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STRESS DEVELOPMENT AND ITS DETECTION IN YOUNG OIL PALMS IN NORTH KEDAH, MALAYSIA

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ABSTRACT

Various methods of detecting and quantifying stress in oil palm are briefly reviewed. Stress is defined loosely as any environmental condition leading to reduced productivity and loss of yield. Common environmental stresses include those induced by water deficit, water logging, low atmospheric humidity, high temperatures, nutrient deficiency and low radiation. Different stress-inducing factors are frequently combined; e.g. *water deficit and high temperature stress, water deficit and nutrient stress; high temperature and low atmospheric humidity stress.*

Results are presented of measurements made on young field palms planted in a dry region in north Kedah, Malaysia. The measurement period spanned wet and dry seasons. Short-term stress responses evaluated were: i) changes in canopy surface temperatures relative to air temperatures, ii) changes in spear leaf extension rates, and iii) changes in the ratio of actual to potential evapotranspiration.

The responses are related to soil water supply, solar radiation, atmospheric vapour pressure deficit and potential evapotranspiration rate. The potential for using canopy surface-air temperature difference (ΔT*) and spear leaf extension measurements as a means to monitor irrigation need is discussed.*

Keywords: oil palm, stress, water supply, canopy temperature, spear leaf growth.

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INTRODUCTION

An adequate supply of water is one of the most important factors determining yield of oil palm and the suitability of areas for its cultivation. In Malaysia, insufficient water has generally been considered a problem only in certain rather localized areas, for short periods of the year, or in years when extreme conditions have prevailed, *e.g.* as a result of severe *El Niño* events (Turner, 1977; Chan *et al*., 1985; Corley and Hong, 1982; Henson and Chang, 1990; Arifin *et al*., 2002). Nevertheless, there is interest in mitigating such conditions, especially in relation to the need to increase the national yield and oil extraction rate and to exploit land in areas previously considered too limiting to productivity. In addition, there are concerns that climatic conditions will worsen due to increasing frequency of *El Niño* (Arifin *et al*., 2002) and the gradual impact of greenhouse gas-induced climate change (Ramadasan *et al*., 2000). Thus, the threat posed by restricted water supplies will increase.

More precise information is required both on the impacts of water deficits on oil palm yields and on the best way of reducing these by irrigation and other means. Where water for irrigation is available, there is still the need to optimize its use in terms of suitable irrigation infrastructure and amount and frequency of water application. Studies previously undertaken on this have generally been rather empirical and *ad hoc*. The decisions when to irrigate, how much to apply, how frequent and by what procedure, presently lack a firm theoretical foundation.

While yield is known to be greatly affected by periods of drought, due to the long developmental

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period involved in bunch production, impacts only become apparent some time after the event. Methods are required that allow early and rapid detection of water deficit that can serve as a basis for decisions on irrigation strategy.

METHODS FOR DETECTING STRESS IN OIL PALM

There are various methods of detecting and quantifying abiotic stress in crop plants. Abiotic stress (*i.e.* stress resulting from physical as opposed to biological factors) is rather a general term and is defined here as any environmental condition leading to reduced productivity and loss of yield. Common environmental stresses include those induced by water deficit, water excess, low atmospheric humidity, low or high temperature, nutrient deficiency and low radiation. Different stress-inducing factors are frequently combined, *e.g.* water deficit and high temperature stress, water deficit and nutrient stress; high temperature and low atmospheric humidity stress. We are concerned here only with water deficit and the associated stress resulting from high temperature and low atmospheric vapour pressure.

Indicators of stress and detection methods either used or of possible application to oil palm are listed in *Table 1*. In general, the more rapid techniques involve expensive and complex instrumentation, require skill and care in making the measurements and in interpreting results, and hence are rather impractical for routine use. On the other hand, the simpler, inexpensive and undemanding methods such as those stemming from yield observations, are insensitive and too long-term to be of use for irrigation management. A compromise is necessary between technically complex but precise and rapid detection methods and simple but slow ones. In the study described below, we consider a few of the most promising of these compromise methodologies.

This report describes some preliminary studies aimed at early, rapid detection of stress in oil palm associated with water deficit. The work was undertaken using a new area of oil palm planted mid 2000 on an estate in a dry area in northern Kedah, close to the border with Thailand. This region generally experiences two to three months of low rainfall each year (*Figure 1*). Because of this, rubber, rather than oil palm, has been the main plantation crop in the area.

The study was carried out as part of a collaborative exercise between MPOB agronomists and crop physiologists and the oil palm estate management. The measurements described were made between late October 2002 and May 2003, spanning the dry season that occurred from January to March 2003.

SITE, MATERIALS AND METHODS

Site Characteristics

The study was conducted at Tanjung Genting ESPEK estate near Sintok, Kedah, Malaysia (6º 27′N, 100º 29′E). The area routinely experiences an annual dry season generally starting in mid or late December and ending in March. The long-term rainfall pattern recorded by the estate is shown in *Figure 1*. This pattern is confirmed by records from two nearby stations managed by the Malaysian Meteorological Service (MMS) at MARDI Bukit Tangga (6º 28′N, 100º 30′E) and Chuping (6º′ 29′N, 100º 16′E). *Figures 2* and *3* show respectively the corresponding seasonal patterns for air temperature, and for total short-wave solar radiation and pan evaporation recorded at Chuping. (These data were not recorded at Bukit Tangga.)

The oil palm was planted in July 2000 at a density of 148 palms ha^{-1}. The seedling DxP palms were obtained from a large commercial supplier. The oil palm replaced a previous stand of rubber. The soil where the experimental plots were located is a moderately deep sandy clay loam [series: Batu Lapan, order: Plinthic Hapludult (USDA classification)]. The soil proved to be relatively uniform with preliminary samples showing two main horizons differing in clay content. The terrain is gently undulating but a level area was chosen for the plots. A leguminous cover crop (a *Centrosema pubescens*/*Pueraria phaseoloides* mixture) was established at planting and, except where stated otherwise, normal estate management practices were carried out.

Plot Layout and Instrumentation

Six plots each of 16 palms (four palms in four rows) were marked out and fenced off to prevent entry and damage by straying cattle. Within each plot, triangular areas, each bordered by three palms, one in a harvest path and one in the inter-row, were marked out according to the scheme for root sampling proposed by Tailliez (1971). In each of these areas, 10 cylindrical access tubes were installed for monitoring soil moisture using a Delta-T Profile Probe (Delta-T Devices Ltd., Cambridge, UK), as shown in *Figure 4*.

On two of the plots, scaffolds were erected for mounting meteorological instruments, data loggers and power sources (*Table 2*). The latter comprised two solar panels each with storage batteries. This arrangement allowed for continuous, unattended operation of loggers and instruments.

