KFRI Research Report 110

WATER RELATIONS AND PHOTOSYNTHESIS OF THE OIL PALM IN PENISULAR INDIA

Jose Kallarackal

KERALA FOREST RESEARCH INSTITUTE
PEECHI, THRISSUR

December 1996 Pages: 42

CONTENTS

ABSTRACT

This project, "Water relations and photosynthesis of oil palm in Penisular India" was sponsored by the Department of Biotechnology (DBT), Government of India to investigate the environmental constraints, if any, related to the optimum physiological performance of the newly introduced oil palm *(Elaeis guineensis* Jacq.)in the three States of Andhra Pradesh, Karnataka and Maharashtra. This report presents the results of the studies on microclimate and its effects on water consumption and photosynthesis of the crop planted in three sites, one each in the above States

Using an automated weather station, microclimate parameters such as atmospheric temperature, relative humidity, vapour pressure deficit (VPD), wind velocity, photosynthetically active radiation measured as photon flux density (PFD), net radiation, soil temperature and soil heat flux were studied at the three sites during 7-8 visits spread over 19 months

Temperature at the study sites ranged between 12°C and 35°C The VPD ranged between 0.3 and 4.5 kPa The PFD was not limiting at any site.

The water and carbon dioxide exchange through the leaves showed that leaf No.8 or 9 showed the maximum values for the above parameters. The light saturation of photosynthesis was obtained at =1000 μmol $m^{-2}s^{-1}$.The maximum photosynthetic rate obtained ranged between 7.5 and 11.5 μmol $m^{-2}s^{-}$ This range is at the middle level when compared to reported values from other oil palm growing countries. Similarly the maximum stomatal conductance obtained was 500 mmol $m^{-2}s^{-1}$. Closure of stomata was noticed when the VPD increased from 1.0 kPa. The stomatal conductance was severely reduced when the VPD reached =1.9 kPa so that this would reduce the photosynthesis considerably.

The water status of the plants as examined from the predawn water potentials indicate that the plants were not water stressed during the study period because the plants were irrigated in all the sites. All the sites had a prolonged dry Season that created high levels of water deficits and as such, at none of the sites, oil palm could be grown as a rainfed crop. Soil water availability has been found a major factor effecting the crop yield in oil palm studied elsewhere Although several management practices are available for soil water management, irrigation might be the only alternative at all the sites studied

Water loss by transpiration as estimated for a dry day (without rain) showed that, it ranged from 2.0 to =5.5 mm per diem There is a possibility that this figure would get reduced when the plants reach maturity because of canopy closure that will reduce ventilation

The leaf growth has been measured from the increase in leaf number and leaf area At all the three sites, the leaf number increased by approximately 2 per month and leaf area increased by 5 to 1m^2 per month. However, the leaf area increase was much lower when compared to the data for similar aged plants in Malaysia The best growth was noted at the site in Karnataka.

Based on the conclusions drawn from the above study, several recommendations have been given.

1. INTRODUCTION

The history of oil palm in India goes as far back as 1836 when this tree was first introduced into the National Botanic Garden, Calcutta. Ever since, minor scale introduction of this oil yielding palm has been taking place in the different States of India. However, the first large scale plantations were raised in Kerala and the Andaman Islands, where they have been facing problems of the yield as well as suitable extraction methods. The historical details of the oil palm introduction to India can be found elsewhere (Chadha and Rethinam 1991)

The Department of Biotechnology, Government of India launched oil palm demonstration projects in 1988-89 in collaboration with the Governments of Andhra Pradesh, Karnataka and Maharashtra with the intention of demonstrating the feasibility of oil palm cultivation under irrigated conditions over an area of l000 ha each in the above States. Probably this is the first large scale systematic trial conducted in India outside the State of Keraia. In Andhra Pradesh and Karnataka, this trial has been conducted with the participation of small holders and in Maharashtra, on a large holding managed by the Development Corporation of Konkan Ltd (DCKL). The Tenera sprouted seeds imported from ASD Costa Rica and the indigenous material from CPCRI Palode in the ratio 4 have been used in these plantations.

The plantations have been raised in the Krishna, East and West Godavari Districts of Andhra Pradesh, in Shimoga District of Karnataka and in Sindhudurg District of Maharashtra

It should be mentioned that the Department of Biotechnology launched the above demonstration plots to study the performance of oil palm in detail, and thus to demonstrate the possibility of introducing this crop on a massive scale. But even before the demonstration plots started giving the yield, a large number of private growers have started planting the palms in large and small holdings. Although this is a good sign as far as the popularisation of a crop in a new area, much caution has to he exercised before such large-scale introduction

Several studies on various aspects of growth and reproduction of the crop have been undertaken in these sites where the crop has been newly introduced. This project is one of them, sponsored by the DBT to investigate the physiological aspects of the performance of the crop in the new sites with respect to water relations and photosynthesis. The studies extended for a period of three years from 1992 to 1995 The results of the studies are presented in eight chapters as given below

1. Introduction
2. Plantation site details and microclimate
3. Gas exchange in relation to environmental factors
4. Water relations
5. Transpiration
6. Leaf growth
7. Conclusions
8. Recommendations

2. PLANTATION SITE DETAILS AND MICROCLIMATE

The Department of Biotechnology, Government of India set up demonstration plots in the three States of Andhra Pradesh, Karnataka and Maharashtra in the year 1988-89 with approximately 1000 ha in each of the three States (Fig. 1). Three representative plantations, one from each of these States, were chosen in the present study for detailed monitoring.

The sampling dates at each of the sites during the period of study are given in Table 1. All the measurements mentioned in this report were made during these dates.

Table 1. Sampling dates at each site during the period of study

Site	Year and Month of visit																		
	1993						1994												95
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J
Andhra Pradesh	✓			✓			✓			✓				✓	✓		✓	✓	
Karnataka		✓			✓			✓							✓	✓		✓	✓
Maharashtra						✓			✓			J		J		J		J	J

Microclimate measurement methods

A 5 m high, steel scaffold tower was installed at each of the sites to mount the meteorological equipment through and above the canopies. The meteorological sensors were mounted at the top of these towers. Temperature and relative humidity were measured using a shielded thermistor and a carbon-electrode RH chip (Model 207 temp and RH probe, Campbell Scientific Inc., Utah, USA). Wind speed was measured using a cup counter anemometer (Model 014A, Met One, Sunnyvale, CA, USA) with a switch closure mechanism. Net radiation was measured using a net radiometer of the Fritschen type (REBS Inc., Washington, USA). Photon flux density (PFD) was measured using a quantum sensor (Model LI-190SA, Li-Cor, Nebraska, USA). Soil temperature was measured at two depths, 10 cm and 30 cm, using a thermocouple sensor (Model 107, Campbell Scientific Inc., Utah, USA). Soil heat flux was monitored by a flux plate (HFT-1,REBS lnc., USA) buried 5 cm below the soil surface, in between the rows of plants

All the above sensors were connected to a data logger (Model CR10, Campbell Scientific Inc Utah, USA). Logging was every 5 seconds and hourly averages were stored. The microclimate was monitored continuously for 2 to 3 days, once in three months, for two consecutive years

Observations at the sites

Andhra Pradesh

In Andhra Pradesh a total of 1200 ha of fragmented plantations (area ranges from 0.5 ha upwards) were raised by private land owners in the districts of East Godavari (350 ha), West Godavari (350 ha) and Krishna (300 ha). The funding was provided by DBT and the technical help for these plantations was rendered by the Andhra Pradesh Department of Horticulture. Both indigenous (Palode) and exotic Tenera hybrid seedlings of oil palm were planted 9 m apart in a triangular system, accommodating 143 palms ha^{-1} Basin irrigation was practised in all the plantations.

The plantation chosen in this study is a 15 ha plantation at Sree Rama Estate, Pothepally Bhimadole Taluka, Dwaraka Tirumala Mandalam, which is 50 km. from the district headquarters Eluru of West Godavari District. The average annual rainfall for the area is approximately l000 mm and the potential evapotranspiration (PET) is approximately 1700 mm (Rao *et al.* 1984). The elevation of the site was approximately 80 m.

Measurements of the microclimate parameters made at the study site in Andhra Pradesh are presented in Fig. 2 to 9

The atmospheric temperature at the study site generally ranged between 20°C and 35°C during the year. It rarely went below 20°C during December and January

The vapor pressure deficit (VPD) at the study site is indicated rather than the relative humidity (R.H.). This is because VPD describes the relation between temperature and humidity better than the r.h. alone. The VPD of the study site varied between 0.4 and 4.5 kPa. The variations were least in August due to the influence of the monsoon rains. The maximum VPD was from March to July when it reached a value of 4.5 kPa during midday. VPD is an important microclimate parameter as may be seen in future chapters, because the stomatal behavior is strongly regulated by VPD.

Wind velocity at the study site ranged between 0.4 and 3.5 m s^{-1} (1.7 to 12.6 km h^{-1}). The maximum wind speed was measured in October

The photon flux density (PFD)) at the study site showed a maximum of 1500 μ mol m^{-2} s^{-1} during the two years of mcasurcmcnt. As seen from the measurements during the various months PFD was never limiting at the site.

The maximum net radiation at the study site reached approximately 600 W m^{-2}. The net radiation was approximately 78 per cent of the total solar radiation.

The soil heat flux reached nearly 80 W m^{-2} in October

Karnataka :

In Karnataka, individual plantations totalling an area of 1114 ha were raised by private land owners in the district of Shimoga in Bhadra Project Command Area which includes the Talukas of Shimoga (273 ha). Channagiri (280 ha), Honnali (275 ha) and Bhadravati (286 ha). The funding was provided by DBT and the technical help for these plantations were rendered by the Andhra Pradesh Department of Horticulture. Both indigenous (Palode) and exotic Tenera hybrid seedlings of oil palm were planted 9 m apart in a triangular system, accommodating 143 palms per hectare. The planting was done in July 1990)Basin irrigation was practised in all the plantations.

The plantation chosen for continuous monitoring was a 10 ha plantation in Bhadravati Taluka. This was irrigated twice weekly by basin irrigation using water from several bore wells. The annual rainfall for the area during 1993-94 was 1144 mm, most of which falls during the South-West monsoon.

The PET is approximately 1380 mm (Rao et al. 1984). The elevation of the site was approximately 650 m.

Measurements of the microclimate parameters made at the study site in Karnataka are presented in Fig. 10 to 7

The atmospheric temperature at the site ranged between 15°C and 35°C

The VPD varied between 0.3 kPa and 4.5 kPa. During August and September, the variations were minimal, recording 0.6±0.2 kPa. This may be due to the wet climate prevailing during the above months. The higher values of VPD were seen starting from December to March/April.

The wind velocity ranged from 0.47 to 4.5 m s^{-1} (1.7 to 16.2 km h^{-1}). The maximum wind speed was observed in November.

The PFD at the study site showed a maximum value of 1700 μ mol $m^{-2}s^{-1}$ during the period of measurement. The maximum net radiation reached a little more than 600 Wm^{-2} during the measurement period

The soil heat flux reached a maximum value of 60 Wm^{-2} in October. The range was very minimal in January

Maharashtra

In Maharashtra, plantations to a total extent of 1000 ha were raised at Kankavli in the district of Sindhudurg by the DCKL, a public enterprise. The funding was provided by DBT and the technical help for these plantations were rendered by the DCKL. Both indigenous (Palode) and exotic Tenera hybrid seedlings of oil palm were planted 9 m apart in a triangular system, accommodating 143 palms per hectare. Five hundred hectares were planted in June to August 1990 and the remaining 500 ha were planted in July to September 1991. Basin irrigation was given in all the plantations

The plantation chosen for intensive monitoring was at Osram which has an area of 263 ha planted in 1990. The plantation was frequently irrigated by water from a nearby river by basin irrigation The average annual rainfall of the area was ≈4000 mm and the PET was approximately 1600 mm (Rao et al. 1984). The elevation of the Site was approximately 100 m.

Measurements of the microclimate parameters made at the study site in Maharashtra are presented in Fig. 18 to 25

The atmospheric temperature at the site ranged between 12°C and 35°C. Of the three sites in the three States, this site experienced the lowest temperatures

The VPD at the site varied between 0.3 kPa to 4.5 kPa. The maximum variations were noted in November and December, and the minimum in August.

The wind velocity ranged between 0.47 and 2.00 m s^{-1} (1.7 km h^{-1} to 7.2 km h^{-1}). The maximum wind speed was recorded in September. Among the three sites, this site had the least wind velocity

The PFD at the site showed a maximum value of 1600 μ mol $m^{-2}s^{-1}$. The maximum net radiation was a little more than 600 W m^{-2} at the site during the measurement period

The soil heat flux measurement gave a maximum value nearing 50 W m^{-2}.

Discussion

A comparison of the different microclimate parameters in the three sites is given in Table 2. The microclimate parameters are important in judging the suitability of the Sites where oil palm has been introduced. The maximum atmospheric temperature at all the three sites rarely crossed 35°C. This is not much beyond the maximum temperature (33°C) prevailing in ideal oil palm growing locations (see Hartley 1977). However, the minimum temperature in Karnataka and Maharashtra sites drops considerably below the ideal minimum temperature of 20°C. Since these low temperatures prevail for 2-3 months at the above sites, this

Table 2. Comparison of the microclimate data collected at the three experimental sites.

Parameter	Andhra Pradesh	Kamataka	Maharashtra
Atmos. Temperature (°C)	20 - 35	15 -35	12 - 35
VPD (kPa)	0.4 - 4.5	0.3 - 4.5	0.3 - 4.5
Wind velocity ($m\,s^{-1}$)	0.4 - 3.5	0.5 - 4.5	0.5 - 2.0
PFD max. ($mmol\,m^{-2}\,s^{-1}$)	≈ 1500	≈ 1700	≈ 1600
Net radiation max. ($W\,m^{-2}$)	≈ 600	≈ 600	≈ 600
Rainfall annual avg. (mm)	1000	1144	4000
[1]PET (mm)	1700	1380	1600
Soil heat flux max.($W\,m^{-2}$)	80	60	50

1 Data obtained for the area from Rao et al. (1984)

could be a factor for reducing the yield in these sites. Of all the three locations, the site in

Andhra Pradesh seems to have the most ideal temperatures for oil palm cultivation

VPD is an important microclimate parameter because the stomata1 behaviour is strongly influenced by this. In all the three sites, the range of VPD is large, from 0.4 to 4.5 kPa The atmospheric dryness is also an important parameter to be considered in choosing newer locations for oil palm introduction. This aspect will be dealt with from a physiological angle in the forthcoming chapters

The light availability at all the three sites seems to be not limiting, although the high seasonal rainfall and cloudiness at the Maharashtra site could restrict sunshine hours to less than 5 ha day for several days. This could be probably a factor (see Hartley 1977) reducing the yield at the Maharashtra site .

The relatively high soil heat flux density at all the sites is due to the gaps existing in the canopy. Once the canopy closure occurs, this would be expected to reduce considerably

3. GAS EXCHANGE IN RELATION TO ENVIRONMENTAL FACTORS

The total dry matter (DM) production of an oil palm crop is about 50 t_{DM} ha^{-1} $year^{-1}$, with 30 t_{DM} ha^{-1} $year^{-1}$ in above-ground parts (Corley 1976; Dufrene et al. 1990). Thus it exceeds that of tropical and temperate deciduous forests and equalling that of temperate evergreen forests (see Table 2). Despite the high productivity of oil palm, very few studies have been undertaken to understand its physiology. The responses of the oil palm to environmental variables like light, temperature, vapor pressure deficit (VPD) etc. have not been subjected to any study in India. While introducing this crop on a large scale in different parts of India, it is only essential that such factors are studied so that the problems of yield at a later stage can be managed in a suitable way. This is especially important in India, which experiences seasonal rainfall (mainly due to monsoons) and prolonged drought period during a few months of the year. Although majority of the Indian crop is irrigated, environmental limitations to growth and productivity still exist.

Table 2. Above-ground production of various forested ecosystems (modified from Dufrene and Saugier 1993).

Ecosystem	Above-ground production (tDM ha-1 year'')
Tropical rain forest	10.3 to 22.9
Temperate deciduous forest	8.7 to 17.9
Temperate evergreen forest	6.5 to 35.2
Oil palm plantation	30.0

In this study on gas exchangc, the following aspects have been investigated:

1. The response of the stomata to the varying environmental factors prevailing in the three States.
2. The extent of stomata1 limitations on photosynthesis.
3. Reasons for the wide differences between reported values of photosynthesis and the values obtained in the three States.

Material and Methods

Four-year old plants mentioned in Chapter 2 were used for this study. After some preliminary measurements in April 1993 to determine the leaf rank on which to take the majority of measurements, more or less regularly spaced measurements were started in September 1993. Since the plants were easily accessible from the ground: no scaffolding was used.

Net carbon dioxide (CO_2) assimilation (A) and stomatal conductance (g_s) were measured using a portable infrared gas analyzer system (Li-6200, Li-COR, Nebraska, USA). A one-liter chamber was used throughout. A leaf lamina area of 12 cm^2 was enclosed in the chamber. The measurements were carried out in such a way that the leaf lamina did not remain inside the cuvette for more than a minute. All the diurnal measurements were made in natural daylight. For plotting the light saturation curve, neutral filters were used to make measurements at lower PFD. Sufficient time was allowed to acclimate the leaf to the new light environment before making such measurements.

Aand g_s were calculated using the software supplied with the instrument. Besides, the cuvette also measured the leaf temperature using a thermocouple attached to it.

Diurnal measurements were done at one hour intervals which were continued far 2-3 days. once in three months at each site. The long distances between the sites limited more frequent sampling. The sampling dates at all the three sites are given in Table

Observation and discussion

Preliminary measurements have shown that leaf no.8 or 9 (when counted from the centre with the youngest leaf as no. 1) shows the maximum values for gas exchange parameters, This agrees with measurements done by other investigators (Dufrene and Saugier 1993).

Fig. 26 shows the photosynthesis light response curve plotted from measurements made at the site in Andhra Pradesh. Maximum photosynthesis was obtained at =1000 mmol m^{-2} s^{-1}. A plot of the light response curve of g_s is also shown in Fig. 27

The maximum values of g_s measured at all the three sites showed ≈ 500 mmol m^{-2} s^{-1}. Diurnal measurement of the g_s showed that they peaked in the morning (Fig. 28) If we look at the above figure along with the microclimate data collected at all the stations, the reduced conductance toward the afternoon is not due to the insufficiency in PFD. Although the light saturation in oil palm is at approximately 1100 µ mol m^{-2} s^{-1} (Dufrene & Saugier 1993 and the present work), this quantum of light is available far nearly 7 to 8 hours (≈ 10.00 h to 17.00 h) at the study sites (Fig.2 to 25). However, within the above period, the g_s showed much fluctuations which can be reasonably assumed to be due to changes in VPD or leaf temperature. Hence these variables were regressed against g_s data obtained at the three sites separately. Fig. 29 gives the indication that invariably at all the three sites the g_s is strongly regulated by VPD. By using g_s data collected at or above the light saturation level in the above Figure, it is apparent that the regulation of stomatal function is mainly due to VPD. At lower values of VPD (< 1 .5 kPa), the gs decreases exponentially at all the three sites. 1lowever, with further increase in VPD (> 1 .5kPa), the decrease in g_s is rather slow. As seen from the figure, the g_s at this time remains more or less steady at ≈ 100 mmol $m^{-2}s^{-1}$ Complete stornatal closure was not observed at any of the three sites with further increase in VPD. Dufrene and Saugier (1993) reports the nearly complete closure of stomata (g_s 50 mmol m^{-2} s^{-1}) at a VPD value of 4.5 kPa.

Higher VPD values resulting from low air humidity and high air temperature have been shown to cause stomatal closure in many plants (Schulze and Hall 1982, El Shakawi et a1 1983, Chiaricih 1984 and Schulze and Hall 1986). This is referred to as feed back control of environment on stornatal conductance with feed forward control of stomata on plant water relations (Cowan 1977; Farquhar 1978). Smith (1989) concluded that stornatal closure in oil palm is induced by high VPD values, which will be further enhanced by soil water deficits

Stomata1 closure due to increasing atmospheric VPD has been reported from Nigeria (Rees 1961), Colombia (Smith 1989) and Ivory Coast (Dufrene and Saugier 1993). Reduction in g_s due to stornatal closure can considerably reduce the diffusion of CO_2 through the stomata, thereby reducing photosynthesis. However the threshold value of g_s at which photosynthesis is affected varies in plants. Smith (1989) has indicated that photosynthesis in oil palm begins to be significantly limited at a g_s < 125 mmol m^{-2} s^{-1}, which requires a VPD of more than 3.8 kPa. This was found to be true when air temperature is 38°C and R.H. below 40 per cent.

The results of the present study are not in full agreement with that of Smith (1989). It was found that in all the three States, the A_{max} of photosynthesis is much below that reported by several investigators which range From 14 to 24 μ mol m^{-2} s^{-1} (Corley 1983, Gerritsma 1988, Dufrene and Saugier 1993). However, the present values are above those reported by Hirsch (1975), Adjahossou (1977, 1983) and Smith (1989) In the present study, the Amax was approximately 10 mmol m^{-2} s^{-1} in Andhra Pradesh, 1.5 μ mol m^{-2} s^{-1} in Karnataka and 7.5 μ mol m^{-2} s^{-1} in Maharashtra (Fig. 30). Thus they are somewhat intermediate when compared to the A_{max} values of oil palm reported from elsewhere. Factors such as plant age, leaf age, leaflet position and environmental factors have been ascribed to as the cause for the wide range in A_{max} reported in the literature. However, the tree or leaf effect cannot be given as the cause fur this variation unless leaves older than one year are used (Dufrene and Saugier 1993). From a survey of the previous work, it is apparent that the $g_{s\ max}$ values reported by Dufrene & Saugier (1993) were more than 800 mmol m^{-2} s^{-1} when they got A_{max} values in the range of 20-24 μ mol m^{-2} s^{-1} . The $g_{s\ max}$ values of Smith (1989) did not cross 150 mmol m^{-2} s^{-1} when he reported an A_{max} of approximately 2.5 μ mol m^{-2} s^{-1}. In the present study, the gsmax was approximately 500 μ mol m^{-2} s^{-1} when the A_{max} values ranged between 7.5 and 1.5 μ mol m^{-2} s^{-1} in the three States. From the above account, it appears that photosynthesis is basically a function of stomata1 conductance in oil palm

It is noted that the A_{max} at all the three sites is reached when the g_s is approximately 250 mmol m^{-2} s^{-1} (Fig. 30). It is therefore apparent that when the g_s values are <250 mmol m^{-2} s^{-1} the net photosynthesis will be affected at a rate as shown in Fig. 30. Corley and Lee (1992) have stressed the importance of selecting populations with higher photosynthetic rates.

From Fig. 29, it may be noted that at VPD values > 1.0 kPa, the g_s falls to values < 250 mmol m^{-2} s^{-1} . In order to assess the percentage of time when the photosynthetic CO_2

conductance into the leaf is not at its full potential the above information along with the information on VPD ranges (Fig. 31) is used to develop the Table 3.

Dufrene and Saugier (1993) have observed that transpiration rate decreased exponentially when VPD increased from 0.4 to 1.8 kPa, but then decreased linearly. The decrease in A_{max} was only about 10% when $g_{s\ max}$ decreased by 50% (from 750 to 350 mmol m^{-2} s^{-1}) with VPD changing from 1 to 1.8 kPa.

Month	Andhra Pradesh	Karnataka	Maharashtra
January	100	100	90
February		100	
March			100
April	100		
May		80	
June			90
July	100		
August	0	0	0
September	90	0	5
October	100	90	100
November	100	100	90
December	100	100	100

Note: *The above data are based on at least two days measurements in each month. Blank cells indicate data not available.*

The influence of atmospheric temperature on g_s has been worked out at the three sites Fig. 32 indicates that the relationship is almost similar to that of g_s vs. VPD. This is because the VPD increases as a result of increase in atmospheric temperature. Hence it is difficult to separate the effect of VPD on g_s from that of temperature. However, the general tendancy for the oil palm is reduced conductance at higher ranges of VPD when compared to lower VPD levels (Dufrene and Saugier 1993).

Thus it is apparent that the three parameters *A*, g_s and VPD are highly correlated in oil palm. All the available investigations show that g_s is strongly affected by VPD. However, the g_s value at which *A* is strongly impaired is reported to be varying in different locations. The values reported by Dufrene and Saugier (1993) seem to show maximum similarity to the values reported in this investigation.

4. WATER RELATIONS

Soil water deficits have long been recognized as a major constraint to oil palm productivity (Devuyst 1948, Sparnaij et a1.1965, Dufrene et al. 1992). In this chapter, the water status of the trees grown at the three sites in the three States have been examined. These three sites are representatives of the plantations raised in their localities. Hence it is reasonably assumed that the observations presented here are applicable to the rest of the plantations raised in these three States by the DBT programme.

Methods

Water status of the oil palm plants was followed by measurements of the leaf water potentials (Ψ). A scholander pressure chamber (PMS model) was used for the measurement of Ψ. Since the leaflets were very long for the chamber, they were rolled while keeping in a polythene hag before detachment from the plant. The leaflets were inserted in the polythene bag just before detachment. A part of the lamina was removed from the base of the leaflet so that the central rachis of the leaflet projected through the sealing device of the pressure chamber. Measurements were made at one/two hours intervals starting from predawn till dusk.

Results and discussion

The diurnal changes in water potential measured at the three sites are depicted in Fig. 33 to 42. The general trend shows that the water potential decreases from morning till noon, thereafter the values tend to increase.

The predawn water potential is a good indicator of the water availability to the trees (Crombie et al. 1988). This is because the root tissues, and later, the leaves tend to equilibrate with the available water in the soil overnight. Hence, a measurement of the predawn water potential is a good indicator of the soil water content surrounding the roots. The midday water potential is a good indicator of the maximum water stress to which a plant is subjected in the existing surroundings. Fig. 43 to 45 show the predawn and midday water potentials prevailing in the three States. From the predawn values, it is apparent that the water status of the plants at the three sites examined is relatively high. This is because the water potentials are very near zero, which is the maximum water potential possible. The midday water potential values also do not indicate any extreme level. This rightly gives us the indication that the irrigation given at present is sufficient to prevent any water stress development.

Oil palm as a rain-fed crop in the three states

Oil palms are successfully cultivated in areas of very heavy to moderate rainfall. In areas with very high rainfall (> 5000 mm), the rainfall is usually in excess of evapotranspiration. In such areas, constant cloudiness could limit the productivity. This is found along the Pacific plain of tropical South America (Hartley 1977). However, in the three States in India under study, rainfall amount varies from a little more than l000 mm in Karnataka to more than 4000 mm in Maharashtra sites (Fig. 46).

From a survey of the rainfall data in the major oil palm growing areas of Asia, Africa and America, it may be noted that oil palm is not grown in any location with rainfall as low as that of A.P. and Karnataka. The most similar location is probably Dahomey in Africa where the annual rainfall is 1232 mm. There, like in the Indian locations, the period of four months from November to February is almost devoid of rain (Hartley 1977). However, the productivity of the palms in Dahomey is reasonably good which is ascribed to the high water-holding capacity of the soil.

An estimate of the water deficits at the various sites can be worked out using the following formula.

$$B = Res + R - E_{tp}$$

where,

B = the water deficit at the end of the period,

Res = soil reserve at the beginning of the period,

R = rainfall and

E_{tp} = potential evapotranspiration during the period.

Using the above equation, it is possible to work out the water deficit at the end of the drought period at all the three sites under study. In calculating this, it is assumed that the soil water reserve *(Res)* at the beginning of November is 250 mm and is under field capacity (Harding et al 1992). The Same value has been taken for all the three sites, although this could be an overestimation for the soil especially at the Maharashtra site. The Penman potential evapotranspiration *(Etp)* for the sites were taken from the published values of Rao et al. (1971). The results are presented in Table 4.

Table 4. Water deficits at the three sites by the end of the dry period (May) as worked out by Equation (1).

Site	*Res*	*R*	E_{tp}	*B*
Andhra Pradesh	250	123	997	-624
Karnataka	250	133	875	-492
Maharashtra	250	100	1003	-653

Note: *see text for abbreviations.*

From Table 4, it is apparent that in all the three sites, there is a drought period, at the end of which the water deficits are considerable. This means that oil palm cannot be successfully grown at any of these sites as a rain-fed crop. Proper irrigation is necessary to get a better growth and yield from the oil palm.

The oil palm trees have the capacity to use water at great depth in the root zone. For example in Ivory Coast, the plant was found to extract water from soil at 5.2 m depth (Dufrene et al 1992). They also found that the fraction of the extractable water in the soil was never reduced below 0.40 even during the dry season. This was due to an early stomata1 closure which occurred when the fraction of extractable water of the top 80 cm of soil decreased below 0.60. Stomata1 closure induced a decrease in transpiration rate.

Water supply has been found to be the major limiting factor for oil palm yield (Comaire et al. 1994). When subjected to severe stress, the trees not only reduce production with less than 5 t_{FFB} ha^{-1} (Fresh fruit bunch per hectare), but also suffer vegetative damage. A very good example for this can be found in the State of Kerala, India, where 3700 ha have been brought under oil palm mainly in hilly areas. The average yield from these plantations is reported to be MOW 1 t_{oil} ha^{-1} $year^{-1}$ ($\approx$5 t_{FFB} $ha^{-1} year^{-1}$) (Rethinam 1994). In Kerala, there exists a dry period lasting not less than 4 to 5 months, and the crop is unirrigated. In the Andamans where oil palm was introduced in 1976, the productivity is even lesser than Kerala (Thampan 1992). Varghese (1994) has concluded that the oil palm in Kerala requires at least 90 litres of water per diem for optimum production.

