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SHORT-TERM RESPONSES OF OIL PALM TO AN INTERRUPTED DRY SEASON IN NORTH KEDAH, MALAYSIA

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ABSTRACT

The annual dry season in north Kedah, which can extend for two to three months, was interrupted in 2006 by three substantial rains at approximately monthly intervals. Measurements of CO_2, latent heat and sensible heat fluxes above the canopy of five and a half year-old oil palm, supplemented by growth measurements, soil water and supporting meteorological data, indicated considerable mitigation by the rainfall of the effects of the dry season. Thus, reductions in CO_2 uptake, canopy conductance and evapotranspiration, and increases in sensible heat flux and accumulation of spear leaves, were less than expected.

The data suggest that even infrequent irrigation during a dry season may suffice to prevent a substantial build-up of stress in the palms under the edaphic conditions of the trial. Further observations to determine the long-term impacts on yield are, however, necessary.

Keywords: oil palm, dry season, canopy photosynthesis, evapotranspiration, micrometeorology.

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INTRODUCTION

In northern Kedah, close to the border with Thailand, there are usually two or three months (from as early as mid December through to late March) with little or no rain when unirrigated crops become very dependent on soil water reserves and ground water supplies. MPOB has established a trial there to assess the impact of the seasonal drought on oil palm physiology, growth and yield.

In previous work at this site in 2004 (Henson and Mohd Haniff, 2005), it was found that the uptake of CO_2 from above the canopy (CO_2 flux) by the crop and other vegetation, and the total surface evapotranspiration (ET), were both severely curtailed, while the flux of sensible heat (H) was substantially elevated, during the second half of February after two months with minimal rain, as compared with values in the following wet months of April to June. However, such measurements should be repeated for the whole dry season together with the periods that precede and follow it, in order to obtain a continuous assessment of the changes. This was the main objective of the present study. From such data, the rate at which oil palm responds to climatic shifts, and the lag periods before measurable responses, can be assessed.

While the conditions at the end of 2004 and in early 2005 were very suitable for such a study, they were precluded by instrumentation problems and it was only late in 2005 that these were overcome. Plans were then made to cover the dry period expected to commence in December 2005 or January 2006. The results for this season, which in terms of the rainfall pattern proved a marked contrast to the years immediately preceding, are reported here.

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MATERIALS AND METHODS

Site, Climate and Crop

The experimental site is located at 6.27° N, 100.29° E at Sintok in Kedah, close to the border with Thailand. The rainfall is very variable, both between the months within a year and between years (*Appendix 1*). However, the minimum rainfall per month normally falls in January and February, and the maximum in October.

The oil palm stand was planted in July 2000 and was, therefore, more than five years old at the time the measurements reported here were commenced. The *tenera* palms were planted at a density of c. 148 ha^{-1} on c. 300 ha^{-1} of a sandy clay loam of Batu Lapan series (Plinthic Hapludult, USDA classification). The soil had a calculated available water holding capacity in the top 1 m of about 111 mm (Henson *et al*., 2005) and was unirrigated. Other oil palm stands of similar age, but on different soils, were located to the north and south of this planting. Further details of the site, crop and climate are given in previous papers (Henson *et al*., 2005; Henson and Mohd Haniff, 2005).

Measurements

The site was equipped with a range of instruments to monitor meteorological conditions above the crop canopy (Henson *et al*., 2005; Henson and Mohd Haniff, 2005). Continuous measurements were made of air temperature, canopy surface temperature, atmospheric humidity, wind speed and direction, short-wave solar radiation, net radiation and photosynthetically-active radiation (PAR). The vertical exchanges of carbon dioxide, water vapour and sensible heat between the canopy and the atmosphere above were assessed by eddy correlation using a sonic anemometer and an open-path CO_2/H_2O gas analyser, as described previously (Henson and Mohd Haniff, 2005). Soil heat fluxes were measured using thermopiles.

Soil water content (SWC) was measured manually at monthly intervals in six sub-plots using a Delta-T Devices (Burwell, UK) profile probe (Henson *et al*., 2005). Each sub-plot consisted of a triangular area bounded by three palms and contained 10 regularly spaced access tubes to receive the probe, each inserted to a depth of 1.1 m. A separate probe was permanently installed in one of the sub-plots close to the meteorological recording instruments and its output recorded hourly using a Delta-T DL2 data logger that converted the mV output to volumetric water content (m^3 m^{-3}) using the supplied calibration option for mineral soil. As the SWC recorded by the *in situ* probe, particularly at the lowest depths, was possibly influenced by water collecting in the tubes over time, data are presented only for the 300 and 400 mm depths (means of both). These showed a good correlation and a closer agreement than the output for other depths, with the mean plot values obtained manually during monthly sampling (r= 0.652; p<0.001).