TABLE 1. LIST OF METHODS CURRENTLY AVAILABLE FOR DETECTING WATER DEFICIT AND ASSOCIATED STRESSES (low humidity, high temperatures) IN OIL PALM

Method	Time scale for measurement or response	Sensitivity of detection method	Special instrumentation required?	Ease of interpretation	References
Leaf or canopy temperature	minutes	high	yes	moderate	Henson (1991b)
Leaf chlorophyll fluorescence	minutes	high	yes	moderate	MPOB (2002)
Leaf gas exchange	minutes	high	yes	moderate to difficult	Henson (1991a), Dufrene *et al*. (1992)
Leaf water potential	minutes	high	yes	difficult	Henson and Chang (1990), Villalobos *et al*. (1993)
Canopy gas exchange	hours, days	medium	yes	moderate to difficult	Henson (1995)
Sap flux	hours, days	high	yes	moderate	Dufrene (1989), Henson (1998)
Evapotranspiration	hours, days	medium	yes	moderate	Dufrene *et al*. (1992)
Soil water depletion	days	medium	optional	moderate	Dufrene *et al*. (1992)
Calculation of soil water status	days, weeks	medium to low	optional	moderate	Surre (1968)
Spear leaf extension	hours, days	medium	no	easy	Henson (1991a)
Spear leaf accumulation	weeks	low	no	moderate	Henson and Chang (1990)
Frond production rate	months, years	low	no	moderate	Henson and Chang (1990)
Single bunch weight reduction	months, years	low	no	moderate	Corley (1996)
Inflorescence abortion	months, years	low	no	moderate	Broekmans (1957)
Reduced sex ratio	years	low	no	moderate	Broekmans (1957)
Bunch number reduction	years	low	no	moderate	Corley (1996)
Reduced FFB yield	years	low	no	low	Corley (1996)
Death of palm	months, years	low	no	low	Cornaire *et al*. (1995)

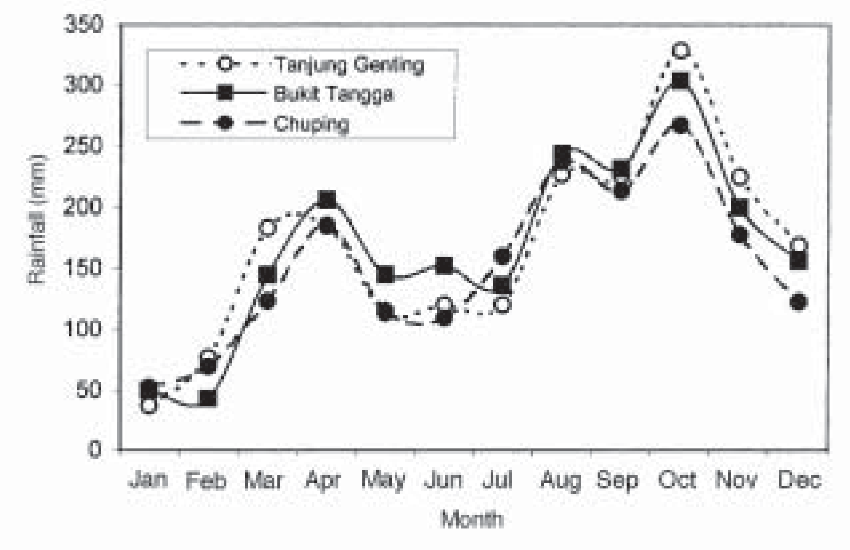

Figure 1. Mean monthly rainfall at Tanjung Genting, Bukit Tangga and Chuping from 1995 to 2002. Mean annual rainfall over the period at the three sites was 2011, 2011 and 1827 mm respectively.

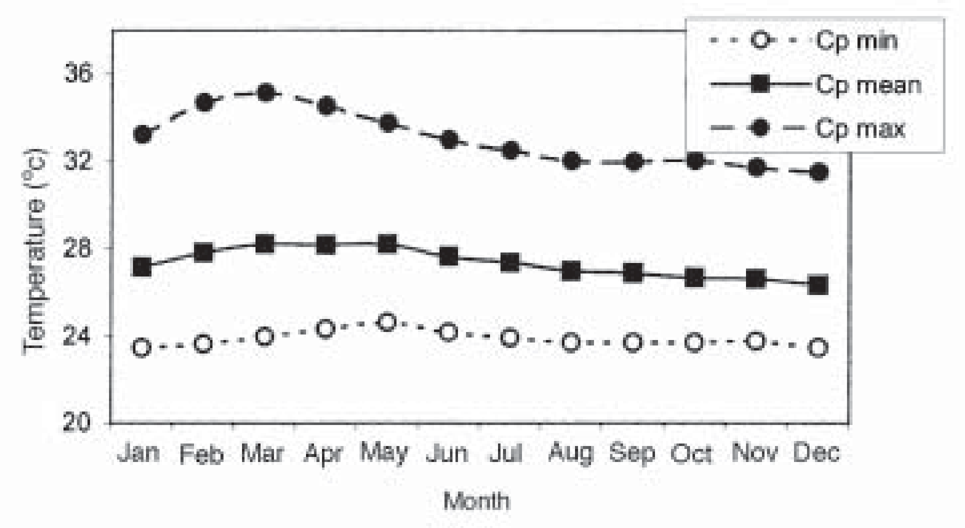

Figure 2. Mean monthly minimum, maximum and mean air temperatures at Chuping from 1995 to 2002.

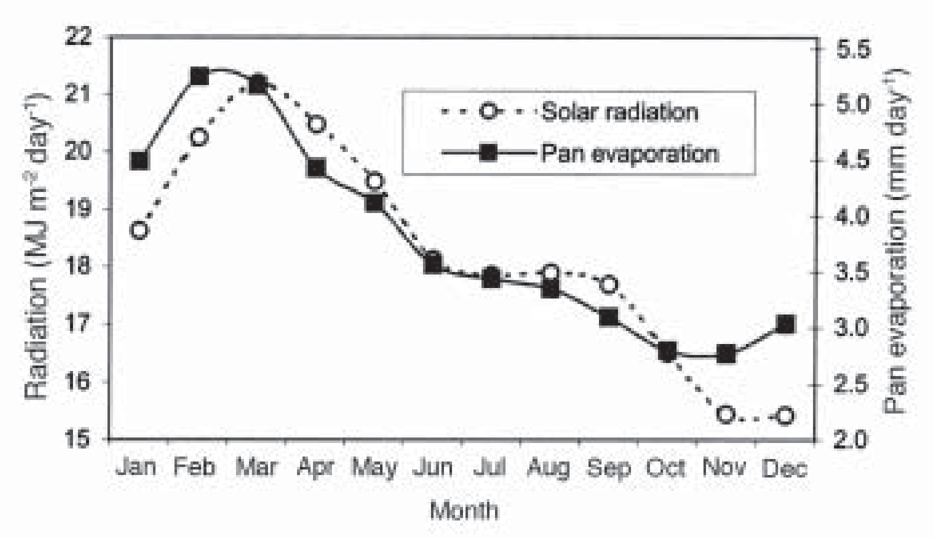

Figure 3. Mean monthly solar radiation and pan evaporation at Chuping from 1995 to 2002.

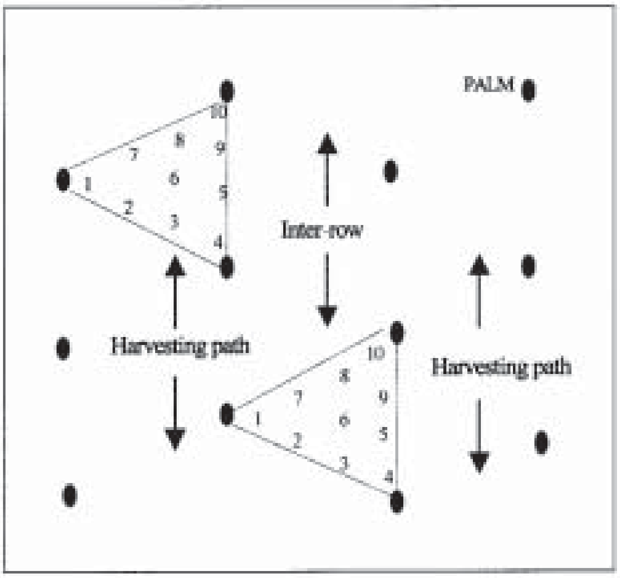

Figure 4. The arrangement of triangular areas, each with 10 access tubes (numbered), used for monitoring soil water content within each of the study plots.

