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NOTES ON OIL PALM PRODUCTIVITY. III. THE USE OF SAP FLUX PROBES TO MONITOR PALM RESPONSES TO ENVIRONMENTAL CONDITIONS

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Using a system developed in France, relative sap flux was measured in trunks and fronds of palms in relation to the potential euapotranspiration (PET) and euapotranspiration (ET) rates deduced from micrometeorological measurements. The method provided a sensitive means of detecting changes in transpirational activity related to radiation, PET, soil water supply and frond aging. Its further use and development are discussed.

INTRODUCTION

Plants experiencing soil or atmospheric water deficit generally reduce their evapotranspiration (ET) rates below the potential rate by stomata1 closure and other mechanisms. Such responses are also accompanied by a reduction in CO, uptake and in dry matter production. The flux of xylem sap through the plant will be closely coupled to whole plant ET and so measurement of this flux is one means of monitoring whether plants are experiencing stress in response to changes in environmental conditions.

In the present studies, a system using pairs of small probes inserted into the trunk or petiole base was used to provide information on 'relative' flux rates. Used in conjunction with micrometeorological measurements of canopy evapotranspiration (ET) and potential ET, a continuous record was possible of palm response to environmental conditions.

MATERIALS AND METHODS

Although several methods of sap flux measurement have been developed, the majority involve use of quite expensive and complex instrumentation. The method used in the present investigations *was* that developed by Granier (1985; 1987a,b). It employed pairs of temperature-sensitive probes, 20mm long, inserted into the conducting tissues. One probe per pair was heated by passage of a constant current through a constantan wire, while the other, placed

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150mm below it, was unheated. Both probes contained a copper-constantan thermocouple wired to a datalogger which recorded the temperature difference between them. The difference in temperature between the probes (dT) served as an inverse measure of the rate of sap flow. The method was first used for oil palm by Dufrene (1989).

The dT readings can be converted into sap flux rates (Sap flux density; u, m/s) using the empirical formula of Granier (1985, 1987b):

$$u = 119 * 10\text{-s} * [(dTo-dT)/dT]^{1.231}$$

where dTo is the temperature difference between the probes under conditions of zero flow. In most instances, the mean dT during the night can be used as a measure of dTo.

Measurements of sap flux were first attempted by inserting probes into the palm trunk. Because the trunks were still covered by cut frond bases these were removed to expose a surface area of trunk about 0.3m square located about half way between the soil and the point of attachment of the lowest intact frond.

As found by Dufrene (1989, and personal communication), probes inserted into the palm trunk lasted only a few days; the deterioration being associated with trunk exudations probably induced by wounding effects. An alternative was to insert the probes into the base of the petiole of a frond. Probes were placed on the underside of a petiole (on the lower 'ridge'), choosing fronds (ca. numbers 9-12) which were, at the time of insertion, in a largely upright position. This approach had the advantage of requiring no tissue preparation, minimizing tissue damage and allowing deeper insertion of the sensing probes relative to the location of conducting tissues than was the case with the trunk. Only results obtained using fronds are reported here.

Potential evapotranspiration (PET) of the canopy and actual evapotranspiration (ET) were calculated from measurements of air temperature, humidity, windspeed, net radiation and ground heat flux as described by Henson (1993). All these measurements, as with sap flux, were calculated as hourly averages. Soil water potential (SWP) was measured at 2-3 day intervals using tensiometers and gypsum blocks inserted at various depths and distances from a palm in the top one metre depth of soil.

The measurements were made on palms nine to ten years after planting at two sites - one on a moist coastal soil and the other on a drier inland soil as described previously (Henson, 1997). Both sites were sufficiently large (94 and 102 hectares respectively) to provide adequate fetch to the centrally located instrument masts.

