higher concentration increased the transpiration rate in *A.mangium* to 8-10 mmol m^{-2} s^{-1} and this was higher than normally watered plants. All the species were found to maintain normal or slightly higher rates of transpiration against lower concentrations of sodium chloride for a period of 21 days.

In salinity stressed (100 mol m^{-3}) plants of *A.auriculiformis*, there was a slight increase in WUE upto 5 days which decreased afterwards. The plants showed a WUE of 0.3 to 2.0 at higher concentration of sodium chloride (200 mol m $^{-3}$). Increased WUE of 2.8 was shown within 9 days by reducing stomatal conductance and **transpiration** Salinity stressed (100 mol m^{-3}) plants of *A.mangium* showed an initial increase in WUE from 0.5 to 1.5 for 3 days which became 1.0 afterwards. It appears that the higher concentration (200 mol m^{-3}) of sodium chloride may lead to increased WUE, when conductance values are lowered.

Flooding improved the water status of plants within short time and was similar to that of normally watered plants. Flooding stress for 12 days, showed a predwan water potential of -0.16 MPa and a midday water potential of -0.9 MPa.

Flooding stress did not result in much variation in photosynthetic rate and the diurnal pattern was almost similar to control plants. But *A.mangium* showed significantly higher photosynthetic rates when compared to control and other treatments. By 9th day, the photosynthetic rate in *A.mangium* was 14 μmol m^{-2} s^{-1} but was around 10 μmol m^{-2} s^{-1} in other days. Continuous flooding stress for 20 days did not hinder photosynthetic rates in *A.auriculiformis*, *A.aulacocarpa* or *A.holocericea*, but in *A.mangium* after 12 days, the photosynthetic rate decreased to < 3 μmol m^{-2} s^{-1}

When water is in excess, *A.auriculiformis* transpires more showing a value of 12-14 mmol m^{-2} s^{-1}. Flooding stress increased transpiration in *A.mangium* also to 12-16 mmol m^{-2} s^{-1} whereas the normally watered plants showed 4-18 mmol m^{-2} s^{-1} After 21 days, water logged plants of *A.aulacocarpa* and *A.holocericea* showed a transpiration rate of 12 and 19 mmol m^{-2} s^{-1} respectively.

Flooding did not improve WUE in *A.auriculiformis* and was similar to that of control plants. But in *A.mangium* a slight increase was noticed, the WUE ranged between 0.5 to 1.5. In other species like *A.aulacocarpa* and *A.holocericea* also WUE was less than the control plants during periods of flooding stress.

Chlorophyll content, chlorophyll stability index, proline content etc. were also examined for different treatments and species. In the salt treated plants total chlorophyll content was high. Drought stressed plants showed better chlorophyll stability index in *A.auriculiformis*. In *A. auriculiformis* salt treated plants showed minimum chlorphyll stabilty, while drought stressed plants had high, indicating that chlorophyll destruction occurs during salinity stressed periods. All the four species of drought stressed plants showed higher amounts of proline in their phyllodes. Of the four species, *A.auriculiformis* had the highest amount of proline after 9 days of drought stress.

The growth in girth of trees measured in plantations of *A.auriculiformis* showed an increase throughout the year, except in severely stressed periods. However, extension growth was not seen limited in stressed periods. A comparison with the undisturbed leaf litter covered and an open plot showed increase in girth for the trees in the former. The open plot represented a girth increment of 14.04% while litter covered plot represented 20.22% during a period of 15 months. Studies on seedling growth of four species showed a height of 120 cm, 110 cm, 95 cm and 60 cm for *A.auriculiformis, A.holocericea, A.aulacocarpa* and *A.mangium* over a period of ten months when grown under identical conditions. Seedlings of *A.auriculiformis* when subjected to repeated drought stress cycles showed 47.0, 22.6, 16.22, 13.7, 13.07 and 6.0 per cent increase in height for 0, 2, 4, 6, 8, 12 and 16 day drought stress cycles respectively.

Introduction

INTRODUCTION

Water is a critical factor influencing the occurrence and growth of trees. It affects the productivity of forest plantations and agronomic crops. Water deficit or water stress refers to situations in which plant water potential and turgor are reduced enough to interfere with the normal functioning. It may affect every aspect of plant growth, including anatomy, morphology, physiology, and biochemistry. Kramer (1983) has stressed the importance of research on water stress by including measurements on growth, water status, physiological and biochemical processes, soil and atmospheric factors. It is a fact that physiological studies on trees are few and in this regard Kozlowski (1982) has remarked that most of the existing literature is on temperate species and information on tropical tree species is lacking.

Acacia auriculiformis A.Cunn. ex. Benth is one of the five priority species recommended by the International Union of Forest Research Organisations for intensive development in the humid tropics (IUFRO 1984). The species has entered as a major component of Social Forestry Programme all over the tropics, and in Kerala since 1980's. Plantations of *A.auriculiformis* were raised throughout the State both in the forest and nonforest environments. It has been estimated that about 560.2 hectares of *Acacia* plantations are existing out of a total of 1,55,071 ha of forest plantations in Kerala (Forest statistics 1994). This comes to around 2.82%. Plantations of *A.auriculiformis* have been proved to show better growth in Kerala than in other States and is comparable to that of other growing countries. Regarding the productivity and yield, the tree has been found to yeild extremely well in Kerala with a mean annual increment (MAI) of 10-64 m^{-3} ha^{-1} of commercial volume in 7 years from 2000 trees per hectare (Jayaraman and Rajan 1991). The yield is almost equal or better than that of other countries. The species is usually valued for its timber and high quality pulp (Turnbul,1986). However, the real interest in making profitable and viable plantations of *A. auriculiformis* is yet to take off in Kerala.

This study was aimed to find out some of the physiological constraints imposed on the growth of *Acacia,* under natural and experimental conditions. Since it is comparatively a new species introduced to Kerala by the 1980's, study of the reasons behind the environmental constraints to the growth of *A. auriculiformis* will be advantageous to the plantation forestry. As a first approach, the plant's response to water stress, flooding and salinity have been studied. Responses included the measurements of growth of seedlings and trees, photosynthesis, transpiration, water status and water potential changes of phyllodes. Physiological responses of the seedlings to varying environmental conditions and trees in the plantation level under stressed and nonstressed periods have been investigated.

Detailed observations on the effect of water stress on *Acacia* have been conducted because in Kerala a prolonged dry period lasting 4 to 5 months imposes considerable water stress in the plantations. Plant water relations combined with the study of leaf gas exchange reveal the plant's responses to drought. Water potential measurements in the stressed and nonstressed conditions can be also used to predict root signalling. It has been observed that the leaf area index (LAI) remains almost constant throughout the year in *A. auriculiformis* trees and drought stress did not harm the evergreen nature of the canopy. As acacias are regarded as fast growing species there are social and environmental concerns about the water consumption of these trees. Whether *A. auriculiformis* also consume more water as many fast growing trees do, has been a topic of debate.

By subjecting the seedlings of *A. auriculiformis* to flooding effect, adaptation of the plant's capacity to waterlogged areas are known. Salinity is another serious problem to be tackled when growing trees in the long coastal belt of Kerala. Although the problem of salinity does not exist in the interior Kerala, much of the agricultural and forest lands in developing countries face the problem of salinity. Nearly 50% of the irrigated land in semiarid and arid regions of the world are affected by excess salinity (Epstein *et al.* 1980, Abrol *et al.* 1988). Reports show that excess salinity has affected afforestation projects in India (Madhur and Sharma, 1984), coastal wasteland forests in the eastern U.S. (Allen 1992), roadside trees in the northern US and Canada (Dochinger and Townsend 1979) and forests near oil, gas or salt mining facilities (Rincon Mautner 1980). Morris (1982), Thomson (1987) and Aswathappa *et al.* (1987) have reported the salt tolerance, growth and survival of some *Acacia* species. The potential of planting *A. auriculiformis* under saline conditions will be very much useful for ecosystem restoration, where many of the plant species did not grow. The idea of protecting the sea coast from erosion by planting *A.auriculiformis* can also be considered in due course.

Removal of leaf litter by the local community for use as a fuel has forced some concerns about nutrient and water cycling in *Acacia* plantations in Kerala. In the present study, the effectiveness of leaf litter in conserving water in the *Acacia* plantations has been verified. Seedlings of other phyllodinous species of *Acacia*, which are similar in nature to *A. auriculiformis* like *A. mangium*, *A.holocericea* and *A. aulacocarpa* were also sbjected to various stress conditions and results have been compared.

Review of Literature

REVIEW OF LITERATURE

A.auriculiformis is a leguminous species belonging to the subfamily Mimosoidea of the family Leguminosae. This is commolnly known as Northern Black wattle, Earpod wattle, Darwin black wattle, Papua wattle etc. In India it is known as Kaira and Bengali Jali. In a reclassification of the genus *Acacia*, majority of Australian acacias including *Acacia auriculiformis* have been placed in a new genus *Racosperma* (Pedley 1986). About 1100 species of acacias have been reported so far. Turnbull (1987) considered that *A.auriculiformis* can improve soil environmental conditions. It is considered as an ornamental tree that withstands city heat better than most broad leaved trees and requires little attention. The species is susceptible to fire in grasslands (Banerjee 1973a). Pinyopusarek (1990) attributed *A.auriculiformis* as one among the most promising species for plantation forestry in the tropics. The main drawback of the species is its poor form. The tree has been mainly used for fuelwood production, land amelioration and amenity planting. Basha (1989) has mentioned about the good qualities of the tree and the reason for wide introduction of the species in Kerala is its multiple uses. In Kerala, the wood of *A.auriculiformis* is now very much in demand for pulp production.

Reviews dealing with the cultivation of *A.auriculiformis* have already been published by Parry (1956), Streets (1962), Fenton *et al.* (1977), National Academy of Sciences (1979,1980) and Webb *et al.* (1980). Being legumes, most acacias are a source of nitrogen in forest ecosystems and agroforestry land use systems. Soil conservation authorities have used the genus for many years for stabilization of shifting sand (Roux and Meddlemiss 1963, Barr 1965, Aveyard 1968, Barr and Atkinson 1970). Chandrababu *et al.* (1987) found significant differences in drought adaptive characters viz. leaf temperature, stomatal resistance, stem water potential, relative bark moisture and proline content. One of the factors associated with drought resistance is the ability of the plants to retain high moisture potential in their tissues under drought conditions. Basappa (1983) have reported that *A. auriculiformis* performs well on saline, alkaline and stony soils.

Precise information on the species differences in the performance under moisture stress conditions in forest trees is inadequate (Gerold and Sacksteder 1982). The understanding of mechanisms of adaptation of *Acacia* species to inhospitable sites (water- stressed, water- logged, alkaline and saline) is incomplete. There is a need for research into physiological responses to the stresses, and water use under different conditions, for developing rapid screening procedures and introduction to new sites. Research is also required on below-ground processes (like rooting patterns) involved in stress tolerance.

1. **Water relations**

Growth of trees depends mainly on water availability than on any other environmental factor. When transpiration exceeds absorption of water, leaf moisture content decreases leading to stomatal closure. Water deficits alter growth of trees both quantitatively and qualitatively. Among the well known effects of internal water deficits are stomatal closure, reduced transpiration, reduced photosynthesis and starch hydrolysis. Changes in chemical composition and growth of trees may occur even with mild water deficits.

1.1. *Moisture content*

Chandrababu *et al.* (1987) have reported 97% relative bark moisture content in *A.auriculiformis*. Rajeshkumar *et al.*, (1993) have estimated a comparative moisture content in roots (73.9%), stem (76.08%) and leaves (85.47%) of *A.nilotica*. They also report that reduction in moisture level seems to be an indicator of leaf fall.

1.2. *Water potential*

Drought tolerant varieties were found to have higher leaf water potential than the susceptible types (Cruz and O'Toole 1984). *A.auriculiformis* is found to have maximum stem water potential (-0.6 MPa). Brodrib and Hill (1993) report that as the water potential of the phyllodes of *A.melanoxylon* decreases, uptake of CO_2 also decreases. Phyllodes were able to recover from drought periods having water potential of < -5.5 MPa. Turnstall and Connor (1975) have reported that *Acacia harpophylla* can withstand -7.2 MPa without damage. They also found that leaves contribute very little by way of photosynthesis at water potentials less than -2.0 MPa. It is contrary to the findings of Hansen (1985), who claims that the leaf stomata of *A.koa* is insensitive to water potentials less than -3.0 MPa despite loss of turgor at -2.0 MPa. Osonubi *et al.* (1991) found that drought stressed *A.auriculiformis* tolerated lower xylem pressure potentials and larger water losses. The higher the mycorrhizal dependency, the lower the drought tolerance expressed in terms of drought response index.

1.3. *Water use efficiency* (WUE)

WUE was significantly higher in seedlings of drought stressed treatments than in the well-watered controls (Phillips and Riha 1993). Mooney *et al.* (1978) have correlated decreased specific leaf area with improved WUE as has decreased g_s with WUE by Nobel (1983). It has also been noticed that the WUE was lower in the severely drought stressed seedlings than moderately stressed ones. Hansen and Steig (1993) found that the phyllodes of *A.koa* possessed higher WUE and lower internal CO_2 than juvenile leaves.

1.4. *Water consumption*

Water consumption of tree species may depend upon composition, age, density, stand structure and many other silvicultural factors. Chaturvedi *et al.* (1988) using a lysimeter study, reported that seedlings of *A.auriculiformis* consume 0.86 litres of water to produce 1 gm of biomass. Seedlings consumed 1475 liters of water to produce 1713 gms of biomass within a period of 5 months. Srivastava and Misra (1987) also conducted a lysimeter study incorporating 7 tree species having an age of 20 months and noticed that in *A.auriculiformis,* tree consumes 1251.4 liters of water during a period of 1 year. *Eucalyptus tereticornis* used double the amount of what *A.auriculiformis* used while *Pongamia pinnata* 454.8 liters.

1.5. *Pressure volume curve*

Moisture release curves were prepared and analysed for individual fully expanded leaves by periodically weighing and measuring water potential with pressure chamber after the method of Hinkley *et al.* (1980). Phyllodes of *A.koa* contain more water relative to tissue and a smaller fraction is lost during reduction of turgor. The osmotic potentials at full turgor ($\Psi_{\pi 0}$) and at turgor loss point ($\Psi_{\pi z}$) for the phyllode is similar to those noted in many temperate broad leaved trees (Roberts and Knoerr 1977) and higher than several temperate conifers (Jackson and Spomer 1979). Estimates of $\Psi_{\pi 0}$ and $\Psi_{\pi z}$ (-2.23 and -2.28 MPa) for phyllodes of *A.aneura* are considerably lower than those found for *A.koa* suggesting that these properties may be environmentally and/or species dependent. Bates and Hall (1981) have shown that stomatal activity can be controlled by changes in soil water independent of bulk leaf water status. The ability to control water balance in phyllodes would lead to an advantage during drought conditions at the expense of photosynthetic rates.

2. Gas exchange

2.1. *Photosynthesis*

A.auriculiformis is endowed with an ability to photosynthesize under all the prevalent temperature and irradiance (Trivedi *et al.* 1992). They observed that highest P_n of 12 μmol m^{-2} s^{-1} was occured at 30°C at a PFD of 1000 μmol $m^{-2}s^{-1}$ Ontogenetic studies have revealed that maximum photosynthetic capacity in *A.auriculiformis* was present in leaves at position 6-8 from the top of the seedling (Pathre *et al.* 1990). At all temperatures P_n was saturated at ≈ 1000 μmol $m^{-2}s^{-1}$, except at 10°C. Brodrib and Hill (1993) have pointed out that the vertical orientation of phyllodes (in *A. melanoxylon*) implies maximum light interception and maximum photosynthesis in the morning and evening and also avoiding midday sun. Walters and Bartholomew (1984) also have reported that vertically oriented phyllodes have higher photosynthetic efficiencies than horizontally displayed phyllodes provided VPD is minimum.

2.2. *Stomatal conductance/resistance*

The phyllodes of *A.auriculiformis* are absolutely unifacial without morphological difference between the two sides as revealed by anatomical studies (Wood 1934, Lange *et al.* 1987). Chandrababu *et al.* (1987) point out that the high stomatal resistance (1.96 s cm^{-1}) in *A.auriculiformis* may reduce excess moisture loss, and at noon hours resistance may increase. Turner and Begg (1981) have reported that this may lead to reduction in transpiration. In the phyllodes of *A.melanoxylon*, Brodribb and Hill (1993) have found a linear relationship between stomatal conductance and transpiration. According to them in *A. melanoxylon*, the photosynthetic efficiency of phyllodes increase at a low *g,* i.e. less than 10 mmol m^{-2} s^{-1}. The rapid decline in CO_2 uptake at lower conductances suggests that increased internal resistance or enzymatic inhibition (Bradford and Hsiao 1982) is limiting photosynthesis in phyllodes resulting in a more rapid decrease in WUE under water stress.

2.3. *Transpiration*

According to Florence (1986), increased crop yield is generally associated with decreased transpiration rate. Out of the 15 different species of *Acacia* studied by Srinivasan *et al.* (1989) and different species studied by Babu *et al.* (1987), *A.auriculiformis* was found to possess lowest values for transpiration rate. *A.auriculiformis* shows very low transpiration rates (12.7 μg H_2O s^{-1} cm^{-2}) even at noon indicating the comparatively better drought tolerance of the species. They also noticed a negative correlation of transpitation with bark moisture content, chlorophyll content and resistance. Trivedi *et al.* (1992) have reported that transpiration increased continuously with increase in temperature up to 40 °C and then dropped off sharply which may be partly be due to an increase in VPD with temperature. Phillips and Riha (1993) found a relation between the transpiration and water potential where transpiration decreased with soil water potential by 5'th day. Florence (1986) has already mentioned that the main factors affecting transpiration are leaf area index, stomatal conductance and VPD between leaf and atmosphere. Tan and Chen (1984) have reported that a transpiration rate of 13631.72 t/ha from a plantation where 1395 sterm /ha are growing.

2.4. *Vapor pressure deficit* (VPD)

Trivedi *et al.* (1992) reports the interesting behavior of *A.auriculiformis* to VPD where transpiration increases with VPD in relation to temperature. P_n remained constant at a given temperature, g_s showed somewhat parallel relationship with P_n but slight decrease was observed at higher VPD, transpiration (E) increased with VPD.

Response of P_n and g_s to changing VPD at given temperature, indicate that a stomatal response to VPD provides an effective mechanism for maximizing WUE with changing leaf temperature. Stomatal closure at the high VPD and high leaf temperature results in a loss of potential photosynthesis but a considerable saving in water. Stomatal closure in response to the increasing VPD caused by increasing leaf temperature decreases the apparent thermal optimum of photosynthesis. In Malaysia strong winds were suggested as a reason for reduced growth of *A.auriculiformis* (Mitchell 1963).

While studying the phyllodes of *A.melanoxylon*, Brodrib and Hill (1993) point out that in the phyllodes, the WUE is constant over a wide range of VPD and the foliar gas exchange decreases as VPD increases. Diffusive conductance of phyllodes also show a linear decrease across the VPD range of 4-16 m bar/bar. Stomatal sensitivity to VPD, which results in decreased transpiration and conductance as VPD increases has been recorded in the field, as midday depression of photosynthesis and transpiration (Grieve and Hellmuth, 1970, Tenhunen *et al.* 1981).

2.5. *Temperature*

The phyllodes of *A.auriculiformis* have been reported to have higher temperatures (28.6°C) which was higher among some other species studied by Chandrababu *et al.* (1987). At all temperatures P_n was saturated around 1000 μmol m^{-2} s^{-1} except at 10°C. Trivedi *et al.* (1992) found that highest P_n of 10 μmol m^{-2} s^{-1} was observed at 30 °C. Transpiration and stomatal conductance increased with irradiance as well as with temperature. At higher temperature of 30 & 40°C, P_n declined beyond saturation of irradiance. VPD also increased with temperature.

2.6. *Water use efficiency*

Morphologically trees may have different root systems but their ability to exploit the soil moisture during drought may be a deciding factor for their survival and growth, and hence their water use as well (Pereira and Kozlowski 1976, Carbon *et al.* 1980). Colquhoun (1984) stressed the importance of physiological controls of water use in plants. Trivedi *et al.* (1992) mentioned that *A.auriculiformis* have high WUE under varying conditions which is advantageous for the plant to compete for harsh conditions of drought and temperature.

3. **Drought adaptive characters**

Chandrababu *et al.* (1987) grouped *A. auriculiformis* as a major forest tree species producing higher biomass under limited moisture supply. Osonubi and Mulongoy (1991) found that inoculation with an ectomycorrhizal fungus (*Boletus suillus*) increased drought resistance in *A.auriculiformis* but not in *A. mangium.*

3.1. *Phyllode*

The evolution of phyllodes in *Acacia* is widely believed to be an adaptation to survive drought (Elias 1981, Boughton 1986). Pedley (1986) suggested that phyllodes may have arisen in response to the shady conditions faced by ancestral rainforest acacias, as a means of increasing photosynthetic area. *Acacia* is reported to shed its phyllodes readily in response to water stress (National Research Council

1983). Farrel's (1973) hypothesis states that pinnae are 'shade leaves' and phyllodes are 'sun leaves' The vertical orientation of phyllodes mean that maximum light interception and photosynthesis occur when sun is low in the sky while the midday sun is largely avoided. Vertically oriented phyllodes have higher photosynthetic efficiencies than horizontally displayed phyllodes (Walters and Bartholomew 1984). The phyllodes of *A.koa* are found to posses higher WUE and lower internal CO2 than juvenile leaves. Phyllodes show adaptation to drought since their stomata respond more rapidly to environmental conditions and hence phyllodes do not develop very low water potentials as those developed in juvenile leaves (Walters and Bartholomew 1984, Hansen 1986). Phillips and Riha (1993) report that decrease in soil water potential may influence the rate of phyllode extension. They noticed that phyllode extension was not initiated until soil water potential decreased to about -1.0 MPa. Phyllode abscission also have increased with decreasing soil water potential. The peak of abscission occurred in the severely stressed seedlings on 17th day.

The age at which the compound leaves are replaced by phyllodes in various species depend on growing conditions (Walters 1981) and origin of population (Farrel and Ashton 1978). Walters and Barthlomew (1984) found a stomatal density of 230 stomata mm^{-2} (stoma length 0.018 mm) on both surfaces of phyllodes of *A.koa*. A higher specific leaf weight of phyllodes (78 g m^{-2}) have been reported by them, which is supposed to increase mesophyll resistance and thus decrease conductance. Hansen (1986) found that stomata of phyllodes tend to be more responsive to environmental variables, especially leaf to atmosphere water vapor concentration, and tend to close at higher water potentials than juvenile leaves. This should result in lower internal CO_2 in the phyllodes.

4. Physiological and chemical characters

4.1. *Chlorophyll content*

The phyllodes of *A.auriculiformis* have strong absorption of solar radiation between 400-700 nm and both surfaces of phyllode show similar pattern. The first phyllode from the top is reported to have lower absorptions of 65% at 550 nm than others and Sinha *et al.* (1996) attribute this to higher reflectance and transmittance. The chlorophyll (a, b and total) content of 8th phyllode was maximum which could be related to its higher photosynthetic activity (Pathre *et al.* 1990). The a/b ratio was around 2 in all the phyllodes at different positions. Sinha *et al.* (1996) report that the total chlorophyll content was 2.8, 3.5, 4.0, 2.5, 2.5, 1.8 mg gm^{-1} at leaf positions 1,4,8,12,16 and 21 respectively Sun (1986) studied the relationship between chlorophyll content, photosynthesis and biomass production in *Acacia* and eucalypts. Of the two species of *Acacia* studied, net photosynthesis in *A.auriculiformis* was 1.15 times higher than *A.confusa*. In *A.auriculiformis*, they reported 3, 1.2, and 4.3 mg g^{-1} of chlorophyll a, b and total chlorophyll respectively. The ratio of chlorophyll a:b was found to be 2.6.

4.2. *Chlorophyll stability index* (CSI)

Lab method described by Kaloyereas (1958) may help to screen for drought hardiness which is based on thermostability of chlorophyll pigments when kept in hot water bath for 1 hour. The more stable the chlorophyll, the more hardy will be the plant. Out of the 3 species of *Acacia* studied by Sivasubramaniam (1992), *A.auriculiformis* showed highest CSI (96.26%), followed by *A. crassicarpa* (92.77%) and least by *A. holocerecea* (84.28%).

4.3 *Proline*

Degree of proline accumulation is considered as an index for assessing drought tolerance in crop plants. (O'Toole and Cheung 1978). Increased accumulation of proline is linked to drought tolerance mechanism. Chandrababu *et al.* (1987) have reported 525 $\mu g\ g^{-1}$ in leaf tissues of *A. auriculiformis*.

5. **Environmental stress**

5.1. *Drought*

Phillips and Riha (1993) studied the effect of moderate and severe water stress on *A. auriculiformis*. They used six month old seedlings and subjected them to 39 days stress. Above ground biomass accumulation decreased by 21% below that of moderately drought stressed ($\Psi = -1.5$ MPa) seedlings and 47% in seriously drought stressed seedlings ($\Psi = -2.5$ MPa). They also noticed decreased specific leaf area and increased WUE under drought stress. Mead and Miller (1991) mention that in *A. mangium*, growth is low when moisture is limiting. Yellowing of the foliage in both drought stressed and waterlogged situations was noticed.

5.2. *Waterlogging*

A.auriculiformis tolerate flooding due to its ability to cope with oxygen deficiency. Vorhoef (1943) have reported that young plants of *A. auriculiformis* are resitant to oxygen deficiency and the plants can survive in oxygen depleted substrates upto 75 days.

5.3. *Salinity*

Reddel and Warren (1987) report that salinity can affect the growth of rhizobium in soil. Aswathappa *et al.* (1986) ranked salt tolerance of three *Acacia* species based on decline in dry weight. Marcar *et al.* (1991a) report that reduction in dry weight, followed by sodium chloride treatment in *A. auriculiformis* may be due to salt effects on nodule initiation. Some other workers on the salinity stress point out that rhizobium is more salt tolerant than its host plants (Bernstein and Ogata 1966, Wilson and Norris. 1970, Lauter *et al.* 1981). Marcar *et al.* (1991a) point out that large differences have been found in salt tolerance between strains of rhizobium capable of nodulating in *A.ampliceps*, *A.mangium* and *A.auriculiformis*. Aswathappa *et al.* (1986) have already remarked that tolerance of the rhizobium strains to salinity will be an additional and useful complement to the high degree of salt tolerance of acacias to improve productivity on saline soils.

Sun and Dickinson (1995) examined the effect of salinity on *A.aulacocarpa* and *A.auriculiformis* along with some other tree species. *A.aulacocarpa* showed the poorest performance. They suggested that species with an ability to maintain relatively large crown and high number of branches when subjected to salinity may be highly salt tolerant. Hafeez (1993) screened the growth of 26 species for 46 months and found that *A.auriculiformis* to be salt tolerant. Nath *et al.* (1991) conducted studies on plantations of nine species of 0.5 to 2 year old trees in coastal areas and found that *A.auriculiformis* performs well in saline soils.

Marcar *et al.* (1991a), studied the effect of root zone salinity on the growth and chemical composition of *A.auriculiformis* and *A.mangium*. There were differences in nodule number, weight per plant, water relations and stomatal conductance in youngest leaves. Marcar *et al.* (1991b) also tested the genetic variability of *A.auriculiformis* to salt and waterlogging. Seedlings from 16 provenances of *A.auriculiformis* showed high tolerance to both salinity (for 51 days) and for waterlogging (75 days). Promising provenances were ranked from number of phyllodes shed and final height. Dart et al. (1991) in their review on the role of symbiotic associations in nutrition of tropical acacias, describe the tolerance of *A.auriculiformis* and *A.mangium* towards acidity and salinity. *A.mangium* is least tolerant affecting growth and nodulation at salinity levels of 100 m mol^{-3} of salt. Desala *et al.* (1989) carried out a study on waterlogged land of pH 9.5 and high salt concentrations using 12 different tree species in Maharashtra. They could find best growth in *A.auriculiformis* along with *Casuarina equisetifolia*.

Ansari *et al.* (1980), conducted pot culture experiments using different salt mixtures and their results show stimulation in growth at low concentrations of salts. Totey *et al.* (1987), tested seeds of *A.auriculiformis* for germination over filter paper kept moist with salt solutions and noticed poor germination percentage. Tomar and Gupta (1985) while studying the performance of some forest tree species in saline soils, noticed that *A.auriculiformis* can grow in areas where salinity is associated with high water table conditions. If both salinity and high water table exists *A.auriculiformis* can be planted on ridges.

5.4. *Mulching*

It is known that low soil water and high temperature in the dry regions cause rapid drying and hardening of surface soil leading to poor establishment and growth of trees. Application of surface mulch may help to modify soil temperature regime and improve plant growth (Prihar *et al.* 1977, Gupta and Gupta 1982, Singh *et al.* 1988). In a mulching study conducted by Singh *et al.* (1991) on the seedlings of *A.auriculiformis*, the seedling biomass and WUE were found to increase but the effect was not significant on relative growth rate. They also report that irrigation regime had no significant effect on mean WUE of *A.auriculiformis*. Singh *et al.* (1991) attribute this to the high water requirement of *A. auriculiformis* as the species has almost equal WUE at all the irrigation levels with a higher relative growth rate and biomass production under higher irrigation levels (120 to 100%).

Gupta (1991), studied the effects of mulching in the initial development of ten species including two acacia species. Management practice with coir pith mulching application with fertilizer enhanced survival by 8-18% and aboveground biomass by 13.7 times. Moody *et al.* (1963), Khera *et al.* (1976) and Gupta and Gupta (1983) have found that various mulches improve crop yields in dry zones. Weirsum and Ramlan (1982) found that after four months 67% of leaf litter was still remaining in the plots of A.auriculiformis, which will provide for better erosion control.

6. Seed and Seedling growth

6.1. *Seed*

Weirsum and Ramlan (1982) have mentioned that seed production usually starts in July to November. The number of seeds per kilogram is found to vary between 53,000 - 62,000. Seeds germinate within 6 days and can be stored for 18 months without loss of viability.

6.2. *Growth of Seedlings*

Growth of seedlings of *A.auriculiformis* have been reported by many authors in different countries under different climatic and soil conditions (Wasigsadicljaja 1977, Sastroamidjojo 1964). Dijk (1991) reported a germination of 25% in water treated and 58% in acid treated seeds of *A.auriculiformis*. Dutt and Jamwall (1991) report that 10 month old seedlings attained a height of 44 cm with 20 phyllodes. Ngulube (1990) has measured growth of 3 month old seedlings as 12 cm. having 4 nodules per seedling. The total dry weight of seedlings were found to vary between 0.7-1.0 gm. Sreenivasan *et al.* (1989), in a study of 15 different species planted after 3 years, have reported that *A. holocerecea* and *A.auriculiformis* were tallest with respect to height and DBH. In a glass house experiment Phillips and Riha (1993) studied the effects of decreased soil water potential on phyllode extension, abscission and solar conversion efficiency in 6 month old seedlings of *A.auriculiformis*. Over a period of 39 days treatment, they obtained 21% increase in biomass accumulation in moderately stressed ($\Psi > -1.5$ MPa) and 47% in severely stressed ($\Psi > -2.5$ MPa) over well watered ($\Psi > -0.5$MPa) plants. Specific leaf area and WUE were also found to increase in response to drought stress. The accumulation of aboveground biomass was greatest in well watered seedlings and decreased with decreasing soil water potential.

Seedlings of *A.auriculiformis* and *A.mangium* sown after 50 days have been examined for shoot length, leaf number, root length, root nodules, relative growth rate etc. by Jayasankar & Mohankumar (1992). They have reported that growth rates were high in both species in the early stages and relative growth rate can be considered as a function of dry matter accumulation.

7.2. *Growth of trees*

The mean annual increment (MAI) in Jawa was reported to be 15-20 m^3 ha^{-1} where as in Kerala a MAI of 10-34 m^3 ha^{-1} (at 7 years with 2000 trees ha^{-1}) was calculated (Jayaraman and Rajan 1991). The measurements made in the plantations of Karnataka also supports this (Kushalappa 1991). It has already proved that mean annual volume increment reaches maximum or near maximum at 7 years for all site quality and number of trees per hectare. The yeild from the plantations of *A. auriculiformis* in Kerala is much higher when compared to other parts of the continent (Jayaraman and Rajan 1991). The tree reaches a height of 16.57 m with a DBH of 12.8 cm in good sites and 12.67 m with a DBH of 7.5 cm. at ordinary sites at the age of 7 years. But in Palakkad District of Kerala, it has been reported that the growth is very poor, where the trees had a DBH of 4.0 cm only. A similar case has already been reported from Malayasia (Mitchell, 1963) and the reason for this particular retarded growth may be the high wind velocity. It is true that in Palakkad also high winds are prevalent during the postmonsoon period. Lamb's (1975) data from Papua New Guinea indicate that in heavily thinned plots higher production is obtained than in lightly thinned plots. In Kerala, studies on different stand density show that a one hectare plot with 2000 and 3000 trees give only slight difference in yield.

7.3. *Roots*

Banerjee (1973a) reports that due to its rather superficial root system *A.auriculiformis* can grow well on shallow soils. Cohen (1970) has suggested that the root environment and below ground competition can affect relative water use characteristics of plants, even if above ground structures experience similar environmental conditions through root influence on stomatal operation.

Materials and Methods

MATERIALS AND METHODS

Water relations, growth, gas exchange and some physicochemical analyses of seedlings of *A. auriculiformis*, *A. mangium*, *A.aulacocarpa* and *A.holocericea* under various stress conditions.

1. Location and planting material

Seedlings of *A.auriculiformis* were raised following standard hot water treatment. Seeds were treated with hot water (80 °C) for 30 seconds and then soaked in cold water overnight. The seeds were rinsed with 0.5% Emisan, sown in the nursery beds and watered twice daily. Germination started from 3rd day onwards and the seedlings were allowed to grow in beds for one month. One month old seedlings were transplanted to 20x30 cm size polythene bags filled with loam soil and kept as such for 10 months under natural environments prevailing in the KFRI Plant Physiology nursery. The seedlings were watered daily twice, in the morning and evening. Six replications of the seedlings were used for each treatment. The experiments were conducted during summer months so that the seedlings received maximum stress.

2. *Treatments*

2.1 Control - daily watering twice a day
2.2 Drought stress - withholding of water for 12 days continuously
2.3 Salinity stress - applying 100 mol m^{-3} NaCl (5.8 g l^{-1}) day^{-1}

2.4 Salinity stress - applying 200 mol m^{-3} NaCl (11.6 g l^{-1}) day^{-1}
2.5 Flooding stress - keeping the root portion of the plants submerged in water without any aeration.

3. Water status

Water status of the seedlings were checked by the measurements of relative water content (RWC) of phyllodes, predawn and midday water potential of phyllodes of different treatments.

3.1. *Relative water content* (RWC)

Physiological processes are determined by the turgidity of cells which is dependant on available water. Reduction in RWC can cause reduction in photosynthesis. RWC is calculated based on the method suggested by Barrs and Weatherley (1962). Physiologically functional 4th phyllode is selected for the purpose. Discs of 1 cm diameter are cut from fresh phyllodes and the fresh weight (FW) is recorded. The discs are then floated on distilled water in closed petridishes under diffuse light for 4 - 5 hours. Attainment of full turgidity is found out by floating separate discs for various time intervals till constant turgid weight (TW) is attained. The turgid weight of sample discs are recorded and then dried in a hot air oven at 85 °C for 48 hours. The dry weight (DW) is recorded. RWC is calculated as:

$$\text{RWC}(\%) = \frac{(\text{FW} - \text{DW})}{(\text{TW} - \text{DW})} \times 100 \qquad (1)$$

$$\text{Water saturation deficit (WSD)} = 100 - \text{RWC} \qquad (2)$$

3.2. *Water potential* (Ψ)

Predawn Ψ was measured before sunrise by enclosing the phyllode in a polythene bag before pressure chamber insertion. Before taking midday measurements, the phyllodes were enclosed within a polythene bag to minimise transpirational loss of water during measurements (Turner, 1988). A Scholander type pressure chamber (Soil Moisture Equipment Corporation, Ohio, USA) was used for finding the balancing pressures. This balancing pressure was practically taken as the water potential as described below (Milburn,1979).

$$\Psi = \Psi_p + \Psi_s \tag{3}$$

where,

Ψ = water potential and
Ψ_p = the balancing pressure and
Ψ_s = solute potential

3.3. *Pressure- volume curves*

The pressure chamber has been used to estimate leaf osmotic potential by the pressure volume method described by Tyree and Hammel (1972) and Cheung *et al.* (1975). Boyer (1969), Roberts and Knoerr (1977), have described the application of pressure chamber to construct pressure-volume curves. The advantage of this method is that it yields a value for undiluted cell sap (Tyree and Jarvis, 1982).

The pressure volume curve analysis helps to determine the symplastic values of osmotic potential and the turgor pressure of living tissues of plants growing under field conditions. This was done in accordance with the recommendations of Turner

(1988) A leafy (phyllode) twig was cut under water by caring for the non-entry of air bubbles. Initial weight of the leafy twig was taken and it was kept in darkness overnight by dipping the cut end in water and allowing to saturate. The turgid weight was determined. Water potential of the leafy twig was taken at this point and the leaf was allowed to dry under ambient conditions on a laboratory bench. At regular intervals, weighing and 1 Ψ measurements of the phyllode was carried out. The procedure was repeated until the water content of the phyllode declined to 55 to 60 % of the original saturation value. Then the leaf was dried in an oven at 85°C until constant weight. For each measurement the corresponding RWC was calculated as in Equation (1).

A plot of the reciprocal of Ψ on the Y-axis versus RWC on X-axis, yeilded the relationship between them. This was donewith the help of a computer program developed in KFRI. The region over which this relationship became linear was determined graphically with the help of stepwise linear regression. The point of intersection of Y-cooridnate gave the reciprocal of water potential at zero turgor ($\Psi_{\pi 0}$). The Y-coordiante of the line obtained by linear regression at RWC equals 1.0 gives the inverse of the tissue osmotic potential at full hydration ($\Psi_{\pi z}$). The poimt at which this line touches the X-coordinate gives the value of water content of tissue apoplasm.

4. Gas exchange measurements

Measurements of CO_2 uptake provides a direct method of measuring productivity, as it is instantaneous, nondestructive, allowing separate investigation of individual leaves and separation of photosynthetic gain from respiratory losses. The assimilation rate (A) is expressed as amount of CO_2 assimilated per unit leaf area and time (μmol m^{-2} s^{-1}). The rate of assimilation by the leaf is determined by measuring the change in the CO_2 concentration of the air flowing across the chamber where the leaf is enclosed. In a closed system air is pumped from the chamber enclosing the leaf into an infrared gas analyzer which continually records the CO_2 concentration of the system. The air is then recycled back to the chamber. No air leaves the system or enters it from outside. If the leaf enclosed in the chamber is photosynthesizing, the CO_2 concentration in the system will decline, and will continue to decline until the CO_2 compensation point of photosynthesis is reached. In practice the CO_2 concentration is allowed to drop by about 30 ppm from the ambient level. The rate of photosynthesis is calculated from CO_2 depletion rate:

$$\text{Net photosynthetic rate} = \frac{(CO_2 \text{ initial} - CO_2 \text{ final})}{(\text{leaf area} \times \text{time})} \times \text{Volume} \qquad (4)$$

4.1. *Net Photosynthesis* (P_n)

Photosynthesis was measured with a portable infra red gas analyser (IRGA, Model LI-6200, Li-Cor, Nebraska, USA) fitted with a one-litre leaf chamber. The chamber is constructed from polycarbonate for good transmission in the far red and are lined with teflon to minimize CO_2 and H_2O exchange. The leaf chamber has sensors for measuring photosynthetically active radiation (PAR), relative humidity, internal CO_2, leaf and chamber temperatures. The IRGA was frequently calibrated against known gas mixtures of CO_2. The measurements were made on the 4th and

5th phyllodes and recorded in the data logger supplied with the instrument. The net photosynthesis 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.

4.2. *Light response curves*

Net photosynthesis responds hyperbolically to photon flux (Q) as light becomes of decreasing importance as a limiting factor. Individual leaves of many C_3 plants are unable to use additional light above 500 μmol m^{-2} s^{-1} or roughly 25% of full sunlight. The response of assimilation (A) to photon flux density (Q) describes a curve or curvilinear progression, consisting of two phases: 1) an initial phase of increase in A with Q through the light compensation point; 2) a progressive decrease in the slope of the curve (dA/dQ) with increase in Q to a plateau, the light saturated assimilation rate (A_{max}). In many cases the curve may approximate to a rectangular hyperbola.

$$A = \frac{A_{max}\, Q}{k.Q} \tag{5}$$

where

k is the value of Q at which $A = A_{max}/2$

4.3. *Stomatal conductance (g_s)*

Plants expose wet surfaces of leaves to the dry atmosphere to absorb CO_2 for photosynthesis. During this process evaporation of water occurs and cooling results. To prevent too much water loss and dehydration, the plants have leaves with an epidermis composed of cuticle and turgor-operated valves, called stomata. The epidermis reduces the rates of CO_2 and water vapor exchange. It also provides a means of controlling assimilation and transpiration by adjusting the size of the stomatal pores. Thus stomata play a major role in controlling the balance between water loss and carbon gain. The restriction to the movement of CO_2 and H_2O offered by the stomata is defined as resistance. The size of the stomatal resistance is often compared with that of the boundary layer and intercellular process for CO_2 transfer. In order to make meaningful comparisons with the flux of CO_2 and H_2O, or to correlate with some biological variable like water status, water deficit, it is often expressed as *conductance* (1/resistance) rather than as resistance (Burrows and Milthrope 1976, Hall *et al.* 1976, Cowan, 1977).

Stomatal conductance is calculated by measuring the water vapor loss from the leaves enclosed in leaf chambers using gas exchange techniques. Rate of water vapor loss from leaf enclosed in a porometer chamber (Kanemasu *et al.*, 1969) is measured as the diffusive resistance. The rate of loss is determined from the rate at which dry air is added to offset the increase in humidity due to transpiration (null balance porometer). Most of the loss occurs from the stomata, but the cuticular component also becomes important as stomata close (Beadle *et al.* 1979). A steady state diffusion porometer (Model Li-1600, Licor Inc., Lincoln, Nebraska, USA) was used which allow null balance point to be set at ambient humidity. Dry air is introduced to maintain a constant humidity. This instrument measures the time required to produce a predetermined change in humidity by means of a sensor enclosed in a small chamber attached to the leaf. The humidity sensor connected to an electric circuit and a meter, convert the humidity recording to diffusion resistance in s cm^{-1} or to its reciprocal conductance in cm s^{-1} (Kanemasu *et al.* 1969, Slavik 1974).

4.4. *Transpiration*

Transpiration inside the chamber was measured using the Infra red gas analyzer (Model LI-6200, Li-Cor, Nebraska, USA). The values for instantaneous transpiration is calculated by the software provided by the manufacturers. Phyllodes were sampled on different days.

4.5. *Water use efficiency* (WUE)

It is defined as the mass of CO_2 assimilated (P_n) per unit mass of water transpired (E). It is also calculated using the formula P_n/E.

5. **Physico-chemical parameters**

Some of the physico- chemical parameters like chlorphyll content, carotenoid content and proline content are indicators of stress.

5.1. *Chlorophyll content*

Total chlorophyll content was estimated from phyllodes using the method of Hendry and Price (1993). The loss of photosynthetic pigments like chlorophylls and carotenoids are visible indicators of environmental stresses. Similarly the ratio of chlorophyll a to b has been used widely as an early indicator of senescence (Brown *et al.* 1991). Chlorophylls are particularly sensitive to oxidative attack and photodamage, while carotenoids function naturally as antioxidants and in quenching antiinduced excitations. Changes in chlorophyll / carotenoid ratios are partially sensitive indicators of oxidative damage.

Chlorophylls and carotenoids were extracted rapidly from phyllodes and their concentration determined spectrophotometrically. 250 mg of fresh phyllode sample is homogenized with twice the amount of Acetone (80%) using a mortar and pestle. The extract was centrifuged at 3000 rpm for 3 minutes and placed in dark. The supernatant liquid was decanted to another test tube and made up to 10 ml. Absorbance of the sample volumes taken in glass cuvettes was noted for wavelengths of 480, 510, 645, and 663 nm. Using the extinction coefficients provided by Mac Kinney (1941), chlorophyll a, b and total chlorophyll in mg g^{-1} of fresh material are found out.

Chlorophyll a = (12.7 x A663) - (2.69 x A645) x V/W x 1000 mg/gm (6)

Chlorophyll b = (22.9 x A645) - (4.68 x A663) x V/W x 1000 mg/gm (7)

Total Chlorophyll = (8.08 x A663) + (20.2 x A645) x V/W x 1000 mg/gm (8)

Carotenoids were estimated based on the formula given by Bensal *et al.* (1976).

Carotenoids in mg g^{-1} = (7.6 x A480) - (1.49 x A510) x V/W x 1000 (9)
where,

V = the extract volume (ml) and
W = the weight (g) of the plant material used.

5.2. *Chlorophyll stability index* (CSI)

Chlorophyll stability index is a measure of the integrity of membrane under stress conditions. The first change observed on plants suffering from drought is wilting of leaves and a gradual fading of green colour. When colour change exceeds a critical point, recovery is not possible. Chlorophyll molecules are thermosensitive and their degradation occurs when the pigments are subjected to higher temperatures and it is hastened by water stress. Membrane permeability is lost under stress conditions which leads to protein denaturation of the pigment and oxidation of the pigment resulting in lesser capacity to absorb light. Plants that can maintain higher chlorophyll content, even under artificial drought conditions are considered to be drought tolerant. Kaloyereas (1958) reported that the critical temperature beyond which chlorophyll destruction procedes rapidly was between 55 and 56°C. This property of chlorophyll stability is found to correlate well with drought resistance.

250 mg of two fresh phyllode samples were weighed separately and kept in 50 ml of distilled water taken in test tubes. One sample was subjected to a tempearature of 55±1°C for 30 minutes by keeping in a hot water bath. The other sample was left at room temperature to serve as control. Exactly after 30 minutes, the phyllode samples were removed, blotted with a filter paper and ground with 10 ml of acquous Acetone (80%) using a mortar and pestle. The homogenate was centrifuged at 3000 rpm for ten minutes. The supernatant is made up to 25 ml with 80% acetone and absorbance at 652 nm is noticed. The difference in chlorophyll content of the two samples are estimated.

$$\text{Chlorophyll content} = A652/34.2 \times 1000 \times V/1000 \times W \quad \text{mg/gm} \qquad (10)$$

$$\text{CSI} = \frac{(\text{Control - treated})}{\text{Control}} \times 100 \qquad (11)$$

5.3. *Proline*

Severe water stress may induce breakdown of proteins and its constituents (amino acids). This may increase the quantity of nitrogenous compounds in the cytoplasm and may hinter the functioning of enzymes and metabolic activities. Accumulation of free proline is rapid in leaves of stressed plants. It acts as an osmoticum and helps the plant to maintain the turgor under stress.

Estimation of free proline in the phyllodes of four species of acacias under 4 treatments were done based on the procedure given by Bates *et al.* (1973). 250 mg of fresh phyllodes of treated seedlings were homogenized with 3% aquous Sulphosalicylic acid and made up to 10 ml. The contents were centrifuged at 3000 rpm for 10 minutes. Two ml of the supernatant was taken in a test tube and 2 ml of glacial Acetic acid and 2 ml of acid Ninhydrin mixture were added. Acid Ninhydrin mixture was prepared by taking 1.25 mg of Ninhydrin in 30 ml of glacial Acetic acid along with 6 M Phosphoric acid. The mixture is agitated well and stored at 4°C for 24 hours before use.

The extracted sample contents were allowed for reaction at 100°C for one hour and then kept in an ice bath. The reaction mixture taken in a separating funnel was then extracted with 4 ml of Toluene after vigourously mixing for 20 seconds. The upper coloured portion containing Proline is collected, warmed to room temperature and optical density was read at 520 nm. The proline content was expressed in $\mu g\ g^{-1}$ of fresh weight of phyllode material referring to a standard curve by plotting out 10, 20, 30, 40, 80 and 100 μgm of proline.

$$\text{Proline content} = \frac{(\text{Conc.}(\mu g) \text{x OD of sample})}{(\text{OD of standard})} \text{ x } \frac{V}{W} \quad \mu\ g^{-1} \qquad (12)$$

6. Growth

Seedling growth of 4 different species of *Acacia* were noted for 293 days. Increase in height, phyllode number and phyllode area were also taken at different intervals for various stress cycles in *A.auriculiformis* for 60 days.

Water relations, growth and gas exchange of *Acacia auriculiformis* under stressed and non-stressed field conditions

1. Site description

Investigations were carried out in the *A. auriculiformis* plantation located at Kothachira (10° 44'N 76° 8'E) under Palakkad Social Forestry Division, during 1990-91. The experimental site was located at about 20 m above sea level. The site was having a mean annual rainfall of 2500 mm. receiving rainfall from South West Monsoon (June to Sept) and North East Monsoon (October to November). The dry period was from January to May. The 49 ha plantation was raised in 1985 using seedlings planted at an espacement of 1.5 x 1.5 m accomodating 4440 trees ha^{-1}. At the time of study, the 5 year old trees had a height of 10 m and an average GBH of 18.7 cm. The DBH was calculated to be 6.5 cm. The area was influenced by high windspeed during November to February due to the funnel effect of the Palakkad gap of Western Ghats. The potential evapotranspiration for the site has been reported to be 1663 mm having high evaporative demand (Rao *et al.* 1971). The soil was reported to be acidic (pH = 5) and the water holding capacity being 21% (Sankaran *et al.* 1993).

2. Weather and microclimate parameters

Year round weather parameters such as rainfall, maximum and minimum temperatures, relative humidity and wind velocity were collected from a weather station located near the plantation under investigation.

To monitor the microclimate above the canopy, a 10 m high, steel scaffold tower was installed in the plantation. The meteorological sensors were mounted 2 m above the canopy level. Air temperature (T_a) and relative humidity (RH) were measured using a shielded thermistor (Model 207 Temperature and RH probe, Campbell scientific, Inc. Utah, USA). Wind speed (u) was measured with a cup counter anemometer (Model 014A, Met One, Sunnyvale, CA, USA) equipped with a switch closure mechanism. Net radiation (R_n) was measured using a net radiometer of the Fritschen type (REBS Inc. Washington, USA). Total Solar radiation (s) was measured using a pyranometer sensor (LI-200S, LI-Cor, Nebraska, USA). All sensors were connected to a datalogger (Model 21X, Campbell Scientific Inc., Utah, USA) which recorded measurements at every five seconds and averaged hourly. The stored data were later transferred to a computer for further analysis using the software package PC-208 (Campbell Scientific Inc., Utah, USA).

3. **Water status**

In order to determine water status of the trees both soil water content and water potential measurements were taken at monthly intervals.

3.1. *Soil water*

Soil water content was measured gravimetrically by collecting at least three samples from the top two lalyers 0-30 and 30-60 cm at monthly intervals from within the plantation.

3.2. Water potentials (Ψ)

Predawn and midday Ψ measurements were taken on 3 to 4 phyllodes from different trees. Predawn Ψ were indicative of the water availability to the roots and midday Ψ indicates the the maximum tension prevailing in the xylem conducting pathway. Before taking midday measurements, the phyllodes were enclosed within a polythene bag to to minimise transpirational loss of water during measurements (Turner, 1988). The details of pressure chamber methods are described in experiment section 1.

4. **Stomatal conductance (g_s)**

A steady state porometer (Model LI-1600, LI-Cor, Nebraska, USA) was used to measure the stomatal conductance of the phyllodes at ambient relative humidity. Eight leaf samples from at least 3-4 trees accessible from the scaffold tower were measured on an hourly basis from sunrise to sunset. The measurements were made on the upper and lower sides of the phyllodes. Stomatal frequency on both sides of the phyllodes was determined microscopically from epidermal imprints of several samples.

Daily patterns of g_s were followed on sample days randomly chosen at approximately one month interval over a complete year. The measurements of premonsoon months were taken as stressed period and post monsoon as nonstressed period. The sampling of the phyllodes were done mainly on the fully exposed uppermost canopy. Mature 5th phyllode, well-exposed to sunlight were taken for this purpose. The g_s was calculated using the software provided with the instrument. In the infrared gas analyser, a stomatal ratio of 1.0 was fed to the console which in turn calculated the stomatal conductance using the inbuilt software. An Infrared gas analyser (IRGA)system (Li 6200, Li-cor, USA) was also used simultaneously.

5. Canopy transpiration (E_t)

Canopy transpiration was estimated using the Penman- Monteith equation (Monteith, 1965).

$$E_t = \frac{s\,(R_n - G) + \rho c_p D g_a}{\lambda[s + \gamma\,(1 + g_a/g_c)]} \qquad (13)$$

where,
E_t = evapotranspiration rate (mol m^{-2} s^{-1})
s = the slope of the saturation pressure curve for water (KPa K^{-1})
λ = latent heat of vaporisation of water (44200 J mol^{-1} at 20 °C)
R_n = net radiation (W m^{-2})
G = Soil heat flux (which can be ignored for daily calculations)
ρ = density of air (mol m^{-3})
c_p = specific heat of air at constant pressure (J mol^{-1})
D = Vapour pressure deficit (kPa)
g_a = aerodynamic conductance (m s^{-1})

λ = latent heat of vaporisation of water (44200 J mol^{-1} at 20°C)
γ = psychrometric constant (0.066 kPa K^{-1})
g_c = Canopy conductance (m s^{-1})

The E_t measurements obtained in molar units were converted to depth units for convenience. Canopy conductance (g_c) was calculated as follows:

$$g_c = \Sigma\, g_s L \qquad (14)$$

where,

g_s = mean stomatal conductance (m s^{-1}) and

L = leaf area index of the conducting surface.

Mean g_s was obtained by sampling 8 phyllodes distributed at different positions of the canopy at each hour using porometer. Leaf area index (LAI) was measured using the principle of light transmittance through the canopy gaps with the help of a commercially available Canopy Analyser (Model LAI-2000, Li-Cor, Nebraska, USA). This instrument is provided with a fish-eye lens to scan the canopy.

The aerodynamic conductance (g_a) was estimated using the following equation (Monteith, 1965).

$$g_a = (k^2 u \rho)/\ln^2 [(z-d)/z_0)] \qquad (15)$$

where,

k = von Karman's constant (0.41),
u = mean wind speed (ms^{-1}),
z = anemometer reference height (m),
d = zero plane displacement - calculated as 0.64 h, where h = tree height (m),
z_o = roughness length (m) and
ρ = mole desnity of air (mol m^{-3}).

6. Net photosynthesis (P_n)

Leaf net photosynthesis (P_n) was measured using a portable infra red gas analyser (IRGA, Model LI-6200, Li-Cor, Nebraska, USA) fitted with 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, using known gas mixtures of CO_2. The measurements were recorded on the data logger supplied with the instrument. The P_n 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.

7. Growth measurements

The increase in girth of 40 trees were measured at breast height (1.37 m) at monthly intervals using a measuring tape. The measurements were made in the open and litter-covered plots simultaneously.

Results

RESULTS

Experiment I

Physiological response of seedlings of *Acacia auriculiformis* to progressive stresses

1. Control

1.1. *Water potential* (Ψ)

The control seedlings showed an average predawn water potential of -0.19 MPa and midday water potential of -0.65 MPa during the experimenatal period. This shows that the phyllodes of *Acacia auriculiformis* did not face much water deficit (Table 1).

1.2. *Photosynthesis*

The normally watered plants photosynthesised during the whole day. The diurnal variations in net photosynthesis showed two peaks, at 1100 hours and 1500 hours The morning peak showed a net photosynthesis of about 13.4 μmol m^{-2} s^{-1} and the evening peak of about 8 μmol m^{-2} s^{-1} (Fig.1). However photosynthesis was low at midday and evening hours.

1.3. *Stomatal conductance* (g_s)

Fig.. 2. shows consecutive measurements made on the phyllodes at 4th and 5th positions on different plants during the whole day for a period of 14 days in summer months. The g_s ranged between 400-500 mmol m^{-2} s^{-1} during day time and was high up to 1000 hours. But afterwards, there was a depression in g_s down to 260 mmol m^{-2} s^{-1} by 1200 hours. Then the g_s slowly increased to 300 mmol m^{-2} s^{-1} and remained steady upto 1500 hours. The g_s gradually declined to about 100 mmol m^{-2} s^{-1} by 1700 hours. The depression at 1200 hours may be due to partial midday closure of stomata.

1.4. *Transpiration*

In control plants transpiration continued throughout the day starting with 9 mmol m^{-2} s^{-1} by 0800 hours, reaching a maximum of 12 mmol m^{-2} s^{-1} by 1100 hours and afterwards gradually declined to 5 mmol m^{-2} s^{-1} by 1500 hours (Fig. 3). The plants showed comparatively low level of transpiration during 1230 hours. After 1430 hours the transpiration rate gradually decreased reaching a level of 2 mmol m^{-2} s^{-1} by 1700 hours. Stomatal conductance was found to be seriously affecting transpiration. When the g_s was low, transpiration also was low. The maximum transpiration rate of 12 mmol m^{-2} s^{-1} was coincided by a stomatal conductance value of 300 mmol m^{-2} s^{-1}.

1.5. *Water use efficiency* (WUE)

The WUE of normally watered plants were between 0.5 and 1.5 during the experimental period (Fig. 4).

2. Drought

2.1. *Water potential* (Ψ)

After 3 days of water stress the plants showed a predawn water potential of -0.9 MPa and midday water potential of -1.74 MPa. After 5 days the predawn water potential was -1.7 MPa and midday water potential was -2.6 MPa. By 9th day the predawn water potential again declined to -2.3 MPa and the midday water potential to -3.5 MPa. Rewatering of the plants on 12th day morning and measurements on the same day showed a a midday water potential of -1.20 MPa. The details of are presented in Table 1.

2.2. *Net Photosynthesis* (P_n)

The net photosynthesis measured after 3 days of drought stress showed a decrease in photosynthetic rate (Fig. 1). The droughted plants did not show an evening peak as the stress continued. The P_n was seen to decline from 12 μmol m^{-2} s^{-1} to 8.23 μmol m^{-2} s^{-1} at 1100 hours on 4th day and to 2 μmol m^{-2} s^{-1} on 10th day and almost no photosynthesis by 12th day. In the droughted plants the morning peak was seen shifted to 0900 hours by 10th day and the magnitude was very low. Measurements made after rewatering showed only slight improvement within 6 hours.

Table 1. Water potential (Ψ) of seedlings of *A.auriculiformis* under various stress conditions.

Treatment	Dayss	Predawn (Ψ)	Midday (Ψ)
Control	0	-0.19	-0.65
Drought	3	-0.9	-1.74
	5	-1.7	-2.6
	9	-2.3	-3.5
	12	-2.0	-1.2
Flooding	3	-0.2	-0.62
	5	-0.2	-0.7
	9	-0.2	-0.6
	12	-0.18	-0.1
Salinity 100	3	-0.4	-0.5
	5	-0.3	-1.32
	9	-0.4	-2.5
	12	-0.1	-1.4
Salinity 200	3	-0.84	-2.04
	5	-0.5	-1.4
	9	-0.5	-2.9
	12	-0.3	-1.0

2.3. *Stomatal conductance* (g_s)

The stomatal conductance values of drought stressed plants were very low when compared to control plants (Fig. 2). By 2nd day, the values declined to 300 mmol m^{-2} s^{-1} with a morning peak at 1000 hours. By 3rd day, the values were still less having a morning peak of 150 mmol m^{-2} s^{-1} at 1000 hours and about 50 mmol m^{-2} s^{-1} at 1200 hours which gradually rose to 100 mmol m^{-2} s^{-1} by 1400 hours and then decreased. By 7th day the conductance values did not go beyond 100 mmol m^{-2} s^{-1} and then gradually decreased to about 50 mmol m^{-2} s^{-1}. By 10th day the g_s was very poor with peak time g_s was < 50 mmol m^{-2} s^{-1}, which proceeded to still lower values showing almost no conductance. On 13th day there was no conducatance. In the drought stressed plants, although the photosynthesis was very low, most of the photosynthesis occurred in a conductance range of 0-150 mmol m^{-2} s^{-1} and maximum photosynthesis was achieved at conductance value of 130 mmol m^{-2} s^{-1}.

2.4 *Transpiration*

The droughted plants showed comparatively lower rates of transpiration as the drought stress progressed (Fig. 3). On 2nd day, the morning peak of transpiration was around 8 mmol m^{-2} s^{-1} which gradually declined to 5 mmol m^{-2} s^{-1} but remained almost steady, upto 1600 hours. The drought stressed plants showed lower rate of transpiration as the stress progressed. Transpiration was less than 4 mmol m^{-2} s^{-1} from 4th day onwardsa, at peak hours. These plants had a peak of transpiration at 1000 hours, in the initial stages which was seen advanced to 0900 hours. The 2nd peak was also seen advanced to 1300 hours. After 7 days of drought stress, the 2nd peak was missing and by 10th day, transpiration itself was very low, showing less than 2 mmol m^{-2} s^{-1} even in the morning, and by 1600 hours transpiration was not measurable. In general due to the low stomatal conductance, the transpiration values also did not go beyond 6 mmol m^{-2} s^{-1} in the drought stressed plants.

2.5. *Water use efficiency* (WUE)

The drought stressed plants had more WUE than the control plants in the morning and evening (Fig. 4). During the first 7 days of drought stress, the morning values of WUE rose to 3 by 1200 hours which decreased to 1.0 by 1500 hours. It again rose to 2.0 by 1700 hours. But after 7 days, there was a decline in WUE at 1200 hours and on 10th day, the WUE became less than 2.0 after 1400 hours. Due to very low photosynthetic rates, the WUE also was very low on 12th day. Rewatering shows that WUE gets improved slowly.

3.Flooding

3.1 *Water potential* (Ψ)

The water-logged plants showed a predawn Ψ of -0.2 MPa after 3 days along with a midday water potential of -0.62 MPa. The predawn Ψ after 5 days was -0.2

MPa and midday Ψ was -0.7 MPa. After 9 days it was -0.2 MPa and -0.6 MPa. Releasing the plants from flooding by keeping them outside the water showed a predawn Ψ of -0.18 and a midday water potential of -0.1 MPa. It can be seen that flooding also decreases the water potential by about -0.5 MPa in the noon time (Table 1).

3.2. *Net Photosynthesis* (P_n)

The flooded plants behaved more or less similar to the control plants. The plants had a morning peak at 1100 hours, with a P_n rate of 12 μmol m^{-2} s^{-1}, which gradually declined to 4 μmol m^{-2} s^{-1} throughout the period of 12 days (Fig. 5). The 2nd peak was not prominent but can be noticed at 1500 hours. Releasing the plants from flooded condition showed the reappearane of the evening peak at 1500 hours.

3.3. *Stomatal conductance* (g_s)

The flooded plants showed a relatively a high g_s of 500 mmol m^{-2} s^{-1} in the morning at 1000 hours (Fig. 6). The usual depression at 1230 hours observed in control plants was seen advanced to 1100 hours by 4th day. This may be due to the early occurrence of stomatal closure. It has also been noticed that the higher g_s values decreased gradually and reached 200 mmol m^{-2} s^{-1} by 1600 hours. The higher conductance values in the flooded plants was accompanied by a higher photosynthetic rate.

3.4 *Transpiration*

The transpiration in flooding stressed plants was slightly higher than control plants (Fig.. 7). They initially showed a steady state of transpiration which gradually declined from 10 to 4 mmol m^{-2} s^{-1} by 1700 hours. After 4 days, alternate peaks were noticed at 1100 and 1300 hours. By 10th day, a peak having 14 mmol m^{-2} s^{-1} was noticed at 900 hours and 1200 hours, which gradually declined to 5 mmol m^{-2} s^{-1}. By 12th day the peak was almost steady for 3 hours during 0900 to 1100 hours having a transpiration rate of 14 mmol m^{-2} s^{-1} which declined afterwards. The flooded plants also showed increase in transpiration values as g_s increased, but beyond 200 mmol m^{-2} s^{-1}, the transpiration rate was lower. Recovery of the plants from flooding showed two peaks at 1000 and 1200 hours having a transpiration rate of 14 and 11 mmol m^{-2} s^{-1} respectively.

3.5 *Water use efficiency* (WUE)

The flooded plants showed a WUE ranging between 0.5 to 1.5 (Fig. 8). This shows that WUE is low when water is in excess.

4. **Salinity**

4.1 *Water potential* (Ψ)

Water potential measurements of the salinity stressed (100 mol m^{-3}) plants showed a decrease in water potential but not as severe as in drought stressed plants. Intially after 3 days, the salt treated plants (100 mol m^{-3}) showed a predawn Ψ of -0.40 MPa and midday Ψ of -0.52 MPa. After 5 days the predawn Ψ was -0.3 MPa and midday Ψ was -1.32 MPa. On 9th day it was 0.4 MPa and -2.50 MPa respectively. Rewatering of the plants on 11th day and measurements on following day, showed a predawn Ψ of -0.10 MPa and a midday Ψ of -1.4 MPa. A higher concentration of sodium chloride dissolved in water (200 mol m^{-3}) applied one litre per day per plant showed a predawn Ψ of -0.84 MPa and midday Ψ of -2.04 MPa after 3 days. After 5 days it was -0.5 MPa and -1.42 MPa respectively. After 9 days the predawn Ψ was -0.5 MPa and midday Ψ was -2.9 MPa. Rewatering of the plants on 11th day and measurements on the folowing day showed a predawn Ψ of -0.3 MPa and midday Ψ of -1.0 MPa (Table 1).

4.2. *Net Photosynthesis* (P_n)

Net photosynthesis in salinity stressed plants (100 mol m^{-3}) was comparatively higher than control plants measured simultaneously (Fig. 9). In this case the control plants exhibited a lower photosynthetic rate ranging between 4 to 8 μmol m^{-2} s^{-1}. The salinity stressed plants (100 m Mol) showed a peak in photosynthesis by 1200 and 1300 hours when the photosynthetic rate was 9 μmol m^{-2} s^{-1}. By 3rd day the peak photosynthetic rate was seen decreased to 5.4 μmol m^{-2} s^{-1}, which gradually decreased by 1500 hours.

But in the plants treated with a higher concentration of Sodium chloride (200 mol m^{-3}) initially for 5 days (Fig. 10), the photosynthetic rate was seen to increae to a level of 8 μmol m^{-2} s^{-1}, which gradually decreased after 1300 hours each day as stress progressed. By 9th day, a drastic decrease in the photosynthetic rate was noticed. Rewatering on 11th day and measurements on the following day showed an increase in photosynthetic rate upto 1100 hours which then decreased.