Soil Sampling and Characterization of Soil Water Release Properties

Soil samples were taken from all plots using a cylindrical root auger to a depth of 100 cm. The 8 cm diameter soil cores were separated into six horizons (*Table 3*). Each sample was tightly wrapped in a plastic bag and enclosed in a rigid plastic pipe to ensure it was intact and undisturbed on transport to the laboratory. Samples were then weighed and re-measured to determine bulk density. The relationship between soil volumetric water content (θ; $m^3\ m^{-3}$) and Profile Probe voltage output was then determined using the Delta-T Theta Probe as a substitute for the Profile Probe, as recommended in the Delta-T manual. To establish the relationship, measurements were made both before and after oven drying of the samples at 80ºC-100ºC.

The relationship between θ and soil matric potential (ψ_s; bars) was established using pressure plates, after rewetting the samples. Water release curves were constructed from the data after conversion of ψ_s to pF.

The percentage available soil water capacity (or content) (ASWC) was calculated as:

$$\text{ASWC} = [(\theta - \theta_{wp})/(\theta_{fc} - \theta_{wp})]*100$$

where: $\theta_{wp} = \theta$ at permanent wilting point and $\theta_{fc} = \theta$ at field capacity

taking $\psi_s = -15.0$ bar as permanent wilting point and -0.33 bar as field capacity.

TABLE 2. MICROMETEOROLOGICAL MONITORING EQUIPMENT INSTALLED OVER PLOTS 2 AND 5 OF THE STUDY AREA

Variable measured	Units of measurement	Sensor type	Manufacturer	Number of instruments	
				Plot 2	Plot 5
Air temperature	ºC	thermistor	Skye Instruments Ltd., UK	2	1
Relative humidity	%	capacitance	Hobo, USA	1	-
Canopy surface temperature	ºC	infrared thermocouples	Exergen, USA	2-3	2-3
Shortwave solar radiation	$W\ m^{-2}$	silicon sensor	Skye Instruments Ltd., UK	1	-
Photosynthetic-ally active radiation	$\mu mol\ m^{-2}\ s^{-1}$	quantum sensor	LiCor Inc., USA	1	-
Net radiation	$W\ m^{-2}$	net radiometer	Radiation and Energy Balance Systems Inc., USA	1	-
Horizontal wind speed	$m\ s^{-1}$	cup anemometer	Vector Ltd., UK	1	1
Wind direction	degrees	wind vane	Vector Ltd., UK	1	-
Rainfall	mm	rain gauge	Delta-T Devices Ltd., UK	1	-

TABLE 3. SOME CHARACTERISTICS OF THE SANDY CLAY SOIL FROM THE STUDY PLOTS AT TANJUNG GENTING

Horizon	Depth (cm)	% Silt	% Clay	% Fine sand	% Coarse sand	Bulk density ($g\ cm^{-3}$)	Maximum available water content (mm per layer)
Top soil	0 - 10	22.4	16.0	52.4	9.2	1.51	12.84
	10 - 20	23.7	19.8	48.1	8.4	1.58	13.18
	20 - 30	23.6	22.4	46.4	7.6	1.57	12.53
	30 - 40	24.0	23.8	44.4	7.8	1.61	12.94
Sub soil	40 - 60	22.9	30.9	39.9	6.3	1.53	22.89
	60 - 100	22.8	37.3	34.8	5.1	1.56	36.16
All	0 - 100	-	-	-	-	-	110.54

Note: Data are means of 12 samples.

Both textural and chemical analyses were performed on all samples. The layers analysed relate to the depths of *in situ* soil water measurements. The relevant textural data are given in *Table 3*. The mean bulk density (BD) was 1.56 and the available water capacity to a depth of 1 m was 110.5 mm. A previous analysis, based on 15 cm increments (total depth of 90 cm) and one core per plot gave a mean BD of 1.57 and an ASWC of 117.5 mm.

Calculation of Evapotranspiration

Potential evapotranspiration (PET; mm day^{-1}) was calculated from measurements of net radiation, wind speed and atmospheric vapour pressure deficit using the standard Penman equation. Actual evapotranspiration (AET; mm day^{-1}) is ideally obtained using the following equation:

$$AET = P - In - \Delta q - D - R$$

where: P = rainfall (mm)
In = rainfall interception (mm)
Δq = change in volumetric water content ($m^3\ m^{-3}$)
D = deep drainage (mm)
R = runoff (mm)

In the study, AET was taken as the difference between rainfall and the change in water storage (Δq) in the top 100 cm of soil. Neither runoff nor deep drainage were measured, but both can be assumed to be negligible during the dry season during which measurements were concentrated. Interception (which should strictly include an allowance for dewfall) is here regarded as part of AET.

Measurement of Spear Leaf Extension Rates

This was carried out as described previously (Henson, 1991a). Briefly, two or three unopened spears were selected per palm and a mark was applied near the base of each using a water resistant felt-tipped pen. Reference marks were applied at the same height as this mark to the petiole of adjacent fully opened fronds either side of the spear leaf. The change in height of the marks on the spear leaves in relation to the reference marks was assessed approximately 24 hr later, with the time interval being recorded. The extension rate was calculated in mm day^{-1}. The measurements were carried out on all palms of the inner two rows of each plot (*i.e.* a total of 48 palms; except during September and October 2002 when only 32 palms were sampled).

RESULTS

Meteorological Conditions

Rainfall events at the study plots between late October 2002 and mid May 2003 are shown in *Figure 5*. Between 1 January and 18 March 2003, only 23.7 mm rain were recorded at the plots.

The PET at the plots was calculated hourly from the on-site meteorological data. PET showed an increasing trend over the period of measurement and this was paralleled by corresponding increases in radiation and vapour pressure deficit (*Figure 6*).

AET was calculated using a water balance method. However, this was only valid during the dry season as no measurements were made to assess deep drainage or runoff from the site during periods of excessive rainfall. During such periods, AET was assumed equal to PET. The effects of the dry season are most clearly seen by examining the AET/PET ratio (*Figure 7*).

The reduction in AET/PET was assumed to be due largely to stomatal closure of the palms. Additional factors contributing were drying of the soil surface and death of the ground cover vegetation from herbicide application at the start of the dry season. There was also some reduction in palm leaf area (amounting to 10%-15% as assessed visually) due to an attack by nettle caterpillar.

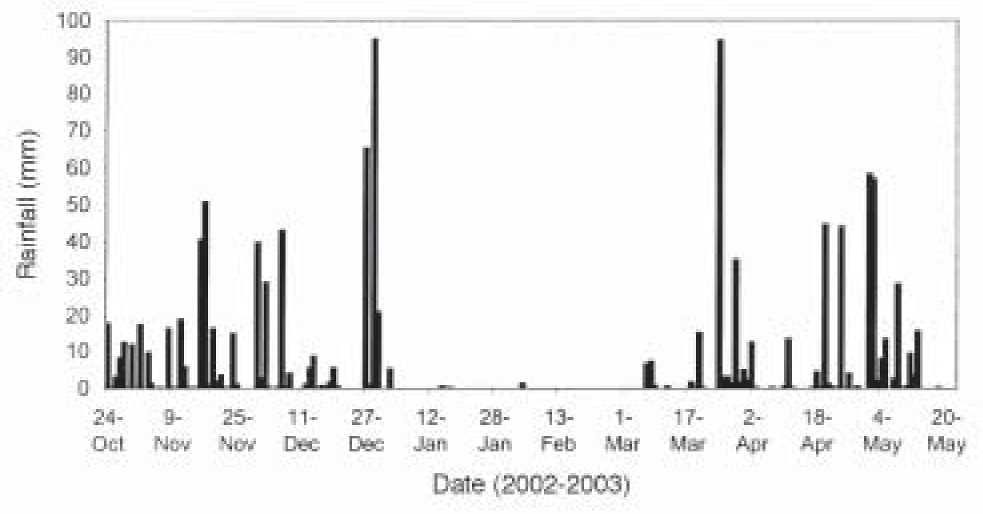

Figure 5. Daily rainfall at the Tanjung Genting study plots from October 2002 to May 2003. Note the prolonged dry period from the end of December to mid March.