The above-ground growth of the oil palm was assessed on 48 recording palms in three plots of 16 palms each, at three- to six-monthly intervals during the course of the study using conventional non-destructive techniques (Hardon *et al*., 1969; Corley *et al*., 1971). Age-dependent corrections were applied to the leaf area and dry matter data as described by Henson (1993). Counts on each palm of visible, separated spear leaves (*i.e*. readily distinguishable as individual leaves) were made on all palms at approximately monthly intervals.

Data Collection and Analysis

All meteorological data were automatically logged and stored as hourly means or totals. Data collection and analysis followed the procedures described earlier (Henson and Mohd Haniff, 2005).

RESULTS

Climatic Conditions

The 2005-2006 dry season was interrupted by several substantial rains so that the longest period without rain (neglecting falls <5 mm day^{-1}), which began on 19 December 2005, was only 54 days. The first months of 2006 were then effectively broken up into three main dry periods by major rains (*Figure 1*). The second of these periods could be split into an initial and a later phase (labelled 2a and 2b, respectively), based on the climatic conditions and canopy responses.

The conditions prevailing during each period are summarized in *Table 1*.

TABLE 1. AVERAGE CLIMATIC AND OTHER ENVIRONMENTAL CONDITIONS DURING THE DROUGHT PERIODS FROM DECEMBER 2005 TO APRIL 2006[1]

Period	Start date and day of year (in brackets)	Duration (days)	Rain (mm day^{-1})	SWC (m^3 m^{-3})	U (m s^{-1})	VPD (kPa)	SRAD (MJ m^{-2} day^{-1})	PET (mm day^{-1})
1	19 Dec (353)	54	0.57	0.561	1.15	1.18	14.18	3.73
2a	16 Feb (47)	21	0.74	0.488	1.19	1.88	17.05	5.02
2b	9 March (68)	11	0	0.379	1.05	1.94	19.29	5.34
3	22 March (84)	19	2.01	0.450	0.67	1.01	15.99	4.46

Notes: [1]SWC is the mean volumetric soil water content at 300 and 400 mm depths as given by the *in situ* probe; U, the horizontal wind speed above the canopy measured by a sonic anemometer; VPD, the atmospheric vapour pressure deficit above the canopy; SRAD, the total short-wave solar radiation; and PET, the potential evapotranspiration. The data were recorded hourly, from which daily means, or in the case of rainfall, SRAD and PET, daily totals, were calculated, and averaged over each period as indicated. The periods were demarcated by major rainfall events (one or more days with >50 mm day^{-1}) with Period 2 being divided into two parts determined by differences in conditions and response (see text). Due to missing data, the SWC for Period 2a is an estimate only, and a smooth trend is assumed in the interval between measurements.

Responses of the Stand

Period 1. (From 19 December 2005 to 10 February 2006; day of year [DOY] 353 to 41.) Although Period 1 was the longest of the dry periods, it commenced with a fully saturated soil and maintained a relatively high mean SWC as compared with later periods (*Table 1*). Atmospheric vapour pressure deficit (VPD), solar radiation (SRAD) and potential evapotranspiration (PET) were lower than during the other times and this would have favoured a lower actual evapotranspiration (AET), leading to a less rapid depletion of the soil water reserve. The mean response data (*Table 2*) give little indication of plant stress during this period as shown by the normal rates of CO_2 uptake, levels of canopy or surface conductance to water vapour (g_c) and AET, and by the low sensible heat flux (H), low Bowen ratio (β; = H/LE, where LE is the latent heat flux), the small increase in the canopy – air temperature difference (ΔT), and the high AET/PET ratio.

However, while not apparent from the mean values, both SWC and g_c decreased steadily during this period, reaching low levels just prior to major rains on days of year (DOY) 45 and 46, when there were also transient reductions in CO_2 uptake, AET and AET/PET. These occurred partly due to lower solar radiation, which also caused PET to fall. At the same time there were increases in H and β (*Figures 1* and *2*).