RESULTS AND DISCUSSION

Some results of initial measurements on fronds at the coastal site where soil moisture stress was absent (SWP>-0.03 bars) are shown in Figure 1. It can be seen that sap flux varied closely with changes in PE, both tending to zero overnight and also decreasing during the day in response to heavy cloud cover (e.g. 8 January). Evapotranspiration rates closely followed

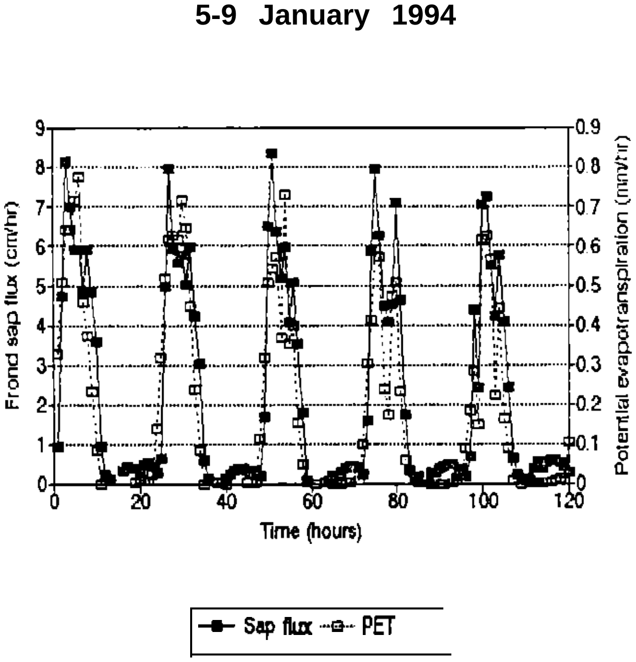

Figure 1. Hourly changes in single frond sap flux rate and in potential evapotranspiration (PET) by the canopy over five days at a coastal site with mean soil water potential > -0.03 bars.

those of PET (results not presented). Nevertheless, the relationship between sap flux and evapotranspiration was not simple. In the morning, sap flux lagged behind ET and PET, as demonstrated in Figure 2. The morning rise in ET in the absence of flux through the palm can be explained as due to the evaporation of dew from the canopy. Later, however, sap flux often peaked earlier than PET probably due to the tendency of stomata to close after mid-day as atmospheric vapour pressure deficit increased.

5-9 January 1994

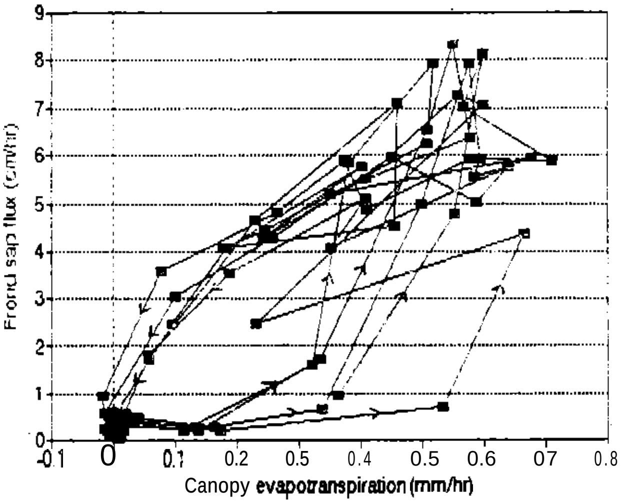

Figure 2. Hourly changes in *single* frond sap *flux* rate *over several days* at the coastal site plotted against *whole canopy evapotranspiration (ET)*. Arrows *show* the direction of change.

The tendency for sap flux rate to decline ahead of PET was more pronounced at the inland site and particularly during dry periods *(Figures 3a* and *3b)*. Following rains a closer correspondence was observed between flux and PE (Figure *3c*).

The validity of the frond measurements was demonstrated by removing the frond above the point of probe insertion. This resulted in a rapid damping of the rate of sap flux (Figure *4)*.