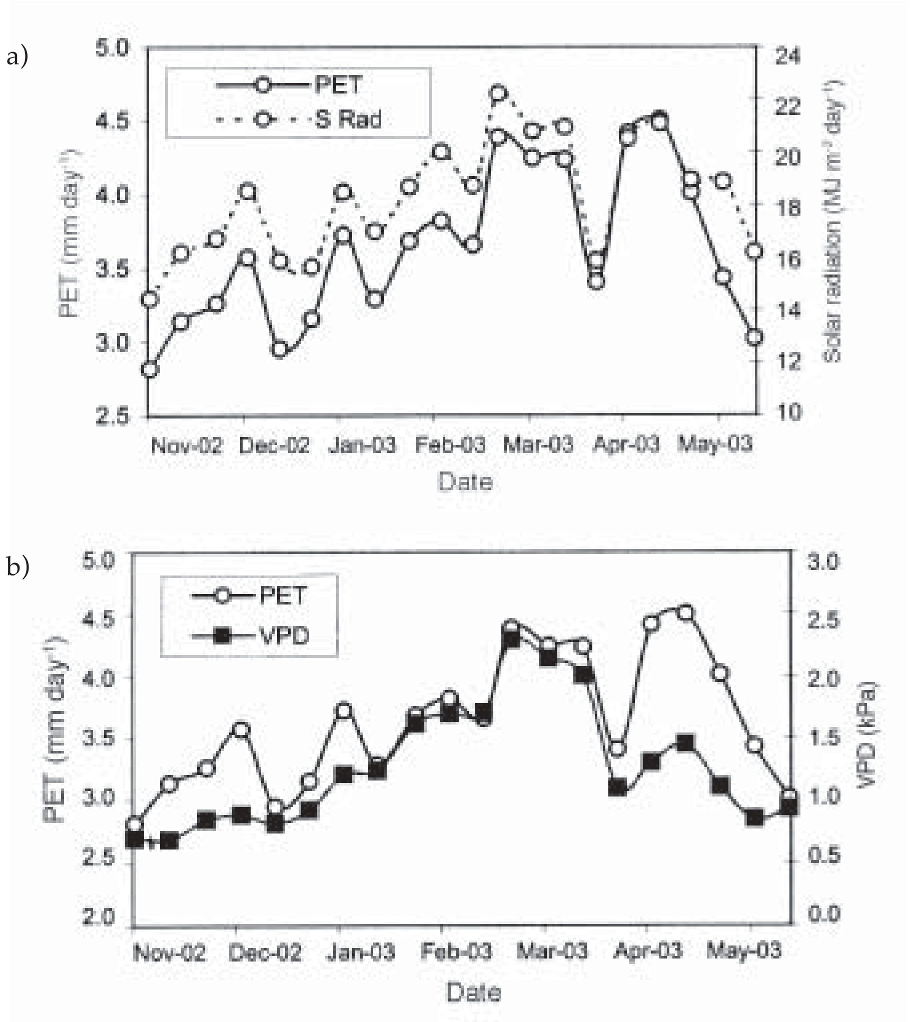

Figure 6. Changes at the study site in (a) daily potential evapotranspiration (PET) and solar radiation (S Rad) and (b) in daily PET and vapour pressure deficit (VPD) averaged over c. 10 day periods from November 2002 to mid May 2003.

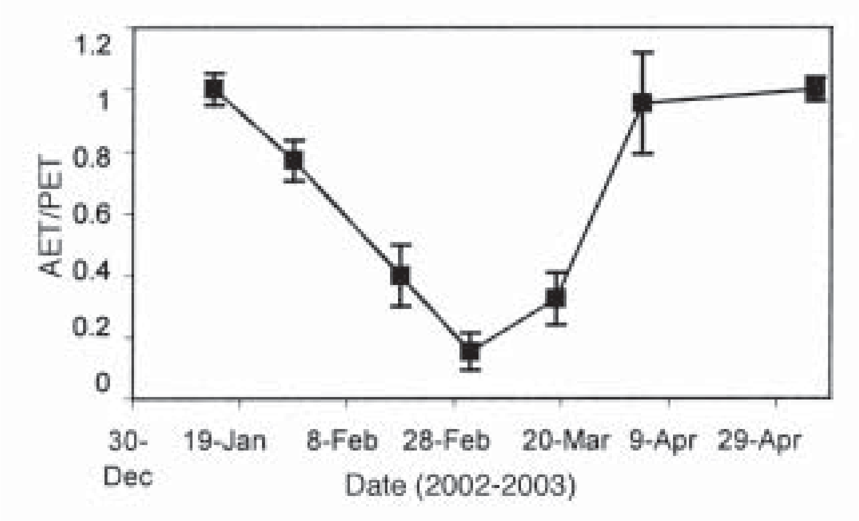

Figure 7. Changes in the ratio of actual to potential evapotranspiration (AET/PET) at the study plots during the 2003 dry season. The points represent the average ratio during each preceding interval. Vertical lines indicate ± s.e.m. (n=12). The maximum ratios were set to unity (see text for details).

Soil Water Relations

Soil water content was regularly monitored at the access tube sites using a Delta-T Profile Probe. Following the cessation of rainfall in early January and until the resumption of rains in late March, a general and continuous reduction was seen in all plots for all parameters. Mean changes in θ, and ASWC over time are shown in *Figure 8.*

Figure 9 indicates the soil depths from which water was being extracted. Greatest changes occurred in the surface layers, presumably as a result of higher rooting densities.

Relationships between Evapotranspiration and Soil Water Status

The AET/PET ratio is plotted against ASWC and soil matric potential in *Figure 10*.

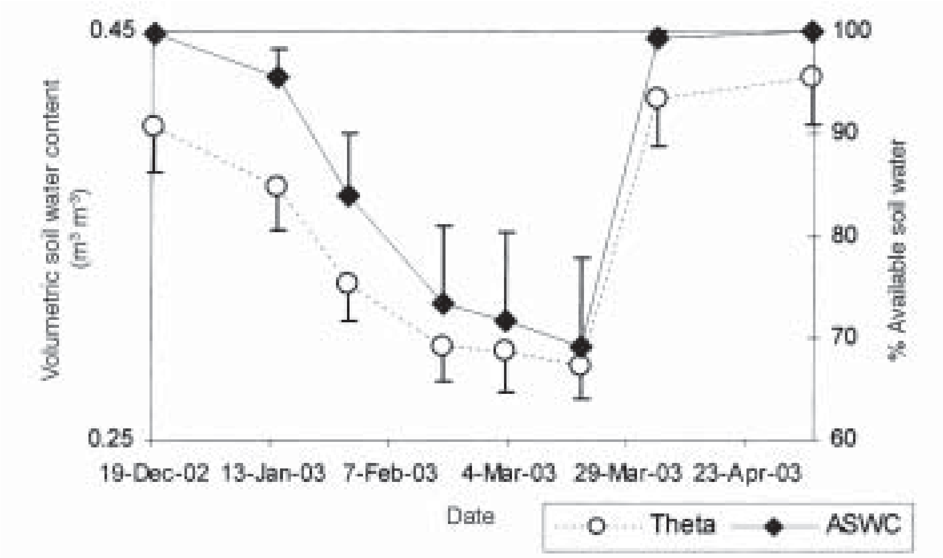

Figure 8. Changes in volumetric soil water content (theta) and available soil water content (ASWC) prior to, during and following the 2003 dry season. Vertical lines indicate + or - s.e.m. (n=12).