4.3. *Stomatal conductance* (g_s)

The stomatal conductance in salinity stressed plants (100 mol m^{-3}) were higher than that of control plants (Fig.11). Upto 3 days the conductance values were near 200 mmol m^{-2} s^{-1} in the morning, which gradually decreased to 100 mmol m^{-2} s^{-1} in the evening hours. By 5th day the conductance values were seen increased to 400 mmol m^{-2} s^{-1} at 900 and 1000 hours which gradually decreased to 100 mmol m^{-2} s^{-1} by evening. The higher salt concentration (200 mol m^{-3}) treatment did not show such a sharp increase in the early stages of treatment but slightly higher conductance values of 200 mmol m^{-2} s^{-1} were noticed during 900 to 1100 hours which gradually decreased to 50 mmol m^{-2} s^{-1} (Fig.12). From 5th day onwards the salt stressed plants (200 mol m^{-3}) showed comparatively lower conductance values ranging between 50 to 100 mmol m^{-2} s^{-1}. Rewatering of the plants with pure water on 11th day and measurements on 12th day, showed improvemet in conductance values which became more or less same as in control. It has been observed that most of the photosynthesis occurred at conductance values below 250 mmol m^{-2} s^{-1}.

4.4 *Transpiration*

The salinity stressed plants (100 mol m^{-3}) showed comaparatively higher transpiration rates than control plants (Fig.13). In the case of control plants, the transpiration rate was 15 mmol m^{-2} s^{-1} at 1300 hours, whereas in salinity stressed plants it increased to 14 mmol m^{-2} s^{-1} by first day itself. During the whole day, transpiration rates of salinity stressed plants (100 mol m^{-3}) was higher than control. In all cases after 1400 hours the transpiration was found to decrease, gradually reaching to 4-6 mmol m^{-2} s^{-1}. Rewatering of the plants on 11th day and measurements on the following day showed similarity in values with that of control.

Streesing with a higher concentrtion of Sodium chloride (200 mol m^{-3}), the transpiration rate increased only up to 8 mmol m^{-2} s^{-1} initially, but by 3rd day, the trend was to show lesser values from 1000 hours onwards (Fig. 14). Thereafter on 5th and 9th day the transpiration rate did not improve at all and remained between 2 to 4 mmol m^{-2} s^{-1} throughout the day. Rewatering of the plants on 11th day and measurements on the followig day showed recovery of the plants to maintain normal transpiration which prevailed in control plants viz. 6 to 7 mmol m^{-2} s^{-1} up to 1200 hours which gradually declining to 2.2 mmol m^{-2} s^{-1} by 1300 hours. In salt stressed plants (200 mol m^{-3}), the transpiration rate slowly increased with g_s but after a g_s of 200 mmol m^{-2} s^{-1}, the values of transpiration was comparatively low.

4.5. *Water use efficiency* (WUE)

The WUE of salinity stressed plants (100 mol m^{-3})was almost same as that of control plants but slightly decreased after 1300 hours (Fig. 15a). The decrease of WUE in the evening hours was more in salinity stressed than control. A more or less similar trend was noticed in the plants treated with the higher concentration of salt (200 mol m^{-3}). Here in the morning hours the WUE was around 2.0 for 5 days which was found to decrease afterwards. The WUE was invariably low (1.0) at 1100 hours (Fig. 15b).

Experiment II. Effect of Leaf Position and gas exchanges in *A.auriculiformis*

The phyllodes of *A.auriculiformis* at different positions were observed for their photosynthesis, stomatal conductance and transpiration characters at 1200 and 1500 hours using an infrared gas analyser under normal watering conditions. The results are given below.

1. Photosynthesis (P_n)

The net photosynthesis rate in various phyllodes present on a seedling kept under normal watering was examined. The fully opened phyllodes at the top of the seedling, which has developed to the normal size of phyllodes, was counted as the first phyllode. Normally there will be two more new phyllodes above this position which will be closed with a young bud above. The phyllodes at positions 4 to 15 were found to have a photosynthetic rate of > 10 μmol m^{-2} s^{-1} at 1500 hours (Fig. 16). The young leaves at positions 1 to 3 showed a photosynthetic rate varying between 9 - 12 μmol m^{-2} s^{-1} in the morning but this was very low in the afternoon (2 to 2.5 μmol m^{-2} s^{-1}). Similarly, leaves at positions 17 to 20 also showed a decreasing trend in the evening. It can be inferred that the photosynthetic rate is low in young and old leaves. The 8th and 15th phyllodes were found to have maximum photosynthesis at 1200 hours reachig up to 15 μmol m^{-2} s^{-1}. Other phyllodes showed an average of 10 μmol m^{-2} s^{-1} at postions between 4 and 15.

2. Stomatal conductance (g_s)

Stomatal conductance varied between 200 and 350 mmol m^{-2} s^{-1} in phyllodes at positions 4 to 15. The morning values of g_s were near 150 mmol m^{-2} s^{-1} in phyllodes at positions 1 to 3 while evening values reached less than 50 mmol m^{-2} s^{-1}. Phyllodes at positions 16 to 20 also showed lower g_s both in the morning and evening and the values varied between 50 -150 mmol m^{-2} s^{-1}.

3. Transpiration

Transpiration was normal in phyllodes from 2 to 17 in the morning having a rate of 10 to 11 mmol m^{-2} s^{-1}. But at 1800 hours the younger phyllodes had a lower transpiration rate of 5.0 mmol m^{-2} s^{-1}. The phyllodes at positions 16 to 20 also showed values between 5 to 8 mmol m^{-2} s^{-1} at 1200 hours, and 2 to 5 mmol m^{-2} s^{-1} at 1500 hours.

Experiment III. Light response curves

Seedlings of four species of *Acacia* subjected to normal watering were exposed to different light intensities during peak time of photosynthesis, viz., between 1000 and 1200 hours. Photosynthetic measurements were made using IRGA. Different light intensities ranging form 0 to 2000 μmol m^{-2} s^{-1} were created under natural sunlight using neutral filters made of white muslin cloth kept above the plant.

Results show that *A. auriculiformis* is able to photosynthesise maximum at a PFD of 1200 - 1400 μmol m^{-2} s^{-1}. The A_{max} is 14 μmol m^{-2} s^{-1}. At higher light intensities, the net photosynthesis is not increased The assimilation maximum (A_{max}) for field grown *A. auriculiformis* has been found to be 15 μmol m^{-2} s^{-1}. Light compensation point for photosynthesis is near 50 μmol m^{-2} s^{-1} (Fig. 17).

In *A.aulacocarpa* the photosynthetic rate was less than of *A.auriculiformis* (Fig.18). The A_{max} was 9 - 10 μmol m^{-2} s^{-1}observed at a PFD of 1000-1200 μmol m^{-2} s^{-1}. The light compensation point for photosynthesis was found to be near 50 μmol m^{-2} s^{-1}.

In *A.holocericea* the light saturation was between 1100-1300 μmol m^{-2} s^{-1} (Fig. 19). Initiation of photosynthesis required about 100 μmol m^{-2} s^{-1}. A higher photosynthetic rate (A_{max}) of 23 μmol m^{-2} s^{-1} was noticed in *A. holocericea.*

A.mangium required about 90 μmol m^{-2} s^{-1} of PFD to initiate photosynthesis (Fig. 20). Maximu photo synthesis (A_{max}) was 13 μmol m^{-2} s^{-1}. The ligt saturation was near 1200 μmol m^{-2} s^{-1}.

Relative water content: (RWC)

The relative water content of the phyllodes of *A.auriculiformis* growing in the campus were checked for its RWC for different months (Fig. 21). During February to May the RWC was low, showing a maximum water deficit of 23.7% in May. Maximum RWC was found to occur in June (96.71%) with meager water deficit of 3.2%. The postmonsoon periods normally maintained high RWC except October (82%), where shortage of rainfall, increased windspeed and VPD might have lowered the RWC.

In the case of plants kept under different environmental conditions for 15 days, the control plants maintained an RWC of 88±6. The drought stressed plants showed a decrease in their RWC and reached below 70%. The flooded plants were able to maintain higher amounts of RWC (>96 %). The water deficit in drought stressed plants was found to increase up to 31% after six days. The control plants showed a water deficit of 10-20% while flooded plants 3-13% (Fig.22).

Experiment. IV. Responses of seedlings of *Acacia mangium* to progressive water stress, flooding and salinity.

Seedlings of *A. mangium* were grown for 12 months in polythene bags filled with forest soil and watered twice a day in the morning and evening. The plants were subjected to 5 treatments with 6 replications. Treatments include:

1. Control (with normal watering)
2. Water Stress (water was withheld)
3. Salt stress (100 mol m^{-3} Nacl)
4. Salt stress (200 mol m^{-3} Nacl)
5. Water logging (flooding with stagnant water)

1. Control:

1.1. *Water potential* (Ψ)

Water potential measurements on the 4th and 5th phyllodes from different plants kept under normal watering twice a day showed a predawn Ψ of -0.12 MPa and midday Ψ of -0.7 MPa throughout the experimental period (Table.2).

1.2. *Net Photosynthesis* (P_n)

Diurnal measurements of photosynthesis in control plants showed two peaks with a P_n of 4 and 8 μmol m^{-2} s^{-1} at 1000 and 1400 hours respectively (Fig. 23). The photosynthesis decreased to 2 μmol m^{-2} s^{-1} at 1300 hours which again increased to 8 μmol m^{-2} s^{-1}.

1.3. *Stomatal conductance* (g_s)

The g_s values were below 200 mmol m^{-2} s^{-1} which gradually decreased to around 150 mmol m^{-2} s^{-1} by 1100 hours and to 50 mmol m^{-2} s^{-1} by 1300 hours, indicating a partial stomatal closure (Fig. 24). Thereafter, g_s values remained somewhere near 50 mmol m^{-2} s^{-1} up tp 1600 hours. The stomatal conductance was found to decrease with increase in VPD.

1.4. *Transpiration*

Diurnal measurements in the control plants showed, a transpiration rate of 4 mmol m^{-2} s^{-1} up to 1200 hours which then got decreased to 2.5 mmol m^{-2} s^{-1} by 1300 hours and again increased to 10 mmol m^{-2} s^{-1} by 1400 hours (Fig. 25). Thereafter the values decreased suddenly to 2.5 by 1500 hours. Transpiration was found to increase as g_s was increased. It was noticed that the transpiration rate of 10 mmol m^{-2} s^{-1} was found to occur at a g_s of 300 mmol m^{-2} s^{-1}.

1.5 *Water use efficiency* (WUE)

The water use efficiency of control plants ranged between 0.5 to 1.2 (Fig. 26).

2. Drought:

2.1 *Water potential* (Ψ)

Water potential of drought stressed plants decreased as the stress period increased. After 3 days, the drought stressed plants showed a predawn Ψ of -0.80 MPa and midday Ψ of 1.64 MPa. After 5 days the predawn Ψ was -1.4 MPa and midday Ψ was -2.02 MPa. By 9th day the predawn water potential again declined to -1.6 MPa and the midday Ψ to -2.22 MPa. Rewatering of the plants on 11th day and measurements on 12th day showed a predawn Ψ of -0.2 MPa and a midday Ψ of -1.48 MPa (Table 2).

2.2. *Photosynthesis* (P_n)

Measurements on diurnal variations of P_n show that in the initial stages up to 3 days there is significant increase in photosynthetic rate (Fig.23). After one day of drought stress, the seedlings exhibited 9.8 μmol m^{-2} s^{-1} during 1000 to 1400 hours. The plants reduced their photosynthetic rate to 2 μmol m^{-2} s^{-1} after 5 days of drought. Photosynthesis was not measurable after 1300 hours in 9 days drought stress. Rewatering the plants on 11th day and measurements on the following day also did not show much improvement where photosynthesis during 900 hours was improved to 2.5 μmol m^{-2} s^{-1} and thereafter decreased to 0.5 μmol m^{-2} s^{-1} It appears that the plants may require more time to recover from drought. The recovered plants were able to perform photosynthesis at a lower PFD of 250 μmol m^{-2} s^{-1}. It can be seen that a wider range of PFD is utilized by the drought stressed seedlings.

2.3. *Stomatal conductance* (g_s)

Initially, drought stress for 3 days increased the g_s in the morning hours reaching up to 550 mmol m^{-2} s^{-1} (Fig. 24). But the plants reduced their g_s considerably by 5th day onwards. The g_s was around 150 mmol m^{-2} s^{-1} up to 1000 hours which gradually decreased to 50mol m^{-2} s^{-1} by 1600 hrs. During 1300 hrs, Table.2. Water potential (Ψ) measurements for various stress treatments for various days in *Acacia mangium*

Treatment	Days	Predawn Ψ (MPa)	Midday Ψ (MPa)
Control	0	-0.12	-0.70
Drought stress	3	-0.80	-1.64
	5	-1.40	-2.02
	7	-1.60	-2.22
Rewatering	12	-0.20	-1.48
Flooding	3	-0.18	-0.50
	5	-0.60	-0.40
	9	-0.74	-0.40
Release	12	-0.06	-0.10
Salinity 100	3	-0.20	-1.24
	5	-0.60	-1.74
	9	-1.02	-2.0
Rewatering	12	-0.32	-1.50
Salinity 200	3	-0.52	-1.60
	5	-0.60	-1.80
	9	-1.04	-2.10
Rewatering	12	-0.38	-1.20

g_s was comparatively low in the drought stressed plants. Rewatering of the plants on 11th day and measurements on 12th day showed increase in g_s upto 1100 hours which then reduced to < 50 mmol m^{-2} s^{-1}.

2.4. *Transpiration*

In the drought stressed plants the transpiration rate increased to 17.3 mmol m^{-2} s^{-1} at 1300 hours which gradually declined to 6.3 mmol m^{-2} s^{-1} by 1400 hours on the first day (Fig. 25). From 3rd day onwards, a lower transpiration rate of 8 mmol m^{-2} s^{-1} was found to occur at 0900 hours, which gradually declined to 1.7 mmol m^{-2} s^{-1} by 1600 hours. After the compleltion of 4 days drought stress meaurement on 5th day showed comparatively lower rates of tranpiration (<4 mmol m^{-2} s^{-1}). In both control and drought stressed plants transpiration was low during 1300 hours. Rewatering of the plants on 11th day and measurements on 12th day showed increase in tranpiration values up to 4.6 mmol m^{-2} s^{-1} by 1100 hours.

3. Salinity

3.1 *Water potential* (Ψ)

The salt treated plants (100 mol m^{-3}) showed a predawn Ψ of -0.20 MPa and midday Ψ of -1.24 MPa after 3 days. After 5 days the predawn Ψ was -0.6 MPa and midday Ψ was -1.74 MPa. On 9th day it was -1.52 MPa and -2.0 MPa respectively. Normal watering on 11th day and measurements on the following day showed a predawn Ψ of -0.32 MPa and a midday Ψ of -1.5 MPa (Table.2).

Salt treatment at higher concentration (200 mol m^{-3}) showed a predawn Ψ of -0.52 MPa and midday Ψ of -1.6 MPa after 3 days . After 5 days it was -0.6 MPa and -1.3 MPa respectively. After 9 days the predawn Ψ was -1.4 MPa and midday Ψ was -2.1 MPa. Rewatering of the plants on 11th day and measurements on the following day, showed a predawn Ψ of -0.38 MPa and midday Ψ of -1.2 MPa (Table 2).

3.2. *Photosynthesis* (*P_N*)

Diurnal measurements show that salt stressed (100 mol m^{-3}) plants photosynthesized irrespective of time at a higher rate viz. between 8 and 12 μmol m^{-2} s^{-1} in the morning and between 4 and 8 μmol m^{-2} s^{-1} in the afternoon up to 1700 hours (Fig. 27). Unlike control, there was not much decrease in photosynthesis at 1300 hours in salinity stressed plants (100 mol m^{-3}) showing more than 4 μmol m^{-2} s^{-1}, during the first 5 days. Rewatering of the plants on 11th day and measurements taken on the following day, show that the plants maintain higher photosynthetic rates than control.

In higher concentration of salinity stress (200 mol m^{-3}) photosynthesis was higher than control plants up to the 9th day (Fig. 28). By 5th day the plants had comparatively high photosynthetic rates at 1000 and 1400 hours, the values being 9.6 and 14.6 μmol m^{-2} s^{-1}. But after 9 days the photosynthetic values remained below 4 μmol m^{-2} s^{-1}, suggesting that there was no increase in photosynthesis when compared to control. It can be seen that the evening peak of photosynthesis (at 1500 hours) is high in salinity stressed (200 mol m^{-3}) plants. At midday, the photosynthetic rate was comparatively low. Rewatering of the plants on 11th day and measurements on the following day improved the photosynthetic capacity of stressed plants when the photosynthetic rate was seen to increase as in control plants.

3.3 *Stomatal conductance* (*g_s*)

Salt stressed plants (100 mol m^{-3}) showed steep decline in g_s from 0900 hours (Fig. 29). Starting with a high g_s of 350 mmol m^{-2} s^{-1}, it decreased to 45 mmol

m^{-2} s^{-1} on the first day itself. By 3rd day also a similar trend was noticed having a decrease from 435 to 54 mmol m^{-2} s^{-1} by 1500 hours. But from 5th day onwards the initial g_s was low and the decrease was from 200 to 50 mmol m^{-2} s^{-1}. By 9th day, the conductance values were poor showing less than 50 m mol m^{-2} s^{-1}, during most of the day. Rewatering of the plants on 11th day and measurements taken on the following day shows increase in g_s values up to 306 mmol m^{-2} s^{-1} at 1000 hours. Midday stomatal closure was not much prominent in salt stressed plants (100 mol m^{-3}) when compared to control.

The plants treated with a higher concentration of salt (200mol m^{-3})also showed higher g_s values when compared to control (Fig.30). Up to 5 days there was increase in g_s reaching about 300 mmol m^{-2} s^{-1} in the morning (upto 1200 hours) and 170 mmol m^{-2} s^{-1} up to 1600 hours with a decrease to 74 mmol m^{-2} s^{-1} by 1300 hours. The g_s values were higher than control, but less than the plants treated with 100 mol m^{-3} sodium chloride. Rewatering of the plants on 11th day and measurements on 12th day, showed rapid increase in g_s to 514 mmol m^{-2} s^{-1} by 1000 hours.

3.4. *Transpiration*

One-day salt stressed (100 mol m^{-3}) plants showed a transpiration rate of 10.3 mmol m^{-2} s^{-1} at 1000 and 1100 hours which gradually declined to 2.4 mmol m^{-2} s^{-1} at 1500 hours (Fig. 31a). As salt stress advanced, there was slight decrease in transpiration, the transpiration rate after 9 days became lower than that of control plants. After 3 days, there was a small depression in the transpiration values at 1100 hours whereas in control, it was at 1300 hours. In the case of salt stressed (100 mol m^{-3}) plants, there was no decrease in transpiration at 1300 hours, but decreased after 1400 hours.

The plants treated with a higher concentration of Sodium chloride (200 mol m^{-3}) also showed higher transpiration values than control (Fig. 31b). By 1100 hours the transpiration was around 8 mmol m^{-2} s^{-1} on the first day of salinity treatment. On third and fifth days the transpiration rates were between 4 and 9 mmol m^{-2} s^{-1}. The plants showed slightly lower values during 1300 hours indicating partial stomatal closure. The 200 mol m^{-3} salt treated plants also showed good rate of transpiration ranging between 8 and 10 mmol m^{-2} s^{-1} Salt stressed plants transpired at a faster rate even when the g_s was low. At a higher g_s of 200 and 300 mmol m^{-2} s^{-1}, the rate of transpiration was between 8 to 10 mmol m^{-2} s^{-1}. Rewatering of the plants on 11th day and measurements taken on the following day showed increse in tranpiration upto 11.5 mmol m^{-2} s^{-1} at 1000 hours and thereafter decreased to 8 mmol m^{-2} s^{-1} by 1200 hours.

3.5. *Water use efficiency* (WUE)

The water use efficiency of salt stressed plants (100 mol m^{-3}) ranged between 0.4 and 2.0. However it was higher than control (Fig. 32). Salinity stress (200 mol m^{-3}) showed lesser WUE except on the 5th day when the WUE was found to increase during the afternoon hours (Fig. 33).

4. Flooding stress:

4.1. *Water potential* (Ψ)

The flooding stressed plants showed a predawn Ψ of -0.18 MPa after 3 days and a midday Ψ of -0.5 MPa (Table.2). The predawn Ψ after 5 days was -0.6 MPa and midday Ψ was -0.4 MPa respectively. After 9 days it was -0.74 MPa and -0.4 MPa. Releasing the plants from flooding stress by keeping them outside the water, showed a predawn Ψ of -0.06 MPa and a midday Ψ of -0.10 MPa. The reason behind the higher values of midday Ψ may be lower conductance and transpiraion during 1100 to 1300 hours as observed in flooding stressed plants of *A. mangium*.

4.2. *Net Photosynthesis* (P_n)

Flooding stress improved photosynthesis to a great extent (Fig. 34). From a low rate of 4 μmol m^{-2} s^{-1} the photosynthetic rate increased to 14.3 μmol m^{-2} s^{-1} by 9th day. The photosynthesis was high in the morning up to 1200 hours. After a decline at 1300 hours again there was a peak in photosynthesis by 1400 hours and then gradual decrease. During the whole experimental period photosynthesis was higher in flooding stressed than in control plants. Withdrawal of the plants from flooding stress also did not hinder net photosynthesis measured on 12th day. In all cases there was a decrease between 1200 and 1300 hours.

4.3. *Stomatal conductance* (g_s)

Flooding stressed plants showed comparatively higher g_s values reaching up to 338 mmol m^{-2} s^{-1} by 10 hours on 9th day (Fig. 35). In control plants it was about 150 mmol m^{-2} s^{-1} By 3rd day the g_s in treated plants increased to 300 mmol m^{-2} s^{-1} reaching a maximum on 9th day. There is drastic decrease in stomatal conductance values from 1100 hours to 1300 hours and thereafter there is increase upto 1400 hours and again decrease. The stomatal conductance is minimised during 1230 hours so that partial stomatal closure is achieved.

4.4. *Transpiration*

Flooding stress improved the transpiration rates of plants both in the morning and afternoon. There was a decrease at 1300 hours. A morning peak at 1100 hours favoured a transpiration rate of 12 mmol m^{-2} s^{-1}, whereas at 1400 hours it was 14.5 mmol m^{-2} s^{-1} on 9th day. (Fig. 36). When the flooding stress was released on 11th day and from the measurements taken on 12 th day it can be seen that, the transpiration rate increases to 18.4 mmol m^{-2} s^{-1}. The process continues till 1000 hours and thereafter transpiration rate decreases to 4 mmol m^{-2} s^{-1}. In general flooding stress induces a higher rate of transpiration than control plants during the whole period.

4.5. *Water use efficiency* (WUE)

During the experimental period flooding stressed plants showed comparatively better water use efficiency than control plants (Fig. 37). The WUE ranged between 0.2 and 1.8. It was also noticed that during 1200 hours the WUE is comparatively less. Nine day's of flooding stress reduced the WUE to 0.25 whereas recovery from flooding stress, increased the WUE measured on 12th day. In all cases morning and evening hours showed higher WUE.

Experiment V. Germination and seedling growth characteristics of four species of acacias.

1. Growth

Seedlings of *A. auriculiformis*, *A. aulacocarpa*, *A. holocerecea* and *A. mangium* were germinated following standard techniques. The seeds were given 30 seconds hot water (80°C) treatment, followed by overnight soaking in cold water. The seeds were treated with a fungicide, Emisan (0.5%) before sowing to prevent damping-off of seedlings. The seedlings were observed for the development of phyllodes in the early stages. Measurements on increase in height growth under natural conditions were measured without any treatment for about nine months for all species (Fig. 38).

1. *A.auriculiformis* A.Cunn ex. Benth

Samples of seeds taken and weighed show that the number of seeds per kilogram comes to around 38333 seeds kg^{-1}. 75-80% of seeds were found to germinate within 3 to 4 days. The radicle comes out first and grows down the soil forming root. Two thick cotyledons along with the seed coat bends upwards and stands erect. A distinct collar like portion has been observed at the junction of the root and shoot. The upper side of the cotyledon is green in colour while that of the lower side is slightly violet. Newly germinated seedlings have once pinnate compound leaves which are succeeded by twice pinnate, partially phyllodinous with pinnate leaves on the tip and pure phyllodes. The first once pinnate leaf has 4 pinnules and the second leaf has 8 pinnules. The 3rd leaf emerges within 17 days after germination and has a small phyllode attached to a bipinnate leaf. The 5th leaf emerges out as a full phyllode. Within one month after germination, the seedlings may have a shoot length of 15 cm and a root length of 11 cm. About 8-9 leaves are present at this time. The pinnate leaves do not persist for a long time in *A.auriculiformis*. The potted seedlings grow to a height of 29.5 cm with 14 leaves by 147 days. It becomes 45.2 cm with 33 leaves by 183 days and 83 cm with 95 phyllodes by 259 days. A total height of 121 cm was achieved in a period of 292 days (Fig. 38 and Table 4).

Table 3. Number of seeds per kilogram in different species

Species	*A.auriculiformis*	*A.aulacocarpa*	*A.holocericea*	*A.mangium*
No of Seeds	38,333	54,000	91,000	100,000

2. *A.aulacocarpa* A.Cunn ex Benth.

The number of seeds per kg was found to be about 54,000. The seeds were pretreated with hot water (80°C) for 30 seconds and kept overnight in cold water. The seeds were sown in soil. The seedlings showed two types of leaves in the early stages, pinnately compound leaves and later phyllodes. Two month old seedlings at the time of potting to polythene bags showed an average shoot length of 13.4 cm and a root length of 11.7 cm. The average number of leaves were found to be 6.2. The seedlings were observed for shoot length and number of leaves after 147, 183 and 259 days. The seedling height was found to be 32.4, 45.4 and 77 cm with phyllode numbers 18, 34 and 90 for the corresponding days (Table 4).

3. *A.holocericea* A.Cunn ex G.Don.

One kg of seed sample contains about 91,000 seeds. The seeds germinate by 3rd day onwards. 30 seconds hot water treatment followed by overnight soaking in cold water was found to be adequate for getting a good percentage of germination. 0.5% Emisan was applied to the seeds before sowing to prevent damping-off of the seedlings in the early stages of growth. The seedlings had a shoot length of 6.5 cm by one month and a root length of 6.6 cm and an average of 6 leaves. The pinnately compound leaves were found to persist for about one month. An average of 3.6 pinnate leaves with phyllodes persisted for about 3 months. By 147 days the height of shoots were found to be 40.7 cm with an average of 7.5 fully developed phyllodes. By 183 days, the pinnate leaves were absent and an average of 16 phyllodes were present per plant. Shoot height was 50.1, 66.7 and 94.3 cm on 147th, 183rd and 259th day respectively (Table 4).

4. *A.mangium* Willd.

The number of seeds per kg was found to be 1,00000 ± 3000. The seedlings germinated within 7 days followed by a pretreatment of the seeds with 30 seconds hot water (80 °C) and overnight soaking in cold water. The radicle emerged first followed by the cotyledons. The first leaves were once pinnate having 4 pinnules and 2nd leaf was twice pinnate (ie 2 branched). The time for initiation of the development of phyllode was found to be delayed. It took more than 40 days to develop a half pinnate leafy phyllode. The first fully pinnate leaf was formed after a period of 20 days of sowing. The pinnate leaves and half pinnate leaves persisted for a long time (about 5 months) in *A. mangium*. After a period of 147 days, the shoot length was 24.6 cm. The average number of fully pinnate leaves were 4.4, pinnate leaves with partial phyllodinous nature were 2.0 and true phyllodes were 7.7. By 183 days the fully pinnate leaf number was reduced to 1.7. The true phyllode number was 7.1. The plants grew to 32, 52 and 65 cms by the completion of 183, 259 and 292 days.

Experiment VI. Water relations of four *Acacia* species to different stress conditions

In order to comapare the response of 4 different species of phyllodinous acacias, seedlings were raised in the campus nursery. Responses of the seedlings of uniform age to different stresses were measured during 0930 hours to 1230 hours. 12 month old seedlings were given five treatments each with 6 replications. Predawn and midday Ψ, variations in net photosynthesis, stomatal conductance and transpiration were measured. The treatments include:

1. Control (with normal watering)
2. Water stress (water was withheld)
3. Salinity stress (100 mol m^{-3} NaCl)
4. Flooding stress (by keeping the polypotted seedlings in big earthenware pots filled with water.)

1. Water Potential (Ψ)

Predawn and midday Ψ of the seedlings of four species of *Acacia* kept under different stress conditions were measured on 0, 7, 9 and 12th day's after treatment.

1.1. *A.auriculiformis*

The control plants of *Acacia auriculiformis* showed a predawn Ψ of -0.08 MPa and midday Ψ of -0.90 MPa. After 7 days, the drought stressed plants showed a predawn Ψ of -1.46 MPa and midday Ψ of -2.38 MPa. After 9 days the predawn Ψ was -2.02 MPa and midday Ψ was -2.64 MPa. By 12th day the predawn Ψ further declined to -2.32 MPa and the midday Ψ to -3.10 MPa (Table.6). Both predawn and midday Ψ decreased in the case of drought stress.

The salt treated (100 mol m^{-3}) plants showed a predawn Ψ of -0.18 MPa and midday Ψ of -0.7 MPa on 7th day. On 9th day predawn Ψ was -1.2 MPa and midday water potential was 1.4 MPa. On 12th day, the predawn Ψ was -2.0 MPa and midday Ψ was -1.60 MPa. Salinity stress also showed decrease in Ψ as salinity stress progressed, but to a lesser extent.

The flooded plants showed a predawn Ψ of -0.08 MPa after 9 days along with a midday Ψ of -0.70 MPa. The predawn Ψ after 12 days was -0.16 MPa and midday Ψ was -0.9 MPa.

1.2. *A.aulacocarpa*

The control plants showed a predawn Ψ of -0.3 MPa and midday Ψ of -0.48 MPa. After 7 days, the drought stressed plants showed a predawn Ψ of -0.19 MPa and midday water potential of -2.2 MPa. After 9 days the predawn Ψ declined to -2.1 MPa and midday Ψ was -2.5 MPa. By 12th day the predawn Ψ further declined to -2.3 MPa and the midday Ψ to -3.2 MPa (Table 5)

The salinity stressed (100 mol m^{-3}) plants showed a predawn Ψ of -0.22 MPa and midday Ψ of -0.68 MPa on 9th day. It was -0.3 MPa and -1.02 MPa on 12th day.

The water-logged plants showed a predawn water potential of -0.08 MPa on 9th day along with a midday water potential of -0.4 MPa. It was -0.12 MPa -0.70 MPa respectively on 12th day.

1.3. *A.holocerecea*

Control plants showed a predawn Ψ of -0.20 MPa and a midday Ψ of -1.1 MPa. By 9th day the drought stressed plants showed a predawn Ψ of -0.12 MPa

Table.5. Water potential (Ψ) measurements for various stress treatments for various days in 4 species of acacias.

Treatment	Species	Days	Predawn Ψ (MPa)	Midday Ψ (MPa)
Control	*A.auriculiformis*	0	-0.18	-0.90
	A.aulacocarpa	0	-0.30	-0.48
	A.holocericea	0	-0.20	-1.10
	A.mangium	0	-0.08	-0.50
Drought	*A.auriculiformis*	7	-1.46	-2.38
	A.auriculiformis	9	-2.02	-2.64
	A.auriculiformis	12	-2.32	-3.10
	A.aulacocarpa	9	-2.10	-2.50
	A.aulacocarpa	12	-2.30	-3.20
	A.holocericea	9	-0.12	-2.10
	A.holocericea	12	-1.80	-2.70
	A.mangium	7	-1.10	-2.04
	A.mangium	9	-1.40	-2.10
Salinity100	*A.auriculiformis*	7	-0.18	-0.70
	A.auriculiformis	9	-1.2	-2.0
	A.auriculiformis	12	-1.2	-1.60
	A.aulacocarpa	9	-0.22	-0.68
	A.aulacocarpa	12	-0.3	-1.02
	A.holocericea	9	-0.24	-0.90
	A.holocericea	12	-0.30	-1.00
	A.mangium	9	-0.35	-1.20
	A.mangium	12	-0.40	-1.50
Flooding	*A.auriculiformis*	9	-0.08	-0.70
	A.auriculiformis	12	-0.16	-0.90
	A.aulacocarpa	9	-0.08	-0.40
	A.aulacocarpa	12	-0.12	-0.70
	A.holocericea	9	-0.06	-0.40
	A.holocericea	12	-0.24	-0.70
	A.mangium	9	-0.04	-0.42
	A.mangium	12	-0.10	-0.62

and a midday Ψ of -2.10 MPa. It was -1.8 MPa and -2.7 MPa respectively on 12th day (Table 5).

The salt treated plants (100 mol m^{-3}) showed a predawn Ψ of -0.24 MPa with a midday Ψ of -0.90 MPa on 9th day. It was -0.3 MPa and -1.0 MPa respectively on 12th day.

The flooded plants showed a predawn Ψ of -0.06 MPa along with a midday Ψ of -0.4 MPa on 9th day. It was -0.24 MPa -0.7 MPa respectively on 12th day.

1.4. *A.mangium*

The control plants had a predawn Ψ of -0.08 MPa and midday Ψ of -0.50 MPa. The drought stressed plants showed a predawn Ψ of -1.1 MPa and midday Ψ of -2.04 MPa after 7 days. It was -1.4 MPa and -2.1 MPa respectively on 12th day (Table 5).

The salt treated plants (100 mol m^{-3}) showed a predawn Ψ of -0.38 MPa and midday Ψ of -1.12 MPa after 9 days. It was -0.4 MPa and -1.5 MPa respectively after 12 days.

The flooded plants showed a predawn Ψ of -0.04 MPa after 9 days along with a midday Ψ of -0.42 MPa. It was -0.1 MPa and -0.62 MPa respectively after 12 days.

2. Net Photosynthesis (P_n)

The net photosynthesis measured on various days followed by different stress conditions during 0900 to 1230 hours in different species are given below.

2.1. *A.auriculiformis*

The net photosynthesis in control plants varied between 7 and 15 μmol m^{-2} s^{-1} during 20 days of experiment (Fig. 39). In drought stressed plants photosynthesis decreased from 10 to 5 μmol m^{-2} s^{-1} by 2nd day. By 10th day it was 2.9 μmol m^{-2} s^{-1} and thereafter showed a lower photosynthetic rate.

The flooded plants did not show much increase in photosynthetic rate when compared to control. The photosynthetic rate was ranging between 7-10 μmol m^{-2} s^{-1} throughout the period.

The salinity stressed (100 mol m^{-3}) plants showed slight increase in photosynthesis having an approximate rate of 10 to 12 μmol m^{-2} s^{-1} for 5 to 10 days of salinity stress. There was not much variation in photosynthesis during the experimental period.

2.2. *A.aulacocarpa*

When compared to other species, the normally watered plants of *A.aulacocarpa* showed a lesser photosynthetic rate of 7 μmol m^{-2} s^{-1} (Fig. 40). The drought stressed plants drastically reduced their photosynthetic rate from 2nd day onwards (4 μmol m^{-2} s^{-1}) and maintained a low rate of less than 2 μmol m^{-2} s^{-1} after five days of drought.

Salinity (100 mol m^{-3}) favoured photosynthesis in *A.aulacocarpa*, in which an initial photosynthetic rate of 7 μmol m^{-2} s^{-1} was increased to 9 μmol m^{-2} s^{-1} by 5th day onwards and again to 11.6 μmol m^{-2} s^{-1} by 12th day.

In the case of flooding, for the first ten days there was an increase in photosynthetic rate to 11.0 μmol m^{-2} s^{-1} when compared to control. But after 10 days, the photosynthetic rate decreased to 6.0 to 8.0 μmol m^{-2} s^{-1} and continued upto 21 days. This indicates that photosynthetic rate in *A.aulacocarpa* increases for a short period when the plants are subjected to flooding stress.

2.3. *A.holocericea*

A.holocericea is found to have very high photosynthetic rate when compared to other species. The control plants showed a photosynthetic rate of 17 to 18 μmol m^{-2} s^{-1} during the experiment (Fig. 41).

Drought seriously affected the plants as they showed very little photosynthetic rate (1.75 μmol m^{-2} s^{-1}) from 5th day onwards.

Flooding also was not much harmful to *A.holocericea*, but the plants showed slight decrease in photosynthetic rate when compared to control as flooding time has been increased. The photosynthetic rate decreased from 17 to 15 μmol m^{-2} s^{-1} by 5th day and maintained a level of 10 μmol m^{-2} s^{-1} from 13th day onwards. The salt stressed (100 m mol) plants behaved favourably showing a net photosynthetic rate ranging between 12 and 17.5 μmol m^{-2} s^{-1}

2.4. *A.mangium*

The photosynthetic rate of seedlings under normal watering varied between 4.2-10.2 μmol m^{-2} s^{-1}during a period of 21 days (Fig.42)

The drought stressed plants reduced their photosynthetic rate to 2.7 μmol m^{-2} s^{-1} by 5th day and to almost zero by 13th day. It can be seen that the photsynthetic mechanism fails to function properly after 12 days of water stress in *A.mangium*.

The flooding stressed plants also showed a decrease in photosynthetic rate from 10 to 2.0 μmol m^{-2} s^{-1} by 13th day and after that the plants maintained a low level of photsynthetic rate.

Salt stressed (100 mol m^{-3}) plants were benefitted by an increase in photosynthetic rate from 8 to 13.4 μmol m^{-2} s^{-1} for first 10 days but afterwards decreased to low photosynthetic rate of 2.5 μmol m^{-2} s^{-1}by 21st day.

3. **Stomatal conductance** (g_s)

Stomatal conductance measured on the phyllodes using an infrared gas analyser during 0900 to 1230 hours on four species of acacias are given below.

3.1. *A.auriculiformis*

The stomatal conductance of control plants ranged between 155 and 491 mmol m^{-2} s^{-1} during a period of 20 days. An average of 200 mmol m^{-2} s^{-1} was prevailing during the time of measurement (Fig. 43).

In drought stressed plants the g_s values decreased from 155 to 40 mmol m^{-2} s^{-1} by second day itself. By 10th day it became 28 mmol m^{-2} s^{-1} and showed further decrease later.

Flooded plants showed gradual increase in their stomatal conductacne followed by an increase in flooding stress. Their g_s increased to 362 mmol m^{-2} s^{-1} by 20th day.

Salinity treatment (100 mol m^{-3}) also favoured similar g_s values to that of control. The g_s values increased to 224 mmol m^{-2} s^{-1} by 2nd day and to 241 mmol m^{-2} s^{-} by 10th day. But by 21st day it decreased to 144 mmol m^{-2} s^{-1}.

3.2. *A.aulacocarpa*.

The stomatal conductance in control plants of *A. aulacocarpa* was comparatively low when compared to other species. The conductance values were between 65 and 116 mmol m^{-2} s^{-1} during the experimental period (Fig. 44). The drought stressed plants had still lesser values ranging between 7 and 43 mmol m^{-2} s^{-1} By 2nd day onwards the values began to decrease. Flooding stress was favorable in increasing g_s values from 110 to 275 mmol m^{-2} s^{-1} by 5th day. But after 10 days the g_s values showed slight decrease. Salinity stress (100 mol m^{-3}) also increased the g_s values to 261 mmol m^{-2} s^{-1} by 16th day.

3.3. *A.holocerecea*

Out of the four species studied, *A.holocericea* showed comparatively higher values of stomatal conductance. The g_s values in control plants showed a maximum of 621 mmol m^{-2} s^{-1} during a period of 21 days (Fig. 45). The drought stressed plants drastically reduced their g_s to 30 mmol m^{-2} s^{-1} by 5th day and thereafter maintained very low conductance. The flooding stress did not did not drastically reduce the g_s which varied between 218 and 400 mmol m^{-2} s^{-1}. S alinity stressed (100 mol m^{-3}) plants showed an increase in g_s from 5th day onwards showing 400 to 500 mmol m^{-2} s^{-1}. By 10th day, the stomatal conductance increased again to 651 mmol m^{-2} s^{-1} but after that gradually decreased to 378 mmol m^{-2} s^{-1}, by 21st day.

3.4. *A.mangium*

In *A.mangium* stomatal conductance during peak hours ranged between 173 and 310 mmol m^{-2} s^{-1} in normally watered plants. Drought stressed plants reduced their g_s to 50 mmol m^{-2} s^{-1} by second day, which again decreased to 13 mmol m^{-2} s^{-1} by 15th day and to 9 mmol m^{-2} s^{-1} by 21st day (Fig 46). Flooding had little effect on g_s where the g_s varied between 200 and 300 mmol m^{-2} s^{-1} for 10 days. After that there was a reduction in g_s to 100 mmol m^{-2} s^{-1}. The salt treatment (100 mol m^{-3}) favoured to maintain comparatively higher g_s values with a maximum of 550 mmol m^{-2} s^{-1} upto ten days. By 12th day the plants showed lower g_s reaching down to 300 mmol m^{-2} s^{-1} and thereafter gradually decreased to 180 mmol m^{-2} s^{-1}

4. Transpiration

Transpiration values were calculated for peak hours starting from 0930 hours to 1230 hours for all species.

4.1. *A.auriculiformis*:

The transpiration rate of control plants, measured during peak hours ranged between 7.8 and 13.2 mmol m^{-2} s^{-1}. In the case of water stressed plants, the phyllodes suddenly reduced transpiration to 3.6 mmol m^{-2} s^{-1} by second day and still less as the stress progressed. But the plants maintained a low transpiration rate of 1.2 mmol m^{-2} s^{-1} after 12 days of drought (Fig. 47). The flooded plants had higher transpiration rates as the days proceeded. The rate of transpiration increased to 14.1 mmol m^{-2} s^{-1} by 20th day. This increase was noticed after 10 days of flooding stress. Salinity stressed (100 mol m^{-3}) plants maintained a transpiration rate of 7 to 11 mmol m^{-2} s^{-1} during the experimental period.

4.2. *A.aulacocarpa*:

Compared to other species of acacias, the control plants of *A.aulacocarpa* showed lower rate of transpiration ranging between 2.6 and 6.4 mmol m^{-2} s^{-1} (Fig.48). The drought stressed plants drastically reduced their transpiration to 1.9 mmol m^{-2} s^{-1} from 2nd day onwards and to almost zero by 13th day. Flooding was favorable to *A.aulacocarpa* as the plants increased their transpiration rate to 12 mmol m^{-2} s^{-1} by 21 days of flooding stress. Salinity treatment (100 mol m^{-3}) showed an increase in transpiration rate after 10 days. Between 10 and 16 days the transpiration rate was nearly 11.0 mmol m^{-2} s^{-1} which then decreased to 8 mmol m^{-2} s^{-1} by 21st day.

4.3. *A.holocericea*.

Acacia holocericea plants kept under normal watering regime showed comparatively higher rates of transpiration than other species. A usual rate of 13 to 21 mmol m^{-2} s^{-1} was observed during the experimental period. But the drought stressed plants reduced their transpiration rate to 1.8 mmol m^{-2} s^{-1} by 5th day and maintained this low rate of transpiration upto to 21st day (Fig. 49). Flooding did not increase transpiration more than control plants, but slightly reduced it after 12 days. The transpiration values ranged between 9 and 14 mmol m^{-2} s^{-1}. The salt treatment (100 mol m^{-3}) maintained high transpirat ion rates of 18-20 μmol m^{-2} s^{-1} as in control plants.

4.4. *A.mangium*:

The control plants showed transpiration values varying between 10.3 and 15.6 mmol m^{-2} s^{-1} (Fig. 50). The drought stress reduced transpiration to 3.5 mmol m^{-2} s^{-1} by 2nd day and by 16th day to near zero (0.63 mmol m^{-2} s^{-1}). Flooded plants maintained a transpirational rate of 8-12 mmol m^{-2} s^{-1} throughout the experimental period. Salt stress also favored transpiration by keeping transpiration at a higher rate between 9.6 and 16.4 mmol m^{-2} s^{-1}.

5 **Water use efficiency (WUE)**

Instantaneous water use efficiency calculated from the measurements of net photosynthesis and transpiration is given below.

5.1. *A.auriculiformis*:

WUE of control plants ranged between 0.6 and 1.2 whereas drought stressed plants improved their WUE to 1.7 by 5th day and was not steady thereafter (Fig.51) Flooded plants showed a decrease in the WUE where an initial WUE of 1.0 was seen reduced to 0.6. Salinity stress (100 mol m^{-3})

improved WUE up to 1.5, but with the advancement of salinity stress slight decrease in WUE was noticed.

5.2. *A. aulacocarpa*

Control plants maintained a WUE within the range of 1 and 1.4, whereas drought stressed plants increased WUE to 2.7 by 12th day and then decreased to 1.4 (Fig. 52). In *A.aulacocarpa* also flooding stress did not improve WUE. The values declined from 1.3 to 0.6. Salinity stress (100 mol m^{-3}) showed an initial increase in WUE (1.8) followed by a decrease (1.0).

5.3. *A. holocericea*:

The WUE in control plants showed values ranging between 0.7 and 1.0. Drought stressed plants showed an increase up to 1.5 by 10th day and then gradually decreased (Fig. 53). Flooding and salinity stress did not improve WUE in *A.holocericea*.

5.4. *A. mangium*

The WUE of control plants was between 0.5 and 1.2 (Fig. 54). Drought stress decreased WUE to 0.2 by 2nd day itself and by 13th day to zero. Flooding showed decrease in WUE after 12 days. Salinity stress maintained the same level of WUE noticed in control plants.

Expt VII. Water relations, growth and gas exchange of seedlings of *Acacia auriculiformis* under different water stress cycles.

Ten month old seedlings of *A.auriculiformis* were subjected to water stress by witholding water for 2, 4, 6, 8, 10, 12, 16 and 20 days starting from 8th Jan

1996. The plants were watered at the end of above periods and droughted again for a similar period. The whole experiment was maintained upto 15th March 1996. Measurements of height, phyllode number, breadth, length and leaf area were taken at different intervals. Each treatment was replicated with 6 seedlings kept in polythene bags (20x30 cm) filled with similar type of soil.

1. **Growth**

Measurements of various parameters including shoot length, number of phyllodes, length and breadth of phyllodes, leaf area, collar diameter at 5 cm above ground level were taken followed by the starting of the experiment on 8th January 1996 and ending on 15 March 1996.

1.1. *Height*

The control plants which received normal watering in the morning and evening grew from 72.33 to 106.33 cm during a period of 66 days. The percentage increase in height over initial height was found to be 47% (Fig. 55). Two day's stress followed by one day of watering, plants having 97 cm height grew to 119 cm indicating 22.6% over initial height. Plants watered on every 5th day after the completion of 4 days stress cycle, grew from 99.6 cm to 115.8 cm over a period of 66 days. This was 16.22% over the initial height. Plants watered after 6 days interval of stress had an initial height of 89.16 cm and a final height of 101 cm. representing 13.27 % increase during the period of study. 8 days water stress interval showed increase in height from 79 to 89.3 cm amounting to 13% increase over initial height. Plants grown at 12 days interval of water stress had an initial height of 93.16 and a final height of 98.8 cm. The percentage increase was only 6.1%. 20 days cycle of stress showed increase in height only for about 20 days, from 90.3 to 92 cm. The plants showed wilting and shedding of their phyllodes by that time (Table. 6).

1.2 *Number of Phyllodes*

The number of phylldoes in control plants showed an increase from 42 to 57 during a period of 54 days (Fig. 56). Two day-stress cycle also showed an increase in number of phyllodes from 49 to 55. But 4, 6, 8, 12 and 16 days cycles of stress showed a decrease in the number of phyllodes. The decrease was severe after the completion of 23 days in 2 day cyclically stressed plants and from 10th

Table.6. Increase in height growth in *Acacia auriculiformis* under different drought stress cycles

Day	Drought stress cycles /Height (cm)							
	0	2	4	6	8	12	16	20
0	72.3	97.3	99.7	89.2	79.0	93.2	62.5	90.3
7	79.2	100.8	103.3	92.0	81.5	95.3	66.8	91.8
15	80.7	103.3	104.2	93.3	82.1	95.5	67.5	92.0
23	83.8	105.5	105.2	95.6	83.8	96.3	67.8	92.5
30	87.7	107.2	108.2	96.6	84.3	96.9	67.8	92.7
39	92.5	109.5	107.6	97.3	85.0	98.3	68.1	93.5
51	95.5	113.0	111.6	99.2	86.8	98.8	69.2	93.5
57	98.8	115.4	115.3	100.3	89.0	98.9	69.2	93.5
66	106.3	119.0	115.8	101.0	89.3	98.9	69.2	93.5
%	45.6	22.3	16.1	13.2	13.0	6.1	10.7	3.5

day onwards in other treatments. Plants watered at 20 day's interval became leafless by 54th day (Table 7).

1.3. *Leaf dimensions*

The length and breadth of phyllodes were found to be almost same in the control plants with a slight decrease during the experimental period (Fig. 57). The plants exposed to 6 days or more stress interval showed comparatively more decrease in phyllode length and breadth. There was decrease in leaf area in the stressed plants which experienced 8, 12, 16 and 20 day's stress cycles. The control plants showed 34.2% increase in leaf area, whereas an interval of 2 day's drought stress for a period of 39 day's showed a decrease of 12% over initial leaf area. For 4 days stress interval, the decrease was 40.2, for 8 day's it was 59.9% and for 16 day's it was 71.7%. For 20 day's cycle the percentage reduction in leaf area by 39 days itself was 82.5 % which by 51st day became 100%.

Table.7. Variations in phyllode number in *Acacia auriculiformis* under different drought stress cycles

Day	Drought stress cycles / Phyllode number							
	0	2	4	6	8	12	16	20
0	42	49	51	47	42	47	36	38
7	46	61	43	42	40	57	36	42
15	50	62	32	35	35	48	31	42
23	52	53	27	28	21	32	21	28
30	52	56	26	36	23	31	18	14
39	57	55	26	36	22	31	18	0
%	35.7	13.3	-49.0	-23.0	-47.6	-34.0	-50.0	-100

Table 8. Variations in phyllode length in *A. auriculiformis* under different drought stress cycles

Day	Drought stress cycles / Phyllode length							
	0	2	4	6	8	12	16	20
0	17.0	17.7	17.5	20.0	17.8	14.7	17.8	19.7
7	18.1	14.5	16.5	17.8	14.6	15.2	16.5	17.8
15	15.6	14.4	16.0	16.3	15.6	13.6	16.9	17.8
23	15.8	14.1	17.1	15.8	14.4	15.1	16.1	15.3
30	16.1	14.3	16.8	14.8	16.2	15.5	15.0	15.8
39	14.5	14.4	18.1	15.9	12.5	11.6	12.1	0
%	14.7	-18.6	-3.4	-20.5	-29.7	-21.1	-32.0	-100

Table.9. Variations in phyllode breadth in *A.auriculiformis* under different drought stress cycles

Day	Drought stress cycles / Phyllode length							
	0	2	4	6	8	12	16	20
0	1.90	3.00	3.20	2.70	2.70	2.30	2.70	3.20
7	2.30	3.50	3.10	2.80	2.80	2.30	2.50	2.40
15	2.50	2.60	3.00	3.10	2.60	2.30	2.30	1.90
23	2.30	2.80	3.30	2.80	2.50	2.50	2.80	1.80
30	2.30	2.60	3.10	2.90	2.80	2.30	2.30	1.60
39	2.40	2.30	3.60	3.10	2.20	2.20	1.80	0
%	24.4	-30.4	9.4	14.8	-18.5	-4.3	-33.3	-43.7

1.4. Collar diameter

The increase in collar diameter of potted seedlings measured at a height of 5 cm above the soil was 21.4% in control plants. It was 7.54, 14.74, 12.5, 19.4, 15.93, 0.51 and 0 per cent, in 2, 4, 6, 8, 12, 16 and 20 days of drought cycles respectively over a period of 51 days.

Table 10. *A.auriculiformis* seedlings variation in collar diameter (mm) under various drought stress cycles.

	Drought stress cycle (days)							
Date of observation	0	2	4	6	8	12	16	20
15	6.45	7.0	6.58	6.16	5.45	5.96	5.80	6.8
51	7.83	7.53	7.55	6.93	6.51	6.91	5.83	
%	21.4	7.6	14.7	12.5	19.4	15.9	0.51	

2. *Water potential* (Ψ)

Water potential measurements were taken in plants on the completion of two stress cycles. Control plants showed a predawn Ψ of -0.32 MPa and a midday Ψ of -1.10 MPa (Table 11). Two days water stress cycle reduced the predawn Ψ to -0.48 MPa and midday Ψ to -1.50 MPa. In 4 day stress interval the predawn Ψ was -0.38 MPa and midday Ψ -1.4 MPa. Six days stress cycle showed a predawn Ψ of -1.1 MPa and the midday Ψ of -2.50 MPa. Eight day stress cycle decreased the values to -2.02 and -2.92 MPa respectively. 12 days stress cycle showed still lower values of predawn Ψ showing -2.32 MPa and midday Ψ -4.0 MPa. 16 day stress cycle interval still decreased the predawn Ψ to -2.54 and midday Ψ to $<$ -4.0 MPa.

3. *Photosynthesis (P_n)*

Measurements were taken in plants after the completion of 2 stress cycles in each treatment. In the well-watered plants net photosynthesis ranged between 9 and 14 μmol m^{-2} s^{-1} in the morning and showed gradual decrease towards evening (Fig. 58). In 2 and 4 day's drought cycles, photosynthesis was low, with values ranging between 3 and 9 μmol m^{-2} s^{-1} showing gradual decrease after 1400 hours. 8 day's drought stress cycle indicated extremely low values showing a photosynthesis of 0.2 to 2.0 μmol m^{-2} s^{-1}.

4. *Stomatal conductance (g_s)*

Stomatal conductance in the control plants varied between 300-400 mmol m^{-2} s^{-1} in the morning which decreased towards 200 mmol m^{-2} s^{-1} in the evening (Fig. 59). Two day's repeatedly drought stressed plants showed lesser values for g_s viz. 100-400 mmol m^{-2} s^{-1} in the morning up to 1200 hours and below 100 mmol m^{-2} s^{-1} in the evening. Four days stress cycle showed almost steady g_s values in the morning and evening and was in between 200 and 300 mmol m^{-2} s^{-1}. 8 days drought cycle also showed steady values but remained below 50 mmol m^{-2} s^{-1} throughout the day.

5. *Transpiration*

The transpiration rate was found to increase with time, up to 1200 hours and afterwards slowly declined. (Fig. 60). A maximum transpiration rate of 16 mmol m^{-2} s^{-1} observed at 1100 hours in control plants. Two-day stress cycle showed lower values ranging between 4 and 7 mmol m^{-2} s^{-1}, but 4 day's stress cycle showed very low transpiration rate which was < 2 mmol m^{-2} s^{-1} 8 days

Table.11. Water potential (Ψ) measurements for various drought stress cycles for *Acacia auriculiformis* and *Acacia mangium*

Species	No of drought stress days	Predawn Ψ (MPa)	Midday Ψ (MPa)
A.auriculiformis	0	-0.32	-1.10
	2	-0.48	-1.50
	4	-0.38	-1.40
	6	-1.10	-2.50
	8	-2.02	-2.92
	12	-2.32	-4.00
	16	-2.54	-<4.00
A.mangium	0	-0.13	-0.54
	2	-0.20	-1.40
	4	-0.42	-1.47
	6	-1.00	-1.73
	8	-1.23	-1.95
	12	-1.46	-2.10
	16	-1.46	-2.20

stress cycle showed higher values but below that of control. It appears that depending upon the availability of water, drought stress adjustment in transpiration exists in *A.auriculiformis*. VPD has deciding effects on transpiration. The well watered plants showed increase in transpiration with increase in VPD.

6. *Water Use Efficiency* (WUE)

WUE of all plants decreased towards evening in all treatmens (Fig. 61) The wue of control plants were btween 0.5 to 1.5. 2 and 8 day stress cycles showed slightly higher WUE after 1200 hours while in 4 day stress interval it was near 0.6. Maximum water use efficiency was found to occur at a VPD of 2.0 - 2.5 kPa particularly in stressed plants.

7. *Internal CO_2*

The internal CO_2, measured along with other parameters using the IRGA indicate almost steady values ranging between 250 and 300 μmol m^{-2} s^{-1} throughout the day but slowly decreased towards evening. Increase in VPD also favored decrease in internal CO_2.

Expt VIII. Water relations and growth response of *Acacia mangium* to various water stress cycles

Four month old seedlings of *A.mangium* were subjected to 0, 2, 4, 6, 8, 10, 12, 16 and 20 days of drought stress interval. Each set of treatment contained 6 seedlings. Measurement of various parameters including shoot length, number of phyllodes, length and breadth of phyllodes were taken, followed by the starting of the experiment on 8th January to 15th March 1996.

1. Growth

The normally watered plants grew from 21.8 cm to 42.0 cm over a period of 66 days. The percentage increase was about 92.66 % over the initial height (Fig.62). In 2 day's stress cycle followed by one day watering, showed an increase from 20.6 cm to 30.8 cm, amounting to 49.5%. There was not much difference between 4 days stress which also showed an increase of 52.1%. But 6 days drought alternatively repeated with one day's watering showed an increase in height from 22.6 cm to 32.7 cm amounting to 44.5%. 8 days drought cycle produced an increase of 6 cm only amounting to 26.38%. 12 days stress has deleterious effects and it showed a meagre increase of 2 cm amounting to 6.5 % over initial height. 20 days repeated drought stress also gave only an increase of 3 cm which also stopped by 39 days and there after dried (Table 12).

Table.12. Increase in height growth in *Acacia mangium* under different drought stress cycles

Day	Drought stress cycles /Height (cm)							
	0	2	4	6	8	12	16	20
0	21.8	20.6	24.1	22.6	23.5	29.1	29.5	28.0
10	24.3	20.8	24.7	24.1	24.1	30.2	30.5	29.0
15	25.3	22.6	26.8	24.7	24.7	30.2	31.8	30.8
23	27.7	22.8	28.0	24.8	26.0	30.3	32.0	31.5
30	28.8	24.3	28.8	26.7	26.4	30.7	31.7	32.8
39	31.5	26.1	29.8	26.8	27.9	30.8	31.7	31.1
51	36.5	27.5	30.8	26.8	29.2	30.0	31.2	31.8
57	38.3	28.2	33.3	29.1	29.6	30.0	32.2	31.4
66	42.0	30.8	36.7	32.7	29.7	31.0	32.5	20.0
%	92.66	49.5	52.1	49.5	26.38	6.52	10.16	12.14

1.1. *Phyllode dimensions*

Treated seedlings of *A.mangium* showed difference in phyllode number, size and phyllode area. All the plants, by the completion of 66 days showed reduction in phyllode size, including length and breadth compared to control. In general reduction in length varied between 8 and 25% and breadth between 4 and 40%. The reduction was prominent in treatments of 6, 8, 12, 16 and 20 days of stress followed by one day watering. 6 days drought stress reduced the phyllode length from 16 to 13 cm causing about 18.12% reduction. The breadth of phyllodes was reduced from 5.91 to 4.0 cm amounting to 32.3% in six day stressed plants. Plants which experienced 12, 16 and 20 days of drought stress showed yellowing of phyllodes followed by shedding of leaves. Drying was prevalent by 39th day in 12, 16 and 20 days of stressed plants.

Table 13. *A.mangium* variations in phyllode (a) length, (b) breadth and (c) number

	Drying cycles (days)							
Day stressed	0	2	4	6	8	12	16	20
(a) Length								
0	18.5	17.8	16.8	16.0	18.5	18.6	17.5	18.0
66	16.5	13.2	14.2	13.1	14.0	17.0	14.0	16.5
% reduction	11.8	25.8	15.5	18.1	24.3	8.60	20.0	8.33
(b) Breadth								
0	5.86	4.91	5.0	5.91	5.50	7.53	5.41	5.75
66	4.90	4.40	4.80	4.00	4.90	4.50	3.10	5.50
% reduction	16.4	10.4	4.0	32.3	10.9	34.9	42.6	4.34
(c) Number								
0	12.0	14.3	14.3	14.0	15.3	17.0	20.6	17.3
66	27.8	19.8	14.8	17.4	16.5	18.1	12.6	0
% increase	131	38.4	3.7	24.2	7.84	7.84	-40	-100

1.2 *Phyllode number*

The average number of phyllodes in control plants increased from 12 to 27.8 showing 131.66% increase over initial phyllode number. But in 2 days stresscycle plants, the increase was from 14.3 to 18.3 amounting to 27.97%. There was only slight increase in phyllode numbers in 4 and 6 day's stress cycles where it amounted to 13.6 and 3.57% respectively. The number of phyllodes in 12 and 16 days stress cycles, were reduced by 29.4 and 38.8% while in 20 days stressed plants the leaf number was reduced to zero.

1. **Water potential** (Ψ)

Control plants maintained a predawn Ψ of -0.13 MPa and a midday Ψ of -0.54 MPa. 2 days drought stress reduced the predawn Ψ to -0.20 MPa and midday Ψ to -1.40 MPa. 4 days stress showed -0.42 MPa and -1.47 MPa ~~respectively~~ respectively. 6 days stress reduced the values to -1.0 MPa and -1.73 MPa. 8 days stress decreased the predawn Ψ to -1.23 and midday *to* Ψ-1.95 MPa. 12 days stress showed a predawn Ψ value of -1.46 MPa and midday Ψ of -2.1 MPa. 16 days stress showed a predawn Ψ of -1.46 MPa and a midday Ψ -2.20 MPa (Table 4). It is interesting to note that the predawn Ψ did not decrease beyond -1.5 MPa and the midday Ψ beyond -2.2 MPa in *A.mangium* even after experiencing a drought cycle of 16 days. But in the case of *A.auriculiformis* the plants experienced a very low value of predawn Ψ of -2.5 MPa and a midday Ψ of $<$-4.0 MPa.

3. **Photosynthesis** (P_n)

Net photosynthesis was found to increase towards noon up to 1600 hrs in well watered plants (Fig.63). The maximum photosynthetic rate observed was 11

μmol m^{-2} s^{-1}. There was not much difference betwen control and 2 days stress cycled plants. In the latter photosynthesis decreased from 11 μmol m^{-2} s^{-1} at 1000 hours to 6 μmol m^{-2} s^{-1} at 1200 hours and to 4 μmol m^{-2} s^{-1} at 1600 hours. In 4 day stress cycled plants, photosynthetic rate was almost steady and was below 3 μmol m^{-2} s^{-1}. The other treatments did not give measurable values.

4. Stomatal conductance (g_s)

The g_s varied between 400-500 mmol m^{-2} s^{-1} in well watered plants and was almost steady up to 1400 hours which was gradually reduced to 250 mmol m^{-2} s^{-1} by 1600 hours (Fig. 64). But drought stressed plants showed drastic reduction in stomatal opening. In 2 day stressed plants g_s values were below 250 mmol m^{-2} s^{-1} at 900 hours which declined to 150 mmol m^{-2} s^{-1} by 1000 hours. It gradually declined to 400 mmol m^{-2} s^{-1} by 1600 hours. 4 and 8 day's stress intervals showed very low values in the morning, viz., less than 100 mmol m^{-2} s^{-1} and almost zero by 1600 hours. This clearly shows that good stomatal closure mechanism exists in *A.mangium*. As VPD increases g_s decreases, but to a lesser extend where soil water is not limiting.

5. Transpiration

The control plants showed increasing transpiration up to 1400 hours which decreased later in the day (Fig. 65). From a transpiration rate of 8 mmol m^{-2} s^{-1} at 1000 hours it reached 18 mmol m^{-2} s^{-1} by 1400 hours and decreased to 9 mmol m^{-2} s^{-1} by 1600 hours. In 2 days drought stressed plants transpiration increased from 4 mmol m^{-2} s^{-1} at 1000 hours to 12 mmol m^{-2} s^{-1} at 1500 hours and decreased to 6 mmol m^{-2} s^{-1} by 1600 hours. In 4 day's stress cycled plants, transpiration decreased from 6 mmol m^{-2} s^{-1} at 0900 hours to 3 mmol m^{-2} s^{-1} by 1000 hours and maintained a rate of 3.0 to 3.5 mmol m^{-2} s^{-1} Full stomatal closure was not observed.

6. Water Use Efficiency (WUE)

The WUE of control plants was between 0.5 - 0.7 whereas 2 day's drought stress cycled plants showed a WUE varying between 0.6 and 1.0. Four day's stress cycled plants also showed a WUE of 1.0 at 0900 hours which decreased by 1200 hours (Fig. 66).

Experiment IX. Physico-chemical studies in four species of *Acacia*

1. Chlorophyll content

The chlorophyll content was estimated using the method of Hendry & Price (1993). Leaf samples (4-6th leaf) from four species of *Acacia* kept under 4 different treatments were taken in the morning hours and Chlorophyll a, b, total chlorophyll and carotenoids were analyzed.

1.1. *Total chlorophyll content*

The total chlorophyll content in the control plants of *A.auriculiformis* were found to be near 1.1562 $\mu g\ g^{-1}$. It was 1.78, 1.69 and 1.43 $\mu g\ g^{-1}$ in the normally watered plants of *A.aulacocarpa, A.holocericea* and *A.mangium* repectively. The drought stressed plants of *A.aurculiformis* showed 1.2324 $\mu g\ g^{-1}$ of total chlorophyll while in *A.aulacocarpa* it was 1.78 $\mu g\ g^{-1}$ The drought stressed plants of *A.holocericea* showed 1.9012 and *A.mangium* 1.354 $\mu g\ g^{-1}$ of total chlorophyll content (Fig. 67 and Table 14). The salt treated plants, showed slightlly higher amount of total chlorophyll showing 1.854, 1.963, 1.84 and 1.284 $\mu g\ g^{-1}$ in the salinity stressed (100 mol m^{-3}) plants of *A.aulacocarpa,*

Table.14 Chlorophyl and proline content in the phyllodes of variously stressed seedlings of four species of *Acacia*

Treatment/ Species	Chl-a mg g^{-1}	Chl-b mg g^{-1}	Total Chl mg g^{-1}	Chl a/b ratio	Proline $\mu g\ g^{-1}$
Control					
A.auriculiformis	0.8152	0.3420	1.1562	2.38	24
A.aulacocarpa	1.1226	0.6590	1.7800	1.70	40
A.holocericea	1.1550	0.5401	1.6936	2.14	44
A.mangium	0.9854	0.4493	1.4334	2.19	32
Drought stress					
A.auriculiformis	0.8682	0.3662	1.2324	2.39	172
A.aulacocarpa	1.1523	0.6365	1.7883	1.81	142
A.holocericea	1.2215	0.6812	1.9012	1.78	82
A.mangium	0.9776	0.6108	1.5870	1.60	76
Flooding stress					
A.auriculiformis	0.9498	0.4501	1.3987	2.11	20
A.aulacocarpa	1.1427	0.6656	1.1806	1.72	84
A.holocericea	1.1616	0.5867	1.7469	1.98	56
A.mangium	0.9320	0.4234	1.3542	2.20	22
Salinity 100 mol m^{-3}					
A.auriculiformis	1.1743	0.6820	1.8547	1.72	140
A.aulacocarpa	1.2176	0.7475	1.9635	1.63	130
A.holocericea	1.1993	0.6430	1.8407	1.87	56
A.mangium	0.8516	0.4337	1.2842	1.96	24

A.holocericea and *A.mangium* respectively. Flooding stress showed 1.398, 1.80, 1.746 and 1.354 μg g^{-1} in the phyllodes of *A.auriculiformis*, *A.aulacocarpa*, *A.holocericea* and *A.mangium* respectively. When the treatments are compared, along with species, salinity stress (100 mol m^{-3}) favoured a higher amount in *A.auriculiformis* and *A. holocericea*. But in *A.mangium* drought stressed plants had slightly higher amounts of total chlorophyll.