Period 2. (From 16 February to 19 March 2006; DOY 47 to 78.) During this second period, SWC decreased more rapidly than hitherto. Unfortunately, the SWC records were not continuous due to a logging failure (*Figure 1b*), but apart from a transient and minor increase as a likely response to the sole rainfall event in this period (15.5 mm rain on DOY 59), the decline in soil water appears smooth and progressive, a trend supported by results of simulating the soil water status using the OPRODSIM model (Henson *et al*., 2007). The mean values for the whole profile obtained with the manual (monthly) probe readings confirmed the general trend revealed at 300 and 400 mm depths by the logged measurements (*Figure 1b*).

The first part of Period 2, termed 2a (DOY 47 to 67), showed little indication of drought stress with all the monitored variables giving values indicative of ample water supply (*Table 2*). In contrast, during Period 2b (DOY 68 to 78), there were obvious declines in CO_2 uptake (*Figure 2a*), g_c (*Figure 2b*), AET (*Figure 1c*) and AET/PET (*Table 2*), and increases in H, β (*Figure 2c*) and ΔT (*Table 2*). In period 2b, AET was 70% of the value in Period 2a, while the CO_2 assimilation rate declined to only 40%. These changes, and the more rapid soil water depletion, were doubtless spurred on by the conditions of higher radiation, VPD and PET that were observed just prior to the declines and during them.

The trends in g_c roughly paralleled the changes in SWC. The occasional spikes in g_c (*Figure 2b*) can largely be accounted for by the evaporation of free water from the plant and soil surfaces after rain.

Period 3. (From 25 March to 10 April 2006; DOY 84 to 100.) This was a phase of recovery as the soil re-wetted with consequent increases in CO_2 uptake, g_c, LE, AET and AET/PET and decreases in H, β and ΔT (*Table 2*).

Vegetative growth. In contrast to earlier years, the dry periods of 2005-2006 were not of sufficient duration to result in any marked accumulation of spear leaves (*Figure 3*). Nor, as found by standard vegetative measurements made in December 2005, March and June 2006, was there evidence of any marked negative impact on shoot growth. The rate of frond biomass production from December 2005 to March 2006 (6.90 t ha^{-1} yr^{-1}) was slightly lower than during June 2005 to December 2005 (6.95 t ha^{-1} yr^{-1}) and fell further to 6.27 t ha^{-1} yr^{-1} between March and June 2006 (despite the latter period being wetter than the preceding one), but this was most likely due to age-related declines in frond production rate. Trunk growth was actually higher in the first six months of 2006 than previously, as was total above-ground biomass production.

TABLE 2. AVERAGE STAND RESPONSES DURING THE DROUGHT PERIODS FROM DECEMBER 2005 TO APRIL 2006[1]

Period	Start date and day of year (in brackets)	CO_2 uptake ($G\ m^{-2}\ hr^{-1}$)	g_c ($mm\ s^{-1}$)	LE (Wm^{-2})	H (Wm^{-2})	β (H/LE)	ΔT (°C)	AET ($mm\ day^{-1}$)	AET/PET
1	19 December (353)	1.63	8.05	177.7	37.6	0.21	0.69	3.17	0.850
2a	16 February (47)	1.79	7.96	224.4	50.0	0.22	1.08	3.86	0.769
2b	9 March (68)	0.71	3.30	138.0	118.0	0.86	1.74	2.69	0.504
3	22 March (84)	1.59	6.89	188.6	36.5	0.19	0.63	3.68	0.825

Notes[1]: g_c is the canopy (surface) conductance to water vapour; LE, the latent heat flux; H, the sensible heat flux; β, the Bowen ratio (H/LE); ΔT, the canopy-air temperature difference; AET, the actual evapotranspiration and PET, the potential evapotranspiration. With the exception of AET, the data are mean daily daytime values for each period where daytime is defined as hours when the mean solar radiation exceeded five W m^{-2}. The drought periods were demarcated by major rainfall events (one or more days with >50 mm day^{-1}) with period 2 being divided into two parts determined by the change in H. The CO_2 uptake and β have been corrected for LE and H, and LE for H. Flux data exclude hours with aberrant readings due to rain droplets on the sensor surfaces.