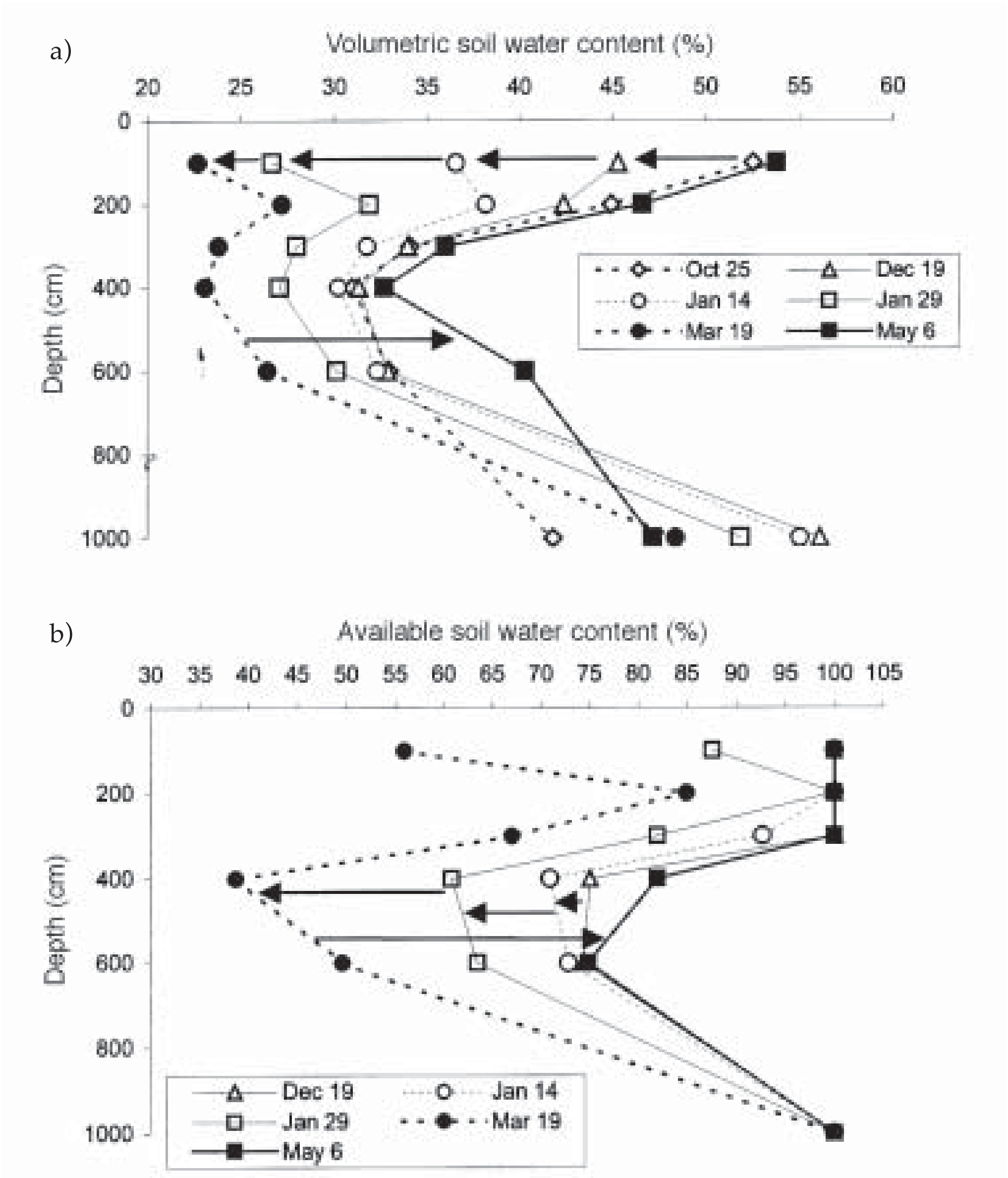

Figure 9. Mean changes in volumetric soil water content (a) and available soil water content (b) at different soil depths over time. Arrows indicate the direction of changes with time.

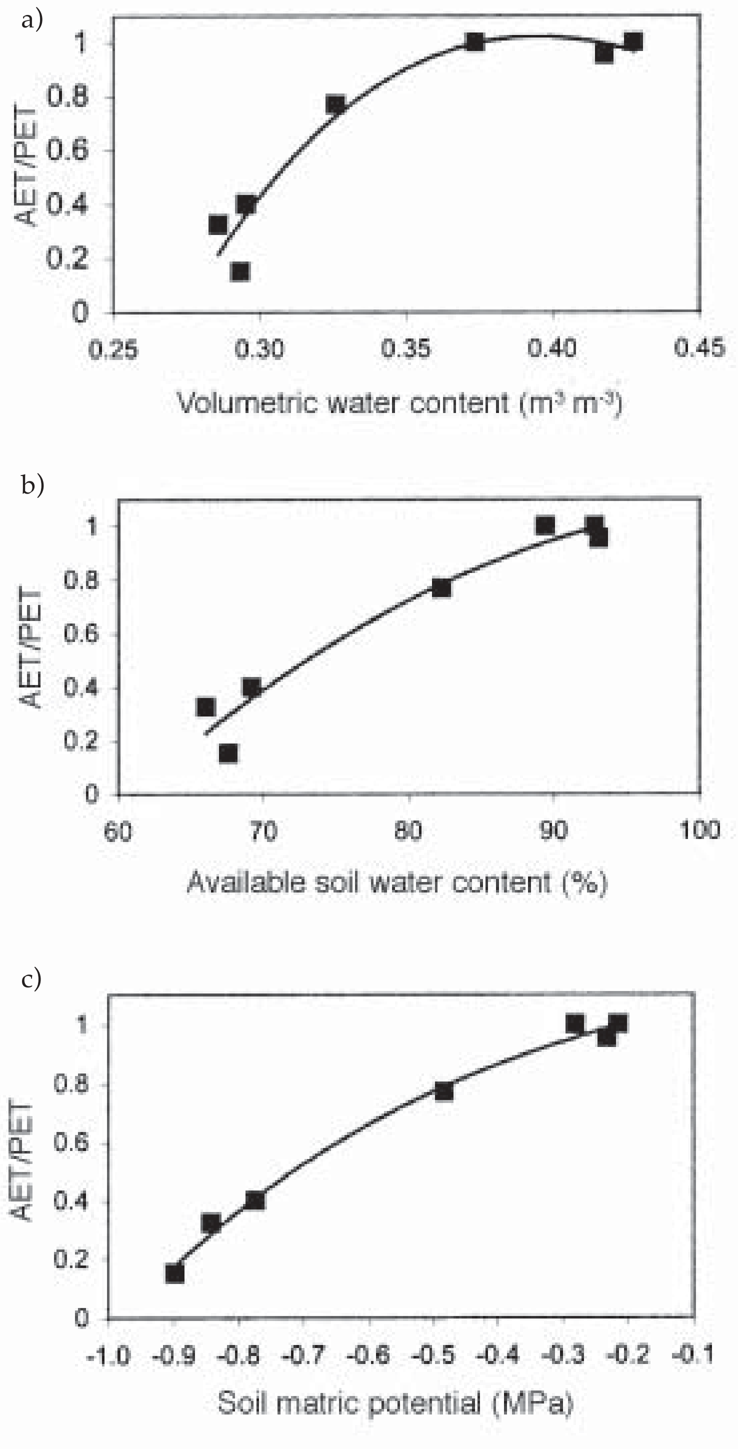

Figure 10. Relationship between the AET/PET ratio and (a) volumetric soil water content, the AET/PET ratio and (b) available soil water content and the AET/PET ratio and (c) soil matric potential. Fitted curves are third order polynomials.