1.2. *Chlorophyll-a*

Chlorophyll-a in the control plants were 0.8152, 1.226, 1.550 and 0.9854 μg g-1 in the phyllodes of *A.auriculiformis*, *A.aulacocarpa*, *A.holocericea* and *A.mangium* repectively. Highest amount of chlorophyll-a was noticed in *A.holocericea*.

Drought stressed plants showed 0.86, 1.15, 1.22 and 0.977 μg g^{-1} in *A.auriculiformis*, *A.aulacocarpa*, *A.holocericea* and *A.mangium* respectively. Among the species *A.aulacocarpa* had maximum chlorophyll-a. Flooded plants showed 0.949, 1.14, 1.16 and 0.932 μg g^{1} in the phyllodes of *A.auriculiformis* *A.aulacocarpa*, *A.holocericea* and *A.mangium* respectively. Salinity stressed plants had 1.174, 1.2176, 1.993 and 0.8516 μg g^{-1} in the phyllodes of *A.auriculiformis* *A.aulacocarpa*, *A.holocericea* and *A.mangium* respectively. Between treatments *A.auriculiformis* showed more chlorophyll-a in the drought stressed while *A.mangium* in control plants (Fig.80b).

In the case of chlorophyll-a, *A.auriculiformis* and *A.aulacocarpa* showed higher amount for salt treated (1.2 μg g^{1}). There was no significant difference between treatments in *A. aualcocarpa*. However *A. holocericea* had higher amounts of chlorophyll-a including control (2.1-2.3 μg g^{-1}). *A.mangium* had not much difference between treatments and the chlorphyll-a content was around 1.0 μg g^{-1}. It is understood that low concentration of of salt (100 mol m^{-3} NaCl) favours chlorophyll-a formation in *A. auriculiformis*, *A. holocericea* and *A. aulacocarpa* but not in *A. mangium*.

1.3. *Chlorophyll-b*

The amount of chlorophyl-b was lower than chlorophyll-a in all cases and was less than 0.8 μg g^{-1}. Among control plants more chlorophyll-b was found in *A. aulacocarpa* (0.659 μg g^{-1}). In other species like *A. auriculiformis*, *A. holocericea* and *A.mangium*, chlorophyll-b was 0.34, 0.54 and 0.44 μgm gm^{-1} respectively (Fig. 67).

Drought stressed plants showed 0.36, 0.636, 0.68 and 0.611 μg g^{-1} in *A. auriculiformis*, *A. aulacocarpa*, *A. holocericea* and *A. mangium*. Chlorophyll-b was higher in *A. holocericea* and lower in *A. auriculiformis*. Flooding stress showed 0.45, 0.66, 0.58 and 0.42 μg g^{-1} of chlorophyll in the phyllodes of *A. auriculiformis*, *A. aulacocarpa*, *A. holocericea* and *A. mangium* respectively. Salinity stress showed 0.68,0.74, 0.64 and 0.43 μg g^{-1} of chlorophyll-b in *A. auriculiformis*, *A. aulacocarpa*, *A. holocericea* and *A. mangium*. Among treatments, salt favoured more chlorophyll-b in *A. auriculiformis* and *A. aulacocarpa*. *In A. holocericea* and *A. mangium d*rought was found to favour the formation of chlorophyll-b (Table.14)

1.4. *Carotenoids*

The carotenoids estimated in the four species against 4 treatments also show comparatively higher amounts in salt treated plants (Fig. 81). In *A.auriculiformis* and *A.aulacocarpa*, the flooded plants had more carotenoid content (0.553, 0.78 $\mu g\ g^{-1}$) respectively than drought stressed and control plants. Drought stressed plants of *A.auriculiformis* showed almost similar amount (0.45 $\mu g\ g^{-1}$) of carotenoids as in control (0.459 $\mu g\ g^{-1}$).

In *A.aulacocarpa* also the amount of carotenoids were almost the same in control (0.668 $\mu g\ g^{-1}$) and drought stressed plants (0.685 $\mu g\ g^{-1}$). It was high in the case of flooded (0.786 $\mu g\ g^{-1}$) and salinity stressed plants (0.723 $\mu g\ g^{-1}$).

A.holocericea showed high amounts of carotenoids in control (0.886 $\mu g\ g^{-1}$) and salt treatment (0.827 $\mu g\ g^{-1}$). Flooding showed lower amounts (0.46 $\mu gm\ g^{-1}$) than drought stressed (0.0684 $\mu g\ g^{-1}$).

In *A.mangium*, drought stressed plants had highest amount of carotenoid (0.601 $\mu gm\ gm^{-1}$) but the amount was less when compared to other species. It was 0.49, 0.473 and 0.49 $\mu g\ g^{-1}$ in control, flooded and salinity stressed plants. The values were between 0.5-0.6 $\mu g\ g^{-1}$ in other treatments. There was not much increase in carotenoid content in salt treated plants.

The chlorophyll a/b ratio was around 2.0 in control plants. It was 2.8, 1.7, 2.14 and 2.19 in *A.auriculiformis A.aulococarpa, A.holocericea* and *A.mangium*. The ratio was comparatively low in salinity stressed plants. In

A.auriculiformis the chlorophyll a/b ratio was similar in control, drought and flooded plants but differed in salinity stressed plants (Table.14).

While checking the chlorophyll to carotenoid ratio, which is an index of the sensitivity of chlorophyll to photooxidative destruction, the drought stressed plants showed 2.74, 2.68, 2.77 and 2.64 in *A.auriculiformis*, *A.aulacocarpa* and *A.mangium*. It is comparatively a better ratio when compared to other plants.

2.0. **Proline**

Phyllodes of the four species of *Acacia* subjected to 9 days of drought stress showed comparatively higher amounts of proline than normal phyllodes (Fig. 68). The fifth phyllode from the treated and control plants were collected and subjected to proline estimation. Drought stressed plants of *A.auriculiformis* had the highest (172 $\mu g\ g^{1}$) amount followed by *A.aulacocarpa* (142 $\mu g\ g^{1}$), *A.holocerecea* (82 $\mu g\ g^{-1}$) and *A.mangium* (76 $\mu g\ g^{-1}$). The control and flooding stressed plants had the lowest amount of proline content in their leaves. However slightly higher amounts of proline were noticed in the control plants of *A.holocerecea* (56 $\mu g\ g^{-1}$). The salinity stressed plants of *A.auriculiformis* (140 $\mu g\ g^{-1}$) and *A.aulacocarpa* (130 $\mu g\ g^{-1}$) also showed high amounts of proline in their phyllodes. It was 56 and 24 $\mu g\ g^{-1}$ in *A.holocericea* and *A.mangium* respectively. The high amount of proline accumulation in the phyllodes of *A.auriculiformis* is an adaptation of the plant to tolerate drought conditions.

Experiment X. Pressure Volume Curve analysis

Leafy twigs of *A.auriculiformis* were enclosed in polythene bags and excised under water. The basal portion of the twigs were kept in distilled water in dim light for rehydration overnight. The leafy twigs were taken out, weighed and water potential was determined using a pressure chamber. The phyllodes were allowed to transpire on a laboratory bench for a few minutes and again weighed after measuring the water potential (Ritchie and Roden, 1984). Measurements were performed in accordance with the recommendations of Turner (1988), in particular, the rate of increase of pressure in the chamber was kept below 0.2 MPa s^{-1} in order to avoid injury to cells (Kikuta *et al.*1985). Wounds are reported to distort the PV curves by freezing solutes in the xylem fluid (Cortes and Sinclair 1985). After taking 6-8 measurements of water potential and corresponding fresh weight of the sample, the twig was kept in an oven at 85°C for 24 hours for dry weight determination. The RWC of the sample was calculated.

A plot of 1/ Ψ *vs* RWC was used to derrive the osmotic potential at full turgor ($\Psi_{\Pi 0}$) and osmotic potential at turgor loss point or zero turgor ($\Psi_{\Pi z}$). The apoplasmic water content (*A*) was found on percent basis. The curves obtained by plotting 1/ Ψ *vs* RWC gave a relatively straight line portion for lower RWC values and a logarithmic portion reaching full turgor at RWC = 100%. The straight line portion of the curve corresponds to non-turgid state, where the Ψ is supposed be equal to osmotic potential (Ψ_{Π}). To extract information from PV curves, a linear regression was performed on the experimental points situated along the straight line portion (non-turgid region) and extrapolated this straight line to the turgid region until RWC = 100%. Extrapolated values are supposed to represent Ψ_{Π} in the turgid region and to give the turgor potential by taking the difference in the actual curve. The intersection of the straight line with the x-coordinate at - $\Psi_{\pi}^{-1} = 0$ yeild the value of apoplasmic water fraction, which is usually supposed to stay finite and constant (Cutler *et al.* 1979).

Following PV curve construction in six samples from normally watered plants of *A.auriculiformis*, values of volume average osmotic potential at full turgor ($\Psi_{\pi 0}$) and osmotic potential at zero turgor ($\Psi_{\pi z}$) were found as shown below.

Tissue osmotic potential at full turgor = -1.299 MPa

Water potential at turgor loss point = -1.33292 MPa

Apoplasmic water content = 0.1853 (18.53%)

The values observed from a graph plotted using the above procedure, the osmotic potential at full turgor ($\Psi_{\pi 0}$) was found to be -1.33 MPa and osmotic potential at zero turgor ($\Psi_{\pi z}$) was found to be 1.408 MPa. The apoplasmic fraction of water was calculated as 0.014 (=1.4%) (Fig.69). Osmotic potential at both full saturation ($\Psi_{\pi 0}$) and at zero turgor ($\Psi_{\pi z}$) were significantly lower in the cyclically water stressed seedlings of *A.auriculiformis*. In 8 day cyclically water stressed plants the values of $\Psi_{\pi 0}$ was -1.53 MPa and $\Psi_{\pi z}$ was -2.127 MPa. The apoplasmic water fraction was 0.29 (=29%) (Fig. 70).

In *A.aulacocarpa* followed by the analysis of PV cuvres, $\Psi_{\pi 0}$ was found to be -1.228 MPa and $\Psi_{\pi z}$ was -1.223 MPa. The apoplasmic fraction of water being 0.485 (Fig.71).

Larger values of $\Psi_{\pi 0}$ imply a better maintenance of cell turgor at a given water potential (Tyree and Jarvis, 1982). Sorbado (1986) have mentioned that evergreen species could develop a higher leaf turgor and lose turgor at lower leaf water potentials than deciduous species. This was related to a lower osmotic potential at full turgor in evergreen species than in deciduous species. Clay and Greene (1983) also have pointed out that drought hardening may involve an increase in bound water content and dry weight (DW): turgid weight (TW) ratio and a decrease in osmotic potential at full turgor and water potential at zero turgor.

Experiment XI. Water relations, gas exchange and growth of *Acacia auriculiformis* trees under stressed and nonstressed periods at the plantation level

Monthly measurements of water potential, soil moisture, microclimate, stomatal conductance, transpiration etc. were carried out by dividing the period prior to the rainy season, as stressed period and after the rainy season, as nonstressed period. During rainy season, gas exchange measurements were not possible due to extremely high relative humidity (>90%).

1. Weather parameters

During the experimental period, weather parameters like rainfall, maximum and minimum temperatures, relative humidity etc. were noted from a weather station, located near the plantation. The rainfall along with temperature and an ombrothermic graph showing wet and dry periods which prevailed in the location is given in Fig. 72(a) and (b). From the figures, it can be seen that maximum rainfall had occurred in July. There were two monsoon seasons operating in the study area. One of them was the South West Monsoon (June-Sept) and the other was North East Monsoon (Oct-Nov). The dry period was bserved from December to March when there was no rain. During April & May ight showers of rain occurred, when the stress was found to be released. The wet eriod was observed from June to November when the trees were able to get nough water and the period was taken as the nonstress period.

. Microclimate

Microclimate measurements were made 2 m above the canopy using ifferent sensors connected to a datalogger. Atmospheric temperature, relative umidity, vapor pressure deficit (VPD) and net radiation were measured at every 5 seconds and averaged for hourly intervals for stressed and nonstressed periods. Details of measurements during stressed and nonstressed period is presented as verage hourly data and are given in Fig. 73 a,b,c and d. A maximum temp. of 39 °C was observed during 2 - 3 pm in March and a low r.h. of 22% during 5 to 6 pm in February. The VPD values remained quite high reaching about 4.35 kPa during 1500 to 1700 hours in February. During stress period VPD values were high in general between 14 to 16 hours, while during the nonstressed period, it was less than 3.0 kPa. This shows that in the dry period, there was an increase in VPD during evening hours. The light intensity measurements showed that net radiation was high during February to May, particularly during noon hours.

3. Soil water

Soil moisture in the upper (0-30cm) and lower (30-60cm) layers showed (Fig. 74a) an increase from April to November and then gradually decreased, and was minimum in March. The soil moisture content was about 15-20% during November and 5-7% in March. The phreatic aquifer available in the nearby wells were at a depth of 15 m in the dry season.

4. Water potential (Ψ)

Predawn leaf Ψ measurements taken for different months, show that from April to November values increase and afterwards decline (Fig. 74b). This indicates that during wet period the plants get enough water to maintain leaf Ψ near to zero. But from December to March, there is a gradual decrease in predawn Ψ reaching a minimum of -1.5 Mpa. These low values in March show that the plants are under stress when compared to post monsoon period. Crombie *et al.* (1988) have mentioned that predawn water potentials indicate water availability to the roots. The midday water potentials showed an increasing trend from April to November and decreasing afterwards (-2.5MPa) towards March. The midday water potentials indicate the maximum tension that is prevailing in the leaf. The plants did not show much external wilting at this low water potential (-2.5 MPa) that prevailed in March. However litterfall was high during this period.

Diurnal measurements taken in the litter-covered plot during the stress period (Fig. 75a) shows that predawn water potentials are a little bit higher in the litter-covered plot than in the open plot. The mean predawn Ψ values were -0.6 MPa and -0.8 MPa respectively. In both plots there was a gradual decline in Ψ upto 1300 hours, when it became -1.3 MPa in litter-covered plot and -2.2 MPa in the open plot. This clearly shows that allowing the leaf litter to remain in the plot of the trees has improved the soil water status by keeping the Ψ at a higher level.

5. Stomatal conductance (g_s)

The phyllodes of *Acacia auriculiformis* show stomata on both sides more r less in equal number. Microscopic observations revealed that the upper side f the phyllode contains 329±6 and lower side 388±4 stomata per mm^2 (Table 15). The stomatal ratio between upper and lower side was found to be 0.85. Morphologically, both sides looked similar and was difficult to distinguish etween. In making stomatal conductance measurements using porometer both ides were measured separately and averages were taken.

Table 15. Stomatal frequency (per mm^2) in the phyllodes of *A.auriculiformis*.

Side	Number of stomata	Standard error
Upper side	329	6
Lower side	388	4

* N= 20

The diurnal variations in stomatal conductance showed a consistent pattern showing low g_s values in the morning from 0900 hours to 1100 hours which then rose gradually, and after 1400 hours it gradually declined. There was a small decline by 1230 hours. During the stress period (December to March) the stomatal conductance was comparatively low (Fig. 76). The trend seemed to be gradual with the advancement of stress. In January, forenoon values were lower than afternoon values, and when the stress became severe in February and March the conductance values remained comparatively lower throughout the day. The nonstressed period following the rainy season, showed comparatively higher conductance values. Stomatal conductance measured in the litter-covered and open plots during the stress period showed that even in litter-covered plots the stomatal conductance was low (Fig. 75a). By examining the water potential (Ψ) and VPD measurements, it is understood that both factors have deciding effect on stomatal conductance. It can be seen that when the water is limiting in the soil, that is, when the water potential of the phyllodes are low, the g_s values are low. Similarly, when the VPD values are low the g_s values are high with comparatively lower conductance during stress period. But in the leaf litter-covered plot, eventhough the water potential of leaves was slightly higher than in the open plot, the stomatal conductance did not show much improvement. However, no complete stomatal closure was observed even at the lowest water potential of -2.5 MPa in March.

It has been seen that the water stress during the premonsoon months decreases the absolute stomatal conductance of the phyllodes along with increase in stomatal sensitivity to the air drying phenomenon. During periods of nonstressed condition in November, the water availability was good. During this period, due to the high wind speed, produced by easterly winds along with increase in VPD, the stomatal conductance was found to increase. This indicates that, when soil water is not limiting, if a higher VPD prevails, stomatal conductance can be high favoring much higher transpiration (Fig. 76b).

6. Transpiration

Transpiration from the plantation has been calculated using Penman-Monteith equation (Equation No:2). The hourly values measured during the stressed and nonstressed periods show that transpiration is slightly higher during the initial stages of stress period, but comes down towards March (Fig. 77a). Maximum transpiration was observed in November when the VPD was high along with high water availability. But in March, due to lesser water availability and low VPD values, the stomatal conductance was low leading to lower transpiration. In the litter-covered and open plots, diurnal transpiration was measured in April. It was seen that transpiration was not much different in the litter-covered plot (Fig.77b). This shows that even after having a better water status in the litter-covered plot, transpiration rate was the same because stomatal conductace did not differ much. The water loss by transpiration, calculated on hourly basis shows that clear difference exists between water stressed and nonstressed trees. The higher VPD observed in summer months may be due to the interaction of temperature But in November the water status was good, temperature was less with high wind speeds, but then VPD rose very high with the interaction of wind. In April and May due to a few summer showers, eventhough the water potentials did not improve much, slightest wetting of soil and canopy, the stomatal conductance and transpiration were favoured inspite of high VPD values. This suggests that the plants are abile to use water effectively from the upper layers of soil. Fig. 77a. shows the diurnal pattern of transpiration where transpiration increases from morning, reaches maximum before noon and then diminishes. The nonstressed period shows slightly higher values and has clear cut difference from stressed period where transpiration is low (Fig.77 c). The chamber transpiration measured diurnally also shows an initial transpiration rate of 4 mmol m^{-2} s^{-1} increases upto 8 mmol m^{-2} s^{-1} by 1100 hours which then decreases to 2 mmol m^{-2} s^{-1} by 1500 hours (Fig. 78b).

7. Photosynthesis

The diurnal pattern of photosynthesis shows two peaks one in the morning by 0900 hours and second by 1230 hours. The photosynthetic rates in the plantations do not seem to be high as it reaches only up to an average 7 μmol m^{-2} s^{-1} during peak hours. (Fig. 78a).

8. *Water use efficiency* (WUE)

Instantaneous water use efficiency was calculated by measuring net photosynthesis and chamber transpiration. Diurnal measurements on 6 different leaves were averaged and the WUE is expressed as mol CO_2 assimilated per mmol of water consumed (Fig.78c). It could be seen that instantaneous WUE is more, when the stomatal conductance values are lower. In *A. auriculiformis*, even when partial stomatal closure occurs, CO_2 diffusion is not blocked which results in higher WUE. The lower values of g_s during morning, midday and afternoon make the plant more water use efficient.

8. Growth

The growth in girth of *A.auriculiformis* was closely followed by measuring the girth at breast height (GBH) of 40 trees in two alternate rows in the open and litter-covered plots. The girth increase in the open plot was 14.04% over initial girth, whereas in the litter-covered plot it was 20.22% (Fig. 79). The average gbh was 18.79 cm in the open plot which increased to 21.59 cm within 15 months. In the case of litter covered plot an initial girth of 17.96 cm was seen increased to 21.59 cm The girth increase occured in all months but from January to April, the growth was less compared to other months. This may be due to the water stress responses like lower stomatal conductance and lower water potentials. The cambial growth may stop during water stress but the extension growth does not seem to be limited as new flushes of leaves are seen in all seasons. In the litter-covered plot even during stressed

Table. 16. Increase in girth in the open and litter-covered plots of *A. auriculiformis* at Kothachira.

Month	Openplot GBH (cm)	Open plot GBH, % increase	Litter- covered GBH (cm)	Litter- covered, GBH % increase
Jul 0	18.797	0	17.96	0
Oct 3	19.473	3.60	18.83	4.84
Nov 4	19.777	5.21	19.22	7.01
Dec 5	20.100	6.93	19.53	8.74
Jan 6	20.143	8.60	19.84	10.44
Feb 7	20.393	8.49	19.88	10.63
Mar 8	20.370	8.37	20.03	11.53
Apr 9	20.540	9.27	20.22	12.08
May 10	20.680	10.02	20.49	14.06
Jun 11	21.230	12.94	21.20	18.01
Aug 13	21.520	14.49	21.55	19.97
Sep 14	21.440	14.04	21.59	20.22

period increase in girth can be noted and is better than in open plot. The leaf area index measurements made also did not show much variations throughout the year. The LAI measured using canopy analyzer by light interception method shows the average values between 3.1 and 3.15 throughout the year.

Discussion

DISCUSSION

Growth

Seeds of *A.auriculiformis* was found to be near 38,400 per kg . The seeds germinated from thrid day onwards followed by standard germination techniques. 80°C hot water treatment for 30 seconds followed by overnight soaking was found to be suitable for getting good percentage of germination. Number and size of seeds differed significantly in all the four species of *Acacia* stuied. Initial development of phyllode also differed in the four species. Studies on the growth of seedlings of four species for 10 months showed a height of 120 cm for *A.auriculiformis*, 110 cm for *A.holocericea*, 95 cm for *A.aulacocarpa* and 60 cm for *A.mangium*. The initial seedling growth of *A.auriculiformis* is better than the other 4 species in the same conditions of water stress. Early growth and nodulation studied for 170 days in *A.auriculiformis* along with five other species of *Acacia* by Mohankumar *et al.* (1992) showed an increase in shoot length from 8.79 cm on 50th day to 21.36 cm on 170th day. However, they noticed better growth in *A.nilotica* and *A.mangium* than for *A.auriculiformis* in the initial stages.

Plants subjected to stress cycles of 2, 4, 6, 8, 12 and 16 days showed only less increase in height compared to normally watered plants showing 22.6, 16.22, 13.27, 13.07 and 6.0% respectively. In 20 day's stress cycle, the growth was seen stunted before 2 months. Drought stress also brought down the number of phyllodes. Phyllode extension was reported to decrease in *A.auriculiformis* under severe stress (Phillips and Riha 1993). In the present study, however, the phyllode dimensions were not seriously affected except in water stress cycles lasting for 16 and 20 days.

The growth in girth of trees measured in plantations of *A. auriculiformis* showed increase throughout the year except in the severely stressed periods starting from January to March. Girth increase in April and May was less when compared to other months of the year. Results show that low stomatal conductance and low water potential have affected growth of trees. Cambial growth might have been arrested during the periods of water stress leading to low girth increments. But the presence of new phyllodes and maintenance of almost the same leaf area throughout the year leads to the conclusion that at least extension growth is not seriously limited by water stress in *A. auriculiformis*. It has been reported that growth of *A.auriculiformis* in Kerala is comparatively better than that of other States (Jayaraman and Rajan 1991). A mean annual increment (MAI) of 1034 m^{-3} ha^{-1} of commercial volume has been estimated by them.

A comparison with a litter-covered and an open plot shows difference in girth. The open plot represented a girth increment of 14.04% while litter covered plot represented 20.22% showing a difference of 6.18% during the year. Leaf litter seems to have improved the water status of trees in the stressed period as revealed by water potential measurements. Even the slightest wetting of the soil caused by summer showers improved the water status of trees and phyllodes, thereby allowing to use such water more efficiently. The leaf litter might have also helped to control surface run off during heavy rains to a certain extent and allowed more water to penetrate into the soil. In many cases mulching has been reported to be helpful in modifying water status, nitrogen content and improve plant growth (Gupta 1991). Khera *et al.* (1976), Moodey *et al.* (1963), Gupta and Gupta (1983) and Singh *et al.* (1991) also report the capability of various mulches in improving crop yeild in dry zones. The better growth in the litter-covered plot of *A.auriculiformis* at Kothachira may also be due to the soil improvement caused by litter addition as reported by Prasad (1991) in a similar study.

Leaf age and physiological activity

In the seedlings of *A.auriculiformis*, phyllodes at positions 4 to 15 are found to be photosynthetically more efficient than younger and older phyllodes. Spectral properties of the phyllodes of *A.auriculiformis* at different positions studied by Sinha *et al.* (1996) also show better absorbance in all phyllodes except the first one. Pathre *et al.* (1990) attribute this higher photosynthetic activity in phyllodes at positions 6 to 8 in *A.auriculiformis* due to higher chlorophyll content. Sinha *et al.* (1996) mention that cholorphyll alone is not responsible for the spectral characteristics in *A.auriculiformis*.

Photosynthesis in leaf positions 4 to 15 was found to be maximum (A_{max}) at a PFD of 1200 μmol m^{-2} s^{-1} after which there was not much increase in photosynthetic rates. A_{max} is found to be 14 μmol m^{-2} s^{1}. In other species like *A.aulacocarpa, A.holocericea* and *A.mangium* the A_{max} was found to be 9, 23 and 13 μmol m^{-2} s^{-1} respectively. Sun (1986) report that *A.auriculiformis* has a net photosynthetic rate of 12.39 μmol m^{-2} s^{-1} which is very close to the present observation. He also reports that the general photosynthetic rate of *A.auriculiromis* is 19.23 μmol m^{-2} s^{-1}.

Leaf water potential

Measurements showed that leaf water potential decreases from morning till noon and tend to increase afterwards. The predawn water potential is a good indicator of the water availability to the trees (Crombie *et al.* 1988) as root tissues and leaves equilibrate with the available soil water during night, when there is no transpiration. The measurements of midday water potential may indicate the maximum water stress suffered by a plant.

Seedlings of *A.auriculiformis* under normal watering regimes showed a predawn Ψ of -0.9 MPa and a midday Ψ of -0.65 MPa. Drought stress for 9 days lowered the predawn Ψ to -2.3 MPa amd mid day Ψ to -3.5 MPa. Phyllode absicission was reported to occcur in *A.auriculiformis* from 4th day onwards when the water potential fell below -2.1 MPa (Phillips and Riha 1993). However, in the present study, the predawn water potential declined at a faster rate, but seedlings were able to withstand a predawn Ψ of -2.3 MPa. In *A.melanoxylon* full recovery from a Ψ of -5.5 MPa has been reported by Brodribb and Hill (1993) whereas in *A.harpophylla*, it being -7.2 MPa (Turnstall and Connor 1975).

Repeated drought stress followed by one day watering was studied in *A.auriculiformis* and *A. mangium*. 12 day stress cycles lowered the predawn leaf water potential to -2.32 MPa and midday water potential to -4.0 MPa after 2 stress cycles. Predawn water potentials still decreased to -2.54 MPa in 16 day water stressed plants with a midday water potential less than -4.0 MPa. Plants were not able to survive for long in such low water potential. 16 to 20 day drought stressed plants became leafless and dried by 34 days, but rewatering rejuvenated some of the plants kept under 16 day stress cycle. 12 day continous drought stress cycle was the maximum stress bearable by the seedlings. It can be assumed that when water is limiting the predawn water potential can go down to -2.3 MPa and midday water potential down to -3.5 MPa, in seedlings kept in polythene bags, beyond which the plant stops its function.

At the plantation level, trees of *Acacia auriculiformis* grown at Kothachira showed higher predawn water potentials during the nonstressed period. There was a gradual decrease in predawn water potential reaching a culmination by March, when stress was maximum. *A. auriculiformis* trees experienced a predawn water potential of -1.47 MPa and midday water potential of -2.6 MPa in March. This probably shows that *A. auriculiformis* can be successfully grown in Kerala on a much wider scale.

Flooding did not allow the plants to lower their predawn water potential below -0.4 MPa and midday water potential below -1.4 MPa. Of the two concentrations of NaCl (100 and 200 mol m^{-3}) applied a higher for 9 days showed a predawn water ptential of -0.5 MPa and a midday water potential of -2.9 MPa while the lower concentration resulted in a predawn water potential of -0.4 MPa and midday water potential of -2.5 MPa.

The relative water content (RWC) of the phyllodes of *A. auriculiformis* subjected to water stress and flooding showed 4% decrease followed by 6 days drought stress, while 6 days flooding improved the RWC by 3%. Marcar *et al.* (1991) report that RWC of phyllodes of *A. auriculiformis* treated with 100 and 200 mol m^{-3} sodium chloride show 8% decrease in RWC than control, while nearly 1% in A.*mangium.*

A. mangium showed a predawn water potential of -0.12 MPa and a midday water potential of -0.7 MPa in normal cases. 9 days drought resulted in the plant's predawn water potential to reach -1.6 MPa and -2.2 MPa respectively. Flooding showed a predawn water potential of -0.06 MPa and midday water potential of -0.4 MPa. Thus the midday water potential also got increased to a higher level followed by waterlogging.

Salinity stress (100 mol m^{-3}) decreased predawn water potential to -0.5 MPa and midday water potential to -1.5 MPa after 9 days of salinity stress. Salinity stress (200 mol m^{-3}) also did not lower predawn water potentials below -0.38 MPa and the midday water potentials below -1.3 MPa.

Of the 4 species of *Acacia* studied, *A. mangium* had the highest predawn water potential (-0.08 MPa) while *A. aulacocarpa* had the lowest (-0.3 MPa). The midday water potential was more in *A. holocericea* than in normally watered plants. Cruz and O' Toole (1954) have mentioned that a higher leaf water potential is an indication of drought tolerant varieties. The high water potential during water stress is an indication for drought tolerance. Thus from the present study *A. mangium* seems to be the most drought tolerant species. This is followed by *A. auriculiformis* and *A. holosericea*. *A. aulacocarpa* is the least drought tolerant out of the four species.

Rewatering of the plants showed recovery of leaf water potential by noon on the same day. Griffith *et al.* (1991) also reported that leaf water potentials, solute water potential and turgor potential of the drought treated plants returned to control values within two hours after rewatering. Brodribb and Hill (1993) and Turnstal and Connor (1975) reported full recovery of plants by rewatering from -5.5 MPa and -7.2 MPa in *A.melanoxylon* and *A.harpophylla* respectively.

Photosynthesis

Seedlings of *A.auriculiformis* under normal watering regime showed a maximum photosynthetic rate of 14 μmol m^{-2} s^{-1} at a PFD of 1200 μmol m^{-2} s^{-1} Trivedi *et al.* (1992) have reported a photosynthetic rate of 12 μmol m^{-2} s^{-1} and Sun (1986) reported a rate of 12 μmol m^{-2} s^{-1} in *A.auriculiformis*. The diurnal pattern of photosynthesis also varied having a peak by 1100 hours followed by a decrease. While analysing the photosynthetic characteristics of *A.auriculiformis*, Trivedi *et al*, (1992) have specified that maximum P_n of 12 μmol m^{-2} s^{-1} was observed at 30°C, at a PFD of 1000 μmol m^{-2} s^{-1}.

At the plantation level the trees showed a maximum photosynthetic rate of 7 μmol m^{-2} s^{-1} between 0900 and 1200 hours while in seedlings a maximum of 14 μmol m^{-2} s^{-1} was noticed at 1100 hours. This is comparatively higher than a value of 12 μmol m^{2} s^{-1} reported for *A.auriculiformis* by Trivedi *et al.* (1992) and Sun (1986). Usually higher rates of photosynthesis were observed in the morning hours which gradually decreased after 1200 hours. The lower rates observed in trees could be due to the interaction of several factors like light, VPD, water potential etc.

Comparative studies on the photosynthetic rates of seedlings under drought stressed conditions show that as the period of drought stress increases photosynthetic rate decreases. The plants can photosynthesise upto 10 days at a very low rate, but later, photosynthesis becomes difficult. Rewatering of the plants after 12 day's drought stress showed only slight improvement in photosynthesis on the same day in the evening hours. Repeated drought stress on the seedlings of *Acacia auriculiformis* showed clear evidence of decrease in photosynthetic rates. Normally watered plants had an average photosynthetic rate of 10 to 14 μmol m^{-2} s^{-1}, whereas 8 day repeatedly drought stressed plants reduced their photosynthetic rate to less than 2 μmol m^{-2} s^{-1}. Similarly in *A. mangium*, by repeated stress for more than 4 days reduced the photosynthetic rate to $<$ 2 μmol m^{-2}s^{-1}. Brodribb and Hsiao (1982) report that in many plants when the leaf Ψ decline below certain level may cause gentle decline in photosynthesis followed by steep drops of CO_2 assimilation reaching a negative photosynthesis due to respiration. They also mention that the rapid decline in CO_2 uptake at lower conductances means an increased internal resistance or enzymatic inhibition which limit photosynthesis in phyllodes resulting in a more rapid decrease in WUE under water stress.

Flooding stress imposed on *Acacia* plants except A.holocericea did not show much increase or decrease in photosynthesis when compared to control plants. But in A. holocericea photosynthesis and stomatal conductance were seen sligtly lowered. In many plants flooding stress is reported to reduce photosynthesis, stomatal conductance and transpiration (Bradford and Yang 1981). an Salinity stressed (100 mol m^{-3}) plants showed improvement in photosynthesis upto 5 days but later decreased. A higher concentration of sodium chloride (200 mol m^{-3}) also did not favour photosynthesis after five days.

The photosynthetic rate in *A. mangium* varied between 4 and 8 μmol m^{-2} s^{-1} By introducing water stress, an increase in photosynthesis on the 1st day was followed by decrease in photosynthesis as stress days advanced. It has been noticed that a midday depression at 1300 hours is prominent in control and drought stressed plants. But in salinity stressed (100 mol m^{-3}) plants, upto 5 days there was not much decrease in photosynthesis but by 9th day it decreased to < 2 μmol m^{-2} s^{-1}. A higher concentration of NaCl (200 mol m^{-3}) increased photosynthesis upto 9 days with a maximum of 14 μmol $m^{-2}s^{-1}$ during 1400 hours. However the morning values of photosynthesis were lower in salt stressed plants. Flooding stress improved photosynthesis in *A.mangium* to a great extent. From a photosynthetic rate of 4 μmol m^{-2} s^{-1}, it rose to 14 μmol m^{-2} s^{-1} by 9th day. When water is not limiting *A. mangium* uses it to a great extent. Another species, namely, *A. aulococarpa* showed a photosynthetic rate of 2 to 8 μmol m^{-2} s^{-1}. Flooding and salinity stress improved photosynthesis in *A. aulococarpa* but drought stress reduced the photosynthesis. In *A. holocericea* photosynthetic rate was higher showing photosynthetic rates of 18 and 23 μmol m^{-2} s^{-1}. There was not much increase in photosynthesis with salinity or flooding. However, water stress decreased photosynthesis to a level less than 3 μmol m^{-2} s^{-1} by 5th day onwards.

Transpiration

The experimental results show that hourly canopy transpiration in the plantation of *Acacia auriculiformis* ranged between 0.1 and 1.4 mm h^{-1}. When cumulated on a daily basis the daily transpiration was found to vary between 3.9 and 9.73 mm d^{-1} with an average value of 5.85 ± 1.68 mm d^{-1} representing the whole year. When extrapolated, the average per tree consumption of water *in Acacia auriculiformis* tress planted at an espacement of 1.5 x 1.5 m having nearly

4440 stems per hectare has been calculated as 14.6 ± 2.7 l d^{-1}. The monthly transpiration rate during the stressed period was low (10 mm d^{-1} in March) when compared to the nonstressed (14.3 mm d^{-1} in November). From this study it can be understood that water loss by transpiration was more during the unstressed condition, followed by monsoon. A higher value for transpiration noticed in November, may be due to atmospheric dryness (higher VPD) caused by easterly winds accompanied by high water availability in the soil.

A.auriculiformis trees are well adapted to face drought conditions not by reduction of the transpiring surface, but by partially closing the stomata during water stress. This partial closure does not seem to sacrifice water use efficiency as CO_2 diffusion is not affected in these trees even when the stomata are partially closed. This may be the reason behind the fast growth of *A.auriculiformis* noted at the study sites.

Seedlings of *Acacia auriculiformis* provided with normal watering showed transpiration thoughout the day. Starting with 9 mmol m^{-2} s^{-1} at 800 hours, transpiration rate reached a maximum of 12 mmol m^{-2} s^{-1} by 1100 hours and then gradually decreased to 5 mmol m^{-2} s^{-1} by 1700 hours. Comparatively lower rates of transpiration was observed in drought stressed plants. After a period of 9 days of drought, transpiration was very low (< 2 mmol m^{-2} s^{-1}) throughout the day. It can be concluded that the plant reduces transpiration in response to water stress. But when water is in plenty, like in the water logged condition, plants transpire at a faster rate of 14 mmol m^{-2} s^{-1} up to 1100 hours, but thereafter gradually reduce to 4 mmol by 1700 hours. It can be inferred that the plants transpire slightly more under water logged condition. and the roots are tolerant to anoxic conditions. Salinity stress (100 mol m^{-3}) increased transpiration to a level to 14 mmol m^{-2} s^{-1}at 1300 hours in the early stages of stress, but later on after 9 days became 9 mmol m^{-2} s^{-1}. But a higher concentration of NaCl (200 mol m^{-3})

increased transpiration rate to 8 mmol m^{-2} s^{-1} initially but by 3rd day onwards decreased to less than 4 mmol m^{-2} s^{-1} and it was lower than control.

Similar studies show that diurnal pattern of leaf diffusive conductance was found to be similar in other phyllodinous species (*A.spondilophylla, A.hilliana, A.monticola, A.cowleana* and *A.coriace*) where stomata opened quickly in the morning reducing to the mximum before noon and then gradually declining (Ullman 1989). Slight reopening of the stomata in the afternoon is associated with increase in water potential and temperature, and double peaked pattern is characteristic of a number of sclerophyll plants (Losch *et al.* 1982). Ullman (1989) mentions that little is known about the actual reduction of transpiring surface per plant in phyllodineous species compared to compound leaved species.

Studies on *A. mangium* reveal that there is an initial increase in transpiration during the onset of drought stress which gets reduced by 3rd day. From a normal transpiration rate of 4-8 mmol m^{-2} s^{-1}, there was an increase to 12-16 mmol m^{-2} s^{-1} which later came to < 4 mmol m^{-2} s^{-1} from the 3rd day onwards. But the transpiration did not come to a stop even after nine days of drought stress. The normally watered plants had a transpiration rate of 4 to 10 mmol m^{-2} s^{-1}. Seedlings exposed to salinity stress (100 and 200 mol m^{-3}) also showed slight increase on the first day but afterwards showed a normal rate of 4 to 10 mmol m^{-2} s^{-1}. Flooding stress increased transpiration in *A. mangium* to a maximum of 12 mmol m^{-2} s^{-1} which was higher than control.

In a comparative study of 4 species of *Acacia* exposed to various stress conditions for different days transpiration measurements during peak hours show that *A. aulacocarpa* is having lowest rates of transpiration ranging between 2.5 and 6.4 mmol m^{-2} s^{-1}, while *A.holocericea* has the highest transpiration rate of 13-21 mmol m^{-2} s^{-1}. *A.auriculiformis* and *A.mangium* showed the middle range of transpiration rate of 10-12 mmol m^{-2} s^{-1} in normally watered plants.

Drought stress was found to affect the transpiration rate of the four species. *A.auriculiformis* maintained a transpiration rate of 4 mmol m^{-2} s^{-1}, whereas *A. aulacocarpa* and *A. holocericea* showed 2 mmol m^{-2} s^{-1}, and *A. mangium* maintained a transpiration rate of 3 mmol m^{-2} s^{-1} upto 12 days. In all species after 12 days of drought stress transpiration rate was poor. *A. auriculiformis*, *A. holocericea* and *A. mangium* maintained rather low levels of transpiration rate viz. < 2 mmol m^{-2} s^{-1}, whereas in *A. aulacocarpa,* it approached zero by 21st day.

Flooded plants of the four species showed more or less the same rate of transpiration like their control plants. The transpiration rate exceeded 8 mmol m^{-2} s^{-1} in *A. holocericea,* and 16 mmol m^{-2} s^{-1} in *A.mangium* after a period of 12 days of water logging. 100 mol m^{-3} sodium chloride applied at the rate of one litre per day, maintained normal rates of transpiration in all species, but with slightly higher rates than control plants in *A.mangium*. The transpiration rate ranged between 8-14, 8-12, 13-18 and 10-16 mmol m^{-2} s^{-1} in the salinity stressed plants of *A.auriculiformis*, *A. aulacocarpa*, *A. holocericea* and *A. mangium* respectively.

Different drought stress cycles have shown decrease in transpiration values as the severity of stress increased. By 8th day transpiration became less than 2 mmol m^{-2} s^{-1}. Two and four day stress cycle maintained a level of 4 to 12 mmol m^{-2} s^{-1}. In *A.mangium* four day stress cycled plants showed values below 4 mmol m^{-2} s^{-1} whereas 2 day stress cycle showed a transpiration rate varying between 4 and12 mmol m^{-2} s^{-1}.

Florence (1986) attributed increased crop yield with decreased transpiration rate. In this study the transpiration rate was found to be low in *A.auriculiformis*. Out of the five species of *Acacia* studied by Chandrababu *et al.* (1987) and 15 species by Srinivasan *et al.* (1990) low values for transpiration are reported in

A.auriculiformis. (12.7 and 13. 7 μg H_2O s^{-1} cm^{2} respectively). Both studies have been conducted at noon hours. It has been reported that *Acacia* species in general need not have peak g_s or transpiration during mid day (Ulmann 1985, 1989). In the present study also, it has been noticed that higher rate of g_s and transpiraion occurs between 1000 and 1100 hours in *A.auriculiformis* in normally watered plants. Drought stressed plants have minimum rate of transpiration particularly when drlught stress exceeds 8 days. Ulmann (1989) also points out that maximum leaf diffusive conductance and high transpiration is associated with predawn water potential in many plants.

Florence (1986) points out that the major factors affecting transpiration rate are leaf area index, stomatal conductance and VPD between leaf and atmosphere. Trivedi *et al.* (1992) also consider increase in transpiration is partly due to increase in VPD with temperature. Phillips and Riha (1993) found that the phyllodes of *A.auriculiformis* are characterized by a low photosynthetic capacity ranging from 10-12 μmol m^{-2} s^{-1} with a broad temperature response and PFD saturation around 1000 μmol m^{-2} s^{-1}. According to them the water transpired per seedling decreased to decreasing soil water potential and differences were apparent by day 5. Grieve and Hellmuth (1970), Tenheunen *et al.*. (1981) have explained the effect of stomatal sensitivity to VPD, resulting in decreased transpiration and conductance as VPD increase leading to midday depression of photosynthesis and transpiration in many plants.

Water use efficiency

Physiological controls of water use appear to be important. The WUE calculated along with the diurnal measurements show that in *A. auriculiformis* plantation, WUE lies between 0.5 ± 2.0 during the whole day. However WUE is more, when the stomatal conductance values are less. It is understood that *A. auriculiformis* uses water most efficiently, mainly due to partial stomatal closure without affecting photosynthesis. From the present work and the avalable literature, during stress periods the tree uses water more economically than many other species.

Phillips and Riha (1993) noticed that in *A.auriculiformis*, WUE was significantly lower in severely stressed than moderately stressed seedlings. They attribute this low WUE in severely stressed plants due to a decrease in specific leaf area. Mooney *et a*l. (1978) have also correlated specific leaf area with WUE in other plants. Detailed studies on the WUE of the seedlings of *A. auriculiformis* for various stress conditions show that there is improvement in WUE followed by the advancement of drought stress for ten days. The values of WUE were ranging between 1.5 to 3.0. But severe stress for more than ten days, did not improve WUE as photosynthetic rate declined drastically.

Studies by Craig *et al.*, (1990) show that some species of *Acacia* are sensitive to waterlogging and show decline in growth after four weeks by a complex interaction of soil conditions including a diminished rate of O_2 diffusion. Bisseling *et al.*. (1980) also mentioned about a decrease in oxygen supply to the root nodules by waterlogging thereby decreasing nitrogenase activity in *Pisum sativum*. Flooded plants had a WUE, ranging between 0.5 to 1.5 for a period of 12 days of flooding. After that WUE did not improve. The salinity stressed plants (100 mol m^{-3}) showed slight increase in WUE for up to 5 days (0.5 to 1.8) but afterwards decreased. Higher concentration of NaCl (200 mol m^{-3}) improved WUE to a range of 1.0 to 2.8 upto 9 days at the cost of reduced stomatal conductance. In normally watered plants of *A. mangium* WUE was found to vary between 0.5 to 1.0. Drought stressed plants showed initially low WUE followed by slightly higher WUE by 5th day, the reason being reduction in the values of stomatal conductance.

From the comparative study of four species of acacias subjected for various stress conditions WUE of *A. auriculiformis* remained between 0.5 and 1.6 under normal drought stress, for 20 days. *A. aulacocarpa* showed a WUE of 0.7 to 2.2. Flooding has reduced WUE in *A. aulacocarpa* but salinity and drought improved WUE more than control. In *A. holocericea* WUE varied between 0.5 to 1.5 having higher values for drought stressed plants up to ten days. Under all stress conditions the WUE of *A.mangium* was less than control plants. The control plants showed a WUE upto 1.2 whereas salinity (100 mol m^{-3}) stressed plants showed 0.8, flooding 0.6 and drought stressed plants 0.2 for a period of 12 days, which then decreased. Water use efficiency in repeatedly stressed plants was similar to that of control plants and was varying between 0.5 and 1.5 in 8 day stressed plants. This may be due to the adaptation of the plant to drought.

Smit *et al.*. (1992) during their studies on Douglas fir and pine seedlings noticed that WUE of tree seedlings may be an important determinant of both survival and plantation productivity. Morphologically, trees differ in their extent to which their root systems expose the soil fabric, and their ability to exploit available soil moisture at depth during drought may be a major factor in their survival and growth, and hence their water use as well (Pereira and Kozlowski 1976, Carbon *et al.* 1980). Trivedi *et al.* (1993) points out that responses of P_n and g_s to VPD provides an effective mechanism for maximizing WUE, with changing leaf temperature.

Stomatal closure at high VPD and high leaf temperature results in loss of potential photosynthesis but a considerable saving in water. Stomatal closure in response to the increasing VPD caused by increasing leaf temperature decreases the apparent thermal optimum of photosynthesis. The studies of Trivedi *et al.*(1993) demonstrates that the potential of *A.auriculiformis* to maintain high WUE under varying VPD conditions constitute an advantage for competing and survival under harsh conditions resulting from drought and high temperature. Phillips and Riha (1993) also found increased WUE in response to drought stress in *A.auriculiformis*.

Physicochemical studies

Physicochemica l studies on the phyllodes of variously stressed plants show increased levels of chlorophyll (a, b and total chlorophyll) in salinity stressed and water logged plants of *Acacia auriculiformis*. Drought stress has led to a reduction in chlorophyll a, b and total chlorophyll. Flooding did not hinder chlorophyll formation, but only slight increase was noticed over control. In *A. mangium* the amount of total chlorophyll was less in flood and salinity stressed plants but drought stressed plants showed slightly higher amounts than control. The amount of carotenoids in salinity stressed plants of *A.auriculiformis* also was higher than that of control plants. While studying the flooding effect in mango trees, Larson *et al.* (1992) noticed that chlorophyll content of leaves were not affected when they measured the leaves on 80th day. But in some cases flooding resulted in lower chlorophyll formation due to decrease in nitrate reductase activity (Ponnamperuma 1984, Larson *et al.*1991 b).

Studies by Pathre *et al.* (1990) show that in *A.auriculiformis* phyllodes at the 8th position had maximum chlorophyll (a, b and total) which could be related to higher photosynthetic capacity Chlorophyll a/b ratio was constant, around 2, in all the phyllodes at different positions. Sinha *et al.* (1996) found that the total chlorophyll content in in 4th and 8th phyllodes were 3.5 and 4.0 mg g^{-1} respectively. Similarly Chl-a was 2.2 and 2.6 and chlorophyll-b was 1.2 and 1.4 mg gm^{-1} in 4th and 8th leaves. According to Sun (1986) the chlorophyll content in leaves of *A. auriculiformis* amounts to 3.0 mg g^{-1}, chlorophyll-a being 1.2, chlorophyll-b being 4.3 mg g^{-1} The chlorophyll a/b ratio was found to be 2.6. However, in the present study the amount of total chlorophyll is less (1.5 mg g^{-1}) than reported values (3.0 mg g^{-1}). But chlorophyll a/b ratio is similar (2.38).

Chlorophyll Stabillity Index (CSI) was correlated with drought resistance in pines by Kolyoreas (1958), and in rice by Murty and Majumdar (1962). Sinha *et al.* (1996) have reported that *A.auriculiformis* had maximum CSI of 96.26%. In *A.crassicarpa* they reported a CSI of 92.77% and in *A. holocericea* a CSI of 84.28%. Under various stress treatments *A.auriculiformis* showed comparatively higher values of CSI in salinity stressed (100 mol m^{-3}) plants. The CSI values were in the order S > C > F > D. In the present study the chlorophyll stability index in *A.auriculiformis* was found to be 54.03%. A higher value of 68.16 % was noticed in 9 day water stressed seedlings which means that chlorophyll stability increases followed by drought stress in *A.auriculiformis*. The CSI of *A.aulacocarpa* (17.9%), *A.holocericea* and *A. mangium* were low when compared to *A.auriculiformis*. In a study to assess the drought hardiness of *Acacia* species, by Sivasubramiam (1992), *A.auriculiformis* had the highest CSI of 96.6% with a CSI value of 84.28% in *A.holocericea* out of the four species of *Acacia* tested.. He attributes that acacias posses better CSI when compared to other plants.

One aminoacid proline is synthesised at an accelerated rate during water stress while its oxidation is inhibited, resulting in large accumulation of proline in water stressed tissues (Boggess *et al.* 1976, Stewart *et al.* 1977). It has been advocated that this is advantageous to the plant in coping with drought and that proline accumulation be used as an indicator in selecting for drought resistance in crop breeding (O'Toole and Cheung 1970, Singh *et al.* 1973). But Hanson *et al.* (1977) suggest that the opposite may be true proline accumulation is indicative of the stress damage (reviewed by Stewart and Hanson 1980). Proline accumulation generally begins after water deficit has become severe enough to prevent growth and stomatal closure (Mc Michael and Elmore 1977). Flowers *et al.* (1977) attribute proline accumulation to be closely associated with survival in the face of environmental stress. Increased accumulation of proline is linked to drought tolerance mechanism. In the phyllodes of *A.auriculiformis*, which experienced 9 day's stress showed 172 μg g^{-1} of proline. It was higher than the amount of proline accumulated due to similar water stress in other 3 species. The amount of proline was 142, 82 and 76 μgm g^{-1} in *A.aulacocarpa, A.holocericea and A.mangium.* In *A.auriculiformis*, an inevitably high amount of proline (525 μgm g$^{-1)}$was reported by Chandrababu *et al* (1987). This may be due to the increased level of drought stress experienced by the plants. In the present studies, proline was also found to accumulate in salt treated (100 m mol^{-3}) plants in *A.auriculiformis* (140 μg g^{-1}) and *A.aulacocarpa* (130 μg g^{-1}S). This may due to the combined effect of water stress and salinity in both species. However, flooding stress did not favor proline formation in any of the species studied. Based on the earlier works on proline it can be concluded that proline also plays a very prominent role during drought stress in *Acacia* species either as an osmotic substance helping in the tolerance mechanism or as an indicator of drought damage.

Summary and Conclusions

SUMMARY AND CONCLUSIONS

1. In *A. auriculiformis* phyllodes from 4 to 15 are physiologically mature.
2. A higher photosynthetic rate was found in seedlings compared to trees of *A.auriculiformis*.
3. Continous water stress exceeding 12 days are harmful to the seedlings of *Acacia*..
4. Partial stomatal closure is prevalent during midday in all the species examined which is helpful to prevent excessive water loss. At the same time this does not adversely affect the photosynthetic rate.
5. Water status of trees becomes poor during stress period and the roots are probably not deep enough to collect water from deeper layers.
6. Trees show very low predawn and midday water potential when compared to many other tropical trees reported in literature.
7. The trees are able to photosynthesise at very low light intensities, the light compensation point being at a PFD of 50 μmol m^{-1} s^{-1}. A maximum photosynthetic rate of 14 μmol m^{-1} s^{-1} at a light intensity of $\approx$ 1200 μmol m^{-1} s^{-1} leads to light saturatation.
8. Transpiration rates vary between 5 to 14 m mol m^{-2} s^{-1} in seedlings and between 2 and 8 mmol m^{-2} s^{-1} in trees.
9. Average water consumption per tree has been extrapolated to be 5.85 mm or 14.6 litre per tree per day with a planting density of 4440 trees ha^{-1}.
10. The plant can overcome short periods of water stress by the accumulation of proline in the phyllodes.
11. Comparatively better chlorophyll stability index in *A. auriculiformis* shows its drought tolerance character.
12. Growth occurs in all seasons but slows down under drought conditions.

13. Plants can survive flooding and salinity stress for short periods.

14. Compared to 3 other species *of Acacia, A. auriculiformis* shows better WUE.

15. *A. mangium* shows higher midday water potential in flooding stressed plants.

16. *A.mangium* shows higher rates of transpiration during flooding stress.

17. Stomatal conductance was very low from 1100 to 1300 hours in *A.mangium.*

18. In *A. auriculiformis,* after 12 days of drought stress photosynthetic mechanism fails to function.

19. Continuous flooding for more than 3 days reduces photosynthetic rate to 3 μmol m^{-2} s^{-1} in *A.mangium* whereas even after 20 days there was no change in *A.auriculiformis.*

20. When water is more, *A.auriculiformis* transpires more showing a value of 12 -14 mmol m^{-2} s^{-1}.

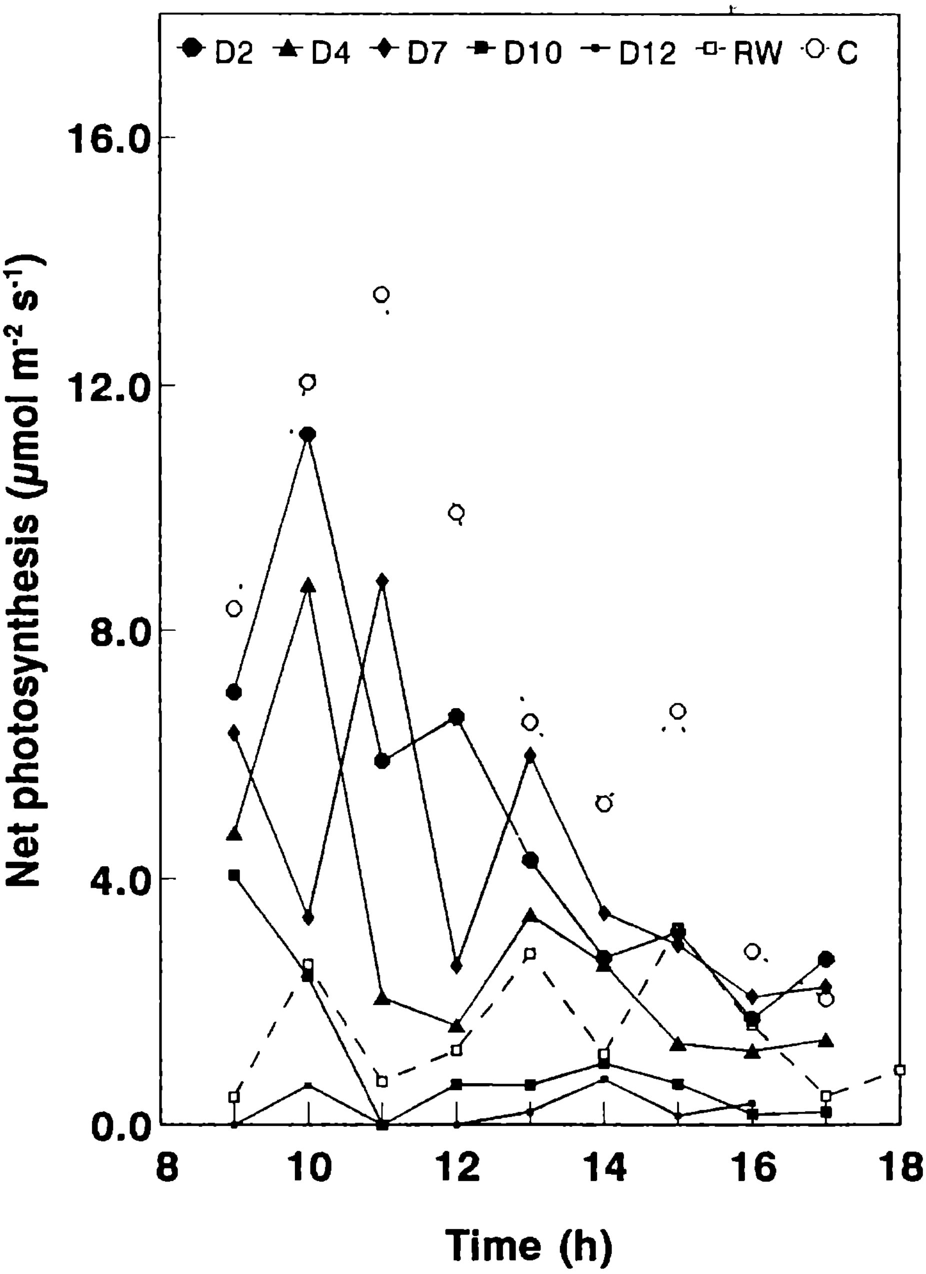

Fig. 1. Diurnal variations in photosynthesis in the seedlings of *A. auriculiformis* under normal watering and drought stress for various days. The symbols D2, D4, D7, D10, D12 indicate water stress days given; RW is rewatering effect and C is control.

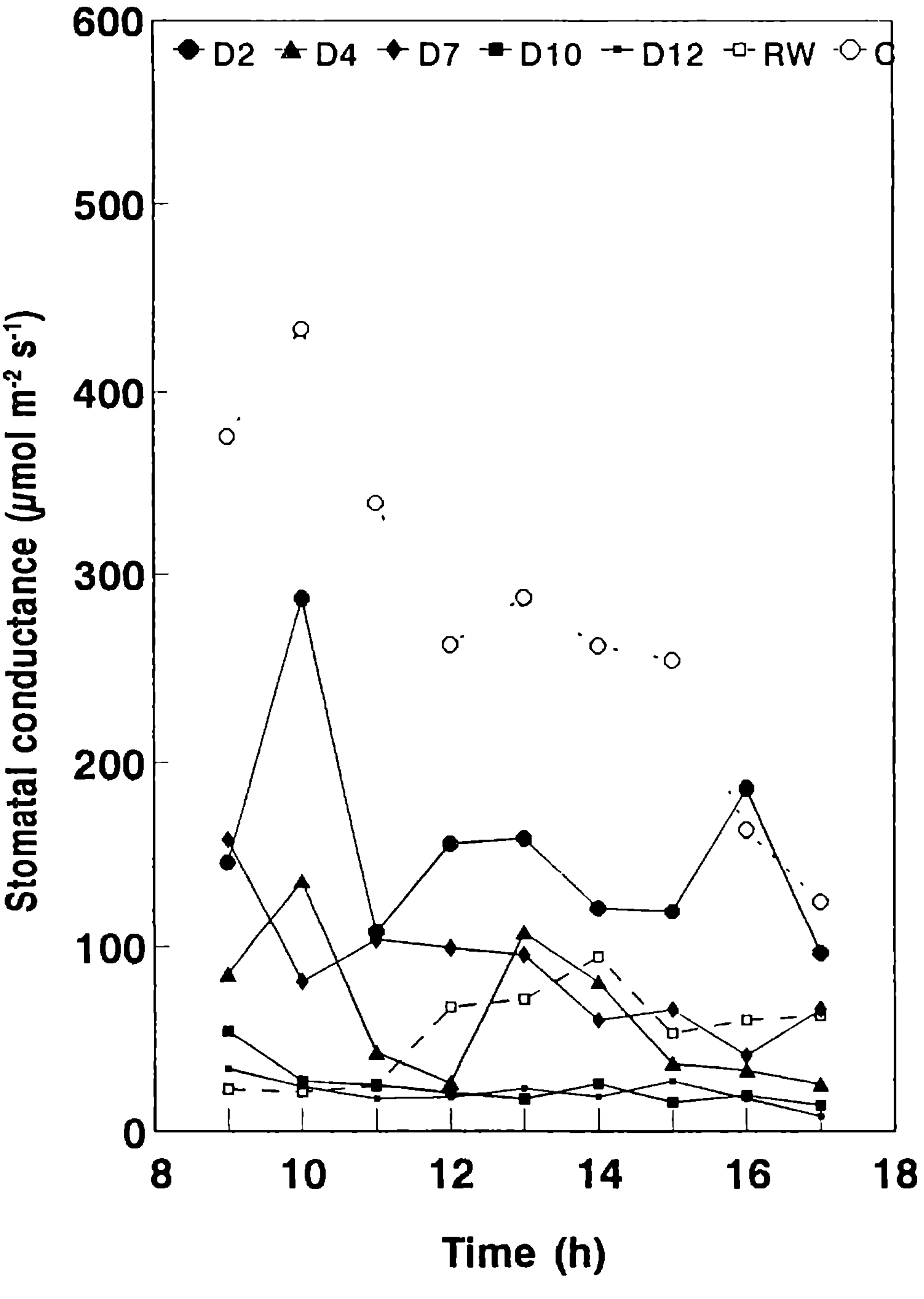

Fig.2 Diurnal variations in stomatal conductance inthe seedlings of *A.auriculiformis* under normal watering and drought stress for various days. The symbols D2, D4, D7, D10, D12 indicate water stress days given; RW is rewatering effect and C is control.

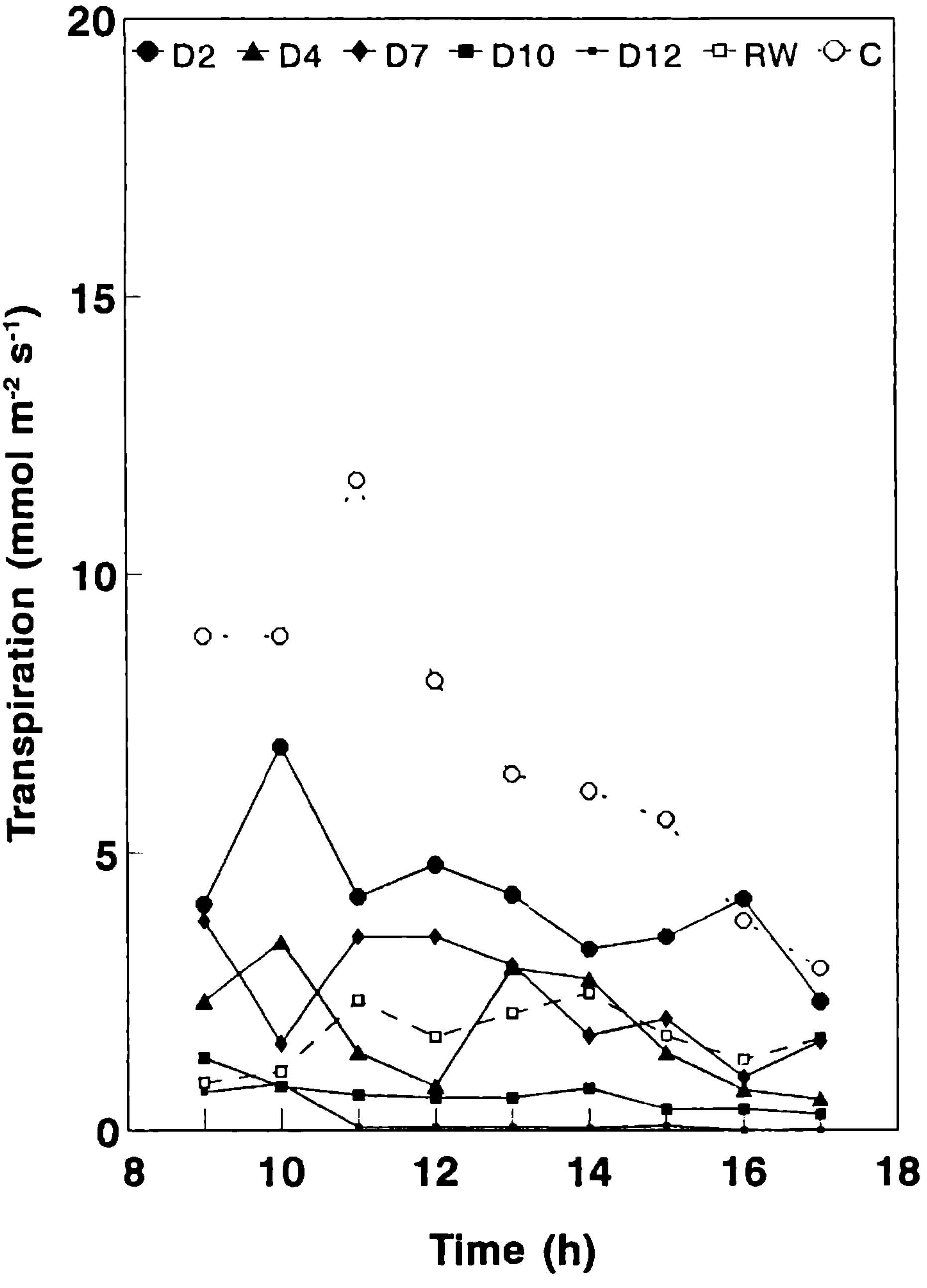

Fig. 3. Diurnal variations in transpiration in the seedlings of *A.auriculiformis* under normal watering and drought stress for various days. The symbols D2, D4, D7, D10, D12 indicate water stress days given; RW is rewatering effect and C is control.