The effects of severe drought on oil palm were first identified by Maillard et al (1974).

They have reported closed spears. broken green leaves, dried out leaves, toppled spear and death of the plant. Interestingly, they noted several plant.. with drought tolerance showing better productivity than others.

Methods to combat drought

The most common method of combating drought in oil palm plantation is by irrigating the plants during the critical period. Drip irrigation has been found to increase the yield substantially in Benin to 31 t_{FFB} ha^{-1} $year^{-1}$ compared to 12 t_{FFB} ha^{-1} $year^{-1}$ for non-irrigated crop. However. even with irrigation, atmospheric drought, if it exists is a strong limiting factor to productivity. Chaillard et al.(1983) have confirmed the reduction in irrigation efficiency during periods when relative humidity is less than 50%. Hence in plantations experiencing a marked dry season, it is difficult to exceed yields of 22-24 t_{FFB} ha^{-1} $year^{-1}$, even with irrigation (Comaire et al. 1994). An average production of 25 t_{FFB} ha^{-1} $year^{-1}$ has been recorded in Andhra Pradesh, India, with an oil equivalent of 4.5 t_{oil} ha^{-1} $year^{-1}$ (Thampan 1996). IRHO (1985), after making a study in Benin found that irrigating the oil palm was not feasible under the domestic and international market conditions. It is to be seen if the same exercise is feasible in India, where the crop is presently irrigated in all the States except Kerala State. Promising results have been obtained in Ivory Coast by following water management techniques such as 'subsoiling' and planting along contour lines (Caliman 1992). It is doubtful if these practices can yield great success in the sites under the present study in India except in Maharashtra where contour planting is possible. In Karnataka and Andhra Pradesh, the planting is presently done on flat terrain which not have much scope for runoff. However, experiences from other countries suggest that water holding capacity of the soil is an important criterion to be taken care of when selecting new sites for oil palm introduction.

How to reduce the effect of drought ?

It is possible to make more water available to individual trees by reducing the density of planting. Houssou et al. (1992) have demonstrated that the mortality of trees due to drought can be considerably reduced by planting at 121 or 100 trees ha^{-1}. However, this need be followed only for marginal areas where the drought is severe. Another way suggested for managing drought is to castrate the bunches when the trees are young. Castration was shown to promote better root development and therefore better drought resistance by the roots exploring deeper into the soil (Daniel et al. 1974).

5. TRANSPIRATION

The high yield of oil palm which can reach 8 t of oil ha^{-1} $year^{-1}$ and the high maximum stomata1 conductance of >800 mmol m^{-2} s^{-1} (Dufrene and Saugier, 1993) would imply a high canopy transpiration rate. Except for the work of Dufrene et al. (1992), very few studies are available on the evapotranspiration in oil palm stands. In this study canopy transpiration has been estimated with the Penman-Monteith equation using physiological and microclimate measurements done at three locations.

Materials and Methods

The three plantations chosen in each of the three states formed the subject of this investigation.

The microclimate data collected 6 m above the ground level were used as described in Chapter 2. Estimation of the canopy transpiration was done using the Penman-Monteith Equation (Monteith, 1965).

$$E_c = \frac{s(R_n - G) + C_m g_a D}{\lambda [s + \gamma (1 + g_a / g_c)]} \qquad (2)$$

where,

E_c = canopy transpiration (mol m^{-2} s^{-1})

R_n = net radiation (W m^{-2})

G = soil heat conduction flux (W m^{-2})

C_m = mole specific heat of air (J $mole^{-1}$)

g_a = aerodynamic conductance of the canopy (mol m^{-2} s^{-1})

γ = psychrometer constant (0.066 k Pa K^{-1})

D = vapor pressure deficit (mb)

s = slope of the saturated vapor pressure versus temperature curve (k Pa K^{-1})

λ = latent heat of water (44,200 J $moll^{-1}$ @20ºC)

g_c = canopy conductance (mol m^{-2} s^{-1})

In the above equation, parameters R_n, G and D were obtained from the microclimate measurements. Tabled values were used for C_m. Canopy conductance, g_c was obtained by the equation,

$$g_c = \Sigma g_s L \qquad (3)$$

where,

g_s = the prometer values of stomatal conductance,

L = the leaf are index measured by the equation (Hardon et al. 1969).

$$L = b \times (n \times lw) \qquad (4)$$

where,

b = correction factor (0.55)

n = number of leaflets

lw = mean of length x middle width for a sample of the largest leaflets

The aerodynamic conductance, g_a, was obtained by

$$g_a = (k^2 uP)/\ln^2 [(z-d)/z_0] \qquad (5)$$

where,

k = von Karman's constant (0.41)

u = mean wind speed measured above the canopy (ms^{-I}),

z = anemometer reference height (m),

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

z_0 = the roughness length (=0.13h),

ρ = mole density of air (mol m^{-3}).

The hourly averaged wind speed data formed the most important variable for the calculation of g_a. The slope of the saturated vapour pressure versus temperature curve, s was calculated using the equation,

$$s = \frac{\lambda e_s (T)}{R (T+273)2} \qquad (6)$$

where,

e_s = saturation vapour pressure at temperature T,

R = universal gas constant (8.314 J mol^{-1} K^{-1}).

The value of E_c obtained in mol m^{-2} s^{-1} was converted to depth equivalents. The canopy transpiration was worked out on an hourly basis (mm h^{-I}).

Results and discussion

The E_c as calculated using the Penman-Monteith Equation shows that the hourly canopy transpiration ranges between 0.1 and = 1.0 mm h^{-1} on a land area basis (Fig. 33). This when cumulated on a daily basis shows that the daily transpiration varies between 2.0 and ≈5.5 mm d^{-1} (Table 5).

If the above quantity is converted to litres day^{-1} $plant^{-1}$ (assuming 143 plants ha^{-1}), it would work out to 140 to 385 litres day^{-1} $plant^{-1}$. It would seem that the transpiration loss is extremely high. However, it should be remembered that the plants in the present sites were well-irrigated. Hence, there is no soil water limitations to achieving full transpiration capability. In the unirrigated condition, the transpiration could be expected to be much lower. The transpiration calculated by the Penman-Monteith Equation is the water loss from the dry canopy. Above a rough surface such as a forest or an oil palm plantation, the ratio g_a/g_c is large which makes Penman-Monteith Equation insensitive to variations in g_c.

The oil palm plantations under investigation in this study had not achieved full canopy closure because they were usually 4-5 years old. Hence the soil heat flux measured in this study would be much more than in a fully closed-canopy plantation.

It would be expected that the water consumption by the oil palm would be lesser when complete canopy closure occurs. This is because of the reduced ventilation within the canopy which would decrease the boundary layer conductance. From that stage it is expected that the water use would get stabilized.

Very few studies have been made on evapotranspiration in oil palm stands. One such study conducted recently by Dufrene et al. (1992) at La Me in Ivory Coast has shown that the evapotranspiration from the dry canopy is 81 per cent of the potential evapotranspiration. The daily transpiration values in their study ranged between 1.25 mm d^{-1} to 2.31 mm d^{-1}. However, the plants were unirrigated. This should explain the lower values obtained by

Table 5. Daily transpiration (mm d^{-1}) obtained by cumulating hourly values at the three oil palm sites.

Year	Month	Andhra	Karnataka	Maharashtra
1993	July	2.063		
	August		3.616	
	September			
	October			
	November	2.351	2.076	
	December			
1994	January	2.823		
	February		4.392	
	March			5.451
	April	4.934		
	May		4.044	
	June			3.120
	July			
	August	2.447		2.269
	September	3.906	5.498	
	October		4.298	5.862
	November			
	December	3.299	4.051	3.204
1995	January		4.123	3.438

them compared to the values obtained in the present investigation.

In the present study, the water loss by transpiration Seems to be more because of the unstressed condition of the plant caused by irrigation. Even with irrigation, it may be noticed from Table 5, that transpiration rates are much lower than during the wet season. This is due to the atmospheric dryness which causes stomata1 closure even with water availability in the soil. This aspect has been already discussed in Chapter 3.

6. LEAF GROWTH

During the younger stages of growth of a plant, leaf area development is an important parameter to monitor the growth quantitatively. This data could be compared with those of plants growing in traditionally suitable localities to assess the growth performance in a newly introduced location. Corley et al. (1971) have given detailed description on monitoring some of the growth parameters including leaf area in oil palm. Hardon et al. (1969) have shown that a good estimate of mean leaf area can be obtained by measuring in detail one or two leaves per palm. Hence, the above method has been followed in estimating the leaf area development in this study.

Materials and Methods

The oil palm plants at the three sites mentioned in the previous chapters have been used for the study.

Leaf number

The number of leaves per palm was determined by counting them. At all the three sites, only the senesced leaves were removed during the observation period. Eight palms selected at random were used continuously during the observation period. The average number of leaves produced per month was obtained by numbering all the existing leaves with indelible paint.

Leaf area

The leaf area per palm is equal to the mean area per leaf multiplied by the number of leaves per palm. Mean area per leaf was estimated as described by Hardon et al. (1969) from the equation (4).

The average leaf area developed per month was worked out from the product of new leaves produced, and the area per leaf worked out by the above equation.

Leaf area index (LAI)

LAI was calculated by dividing the mean leaf area per tree by the land area occupied by the tree. In the present case 143 trees ha^{-1} was the planting density.

Results and Discussion

The mean number of leaves $palm^{-1}$, the average number of leaves produced $palm^{-1}$ $month^{-1}$, the mean leaf area $palm^{-1}$, the average leaf area developed $palm^{-1}$ $month^{-1}$ and the leaf area index are depicted for the three sites in Table 6 to 8.

Table 6. Leaf area development in oil palm at the site in Andhra Pradesh.

Month	No.of leaves palm-1	Leaf production (No. /month)	Leaf area (m2 palm-1)	Leaf area increase (m2/month)	Leaf area index
Jul 93	29.8± 1.47	--	46.70± 1.46	--	0.67
Oct 93	38.0±2.31	2.70	71.30±l.72	8.20	1.02
Jan 94	44.2±1.77	2.06	89.89± 1.62	6.19	1.28
Apr 94	52.2 ± 2.11	2.66	113.09± 1.67	7.73	1.61
Aug 94	59.8±2.31	1.90	141.81±2.18	7.18	2.02
Nov 94	66.4± 1.30	2.20	167.27±2.15	8.48	2.39

Note: *The seedlings were planted at this site in June 1990.*

It may be noted that the monitoring of leaf area development started when the plants were three years old and continued till the plants crossed four year age. The mean number of leaves were nearly the same at all the three sites, with slightly less number in Maharashtra. The average number of leaves produced palm^{-1} month^{-1} was approximately 2 at all the three sites, with slightly better production in Andhra Pradesh. The leaf area increase was maximum in Karnataka and least in Maharashtra. The LA1 started at ≈ 0.6 at all the three sites when first measured, and after nearly 18 months it reached nearly 3 in Karnataka, 2.4 in Andhra Pradesh and 2.24 in Maharashtra.

Highly positive correlation was found between LA1 and crop growth rate in oil palms (Corley *et al.*, 1971). When the LA1 reaches 5; light interception by the canopy crosses

Table 7. Leaf area development in oil palm at the site in Karnataka.

Month	No. of Ieaves/palm	Leaf production (No./month)	Leaf area (m^2/palm)	Leaf area increase (m^2/month)	Leaf area index
Apr 93	28.3±2.1		48.7±2.0		0.69
Aug 93	36.3±2.2	2.00	69.3± 2.1	5.13	0.99
Nov 93	43.0±1.8	2.23	1O2.4±1.9	11.05	1.46
Feb 94	48.6±2.3	1.86	124.9±1.9	7.51	1.78
May 94	53.9±1.9	1.76	144.2±1.4	6.40	2.06
Sep 94	61.2±2.3	1.82	170.6±1.8	8.80	2.44
Dec 94	68.5±2.2	2.30	205.4±1.9	11.60	2.93

Note: *The seedlings were planted at this site in June 1990.*

Table 8. Leaf area development in oil palm at the site in Mahrashtra.

Month	No. of Ieaves/palm	Leaf production (No./month)	Leaf area (m^2/palm)	Leaf area increase (m^2/month)	Leaf area index
Apr 93	30.6± 1.8		40.49± 1.84		0.58
Sep 93	36.9± 1.8	1.26	68.63±1.78	5.63	0.98
Dec 93	42.5±2.6	1.86	85.31±1.89	5.56	1.22
Mar 94	47.5±2.1	1.60	98.86± 1.73	4.51	1.41
Jun 94	52.7±2.1	1.73	119.25±2.24	6.79	1.70
Aug 94	57.3±1.5	2.30	136.25± 1.72	8.50	1.95
Dec 94	62.9± 2.3	1.86	156.82±2.59	5.14	2.24

Note: *The seedlings were planted at this site in June to August 1990.*

90 per cent (Corley *et al.*, 1971). It may be possible to increase the LA1 further by increasing the planting density. However, it has been noticed that the fruting bunch production decreases when the LA1 exceeds about 6.0 (Corley *et al.*, 1971).

In the early stage of growth of the plants, as in the present study, leaf area development is an important criterion to judge the performance of the oil palm in the newly introduced locations. In Fig.46, a comparison of the leaf area development at the three sites is presented along with that of the results obtained in Malaysia (Corley and Gray 1982). It shows that in none of the Indian sites, the leaf area development reaches the same level as that in Malaysia. It is also reported that the maximum number of leaf production may be as high as 40 per annum for a period of one or two years, but eventually falls to between 18 and 24 per annum,. In the sites presently studied, it may be noted that this number is between 19 and 25, from our measurement. Out of the three Indian sites examined, Karnataka site has shown the maximum leaf area development when compared to the other

7. CONCLUSIONS

1. Analysis of the microclimate shows that the maximum temperatures at all the three sites are well within the boundary when compared with the temperatures in areas elsewhere considered suitable for growing oil palm. However, the minimum temperatures in Karnataka and Maharashtra are much lower than the recommended value.

2. The vapour pressure deficit (VPD) at all the three sites goes to a maximum of 4.5 kPa. Except for a couple of months, the VPD at all the sites crosses the 1.8 kPa mark which has been found to affect the photosynthetic rates.

3. The light availability is adequate at all the sites, except in Maharashtra, where during the monsoon season it may be a limiting factor due to overcast sky.

4. The stomatal conductance and photosynthetic rate are much below the values reported from ideal oil palm growing areas in Africa or South America. In spite of good irrigation, the reason for this physiological problem can be ascribed only to higher VPD of the atmosphere or nitrogen deficiency.

5. The oil palm plants at all the three sites were not suffering from any water stress as indicated by water potential measurements.

6. Estimation of the soil water deficits at all the sites indicates that the prolonged dry period creates a severe water deficit.

7. Estimation of transpiration by the Penman-Monteith method indicates a transpiration of

2.0 to 5.5 mm d^{-1} for all the plantations.

8. The leaf area development at all the three sites shows that the average leaf number increased by 2 $month^{-1}$. However, the leaf area development was below the value reported from Malaysia.

8. RECOMMENDATIONS

1. The report throws light on the importance of microclimate in choosing new locations for oil palm introduction. The temperature range of 20°C to 32°C should be taken as an important criterion. Similarly, the vapour pressure deficit is also an important aspect. Sites with VPD less than 2.0 kPa should be preferred as far as possible. Such lower VPD values can be found nearer to the coast.

2. Studies may be conducted as to weather the rate of photosynthesis in plantations can be increased by better nitrogen nutrition. By increasing the photosynthetic rate, better growth can be achieved.

3. Oil palm cannot be grown in any of the three locations as a rainfed crop. The restricted and seasonal rainfall in peninsular India will not be helpful in relieving soil water deficits. There are not many other options for water management in the plains of peninsular India except irrigation.

4. The transpiration estimates show that the 4-year old palm transpire between 120 to 385 liters day^{-1} in the unstressed condition. Any irrigation scheduling should take this value into account. However, this should not be taken as an alarm. As the plants mature, there is a possibility that this rate might come down and stabilize.

5. The yield data collected from the three sites (data not included in this report) show that the yields from 6-year old plants in Karnataka and Maharashtra sites are not satisfactory. Some of the factors mentioned above could be responsible for this.

6. In the light of the above findings, any expansion of oil palm plantations should be

taken up only after closely following the yield data in the above three States for at least three more years. lrrigation facility should be given the highest priority because unimgated oil palm in any of the above site will be totally unproductive.

REFERENCES

Adjahossou, D.F. 1977. Contribution al'etude des caracteres physiologiques de resistance a la secheresse du palmier a huile *(Elaeis guineensis* Jacq.). These 3eme cycle, Universite Paris VIl, Paris, France.

Adjahossou, D.F. 1983. Contribution a l'e'tude de la rdsistance a la secheresse chez le palmier a huile *(Elaeis guineensis* Jacq.). These Doct. Etat, Universite Paris VII, Paris, France.

Caliman, J.P. 1982. Oil palm and water deficit, production, adapted cropping techniques. Oleagineux 47:5.

Chadha, K.L. and Rethinam, P. 1991. Oil palm cultivation in India: Reports, recommendations and achievements. Indian Oilpalm Journal 1:29-35.

Chaillard, H., Daniel, C., Houeto, V. and Ochs, R. 1983. ,Oil palm and coconut irrigation: a 900 ha "experiment" in the Benin People's Republic. Oleagineux 38: 10.

Chiariello, N. 1984. Leaf energy balance in the wet lowland tropics. Physiological Ecology of Plants in the Wet Tropics (eds. E. Medina, H.A. Mooney and C. Vazquez-Yanes), pp.85-98. Proceedings of an International Symposium, Mexico, 29 June - 6 July 1983. Dr W. Junk, The Hague.

Corley, R.H .V. 1976. Photosynthesis and productivity. Oil palm Research, Developments in Crop Science, Vol. 1 *(ed.* R.H.V. Corley, J.J. Hardon and B.J. Woods), pp. 55-74. Elsevier, Amsterdam.

Corley, R.H.V. 1983. Photosynthesis and age of oil palm leaves. Photosynthetica 17:97-100.

Corley, R.H.V., Gray, B.S. and Ng, S.K. 1971. Productivity of the oil palm *(Elaeis guineensis* Jacq.) in Malaysia. Experimental Agriculture 7: 129-136.

Corky, R.H.V. and Gray, R.S. 1982. Growth and morphology. In: Oil Palm Research, R.H.V. Corky, J.J. Hardon and R.J. Wood (eds), Elsevier Scientific Publishing Company, N.Y: 7-21.

Corky, R.H.V.; Hew, C.K., Tam, T.K. and Lo, K.K. 1973. Optimal spacing for oil palms. In: R.L. Wastie and D.A. Earp (eds). Advances in oil palm cultivation. Incorporated Society of Planters, Kuala Lumpur: 52-69.

Corky, R.H.V. and Lee, C.H. 1992. The physiological basis for genetic improvement of oil palm in Malaysia. Euphytica 60: 179- 184.

Cornaire, B., Daniel, C., Zuily-Fodil, Y. and Lamade, E. 1994. Oil palm performance under water stress. Background to the problem, first results and research approaches. Olagineux 49: 1- 1I.

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

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

Daniel, C. and de Taffin, G. 1974. Conduite des jeunes plantations de palmier a huile en zones seches au Dahomey. Oleagineux 28:5.

Devuyst, A. 1948. Influence des pluies sur les rendements du palmier a huile enregistrees a la station de La Me' de 1938 a 1946. Oleagineux 3:137-144.

Dufrene, E., Duhos, B., Rey, H., Quencez, P. and Saugier, B. 1992. Changes in evapot-ranspiration from an oil palm stand *(Elaeis guineensis* Jacq.) exposed to seasonal soil water deficits. Acta Oecologica 13:299-314.

Dufrene, E., Ochs, R. and Saugier, B. 1990. Photosynthese et productivite du palmier a huile en liaison avec les facteurs climatiques. Oleagineux 45:345-355.

Dufrene, E. and Saugier, B. 1993. Gas exchange of oil palm in relation to light, vapour pressure deficit, temperature and leaf age. Functional Ecology 7:97-104.

El Shakawi, M . A., Cock, J. H. and Held, K.A .A. 1984. Water use efficiency in cassava. 2. Differing sensitivity of stomata to air humidity in cassava and other warm climate species. Crop Science 24 : 503-507.

Farquhar, G.D. 1978. Feedforward responses of stomata to humidity. Australian Journal of Plant Physiology 5:787-800.

Gerritsma, W. 1988. Light interception, leaf photosynthesis and sink-source relations in oil palm. Rapport Dept. Theoretical and Productive Ecology, Dept Tropical Crop Science, Agricultural University, Wageningen, Netherlands.

Harding, R.J., Hall, R.L., Swaminath, M.H. and Srinivasa Murthy, K.V. 1992. The soil moisture regimes beneath forest and an agricultural crop in southern India - measurements and modelling. In: Growth and Water Use of Forest Plantations (eds. I.R. Calder, R.L. Hall and P.G. Adlard). John Wiley and Sons, Chichester, England. :244-269.

Hardon, J.J.. Williams. C.N. and Watson, I. 1969. Leaf area and yield in the Oil palm in Malaya. Experimental Agriculture 5 :25-32.

Hartley, C.W.S. 1977. The Oil palm Thetford. Norfolk, Lowe and Brydon Printers Ltd., 806 pp.

Hirsch, P.J. 1975. Premier travaux sur I'assimilation photosythetique du palmier 'a huile *(Elaeis guineensis* Jacq.) Memoire ORSTOM/IRHO, La MC.

Houssou, M., Comaire, B., Omore, A. and Adje, I. 1992. Selection pour la resistance 'a la secheresse du palmier 'a huile. ISOPB, Montpellier, France.

IRHO, Sovimac, 1985. Plantation irriguee de Ouidah (Benin) sur palmier a huile et cocotier. Rapport de synthese. Aspects economiques. IRHO Doc. 1985.

Maillard, G., Daniel, C., Ochs, R. 1974. Analyse des effets de la secheresse sur le palmier a huile. Oleagineux 29:8-9.

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: 205-234.

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

Rees, A.R. 1961. Midday closure of stomata in the oil palm *Elaeis guineensis* Jacq. Journal of Experimental Botany 12: 129-146.

Rees, A.R. 1962. Dry matter production by evergreen perennials. Nature 195: 1118-1I19.

Rethinam, P. 1994. Oil palm development in India. Tree World 3:l-4.

Schulze, E.D. 1986. Carbon dioxide and water vapour exchange in response to drought in the atmosphere and in the soil. Annual Review of Plant Physiology 37:247-274.

Schulze, E.D. and Hall, A.E. 1982. Stomata1 responses, water loss and CO_2 assimilation rates of plant. in contrasting environments. Physiological Plant Ecology, vol. 2, Water Relations and Carbon Assimilation (eds. O.L. Lange, P.S. Nobel, C.B. Osmond and H. Ziegler), pp. 181-230, Springer-Verlag, Berlin.

Smith, G. 1989. The effects of soil water and atmospheric vapour pressure deficit on stomata1 behaviour and photosynthesis in the oil palm. Journal of Experimental Botany 215:647-651.

Sparnaaij, L.D., Rees, A.R. and Chapas, L.C. 1965. Variations de la production annuelle du palmier a huile. Oleagineux 20: 661-666.

Thampan, P.K. 1992. Comments on oil palm development in India. Tree World l(7): 1-3.

Thampan, P.K. 1996. Oil palm and coconut in Andhra Pradesh. Tree World 5: l-3.

Varghese, P.T. 1994. Effect of nutrition as influenced by irrigation on growth and yield of oil palm (*Elaeis guineensis* Jacq.). Ph.D. Thesis, Kerala Agricultural University, Mannuthy, Kerala, India.

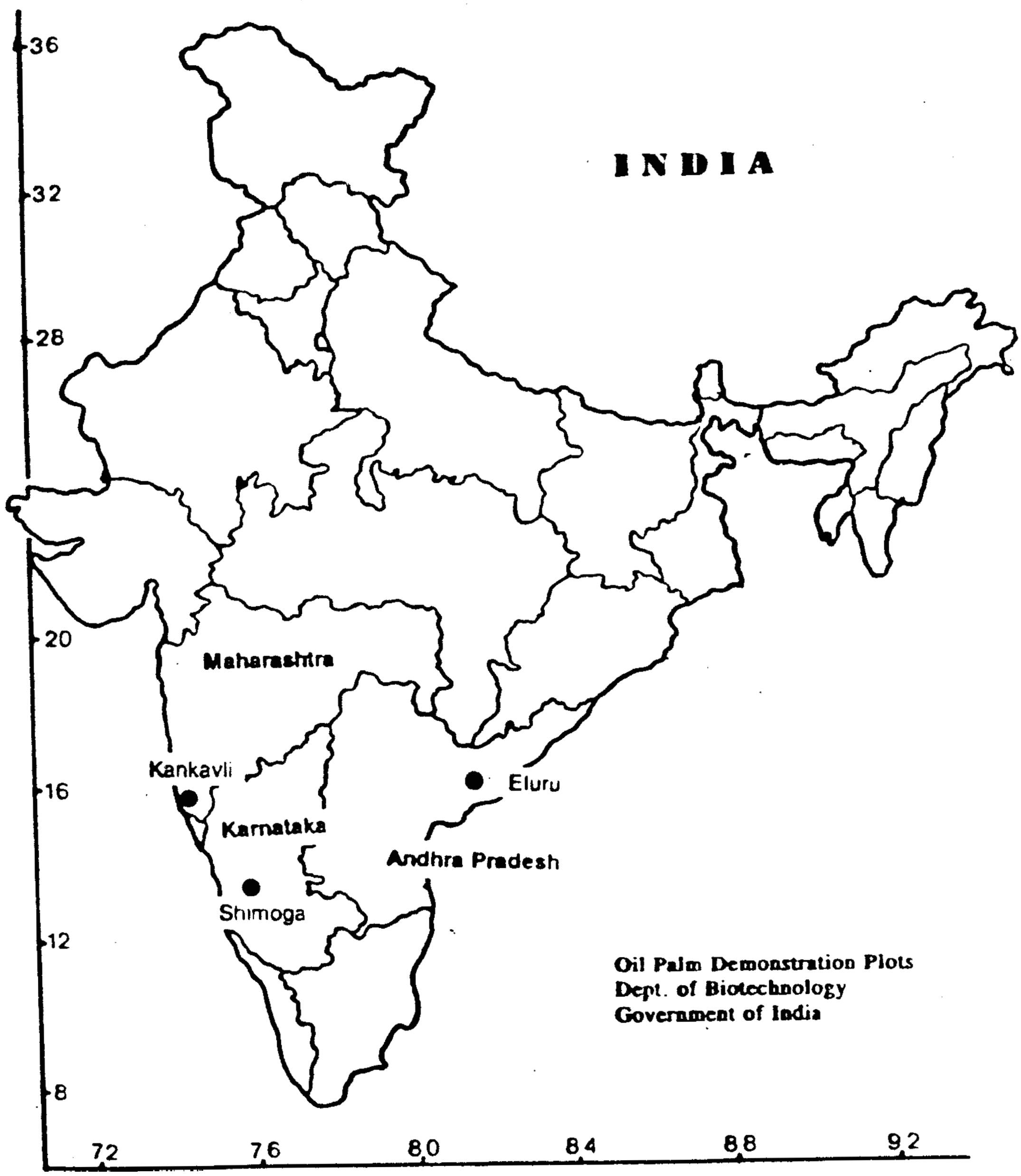

Fig. 1. Map showing the experimental sites in Andhra Pradesh, Karnataka and Maharashtra

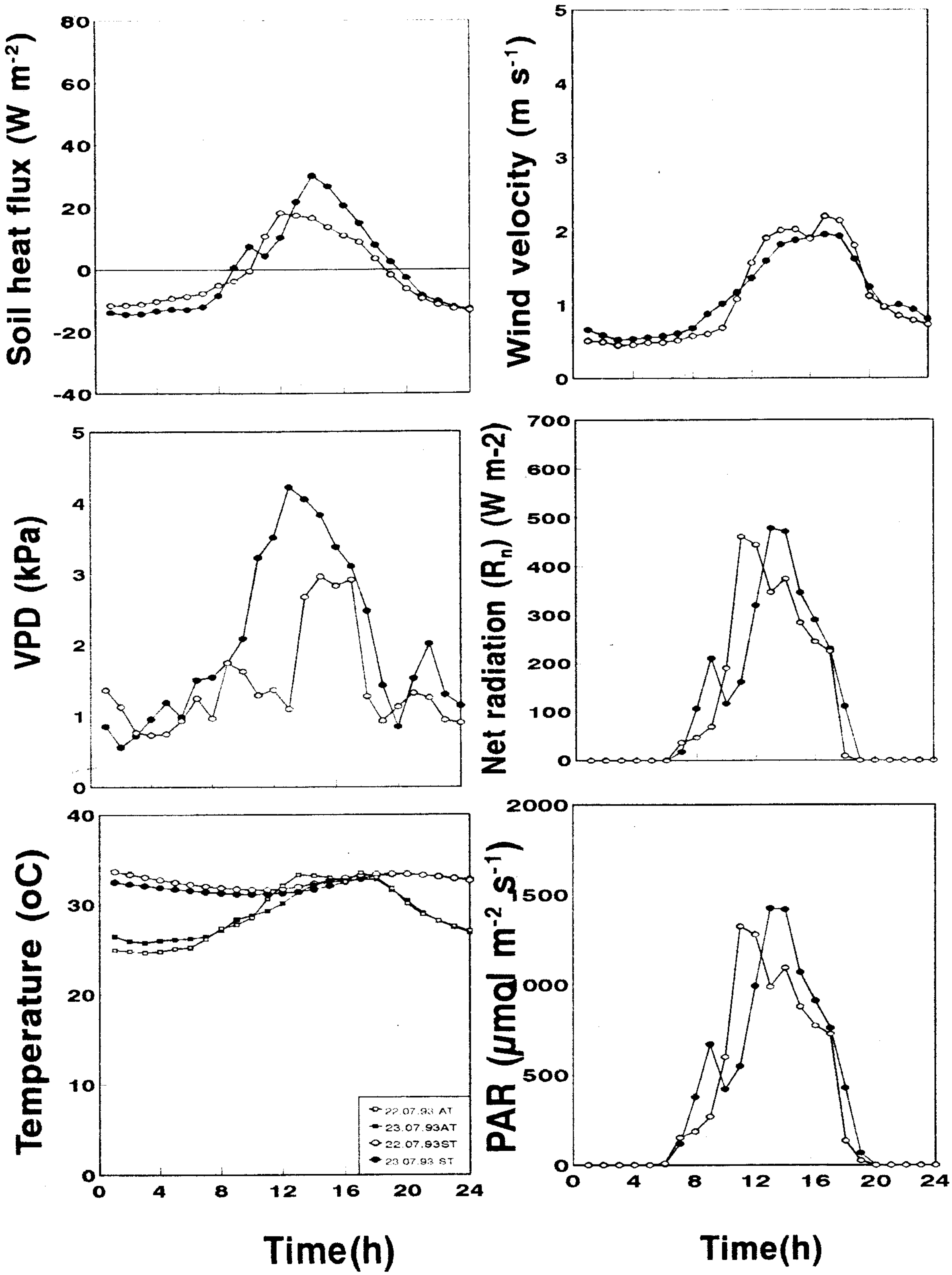

Fig.2. Andhra Pradesh - microclimate - July 1993.