Stress Detection by Measurements of Palm Canopy Temperature

Continuous monitoring of canopy surface temperature was carried out on the two plots equipped with other recording instruments using non-contact infrared thermometers suspended about 1 m above the canopy of two palms in each plot. The canopy-air temperature difference (ΔT) serves as an indicator of plant stress since leaf temperature increases relative to air temperature as stomata close and evaporative cooling due to transpiration is reduced. However, several other factors can also affect the actual ΔT value, the main ones being radiation and atmospheric vapour pressure deficit.

Changes in ΔT were assessed in three ways: i) using *all* hourly mean values recorded throughout 24 hr of each day; ii) using only data collected when solar radiation exceeded five W m^{-2} (defined as daylight) and iii) using only data collected when solar radiation exceeded 100 W m^{-2}. The latter resulted in the largest and most easily detected changes over time (*Figure 11*).

The data show a marked rise in ΔT beginning at the end of January and peaking at the end of March 2003. As shown in *Figure 6*, radiation levels also generally increased during the dry season but the levels were somewhat erratic compared with the more gradual and continuous changes in ΔT. The relationship between ΔT and radiation was variable (*Figure 12*) with ΔT differing at a given radiation level. Nevertheless, there were significant correlations between ΔT and radiation for the three data sets (*Table 4*).

The relationships between ΔT and vapour pressure deficit (VPD) and ΔT and PET were also examined (*Figure 12*). In comparing the three variables, namely, radiation, VPD and PET, the influence of VPD was by far the strongest (*Table 4*).

Relationships between ΔT and soil water characteristics are shown in *Figure 13*. While only tentative, due to relatively few data points, the results indicate a more linear response to soil matric potential than to water content. Only when volumetric soil water content fell below about 0.37 m^3 m^{-3} did ΔT increase.

Spear Leaf Extension Rates

Previous studies (Henson, 1991a) have shown that the extension rate of developing spear leaves is very sensitive to water supply. Results of

TABLE 4. CORRELATION COEFFICIENTS BETWEEN CANOPY-AIR TEMPERATURE DIFFERENCES (ΔT) AND SOLAR RADIATION, ATMOSPHERIC VAPOUR PRESSURE DEFICIT (VPD) AND POTENTIAL EVAPOTRANSPIRATION (PET)

Data set	Radiation		VPD		PET	
	r^2	*P*	r^2	*P*	r^2	*P*
ΔT - all data	0.343	0.01	0.638	0.001	0.245	0.05
ΔT – with RAD>5 W m^{-2}	0.453	0.001	0.831	0.001	0.354	0.01
ΔT – with RAD>100 W m^{-2}	0.441	0.01	0.842	0.001	0.377	0.01

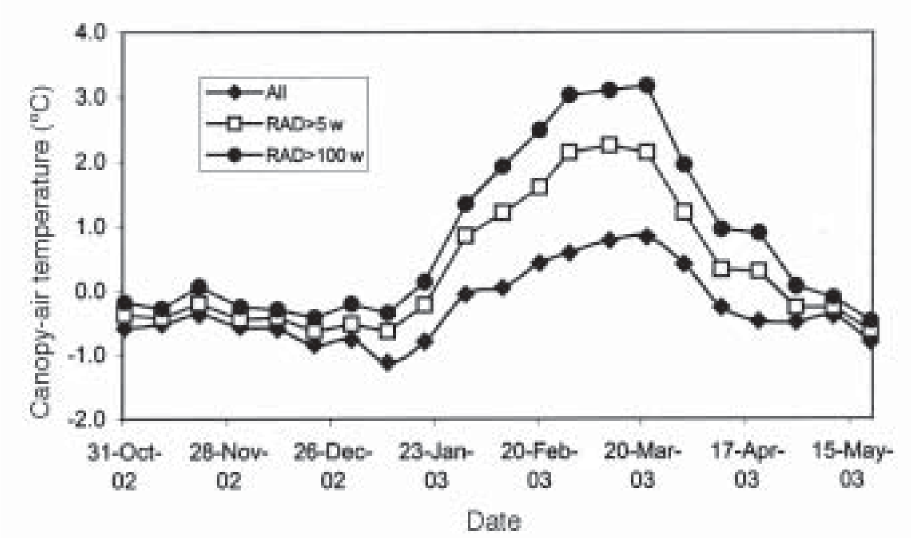

Figure 11. Changes in canopy-air temperature differences (ΔT) over time. Data were either unfiltered 24 hr means, filtered to include only times when radiation exceeded 5 W m^{-2} or filtered to include only times when radiation exceeded 100 W m^{-2}.