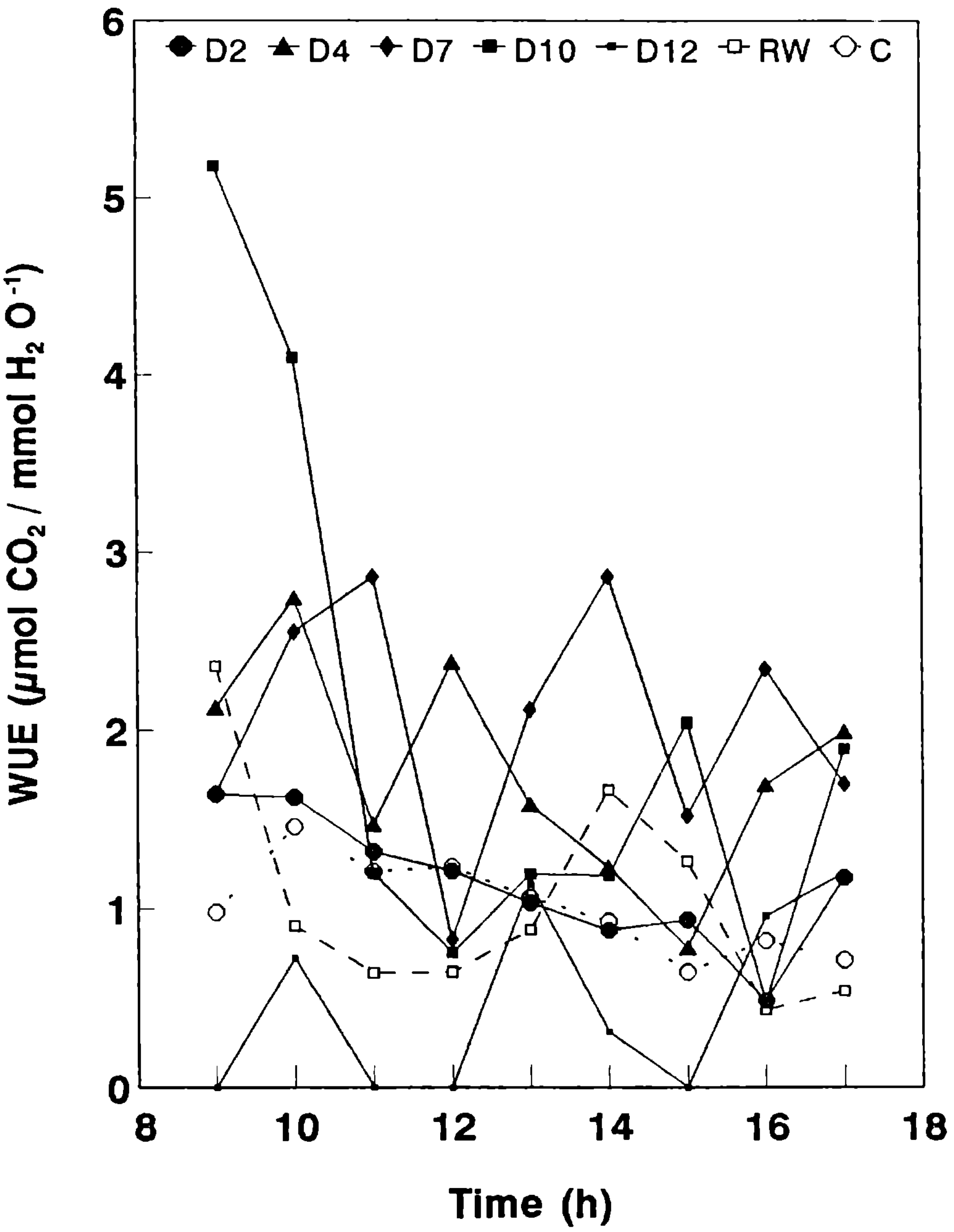

Fig. 4. Diurnal variations in water use efficiency (WUE) in seedlings of *A.auriculiformis* under normal watering and drought stress for various days. The symbols D2, D4, D7, D10, D12 indicate water stress days given; RW is rewatering effect and C is control.

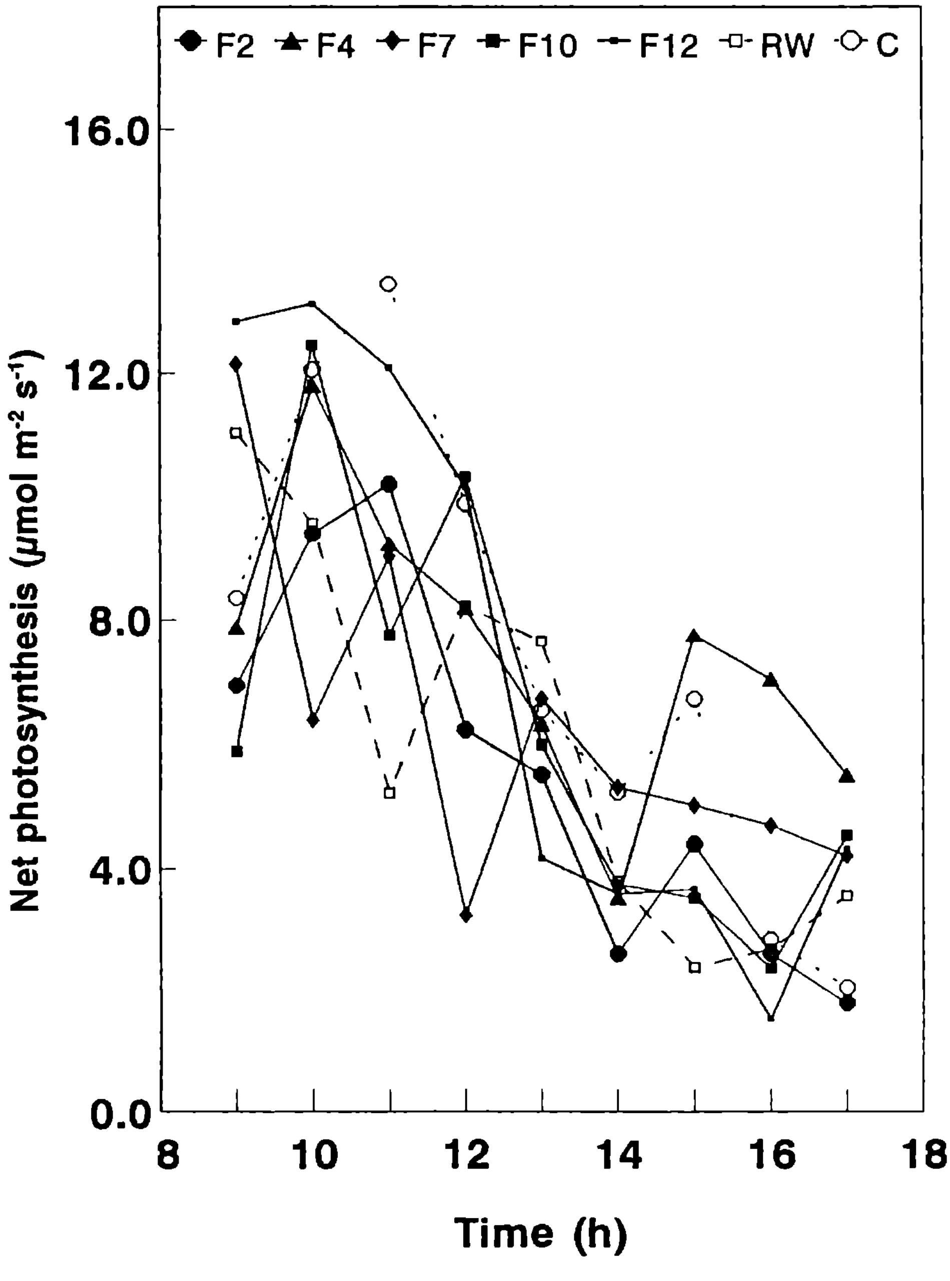

Fig.5. Diurnal variations in photosynthesis in the seedlings of *A. auriculiformis* under normal watering and flooding stress for various days. The symbols F2, F4, F7, F10, F12 indicate flooding stress days given; RW is stress release effect and C is control.

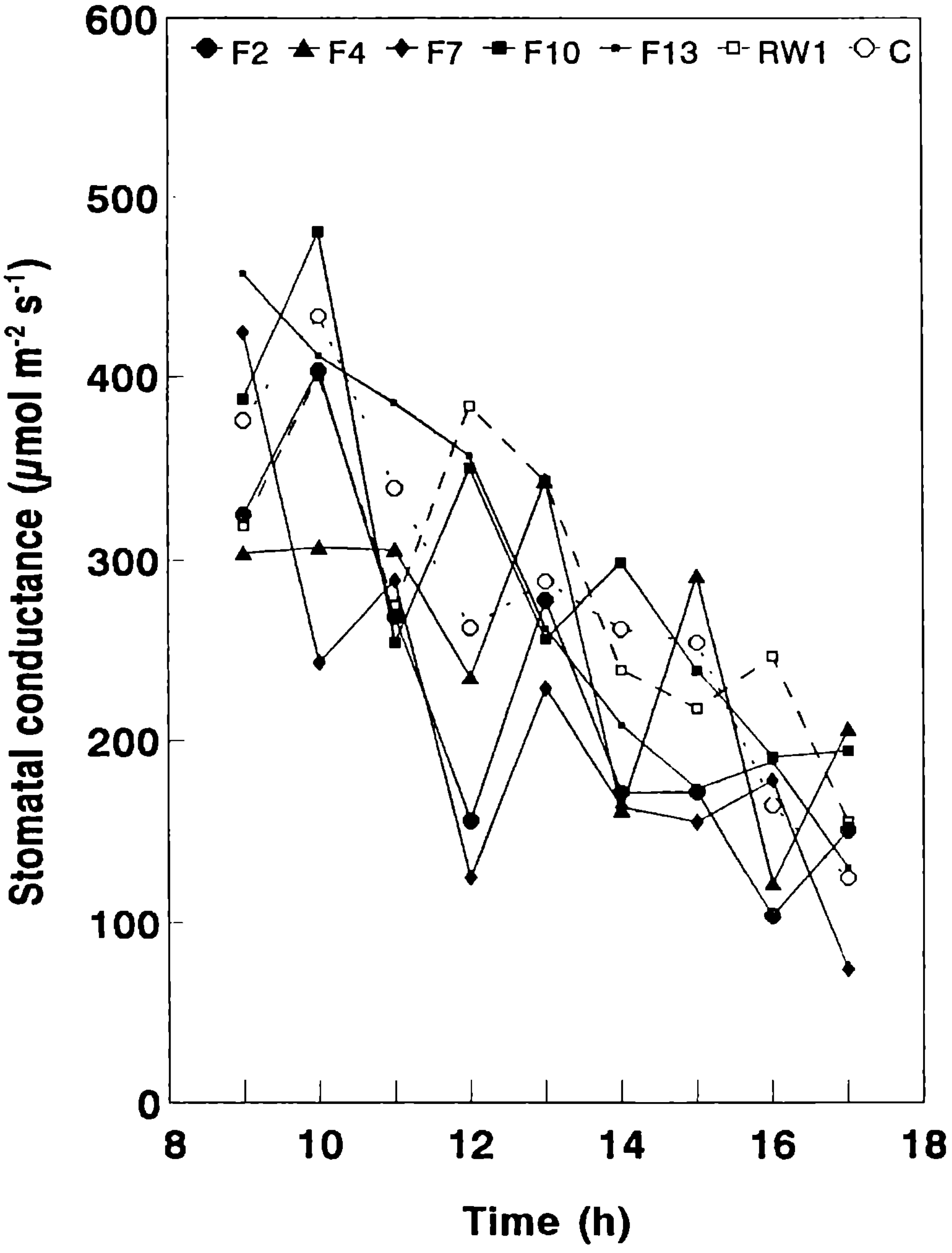

Fig.6 Diurnal variations in stomatal conductance in the seedlings of *A. auriculiformis* under normal watering and flooding stress for various days. The symbols F2, F4, F7, F10, F12 indicate flooding stress days given; RW is stress release effect and C is control.

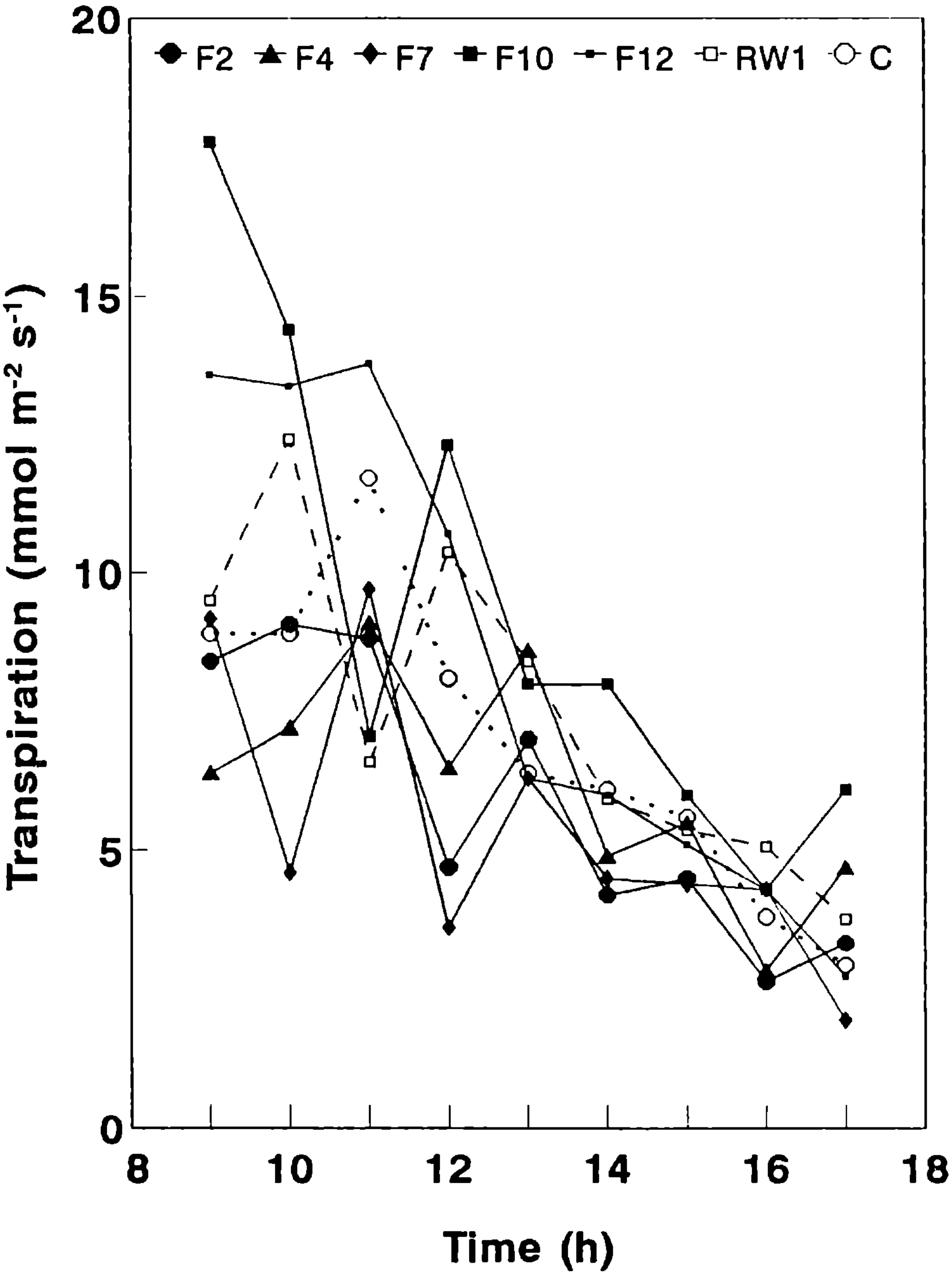

Fig.7. Diurnal variations in transpiration in seedlings of *A.auriculiformis* under normal watering and flooding stress for various days. The symbols F2, F4, F7, F10, F12 indicate flooding stress days given; RW1 is stress release effect and C is control.

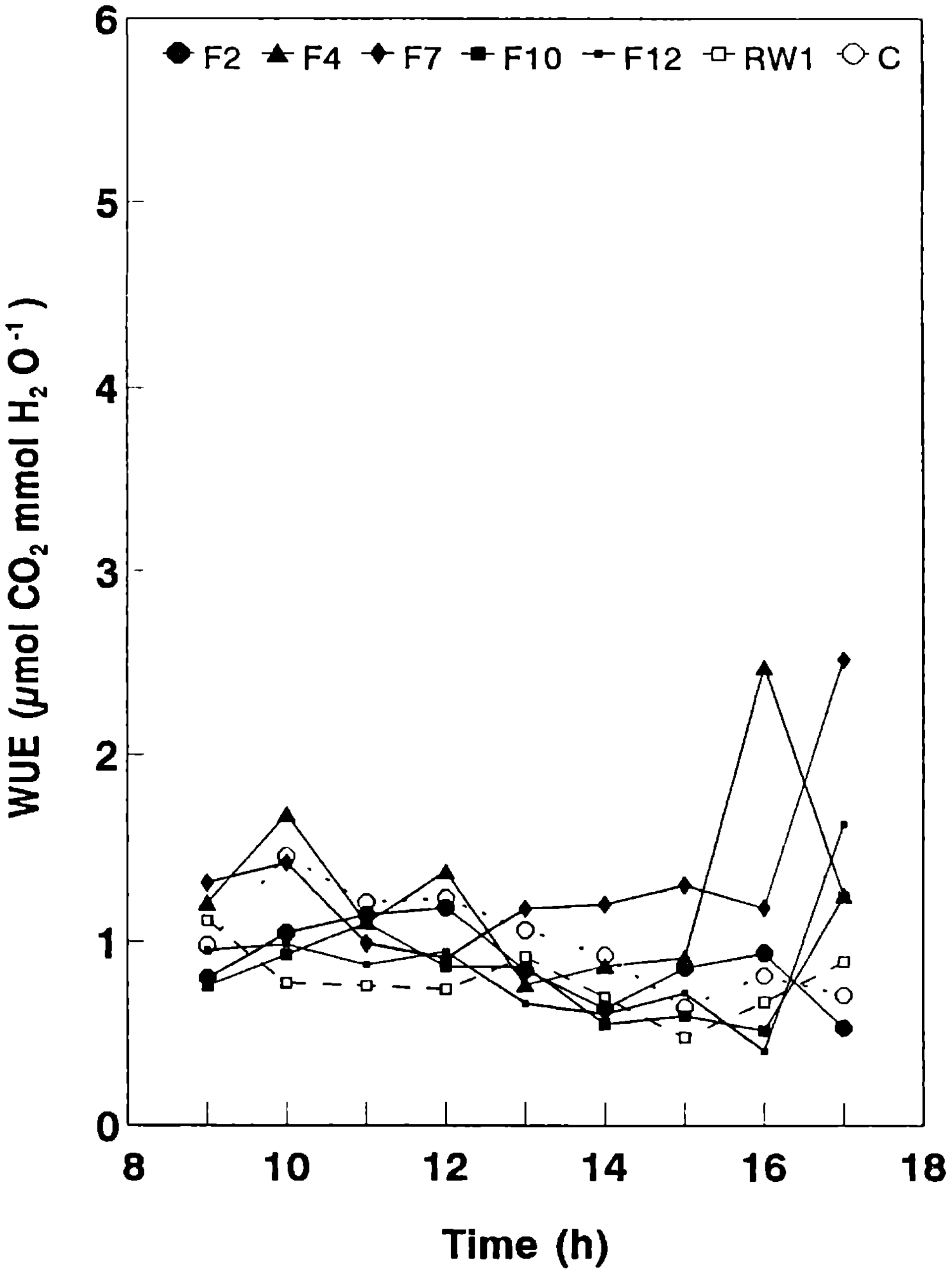

Fig. 8. Diurnal variations in water use efficiency (WUE) in seedlings of *A.auriculiformis* under normal watering and flooding stress for various days. The symbols F2, F4, F7, F10, F12 indicate flooding stress days given; RW1 is stress release effect and C is control.

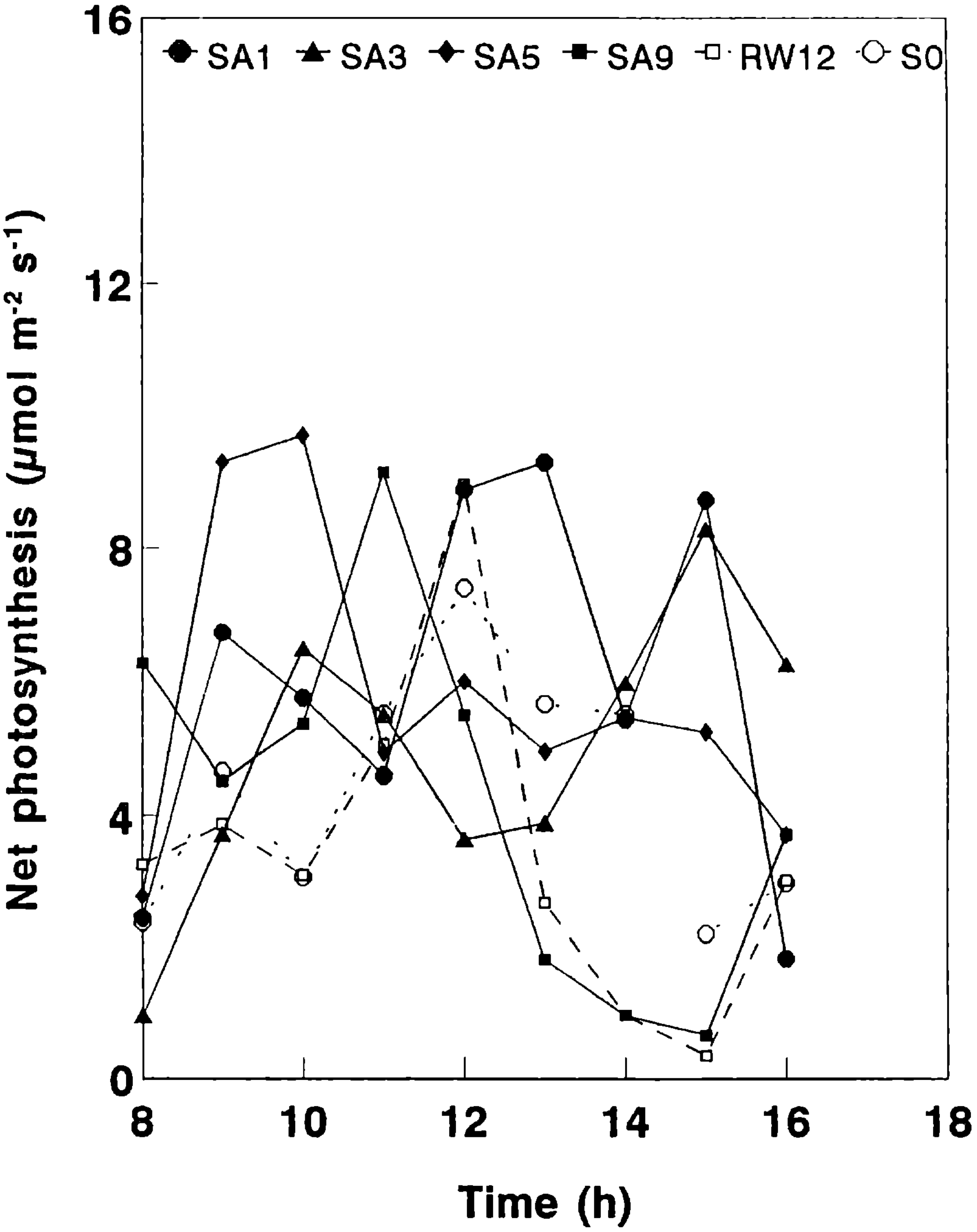

Fig. 9. Diurnal variations in photosynthesis in seedlings of *A. auriculiformis* under normal watering and salinity stress (100 mol m^{-3}) stress for various days. The symbols SA1, SA3, SA5, SA9 indicate days of salinity stress given; RW12 is stress release effect and S0 is control.

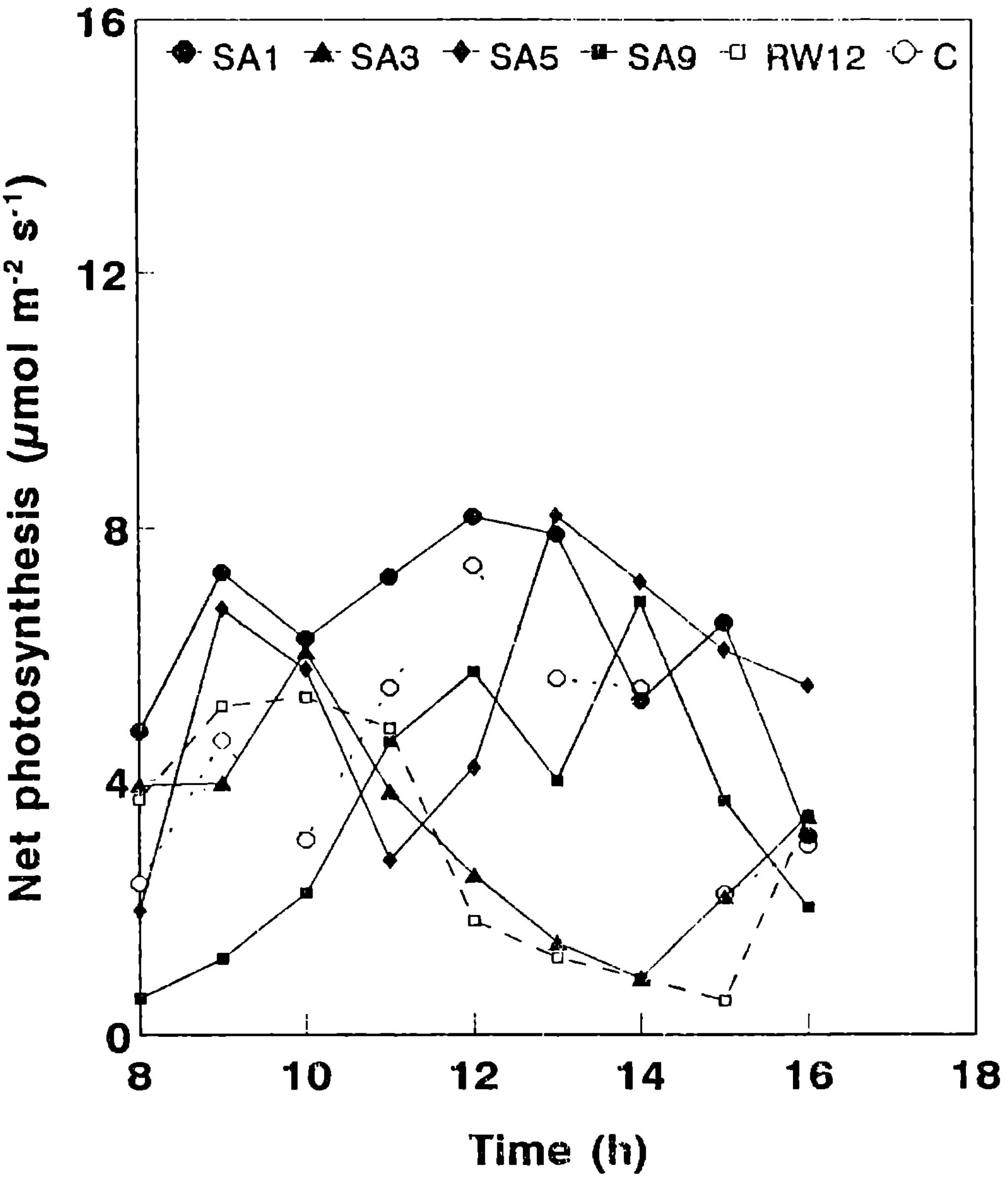

Fig. 10. Diurnal variations in photosynthesis in seedlings of *A. auriculiformis* under normal watering and salinity stress (200 mol m^{-3}) stress for various days. The symbols SA1, SA3, SA5, SA9 indicate days of salinity stress given; RW12 is stress release effect and C is control.

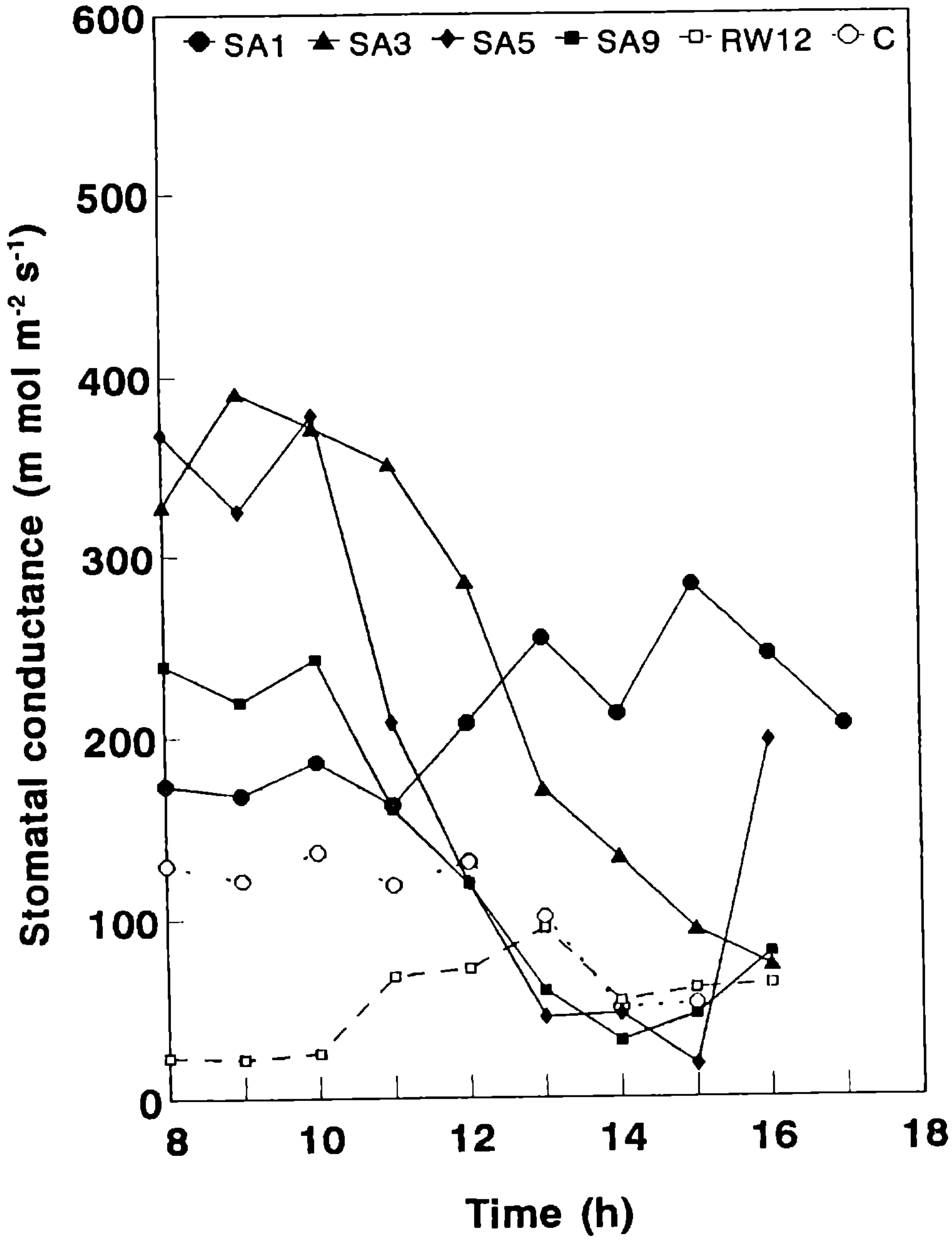

Fig. 11. Diurnal variations in stomatal conductance in seedlings of *A. auriculiformis* under normal watering and salinity stress (100 mol m^{-3}) stress for various days. The symbols SA1, SA3, SA5, SA9 indicate days of salinity stress given; RW12 is stress release effect and C is control.

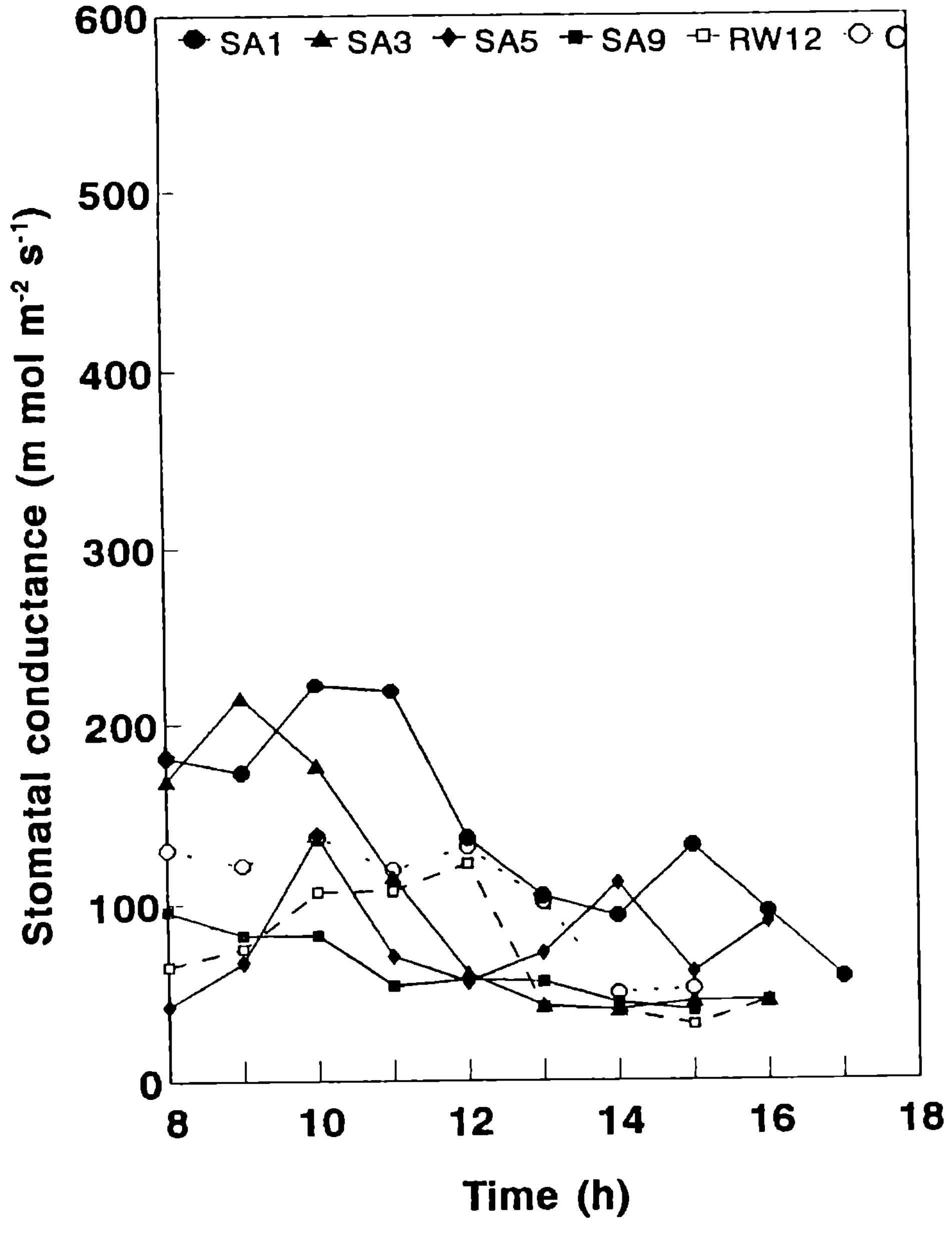

Fig. 12. Diurnal variations in stomatal conductance in seedlings of *A. auriculiformis* under normal watering and salinity stress (200 mol m^{-3}) stress for various days. The symbols SA1, SA3, SA5, SA9 indicate days of salinity stress given; RW12 is stress release effect and C is control.

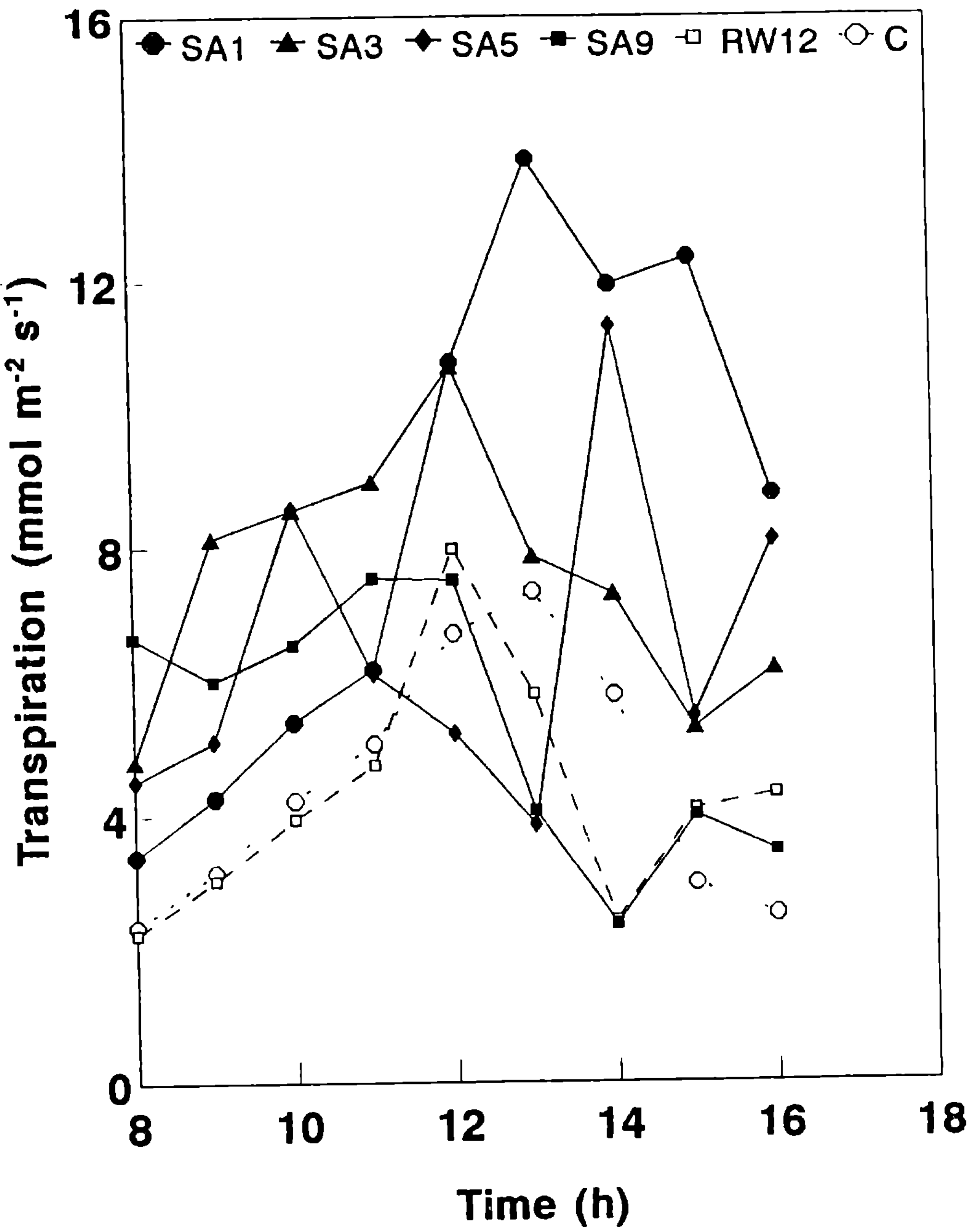

Fig. 13. Diurnal variations in transpiration in seedlings of *A. auriculiformis* under normal watering and salinity stress (100 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate days of salinity stress given; RW12 is stress release effect and C is control.

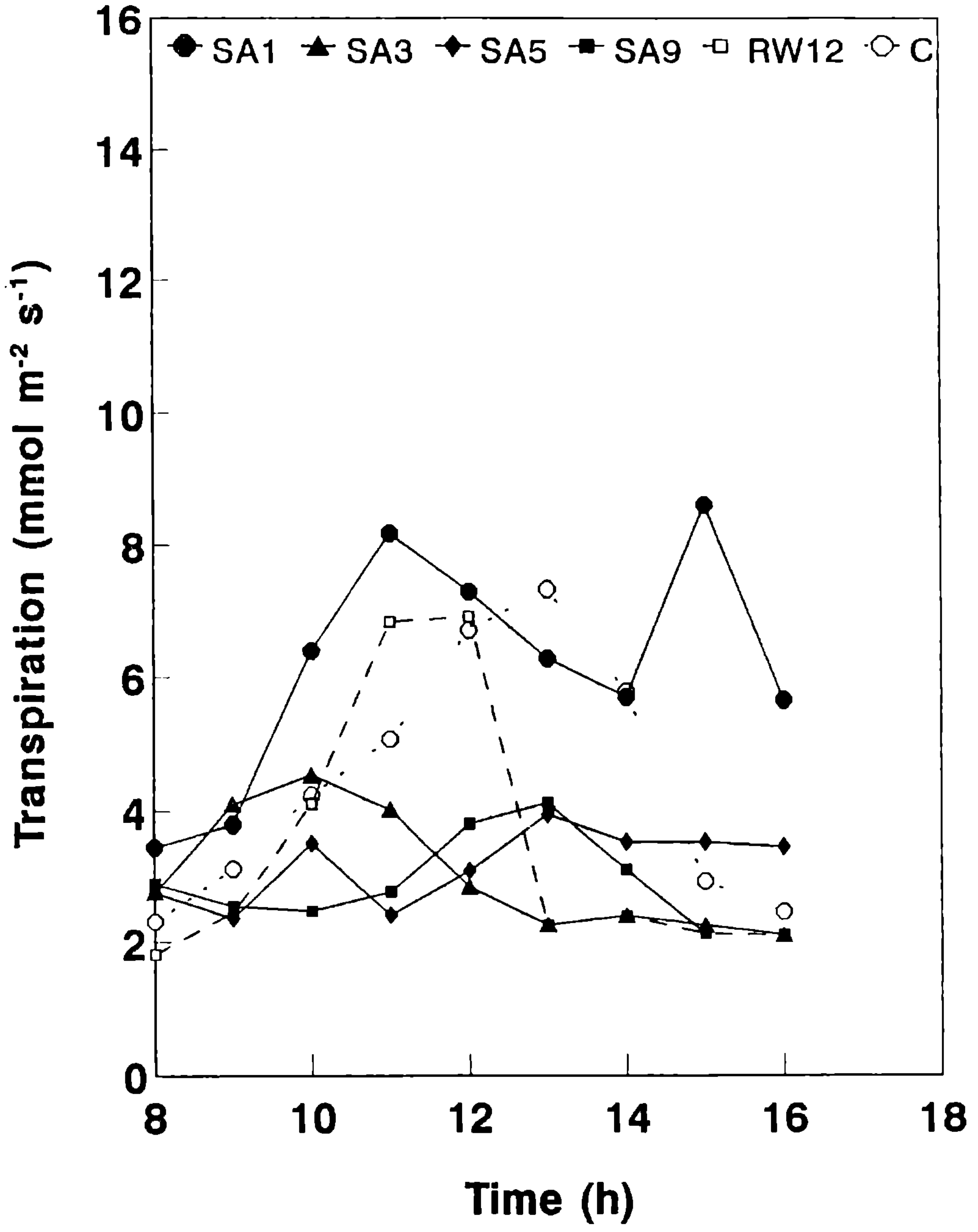

Fig. 14. Diurnal variations in transpiration in seedlings of *A. auriculiformis* under normal watering and salinity stress (200 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate days of salinity stress given; RW12 is stress release effect and C is control.

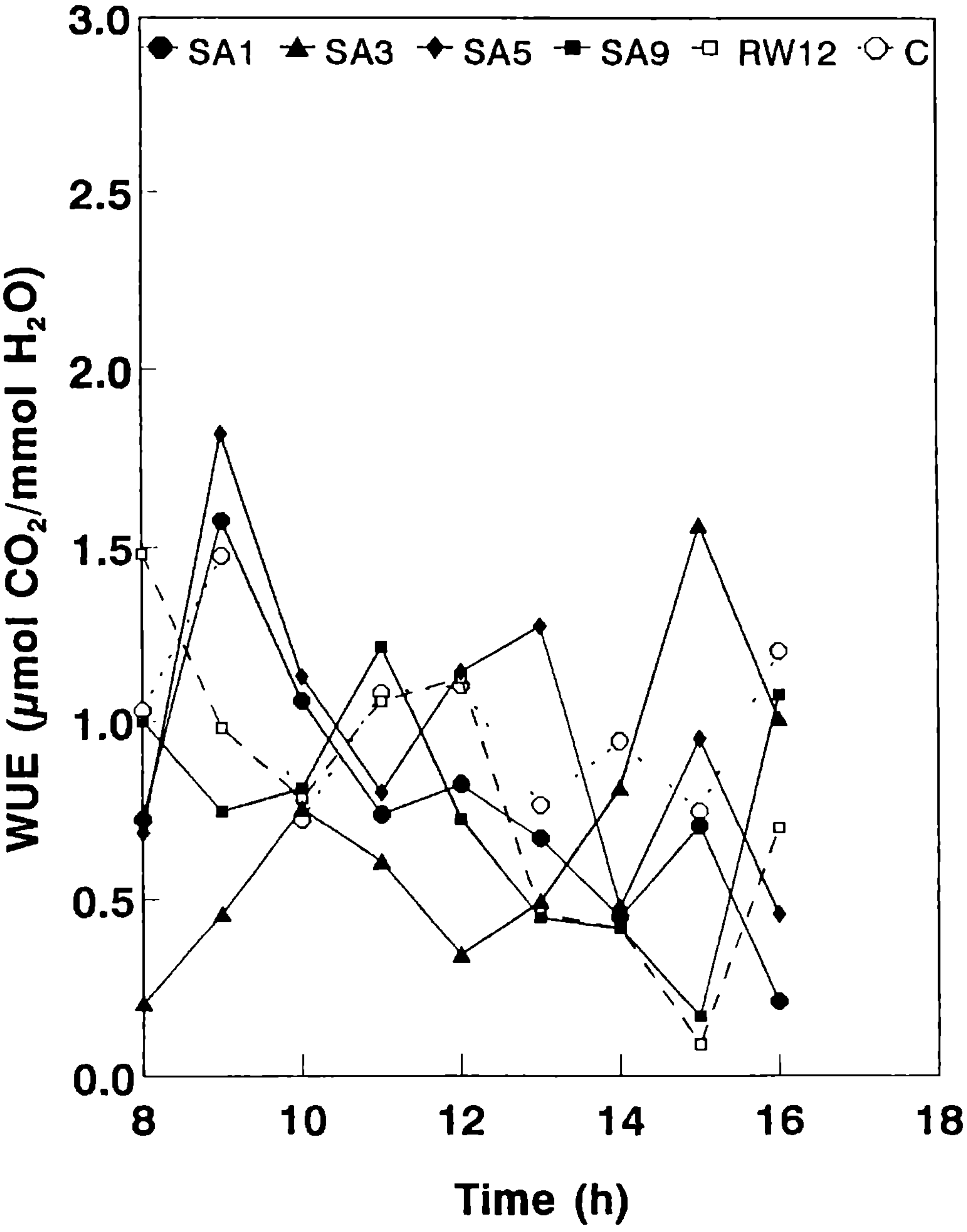

Fig. 15a. Diurnal variations in WUE in seedlings of *A. auriculiformis* under normal watering and salinity stress (100 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate days of salinity stress given; RW12 is stress release effect and C is control.

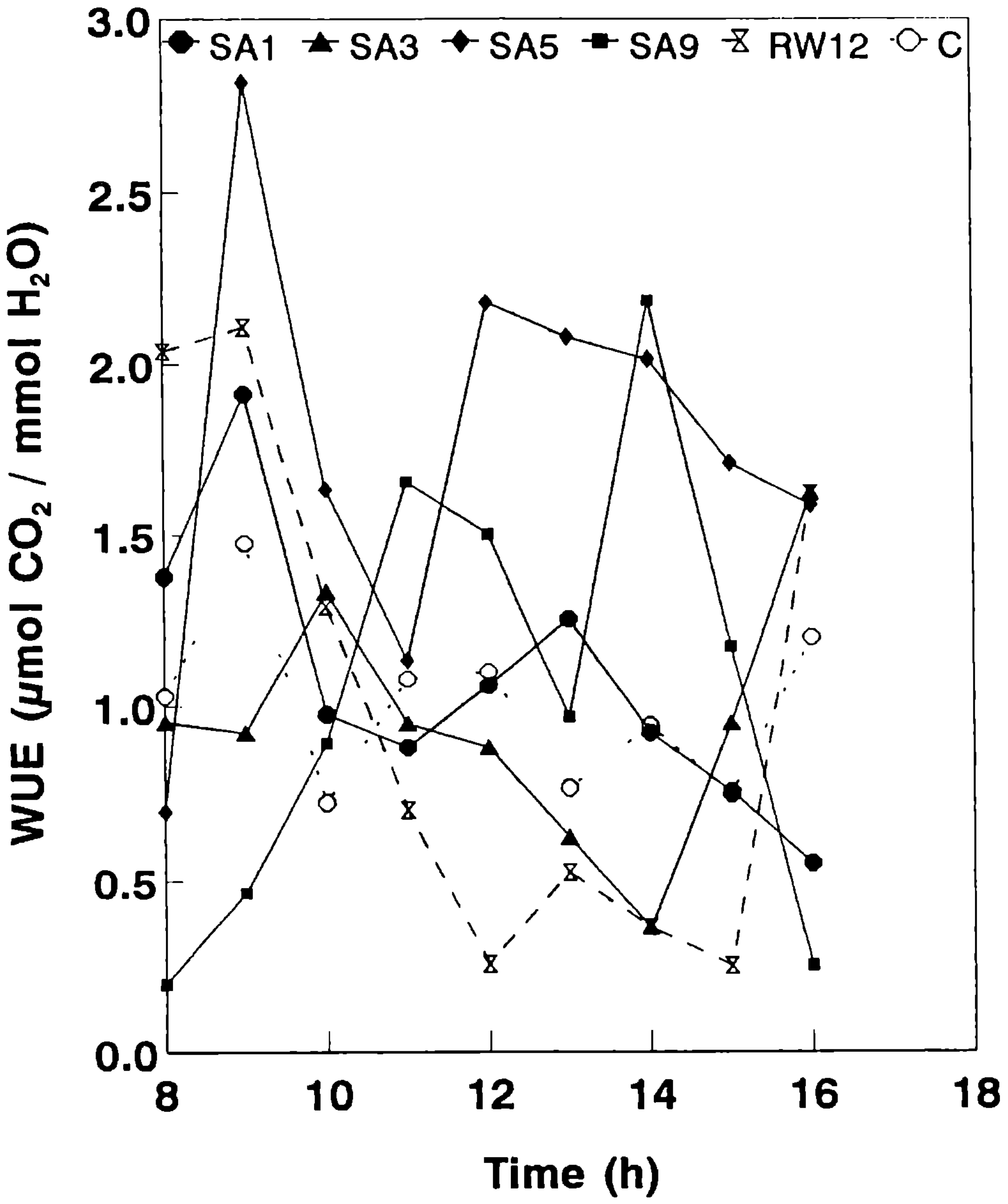

Fig. 15b. Diurnal variations in WUE in seedlings of *A. auriculiformis* under normal watering and salinity stress (200 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate days of salinity stress given; RW12 is stress release effect and C is control.

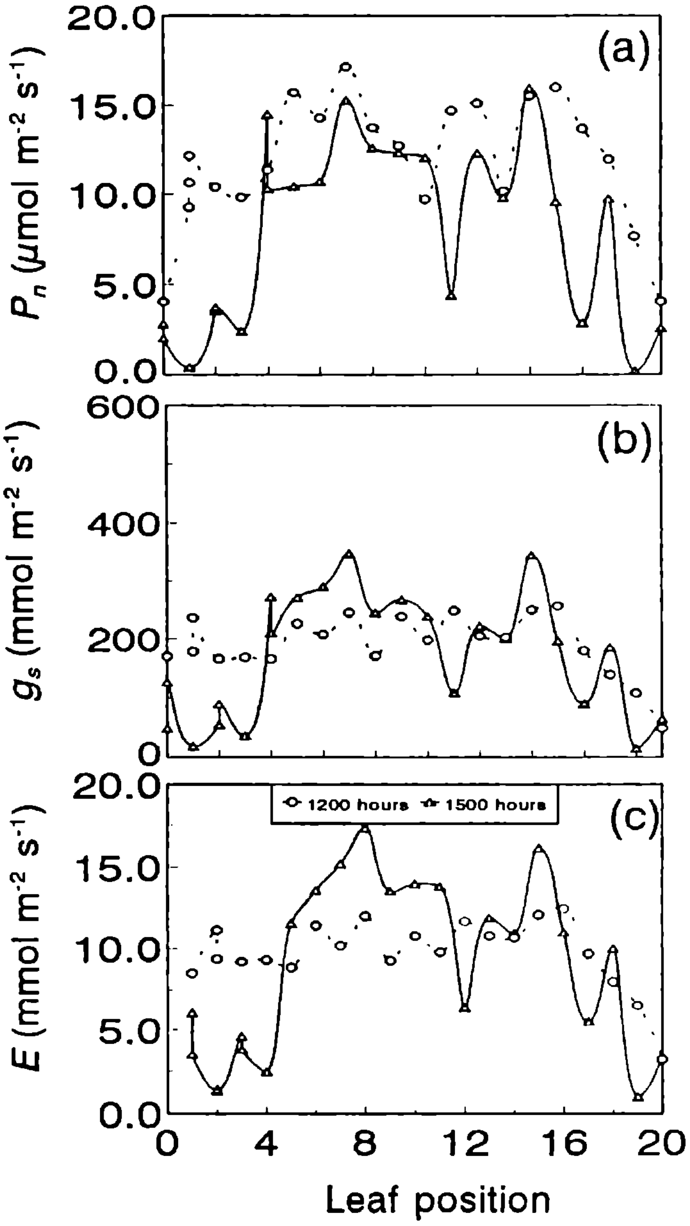

Fig. 16. *A. auriculiformis* Variations in (a) net photosynthesis (P_n), (b) stomatal conductance (g_s)and (c) transpiration (*E*) in phyllodes at different positions measured at 1200 and 1500 hrs.

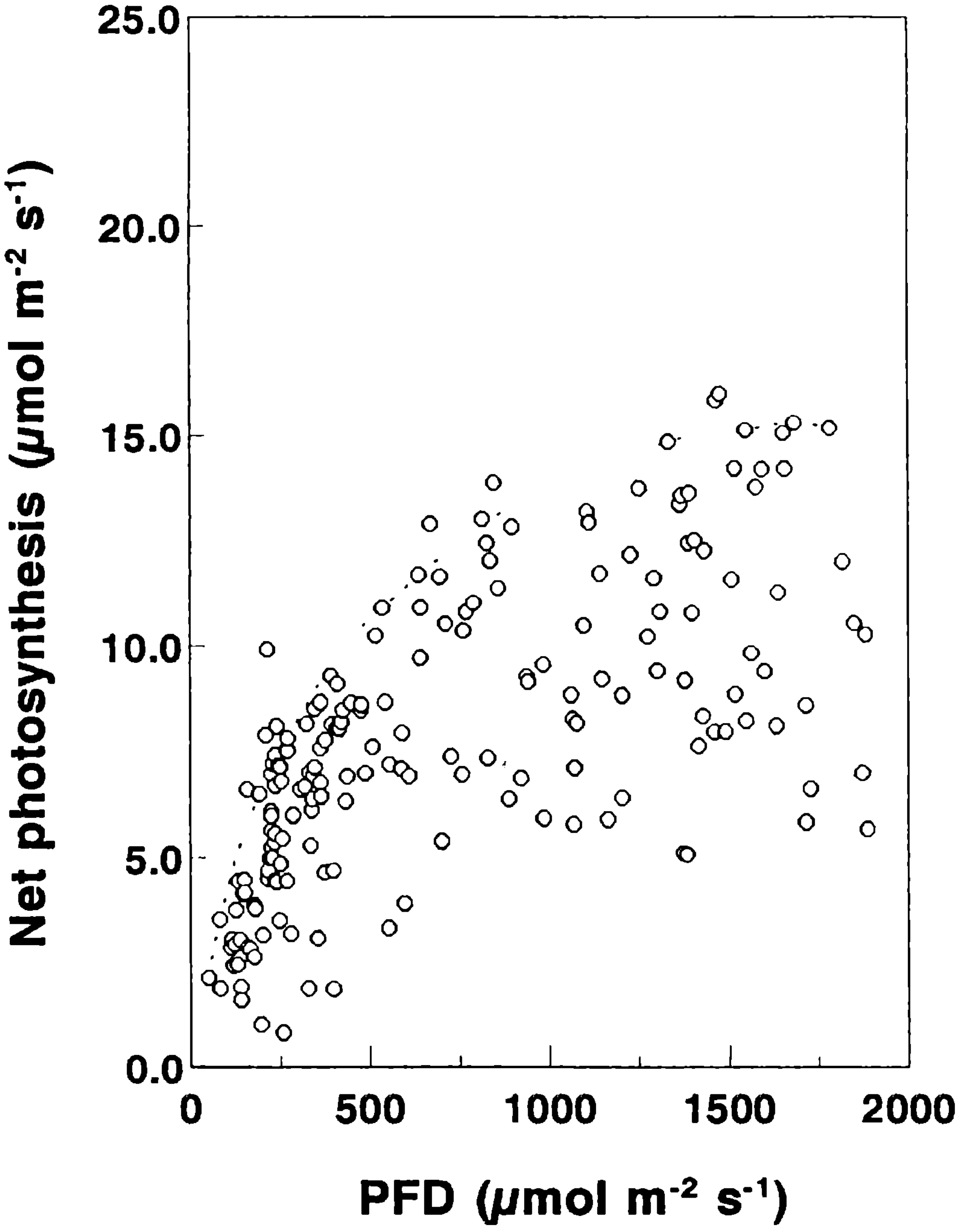

Fig. 17. *A.auriculiformis* - Light response curve

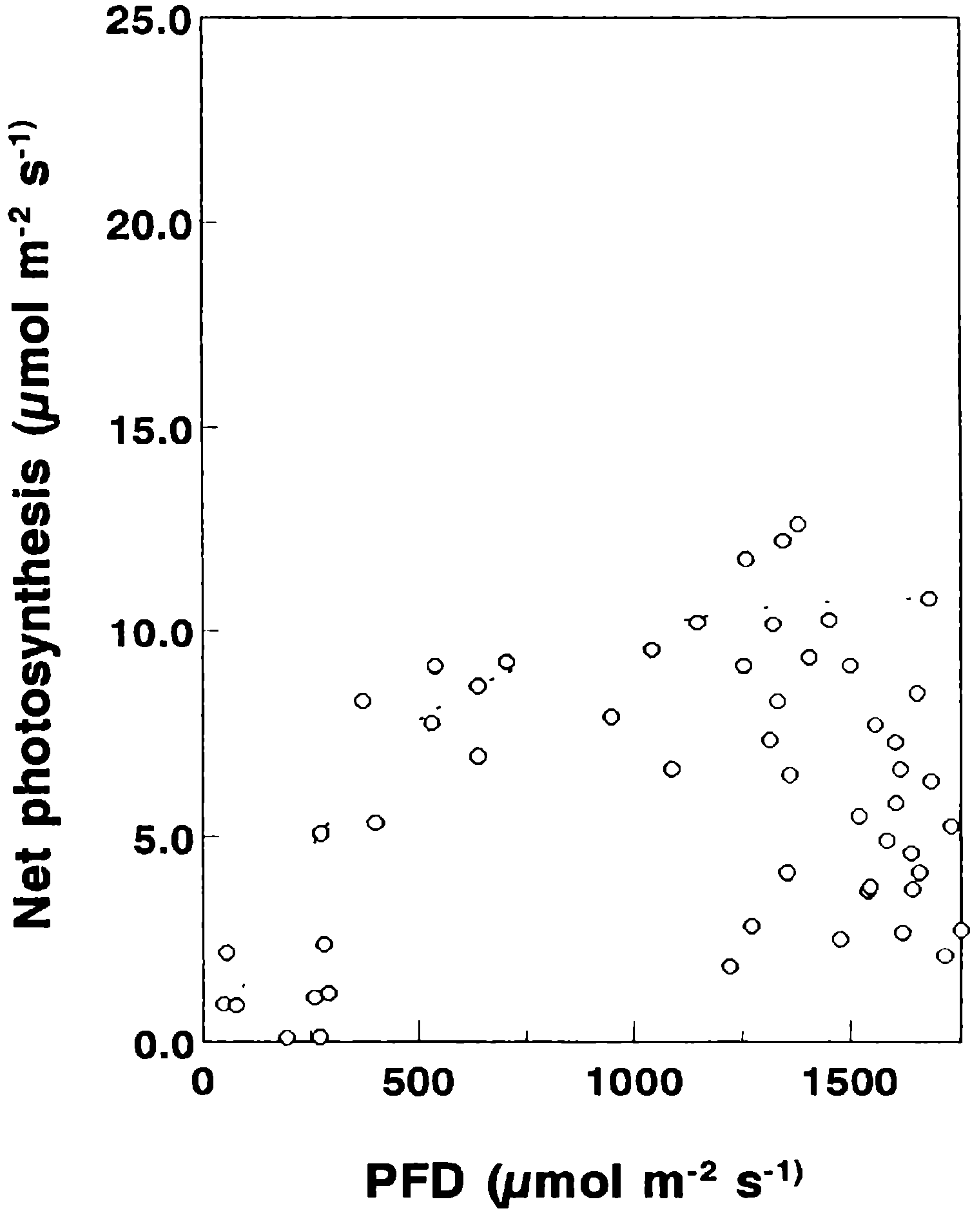

Fig. 18. *A.aulacocarpa* - Light response curve

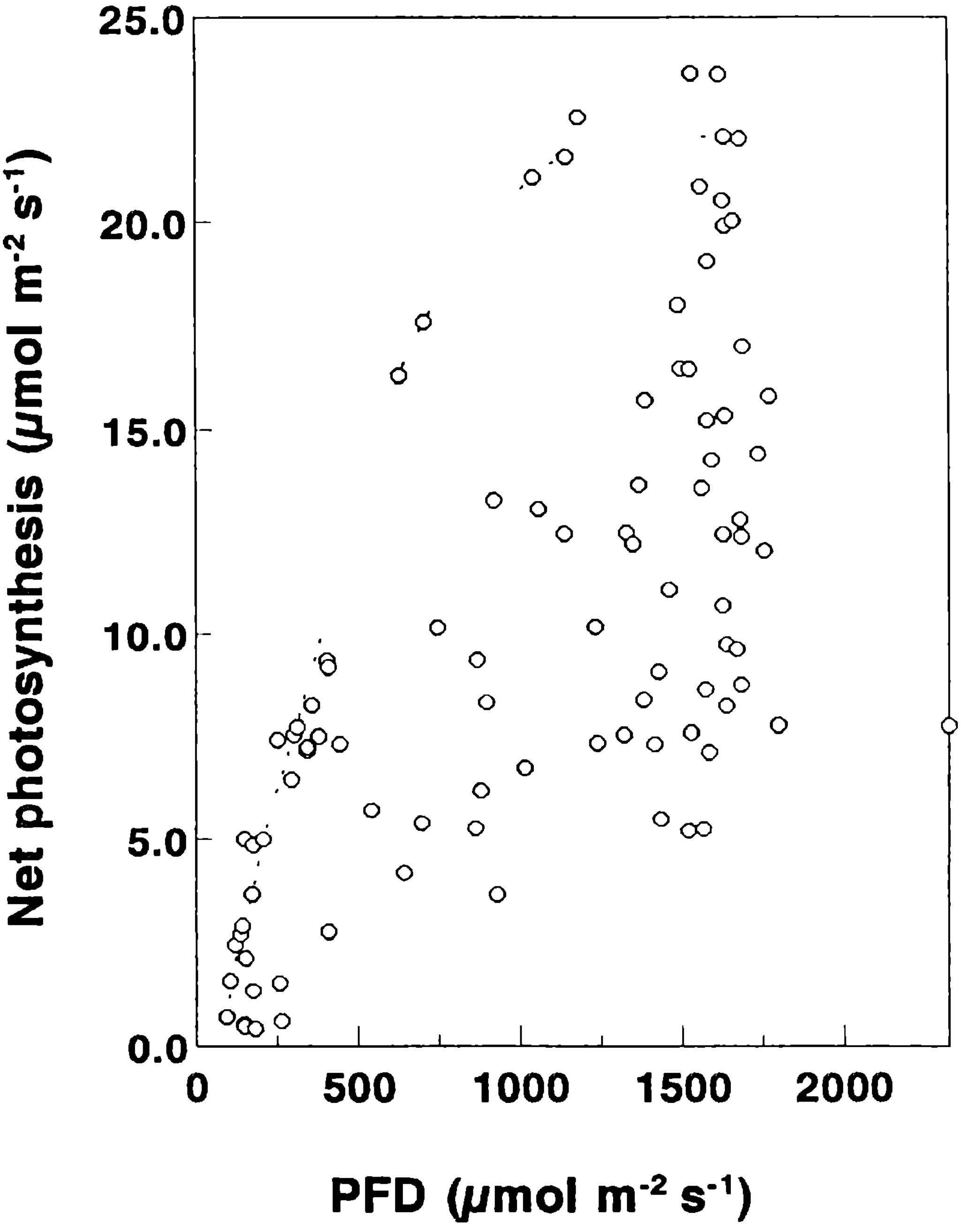

Fig.19. *A.holocericea* - Light response curve

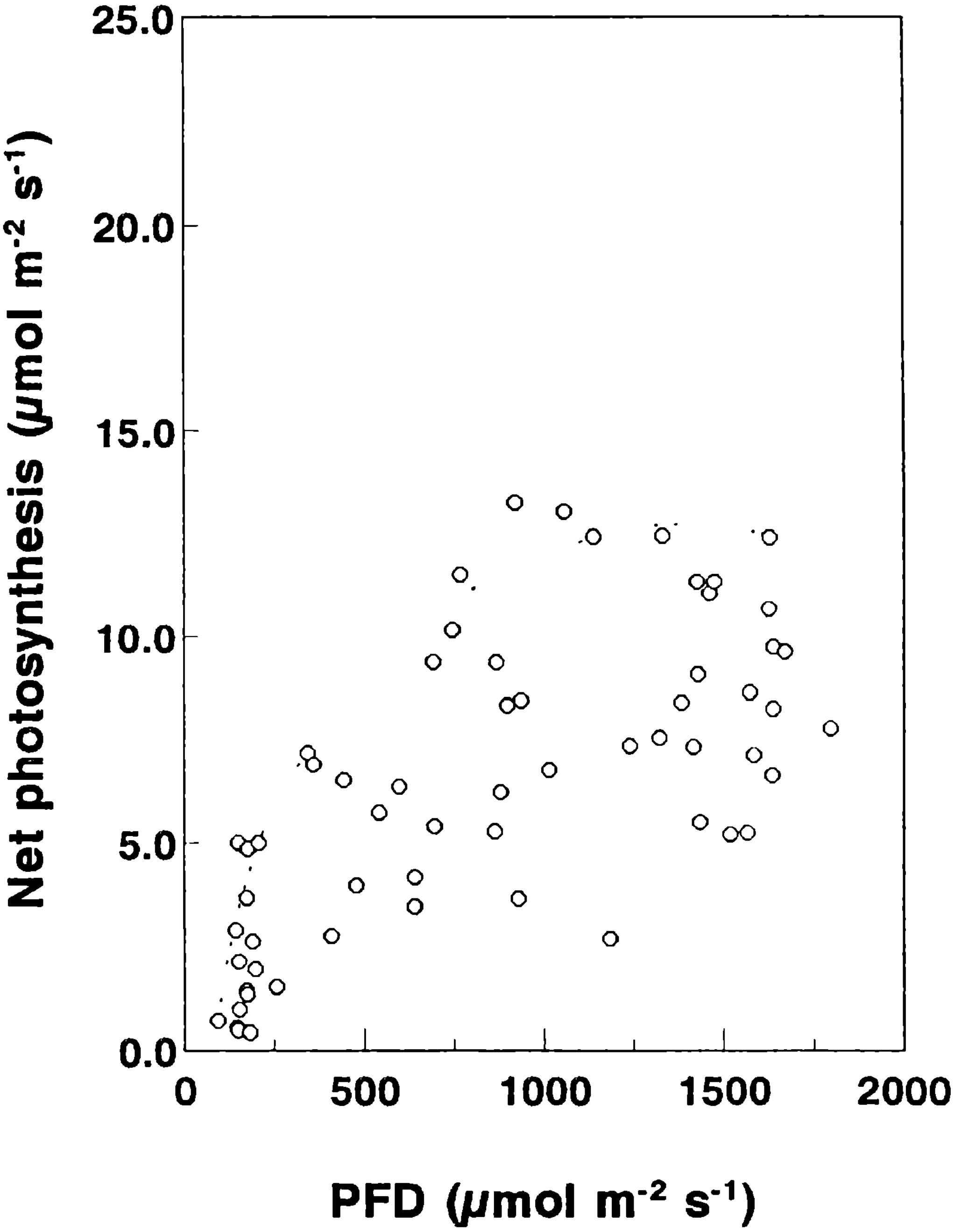

Fig.20. *A.mangium* - Light response curve

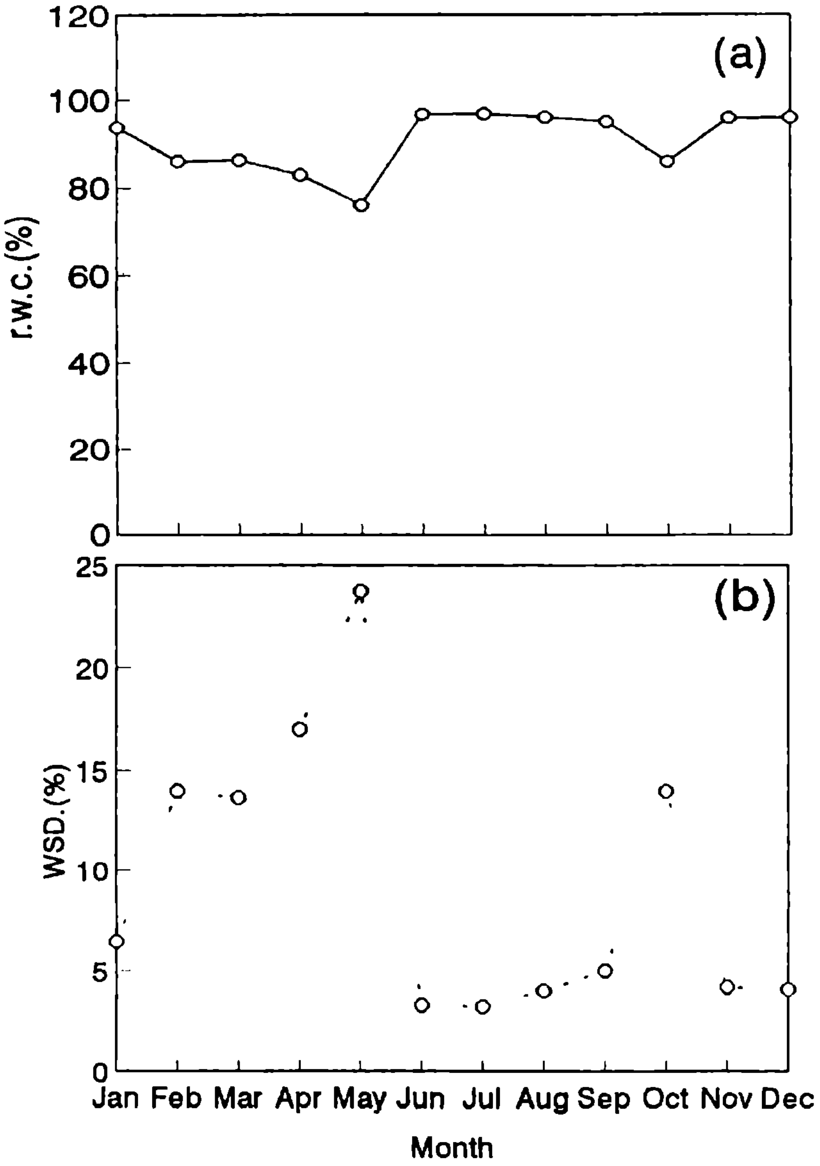

Fig. 21. *A.auriculiformis* - monthly variations in relative water content (RWC) and water saturation deficit in 2 year old *A.auriculiformis*.