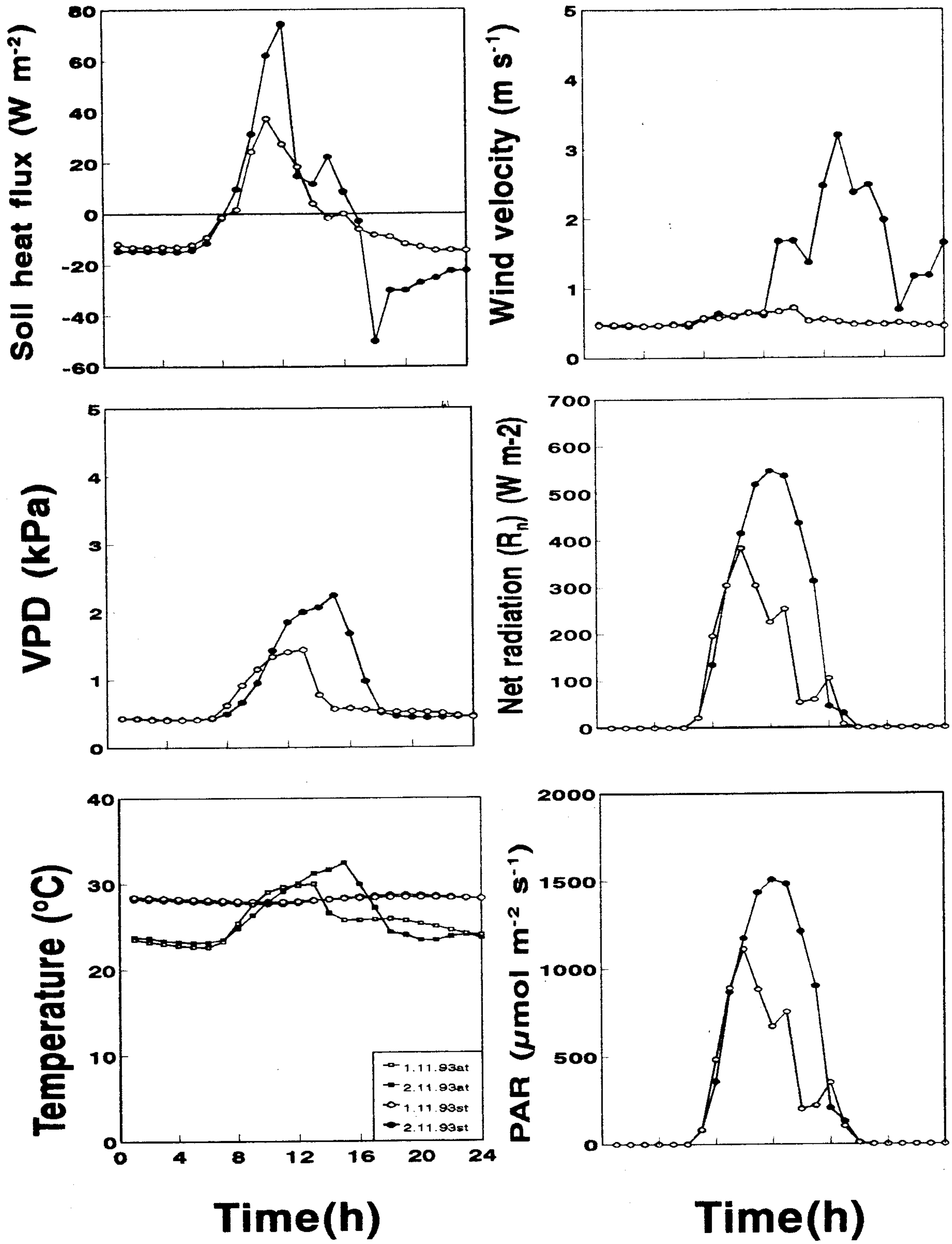

Fig. 3. Andhra Pradesh - microclimate - October 1993.

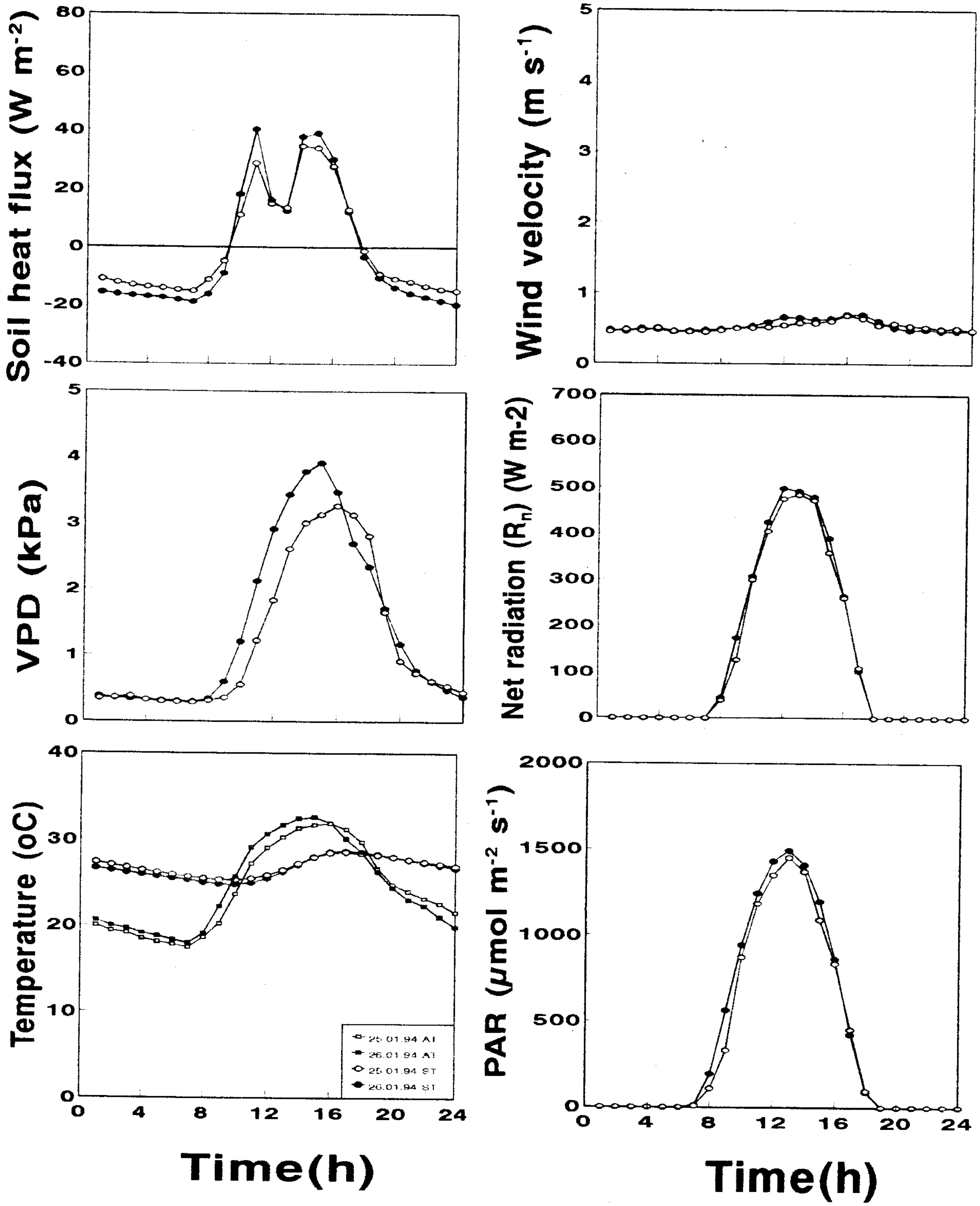

Fig.4. Andhra Pradesh - microclimate - January 1994.

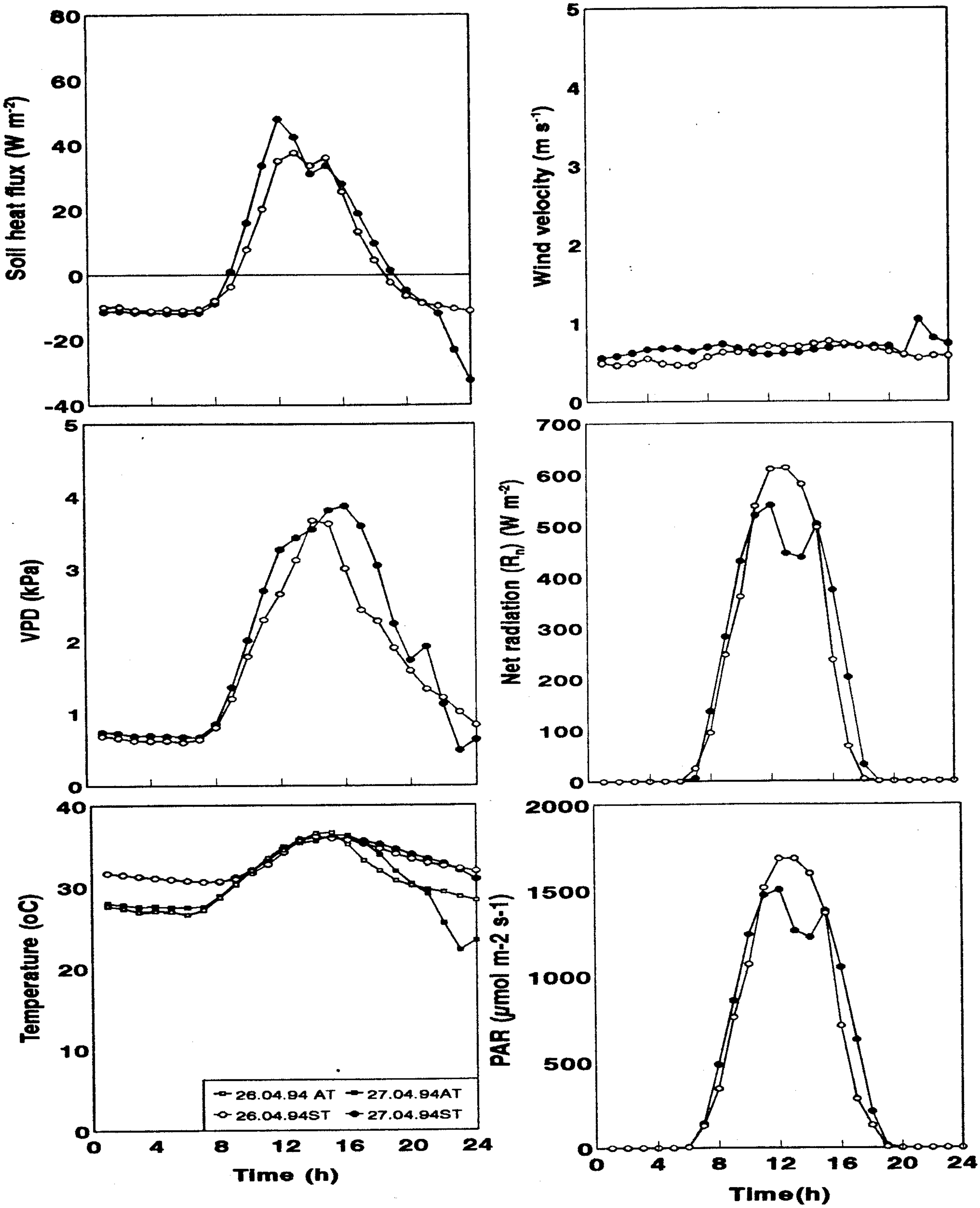

Fig.5. Andhra Pradesh - microclimate - April 1994.

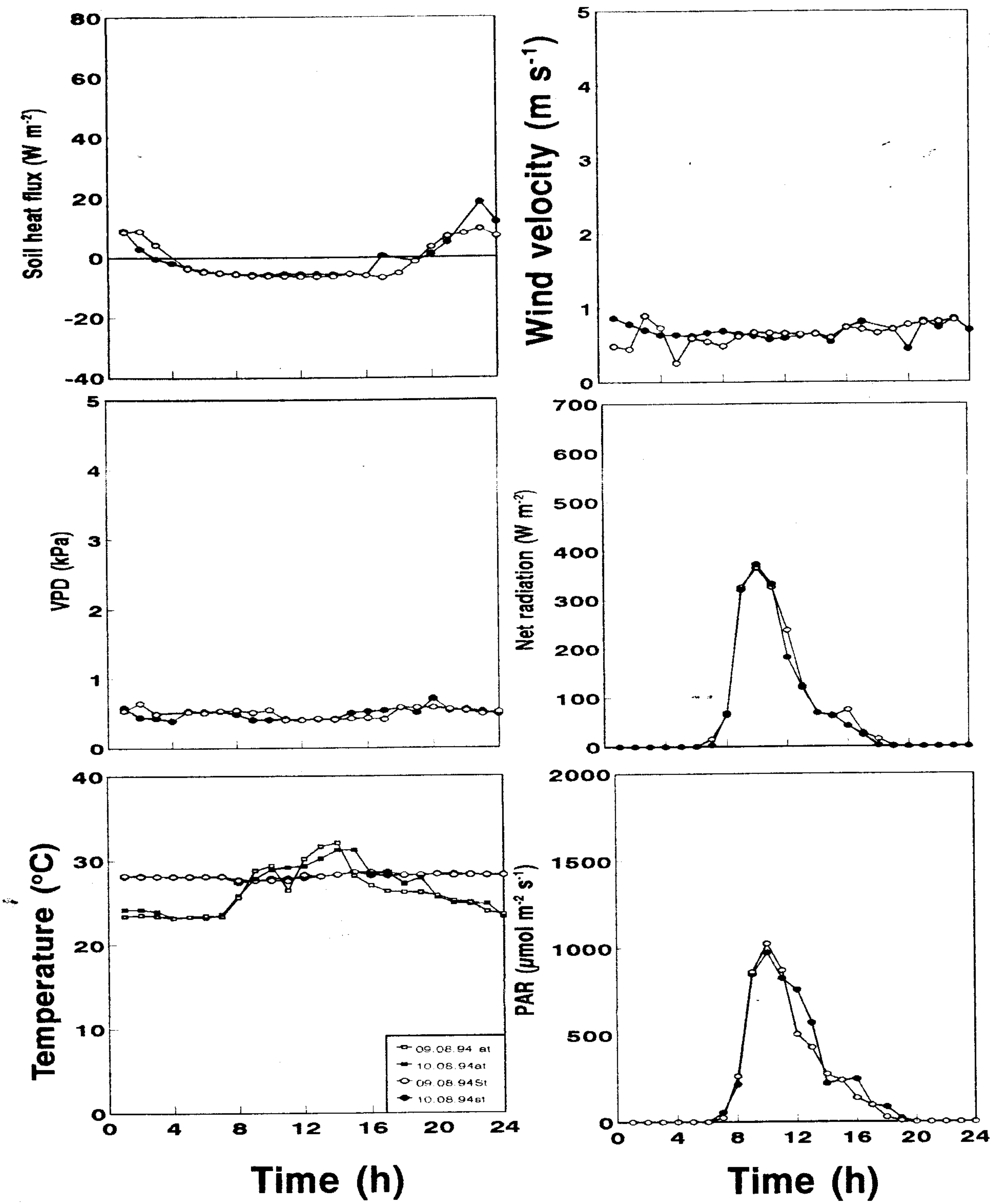

Fig.6. Andhra Pradesh - microclimate - August 1994.

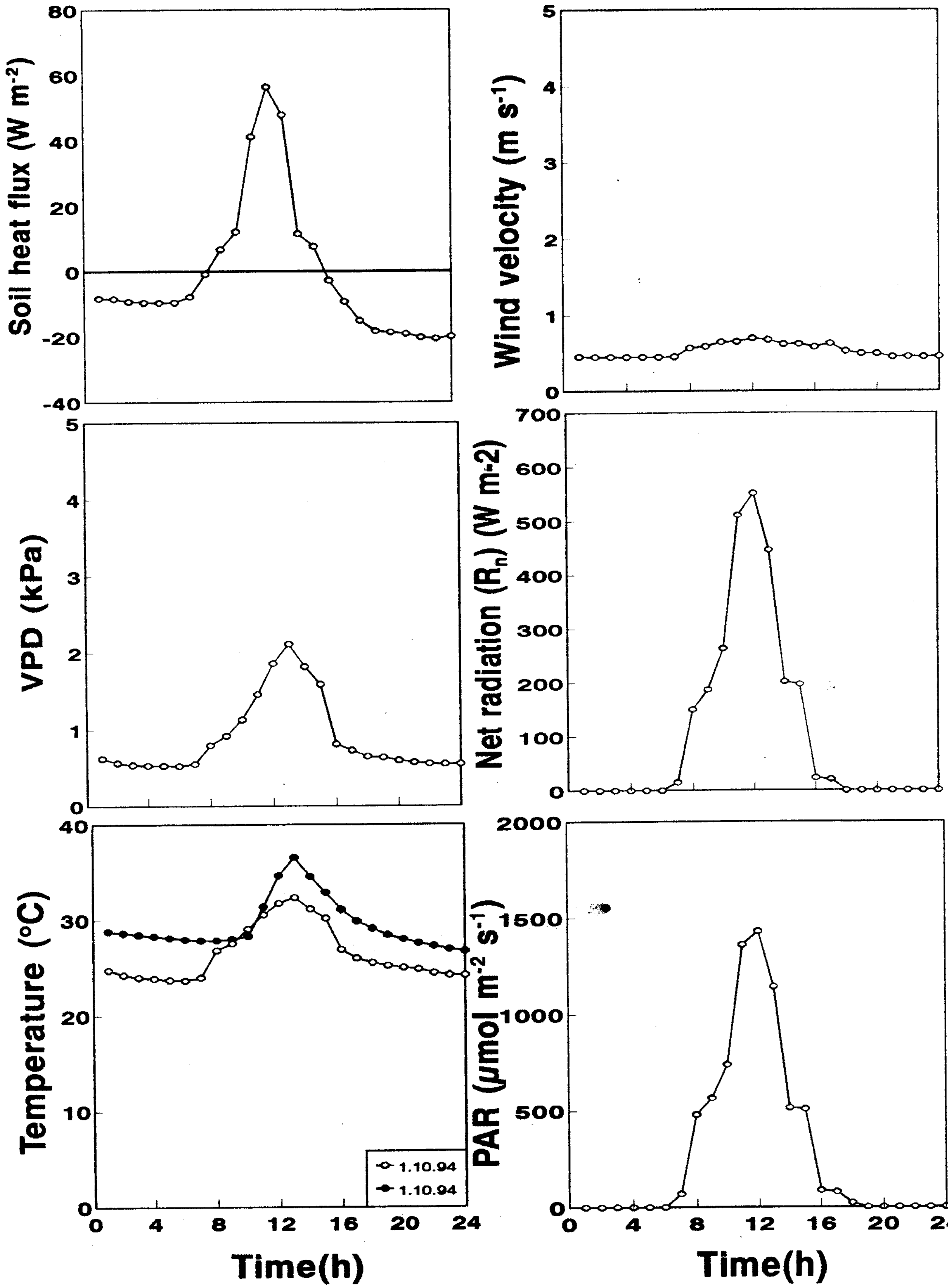

Fig.7. Andhra Pradesh - microclimate - September 1994.

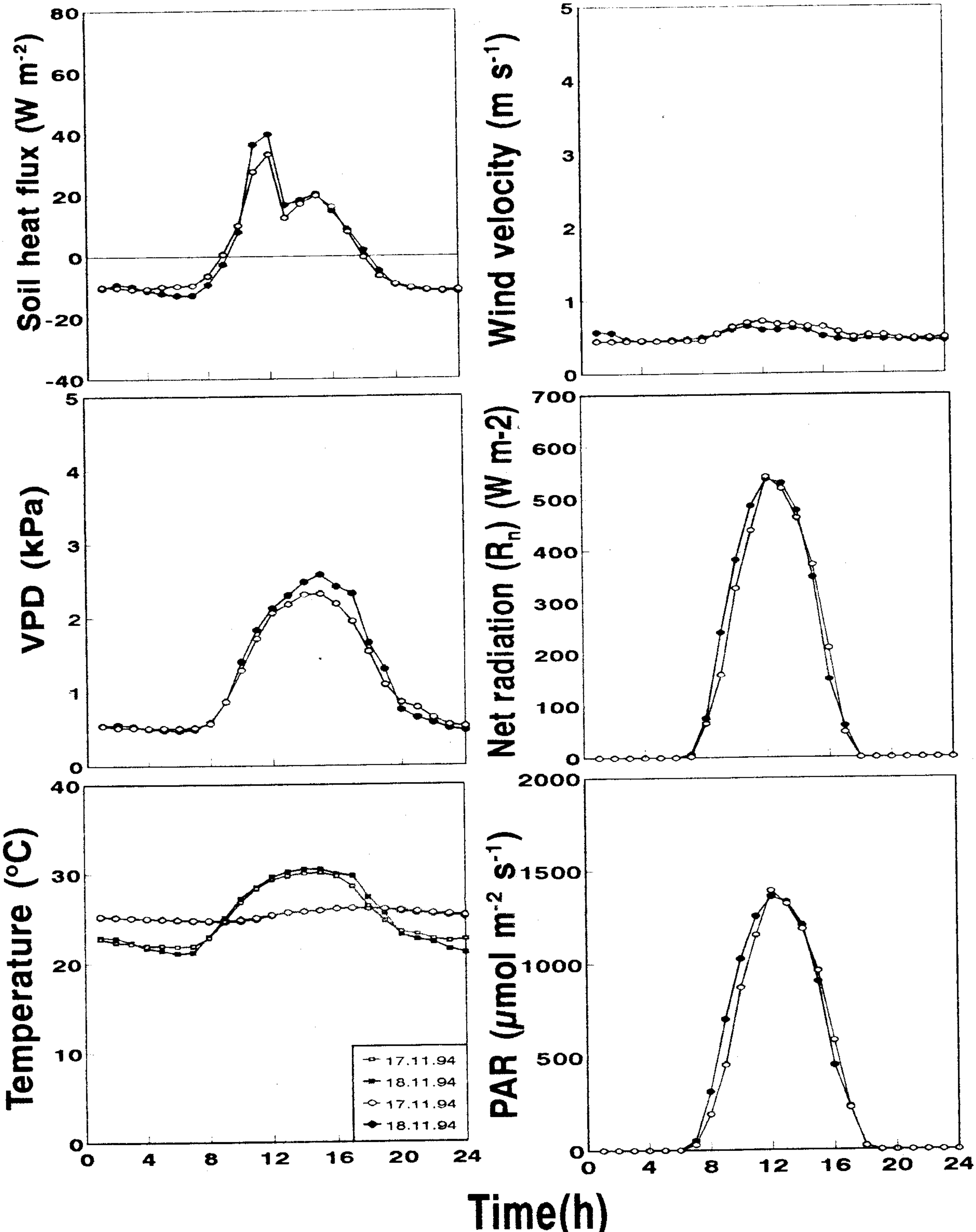

Fig.8. Andhra Pradesh - microclimate- November 1994

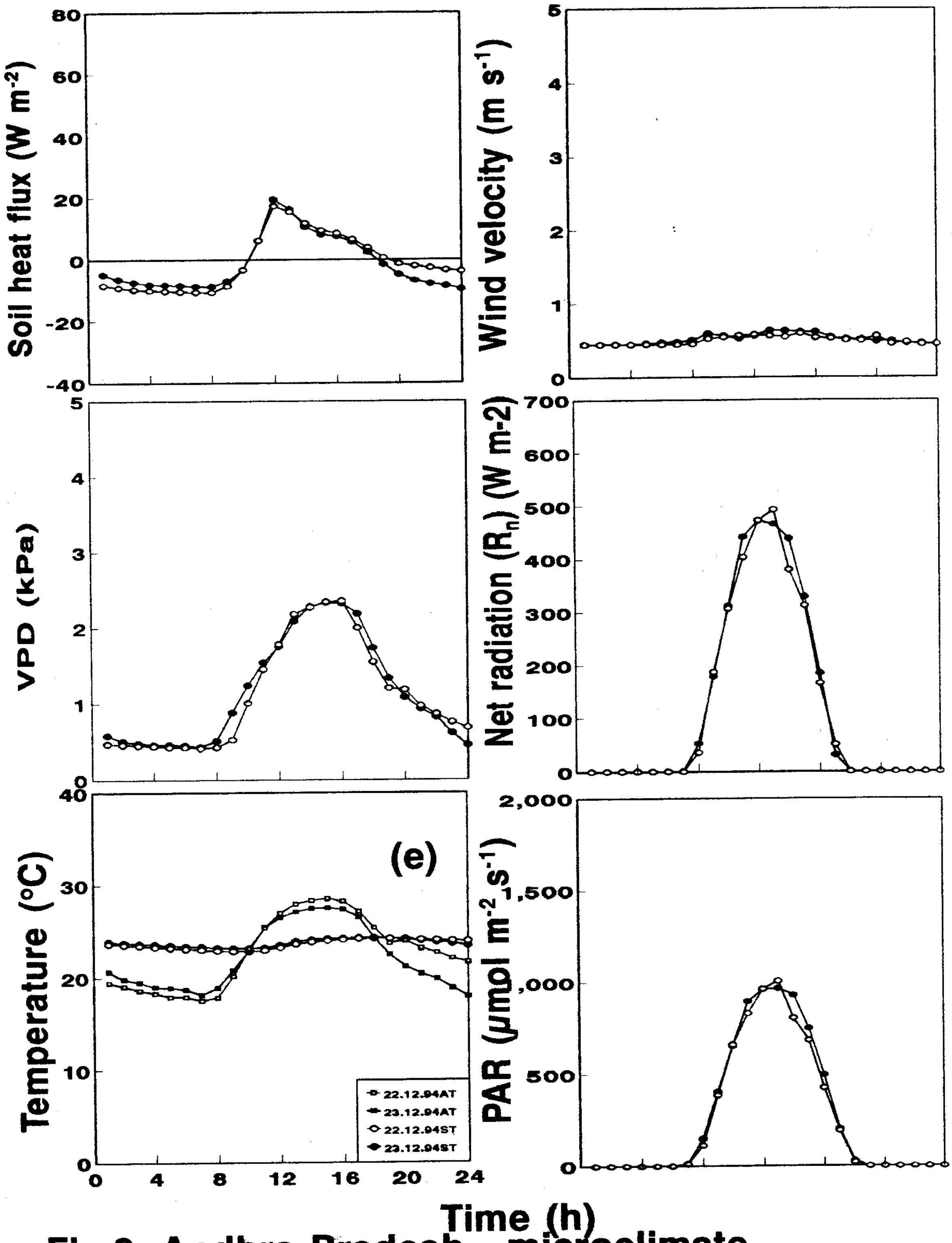

Fig.9. Andhra Pradesh - microclimate - December 1994.