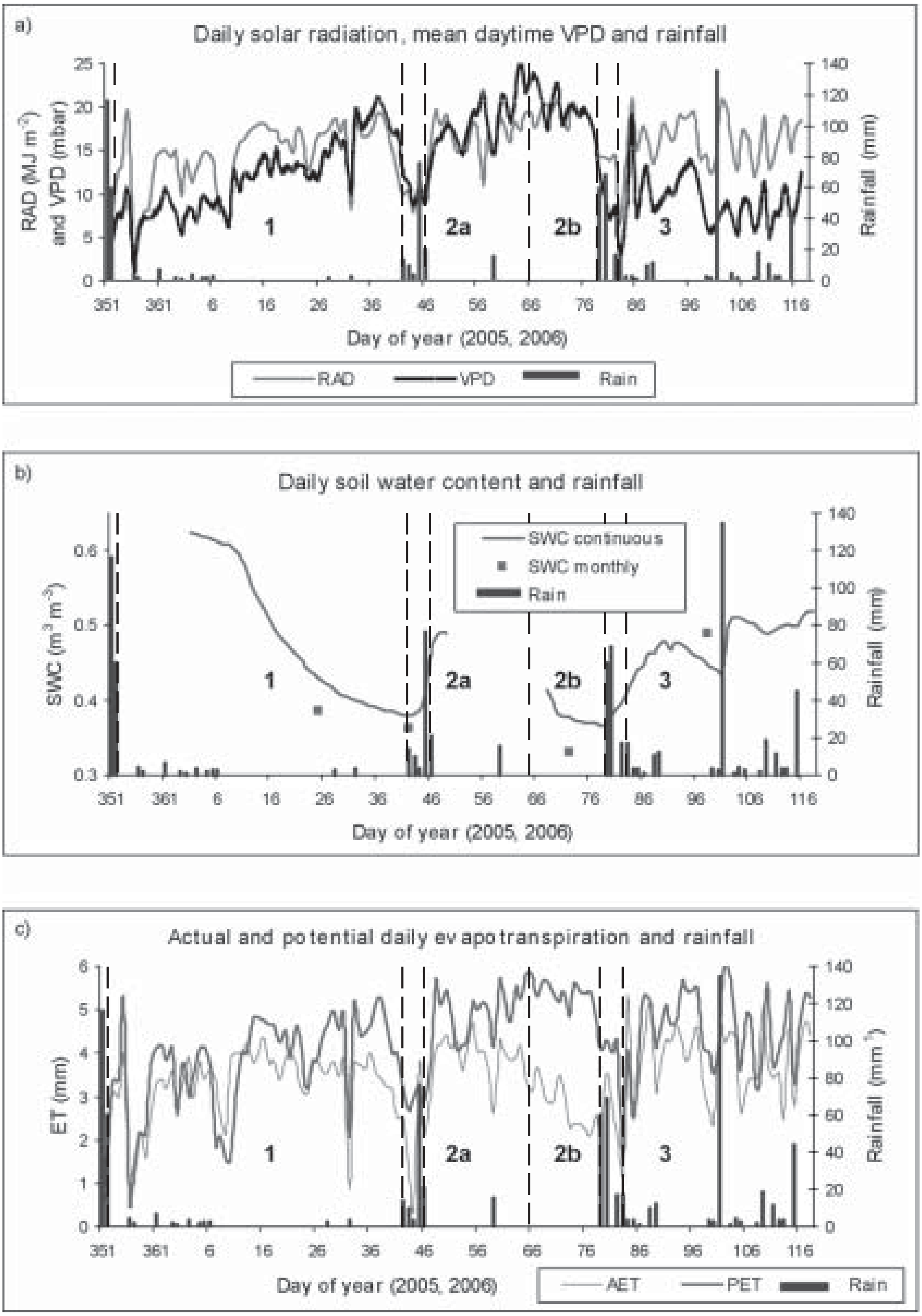

Figure 1. Daily changes in relation to rainfall events from mid December 2005 to late April 2006 in (a) solar radiation (RAD) and vapour pressure deficit (VPD), (b) soil water content (SWC), and (c) actual evapotranspiration (AET) and potential evapotranspiration (PET).

Notes: Soil water content was measured using both a continuously logged profile probe retained at one location (where data are the means of 300 and 400 mm depths) and by a portable profile probe at multiple locations at approximately monthly intervals. In the latter case, data are for the whole profile and are means of six sub-plots with 10 positions per sub-plot. The four dry periods (1, 2a, 2b and 3) referred to in the text are indicated, and demarcated by vertical dashed lines.