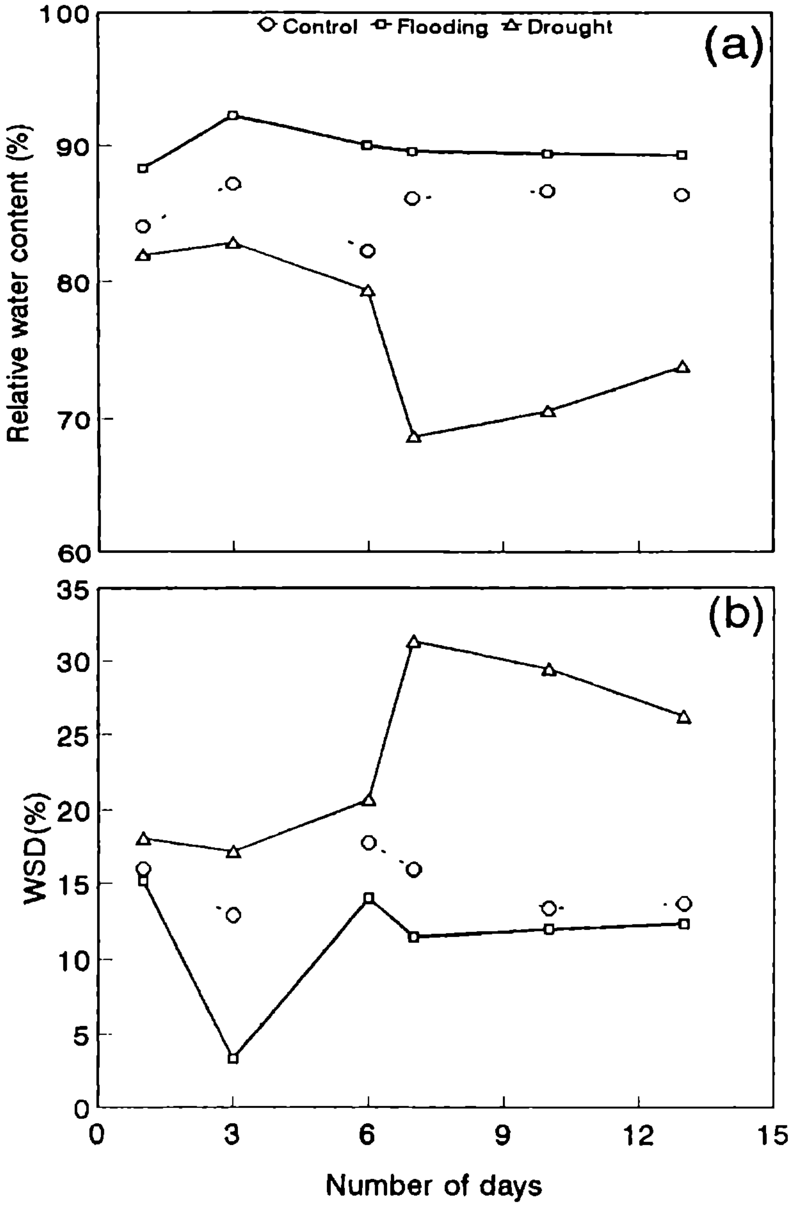

Fig. 22. *A.auriculiformis* - Relative water content and water saturation deficit in the phyllodes under-normal watering, flooding and drought stress for various days.

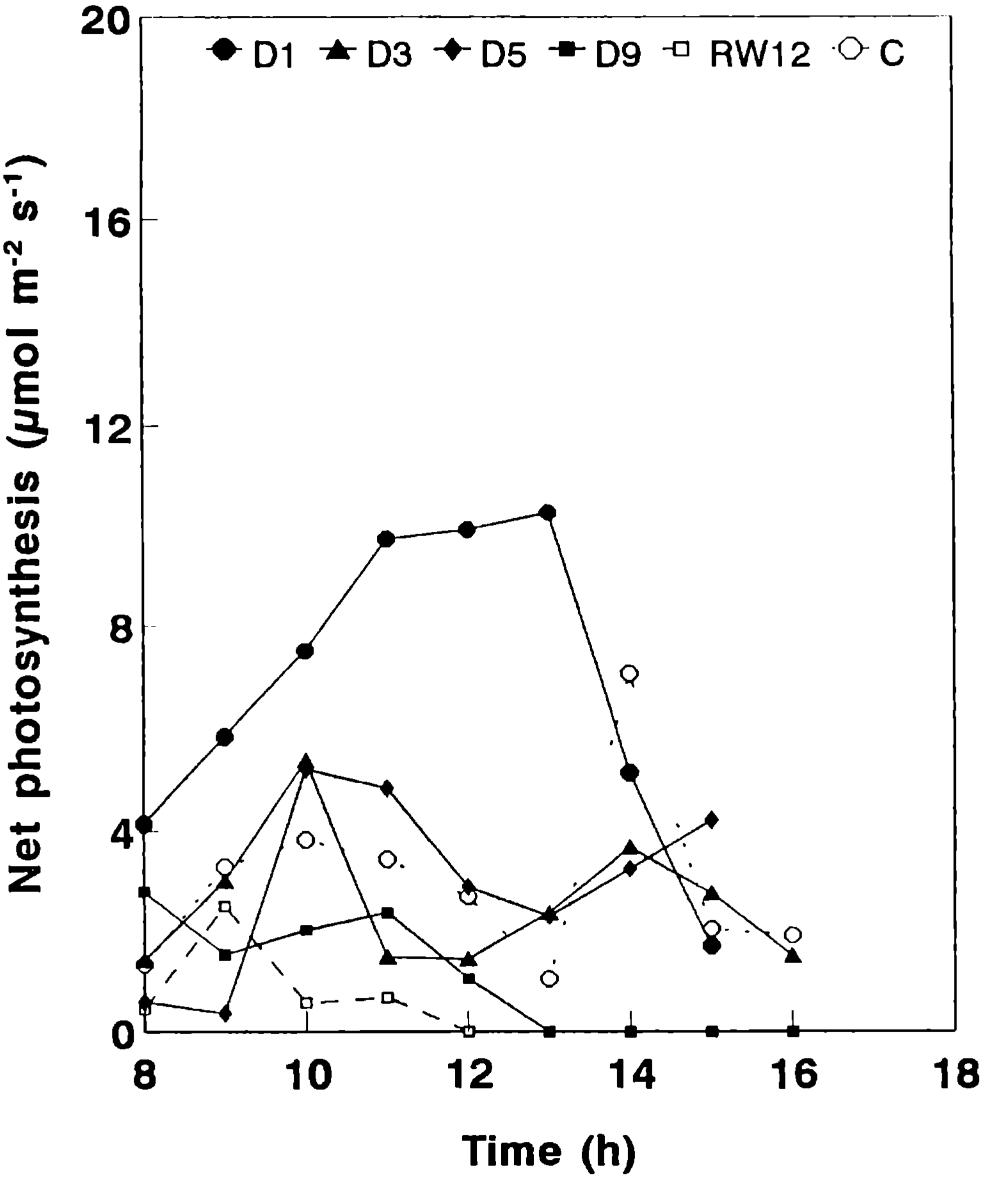

Fig. 23. Diurnal variations in photosynthesis in the seedlings of *A. mangium* under normal watering and drought stress for various days. The symbols D1, D3, D5, D9 indicate water stress days given; RW12 is rewatering effect and C is control.

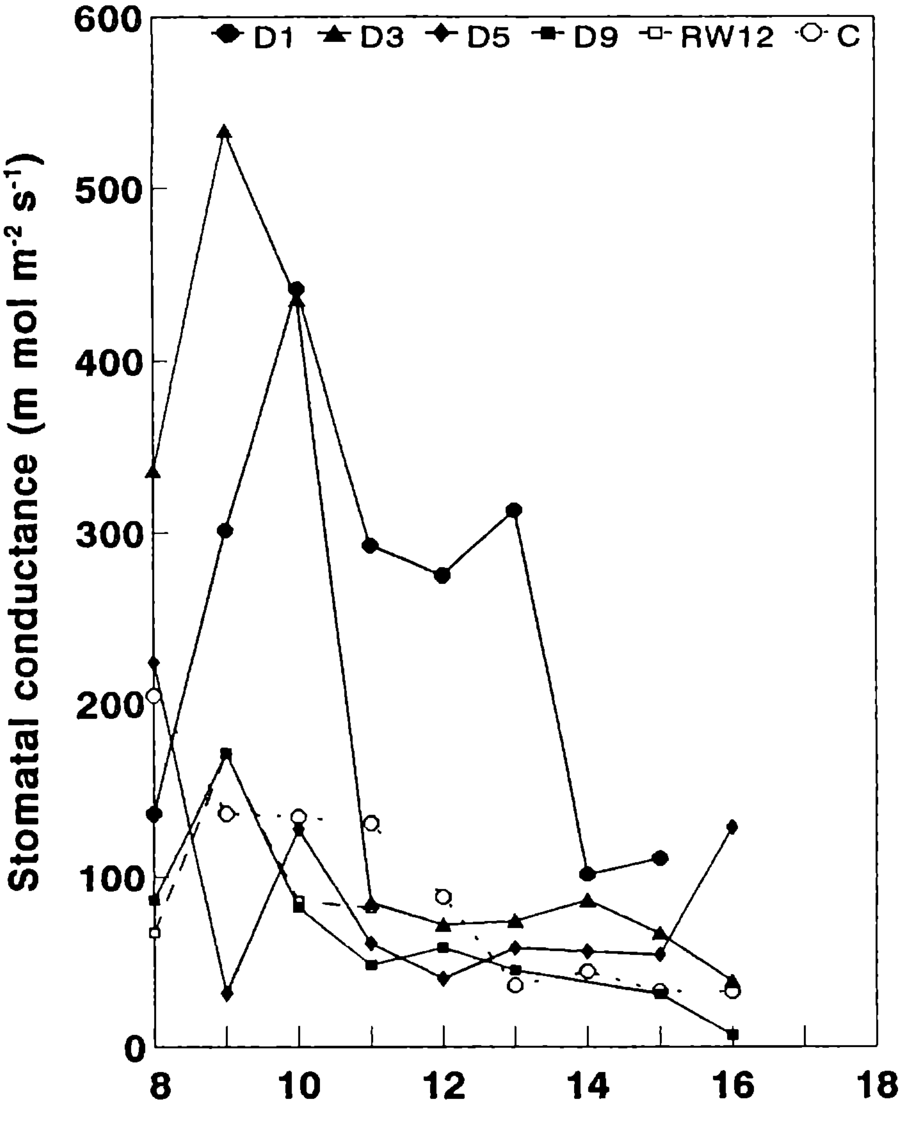

Fig. 24. Diurnal variations in stomatal conductance in the seedlings of *A. mangium* under normal watering and drought stress for various days. The symbols D1, D3, D5, D9 indicate water stress days given; RW12 is rewatering effect and C is control.

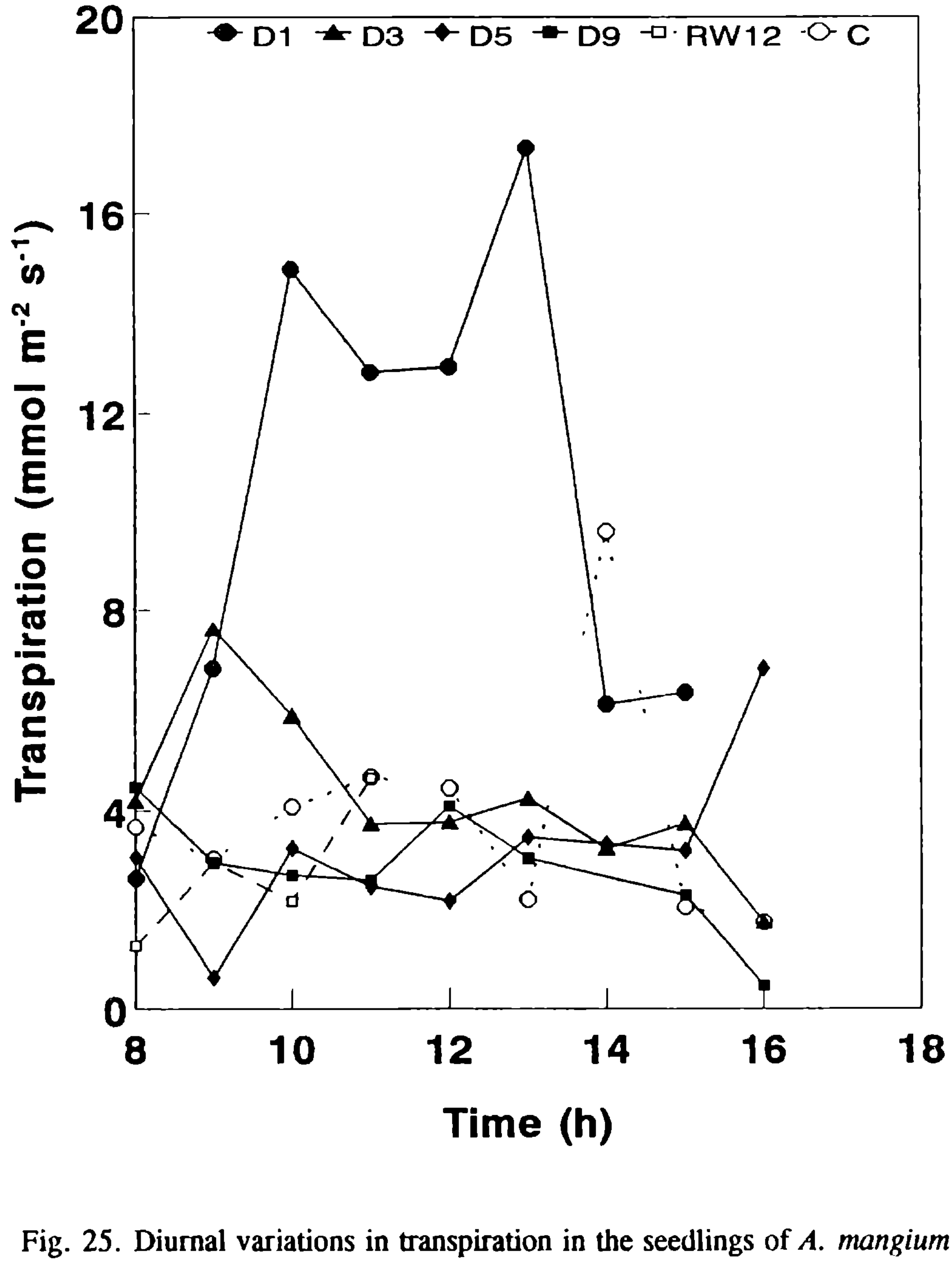

Fig. 25. Diurnal variations in transpiration in the seedlings of *A. mangium* under normal watering and drought stress for various days. The symbols D1, D3, D5, D9 indicate water stress days given; RW12 is rewatering effect and C is control.

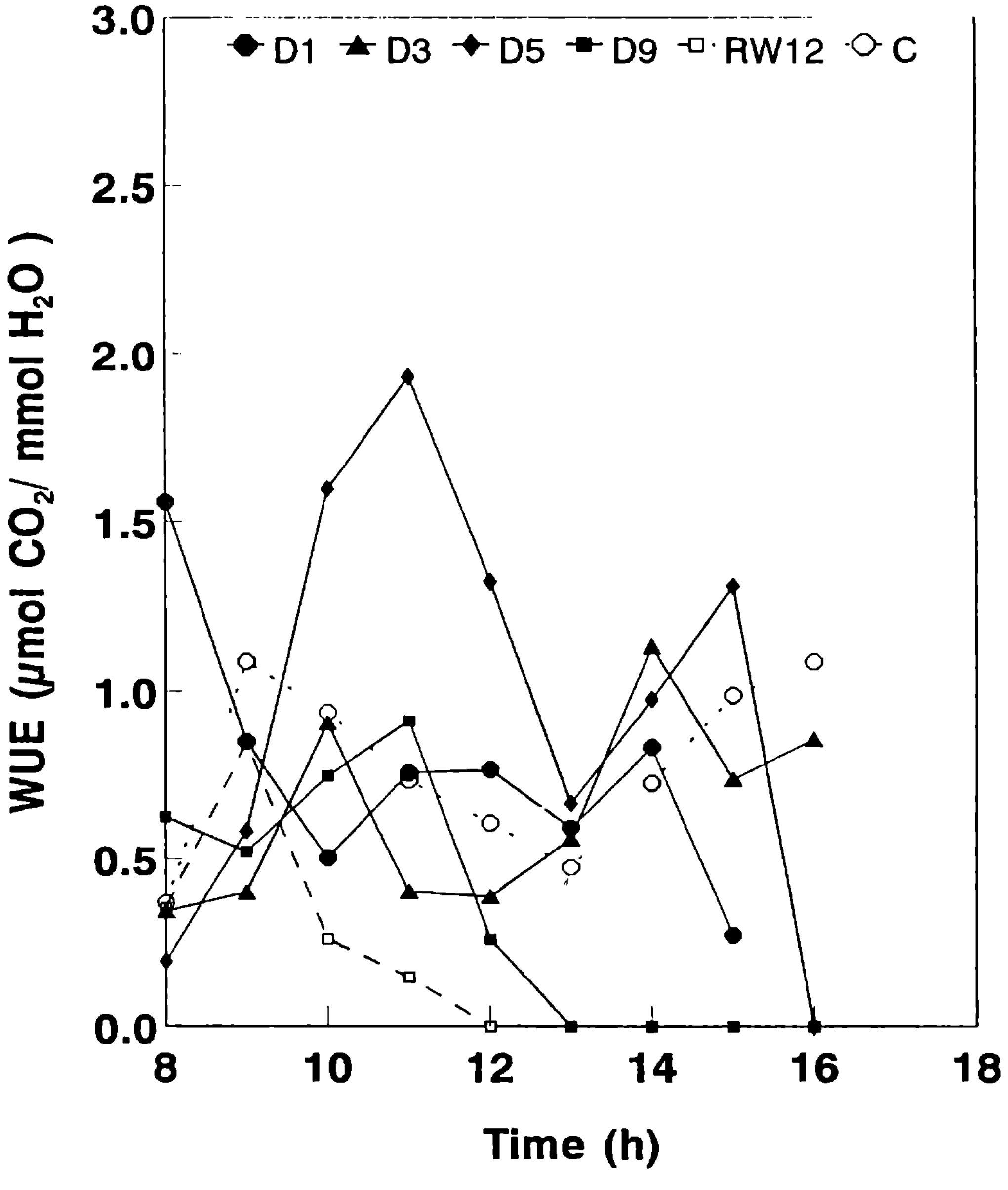

Fig. 26. Diurnal variations in WUE in the seedlings of *A. mangium* under normal watering and drought stress for various days. The symbols D1, D3, D5, D9 indicate water stress days given; RW12 is rewatering effect and C is control.

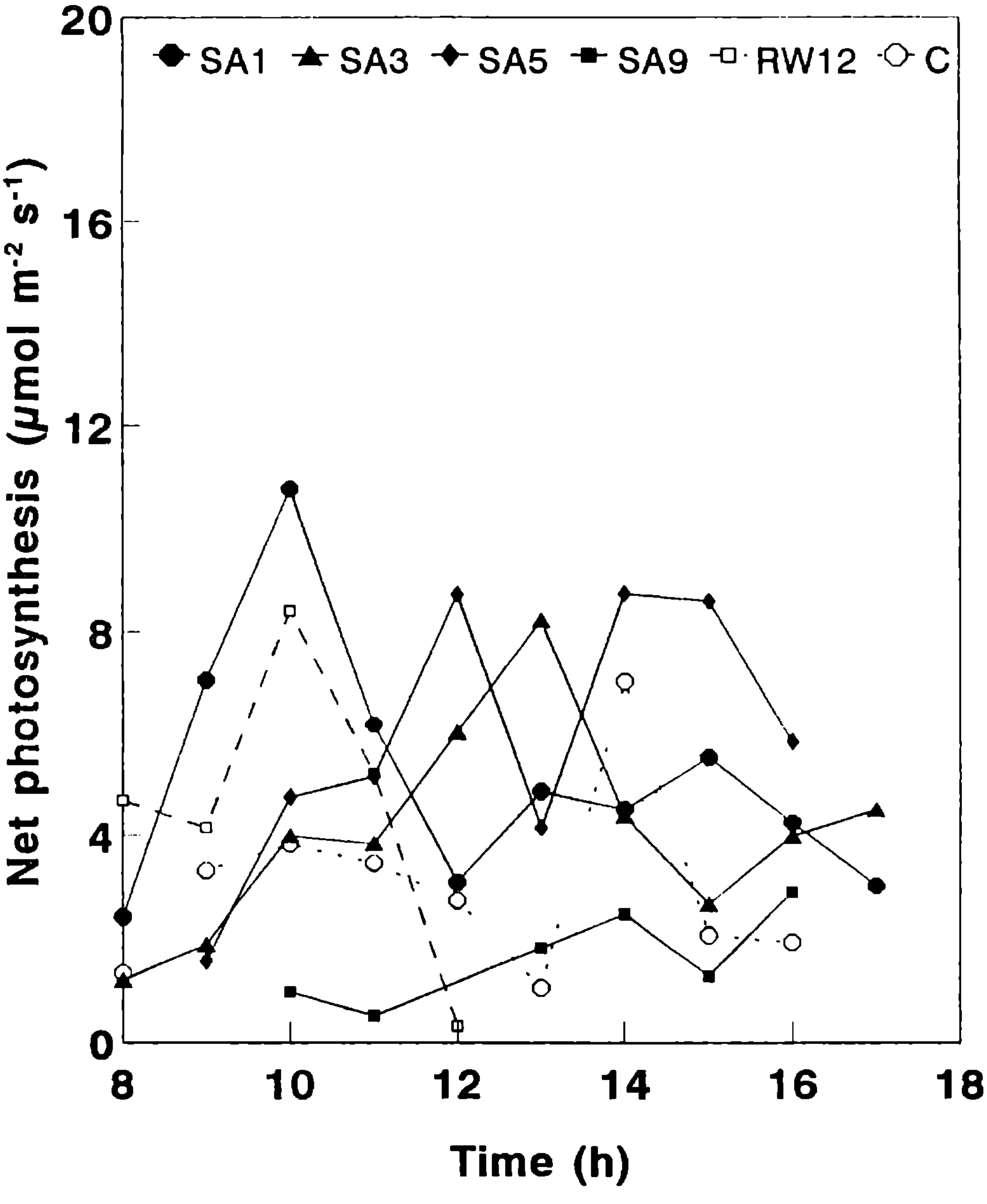

Fig. 27. Diurnal variations in photosynthesis in the seedlings of *A. mangium* under normal watering and salinity (100 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate salinity stress days given; RW12 is stress release effect and C is control.

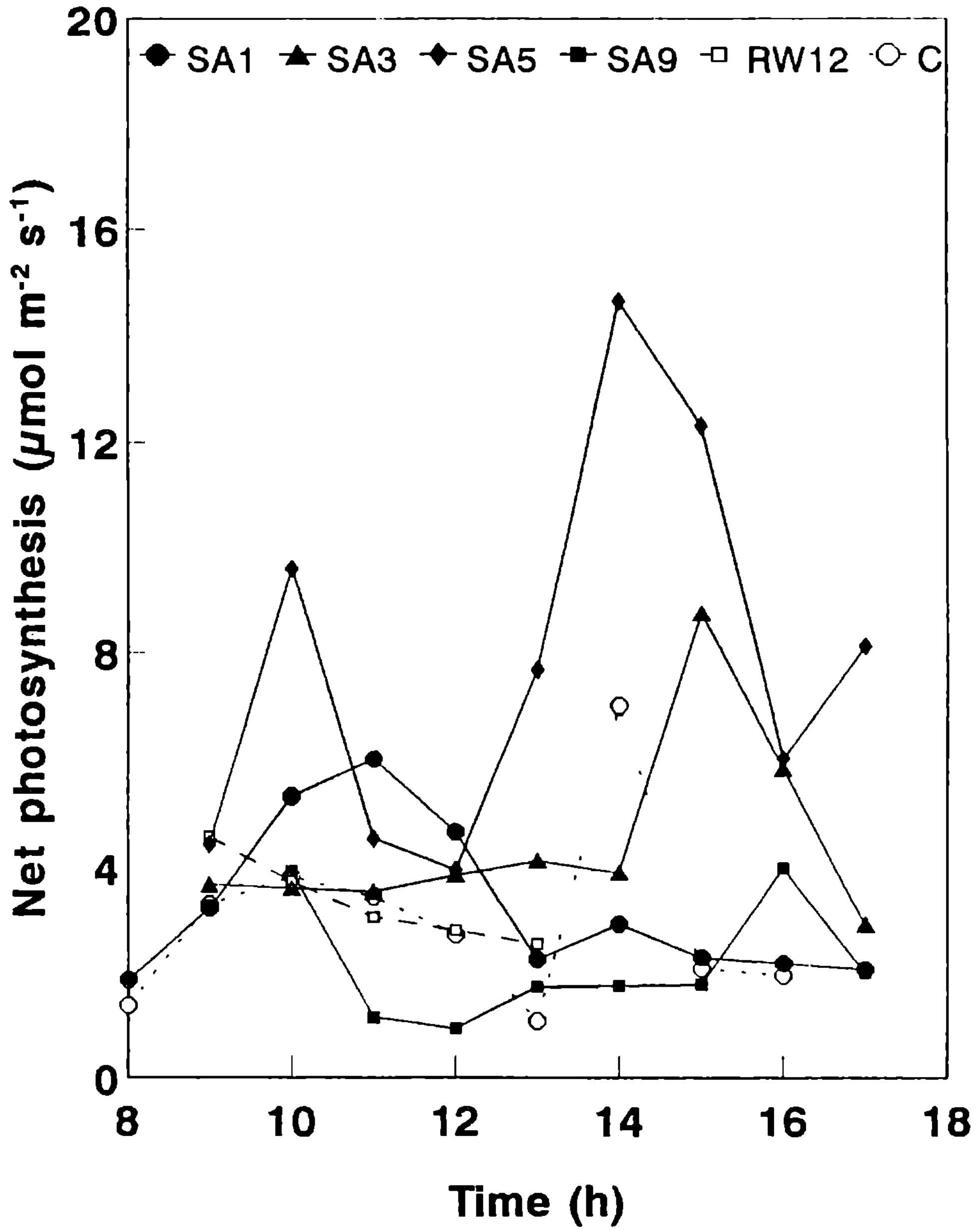

Fig. 28. Diurnal variations in photosynthesis in the seedlings of *A. mangium* under normal watering and salinity (200 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate salinity stress days given; RW12 is stress release effect and C is control.

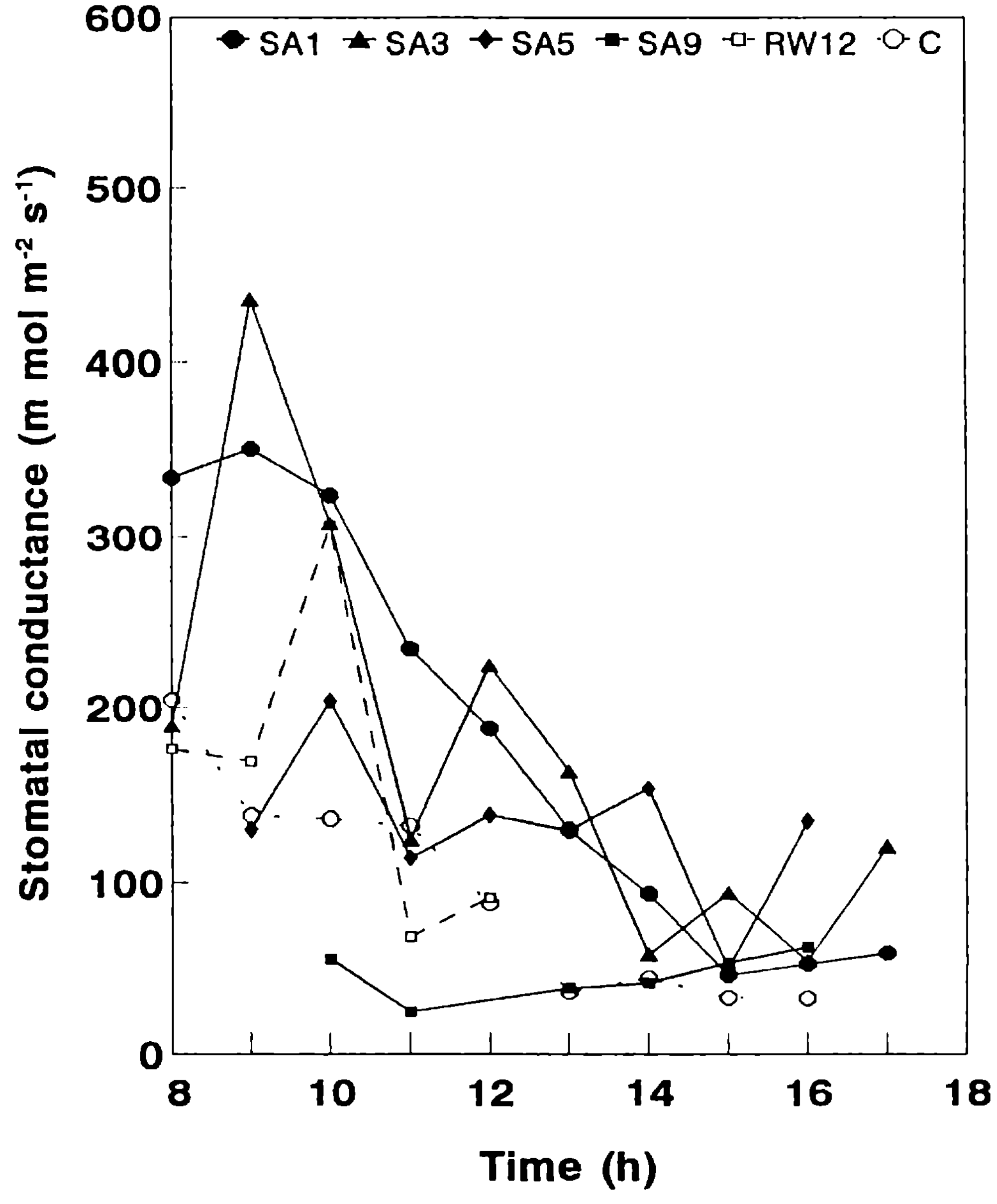

Fig. 29. Diurnal variations in stomatal conductance in the seedlings of *A. mangium* under normal watering and salinity (100 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate salinity stress days given; RW12 is stress release effect and C is control.

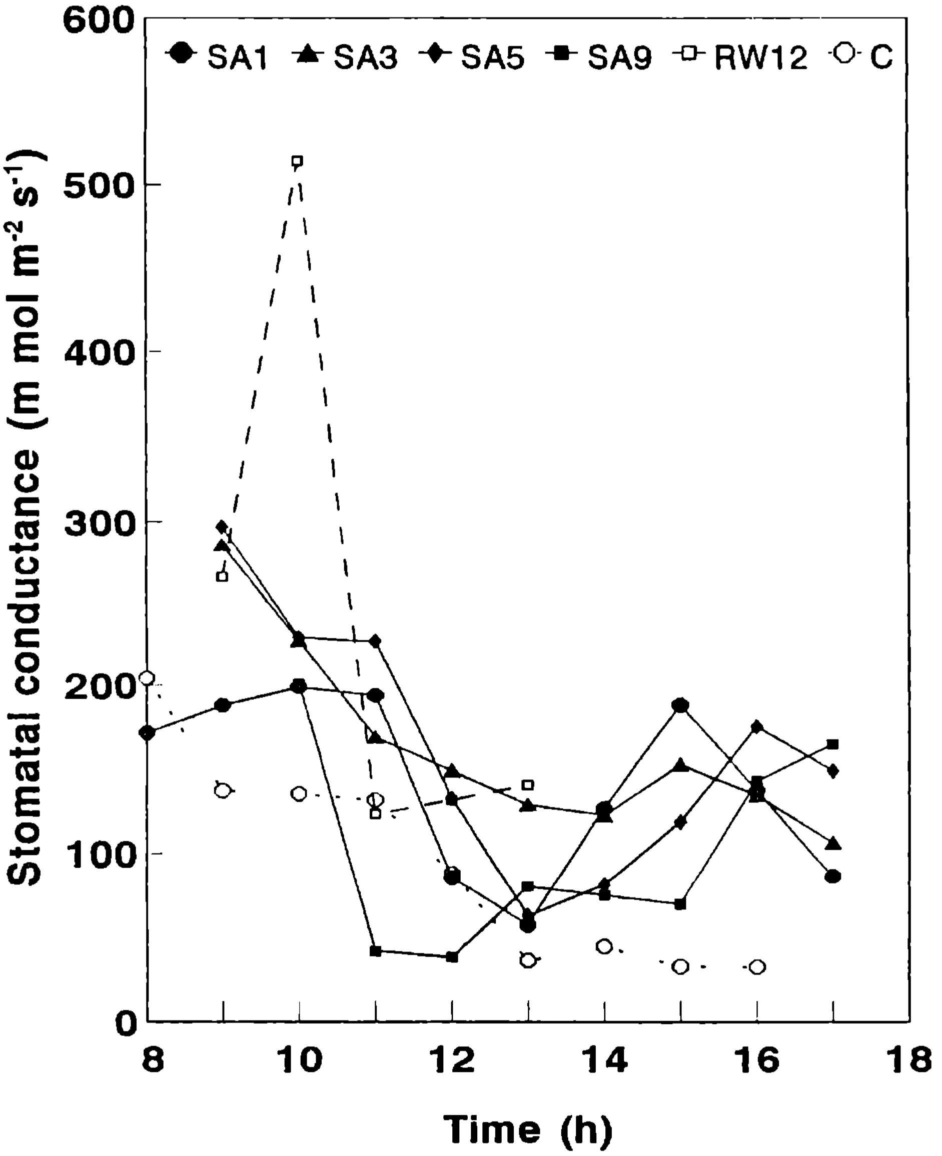

Fig. 30. Diurnal variations in photosynthesis in the seedlings of *A. mangium* under normal watering and salinity (200 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate salinity stress days given; RW12 is stress release effect and C is control.

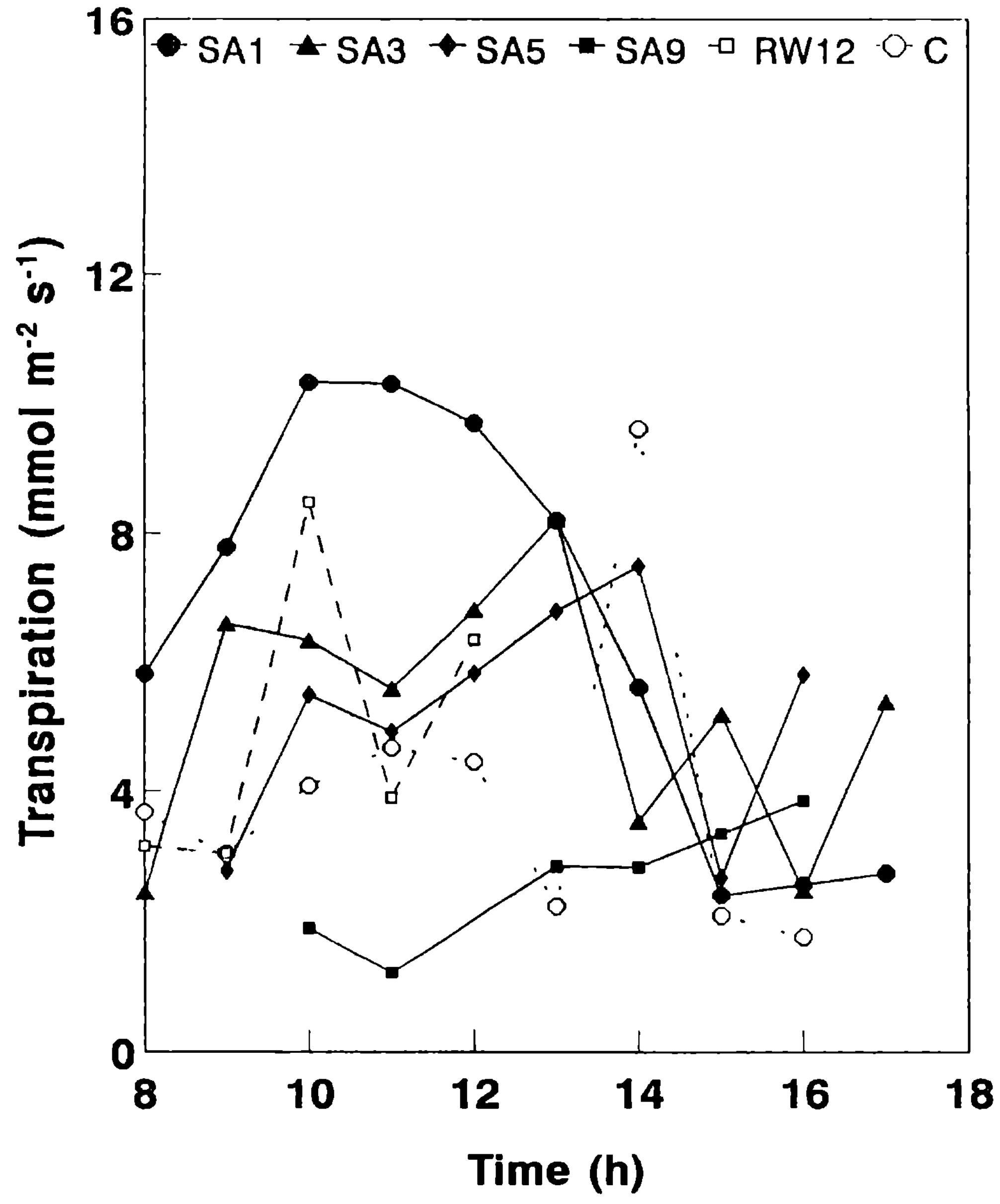

Fig. 31a. Diurnal variations in transpiration in the seedlings of *A. mangium* under normal watering and salinity (100 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate salinity stress days given; RW12 is stress release effect and C is control.

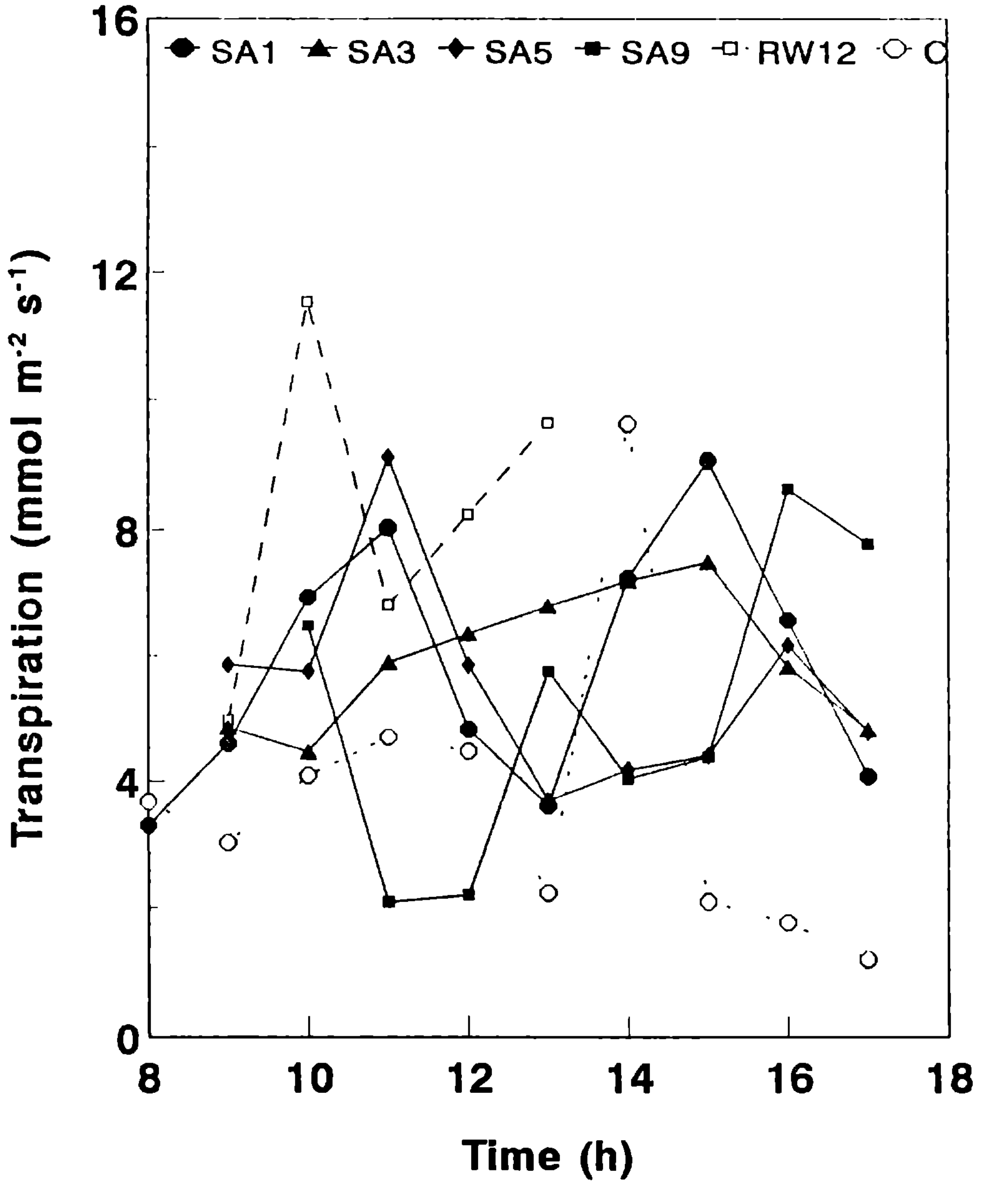

Fig. 31b. Diurnal variations in stomatal conductance in the seedlings of *A. mangium* under normal watering and salinity (200 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate salinity stress days given; RW12 is stress release effect and C is control.

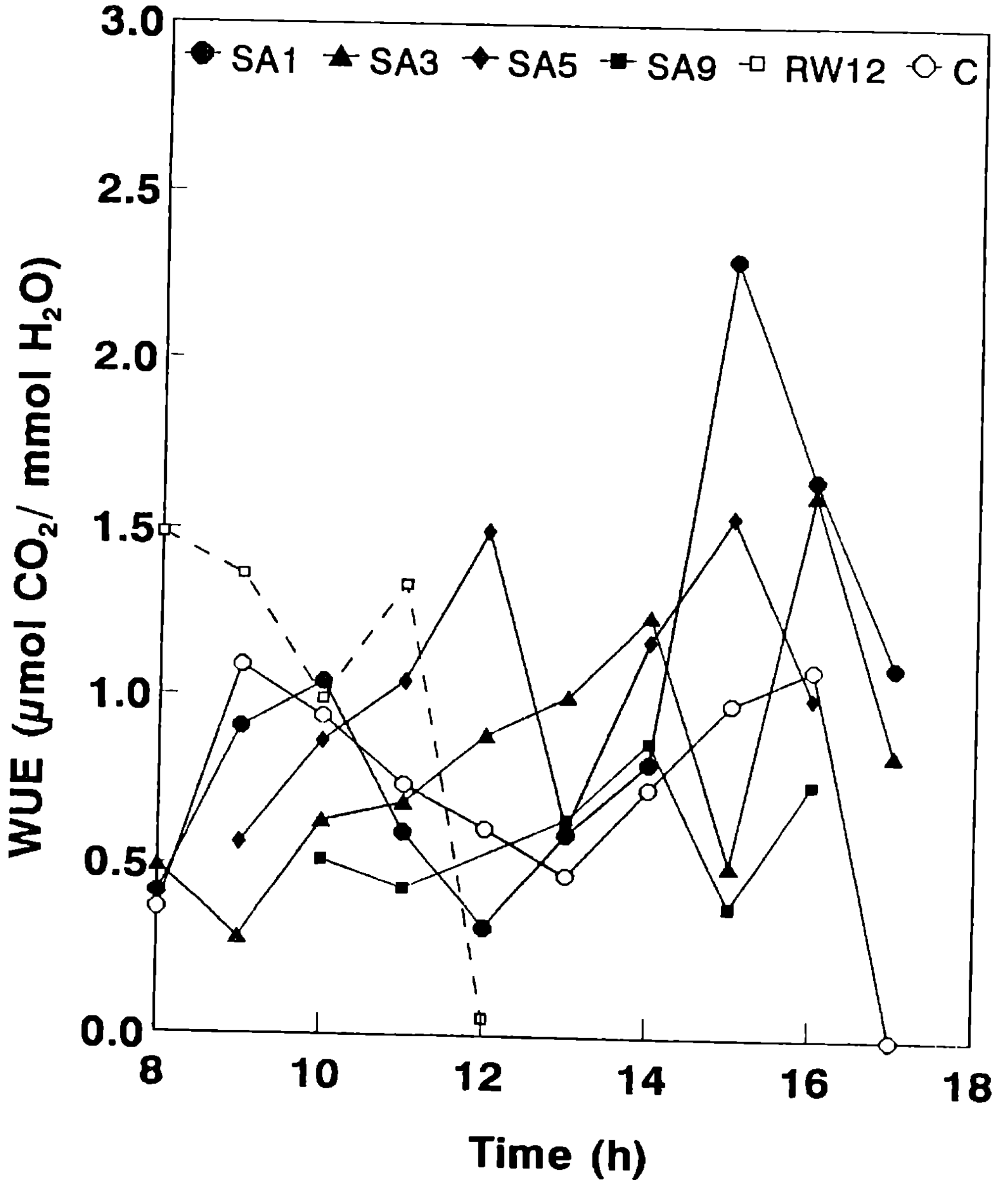

Fig. 32. Diurnal variations in WUE in the seedlings of *A. mangium* under normal watering and salinity (100 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate salinity stress days given; RW12 is stress release effect and C is control.

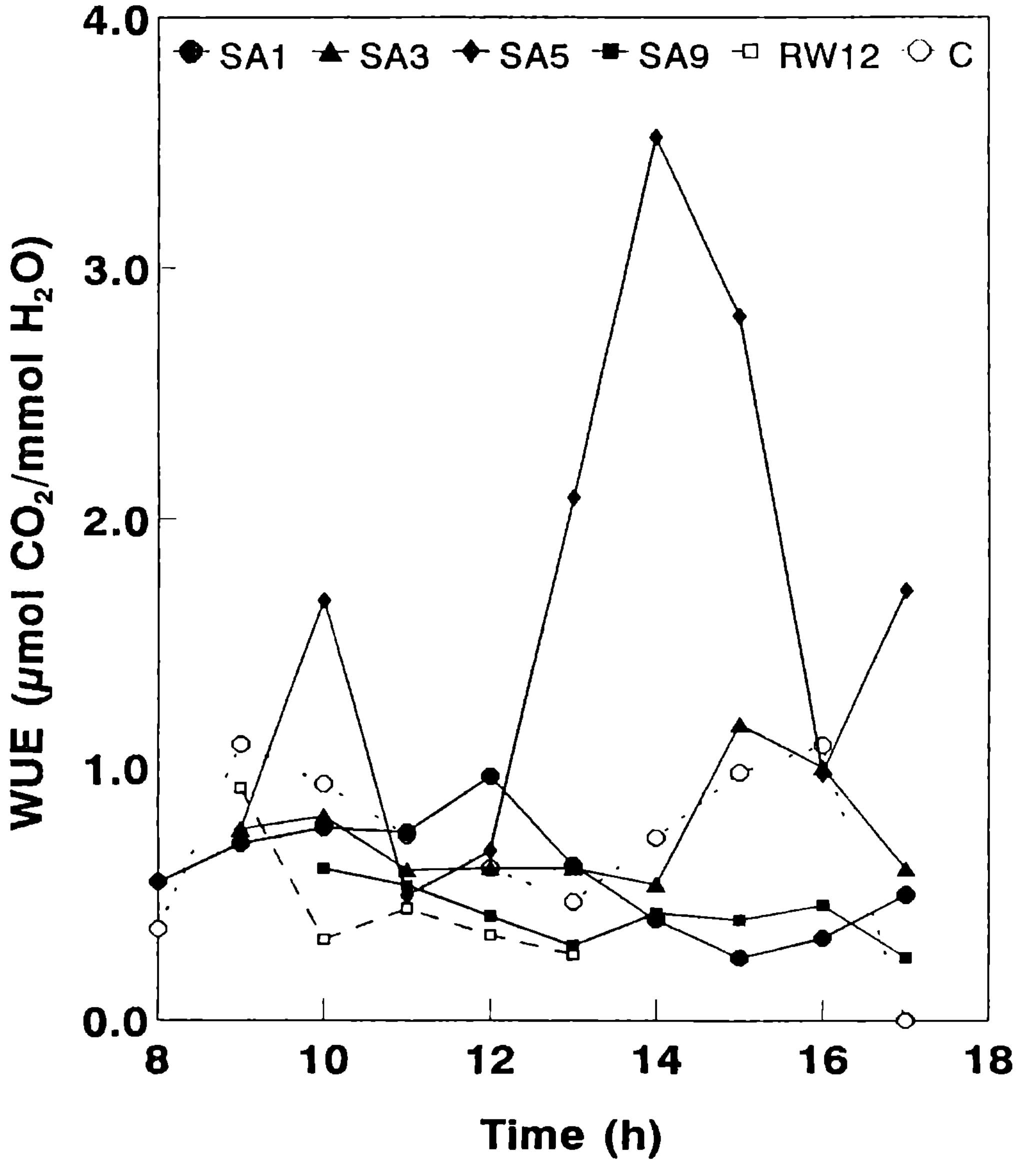

Fig. 33. Diurnal variations in WUE in the seedlings of *A. mangium* under normal watering and salinity (200 mol m^{-3}) for various days. The symbols SA1, SA3, SA5, SA9 indicate salinity stress days given; RW12 is stress release effect and C is control.

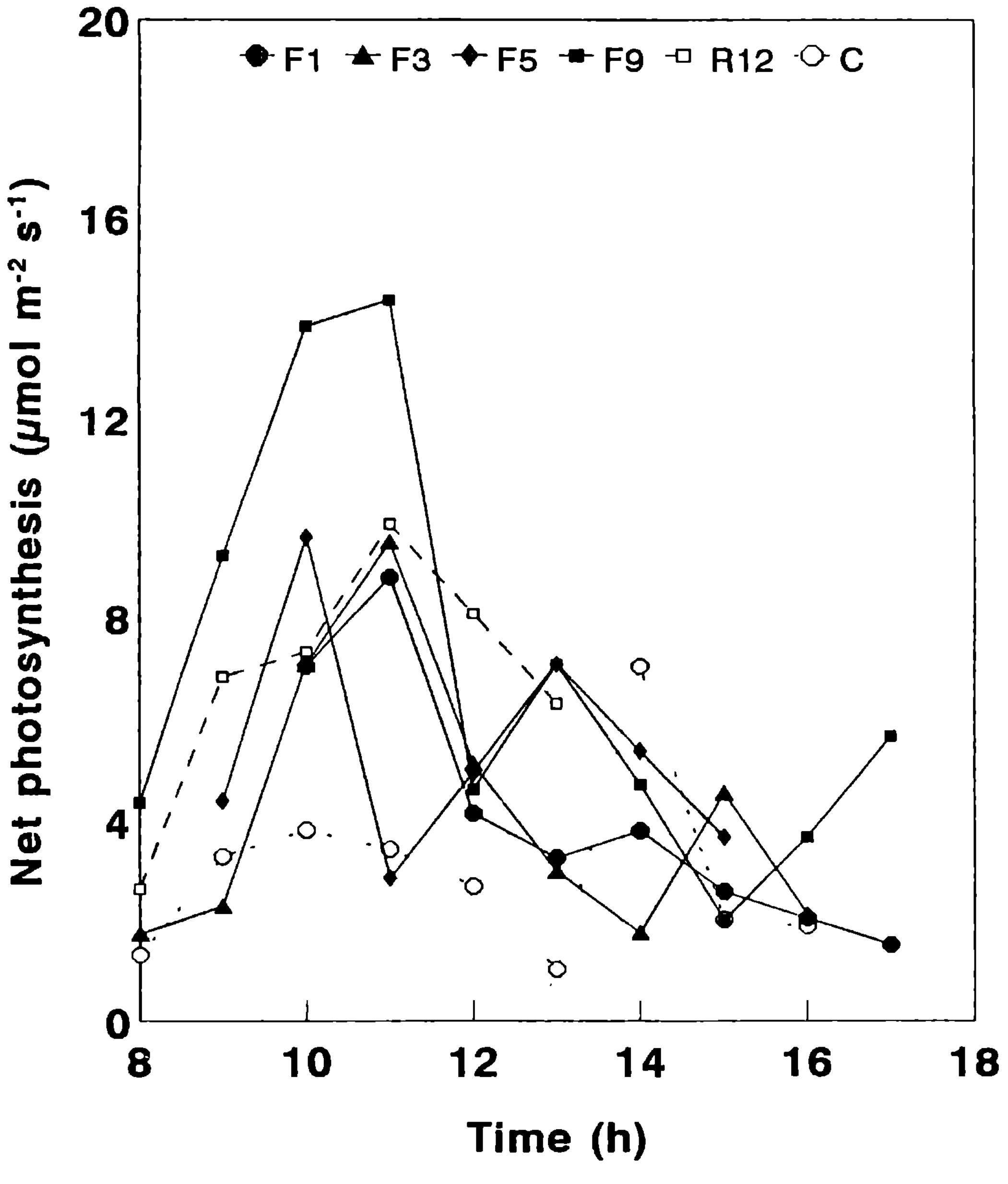

Fig..34 Diurnal variations in net photosynthesis in seedlings of *A.mangium* under normal watering and flooding stress for various days. The symbols F1, F3, F5, F9 indicate flooding stress days given; R12 is stress release effect and C is control.

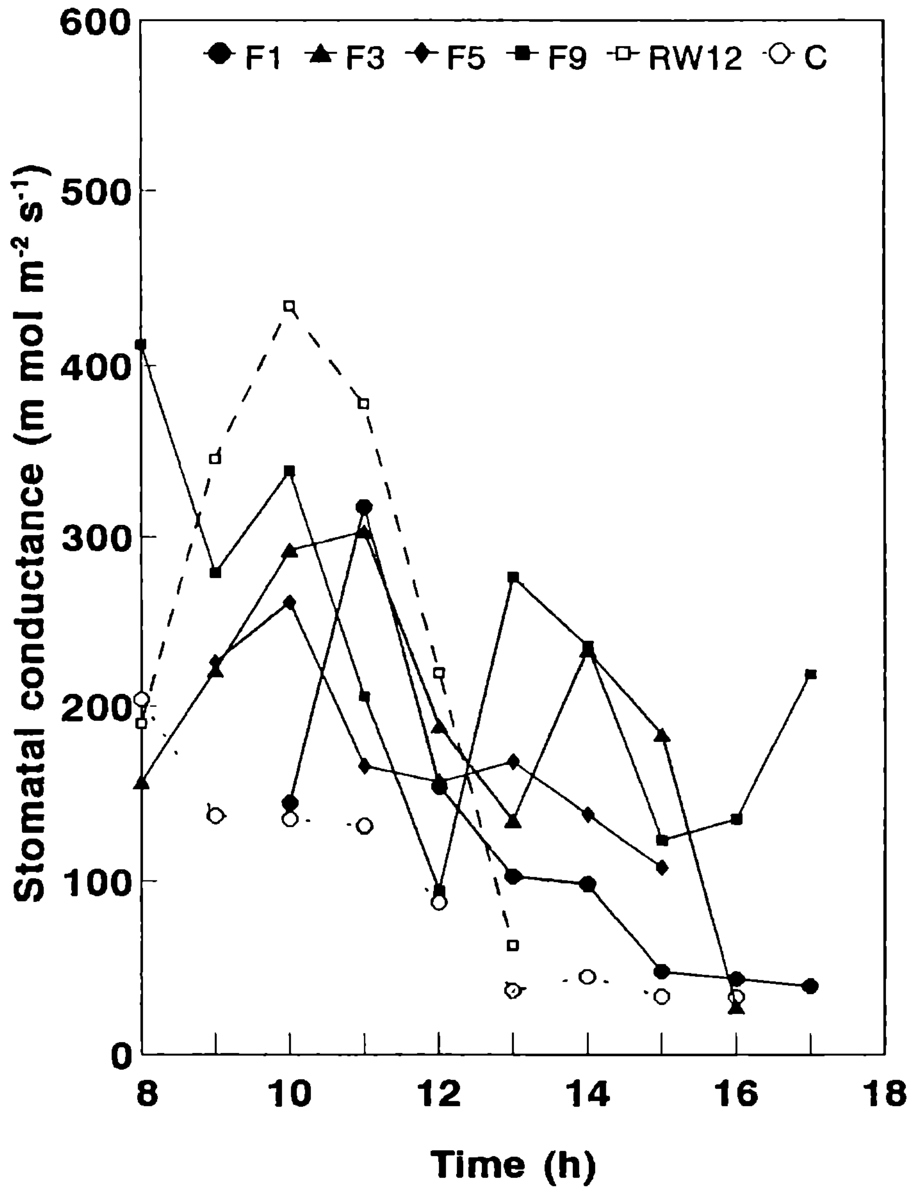

Fig. 35. Diurnal variations in stomatal conductance in seedlings of *A.mangium* under normal watering and flooding stress for various days. The symbols F1, F3, F5, F9 indicate flooding stress days given; RW12 is stress release effect and C is control.

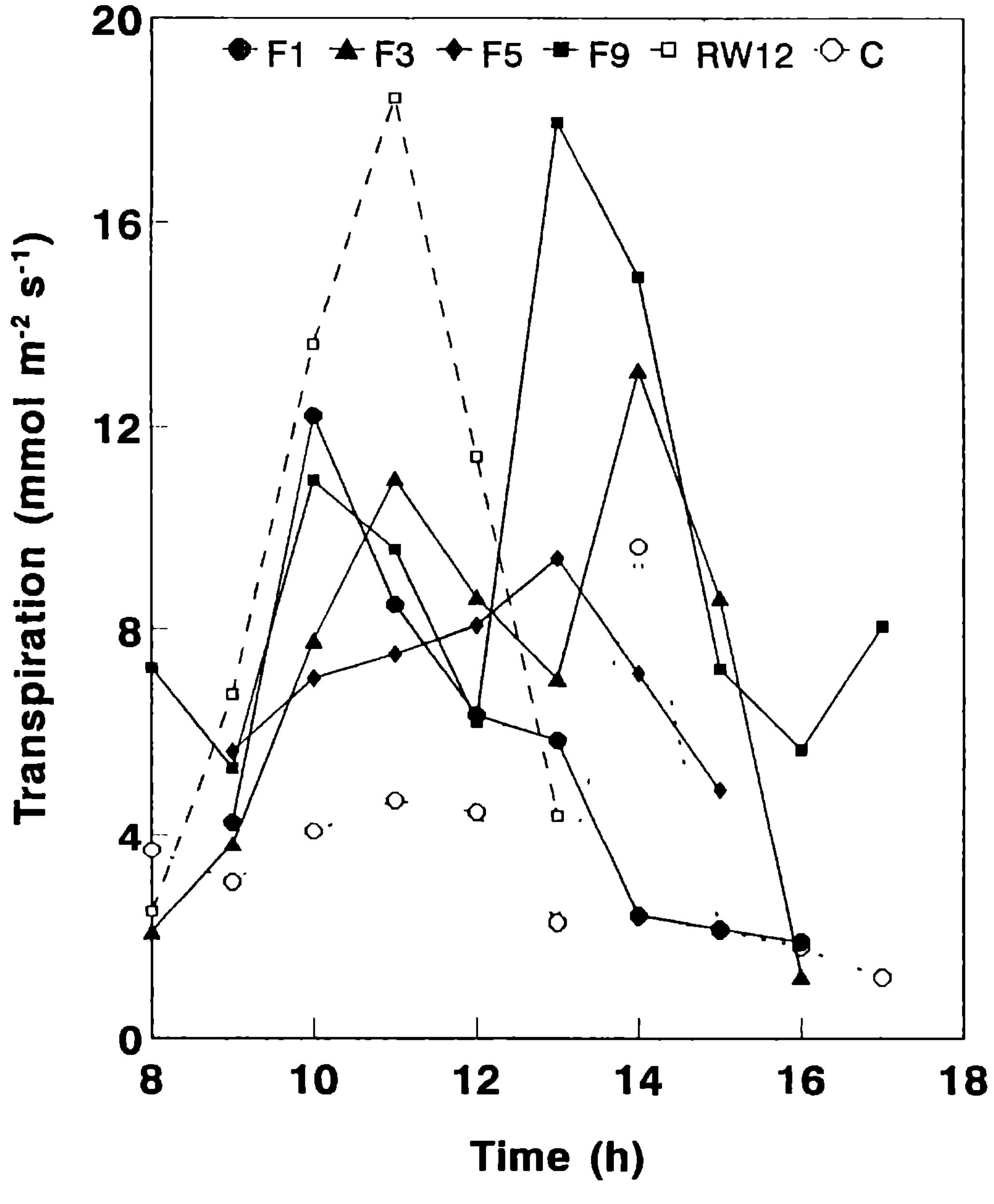

Fig. 36. Diurnal variations in transpiration in seedlings of *A.mangium* under normal watering and flooding stress for various days. The symbols F1, F3, F5, F9 indicate flooding stress days given; RW12 is stress release effect and C is control.

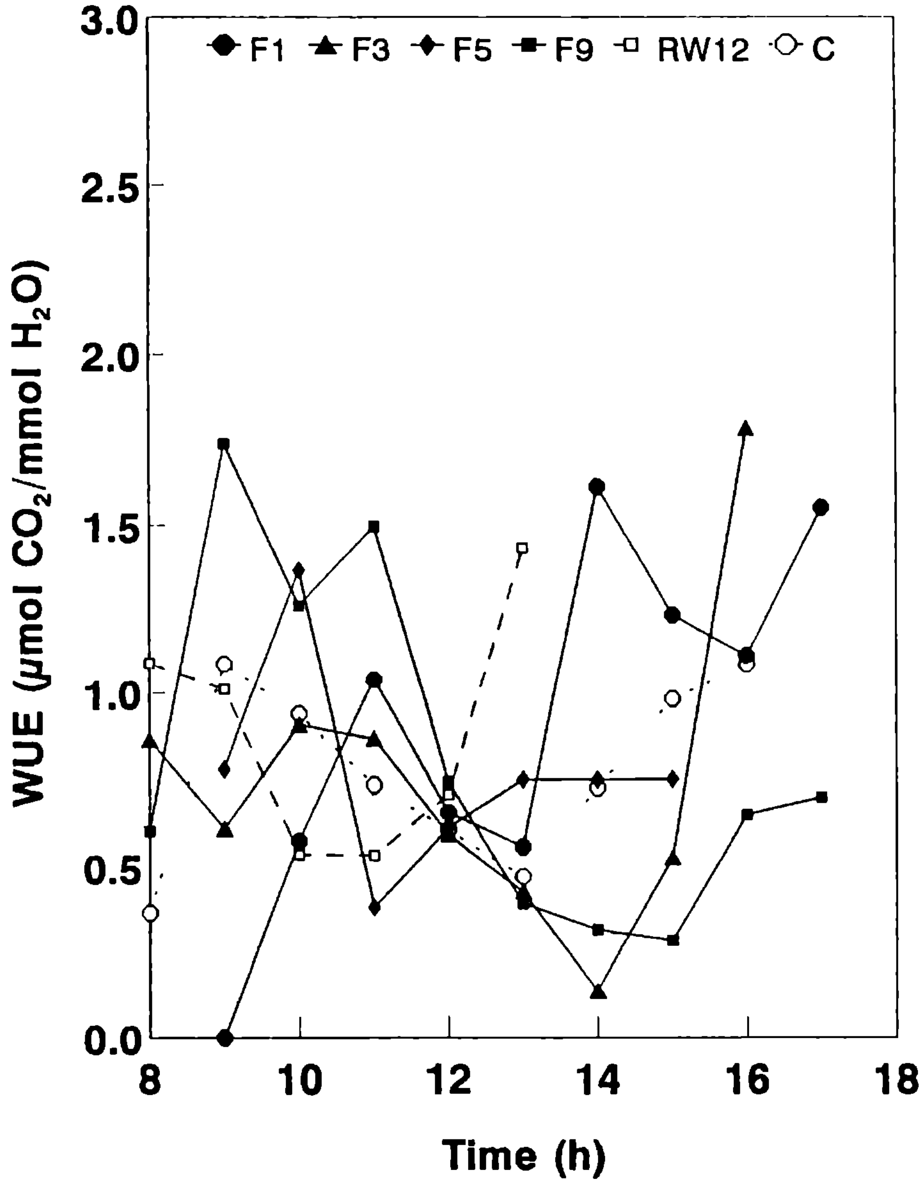

Fig. 37. Diurnal variations in WUE in seedlings of *A.mangium* under normal watering and flooding stress for various days. The symbols F1, F3, F5, F9 indicate flooding stress days given; RW12 is stress release effect and C is control.