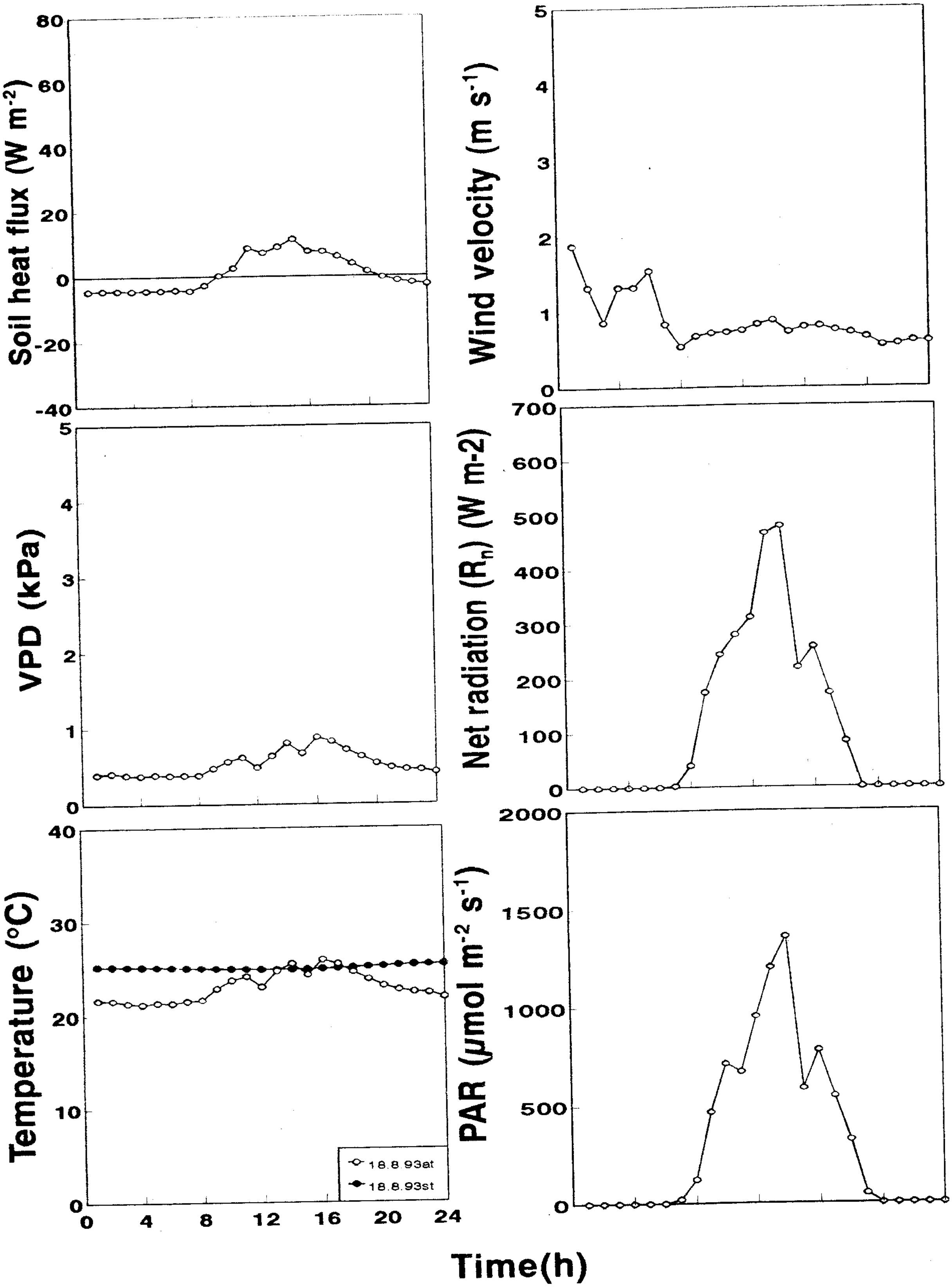

Fig.10. Karnataka - microclimate - August 1993.

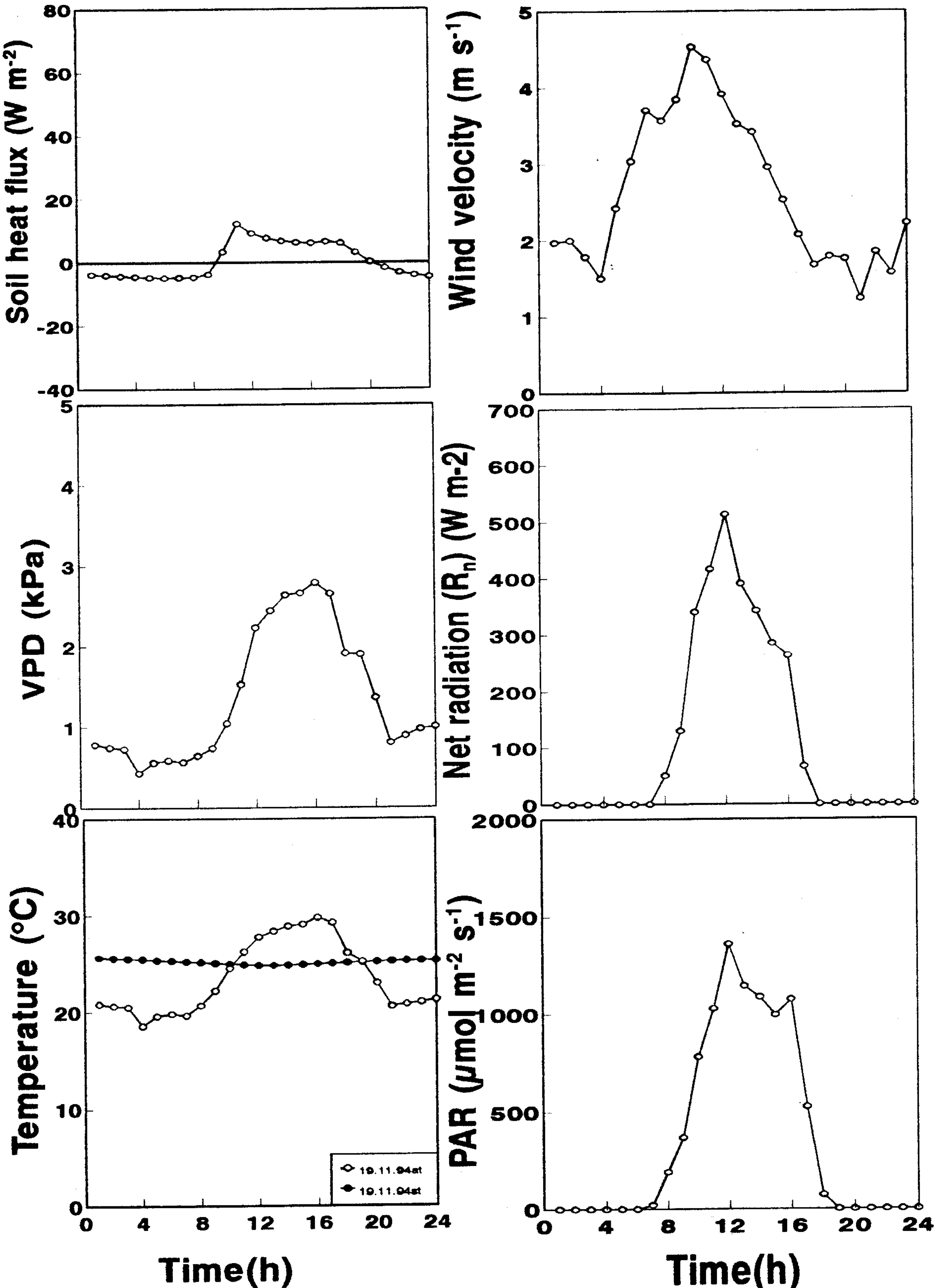

Fig.11. Karnataka - microclimate - November 1993.

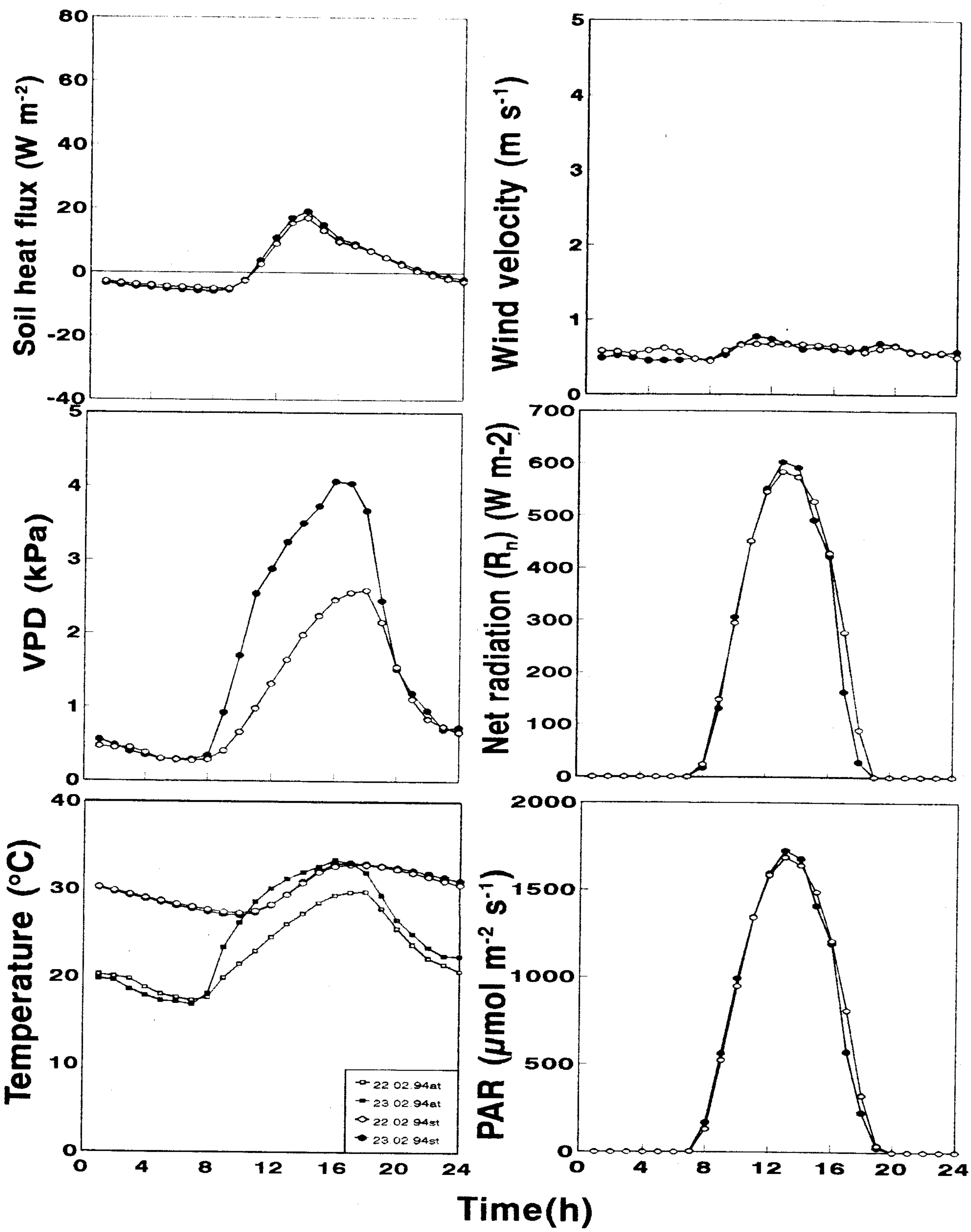

Fig.12. Karnataka - microclimate - February 1994.

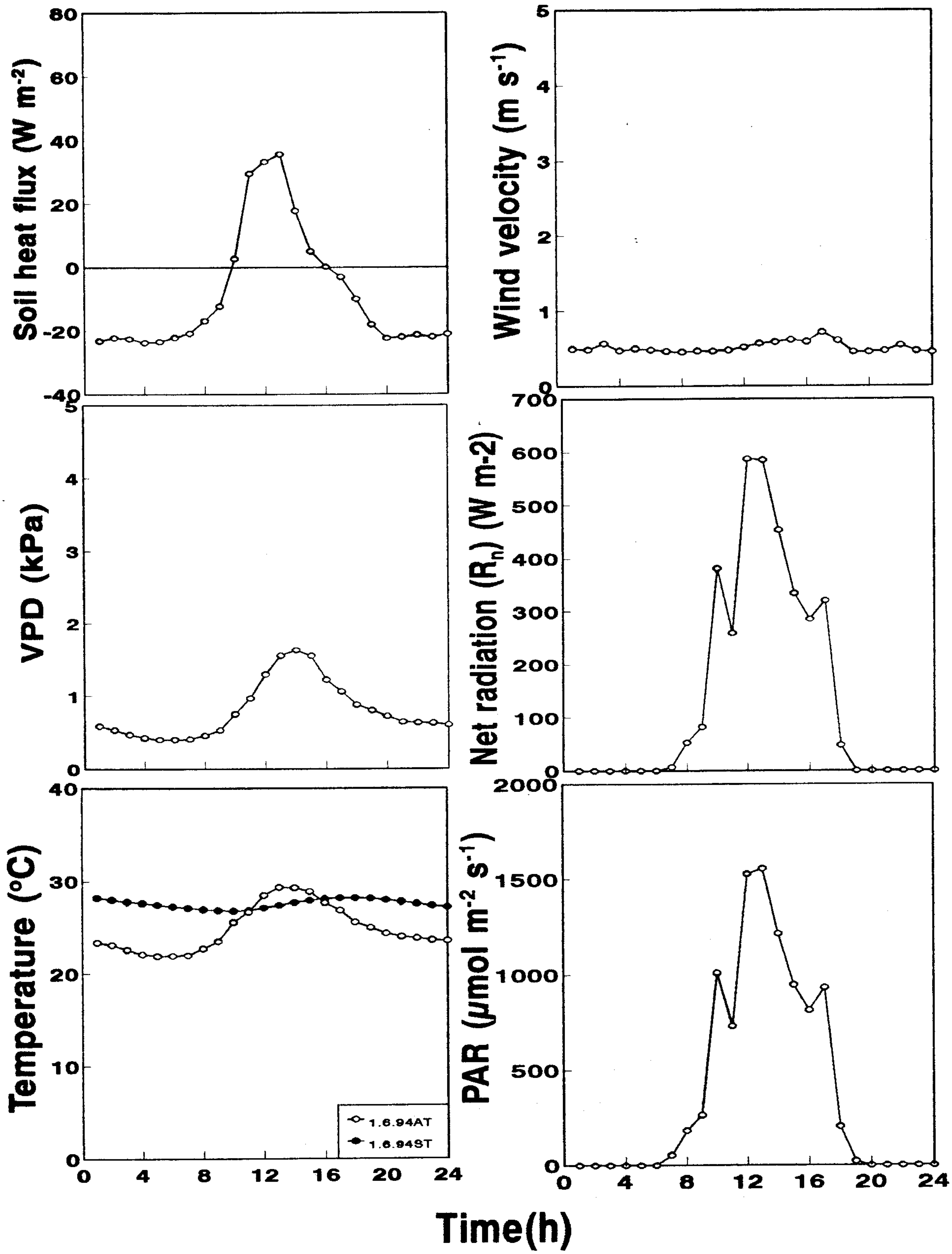

Fig.13. Karnataka - microclimate - May 1994.

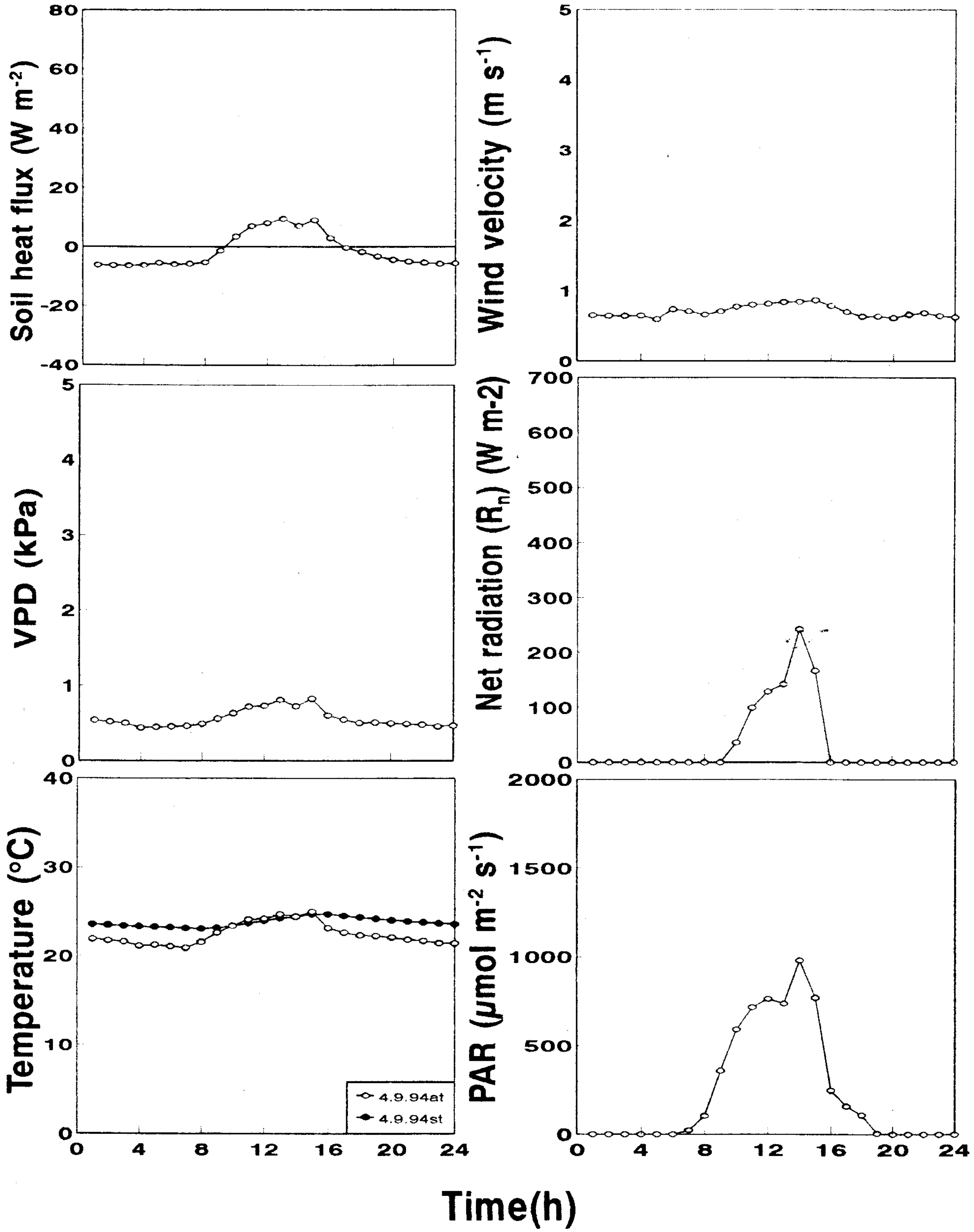

Fig.14. Karnataka - microclimate - September 1994.

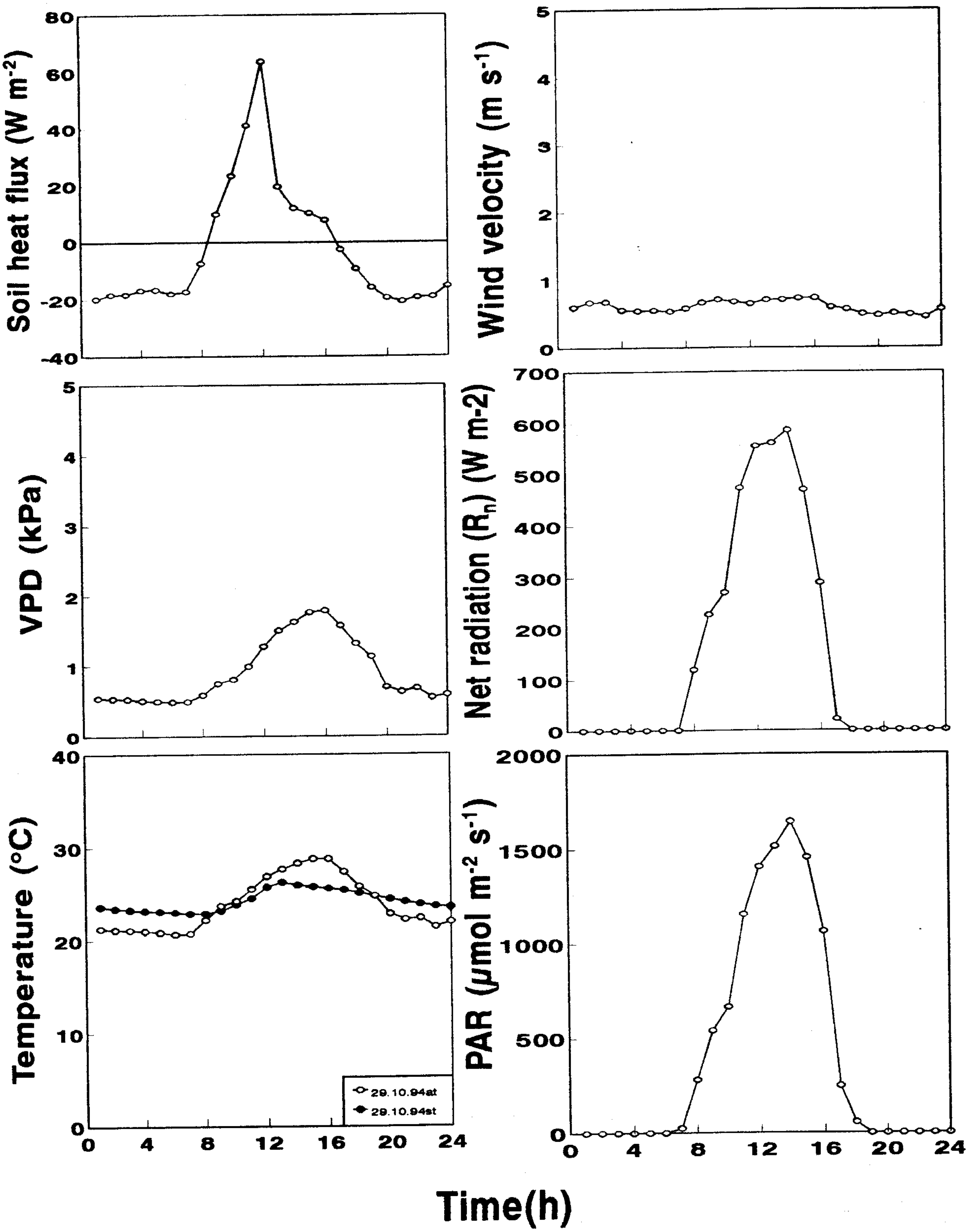

Fig.15. Karnataka - microclimate - October 1994.

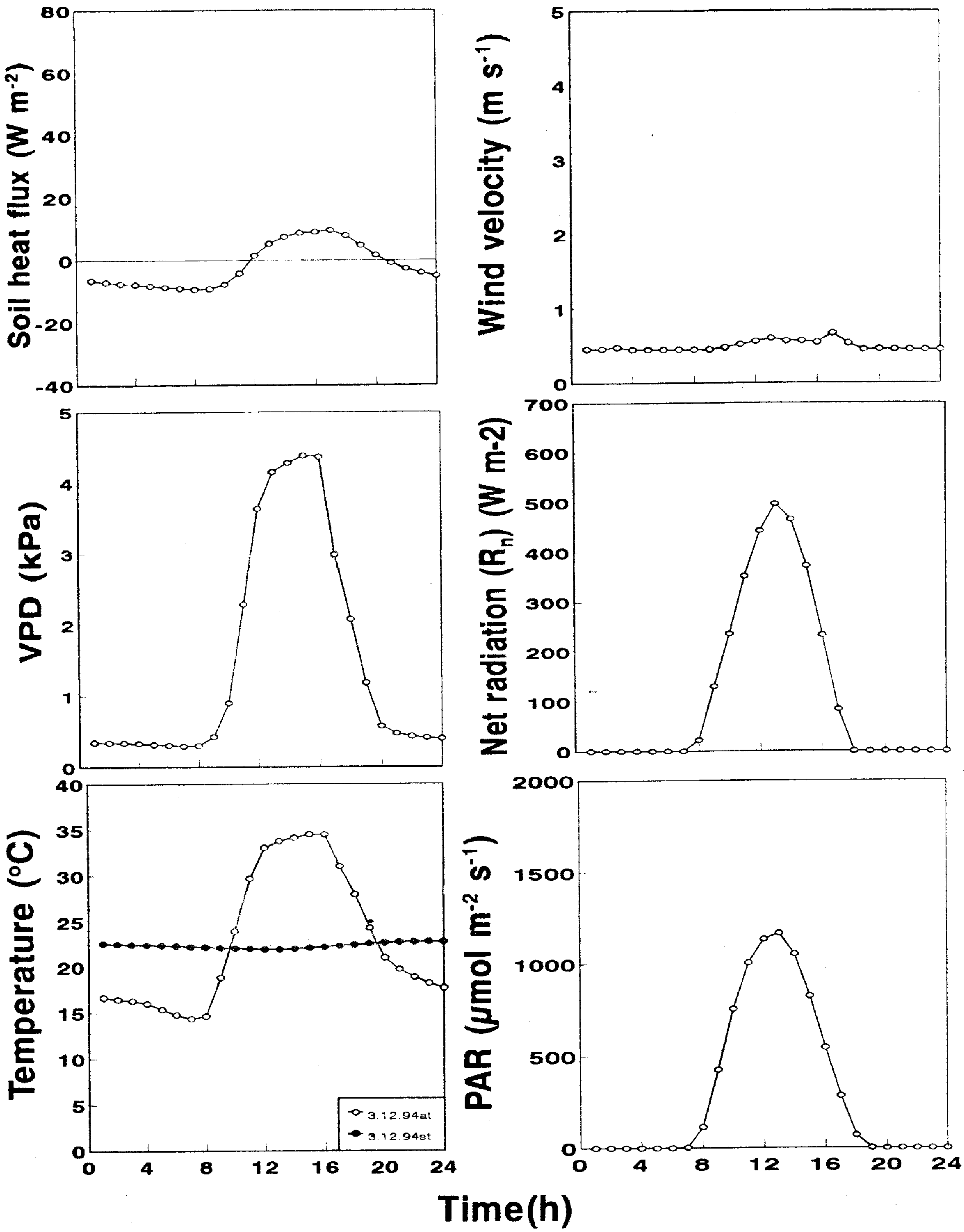

Fig.16. Karnataka - microclimate - December 1994.

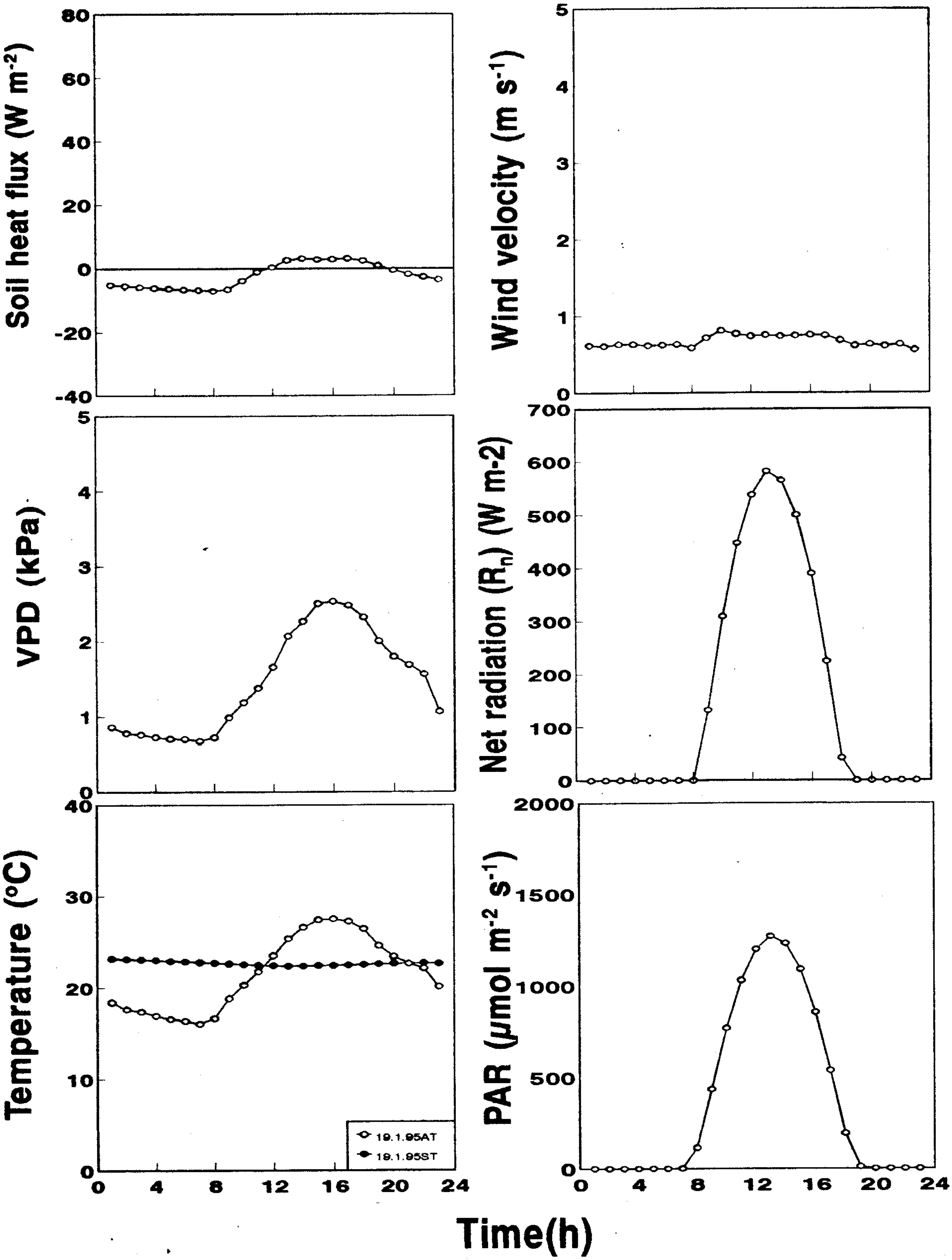

Fig.17. Karnataka - microclimate - January 1995.