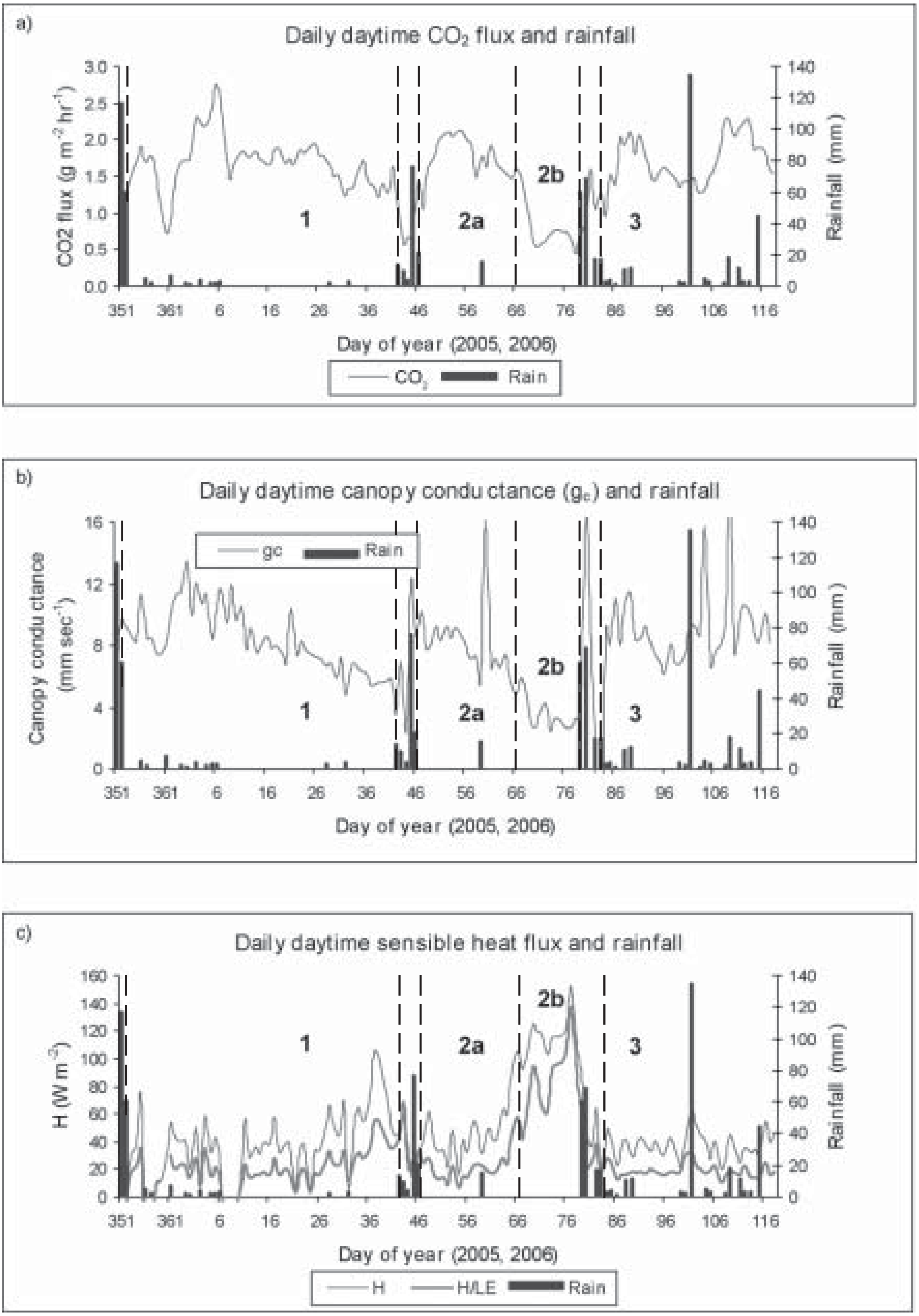

Figure 2. Daily changes in relation to rainfall events from mid December 2005 to late April, 2006 in (a) total daytime CO_2 uptake by the canopy, (b) mean daytime canopy conductance to water vapour, and (c) mean daytime sensible heat flux (H) and the ratio of sensible to latent heat flux x 100 (H/LE).

Note: The four dry periods (1, 2a, 2b and 3) referred to in the text, are indicated, and demarcated by vertical dashed lines.