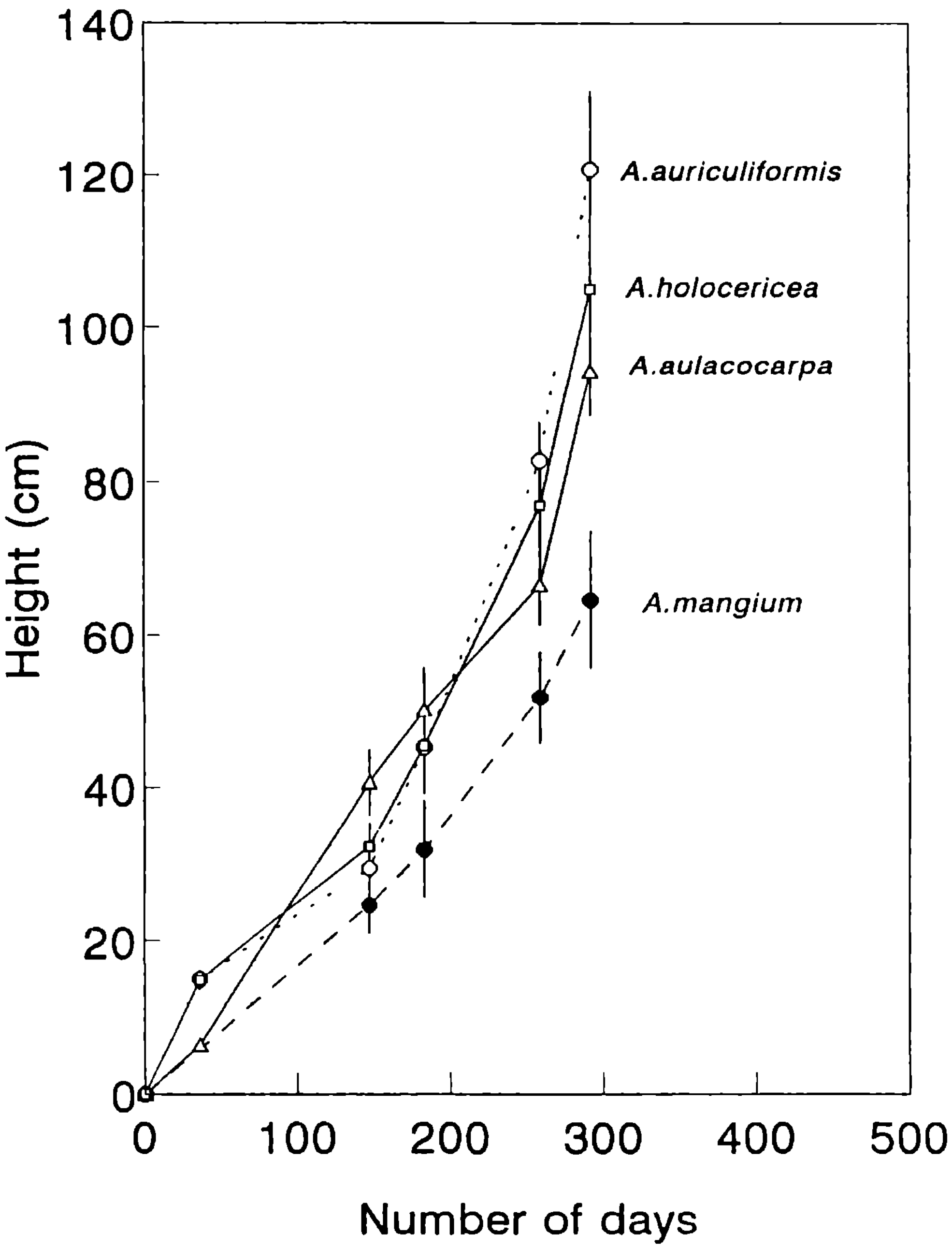

Fig. 38. Growth in height of polypotted seedlings of *A. auriculiformis*, *A. aulacocarpa*, *A. holosericea* and *A. mangium* grown under normal environmental condition.

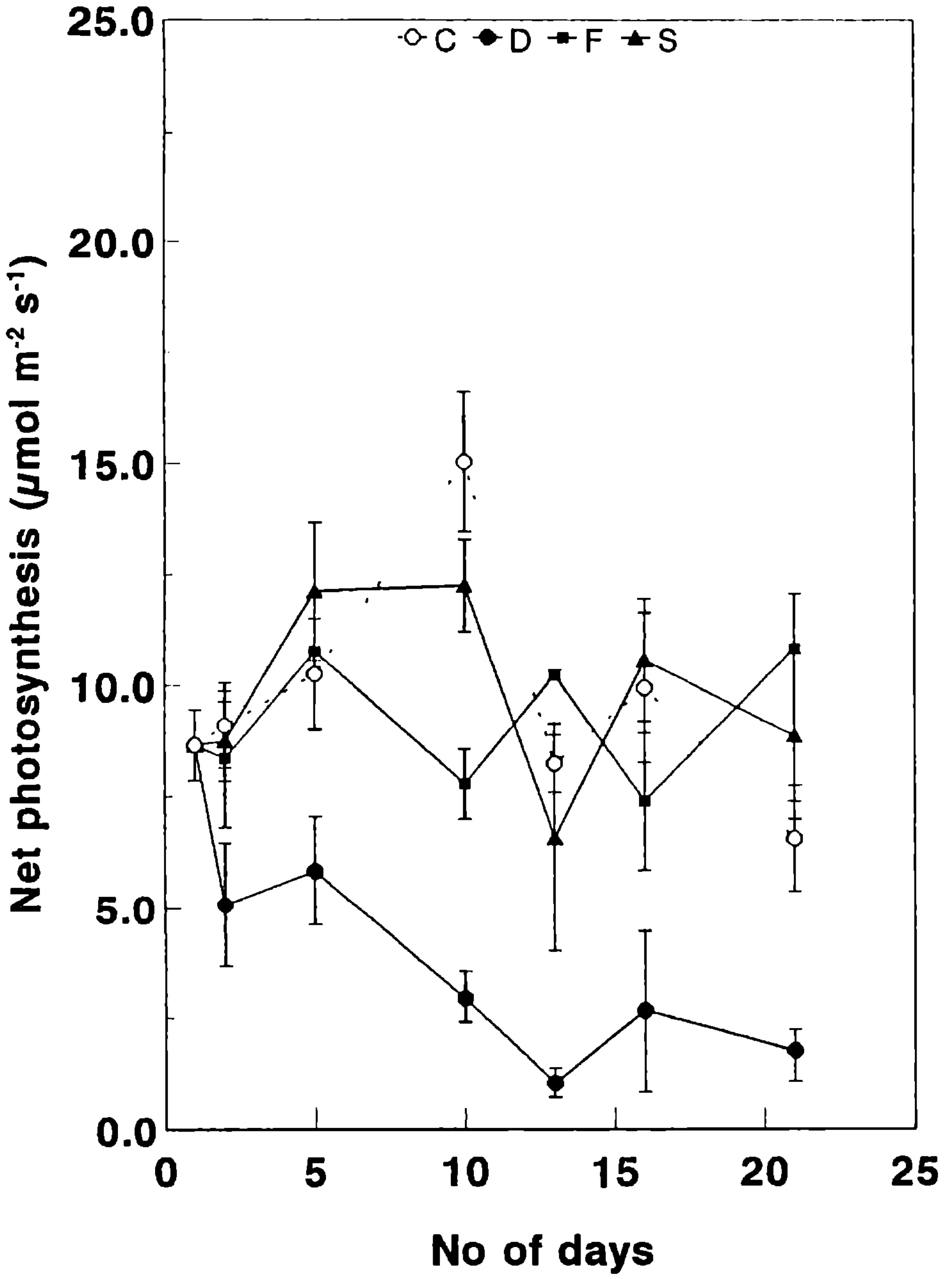

Fig. 39. *A.auriculiformis* - Measurements of net photosynthesis under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

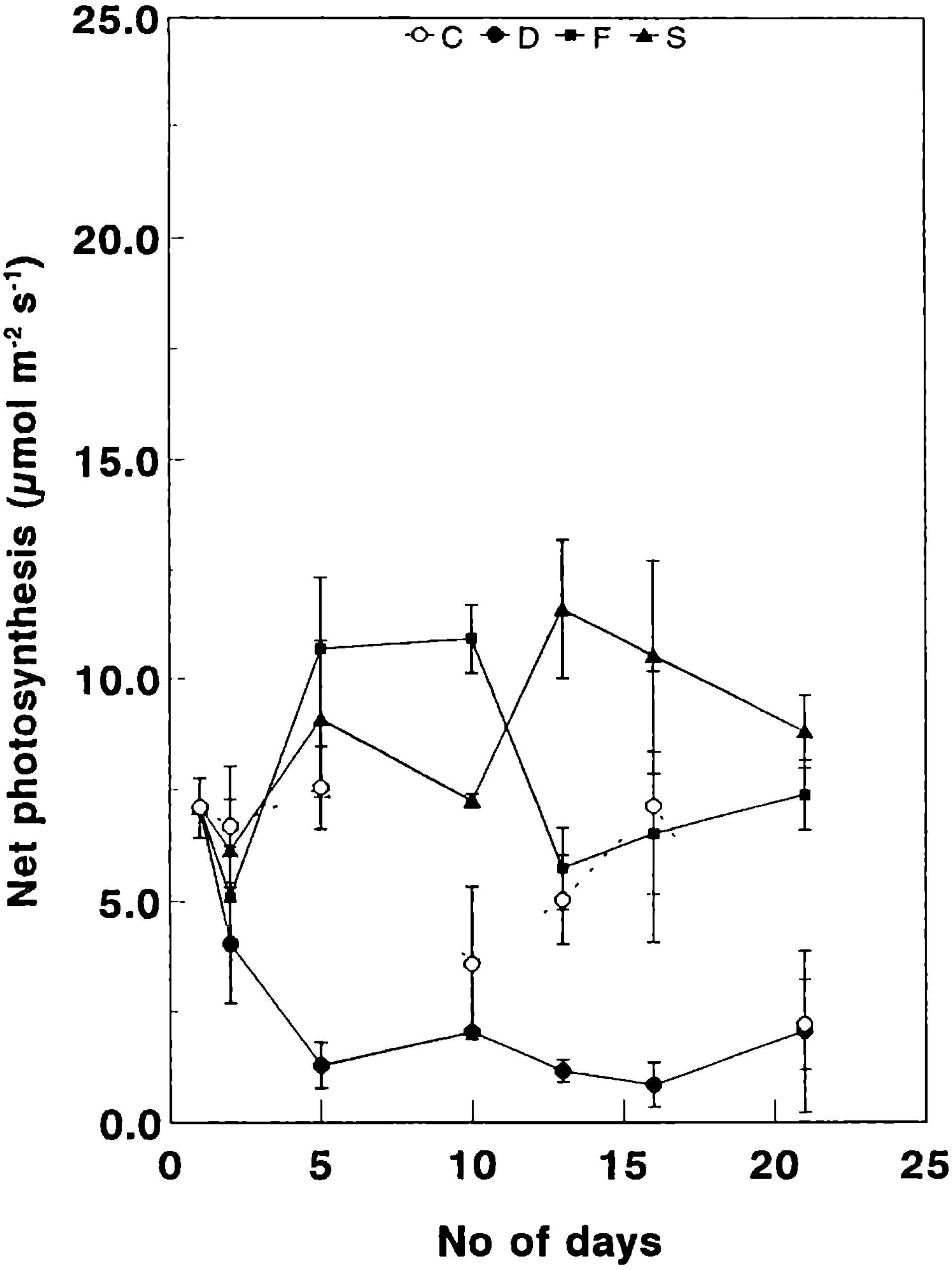

Fig. 40. *A.aulacocarpa* - Measurements of net photosynthesis under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

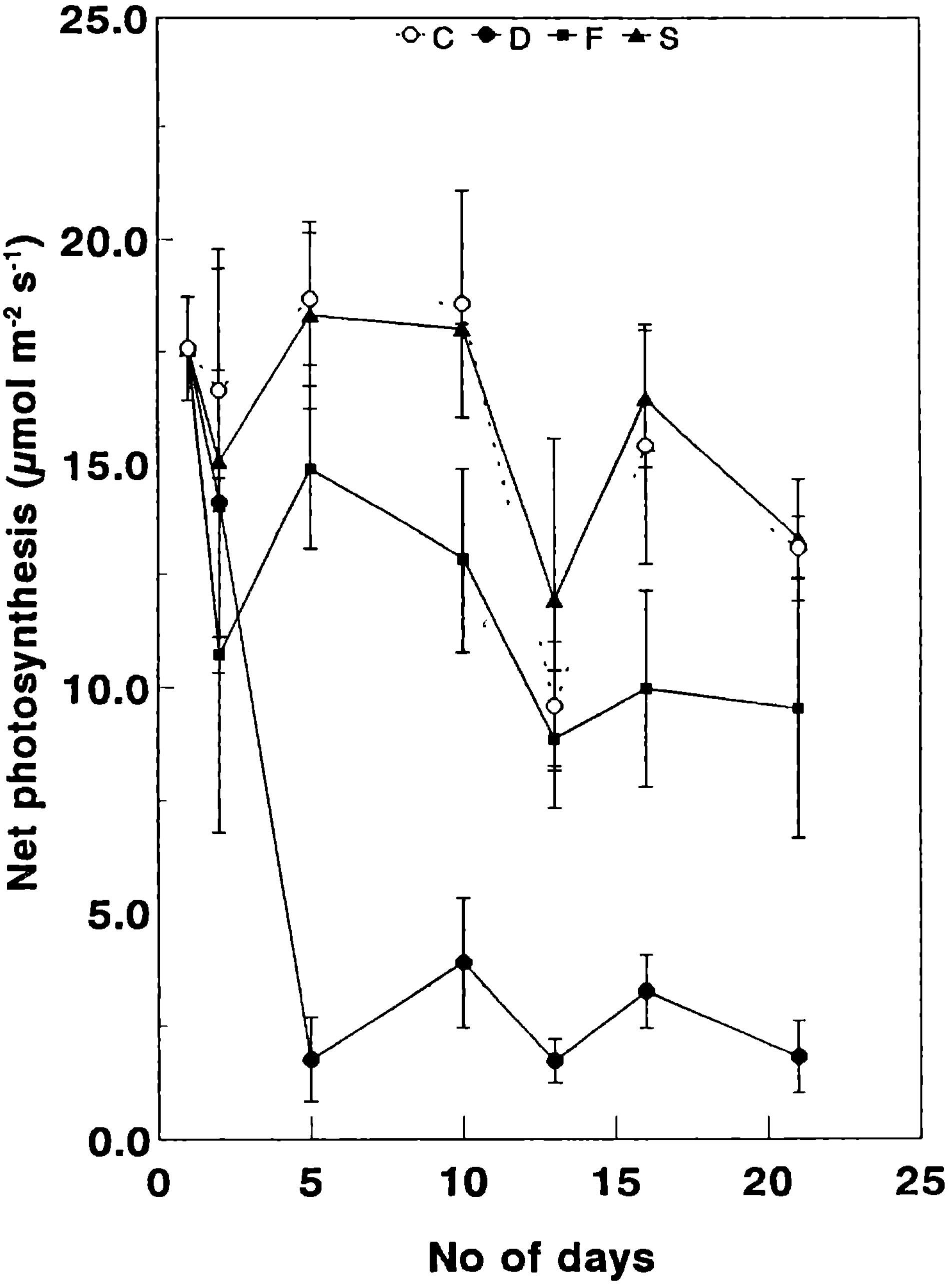

Fig. 41. *A.holocericea* - Measurements of net photosynthesis under different stress conditions for various days during peak hours The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

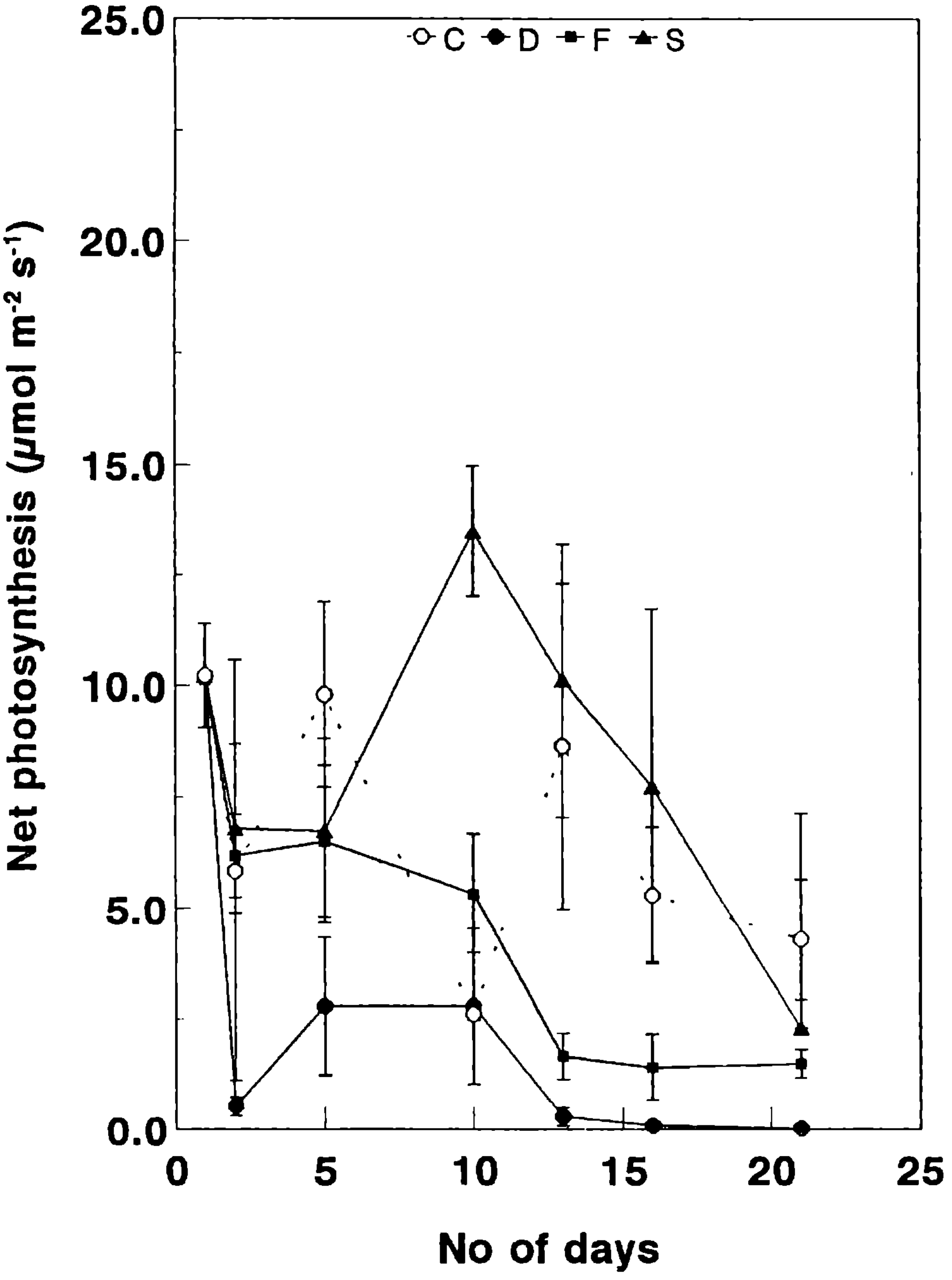

Fig. 42. *A.mangium* - Measurements of net photosynthesis under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

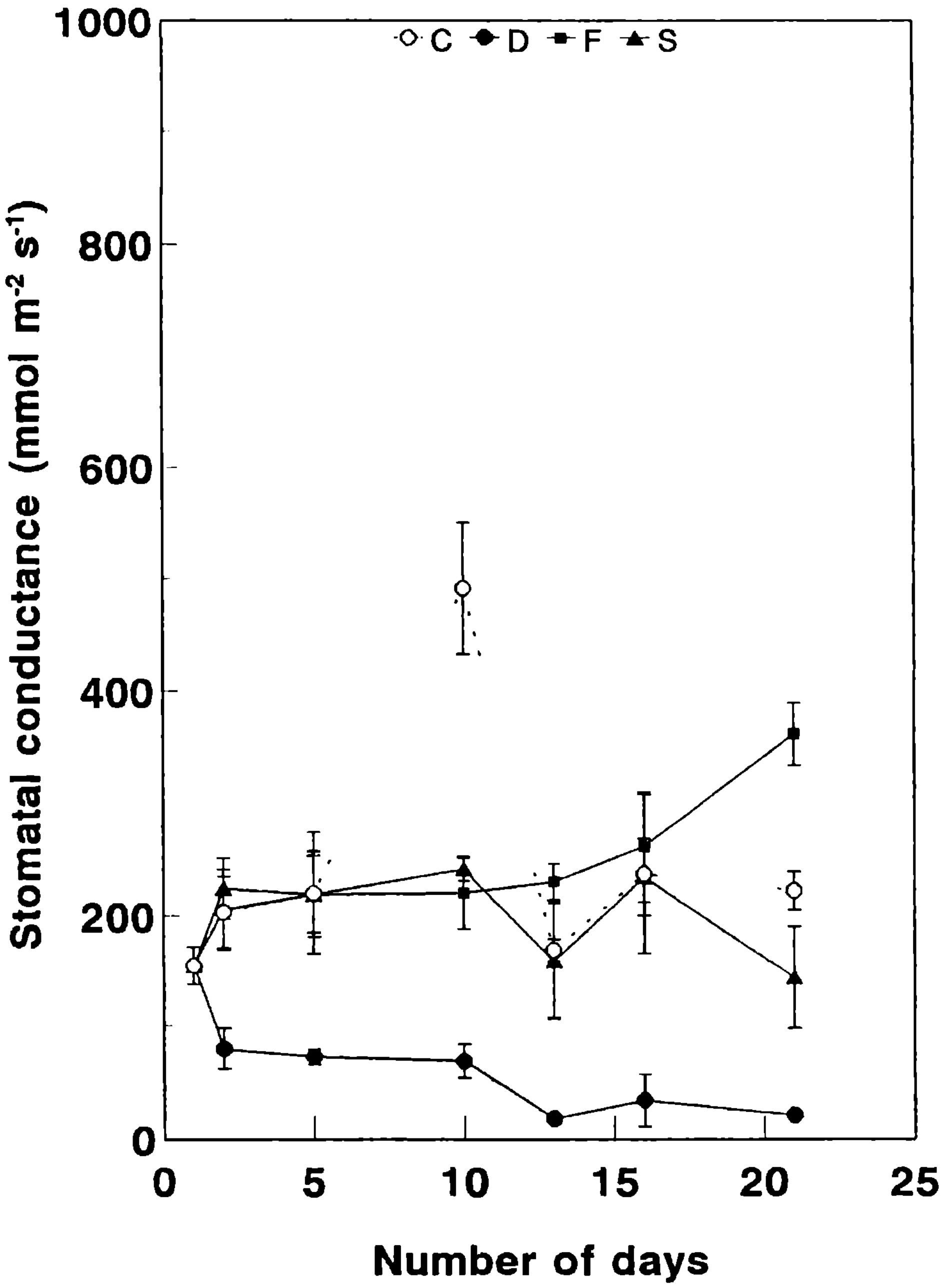

Fig. 43. *A.auriculiformis* - Measurements of stomatal conductance under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

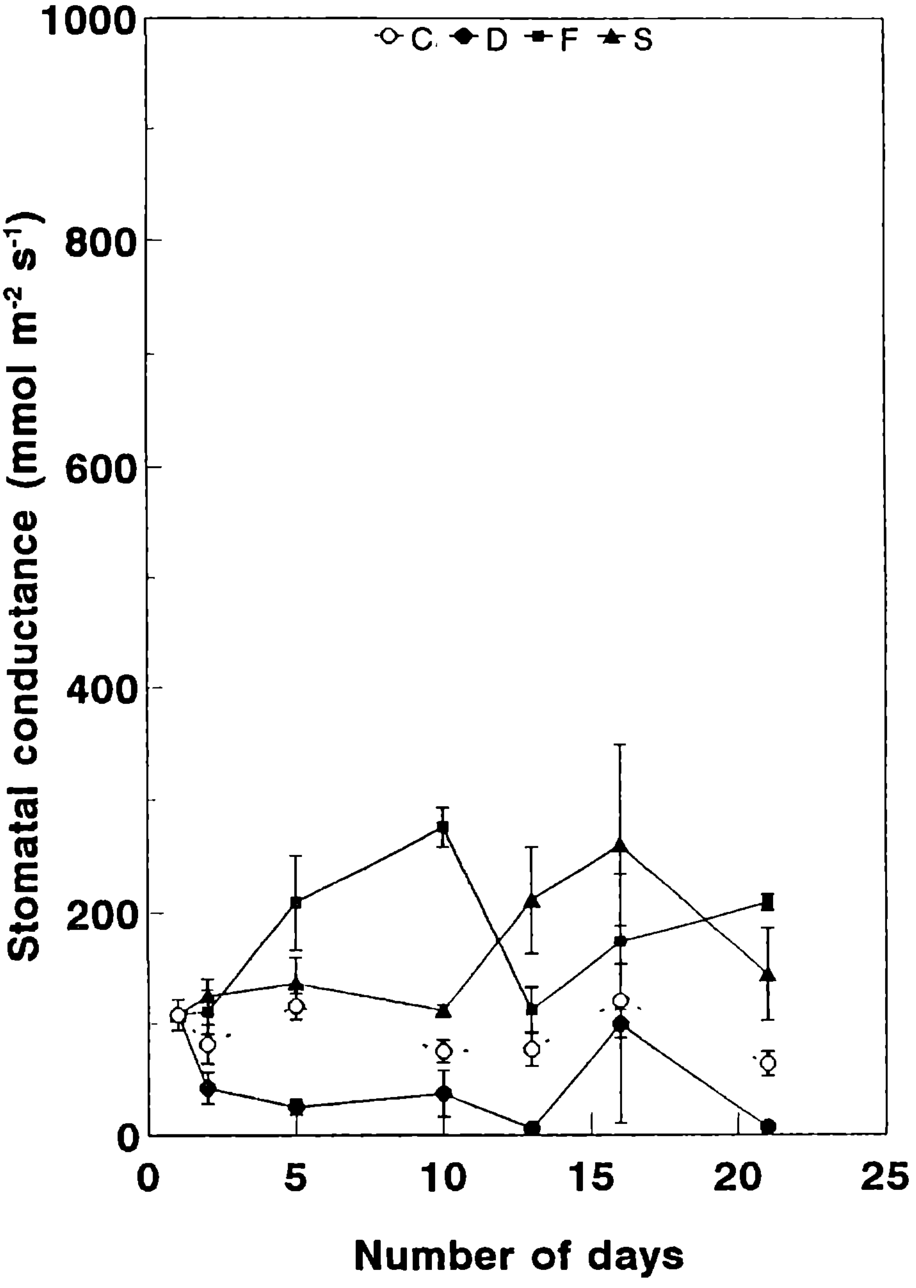

Fig. 44. *A.aulacocarpa* - Measurements of stomatal conductance under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

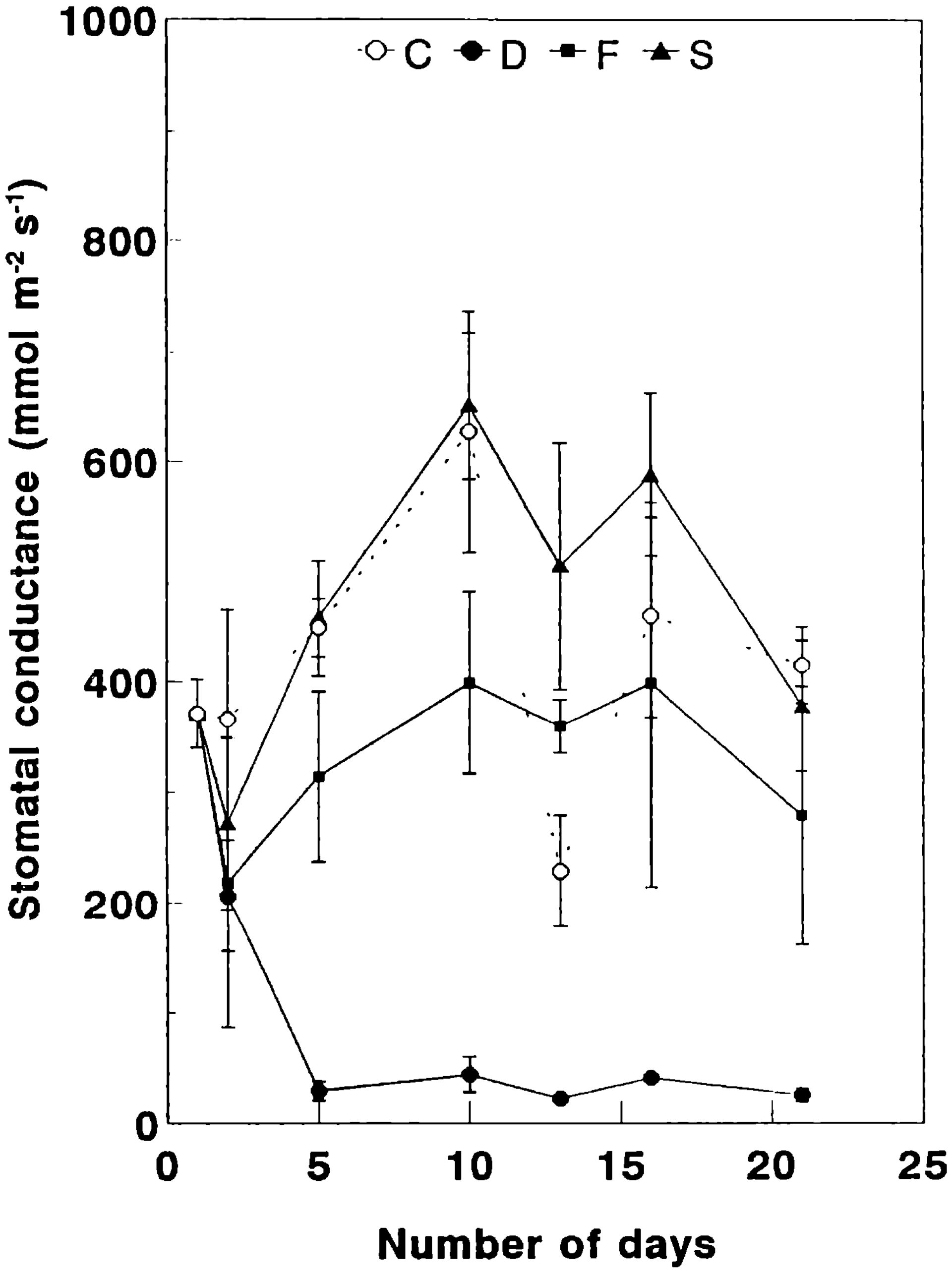

Fig. 45. *A.holocericea* - Measurements of stomatal conductance under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

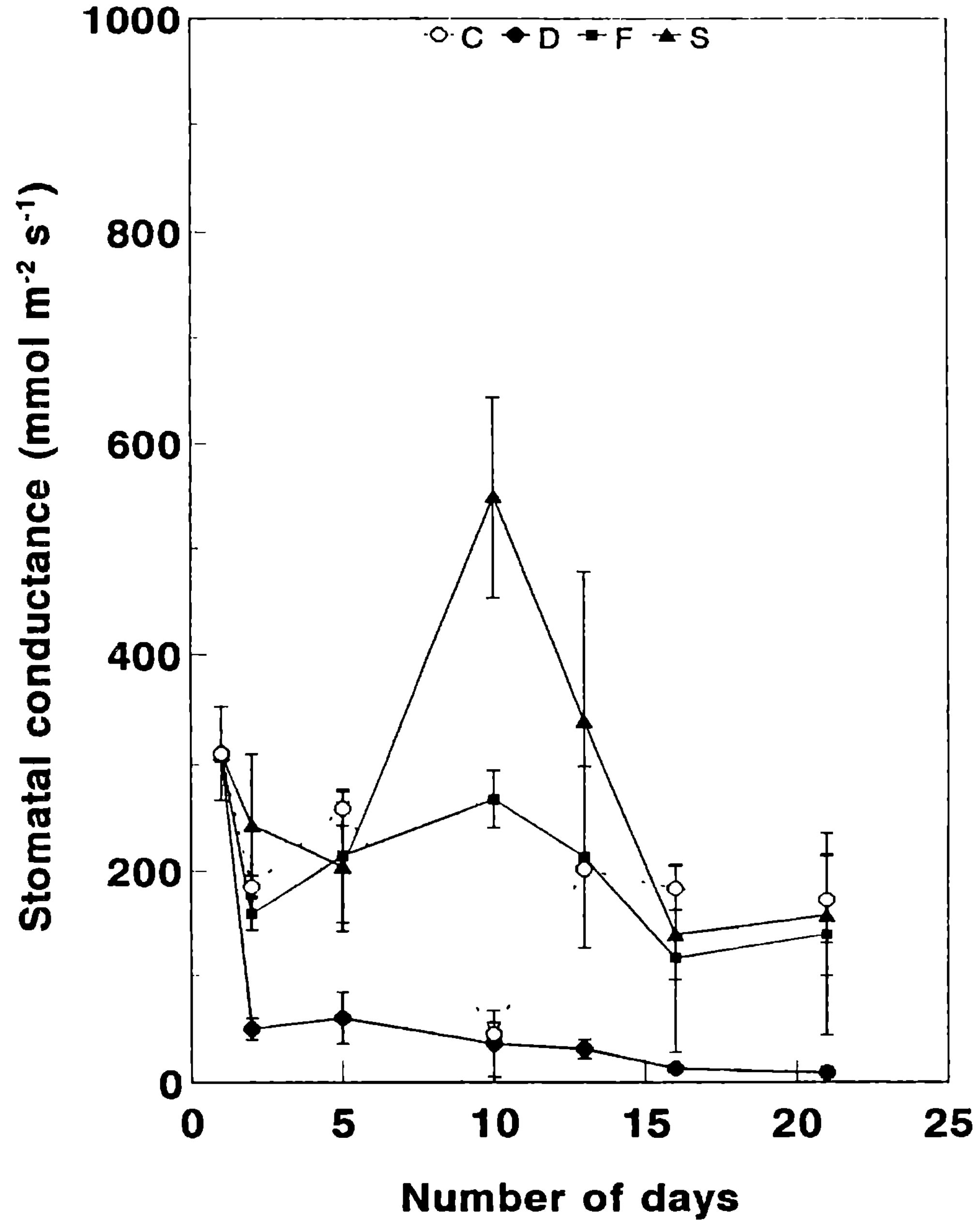

Fig. 46. *A.mangium* - Measurements of stomatal conductance under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

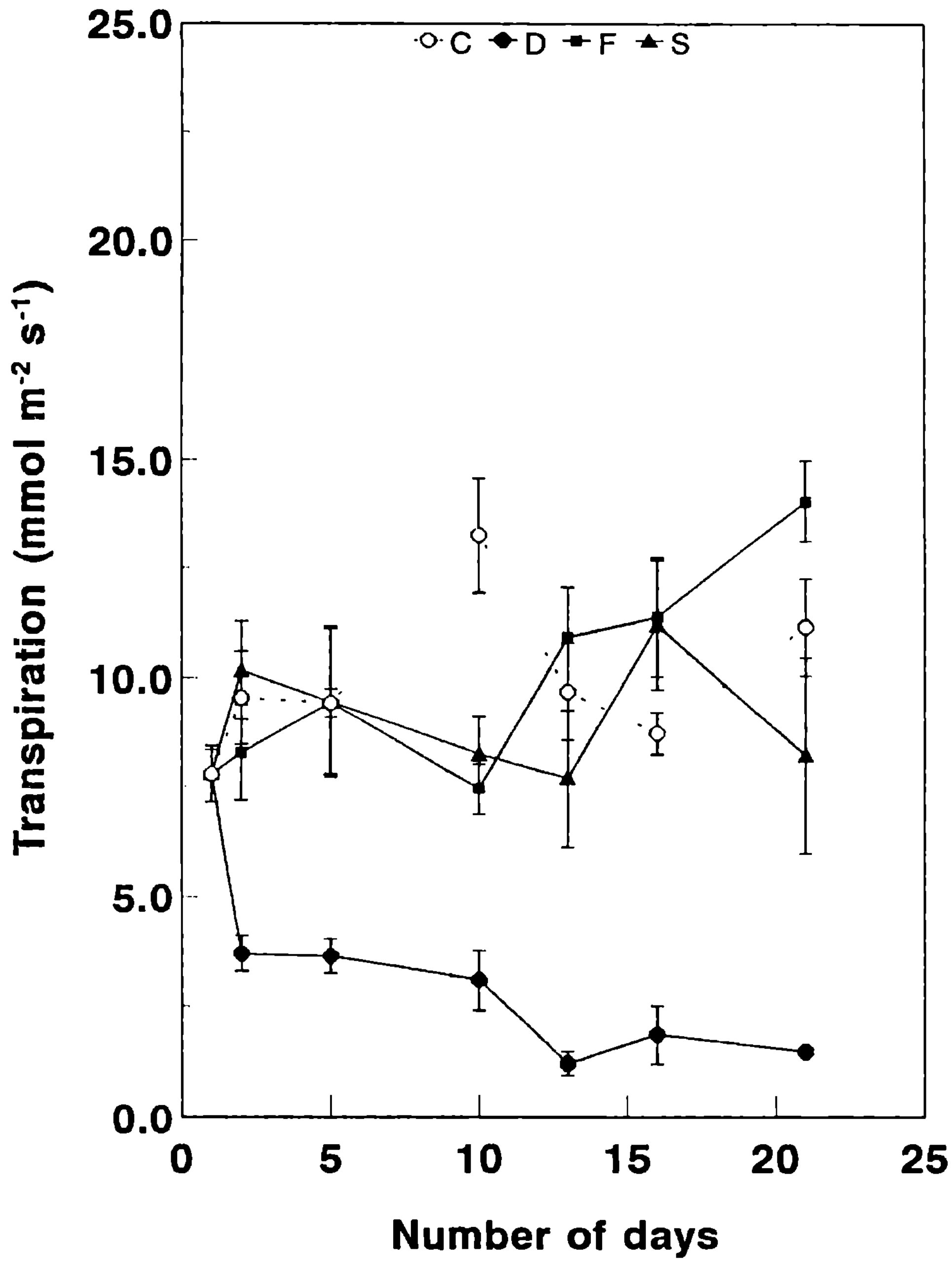

Fig. 47. *A.auriculiformis* - Measurements of transpiration under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

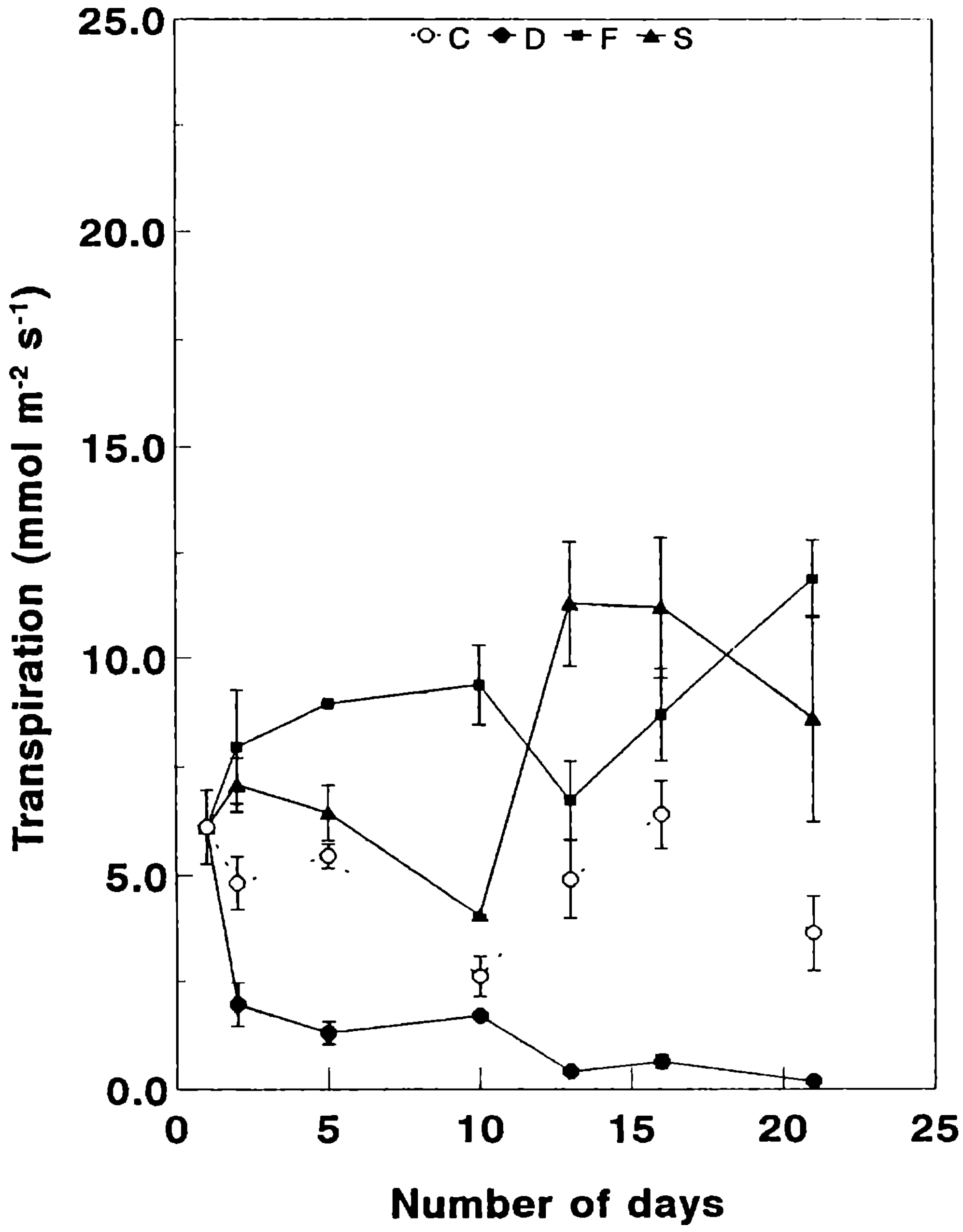

Fig. 48. *A.aulacocarpa* - Measurements of transpiration under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

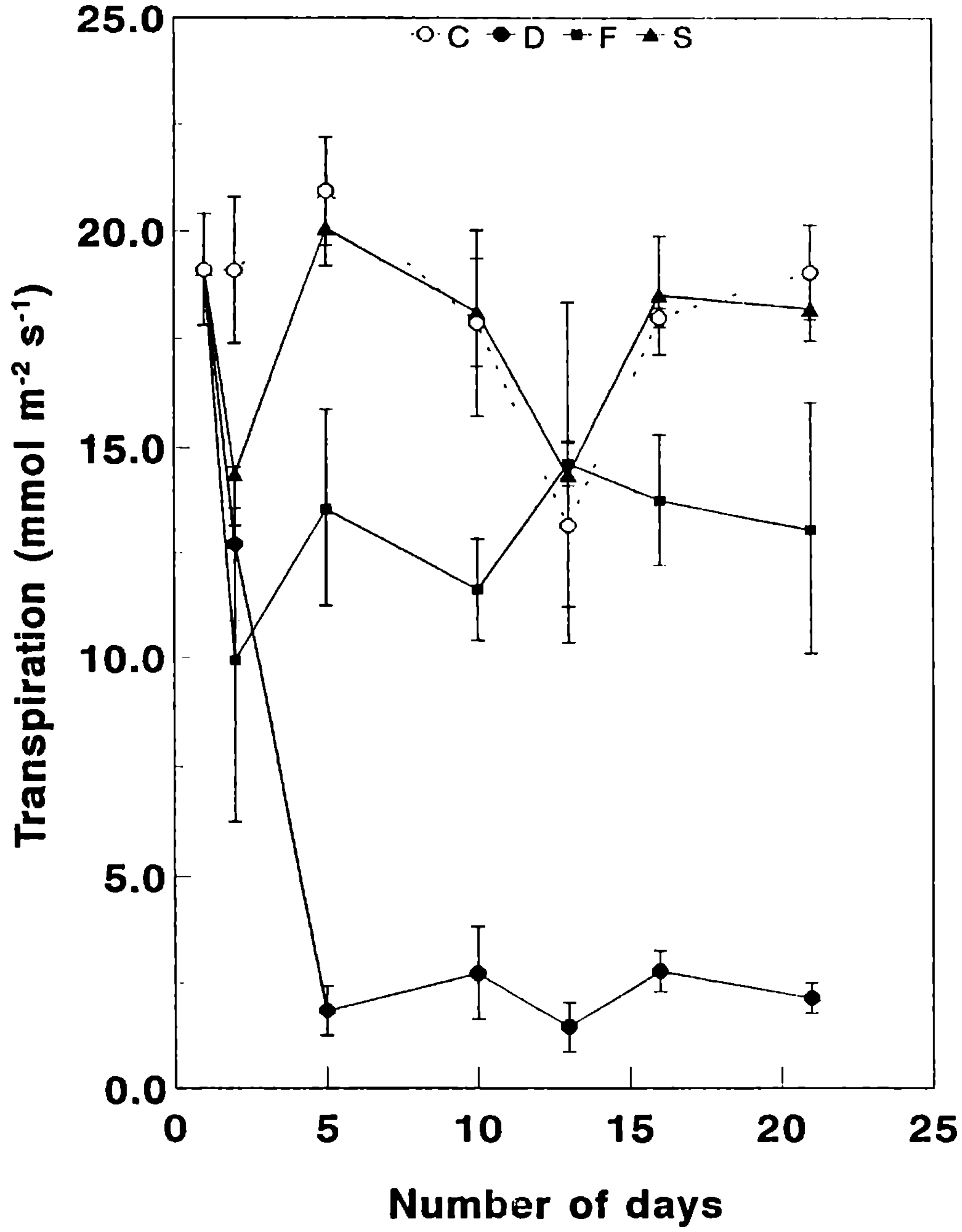

Fig.49. *A.holocericea* - Measurements of transpiration under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

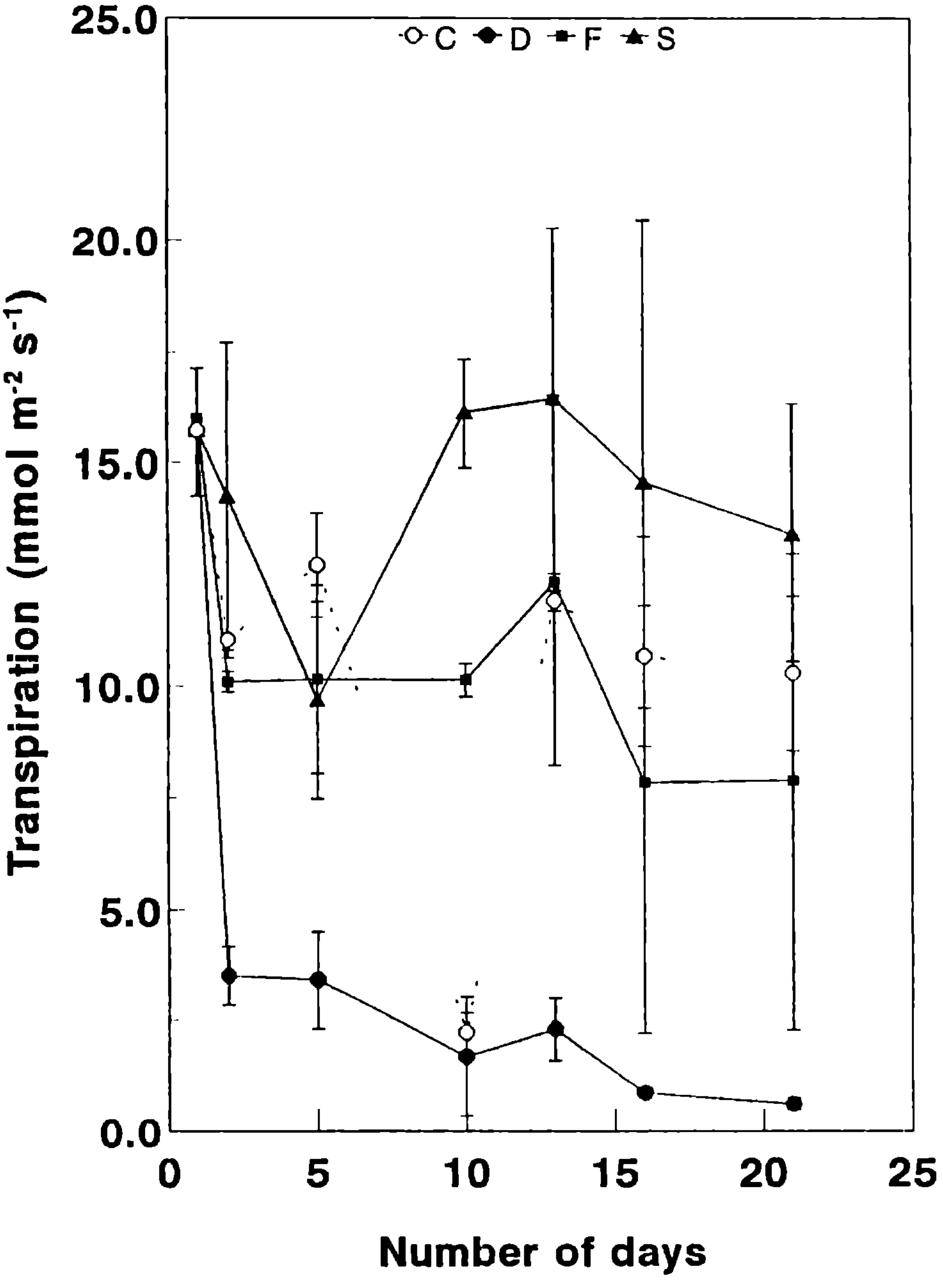

Fig. 50. *A.mangium* - Measurements of transpiration under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

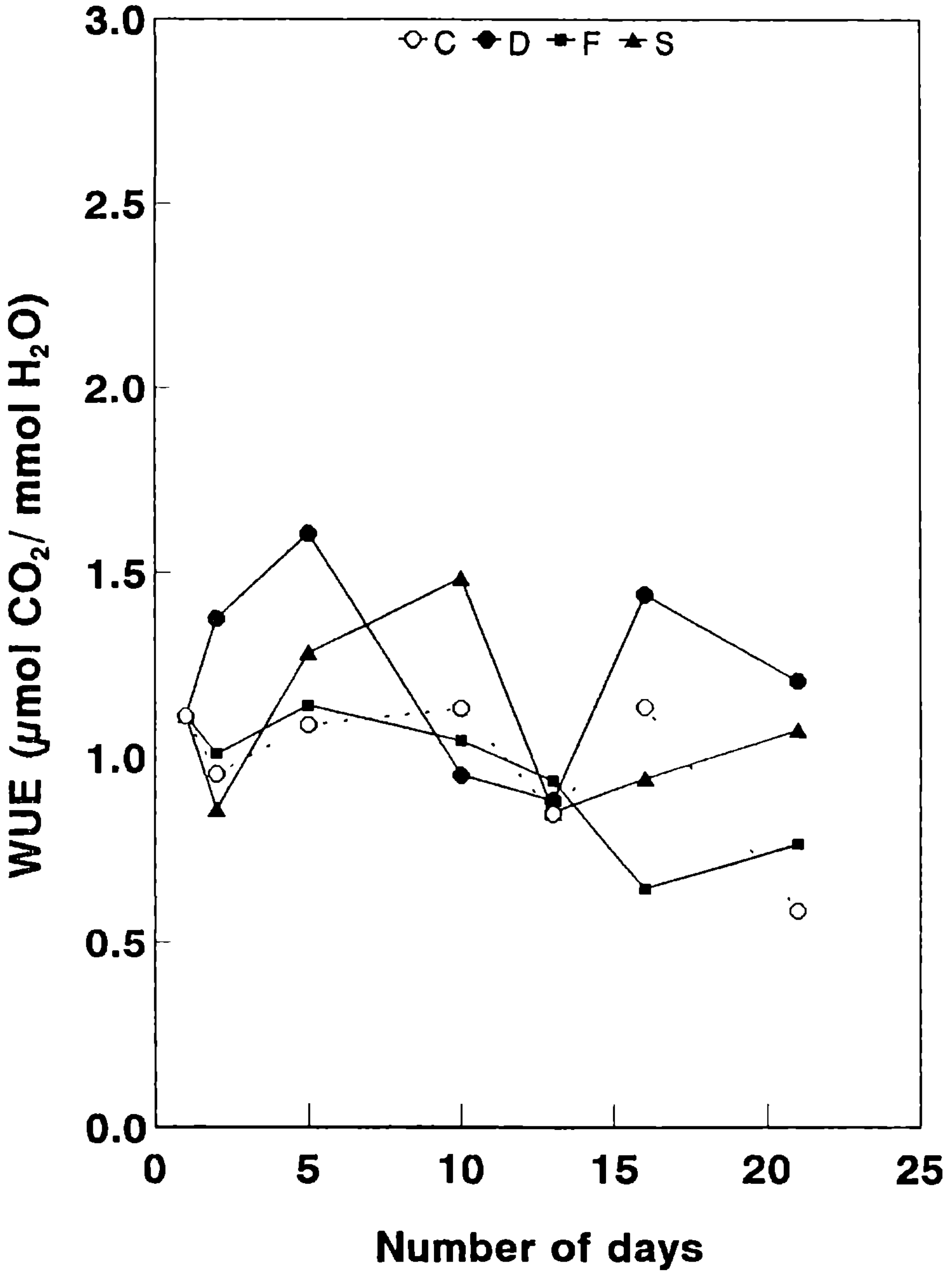

Fig. 51. *A.auriculiformis* - Measurements of WUE under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

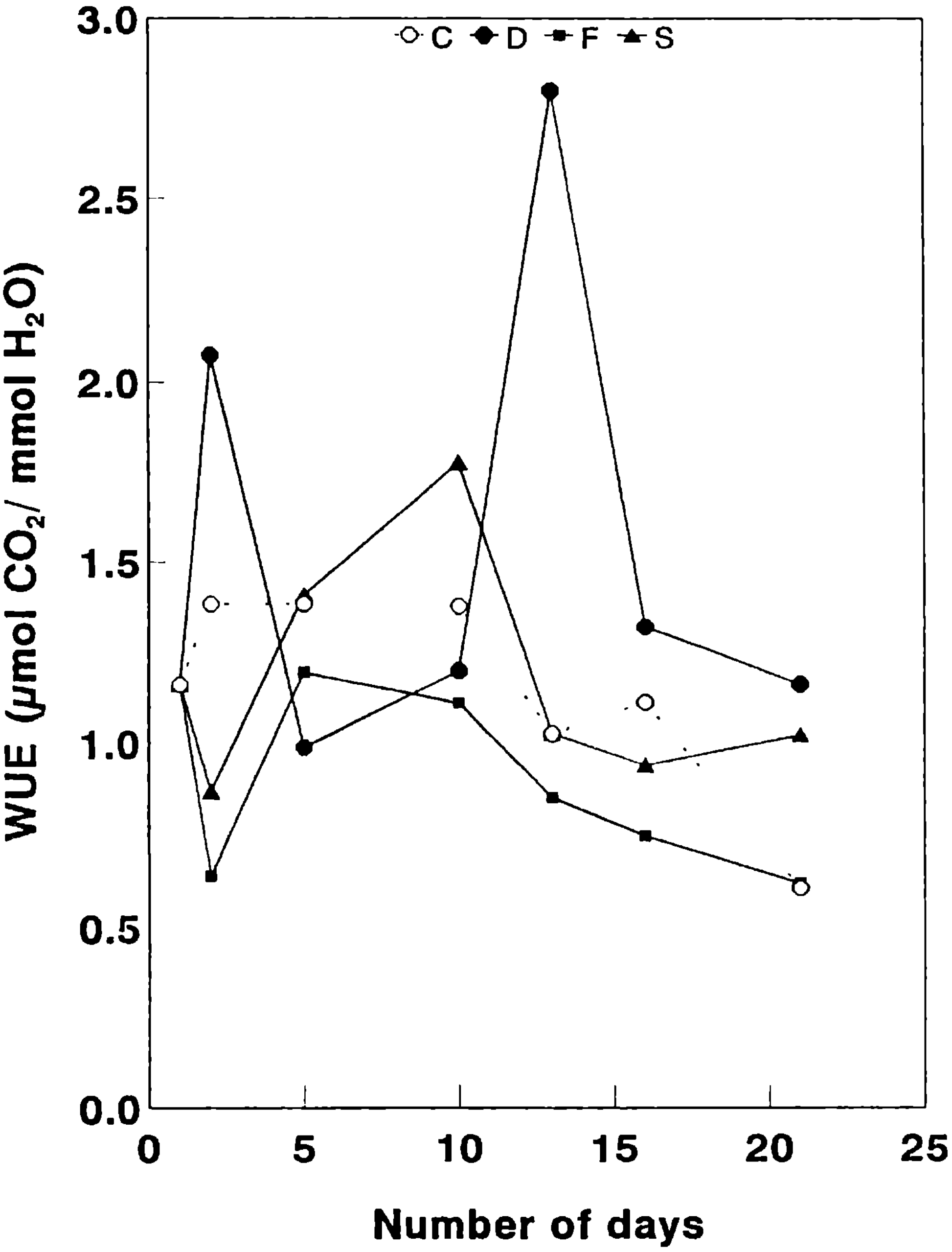

Fig. 52. *A.aulacocarpa* - Measurements of WUE under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

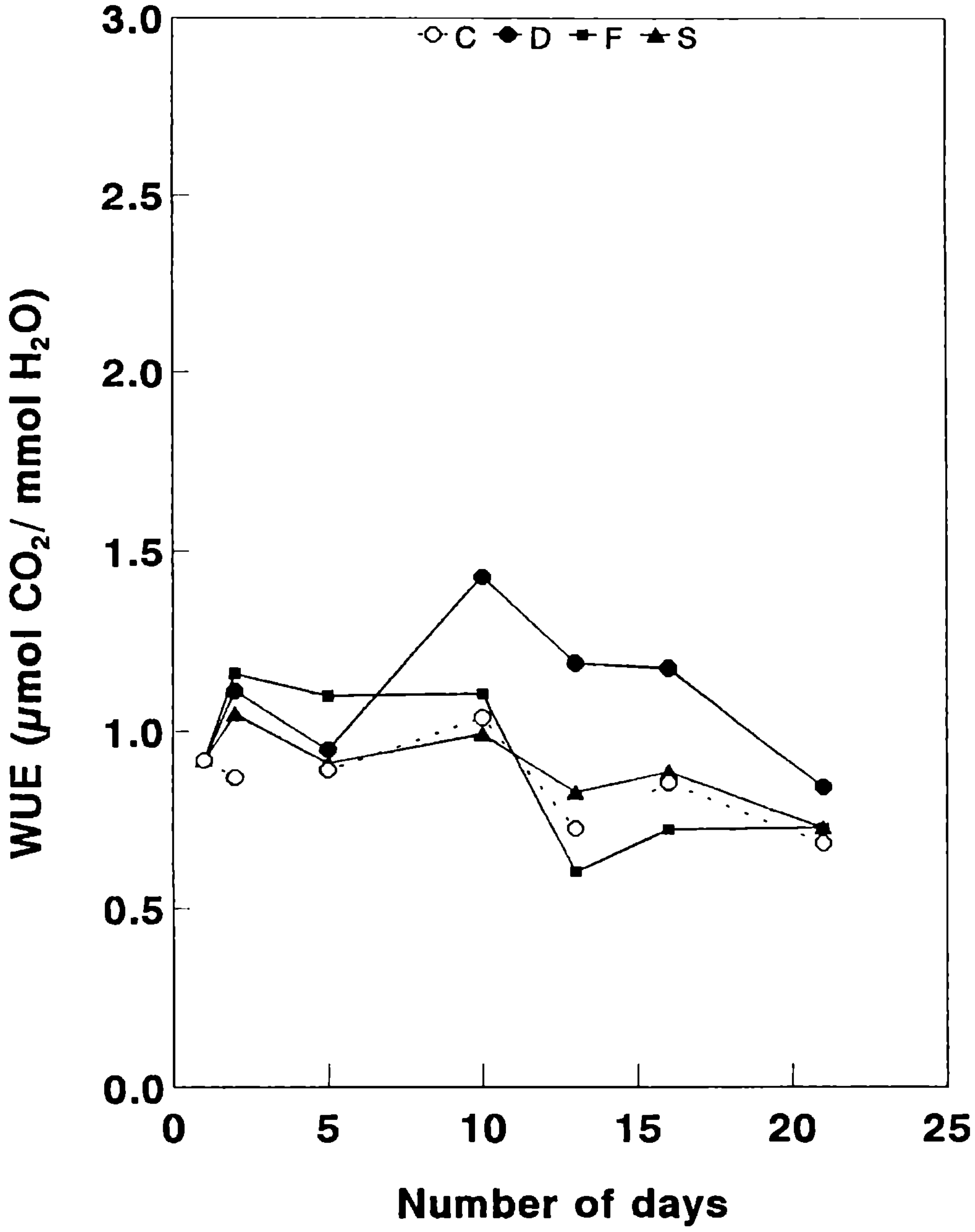

Fig. 53. *A. holocericea* - Measurements of WUE under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

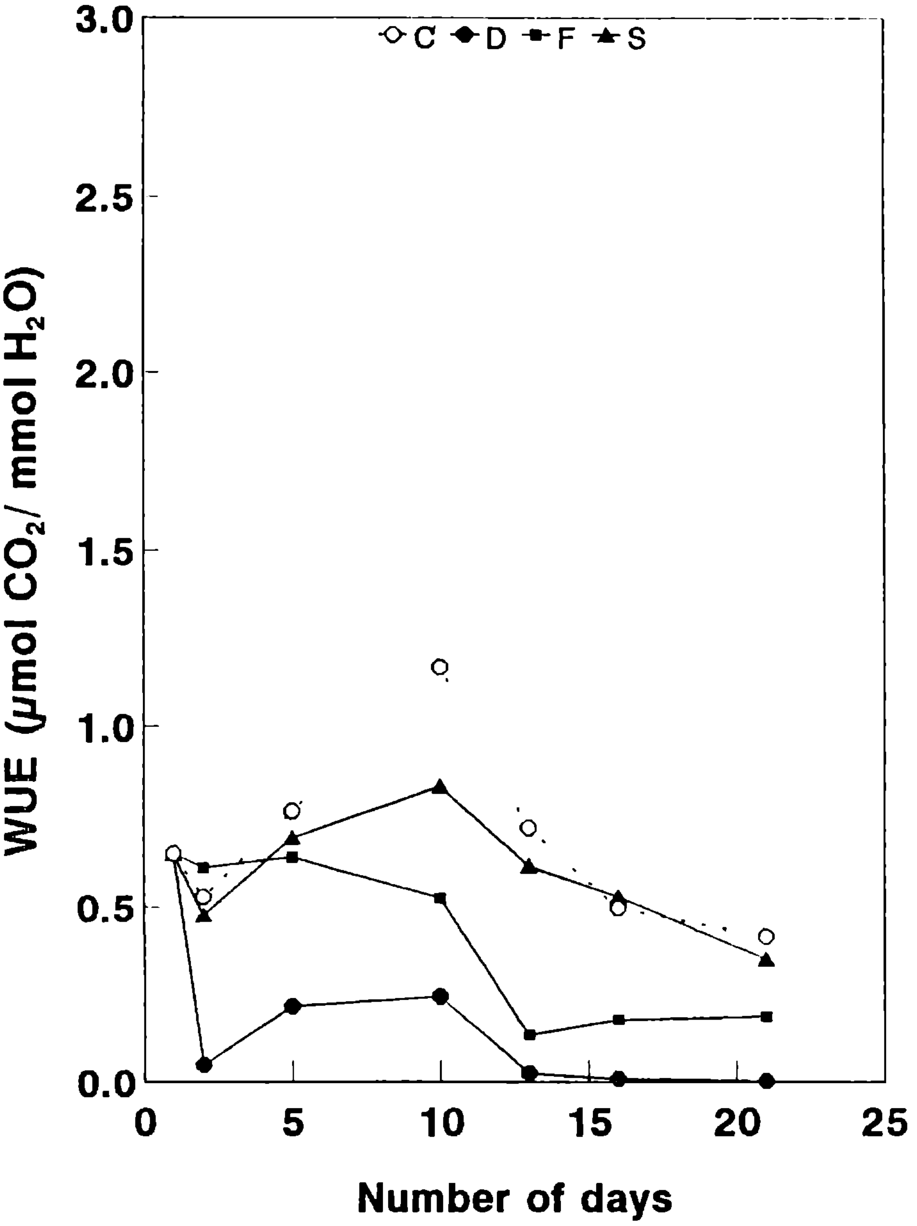

Fig. 54. *A.mangium* - Measurements of WUE under different stress conditions for various days during peak hours. The symbols C is control, D is days of drought stress, F is flooding stress and S is salinity stress.