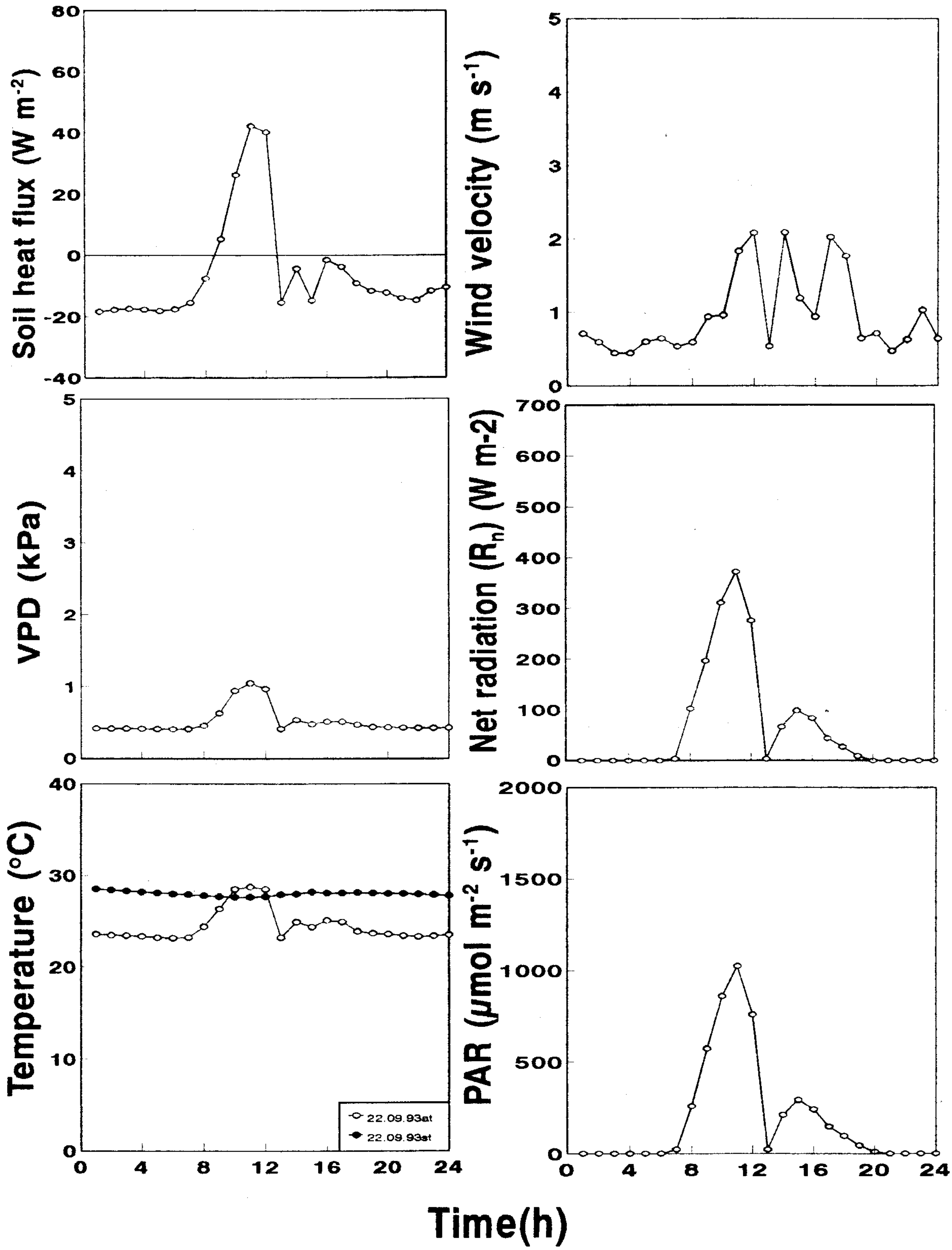

Fig.18. Maharashtra - microclimate - September 1993.

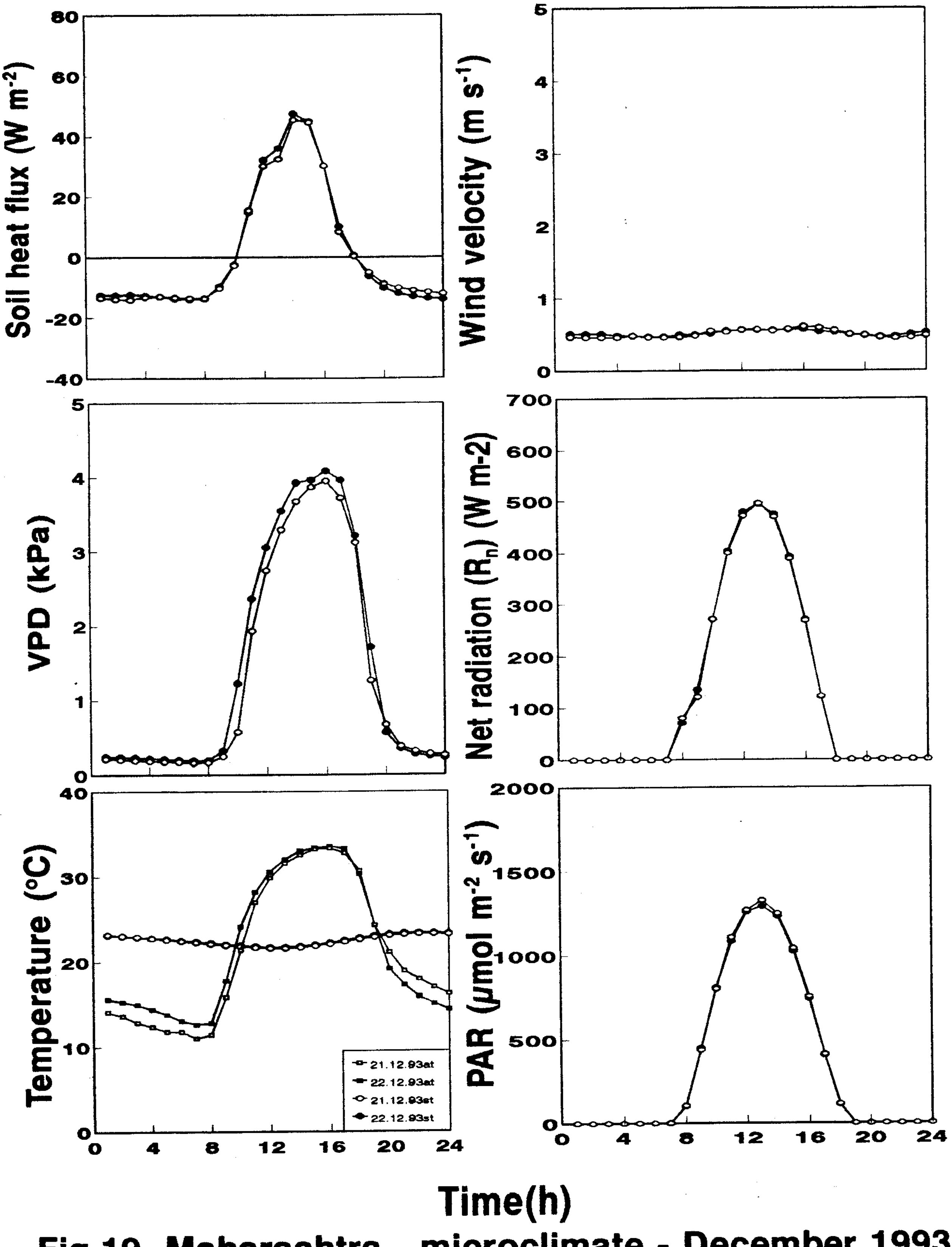

Fig.19. Maharashtra - microclimate - December 1993.

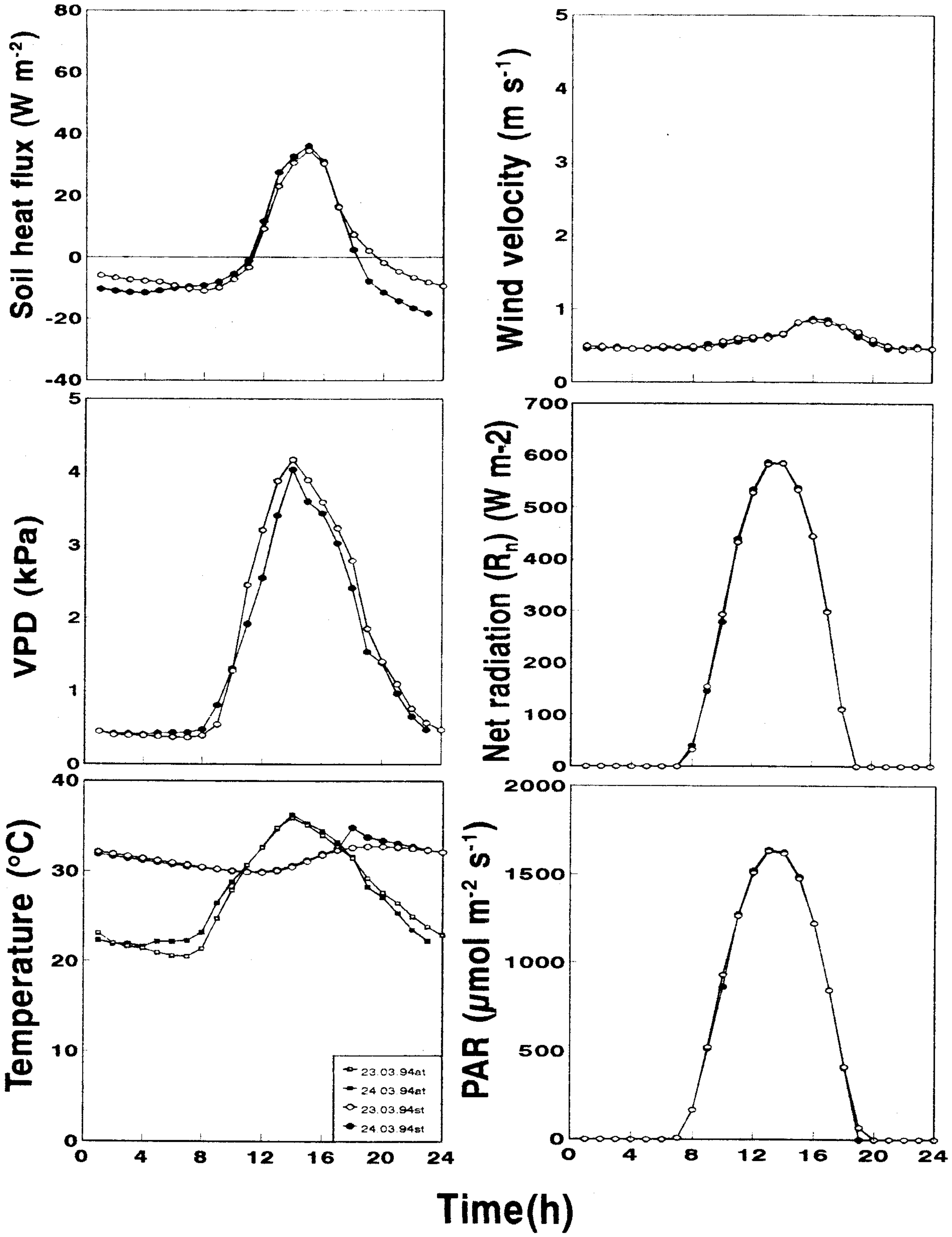

Fig.20. Maharashtra - microclimate - March 1994.

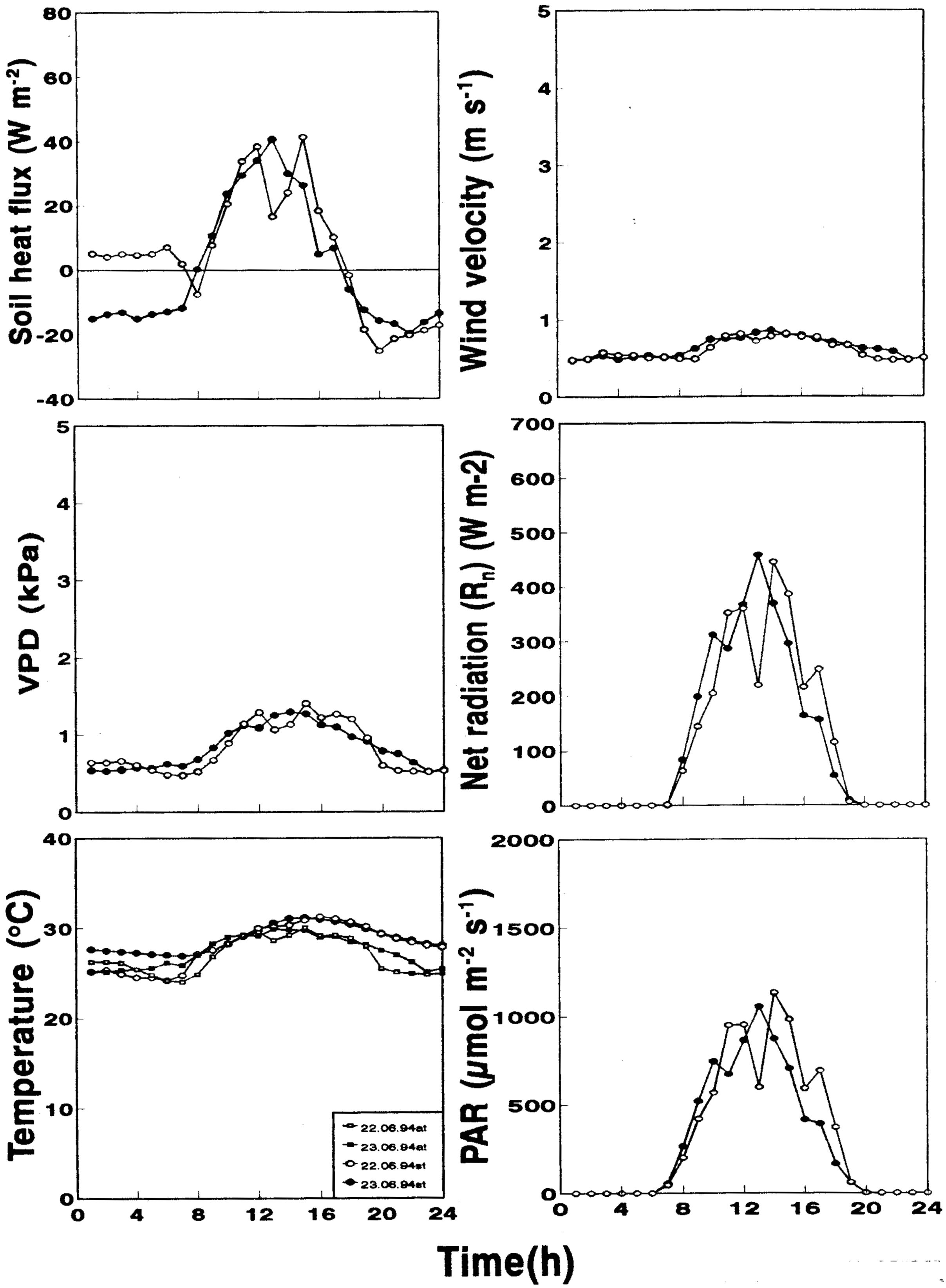

Fig.21. Maharashtra - microclimate - June 1994.

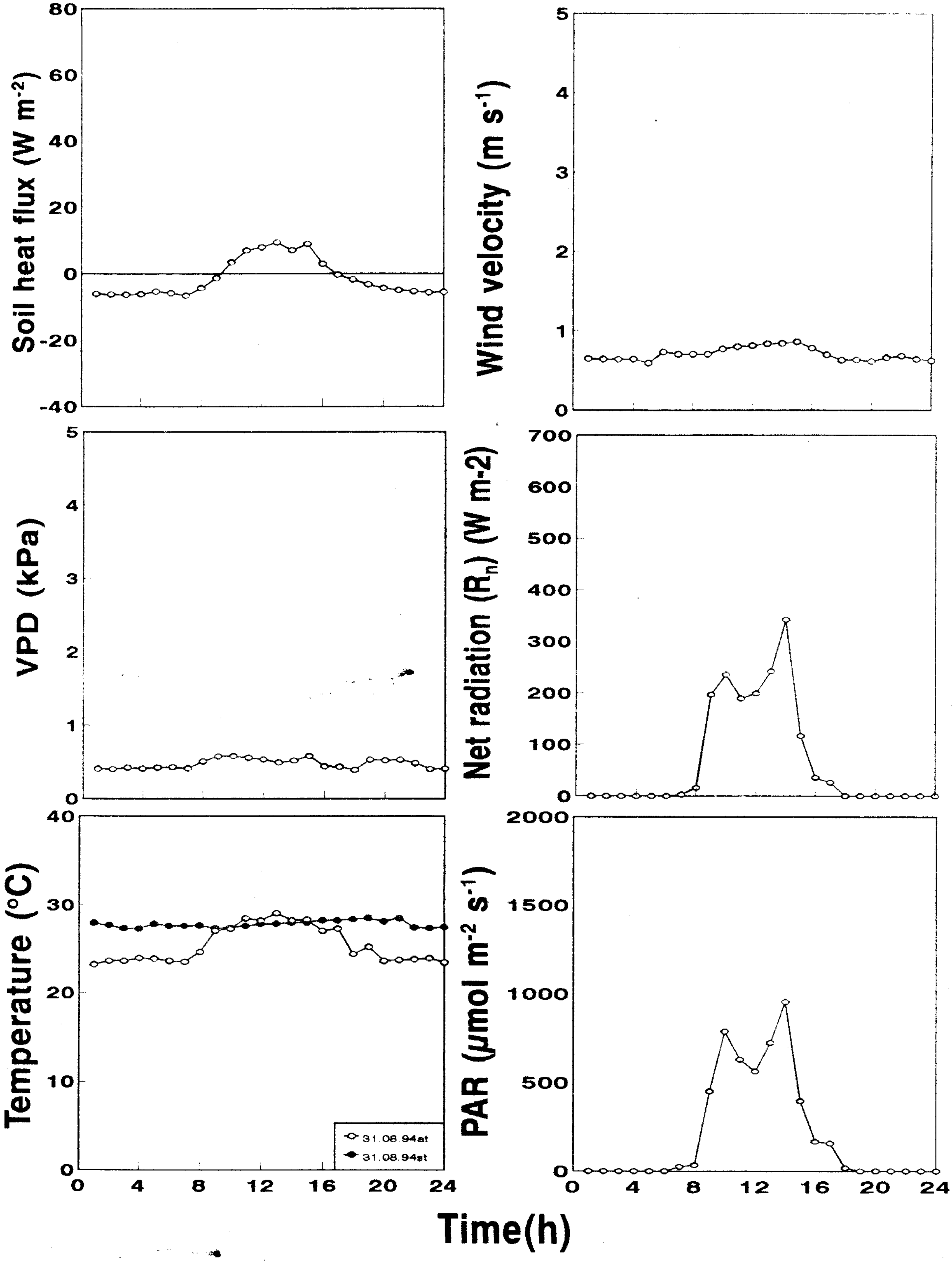

Fig.22. Maharashtra - microclimate - August 1994.

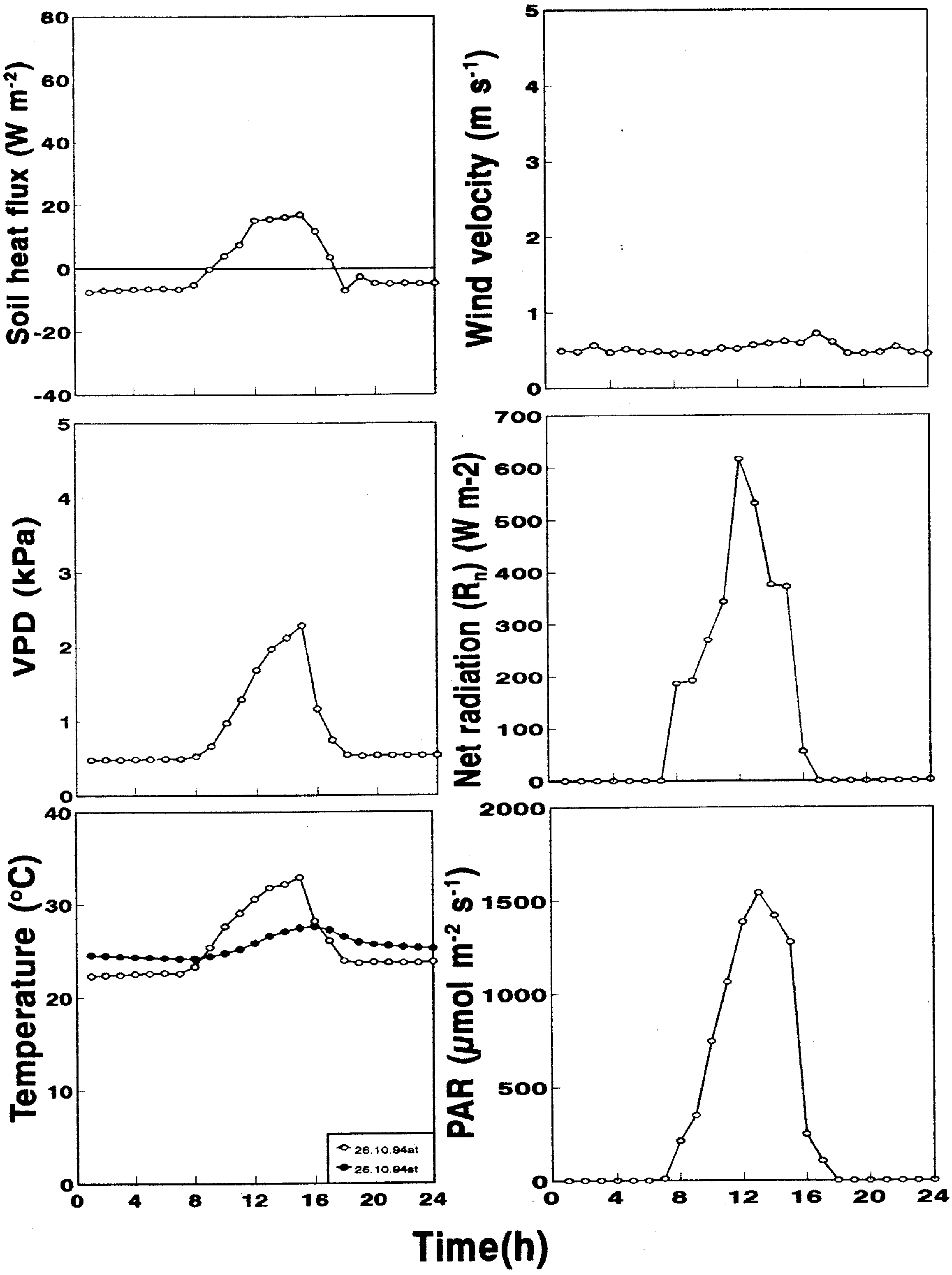

Fig.23. Maharashtra - microclimate - October 1994.

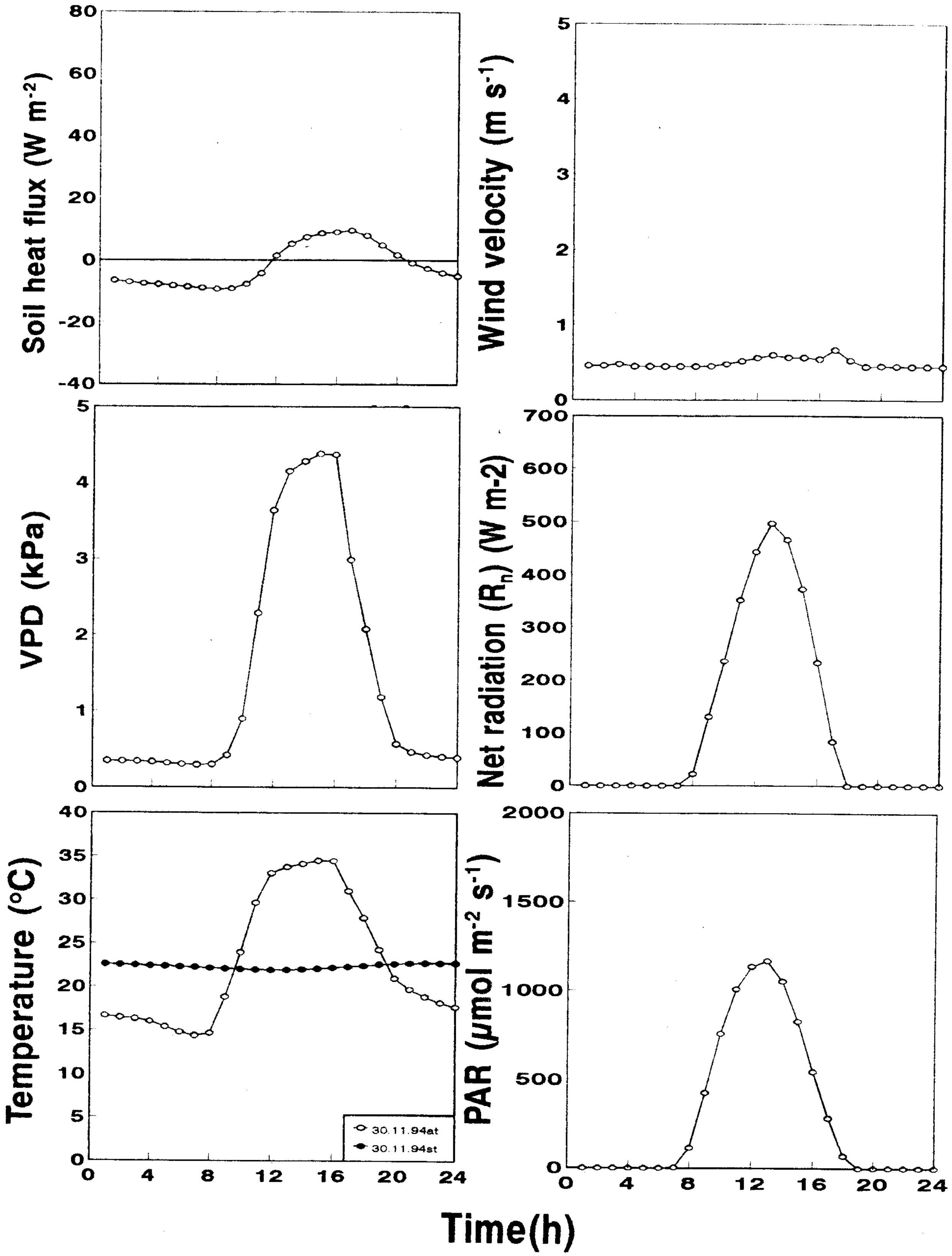

Fig.24. Maharashtra - microclimate - November 1994.

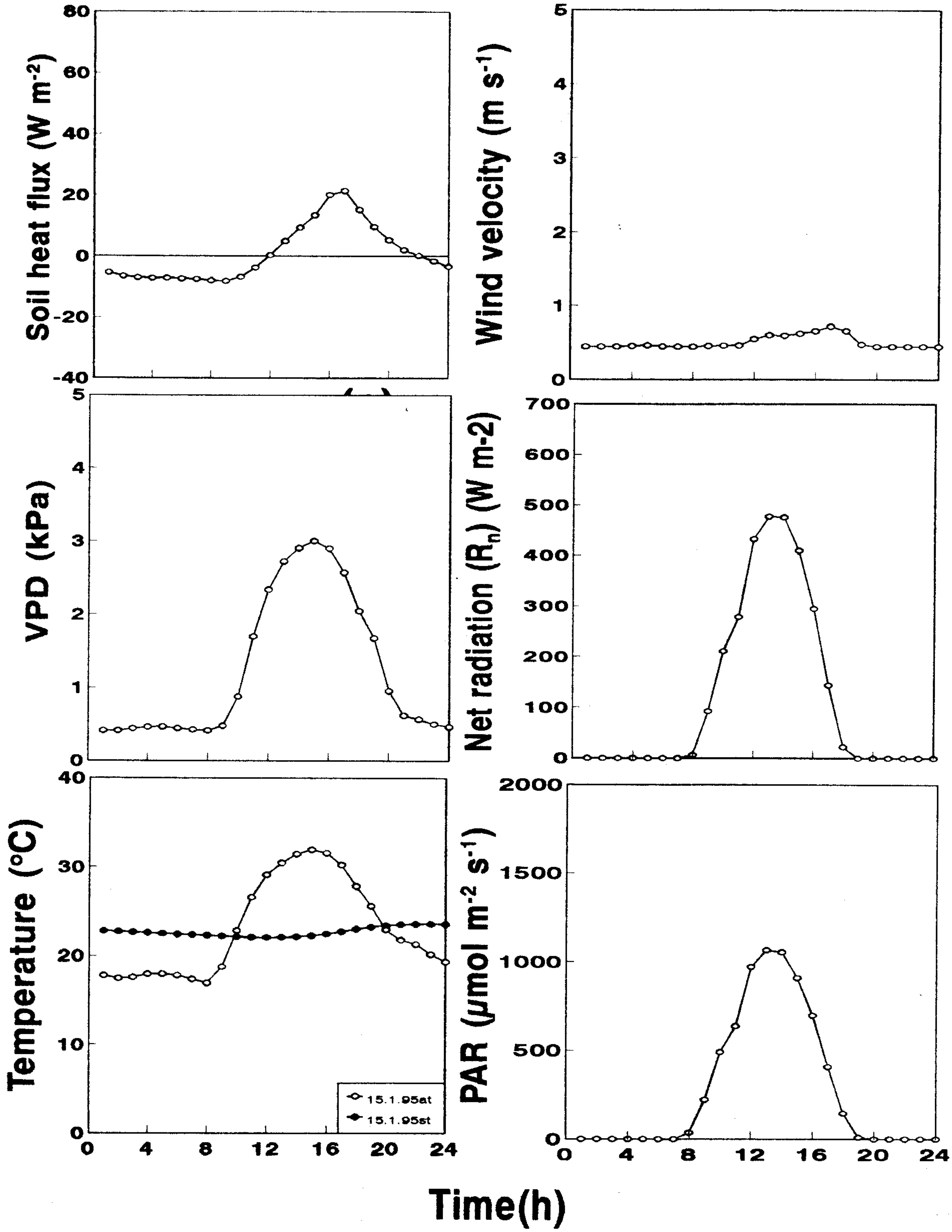

Fig.25. Maharashtra - microclimate - January 1995.