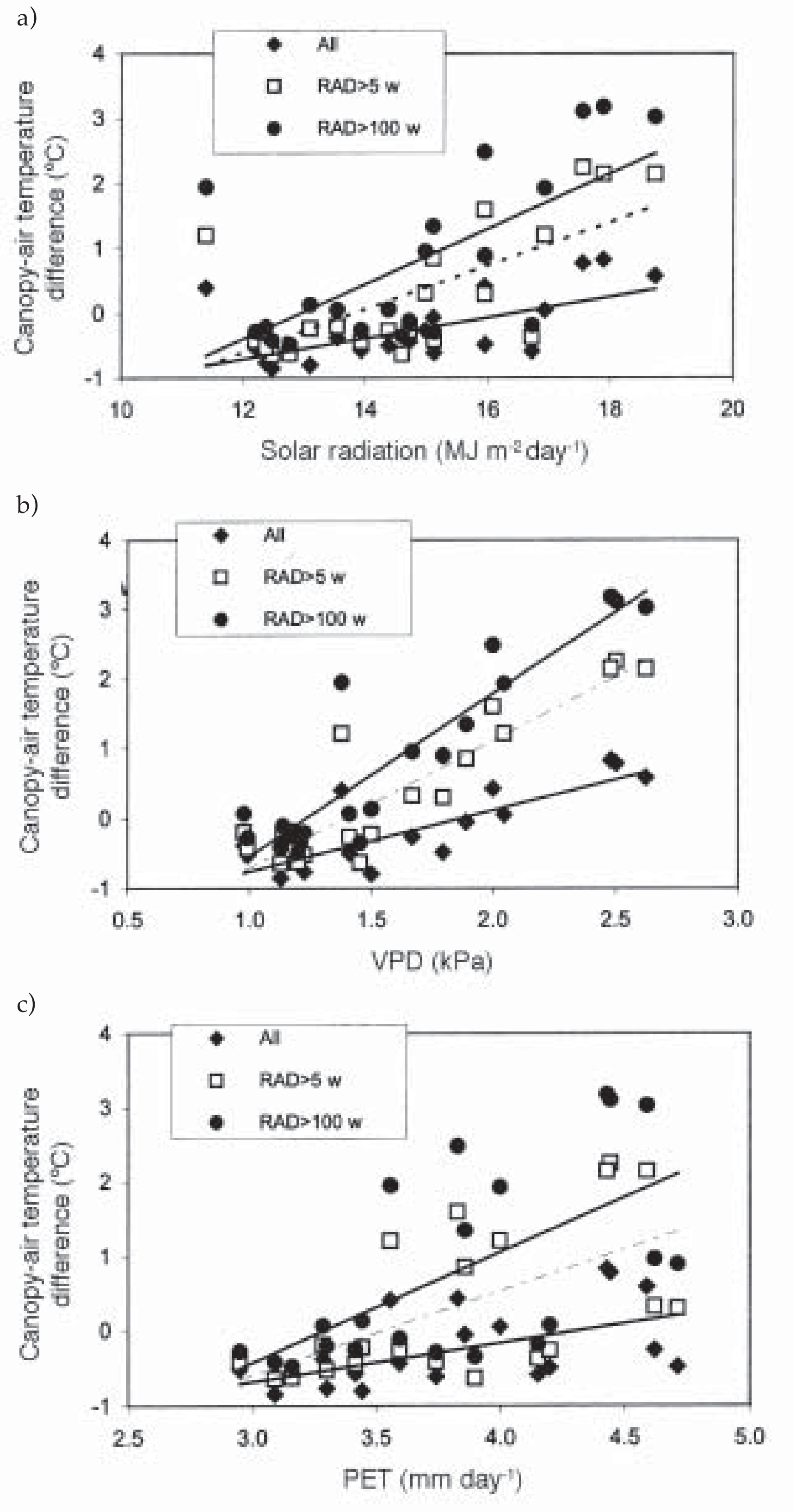

Figure 12. Relationships between canopy-air temperature differences (ΔT) and (a) solar radiation, (b) atmospheric vapour pressure deficit (VPD) and (c) potential evapotranspiration (PET). ΔT values were either unfiltered 24 hr means, filtered to include only times when radiation exceeded 5 W m^{-2} or filtered to include only times when radiation exceeded 100 W m^{-2}. Lines of best fit are shown where in all cases, the lower line is for unfiltered, the middle for radiation >5 W m^{-2} and the upper for radiation >100 W m^{-2}. Correlation coefficients are given in Table 4.

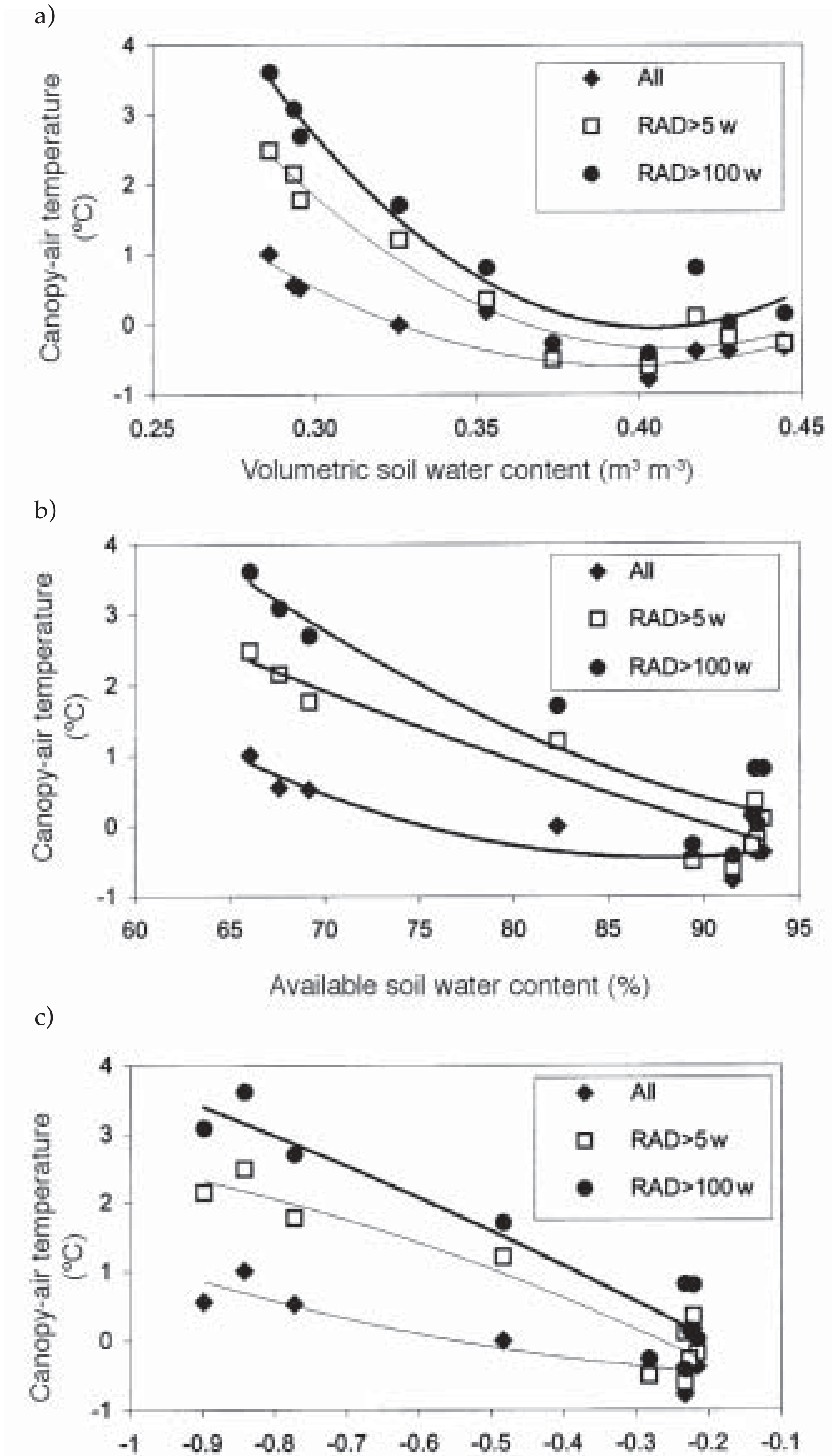

Figure 13. Relationships between ΔT and (a) volumetric soil water content, (b) available soil water content and (c) soil matric potential. Other details as for Figure 12.

measurements made before, during and at the end of the dry season are shown in *Figure 14*. Extension rates declined during the dry period but recovered rapidly following the onset of rains in late March.

Relationships between spear leaf extension rates and soil water supply are shown in *Figure 15*.

DISCUSSION

The regular dry season experienced in north Kedah has restricted cultivation of oil palm in the area. Providing that an adequate source of water is available for irrigation there seems no reason why

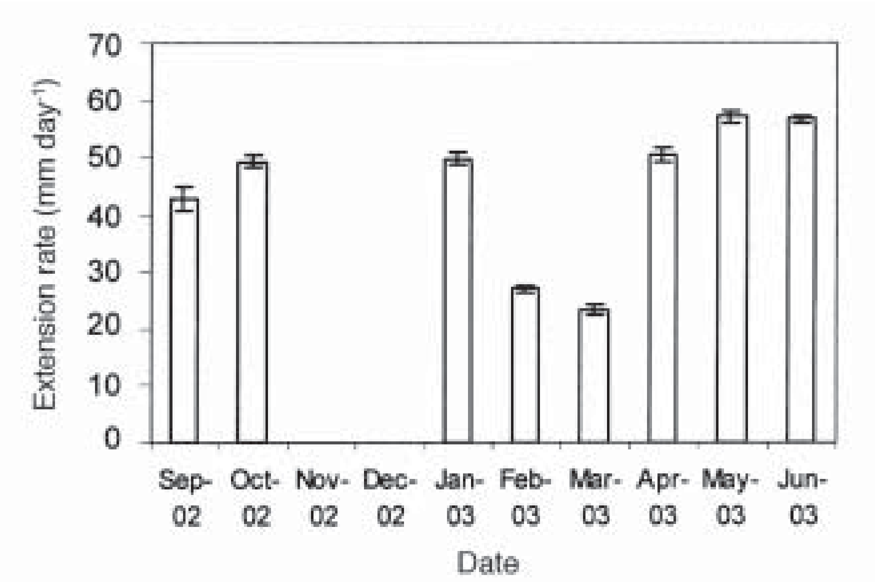

Figure 14. Changes in the extension rate of spear leaves over time. Upright lines on bars indicate ± s.e.m. (n=32 or 48). Measurements were made in the middle of the month. No measurements were made in the wet months of November and December 2002.