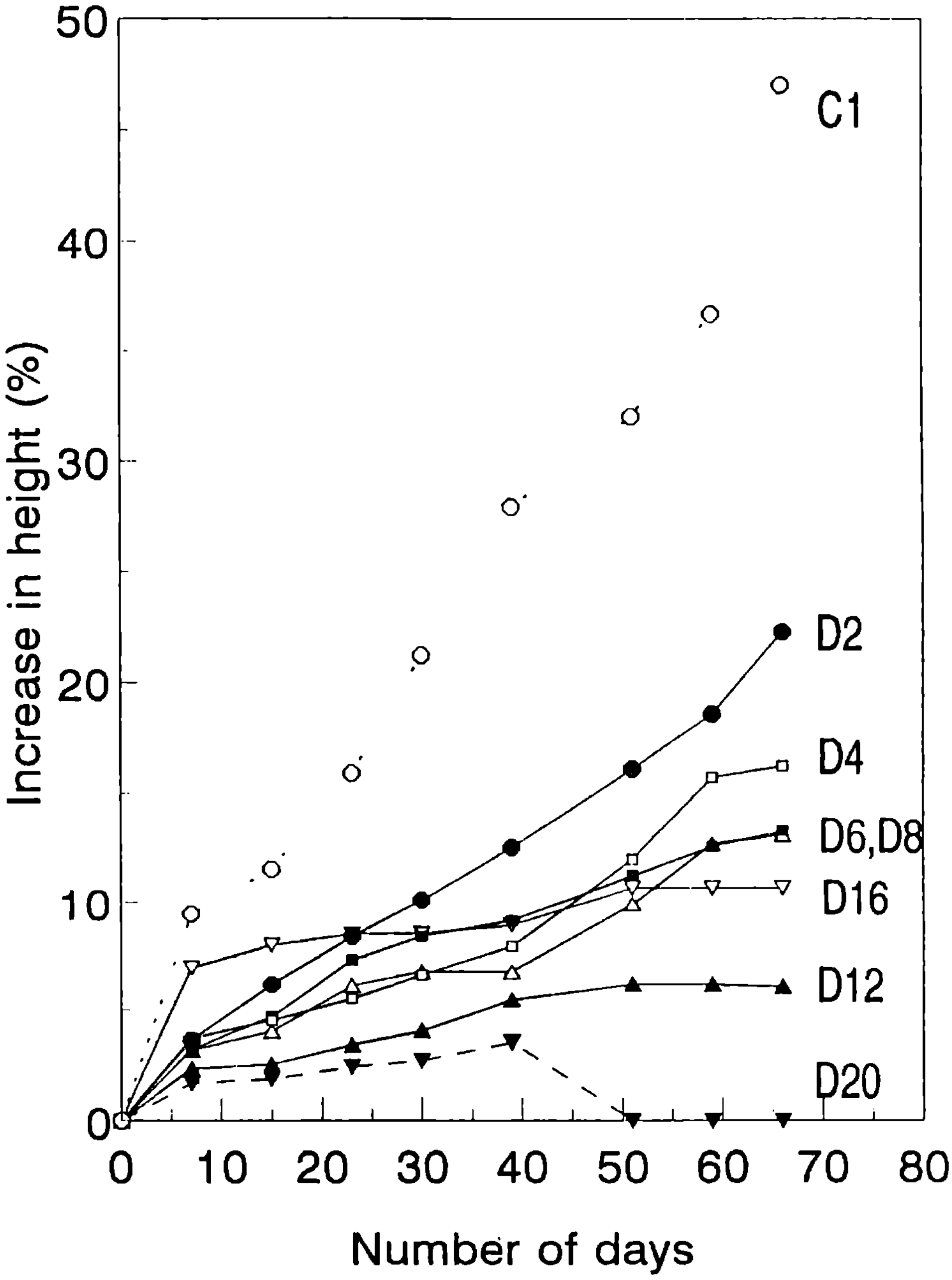

Fig. 55. Percentage increase in shoot length over initial length under various stress cycles in the seedlings of *A.auriculiformis* under different water stress cycles. The symbols C1 is control, D2, D4, D6, D8, D12, D16 and D20 indicate different drought stress cycles.

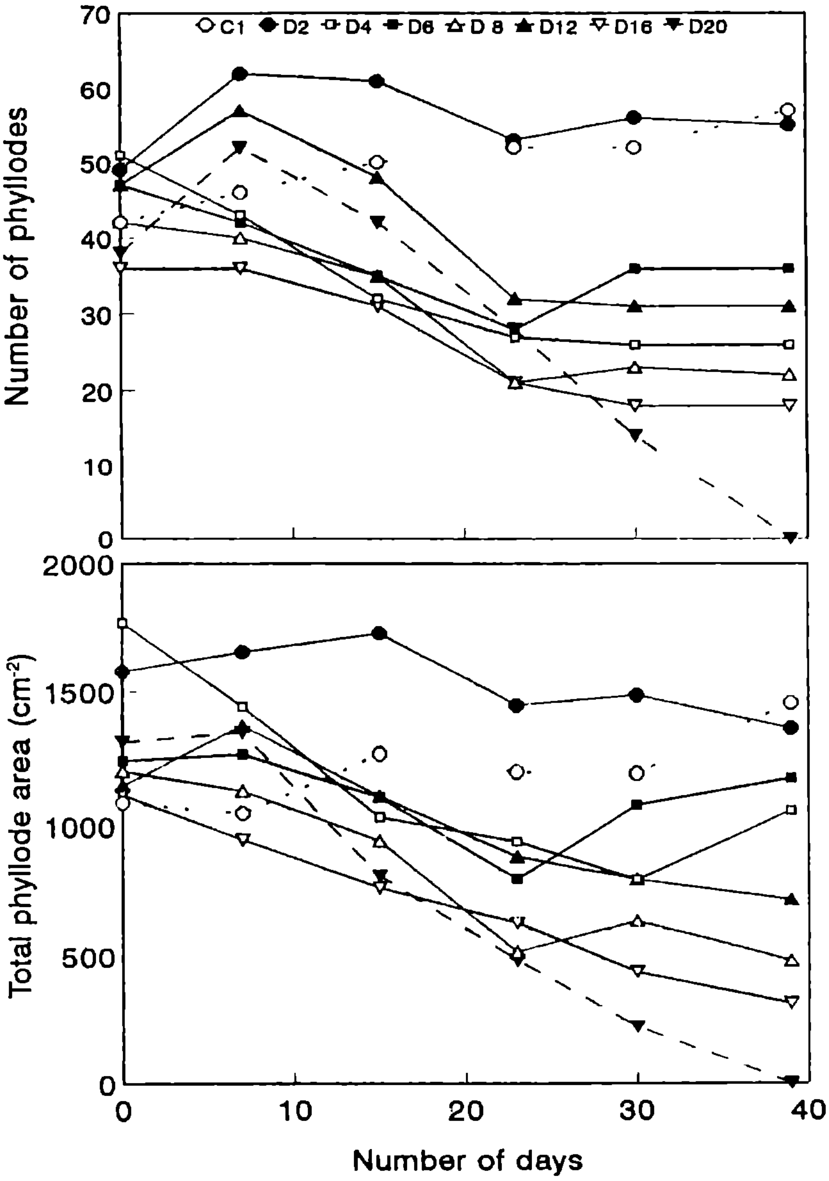

Fig. 56. *A. auriculiformis* - Variations in (a) number of phyllodes and (b) projected phyllode area under different water stress cycles. The symbols C1 is control, D2, D4, D6, D8, D12, D16 and D20 indicate different drought stress cycles.

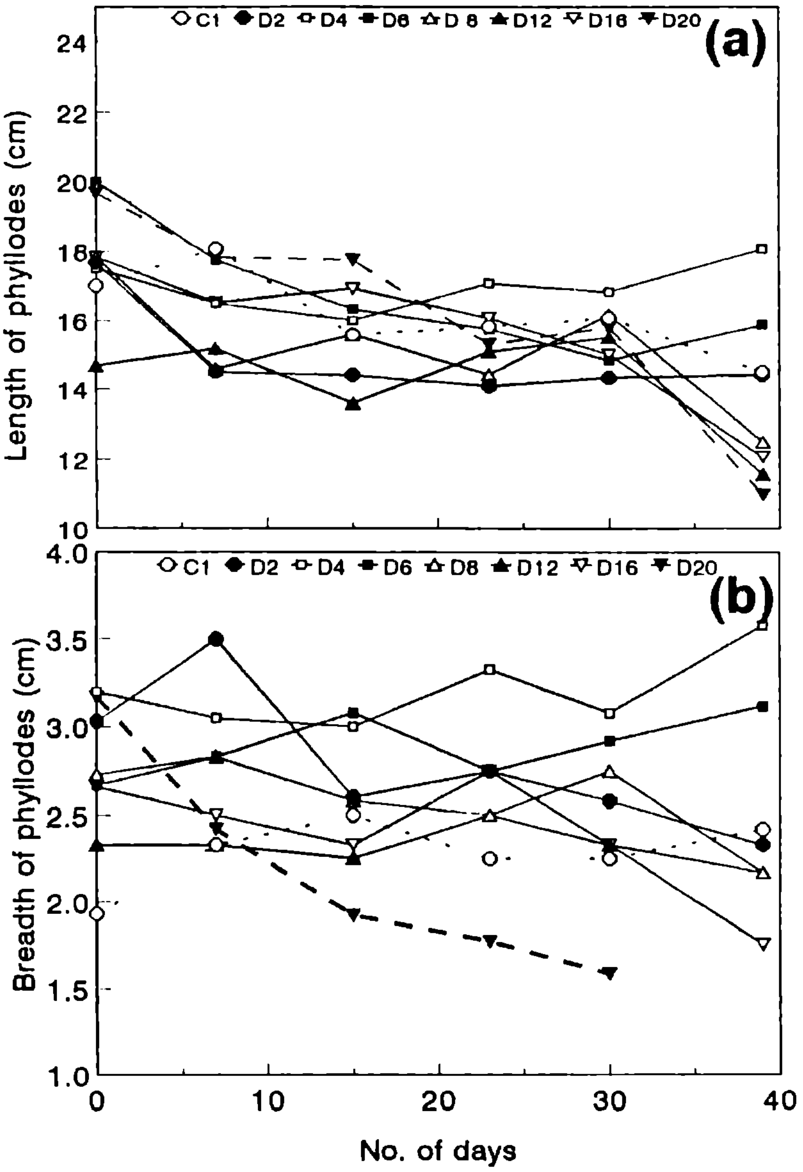

Fig. 57. *A. auriculiformis* - Variations in phyllode (a) length and (b) breadth under different water stress cycles. The symbols C1 is control, D2, D4, D6, D8, D12, D16 and D20 indicate different drought stress cycles.

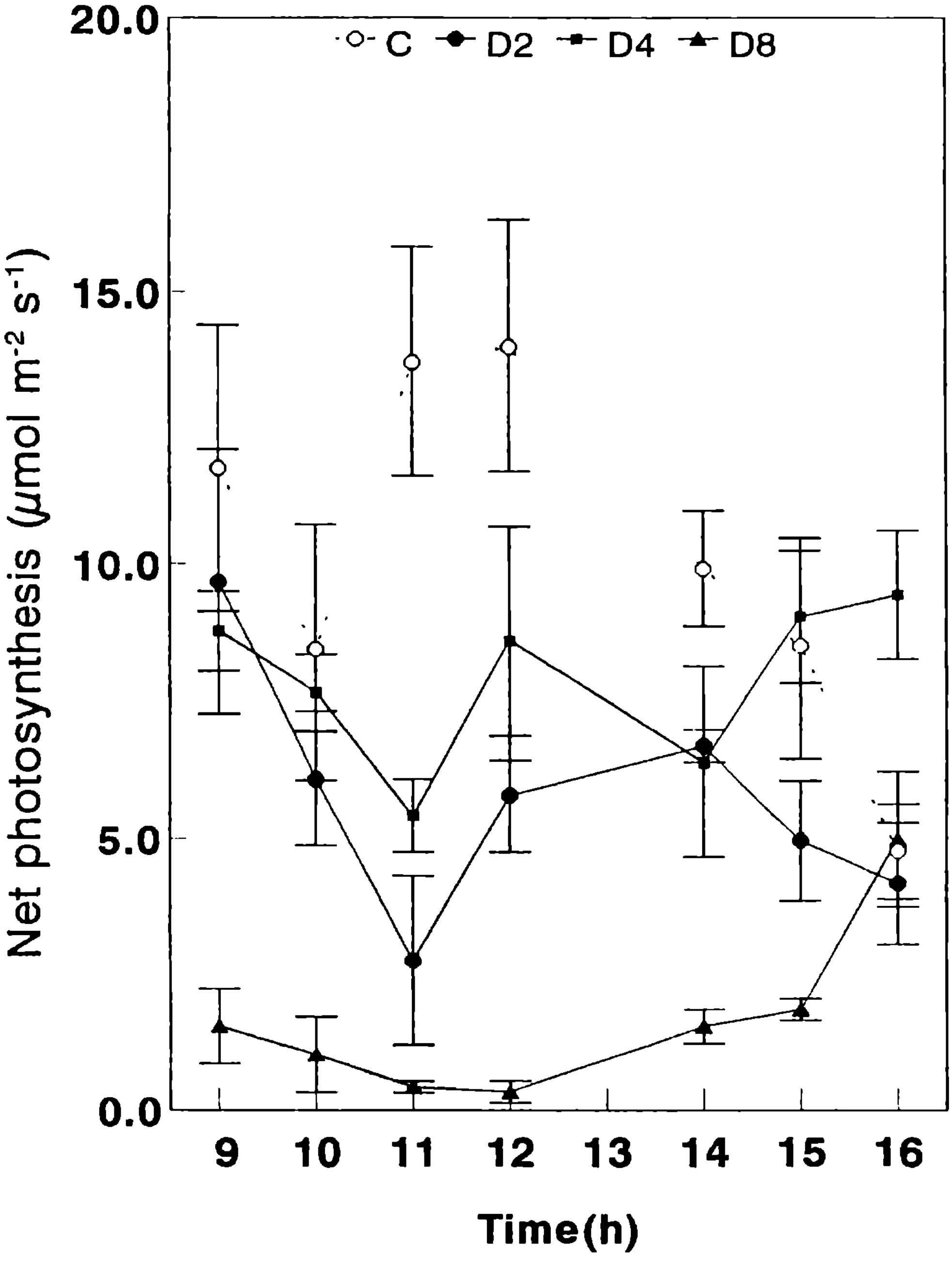

Fig. 58. *A. auriculiformis* - Diurnal measurements of net photosynthesis under various drought stress cycles. The symbols C1 is control, D2, D4, and D8 indicate different drought stress cycles.

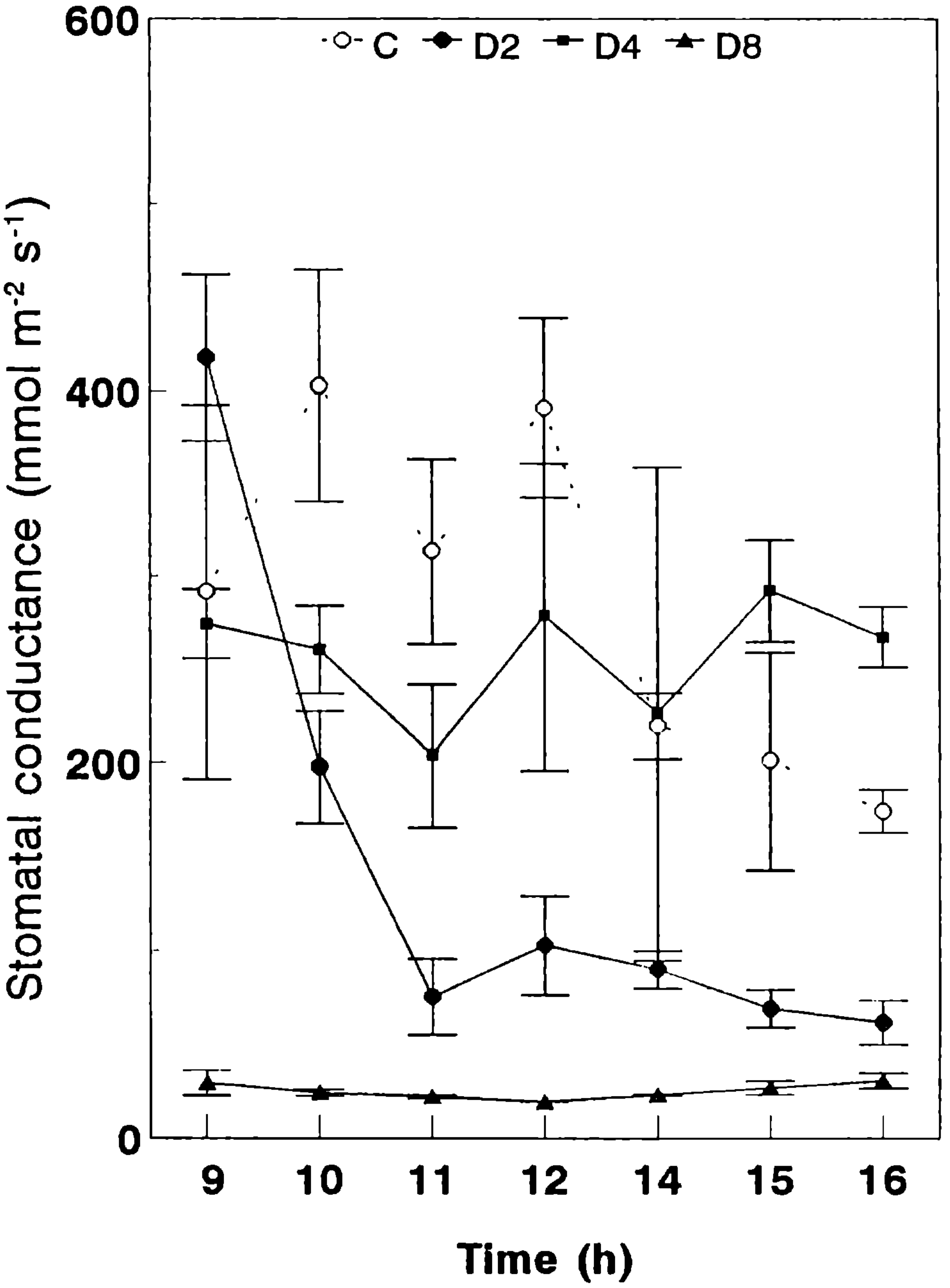

Fig. 59. *A. auriculiformis* - Diurnal measurements of stomatal conductance under various drought stress cycles. The symbols C1 is control, D2, D4, and D8 indicate different drought stress cycles.

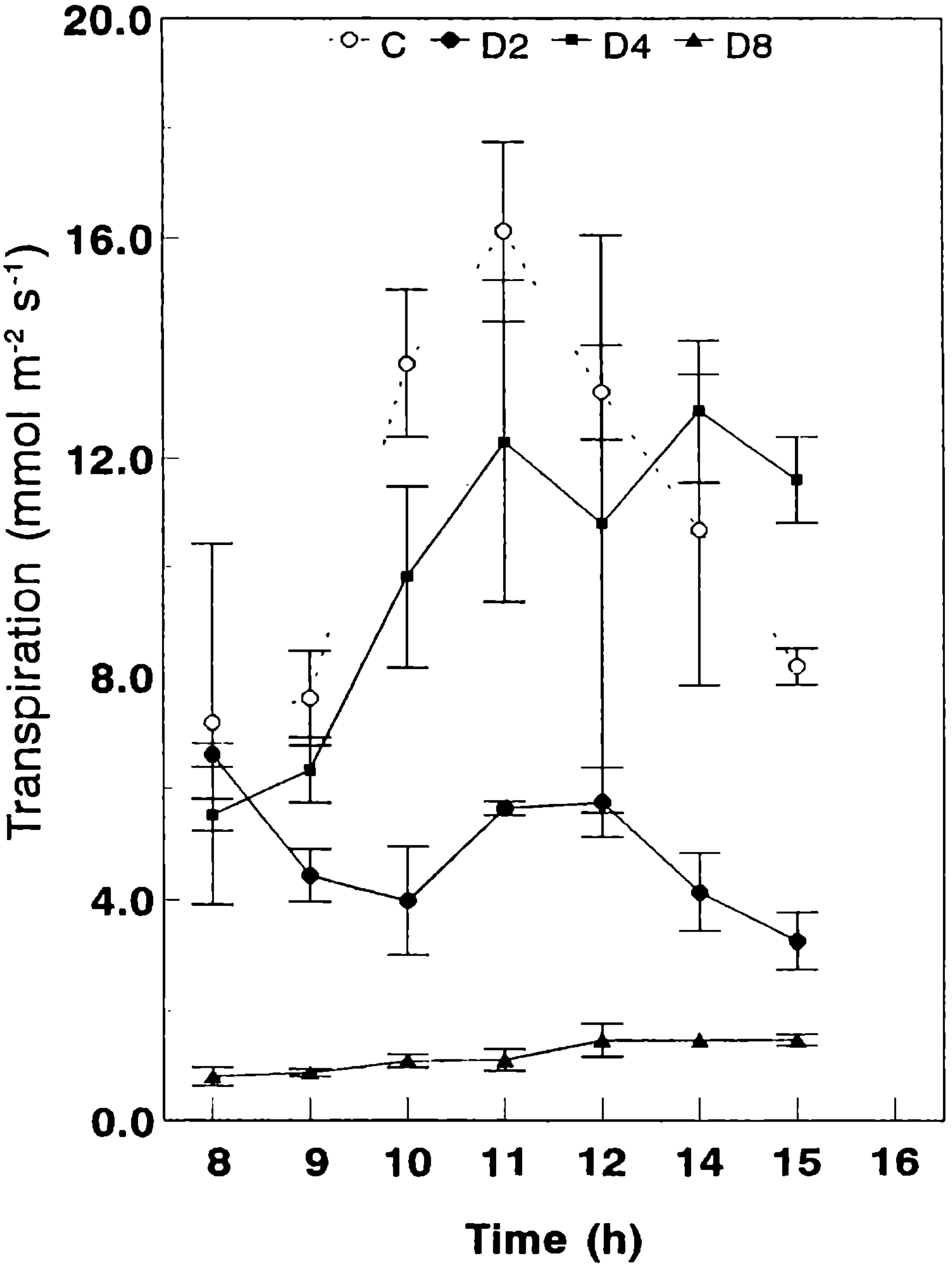

Fig. 60. *A. auriculiformis* - Diurnal measurements of transpiration under various drought stress cycles. The symbols Cl is control, D2, D4, and D8 indicate different drought stress cycles.

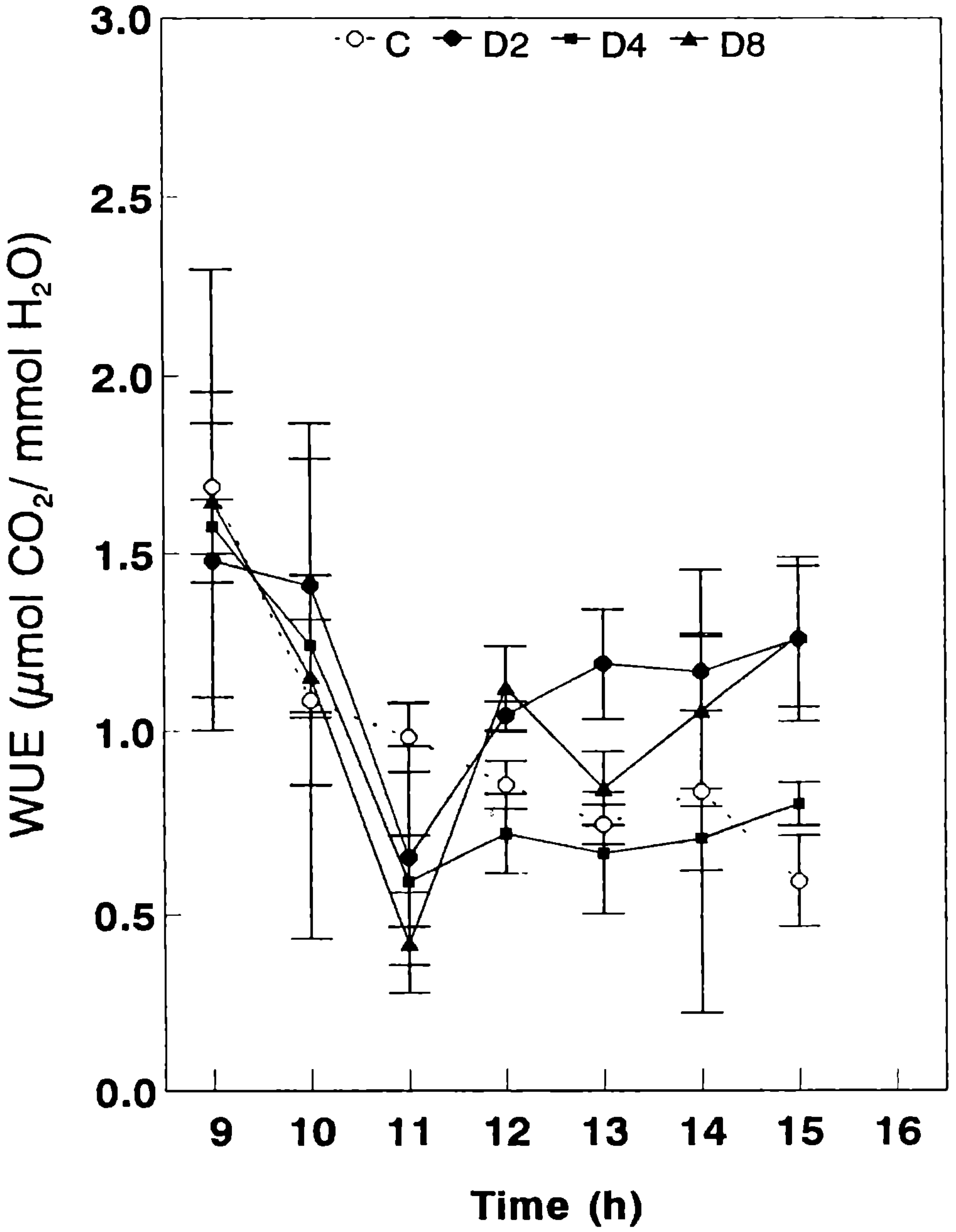

Fig. 61. *A. auriculiformis* - Diurnal measurements of WUE under various drought stress cycles. The symbols C is control, D2, D4, and D8 indicate different drought stress cycles.

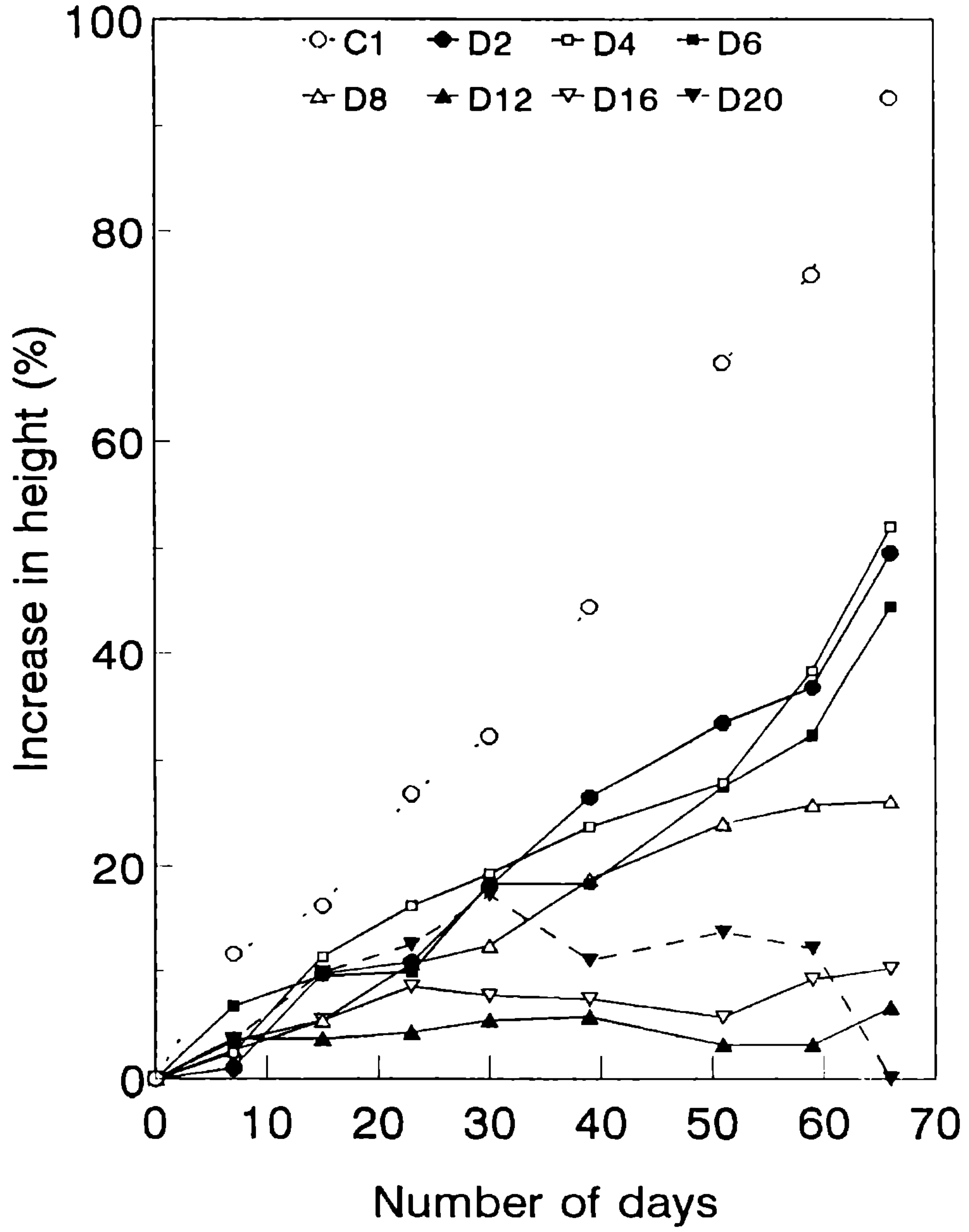

Fig. 62. Percentage increase in shoot length over initial length under various stress cycles in the seedlings of *A.mangium* under different water stress cycles. The symbols C1 is control, D2, D4, D6, D8, D12, D16 and D20 indicate different drought stress cycles.

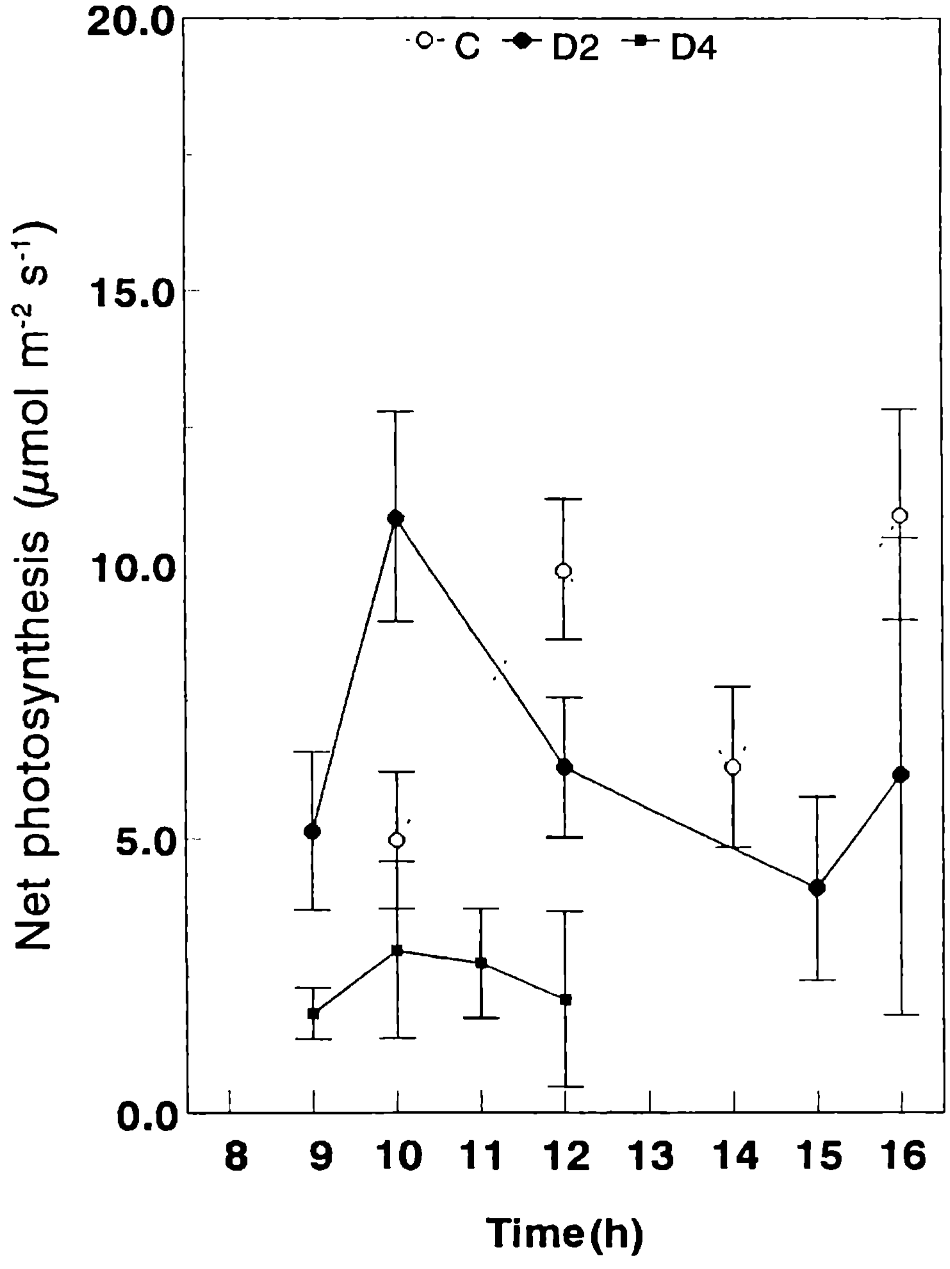

Fig. 63. *A. mangium* - Diurnal measurements of net photosynthesis under various drought stress cycles. The symbols C is control, D2 and D4 indicate different drought stress cycles.

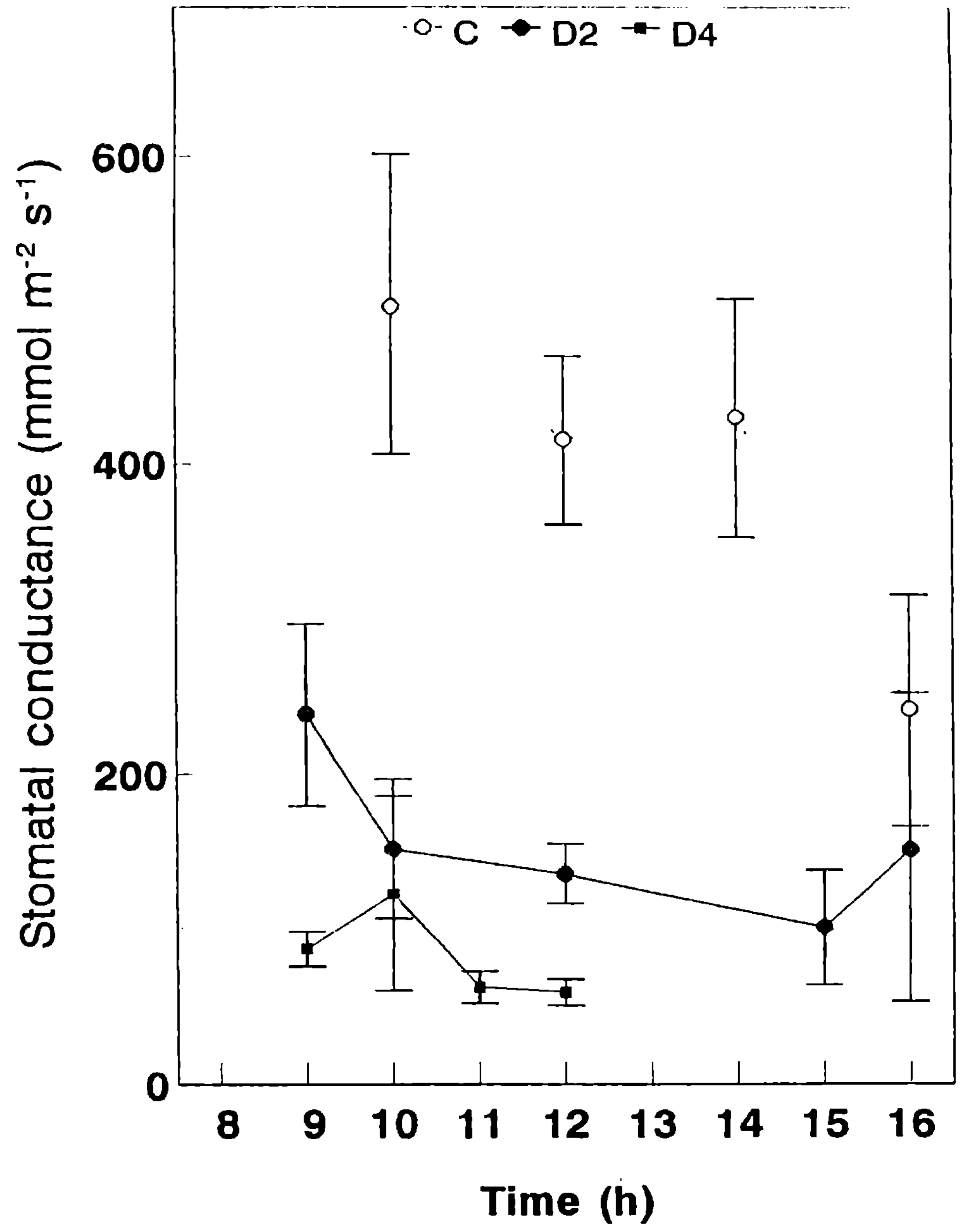

Fig. 64. *A. mangium* - Diurnal measurements of stomatal conductance under various drought stress cycles. The symbols C is control, D2 and D4 indicate different drought stress cycles.

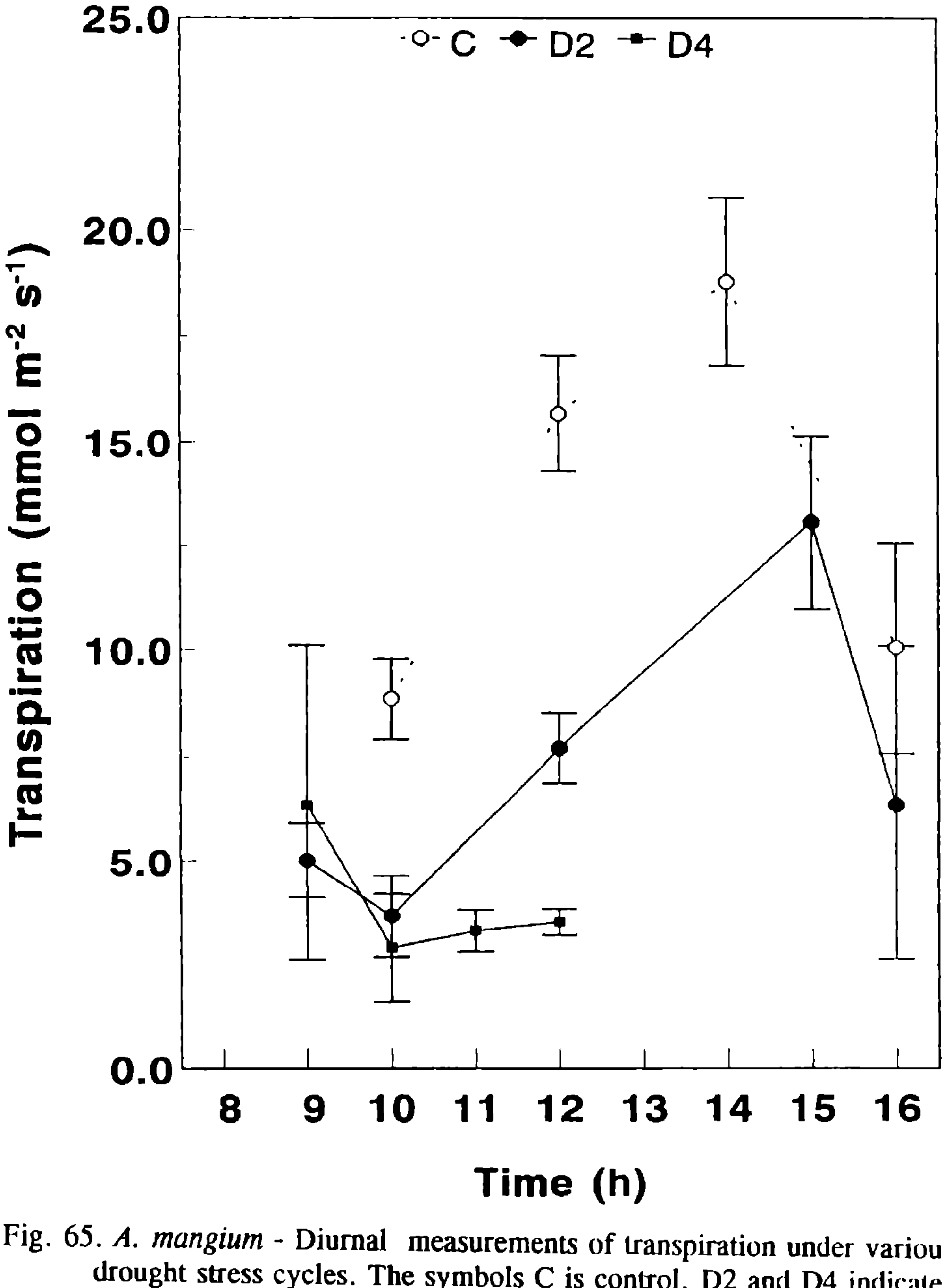

Fig. 65. *A. mangium* - Diurnal measurements of transpiration under various drought stress cycles. The symbols C is control, D2 and D4 indicate different drought stress cycles.

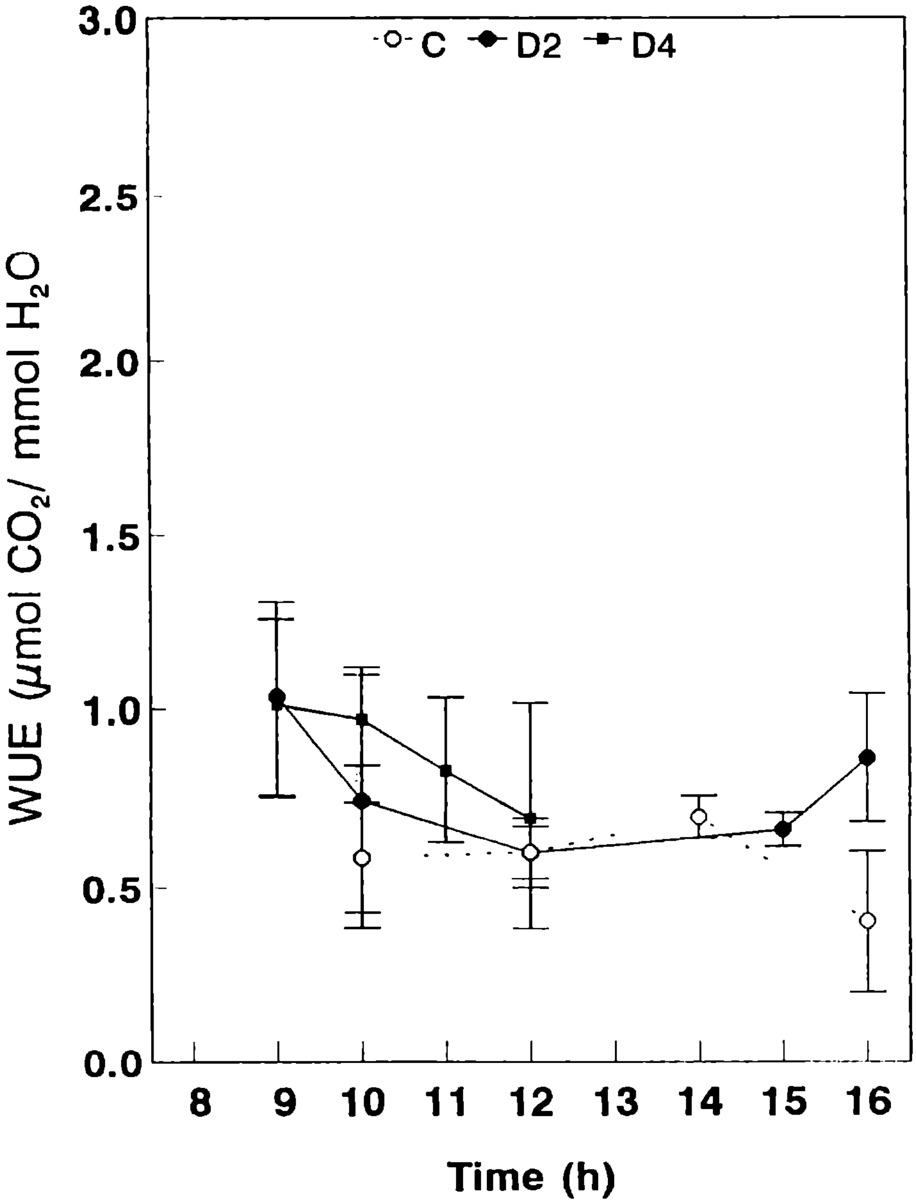

Fig. 66. *A. mangium* - Diurnal measurements of WUE under various drought stress cycles. The symbols C is control, D2 and D4 indicate different drought stress cycles.

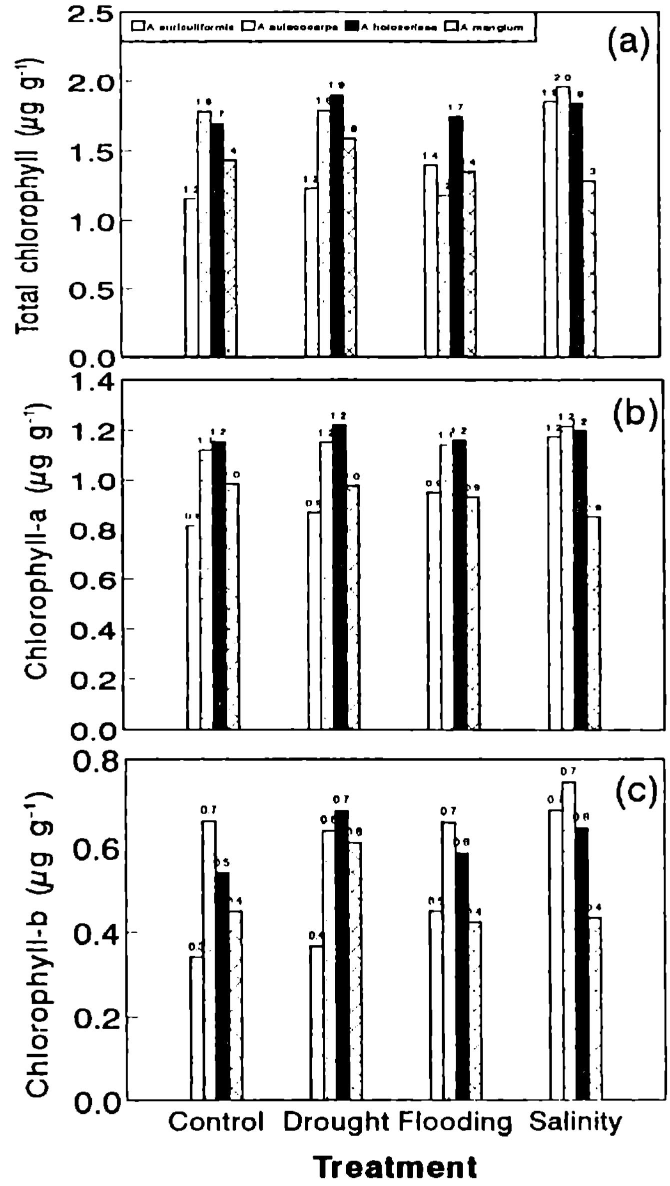

Fig. 67. Variations in (a) Total chlorophyll (b) Chlorophyll - a and (c) Chlorophyll - b content in the phyllodes of four species of acacias under normal watering , drought, flooding and salinity stress.

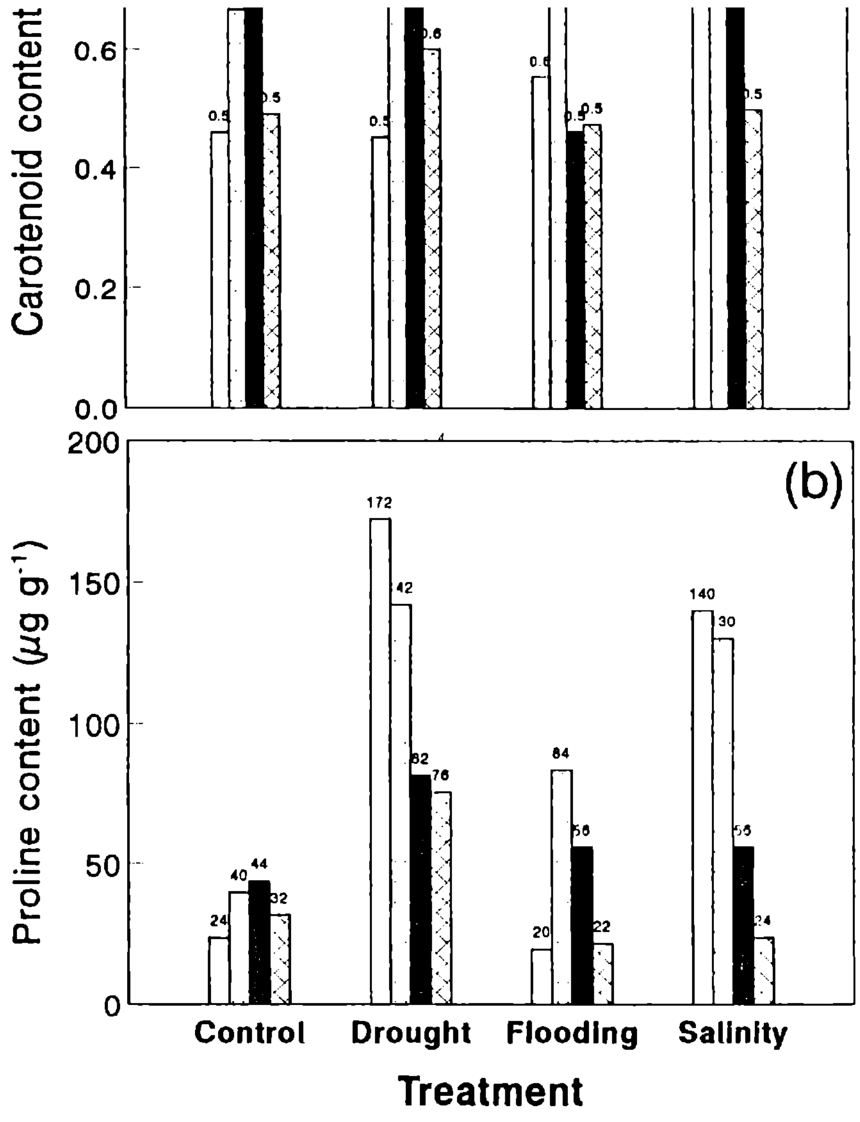

Fig. 68. Variations in (a) Carotenoid and (b) Proline content in the phyllodes of four species of acacias under normal watering , drought, flooding and salinity stress.

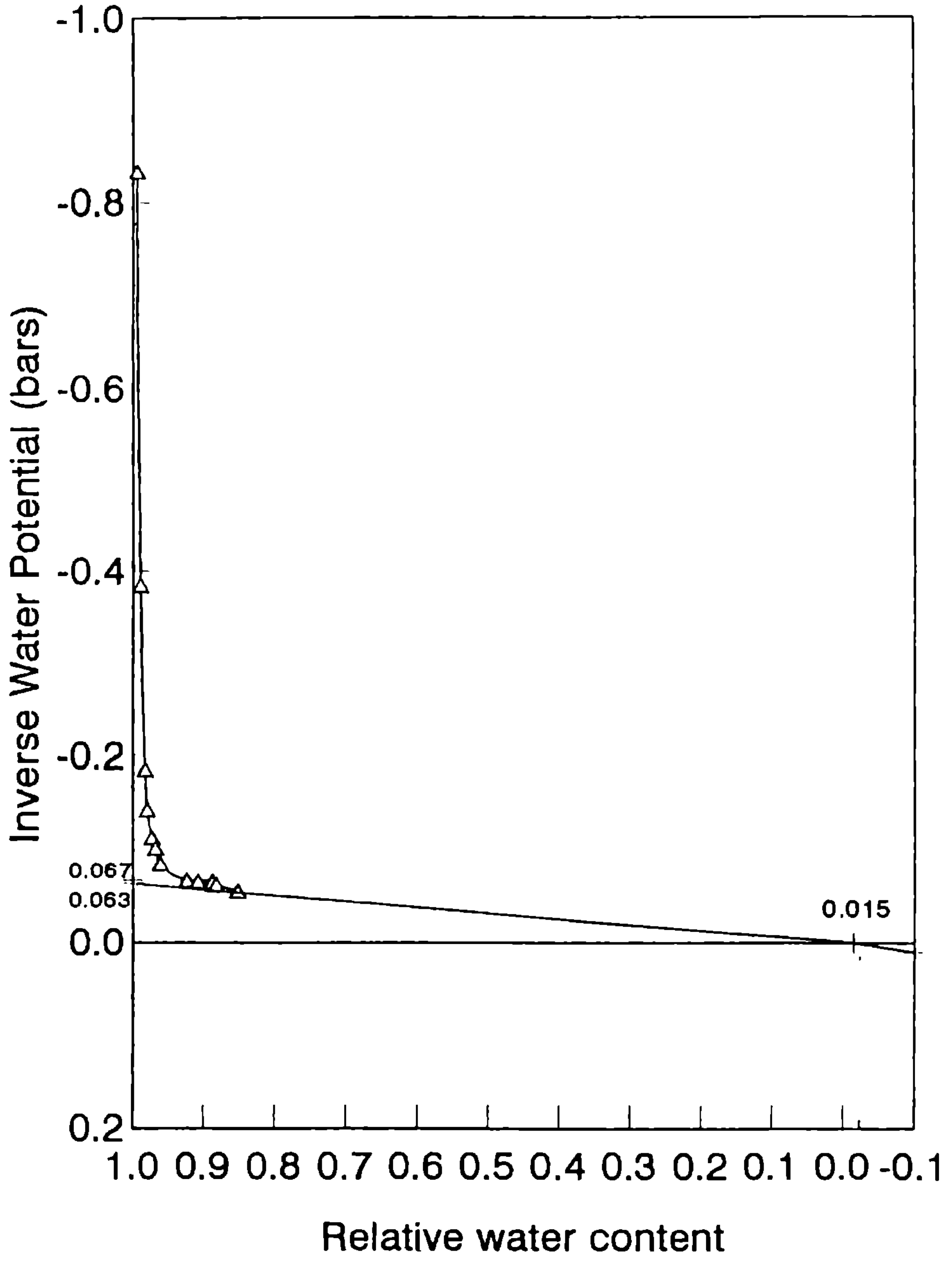

Fig. 69. *A.auriculiformis* - PV curve analysis for normally watered seedlings
($\Psi_{\pi.0}$ = -1.49 MPa, $\Psi_{\pi t}$ = -1.58, A = 1.5 %)

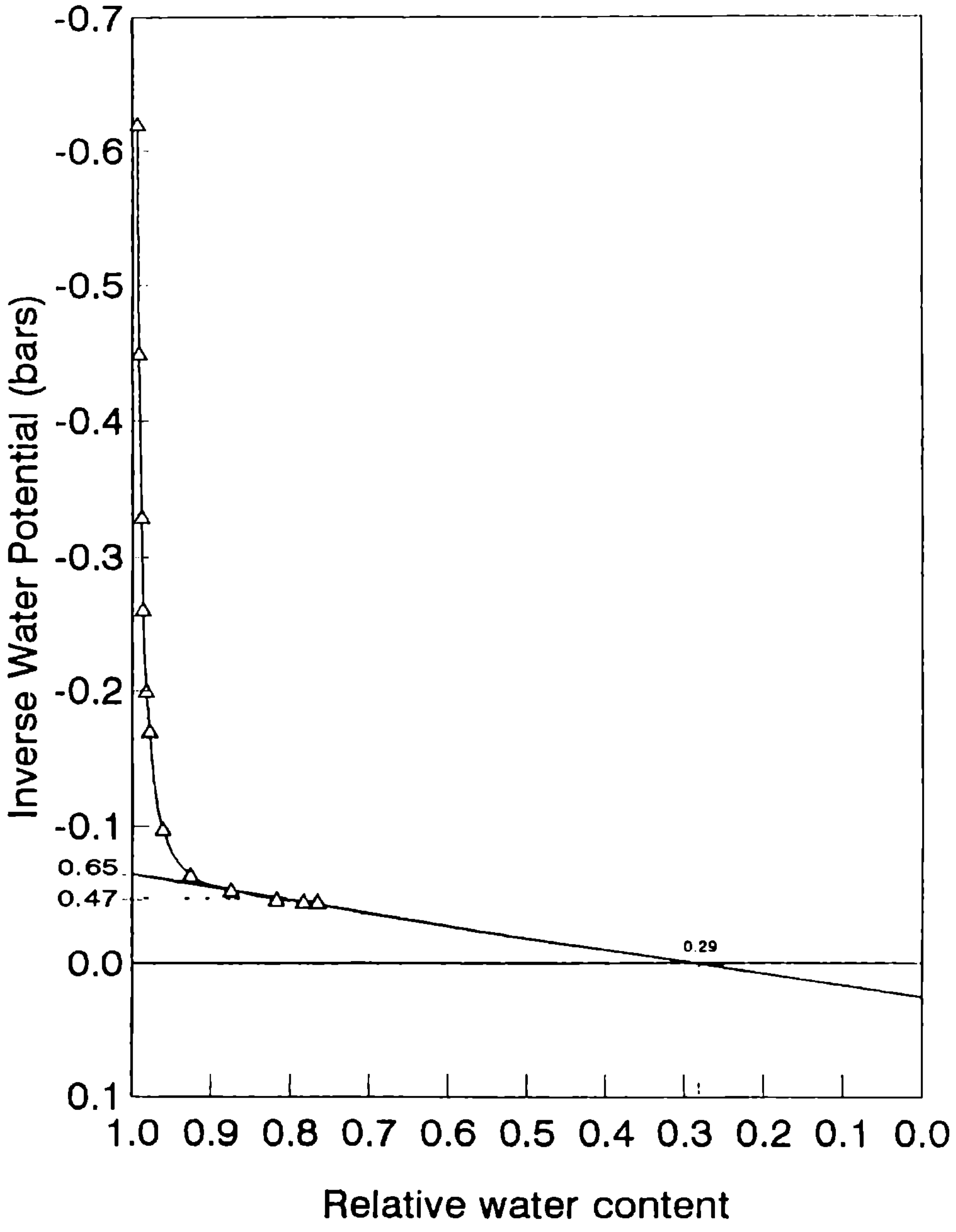

Fig. 70. *A.auriculiformis* - PV curve analysis for 8 day drought stressed seedlings ($\Psi_{\pi,0}$ = -1.53 MPa, $\Psi_{\pi,t}$ = -2.127 , A = 29 %)

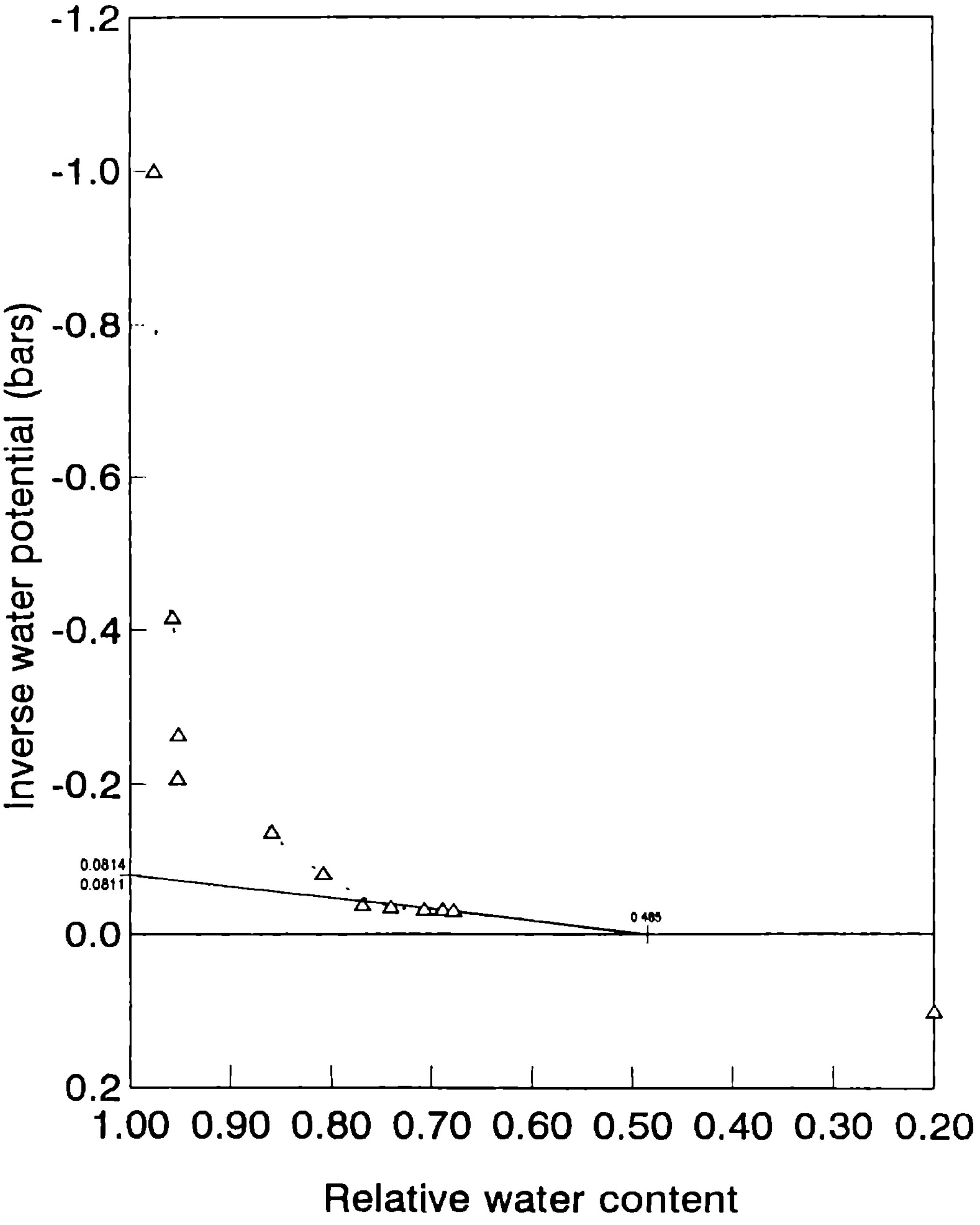

Fig. 71. *A.aualacocarpa* - PV curve analysis for normally watered seedlings ($\Psi_{\pi.0}$ = -1.228 MPa, $\Psi_{\pi.z}$ = -1.213, A = 48.5 %)

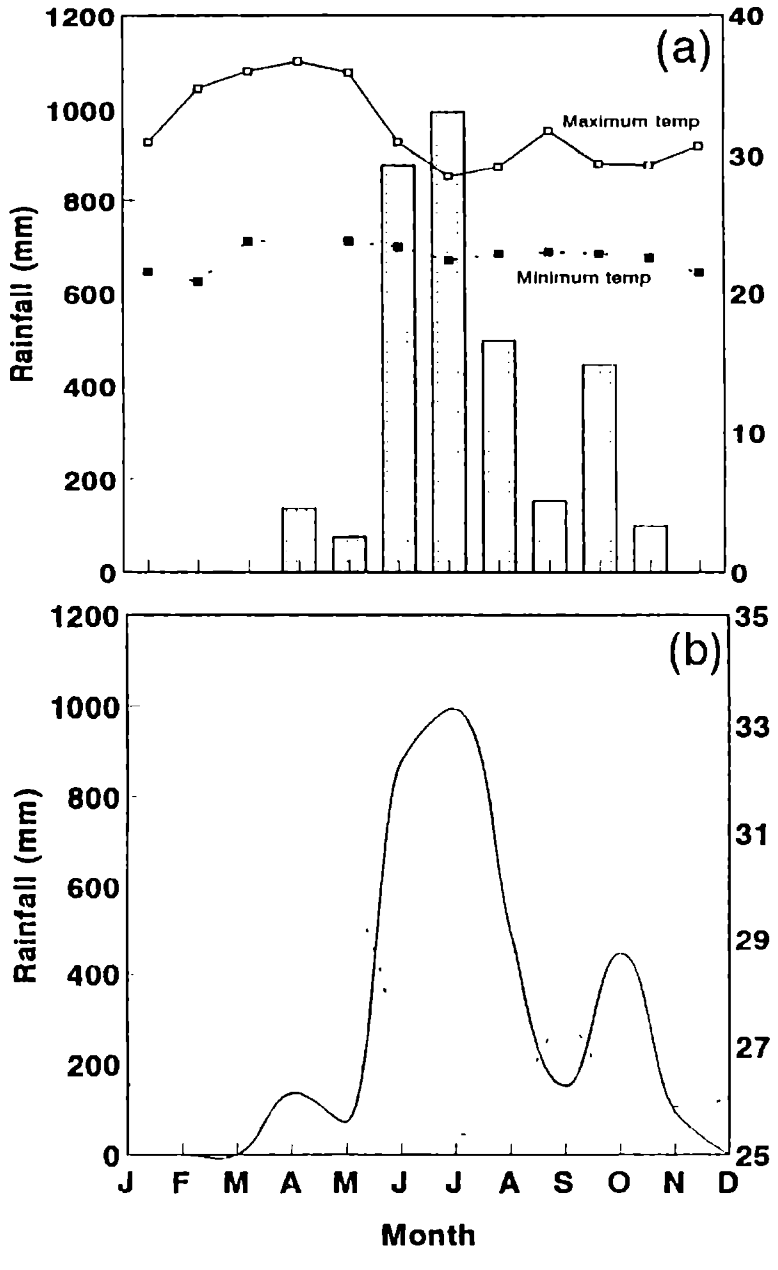

Fig. 72. Weather data at Kothachira during the experimental period showing (a) rainfall and temperature (b) ombrothermic graph showing stressed and non stressed periods.