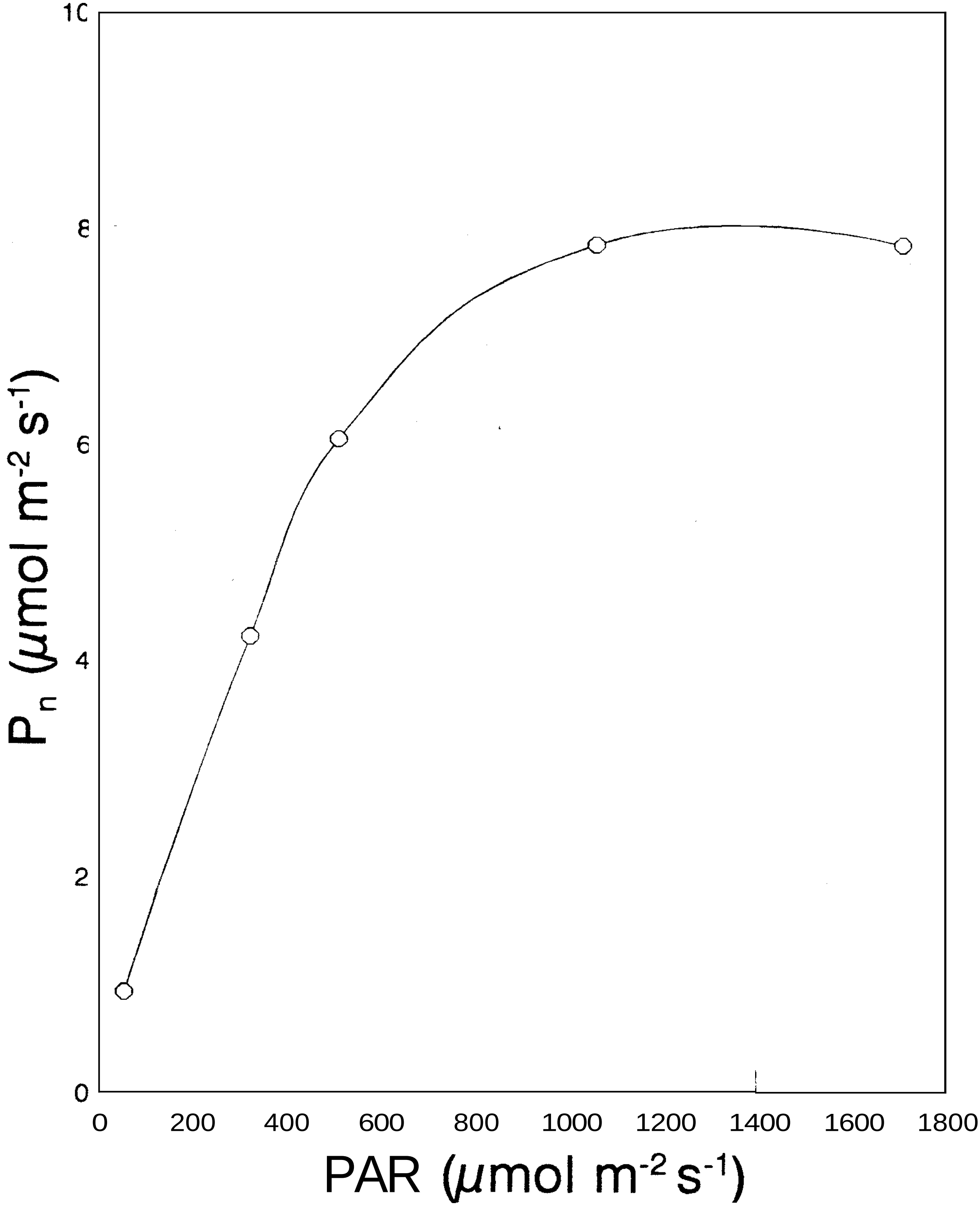

Fig.26. Light response curve for photosynthesis in oil palm plotted using neutral filters in daylight.

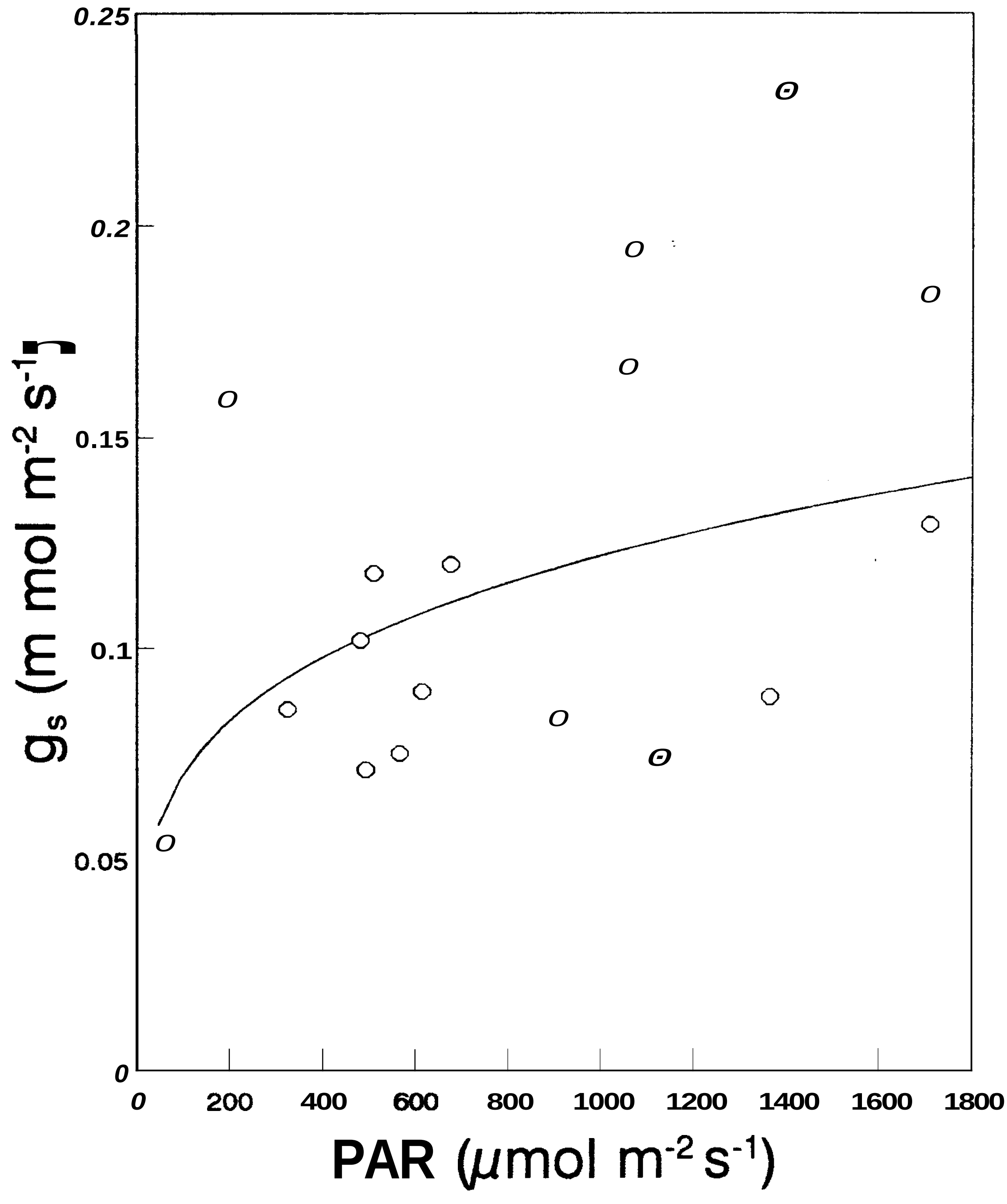

Fig.27. Light response curve for **stomatal conductance plotted** from **the same experiment as shown in fig.26.**

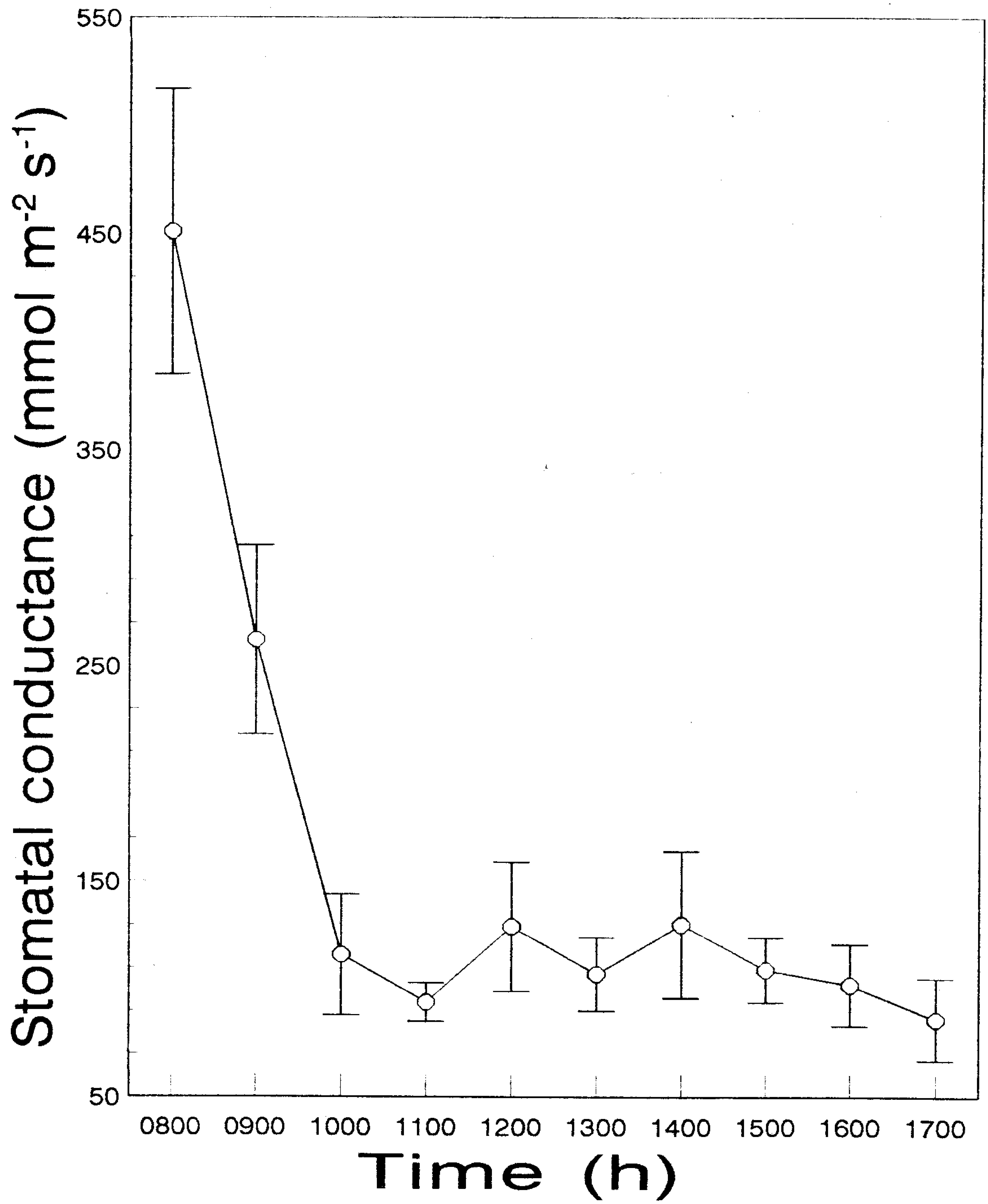

Fig.28. Diurnal variations in stomatal conductance in oil palm. The lower stomatal conductance during the major part of the day is due to higher VPD.

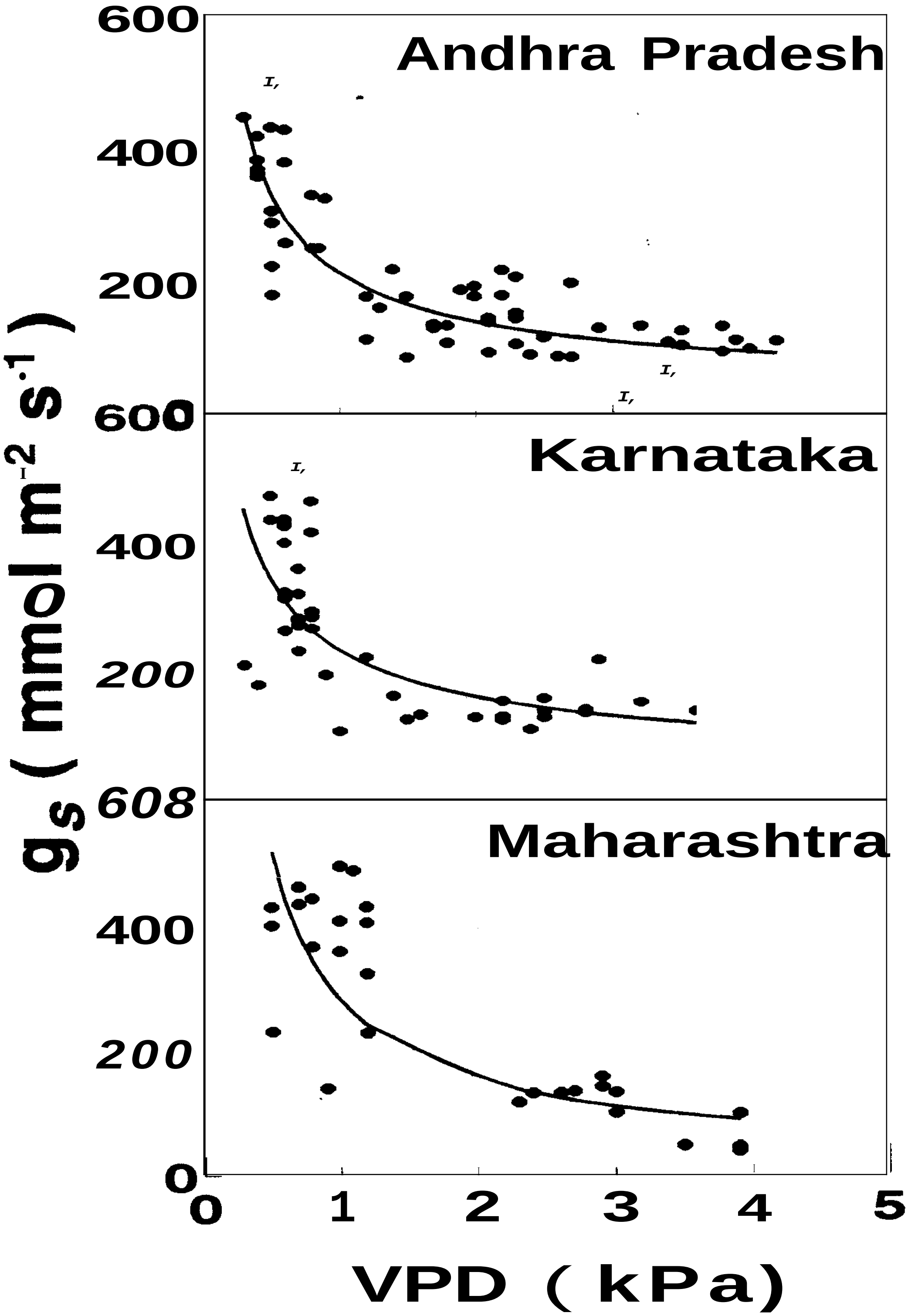

Fig.29. Stomatal conductance in relation to VPD changes in the three States.

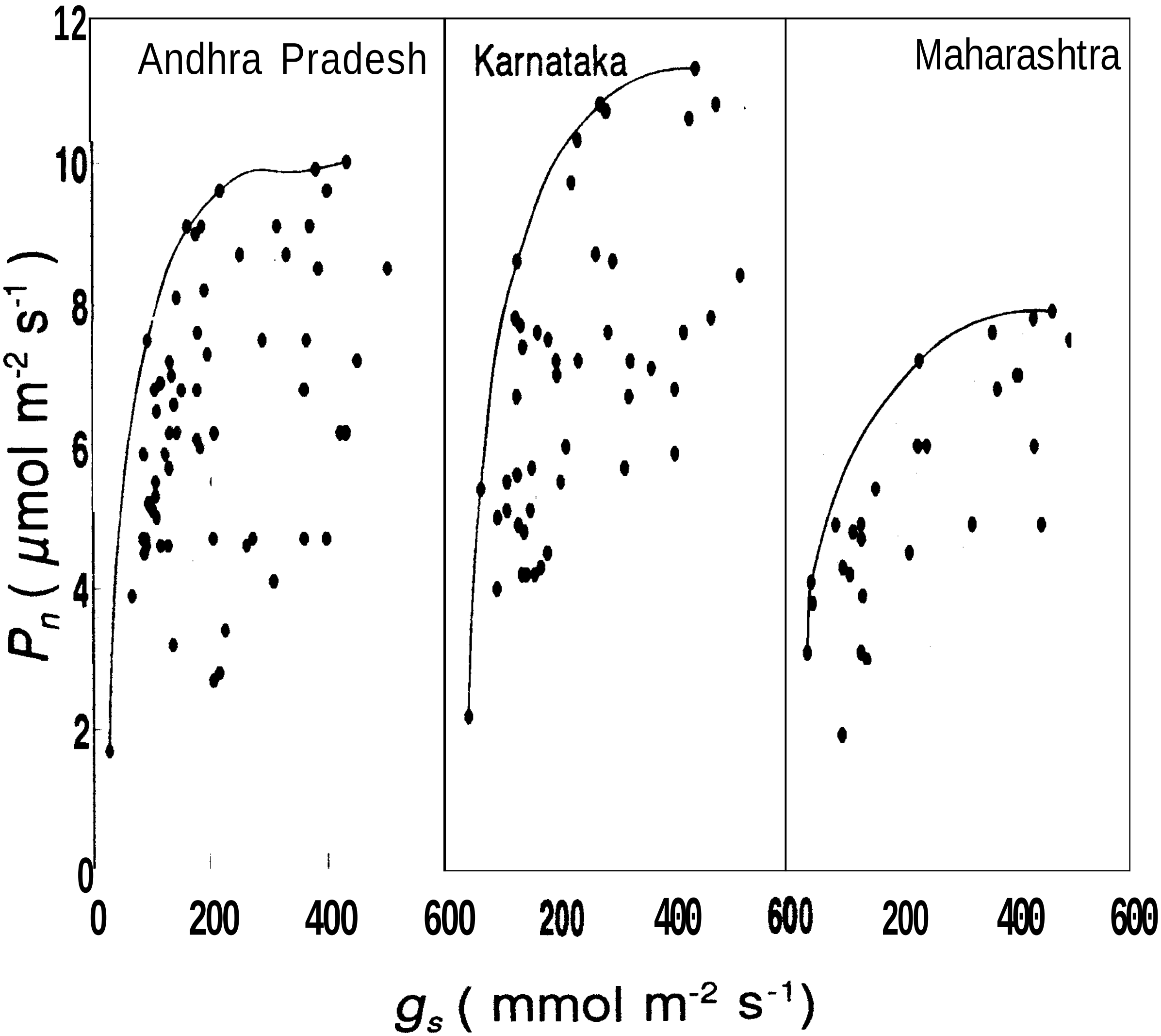

Fig.30 Maximum photosynthesis obtained at the three States in relation to stomatal conductance.

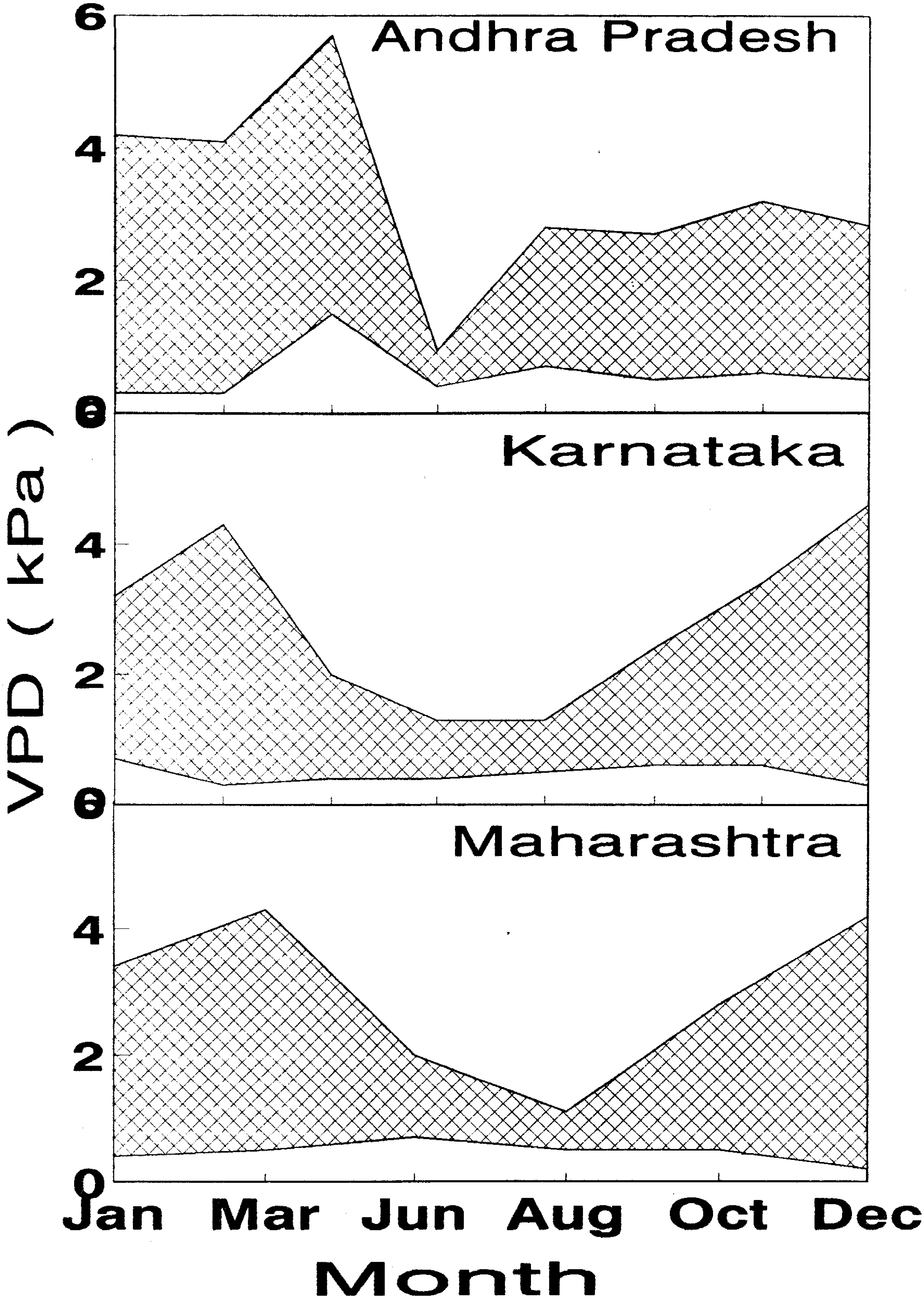

Fig.31. Range in vapor pressure deficit at the three oil palm growing sites.

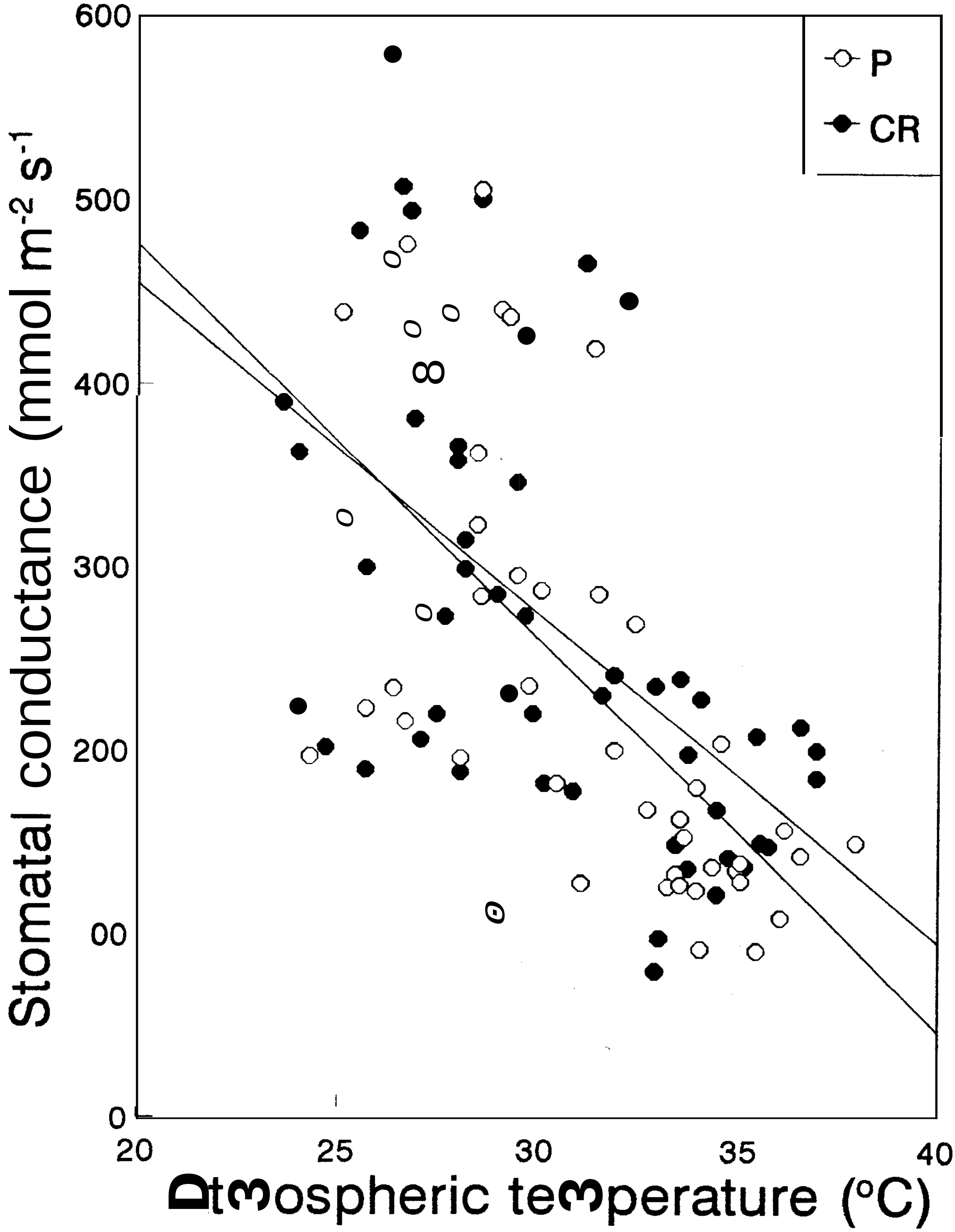

Fig.32. Stomatal conductance in relation to atmospheric temperature (P-Palode plants; CR-Costa Rican plants)

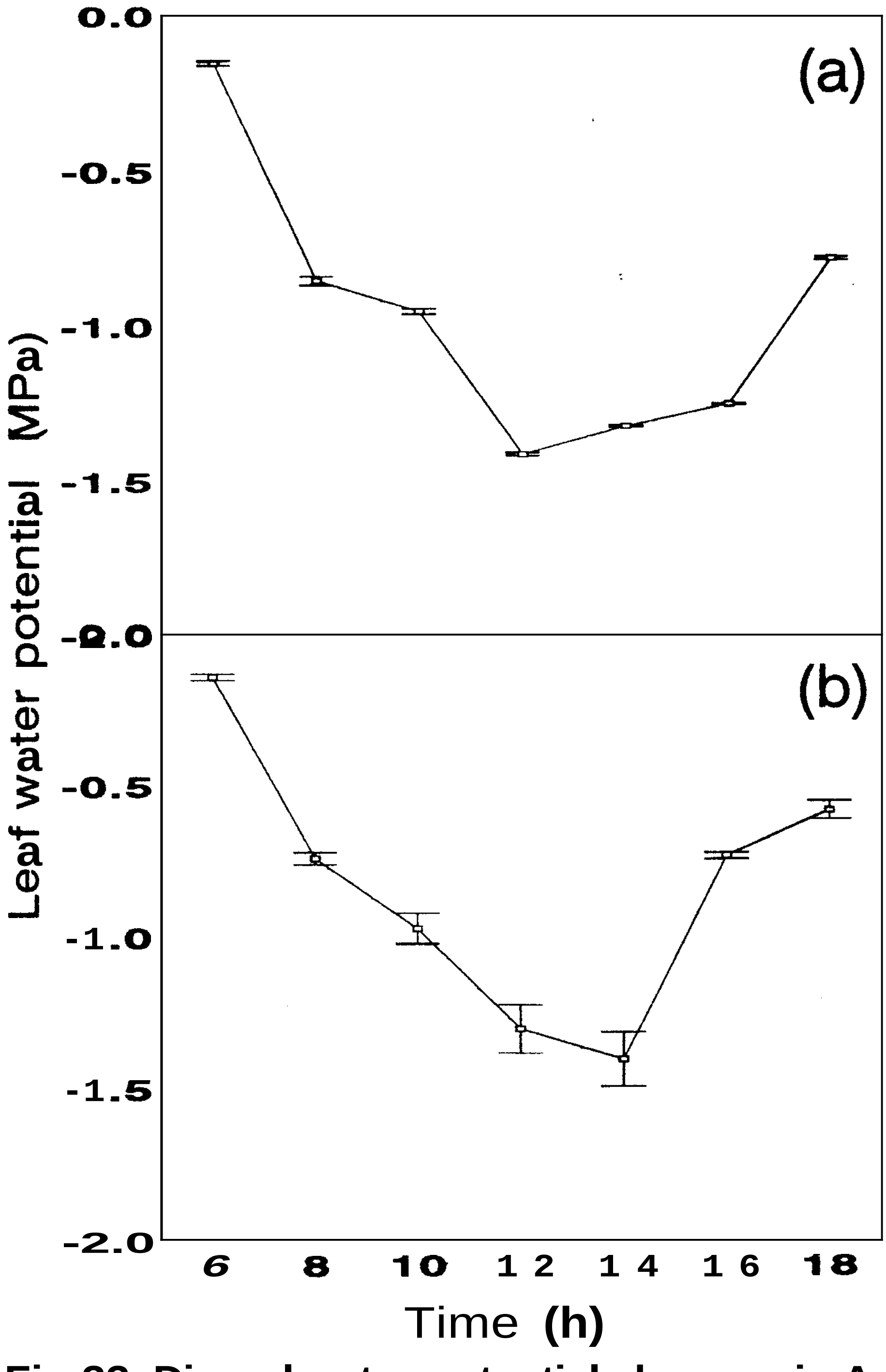

Fig.33. Diurnal water potential changes in Andhra Pradesh during July (a) and October (b) 1993.