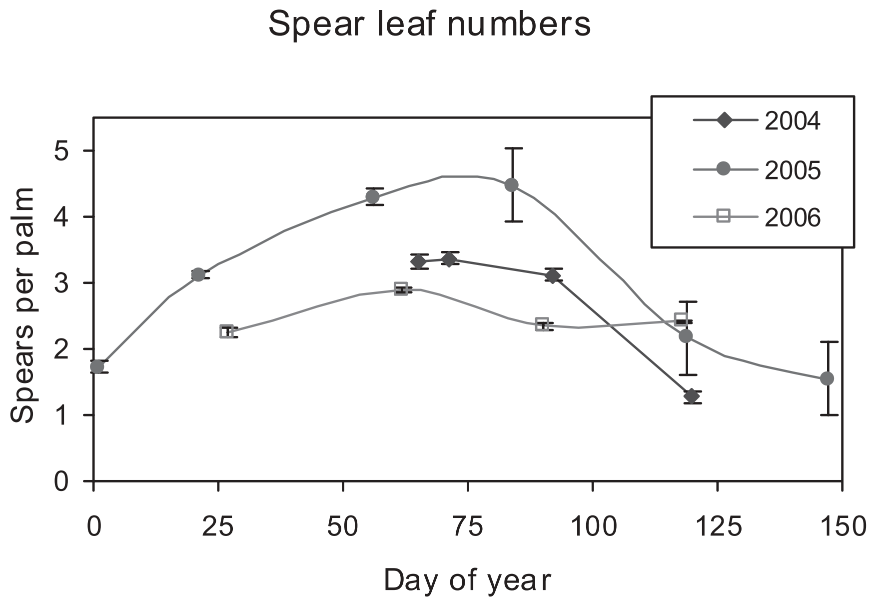

Figure 3. Comparison between three years in spear leaf numbers per palm during the annual dry season.

Note: Data are means of three plots (16 palms per plot) ± standard error.

These observations on vegetative growth are consistent with the very slight impact of the dry season on canopy gas exchange.

Leaf-Level Responses

The measurements of CO_2 flux and canopy conductance may, with certain provisos, be used to calculate the mean leaf (single surface) net photosynthesis (Pn) and conductance (g_l) rates. This is achieved simply by dividing the canopy values by the oil palm leaf area index (LAI) which, during the period covered, averaged 3.02. This calculation neglects the contribution by ground vegetation and AET from the soil surface, but these are likely to be only minor components. The values obtained, converted to the units commonly used in making leaf level measurements with gas-exchange cuvettes, are given in *Table 3.* Both the mean values (daylight hourly means through a day) and the maximum values (the peak hourly value during a day) are given, where the latter are more likely to reflect the values obtained during gas-exchange cuvette measurements (generally carried out only under clear sky conditions or with controlled, high, PAR). Lower values derived from canopy measurements may, however, be anticipated, as these are averaged over all leaves whilst cuvette measurements are generally conducted using only upper, well exposed, fronds. Such measurements made in early February 2006 and again in May after several rains, produced mean values for Pn and g_l ranging from 7.13 to 9.35 µmol m^{-2} s^{-1} and 170 to 280 mmol m^{-2} s^{-1}, which agree well with the canopy data.

TABLE 3. MEAN LEAF SINGLE-SURFACE NET PHOTOSYNTHESIS RATES (PN) AND CONDUCTANCE TO WATER VAPOUR (G_L) DURING THE 'DROUGHT' PERIODS FROM DECEMBER 2005 TO APRIL 2006

Period	Start date	Pn (µmol CO_2 m^{-2} s^{-1})		g_l (mmol m^{-2} s^{-1})	
		mean	max	mean	max
1	19 December	3.50	10.08	107	234
2a	16 February	3.68	6.53	106	210
2b	9 March	1.47	4.76	44	114
3	22 March	3.32	9.86	91	253

Note: Mean values are the average hourly daylight rates and max values, the average daily maximum rates observed during each period, derived from flux measurements.