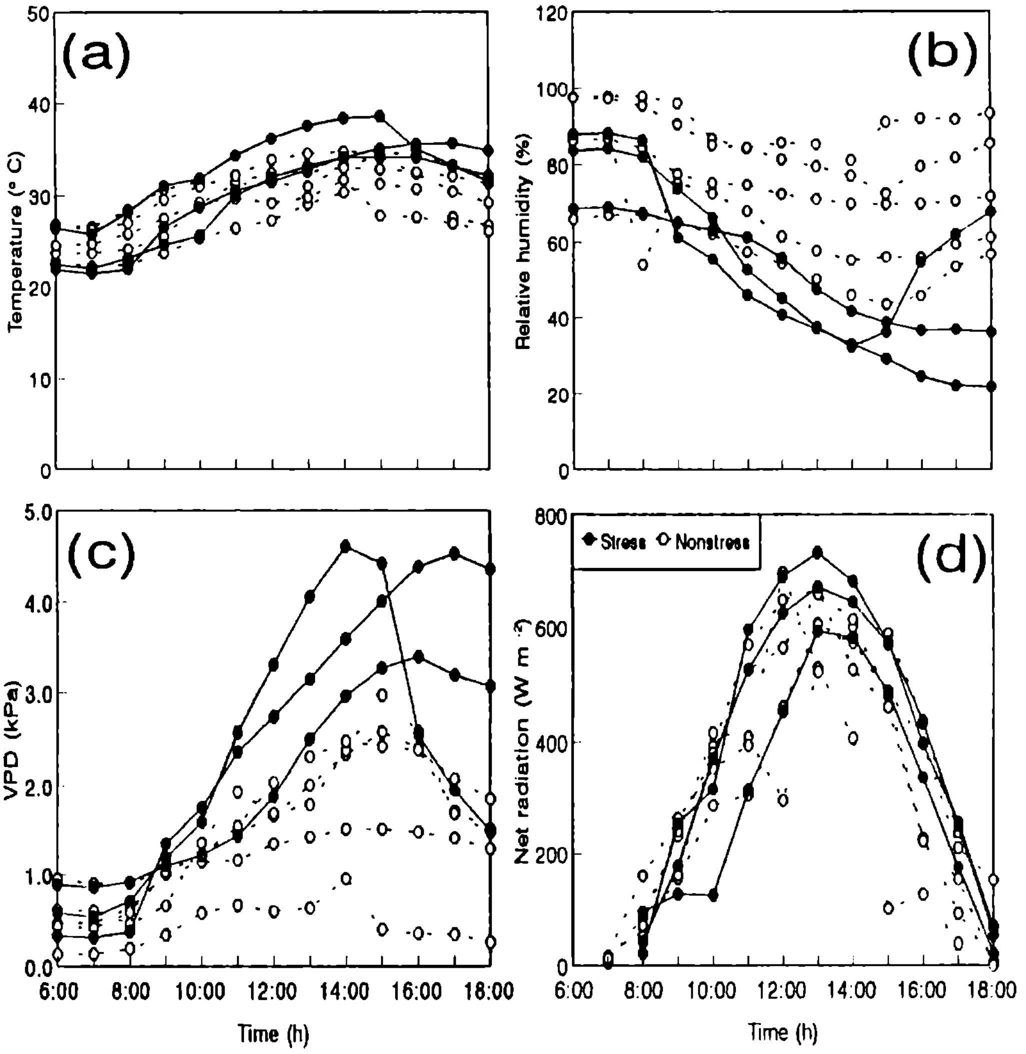

Fig. 73. Microclimate measurements above the canopy of *Acacia auriculiformis* plantation at Kothachira showing variations in (a) temperature (b) atmospheric vapor pressure deficit (c) relative humidity and (d) net radiation during stressed (●) and nonstressed (○) months.

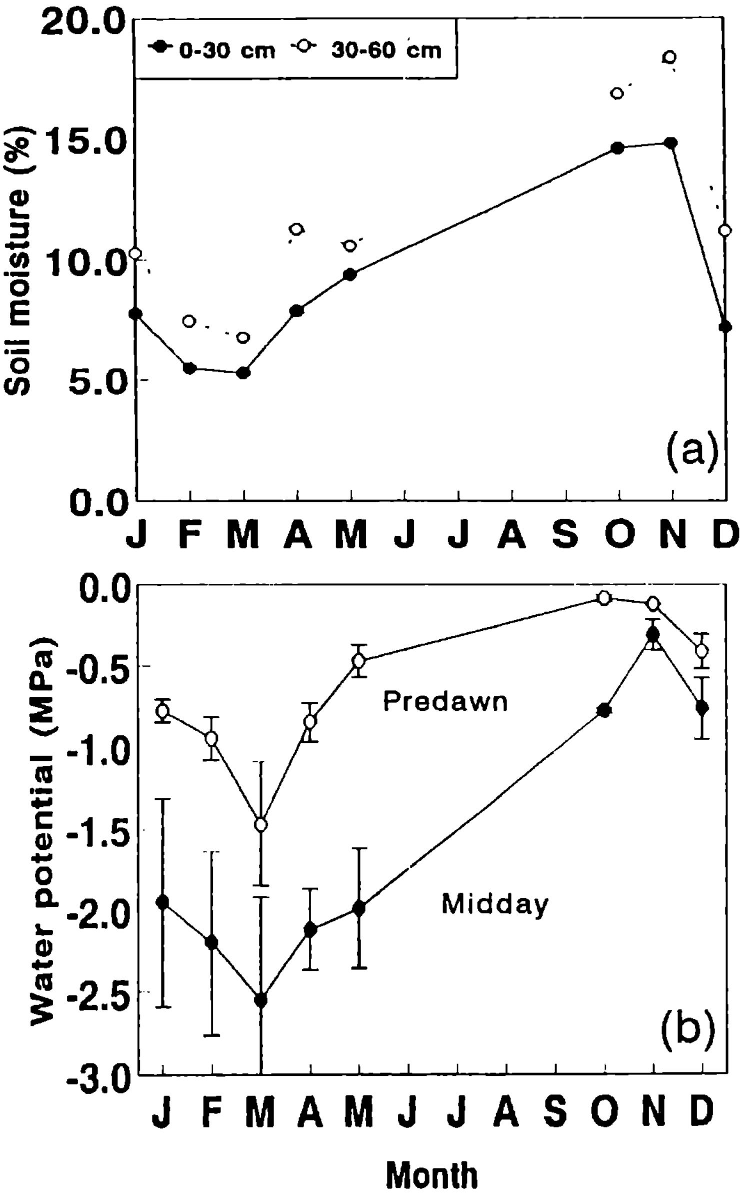

Fig. 74. Monthly variations in (a) soil moisture content within the plantation and (b) predawn and midday water potential measurements during experimental days at Kothachira.

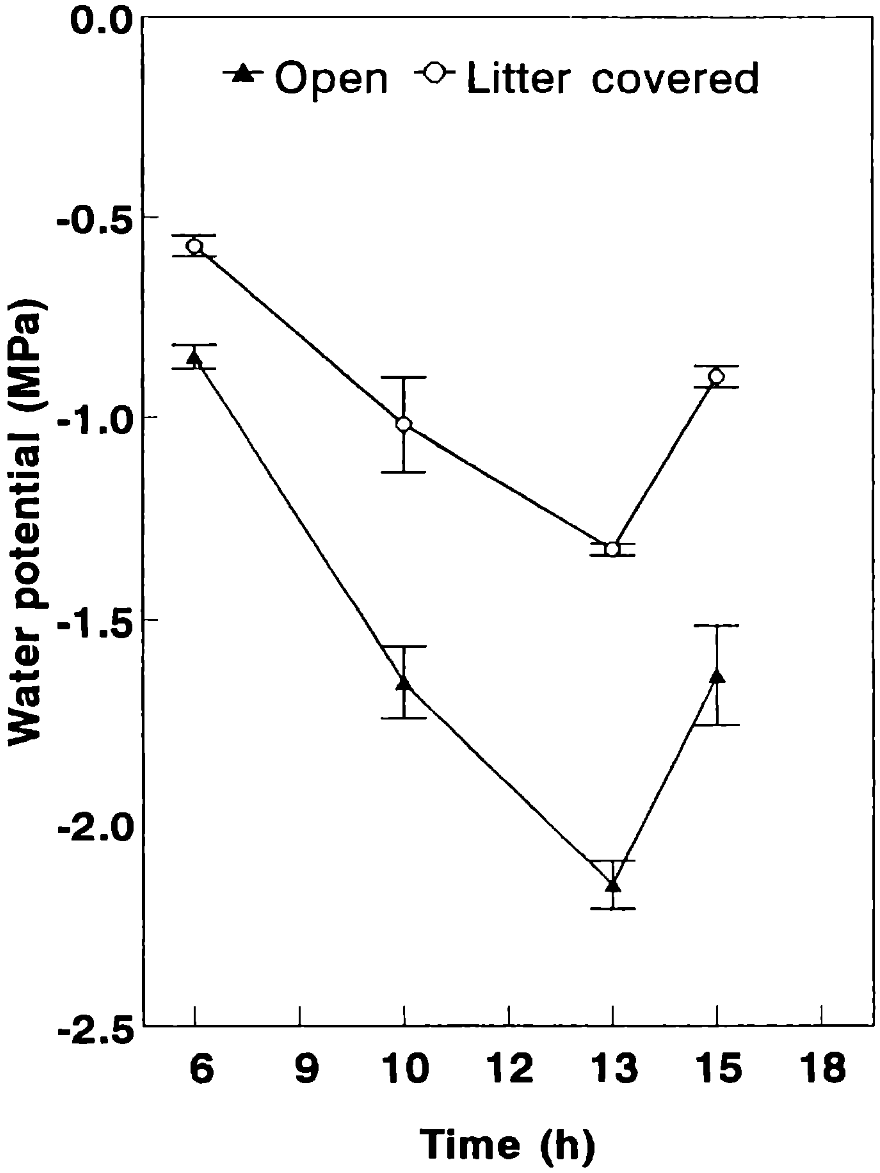

Fig. 75a. Diurnal variations in water potential measured in the open and litter-covered plots of *A. auriculiformis* at Kothachira.

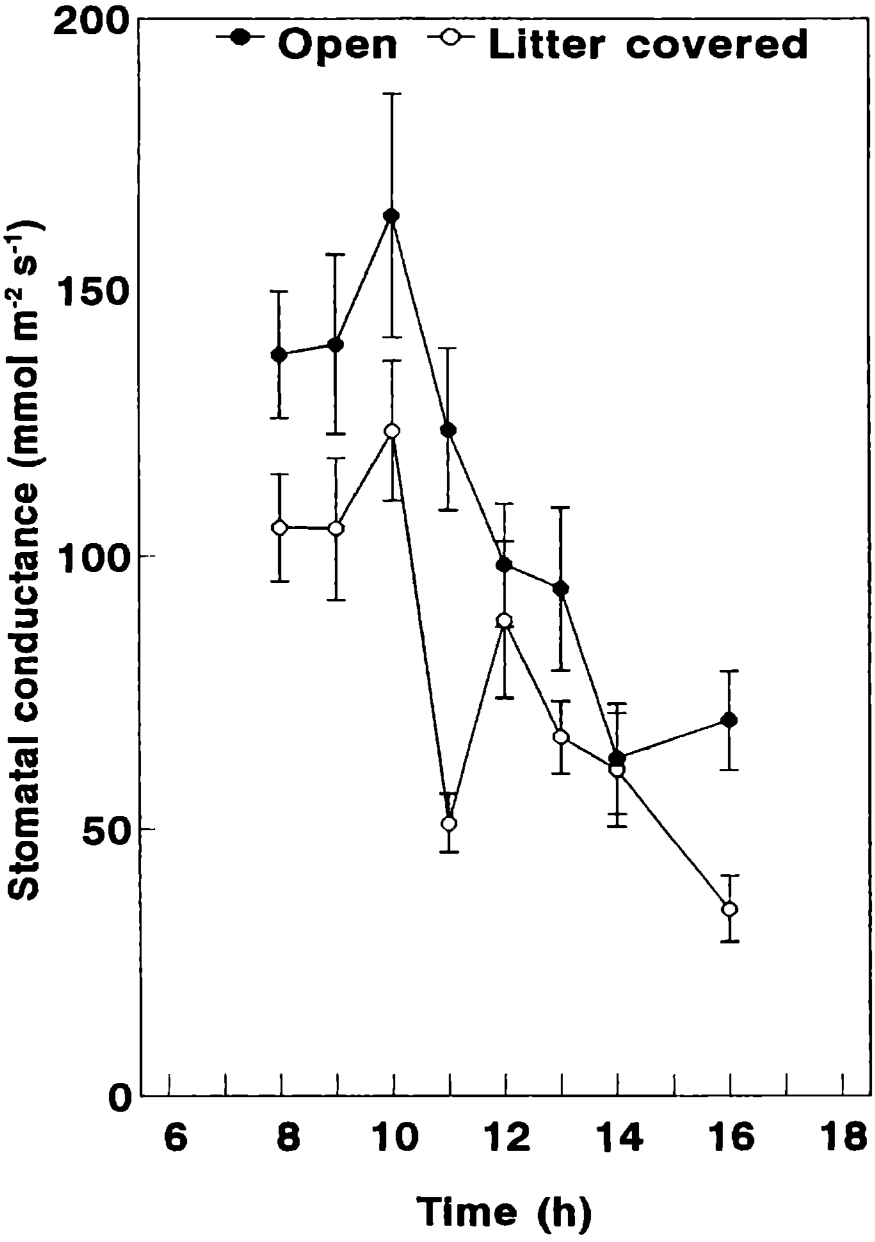

Fig. 75b. Diurnal variations in stomatal conductance measured in the open and litter- covered plots of *A.auriculiformis* at Kothachira.

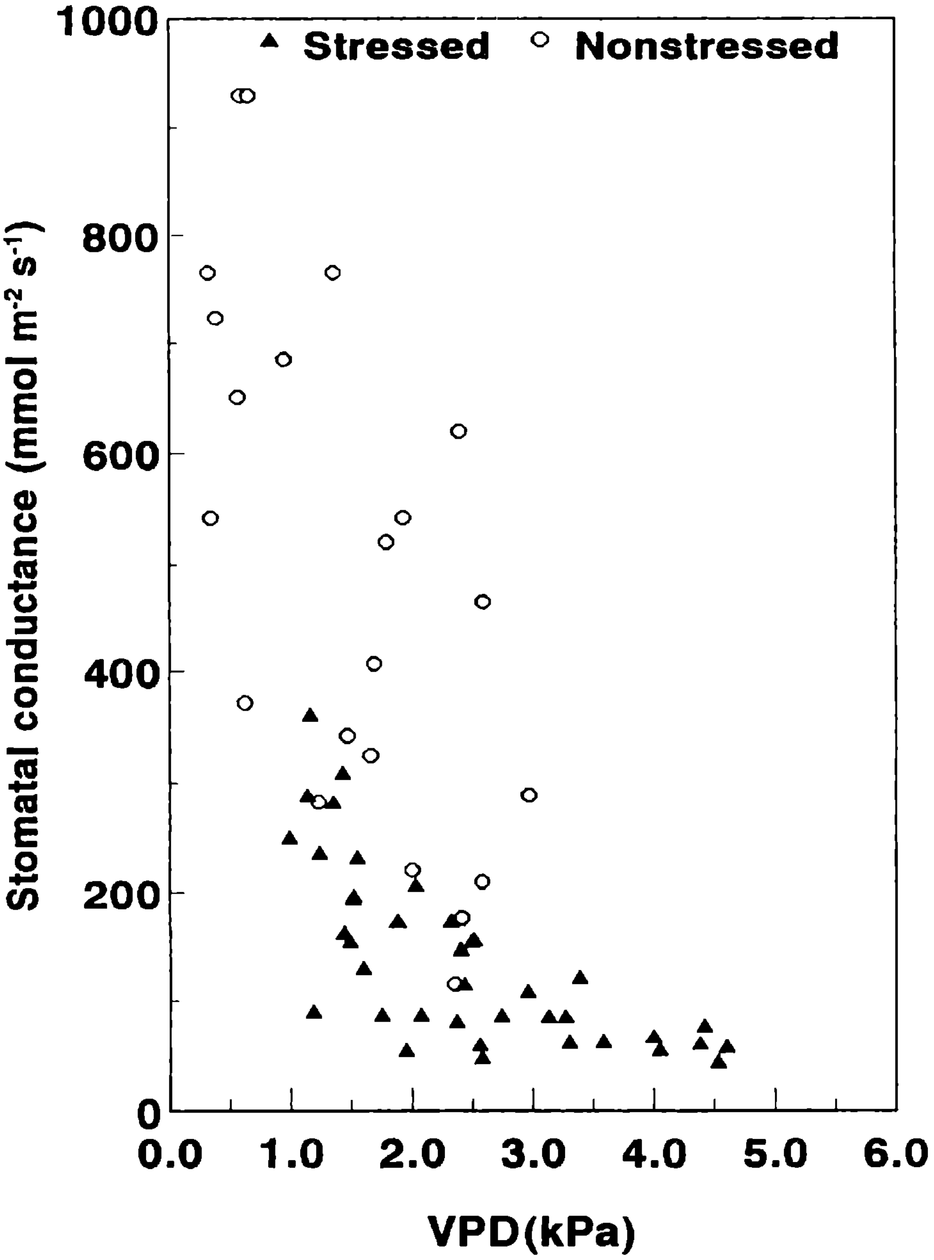

Fig. 76. Stomatal conductance as function of VPD during stressed and nonstressed months in *A. auriculiformis* plantations at Kothachira.

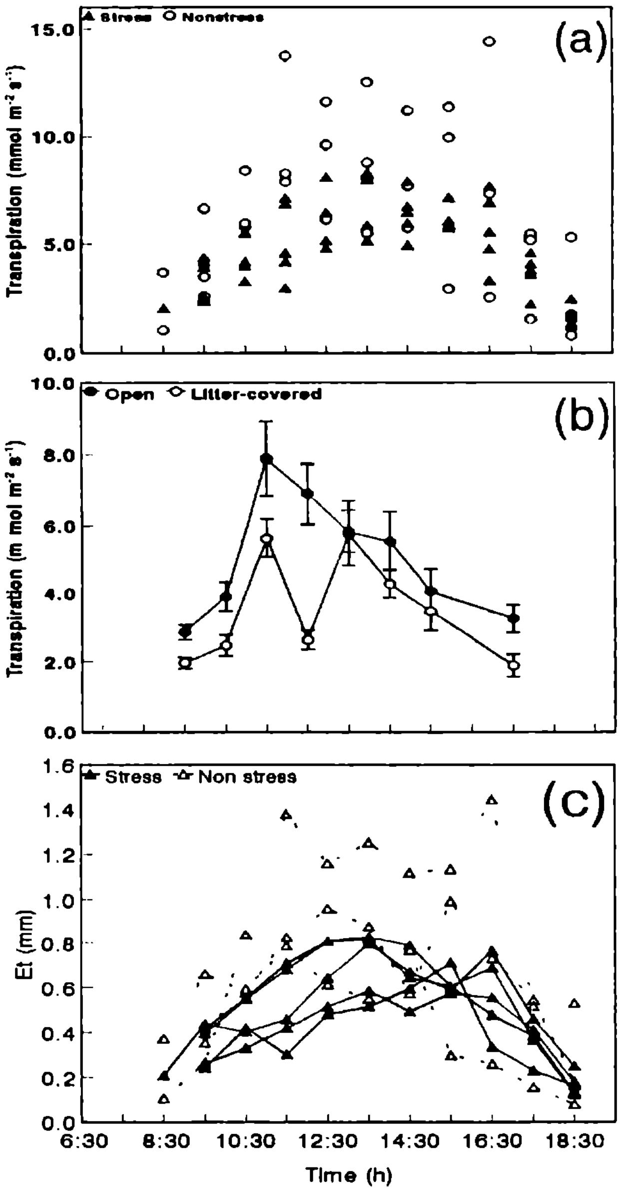

Fig. 77. Diurnal variations in (a) transpiration during stressed and nonstressed months (b) transpiration in the open and litter-covered plots in May and (c) evapotranspiration calculated over time during stressed and nonstressed periods in the *A.auriculiformis* plantation at Kothachira.

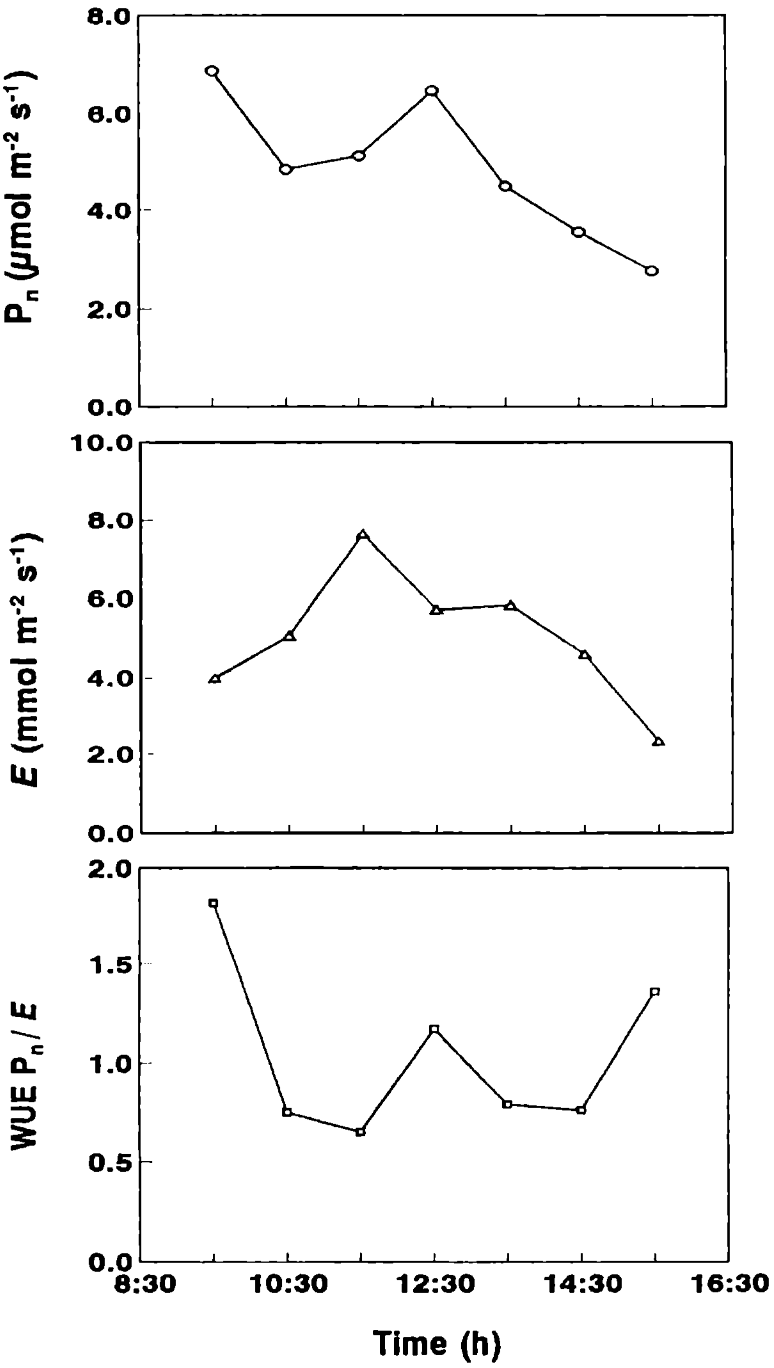

Fig. 78. Diurnal measurements of (a) net photosynthesis, (b) chamber transpiration and (c) water use efficiency of the phyllodes of *A.auriculiformis* trees.

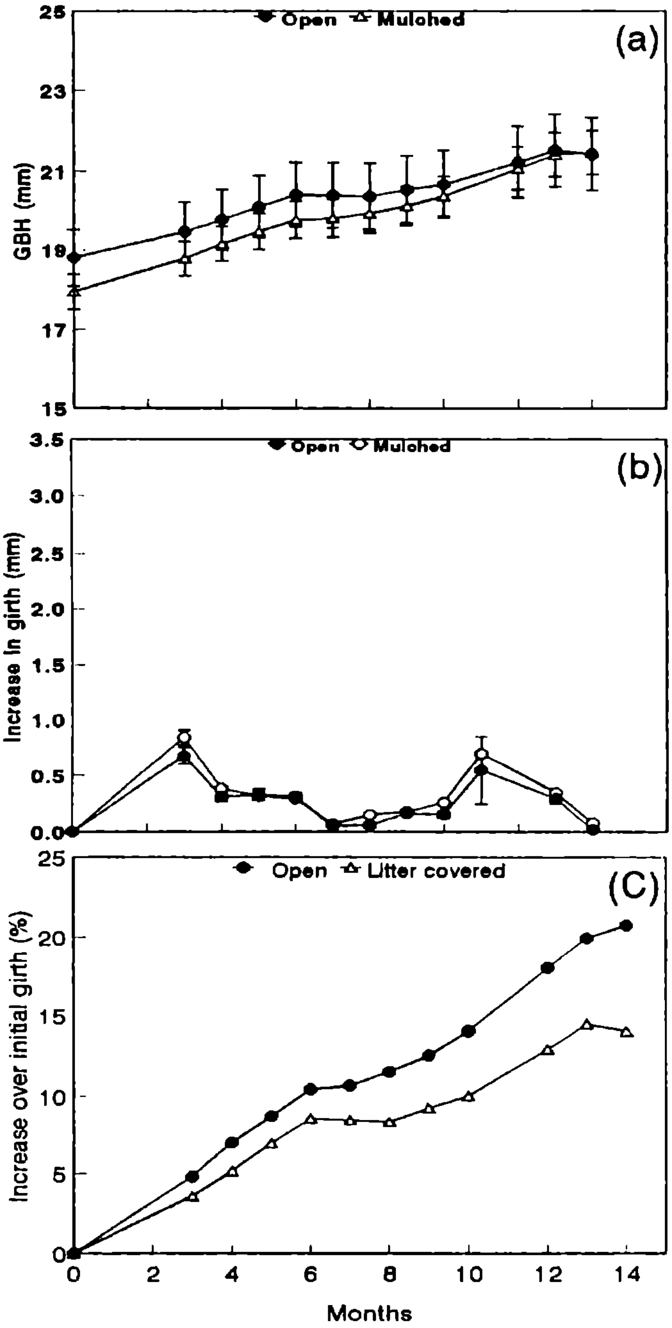

Fig.79. *Acacia auriculiformis* - Increase in girth (GBH) over a period of 14 months (b) monthly increment over previous measurements of GBH (c) monthly increment in GBH over initial girth in the open (●) and litter covered plots (▵).

References

REFERENCES

Abrol, J.P., Yadav, J.S.P. and Massoud, F.I. 1988. Salt affected soils and their management. FAO Bulletin on Soils No. 39, Rome, 131 p.

Allen, J.A., Chambers J.L. and Stine, M.1994. Prospects for increasing the salt tolerance of forest trees, a review. Tree Physiology 14, 843-853.

Ansari, R., Khazada, A.N. and Azmi, A.R. 1988. Introducing multipurpose Australian tree species to salt affected lands of Pakistan. Proceedings of the International Forestry Conference for the Australian Bicentenary, 1988, held at Albury- Wodonga during 25th April to 1st May 1988.

Aswathappa, N., Marcar, N.E. and Thomson, L.A.J. 1986. Salt tolerance of Australian tropical and subtropical acacias. *In*, "Australian Acacias in Developing Countries. (Turnbull J.W., ed.), ACIAR Proceedings No.16, 70-73.

Aswathappa, N., Marcar, N.E. and Thomson, L.A.J. 1987. Screening of Australian tropical and subtropical tree species for salt tolerance. *In* "Afforestation of Salt Affected Soils", (Ed. Rana, R.S.), Volume 2, CSSRI , Karnal, India. 1-17.

Aveyard, J.M. 1968. The effect of seven presowing treatments on total germination and germination rate of six *Acacia* species. Journal of Soil Conservation Service, New South Wales, 24, 43-54.

Babu, R.C., Naterajarathinam,N., Padmanabhan, G. and Dharmaraj, G., 1987. An analysis of drought adaptive characters in certain species of *Acacia*. Indian Forester, 113, 276-278.

Banerjee, A.K., 1973a. Plantations of *Acacia auriculiformis* (Benth) A.Cunn. in West Bengal. Indian Forester 99, 553-540.

Banerjee, A.K. 1973b. Nutritional requirements of *Acacia auriculiformis* (Benth) A.Cunn. Indian Forester 99, 691-697.

Barr, D.A. 1965. Restoration of coastal dunes after beach mining. Journal of Soil Conservation Service, New South Wales, 21, 109-209.

Barr, D.A. and Atkinson, W.J. 1970. Stabilisaton of coastal sands after mining. Journal of Soil Conservation Service, New South Wales, 26, 89-105.

Barrs, H.O. and Weatherley, P.E. 1962. A re-examination of relative turgidity technique for estimating water deficits in leaves. Australian journal of Biological Sciences 15, 413-428.

Basappa, B. 1983. Afforestation of degraded grass lands. My Forest 19(1), 57-61.

Basha, S.C. 1989. *Acacia auriculiformis* - Myths and realities. Vanarasmi 11, 9-11.

Basha, S.C. 1987. *Acacia auriculiformis* - a tree for afforestation in waste lands (In Malayalam). Aranyam. 2-10.

Bates, I.M. and Hall, A.E. 1981. Stomatal closure with soil water depletion not associated with changes in bulk leaf water status. Oecologia 50, 62-65.

Bates, L.S., Waldeen, R.P. and Deare, I.R. 1973. Rapid determination of free proline for water stress studies. Plant and Soil 39, 205

Beadle, C.L. and Jarvis, P.G. 1977. The effects of shoot water status on some photosynthetic partial processes in sitka spruce. Physiologia Plantarum 41, 7-31

Beadle, C.L., Stevemson, K.R., Newmann, H.H.,Thurtell, G.W. and King, K.M. 1978. Diffusive resistance, transpiration and photosynthesis in single leaves of corn and sorgham in relation to leaf water potential. Can. J. Plant Sci. 53, 537-544.

Bernstein, L. and Ogata, G. 1966. Effects of salinity on nodulation , nitrogen fixation and growth of soybeans and alfalfa. Agronomy Journal 58, 201-203

Bisseling, T., Van Staveran, W. and Kammen, A. 1980. the effect of water logging on the synthesis of the nitrogenase components in bacteroids of *Rhizobium leguminosarun* in root nodules of *Pisum sativum*. Biochemical and Biophysical Research Communication 93, 687-693

Boggess, S.F, Stewert, C.R., Aspinall, D., Paleg, L.G. 1976. Effetct of water stress on proline synthesis from radioactive precursors. Plant Physiol 58, 398-401

Boughton, V.H. 1986. Phyllode structure, taxonomy and distribution in some Australian acacias. Australian Journal of Botany 34, 663-674.

Boyer, J.S. 1969. Measurements of water status of plants. Annual Review of Plant Physiology 20, 351-364.

Bradford, K.J. and Yang, S.F. 1981. Physiological responses of plants to waterlogging. Hort. Science 16, 3-8.

Bradford, K.J. and Hsiao, T.C., 1982. Physiological responses to moderate water stress. *In* Encyclopedia of Plant Physiology. (New series, eds. Lange O.L., Nobel, P.S., Osmond, C.B. and Ziegler, H.) Physiological Plant Ecology II, Vol.12B, Springer, Berlin, Heidelberg, New York. pp 263-324.

Brodrib, T and Hill, R.S. 1993. A physiological comparison of leaves and phyllodes of *Acacia melanoxylon*. Australian Journal of Botany 41 (3), 293-305.

Brown, S.B., Houghton J.D. and Hendry, G.A.F. 1991. Chlorophyll breakdown in chloroplasts. (ed. Scheer,H.), CRC Press, Boca Roton, pp 465-489.

Burrows, F.J. and Milthrope, F.L. 1976. Stomatal conductance in the control of gas exchange. *In* "Water Deficits and Plant Growth" (Ed. Kozlowski, T.T), 4, 103-152. Academic Press, New York.

Carbon, B.A., Bartle G.A., Murray, A.M. and MacPherson, D.K., 1980. The distribution of root length and the limits to flow of soil water to roots in a dry sclerophyll forest. Forest Science 26, 656-664.

Chandrababu, R., Naterajarathinam,N., Padmanabhan, G. and Dharmaraj, G., 1987. An analysis of drought adaptive characters in certain species of *Acacia*. Indian Forester, 113, 276-278.

Chaturvedi, A.N., Sharma, S.C. and Srivastava, R. 1988. Water consumption and biomass production of some forest tree species. International Tree Crops Journal 5, 71-76.

Cheung, Y.N.S., Tyree, M.T. and Dainty, J. 1975. Water relations parameters on single leaves obtained in a pressure bomb and some ecological interpretations. Canadian Journal of Botany 53, 1342-1346.

Choudhry, M.A., Hussain, A. and Hussain, A. 1993. Sodium chloride stress studies on growth of some leguminous forest tree seedlings. Pakistan Journal of Forestry 43), 21-27

Cohen, D. 1970. The expected efficiency of water utilization in plants under different competition and selection regimes. Israel Journal of Botany 19, 50-54.

Cowan, I.R. 1977. Stomatal behaviour and environment. Advances in Botanical Research, 4, 117-228.

Craig, G.F., Bell, B.T. and Atkins, C.A. 1990. Responses of salt and water logging stress of ten taxa of *Acacia* selected from natural saline areas of Western Australia. Australian Journal of Botany 38, 619-630

Crombie, D.S., Tipett, J.T. and Hill, T.C. 1988. Dawn water potential and root depth of trees and understory species in south western Australia. Australian Journal of Botany 36, 621-631.

Cruz, R.T. and O'Toole, J.C. 1984. Dryland rice response to an irrigation gradient at flowering stage. Agronomy Journal 76, 178-183.

Dart, P., Garcia, U. M., Almendras, A. and Turnbull, J.M. 1991. Role of symbiotic associations in nutrition of tropical acacias. *In* Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, 13-19.

Davies, W.J. and Zhang, J. 1991. Root signals and the regulation of growth and development of plants in drying soil. Annual Review of Plant Physiology and Molecular Biology 42, 55-76

Desale, J.S., Patil, S. and Khot, R.B.1989. Assessment of tree speceis for salty and high pH soil conditions. Journal of Maharashtra Agricultural University. 413 722, 14, 377-378.

Dijk, K. S. van. 1991. *Acacia auriculiformis*, improved germination through seed pretreatment. Nitrogen Fixing Tree Research Reports 9, 77-78.

Downton, W.J.S., Loveys, B.R. and Grant, W.J.R. 1988. Stomatal closure fully accounts for the inhibition of photosynthesis by abscisic acid. New Phytol 108, 263-266

Dochinger, L.S. and Townsend, A.M. 1979. Effects of roadside deicer salts and ozone on red maple progenies. Environ. Poll. 29, 229-237

Dutt, A.K. and Jamwal, U. 1991. Variation in seed weight and seedling growth in *Acacia auriculiformis* provenances. Nitrogen Fixing Tree Research Reports 9, 79-80.

Elias, T.S. 1981. Mimosoidea. *In* "Advances in Legume Systematics" (Eds. Polhil, R.M. and Raven, P.H.) pp 143-151, Kew Gardens, England.

Epstein, E., Rush, D.W., Kingsbury, R.W., Kelly, O.B., Cunningham, G.A. and Corona, A.F. 1980. Saline culture of crops, a genetic approach. Science 210, 399-404.

Farrel, T.P., 1973. The ecology of *Acacia melanoxylon*. MSc. Thesis, University of Melbourne.

Farrel, T.P. and Ashton, D.H. 1973. Population studies on *Acacia melanoxylon*. I. Variation in seed and vegetative characteristics. Australian Journal of Botany 26, 365-379.

Fenton R., Roper, R.E. and Watt, G.R. 1977. Lowland Tropical Hardwoods - an Annotated Bibliography. External Aid Dept. New Zealand, Wellington.

Florence, R.G. 1986. Cultural problems of *Eucalyptus* as exotics. Commonwealth Forestry Review 654, 141-163.

Flowers, T.J., Troke, T.F. and Yeo, A.R. 1977. The mechanism of salt tolerance in halophytes. Annual Review of Plant Physiology 28, 89-121

Gerold, H.D. and Sackstedar C.J. 1982. Better way of selecting trees for urban planting. Journal of Arboriculture 8, 145-153.

Grieve, B.J. and Hellmuth, E.O. 1970. Ecophysiology of West Australian species. Ecol. Plant. 5, 33-67

Gupta, G.N., Prasad, K.S., Mohan, S. and Manivachakam, P. 1986. Salt tolerance of some tree species at seedling stage. Indian Forester 112, 101-113.

Gupta, G.N. 1991. Effects of mulching and fertilizer application on initial development of some tree species. Forest Ecology and Management 44, 211-221.

Gupta, J.P. and Muthana, K.D. 1986. Effect of integrated moisture conservation technology on the early growth and establishment of *Acacia tortilis* in the Indian desert. Indian Forester 112, 7-485.

Gupta, J.P. and Gupta, G.N. 1983. Effect of grass mulching on growth and survival of legumes. Agric. Water Manag. 6, 375-383.

Hafeez, S.M. 1993. Identification of fast growing salt tolerant tree species. Pakistan Journal of Forestry 43, 216-220.

Hall, A.E., Schulze, E.D. and Lange, O.L. 1976. Current perspectives of steady-state stomatal responses to environment. *In* "Water and Plant Life" (Eds. Lange,O.L, Kappen, L. and Schulze, E.D.) pp 169-188, Springer Verlag, Berlin and New York.

Hansen, D.H. 1986. Water relations of compound leaves and phyllodes of *Acacia koa* var. *latifolia*, Plant Cell and Environment 9, 439-445.

Hansen, D.H. and Steig, E. 1993. Comparison of water use efficiency and internal CO_2 concentration in juvenile leaves and phyllodes of *Acacia koa* from Hawai, estimated by two methods. American Journal of Botany 80, 1121-1125.

Hansen, A.O., Nelson, C.E. and Everson, E.M. 1977. Evaluation of free proline accumulation as an index of drought resistance using two barley cultivars. Crop Science 117, 720-726

Hansen, A.O., Nelson, C.E. Pederson, A.R. and Everson, E.M. 1979. Capacity for proline accumulation during water stress in barley and its implication for breeding and drought resistance.

Hendry, G.A.F. and Price, A.H. 1993. Stress indicators Chlorophylls and carotenoids. *In*: Methods in Comparative Plant Ecology - A Laboratary Mannual (eds.) Hendry, G.A.F. and Grime, J.P. Chapman and Hall, London. pp 148-152

Hinckley, T.M., Duhme, F., Hinckley, A.R. and Richter, H. 1980. Water relations of drought hardy shrubs, osmotic potential and stomatal reactivity. Plant Cell and Environment 3, 111-140.

Jackson, P.A. and Spomer, G.G. 1979. Biophysical adaptations of four western conifers to habitat water conditions. Botanical Gazette 140, 428-432.

Jayaraman, K. and Rajan, A.R. 1991. Yield from *Acacia auriculiformis* plantations in Kerala. KFRI Research Report No. 81. Kerala Forest Research Institute, Peechi.

Jayasankar, S. and Mohankumar, B. 1992. Early growth and nodulation in five *Acacia* species. Nitrogen Fixing Tree Research Reports 10, 102-105.

Jones, H.G. and Corlet, J.E. 1992. Current topics in drought physiology. Journal of Agricultural Science. Cambridge, 119, 291-296

Kaloyereas, S.A. 1958. A new method of determining drought resistance. Plant Physiology 33, 232-233.

Kanemasu, E.T., Thurtell, G.W., and Tanner C.B. 1969. Design, calibration and field use of a Stomatal diffusion porometer. Plant Physiology 44, 881-885.

Kanemasu, E.T. 1975. Measurement of stomatal aperture and diffusive resistance. Bull. 809, College of Agric. Res. Centre, Washington State University.

Khera, K.L., Khera, R., Parihar, S.S., Sandhu, T.S. and Sandhu, K.S. 1976. Mulch, nitrogen and irrigation effects on growth, yeild and nutrient uptake of forage crops. Agronomy Journal 68, 937-941.

Kozlowski, T.T. 1982. Water supply and tree growth, I: Water Deficits. Forestry Abstracts 43, 57-95.

Kramer, P.J. 1983. Water Relations of Plants. Academic Press, Inc. New York.

Lamb, D. 1975. Kujingini plantations 1965-1975. Tropical Forestry Research Note Series, 24. Department of Forest Boroko, Papua New Guinea.

Lange, O.L., Ullman, I., Tenhunen, J.D. and Bannister, P. 1987. Stomatal conductance and transpiration of the two faces of *Acacia* phyllodes. Trees 1, 110-122.

Larson, K.D., Schaffer, B., Davis, F.S. and Sanchez, C.A. 1992. Flooding mineral nutrition and gas exchange of mango trees. Scientia Horticulturae 52, 130-124.

Larson, K.D., Schaffer, B. and Davis, S.F. 1991a. Flooding, leaf gas exchange and growth of mango trees in containers. J. Am. Soc. Hortic. Sci. 116, 156-160.

Larson, K.D., Graetz, D.A. and Schaffer, B. 1991b. Flood induced chemical transformations in calcareous agriculural soils of South Florida. Soil Science 152, 33-40

Lauter, D.J., Munns, D.N. and Clarkin. K.L. 1981. Salt response of chick pea as influenced by N supply. Agronomy Journal 3, 961-966.

Losch, R., Tenhunen, J.D., Pereira, J.S. and Lange, O.L. 1982. Diurnal courses of stomatal resistance and transpiration of wild and cultivated mediterranean perenials at the end of the summer dry season in Portugal. Flora 172, 138-160.

MacKinney, G. 1941. Absorption of light by chlorophyll solutions. Journal of Biological chemistry 144, 315-323.

Marcar, N.E., Dart, P. and Sweeney, C., 1991a. Effect of root zone salinity on the growth and chemical composition of *Acacia ampliceps* B.R. Maslin, *A.auriculiformis* A.Cunn ex Benth. and *A.mangium* Willd. at two nitrogen levels. New Phytologist, 119, 567-573.

Marcar, N.E., Ganesan, S.K., Field, I. and Turnbull, J.W. 1991(b). Genetic variation for salt and water logging tolerance of *Acacia auriculiformis*. *In* Advances in Tropical Acacia Research J.W. Turnbull (Ed), ACIAR Proceedings No. 35, 82-86.

Marcar, N.E. Crawford, D.F. and Leppert, P.M. 1993. The potential of trees for utilization and management of salt affected land. *In* "Pespective use of Saline Land". Proceedings of a workshop held at Perth, Western Australia (Eds. Davidson, N and Galloway R.) ACIAR Proceedings No 42, 17-22.

McMichael, B.L. and Elmore, C.D. 1977. Proline accumulation in water stressed cotton leaves. Crop Science 17, 905-908.

Mead, D.J. and Miller, R.R. 1991. The establishment and tending of Acacia mangium. In: Advances in Tropical Acacia Research (Ed.) Turnbull, J.W. ACIAR Proceedings No. 35, 116-122

Milburn, J.A. 1979. Water flow in plants, Longman, London.

Momen, B., Menke, N. and Welker, J.M. 1992. Tissue water relations of *Quercus wislizenii* seedlings, drought resistance in California evergreen Oak. Acta Oecologia 13), 137-136.

Monteith, J.L. 1965. Evaporation and environment. *In* The State and Movement of Water in Living Organisms (ed G.E. Fogg), 19th Symp. Soc. Exp. Biol., The company of Biologists, Cambridge University Press, pp 205-234.

Monteith, J.L. 1973. Principles of Enivronmental Physics, Edward Arnold, Lodon.

Moody, J.E., Jones, J.N. and Lihard, J.H. 1963. Influence of straw mulch on soil moisture, soil temperature and growth of corn. Proceedings of the American Society of Soil Science 27, 700-703.

Mooney, H.A., Ferrar, P.J. and Slayter, A.O. 1978. Photosynthetic capacity and carbon allocation pattern in diverse growth forms of *Eucalyptus*. Oecologia 36, 103-111.

Morris, J.D. 1982. Screening of ornamental trees and shrubs for salt tolerance. Australian Salinity Newsletter 10, 47-48.

Murthy, K.S. and Majumdar, S.K., 1962. Modification of the technique for determination of chlorophyll stability index in relation to studies of drought resistance in rice. Current Science 31, 470-471.

Nath, S., Das, P.K., Gangopadhyay, S.K., Banerjee, S.K. Balvinder Singh and Singh, B. 1991. Stability of different forest species for social forestry programmes under different conditions. Part III. Coastal soil. Indian Forester 117, 625-631.

National Academy of Sciences, 1979. Tropical legumes, Resources for the Future, Washington DC.

National Academy of Sciences, 1980. Firewood Crops, Shrubs and Trees for Energy Production, Washington DC.

National Research Council, 1983. Mangium and other fast growing acacias for the humid tropics. National Academy Press, Washington DC.

Negulube, M. 1991. Evaluation of the coppicing ability of promising Australian acacias for dry land agroforestry in Malawi. Nitrogen Fixing Tree Research Reports 9, 81-82.

Nobel, P.S. 1983. Biophysical Plant Physiology and Ecology. W.H. Freeman and Co., New York. 635 p.

O'Toole, J.C. and Cheung, T.T. 1978. Drought and rice improvement in perspective. IRRI Research paper, Serial No.4.

Osonubi, O., Mulongoy, K., Awotoy, O.O., Atayese, M.O. and Okali, D.U.U. 1991. Ectomycorrhizal and vesicular arbuscular mycorrhizal fungi in seedlings. Plant and Soil. 1991, 131-143

Osonubi, O. and Mulongoy, K. 1991. Response of two *Acacia* species to drought and innoculation with an ectomycorrhizal fungus. The Rhizospere and Plant Growth (Eds. Keister, D.L. and Cregan, P.B.), No 14, 375p.

Parker, W.C. and Pallardy, S.G. 1988. Pressure Volume analysis of leaves of *Robinia psuedoacacia* L. with the sap expression and free transpiration methods. Canadian Journal of Forest Research 18, 1211-1213.

Parry, M.S., 1956. Tree planting practices in tropical Africa, Forestry development paper, No. 8, FAO, Rome.

Pathre, U.V., Singh, K.K. and Sane, V.P. 1990. Gas exchange and stomatal conductance in *Acacia auriculiformis*, effect of leaf position. Photosynthetica 24, 151-154.

Pedley, L. 1978. A revision of *Acacia* Mill. in Queensland Austrobaileya 1, 75-233.

Pedley, L. 1986. Derivation and dispersal of *Acacia*, with particular reference to Australia, and the recognition of *Senegalia* and *Racosperma*. Botanical Journal of the Linnaean Society 92, 219-254.

Pereira, J.S. and Kozlowski, T.T. 1976. Diurnal and seasonal changes in water balance of *Abies balsamina* and *Pinus resinosa*. Oecol Plant. 11, 397-412.

Phillips, J.G. and Riha, S.J. 1993. Canopy development and solar conversion efficiency in *Acacia auriculiformis* under drought stress. Tree Physiology, 12, 137-149.

Pinyopusarek, K. 1990. *Acacia auriculiformis*, an annotated bibliography. Winrock International, USA, and ACIAR, Australia.

Ponnamperuma, F.N. 1984. Effect of flooding in soils. *In*: Kozlowski, T.T (Ed.) Flooding and Plant Growth, Academic Press, London, 9-45.

Prasad, R. 1991. Use of Acacias in working wasteland reforestation. *In* Advances in Tropical Acacia Research (Ed. J.W. Turnbull) ACIAR Proceedings No. 35, 96-102.

Rajeshkumar, S.K. and Pokhriyal, T.C. 1993. An empirical study of moisture content behavior in *Acacia* and *Eucalyptus* plants. Indian Forester 119, 446-450.

Rao, K.N., George, C.T. and Ramasatri K.S. 1971. Potential evapotranspiration (PE) over India. Science Reporter No.136.

Ravson, H.M., Begg,J.E. and Woodward, B.G. 1977. The effect of atmospheric humidity on photosynthesis, transpiration and water use efficiency of leaves of several plant species. Planta 123, 5-10.

Reddel, P. and Warren, R. 1986. Inoculation of acacias with mycorrhizal fungi. Potential benefits. In: Turnbull, J.W. (ed) Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 50-53.

Rincon Mautner, C.A.R. 1986. Vegetation damage associated with salt mining operations at Avery Island, Louiscana, M.S. thesis, School of Forestry, Wildlife and Fisheries, Louiscana State University, Baton Rouge, LA, 85p.

Roberts, S.W. and Knoerr, K.R. 1977. Components of water potential estimated from xylem pressure measurements in five tree species. Oecologia 28,191-202.

Roux, E.R. and Meddlemiss, E. 1963. Studies on the autecology of Australian acacias in South Africa. South African Journal of Science 59, 286-294.

Sankaran, K.V., Balasubramanian, M., Thomas.P.Thomas and Sujatha, M.P. 1992. Litter dynamics, microbial association and soil studies in *Acacia auriculiformis* plantations in Kerala. KFRI Research Report 91, KFRI, Peechi, India.

Sastroamidjojo, J.S. 1964. *Acacia auriculiformis* A.Cunn. Rimba Indonesisa 9,214-225.

Singh B, Gupta, G.N. and Prasad, K.G., 1988. Use of mulches in establishment and growth of forest species on dry lands. Indian Forester 114, 307-316.

Singh, S.B., Pramodkumar and Prasad, K.G. 1991. Response of various tree speceis to irrigation regimes and leaf residue management. Indian Soc. Soil Sci. 39, 229-232.

Singh, T.N., Paleg, L.C., Aspinall, D. 1973. Stress metabolism III. Variations in response to water deficit in the barley plants. Aust. J. Biol. Sci. 26, 65-76

Sinha, A.K., Shirke, P.A., Pathre, U.V. and Behl, H.M. 1996. Spectral properties of *Acacia auriculiformis*, effect of leaf position. Indian Forester 122, 496-500.

Sivasubramaniam, K. 1992. Chlorophyll Stability Index method for determining drought hardiness of *Acacia* species. Nitrogen Fixing Tree Research Reports 10, 111-112.

Slavik, B. 1974. Methods of Studying Plant water Relations. Springer-Verlag, Berlin and New York.

Smit, J. Driessche, R. van den., van den Driessche, R. 1992. Root growth and water use efficiency of Douglas fir (*Pseudotsuga menziesii* (Mirb)Franco.) and lodge pole pine (*Pinus contorta* Dougl.) seedlings. Tree Physiology 11, 401-410.

Srinivasan, P.S., Vinaya Rai, R.S. and Jambulingam, R. 1990. Acacias, variation between species in early growth and a few drought adaptive attributes. Journal of Tropical Forest Science 21, 129-134.

Srivastava R.J. and Misra, M. 1987. Behavioural study on water uptake by different forest species. Indian Journal of Forestry 10(2), 107-110.

Stewart, C.R., Boggess, S.F., Aspinall, D. and Paleg, L.G. 1977. Inhibition of proline oxidation by water stress. Plant Physiology 59, 930-932.

Stewart, C.R. and Hansen, A.D. 1980. Proline accumulation as a metabolic response to water stress. In Turner, N.C. and Kramer, P.J. (Eds.) Adaptations of Plant to Water and High Temperature Stress. Wiley and Sons. New York. pp 173-189.

Stoneman, G.L., Turner, N.C. and Dell, B. 1994. Leaf growth, photosynthesis and tissue water relations of greenhouse grown *Eucalyptus* seedlings in response to water deficits. Tree Physiology 14, 633-646.

Streets R.J. 1962. Exotic forest trees in the British Commonwealth, Clarenden Press, Oxford.

Sun, D. and Dickinson. 1995. Survival and growth of a number of Australian tree species planted on a saline site in tropical north Australia. Journal of Applied Ecology 32, 817-826.

Sun, J.S. 1986. Relationship between chlorophyll content, photosynthesis and biomass production in *Acacia* and *Eucalyptus* seedlings. In "Australian acacias in Developing Countries" (Ed. Turnbull,J.W.), ACIAR Proceedings, No 16, 139-142.

Tan, S.M. and Chen, B.G. 1984. Studies on the transpiration rate of several tree species. Scientia Silvae Sinicae 20, 72-79.

Tenhunen, J.D. Lange O.L. and Braun, M. 1981. Midday stomatal closure in Mediterranean type sclerophylls under simulated habitat conditions in an environmental chamber. Oceologea 50, 5-11.

Thomson, L.A.J. 1987. Australian acacias for saline soils in the hot, dry subtropics and tropics. In "Australian Acacias in Developing Countries" (Ed. J.W. Turnbull), ACIAR Proceedings No. 16, 66-69.

Tomor, D.S. and Gupta, R.K. 1985. Performance of some forest tree species in saline soils under shallow and saline water table conditions. Plant and Soil 87, 329-335.

Totey, N.G., Kulkarni, R., Bhowmik , A.K., Khatri, P.K., Dahia, V.K. and Arun Prasad. 1987. Afforestation of salt affected wasteland. I. Screening of forest trees of Madhya Pradesh for salt tolerance. Indian Forester 113, 805-815.

Trivedi, P.K., Pathre, U.V. and Sane, P.V. 1992. Photosynthetic characteristics of *Acacia auriculiformis*. Photosynthetica 26, 617-623.

Turnbull, J.W. (Ed.). 1986. Multipurpose Australian Trees and Shrubs lesser known species for Fuelwood and Agroforestry, ACIAR Proceedings No.16, 316p.

Turnbull, J.W. 1987. Recent results of Australian nitrogen fixing trees. Regional wood energy development Program in Asia. GCP/RAS/III/NET, Bangkok, October 1987.

Turner, N.C. and Begg.J.E. 1981. Plant water relations and adaptations to stress. Plant and Soil 58, 97-131.

Turner, N.C. 1988. Measurement of plant water status by the Pressure chamber technique. Irrigation Science 9, 289-308.

Turnstall, B.R. and Connor D.J. 1975. Internal water balance of Brigalow (*Acacia harpophylla* F. Muell) under natural conditions. Australian Journal of Plant Physiology 2, 489-499.

Tyree, M.T. and Jarvis, P.G. 1982. Water in tissues and cells. *In*: Encyclopedia of Plant Physiology . New Series. Vol 12b (Ed)Lange, O.L., Nobel, P.S. Osmond, C.B. and Ziegler, H. SPreinger Verlag, Berlin p. 35-77

Tyree, M.T. and Hammel, H.T. 1972. The measurements of turgor pressure and the water relations of plants by pressure bomb technique. Journal of Expterimental Botany 23, 267-282.

Ullmann, I. 1985. Diurnal courses of transpiration and stomatal conductances of Sahalian and Saharian acacias in the dry season. Flora 76, 383-409.

Ullman, I. 1989. Stomatal conductances and transpiration of *Acacia* under field conditions: similarities and differences between leaves and phyllodes. Trees 3, 45-56.

Van den Dreissche, R., Connor, D.J. and Turnstall, B.R. 1971. Photosynthetic response of Brigalow to irradiance, temperature and water potential. Photosynthetica 5, 210-217.

Verhoef, L. 1943. Root studies in the tropics. VI. Further data on the oxygen requirements of the root system. Korte Medidelingan Bosbouwproefstation (Dutch with English summary).

Walters, G.A. 1981. Photosynthesis, respiration, transpiration and growth of *Acacia koa* seedlings as affected by photosynthetic photon flux density. PhD. dessertation, University of Hawai.

Walters, G.A.and Bartholomew, D.P. 1984. *Acacia koa* leaves and phyllodes, gas exchanges, morphological and biochemical characteristics. Botanical Gazette 145, 351-357.

Walters, G.A. and Bartholomew, D.P. 1990. *Acacia koa* leaves and phyllodes to changes in photosynthetic photon flux density. Forest Science 36, 1050-1060.

Webb, D.B., Wood, P.J. and Smith,J. 1980. A guide to species selection for tropical and subtropical plantations. Tropical Forestry Paper No.15, Commonwealth Forestry Institute, Oxford, 256 pp.

Weirsum, K.F. and Ramlan, A. 1982. Cultivation of *Acacia auriculiformis* in Java, Indonesia. Commonwealth Forestry Review 61, 135-144.

Wilson, J.R. and Noris, D.O. 1970. Some effect of salinity on *Glycine javanica* and its rhizobium symbiosis. Tenth International Grassland Congress. pp. 455-458.

Wood,J.G. 1934. The Physiology of xerophytism in Australian plants, the stomatal frequencies, transpiration and osmotic presssure of sclerophyll and tomentosa succulent leaved plants. Journal of Ecology 22, 69-87.

Plates

Plate. 1. (a) Seedlings of *A.auriculiforms* (b) *A.aulacocarpa* (c) *A.holocericea* and (d) *A.mangium* subjected to various stress conditions

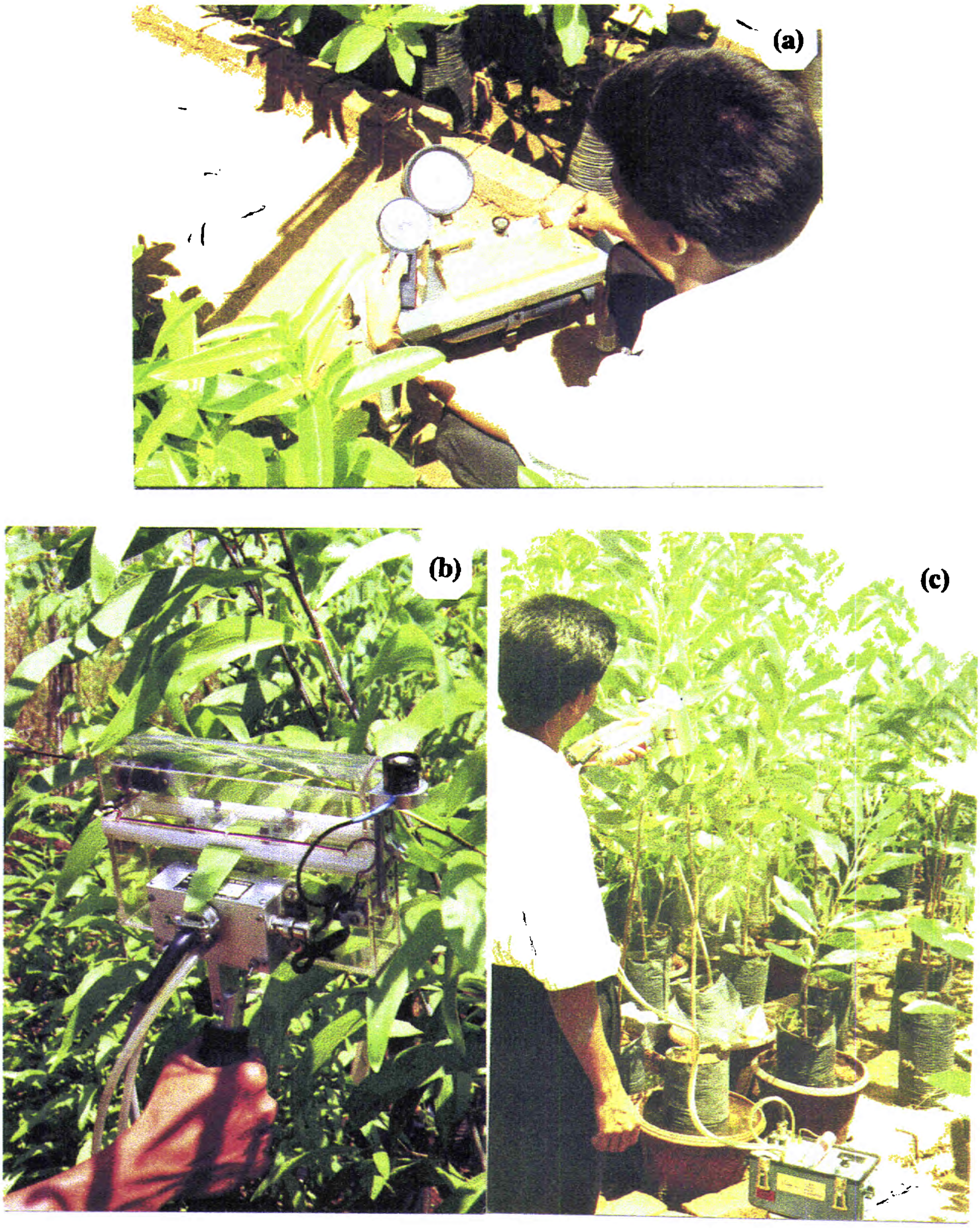

Plate.2. (a) Measurement of water potential using pressure chamber (b) a phyllode of *A.auriculiformis* in the leaf chamber of the photosynthesis system. (c) a phyllode of *A.holocericea* in the leaf chamber of steady state porometer

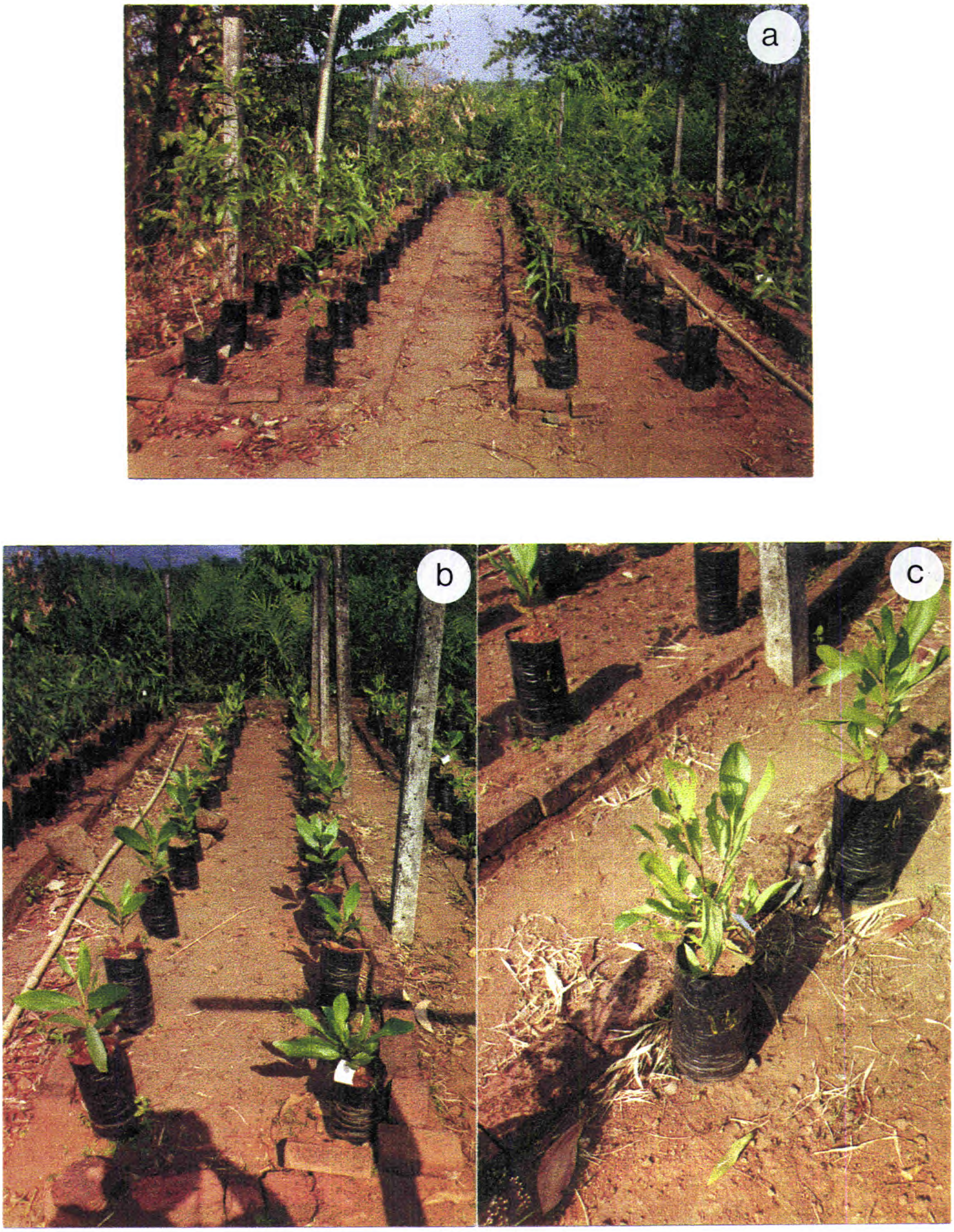

Plate. 3. (a) Seedlings of *A.auriculiformis* (b) *A.mangium* kept for cyclic drought stress (c) Seedlings of *A. mangium* stressed for 16 days showing wilting symptoms

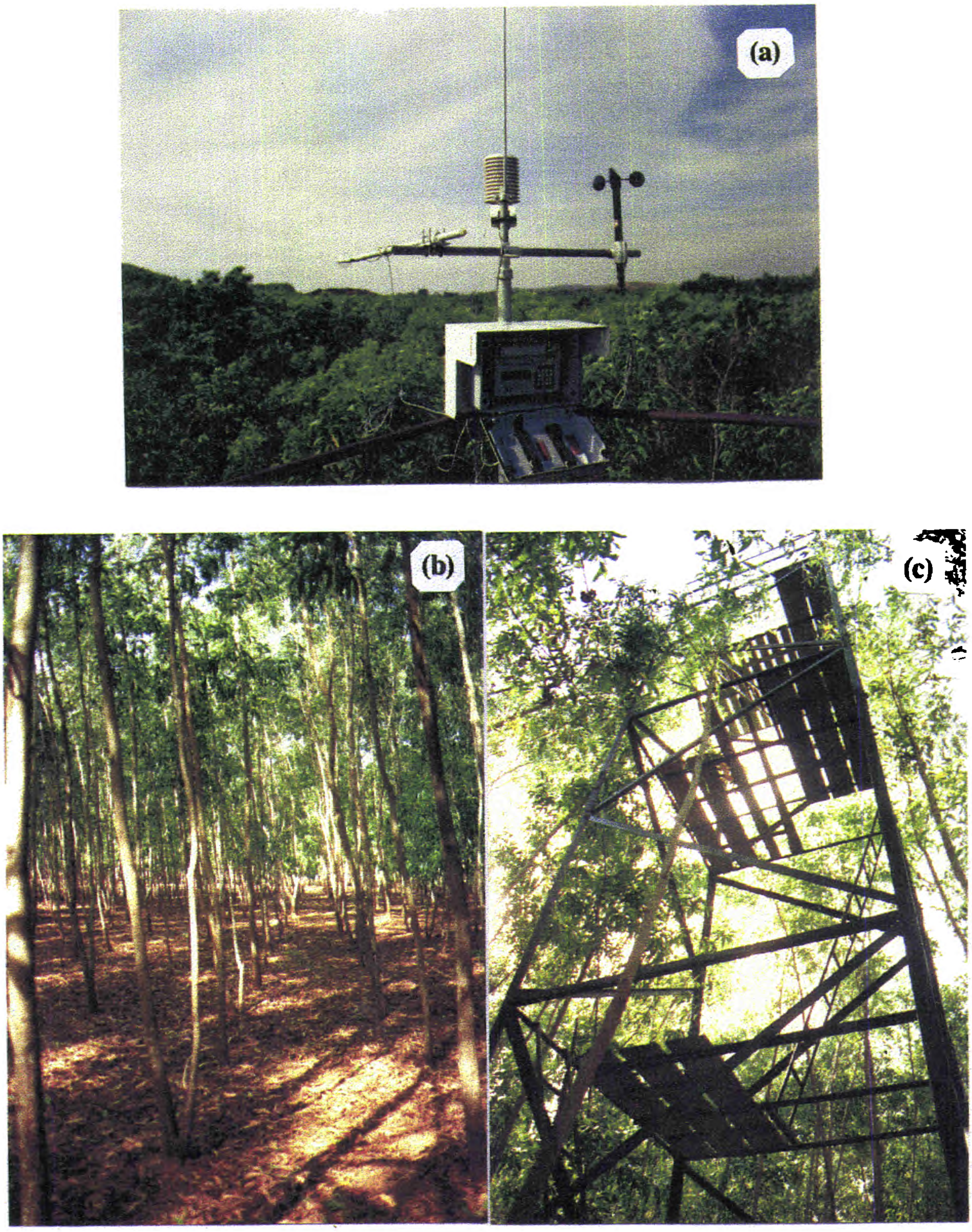

Plate.4. (a) An automated weather station fixed at the top of a Scaffold tower (b) A view of the *A.auriculiformis* plantation used for the study (c) A 10 m high Scaffold tower erected in the experimental site at Kothachira.