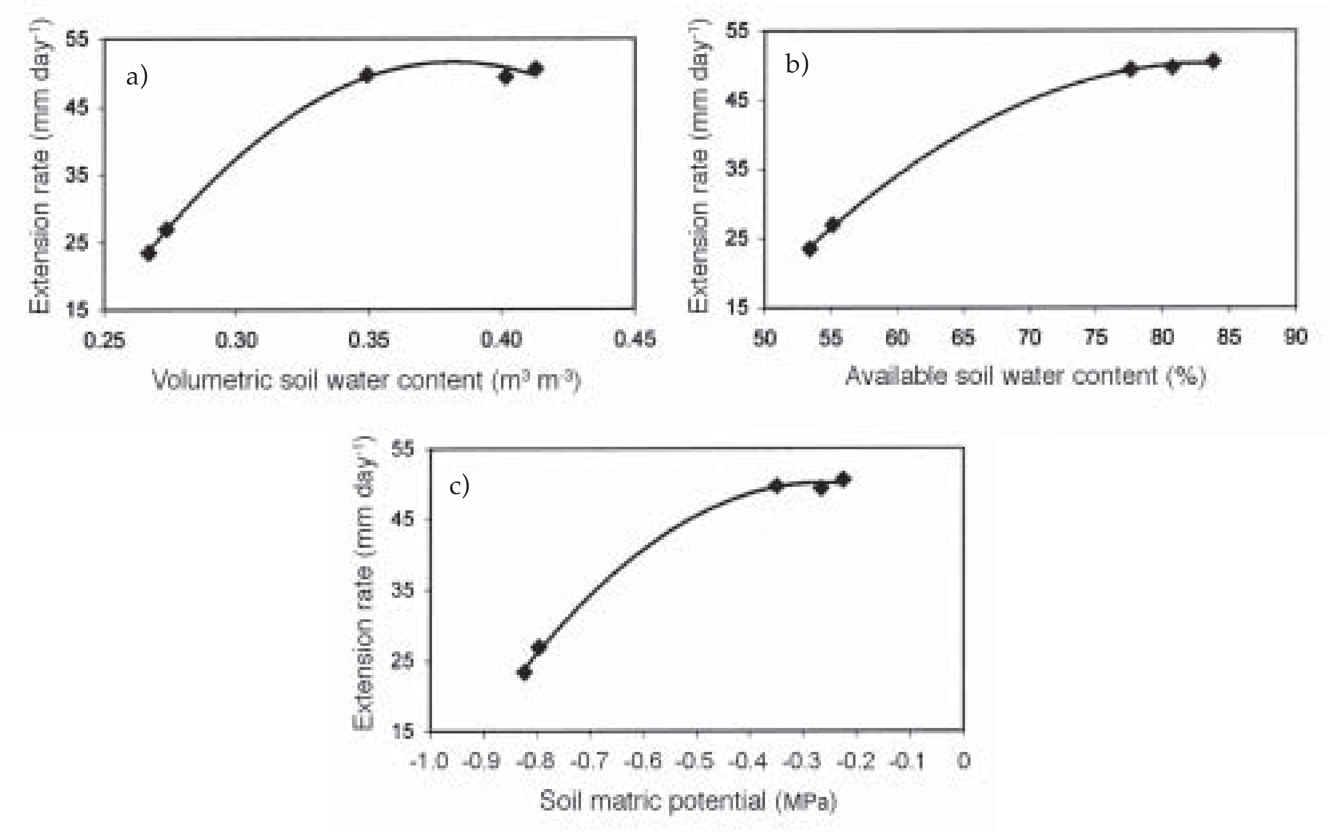

Figure 15. Relationships between spear leaf extension rate and (a) volumetric soil water content, (b) available soil water content and (c) soil matric potential.

cultivation of the crop in this region should not be successful. Presently, however, there are few guidelines on the best irrigation strategies for oil palm.

These should aim to maximize yield while avoiding the wasteful use of water, since supplies could be limited once irrigation becomes widely practiced in an area. Furthermore, additional income from any yield gain due to irrigation must offset the costs of installing, running and maintaining the irrigation system.

Despite various irrigation trials with oil palm having been conducted in the past, there is still little rational basis for determining when to irrigate, how frequently or how much water to apply. The response to irrigation in terms of increased FFB or oil yield usually only becomes apparent after a year or more due to the slow development and yield formation processes. Other, more immediate criteria on which to base irrigation scheduling are required. Any such criteria must of course, ultimately relate to the yield response. This paper reports on only the first stage in such a process, namely, the identification of practical and rapid methods of stress detection in the crop. The relationship between such stress responses and the impact on yield of the crop constitutes the next step and still remains to be determined.

Previous work suggested several possible methods of detecting water deficit stress in oil palm (*Table 1*). The decision to concentrate on palm responses rather than assess the likelihood of stress indirectly through soil or meteorological readings was a consequence of the poor quality or lack of information on the relationships between such parameters. In selecting the responses from those listed, primary considerations were the sensitivity of the response, its ease of detection and the simplicity of the measurement. The methods chosen were measuring the spear leaf extension rate and the canopy-air temperature difference (ΔT). Both fulfil the foregoing criteria to different degrees.

Measuring spear leaf extension rate requires little in the way of equipment and can easily be undertaken by estate workers with a little training. A 24 hr period is adequate to obtain a measurement. However, accessibility may be a problem with tall palms and there is some element of subjectivity in measurement arising from parallax errors. A more rigorous method is proposed using optical equipment. In either case, baseline measurements taken during wet periods or on fully irrigated plots are essential against which to judge effects of any water deficit. There is a likelihood that spear leaf extension rate may vary with genotype with short or compact palms having lower rates. Nevertheless, it is the relative reduction in rates rather than their absolute values that is likely to be most relevant in assessing stress response.

Some data were obtained on the relationship between spear leaf extension rate and soil water supply. However, there are rather too few data points defining this and more information is required to define the threshold values below which extension rates decline.

Measuring ΔT requires instrumentation but has the advantage of being a largely automatic and continuous process. Once equipment is installed, the only work involved is in periodic cleaning and adjusting the position of the sensors and collection and analysis of data from the logger. In the present exploratory study, data were logged hourly but the volume of data collected could be minimized by recording only daily maximum temperatures. A 60-channel logger was used in the present study as several weather variables were being recorded. However, a simpler, less expensive logger would be adequate for routine estate use. Supporting sensors above the canopy could be a problem with tall palms. A telescopic mast might be the most practical solution, allowing for easy adjustment and retrieval of the sensors.

The present study suggests that both the growth and temperature measurements could be used to quantify stress in the palms which otherwise show little overt indication of water deficit. For both, it was possible to relate the responses to some extent to the changes in soil water status. Such relationships may change with age and size of the palms and more data are required to verify the relationships. It is intended to obtain these in subsequent seasons.

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