DISCUSSION

Although the major objective of assessing the immediate responses of oil palm to a relatively long and sustained period of drought and following its relief (in order to determine the rates of change, both as the drought sets in and during recovery) are still to be realized, the present observations are not without interest and are indeed quite relevant in the context of the variable rainfall pattern found in this seasonally dry area of Malaysia. Although an annual dry period is the norm and is to be expected in the early part of the year, an examination of rainfall records (*Appendix 1*) shows that the precise pattern differs from year to year, and years with three or more months with no rain (as in 2004-2005) are probably the exception. Over the last 19 seasons at the study site (December 1987 to March 2006), there were only four years when both January and February were without rain, although in another four the total rainfall for these two months was less than 13 mm (*Figure 4*). For January alone there were seven years with no rain and 14 years with a January rainfall of below 25 mm, so there appears to be quite a high probability of drought in that month. In February there were four years without rain and eight years with rainfall below 25 mm. A completely dry December is unusual (only one was recorded over the period covered), but most of the rainfall in that month is often confined to the first week or two, as was the case in 2003 and 2004. The conclusion from these data is that while a dry season lasting at least two months is usual, it is not inevitable, and that perhaps for one in four years there may be sufficient rain to sustain yields given adequate soil water reserves.

The maximum available soil water content (ASWC) in the top metre of soil at the study site, assessed as 111 mm, would provide for about 28 days requirement with an average AET of 4 mm day^{-1} (actual values were less than this; *Table 2*). This could account for the adequacy of the infrequent, yet substantial monthly rains in largely sustaining gas exchange and AET. However, it is likely that stress responses can set in well before the ASWC is fully depleted, perhaps after only about two-thirds of the water reserve has gone (Dufrene *et al*., 1992; Rey *et al*., 1998), although this may depend on the soil type. The maximum rooting depth of the palm and the presence of ground water will also be critical in determining dry period effects. Roots were assumed to be confined to the top metre of soil as most studies on oil palm have confirmed its shallow rooting nature. However, the possibility cannot be excluded that some of the roots may descend much more deeply, and so tap deeper reserves of soil water. It would be worthwhile carrying out some excavations to examine this.

The continuous soil water measurements made with the logged probe should be considered as approximate only. The probe only monitored the soil water within a ca. 100 mm wide ring of its axis and it was located approximately mid-way between palms in the inter-row, which would have tended to result in higher than average values due to the lower root density in this position. Also, the possibility of water collection in the tube cannot be discounted although the fit of the probe within the tube was tight. A further examination of the soil water measurements is made in a succeeding paper (Henson *et al*., 2007).

The present results suggest that the traditional approach to irrigation often adopted by planters, namely, to apply a large amount of water at protracted intervals (usually by filling the ditches or by flooding), may well be not only the most practical, but also perhaps as efficacious as more refined techniques such as daily drip irrigation. However, even so there will still be a need to adapt the irrigation frequency and amounts to suit the soil water reserves and PET, so as to optimize water use and avoid excessive water loss by drainage that may lead to nutrient losses due to leaching.

While the observed effects of periodic low rainfall were surprisingly restrained during the months studied, the consequences for longer-term palm development remain unknown. Thus, effects on sex determination, inflorescence growth and abortion, and, ultimately, yield, are still uncertain. Furthermore, they may long remain so, as it is difficult to distinguish the effects on reproductive development of the climatic pattern of one year from another. In principle, this might be achieved by applying irrigation sufficient to sustain maximum AET, in all the years following a studied drought

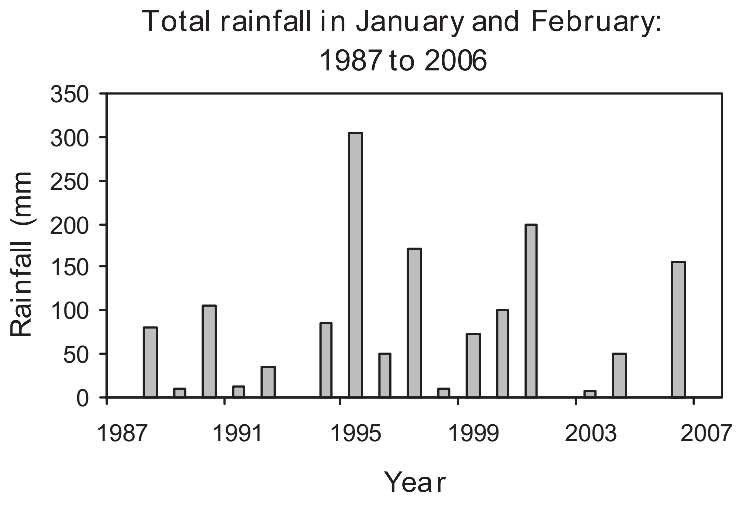

Figure 4. Rainfall at Sintok, Kedah during January and February combined, each year from 1987 to 2006.