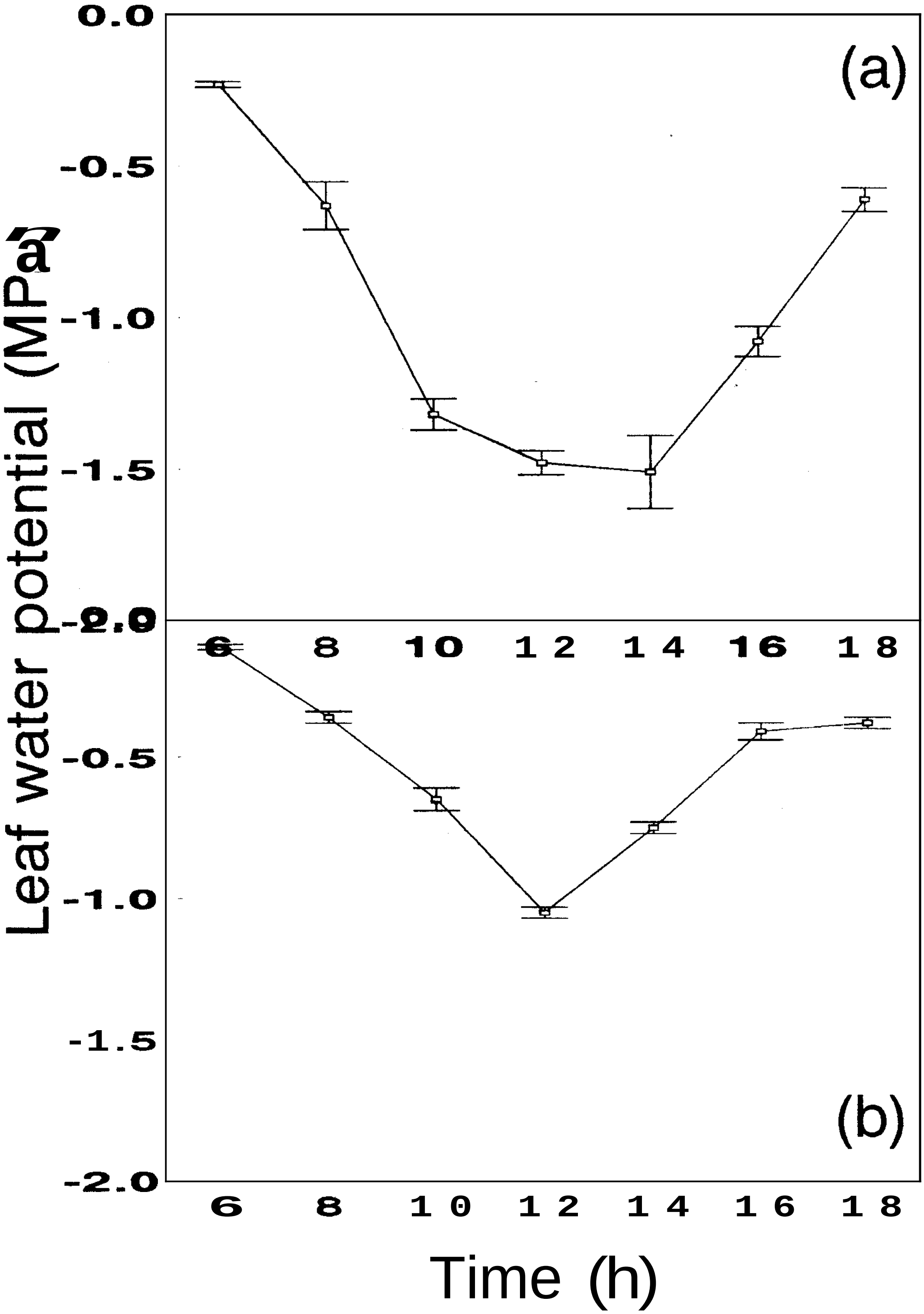

Fig.34. Diurnal water potential changes in Andhra Pradesh during April (a) and August (b) 1994.

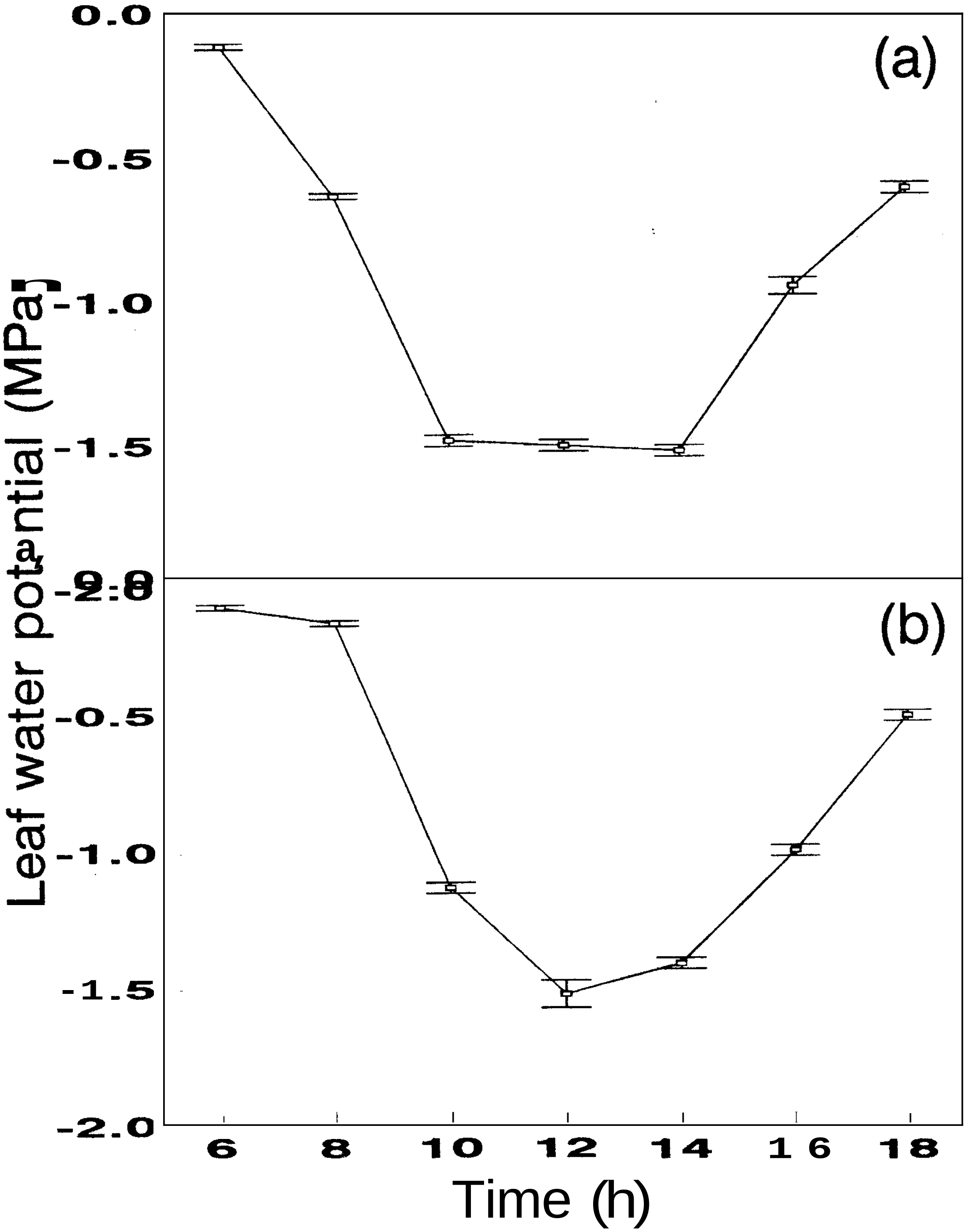

Fig.35. Diurnal water potential changes in Andhra Pradesh during November (a) and December (b) 1994.

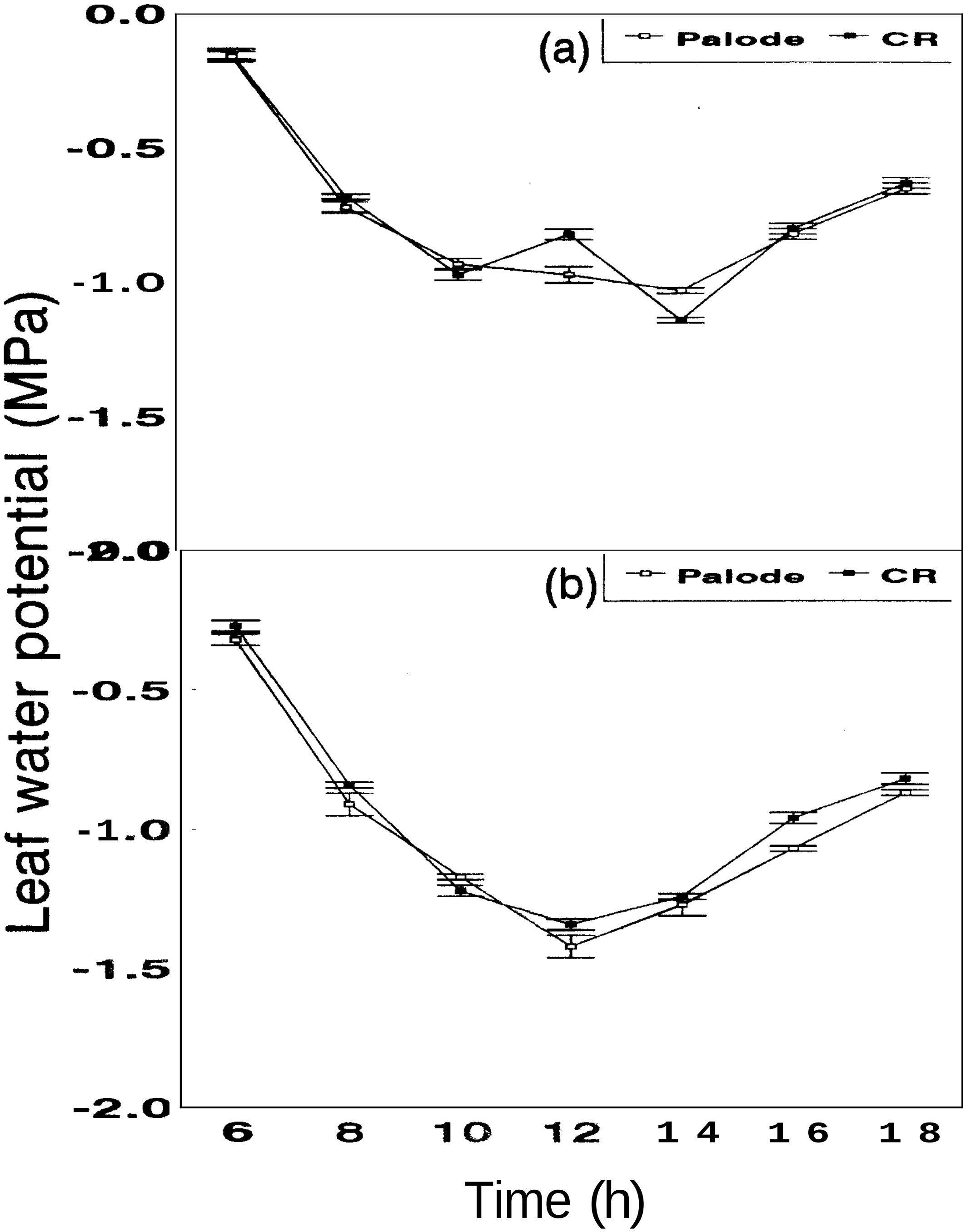

Fig.36. Diurnal water potential changes in Karnataka during August (a) and November (b) 1993.

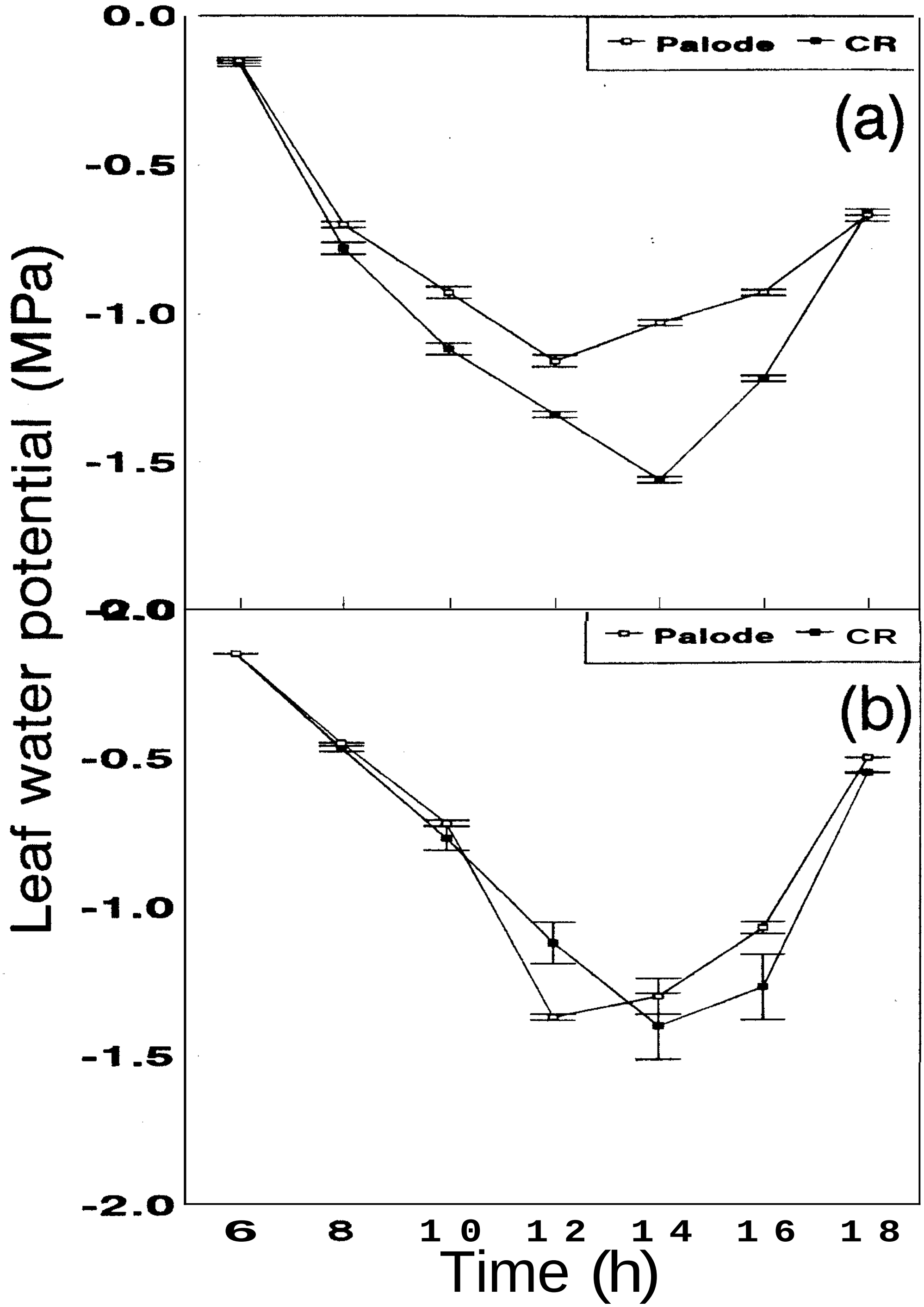

Fig.37. Diurnal water potential changes in Karnataka during February (a) and May (b) 1994.

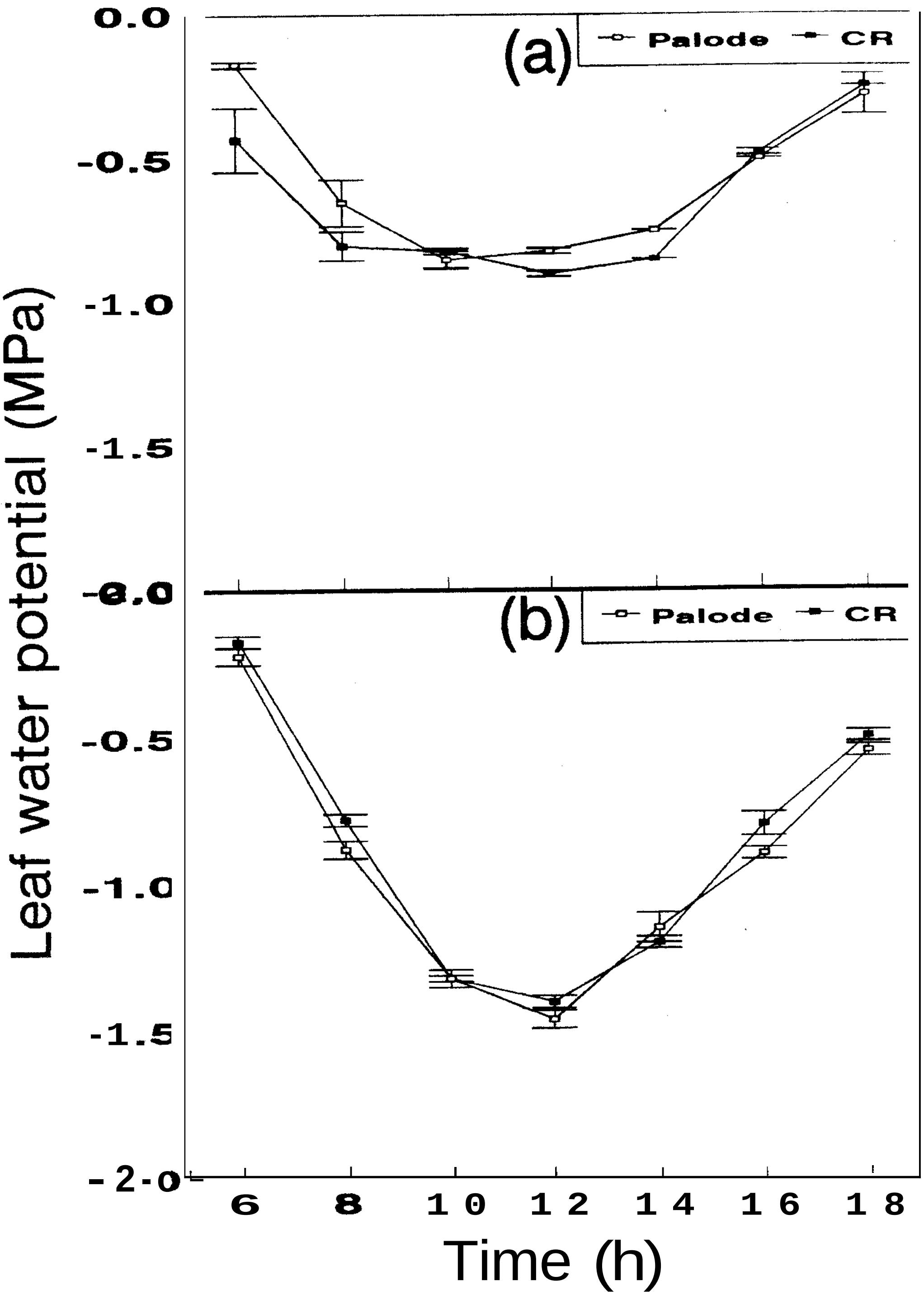

Fig.38. Diurnal water potential changes in Karnataka during September (a) and December (b) 1994.

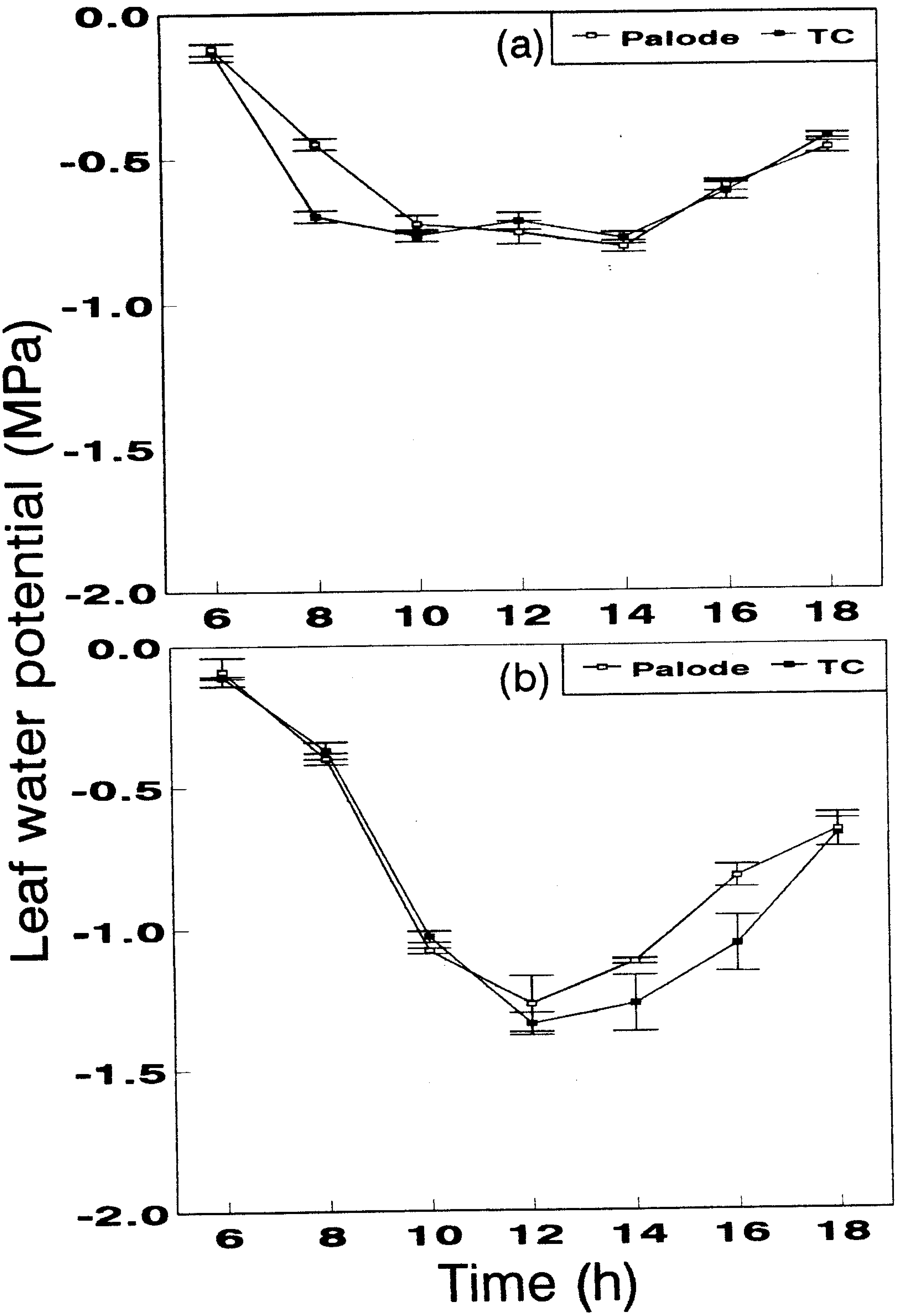

Fig.39. Diurnal water potential changes in Maharashtra during September (a) and November (b) 1993.

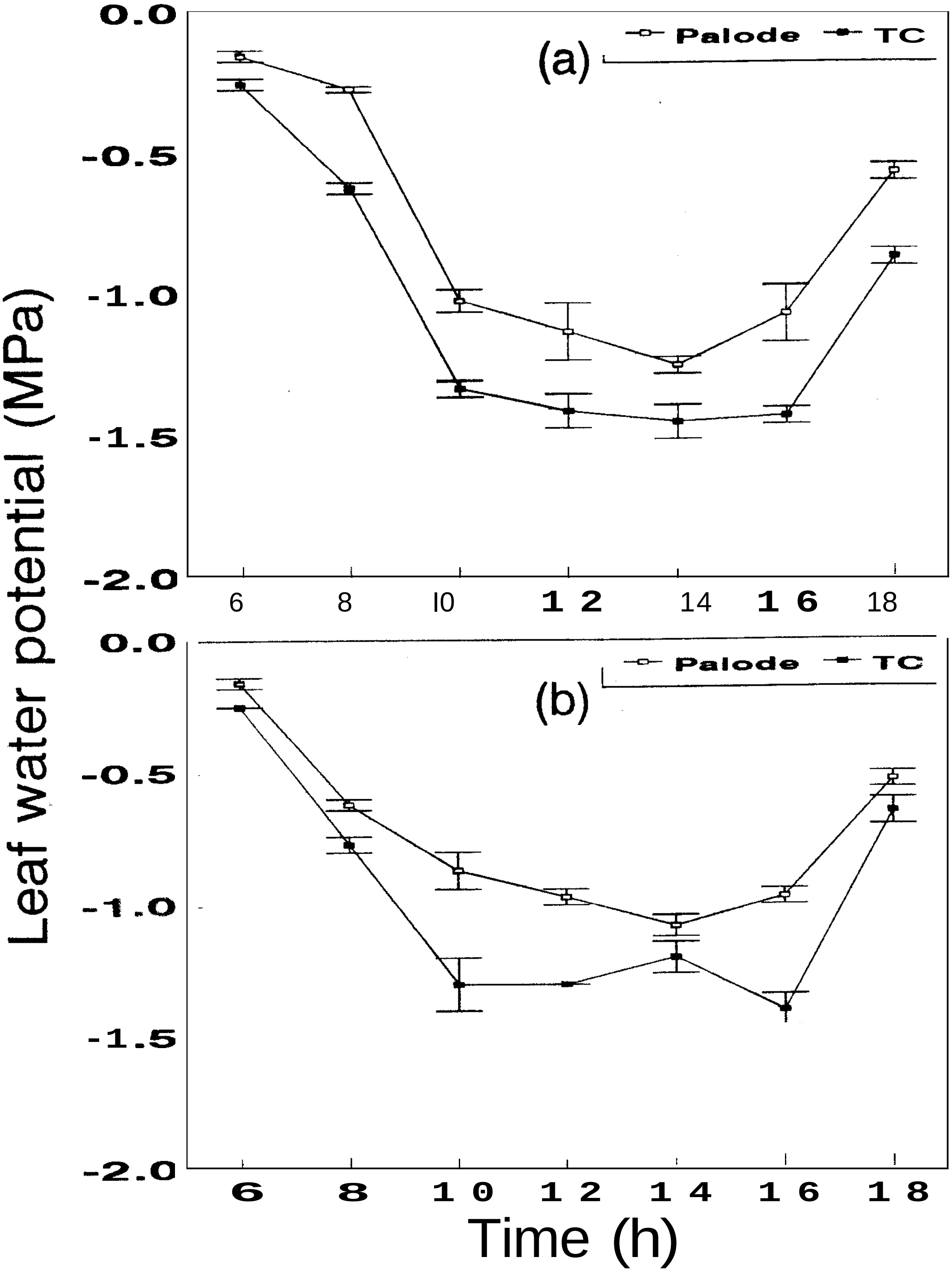

Fig.40. Diurnal water potential changes in Maharashtra during March (a) and June (b) 1994.