Note: There was no rainfall in either month during 1987, 1993, 2002 and 2005.

period, so isolating that particular year's drought effect. However, a parallel irrigated treatment for the drought period in question would also be required and effects of other conditions, such as varying radiation levels, have a potential to confound the results.

CONCLUSION

Although the original objective was hindered, the present study has provided some useful indications regarding the ability of oil palm to function during short-term intermittent dry periods. Adverse effects appear minimal even if substantial rains occur only monthly. This implies that even infrequent irrigation may be effective, providing it is sufficient to substantially restore the soil water reserve. However, as shown by the responses in Period 1, rainfall alone is not the sole determining factor and other climatic conditions need to be allowed for. Thus, the impacts may have been more severe in Period 1 (the longest without rain) had more usual drought conditions (higher radiation, lower VPD) occurred.

Two further provisos apply. The first is that such responses will be influenced by both soil properties and palm root development. The latter needs to be better understood and the ability to extract water at depth requires investigating. For soils with low water holding capacity or with a shallow rooting depth, palms are likely to be susceptible to even short droughts and irrigation frequency will then have to be increased. The other main point is that the longer-term implications for yield still remain uncertain. The careful design and diligent execution of new experiments to resolve these issues is called for.

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Appendix 1

Monthly rainfall (mm) at Sintok, Kedah, 1987 to 2006[1].

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
1987	0	0	205.2	121.2	272.4	110.1	57.7	461.0	439.7	374.3	640.3	261.6	2 944
1988	25.4	54.2	58.9	468.0	306.9	235.2	429.8	443.5	320.8	307.8	604.4	93.3	3 348
1989	9.7	0	160.5	343.9	303.7	205.1	251.5	207.5	316.0	446.8	72.6	0	2 317
1990	32.8	73.7	136.7	144.6	428.3	198.2	220.9	81.3	118.2	646.0	311.7	73.0	2 465
1991	0	12.3	361.7	165.0	285.2	170.9	217.0	286.2	149.1	311.3	207.0	55.5	2 221
1992	9.8	26.3	70.9	75.3	241.7	277.8	369.5	324.1	268.1	510.0	615.5	224.5	3 014
1993	0	0	387.1	182.5	560.5	837.1	1065.9	316.2	283.5	832.9	537.5	695.8	5 699
1994	0	85.0	851.3	484.3	404.3	707.0	187.5	428.5	947.5	1011.5	329.0	30.0	5 466
1995	22.0	283.0	308.0	225.0	122.0	84.0	81.0	410.0	415.0	498.0	249.0	171.0	2 868
1996	20.0	30.0	91.5	169.0	160.5	176.0	119.0	218.0	156.5	207.0	142.0	185.0	1 675
1997	0	170.0	46.5	188.0	136.0	101.0	82.0	268.5	272.5	346.0	72.5	139.0	1 822
1998	6.5	4.5	20.0	66.0	38.9	81.1	187.2	271.6	192.9	452.3	481.1	159.1	1 961
1999	36.0	36.4	255.6	159.3	74.0	173.4	174.4	132.4	265.6	266.5	195.6	307.4	2 077
2000	32.0	67.8	391.9	409.0	131.0	140.9	89.5	228.0	122.0	160.3	326.5	75.0	2 174
2001	178.2	20.5	292.9	192.3	132.7	99.7	43.4	112.0	70.5	355.8	95.3	99.7	1 693
2002	0	0	58.5	66.5	118.5	105.9	186.7	170.9	311.5	346.2	235.9	215.5	1 816
2003	5.8	1.3	190.6	93.6	137.8	167.4	241.1	113.1	192.0	380.4	51.4	42.2	1 617
2004	10.3	40.5	91.7	215.2	240.8	224.6	111.3	142.4	319.9	155.4	16.0	86.0	1 654
2005	0	0	139.5	178.5	140.3	148.7	126.2	111.2	167.1	437.9	247.0	544.7	2 241
2006	0	156.2	193.7	212.9	363.9	129.0	123.9	49.0	329.1	354.8	135.5	45.7	2 088
mean	20.4	47.7	216.8	208.0	229.7	218.7	218.3	238.8	282.9	420.1	278.3	175.2	2 558

Source: [1]Ladang ESPEK Tanjung Genting, Sintok.