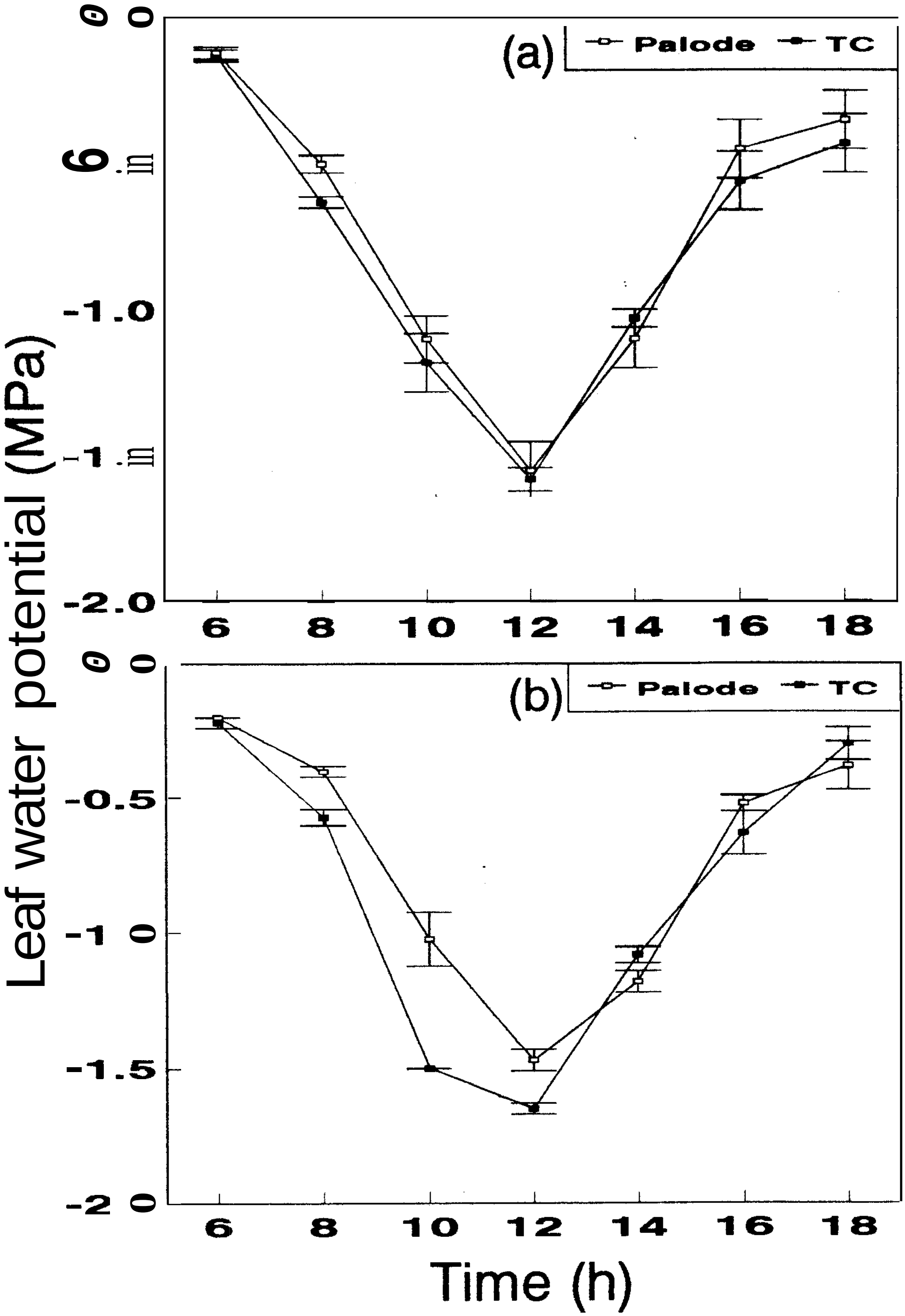

Fig.41. Diurnal water potential changes in Maharashtra during August (a) and October (b) 1994.

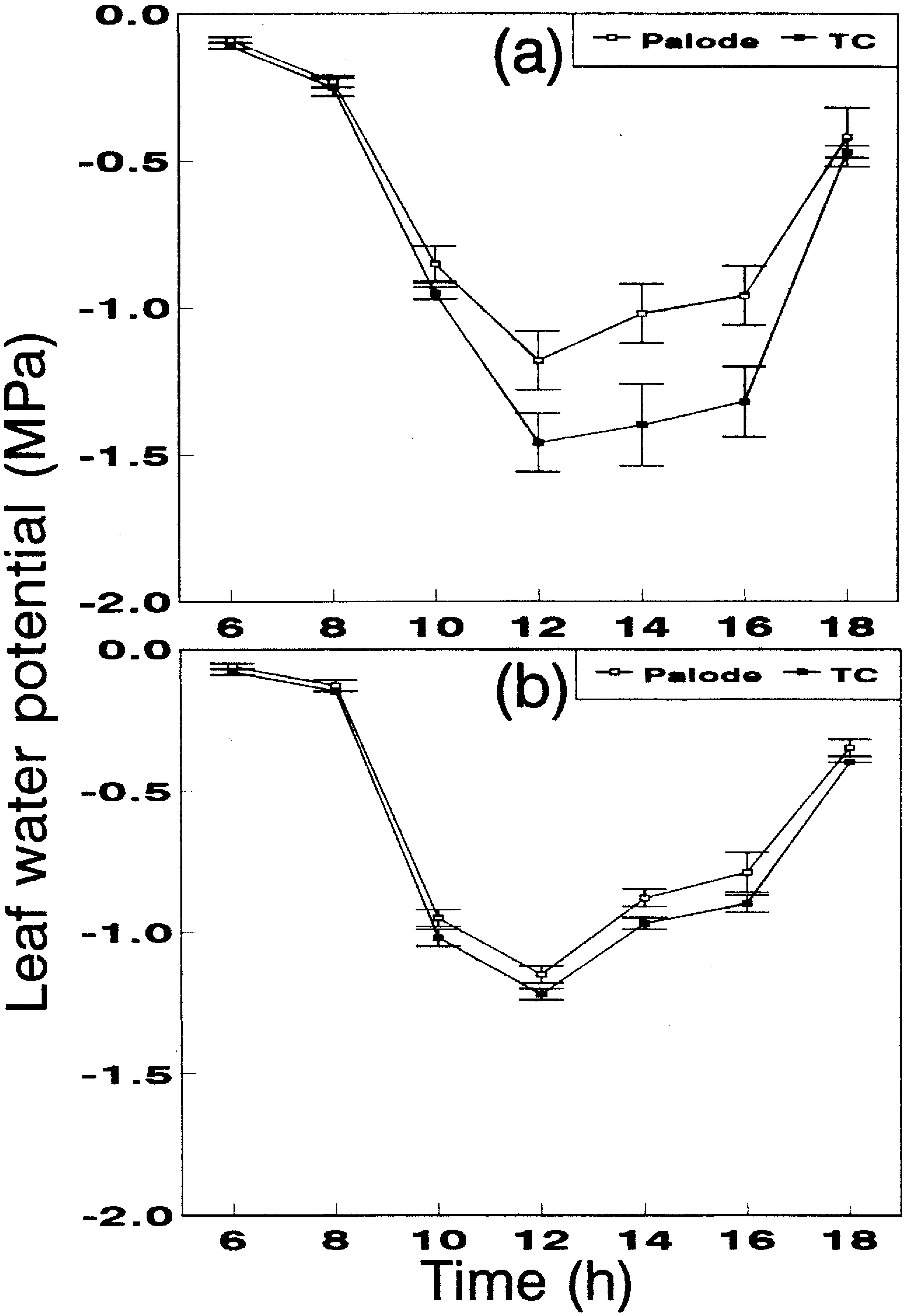

Fig.42. Diurnal water potential changes in Maharashtra during December 94 (a) and January 95 (b).

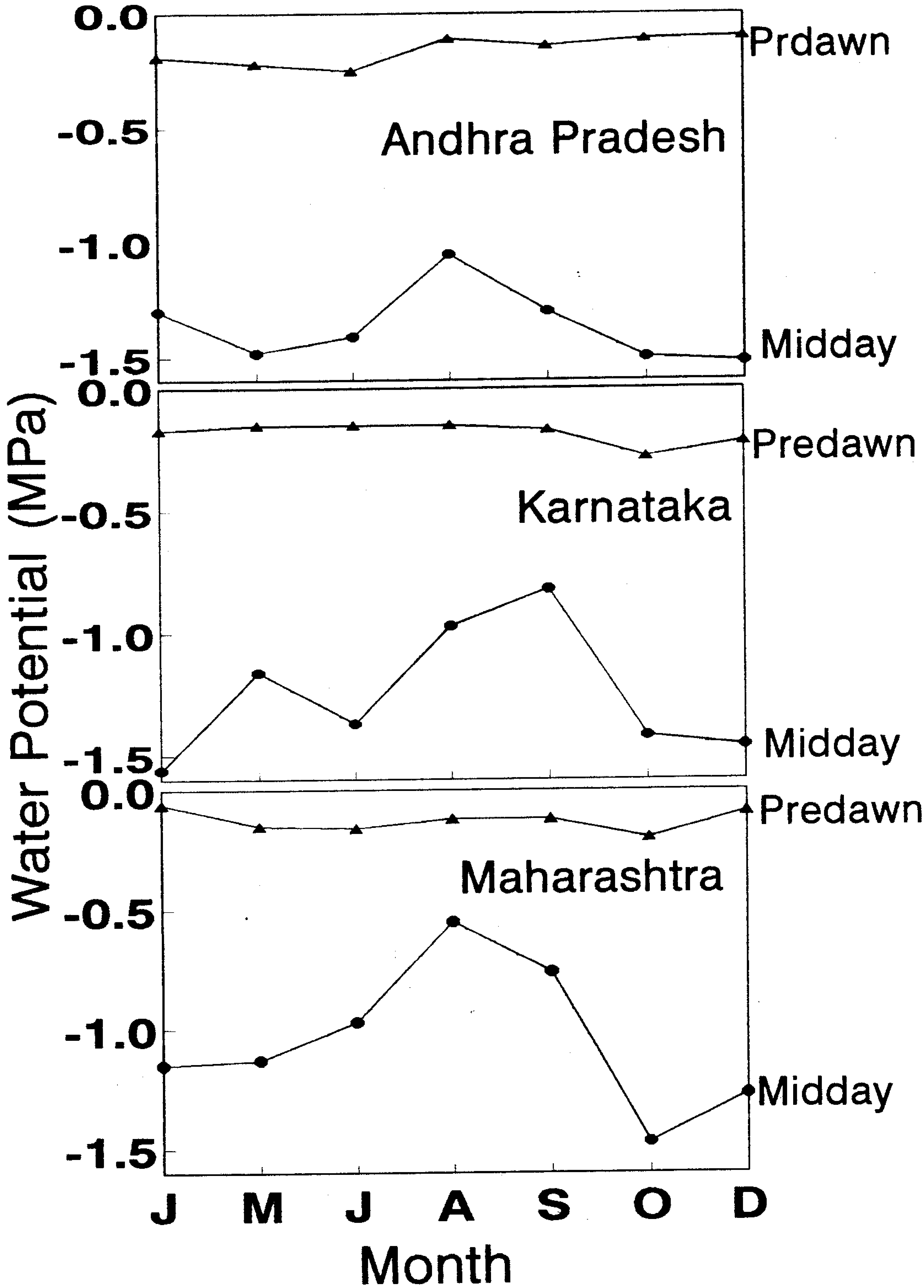

Fig.43. Water potential changes in oil palm leaves during the year. Predawn and midday values are indicated.

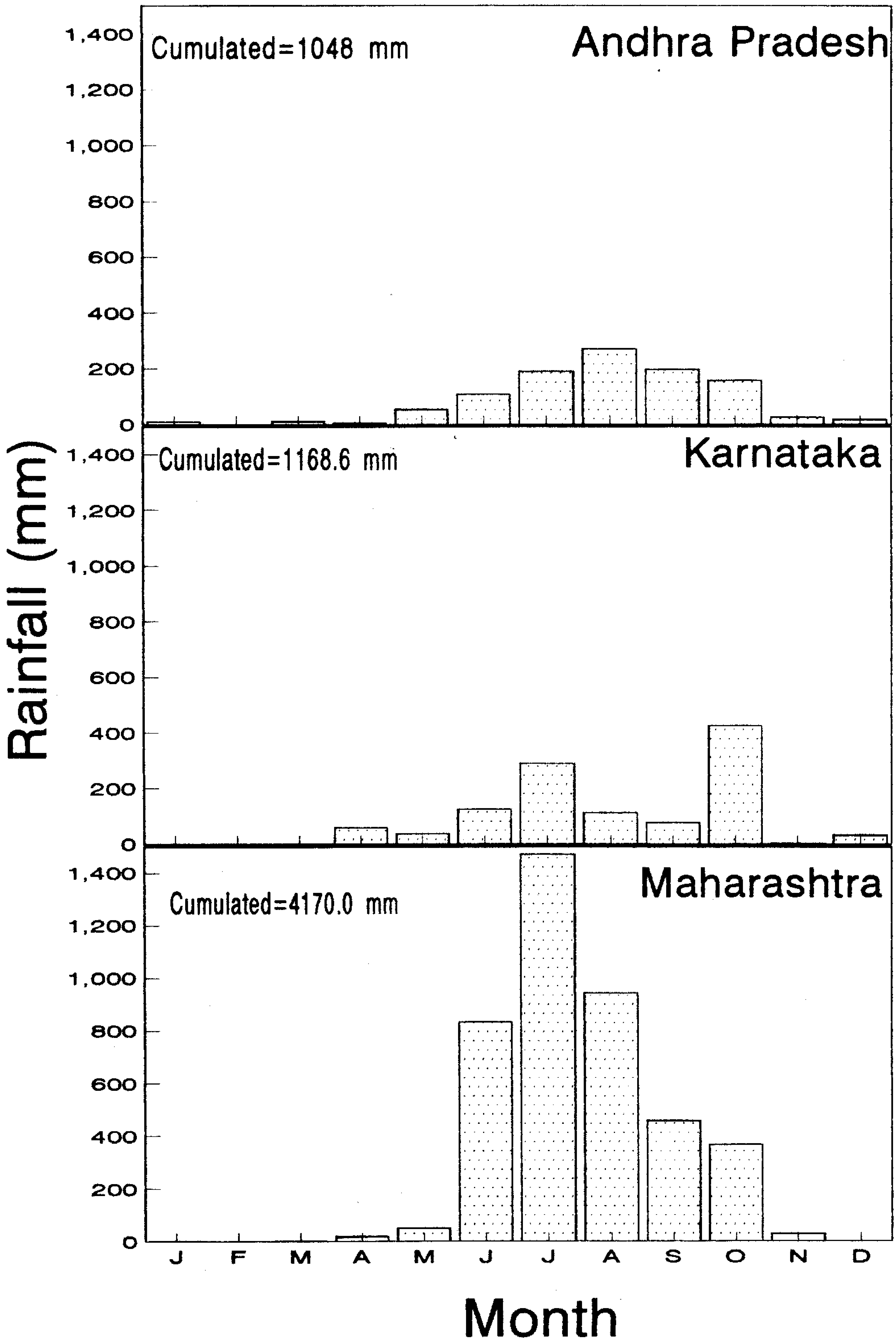

Fig.44. Monthly rainfall near the three study sites (see text for details).

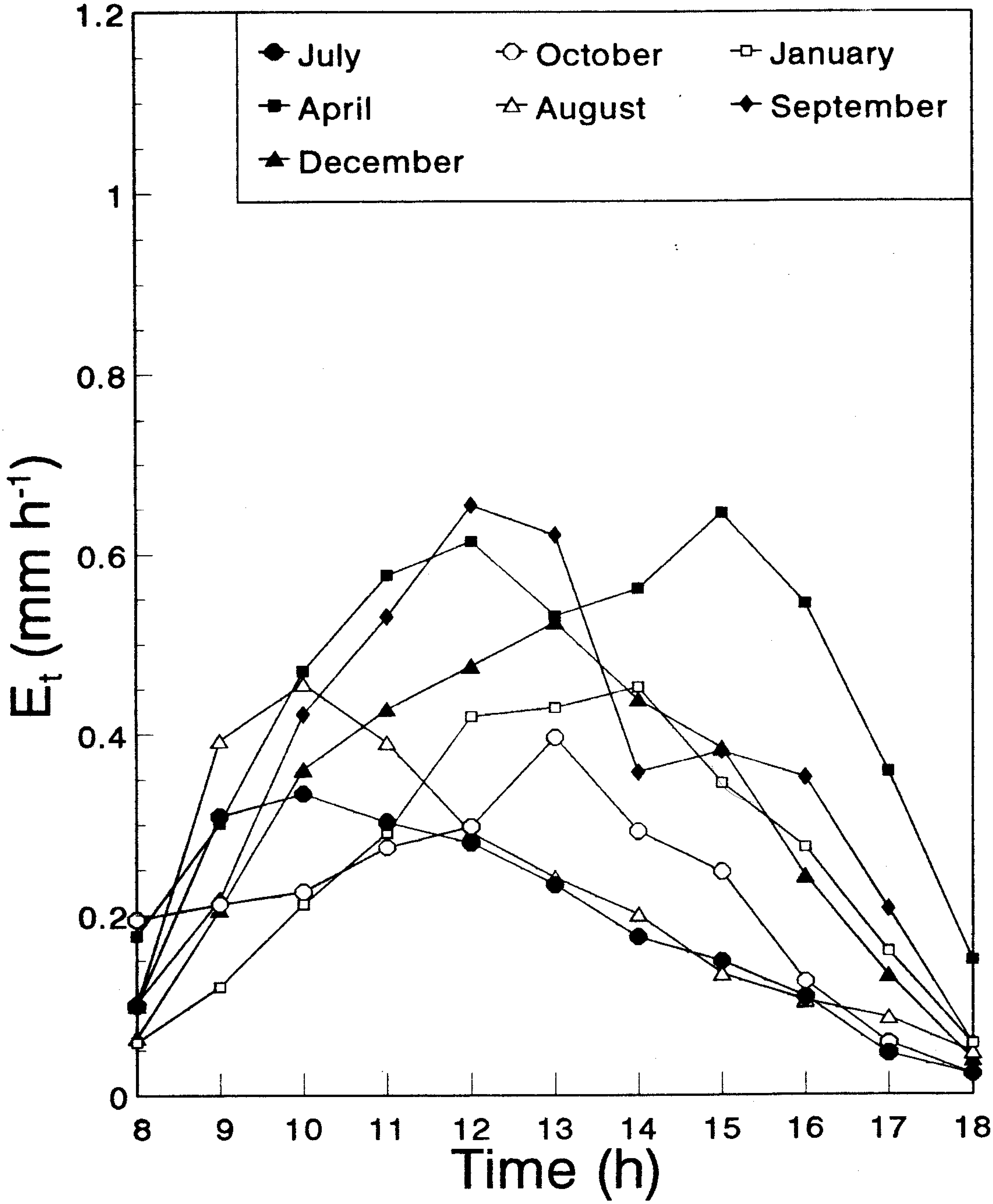

Fig.45. Hourly rate of transpiration calculated using Penman-Monteith Equation for the site in Andhra Pradesh.

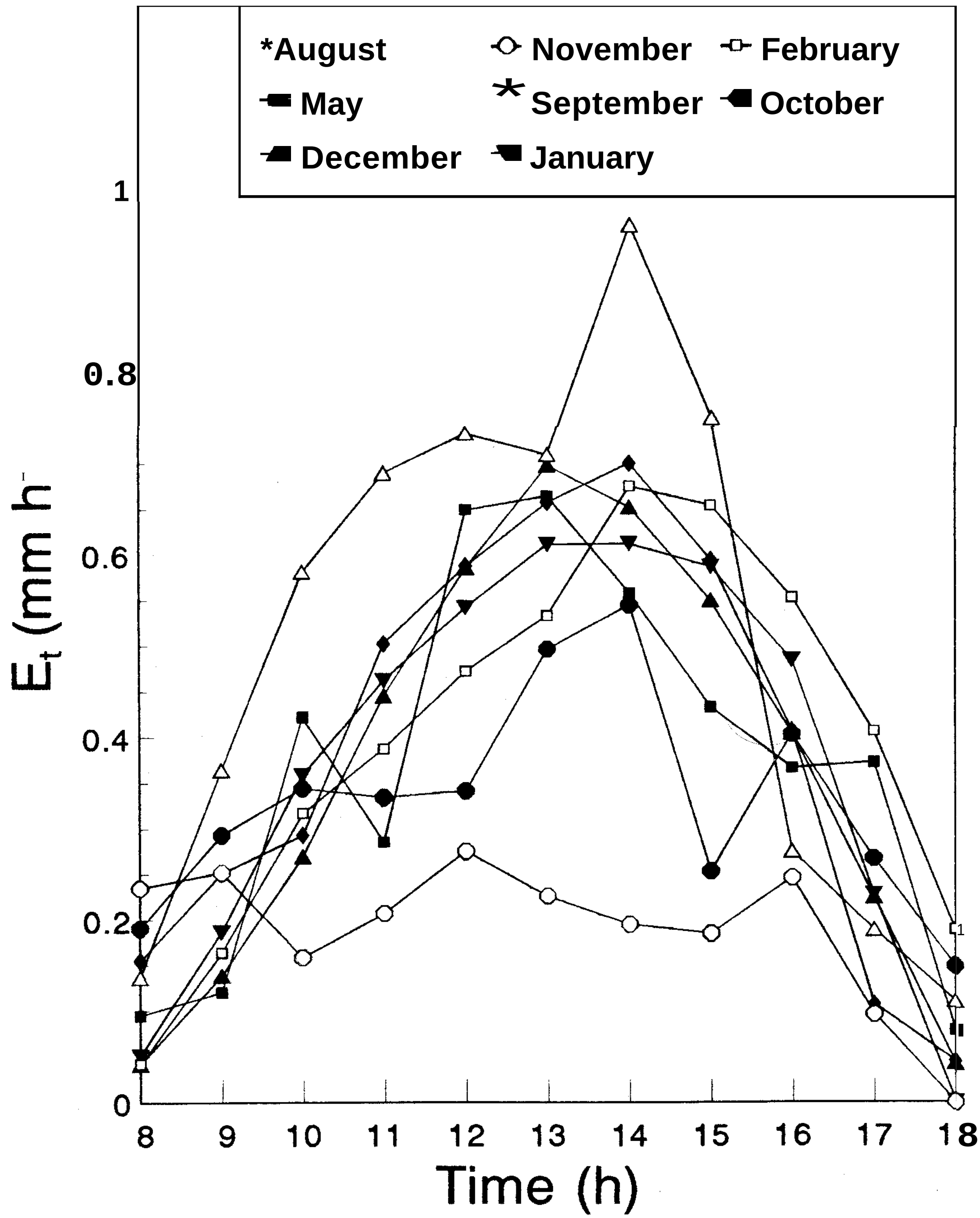

Fig.46. Hourly rate of transpiration calculated using Penman-Monteith Equation for the site in Karnataka.

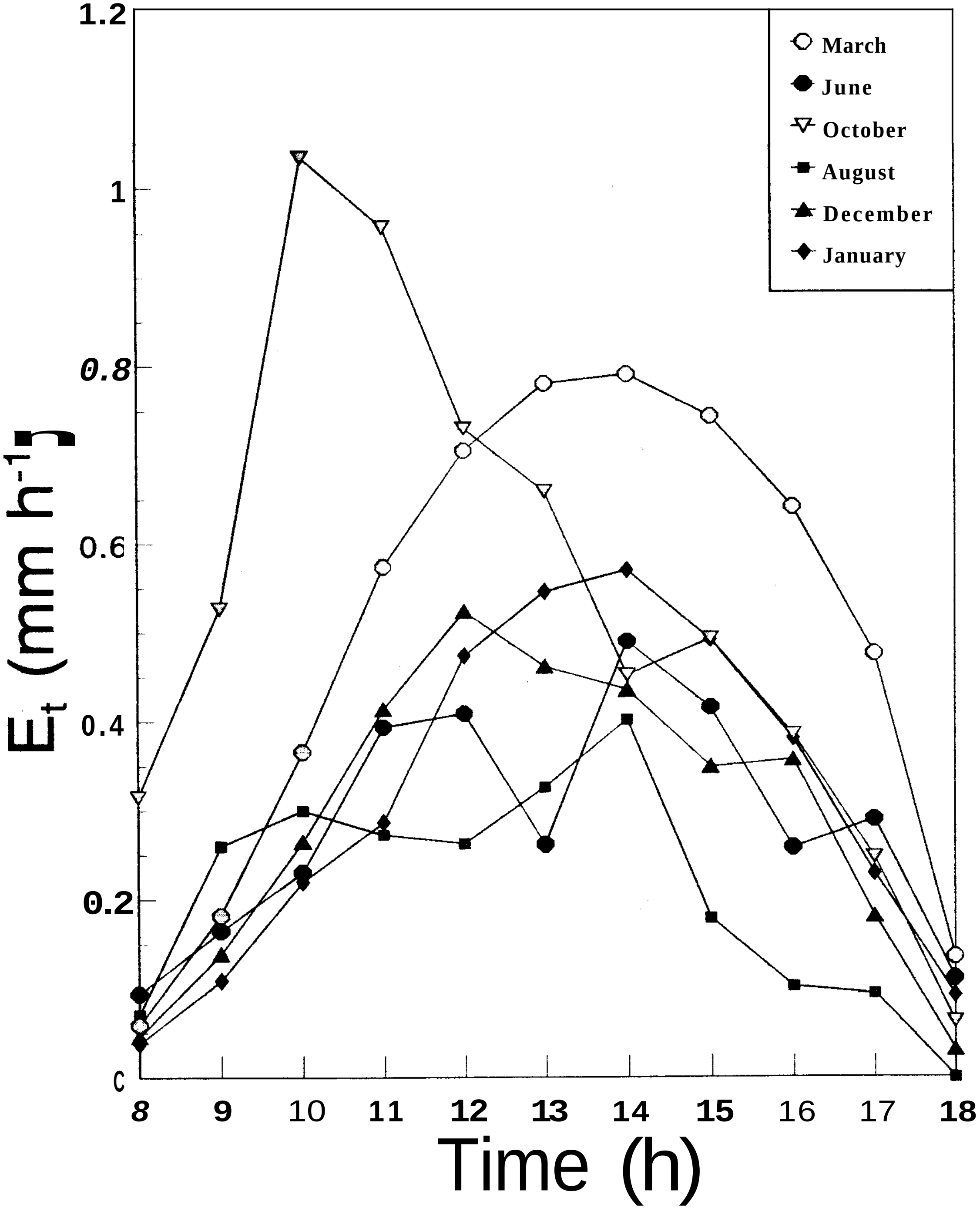

Fig.47. Hourly rate of transpiration calculated using Penman-Monteith Equation for **the site in Maharashtra.**

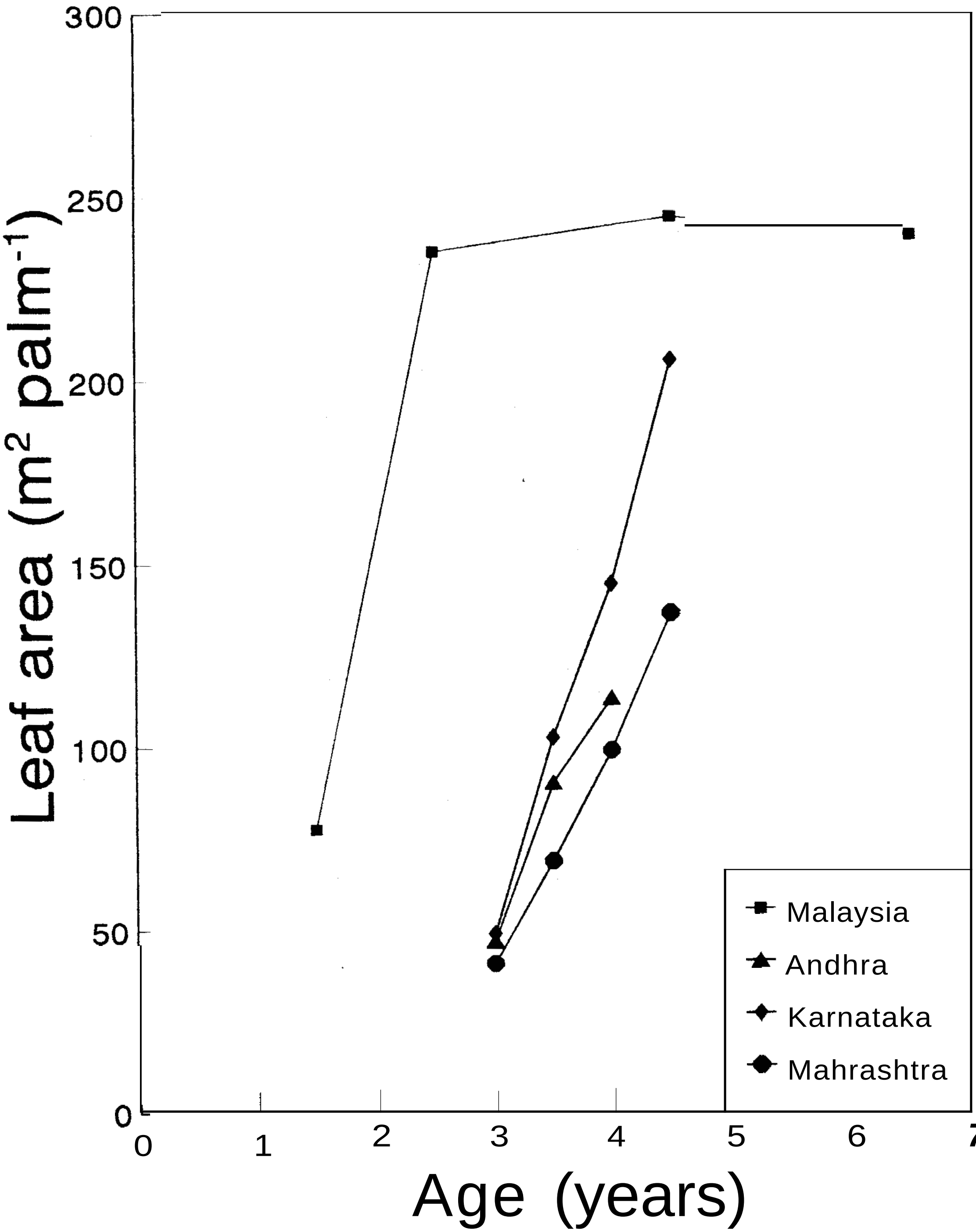

Fig.48. Leaf area development in oil palm in the three States compared with Malaysian data (Corley and Gray 1982).