Once installed on a frond, the probes remained operational for a considerable time. However, it was noted that the maximum daily flux rates gradually diminished over time

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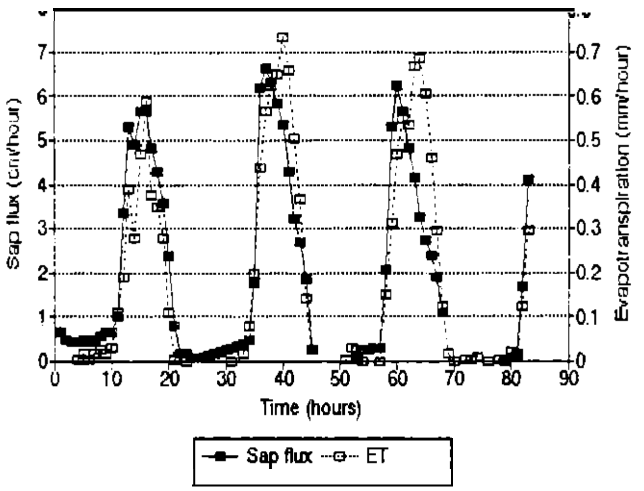
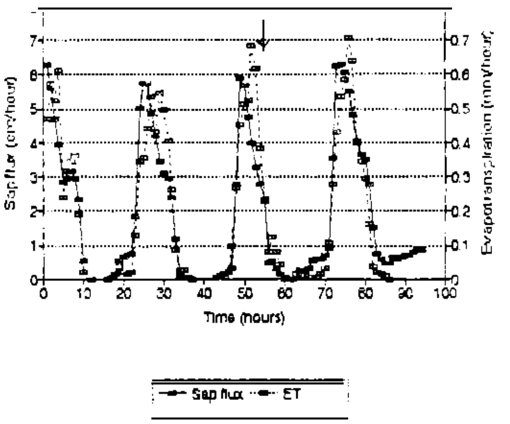


(B) 7-10 August 1994



(C) 15-18 August 1994

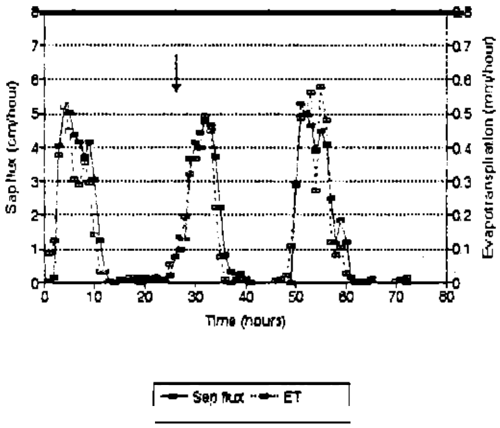


Figure 3. Hourly changes in *single* frond sap *flux* rate and in *evapotranspiration (ET)* by the canopy at an inland site in 1994 at different mean soil water potentials *(SWP)*. *(A)* SWP = -4.56 bars; *(B)* SWP = -5.33 bars; *(C)* SWP = -1.73 bars. Arrows indicate rains: 9 August, *20mm;* 16 August, *46mm*.

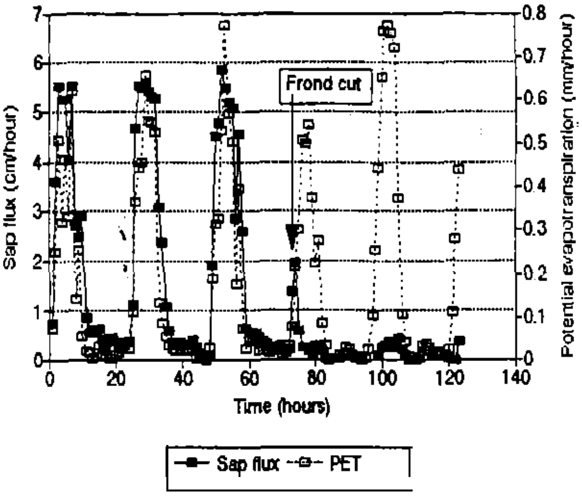
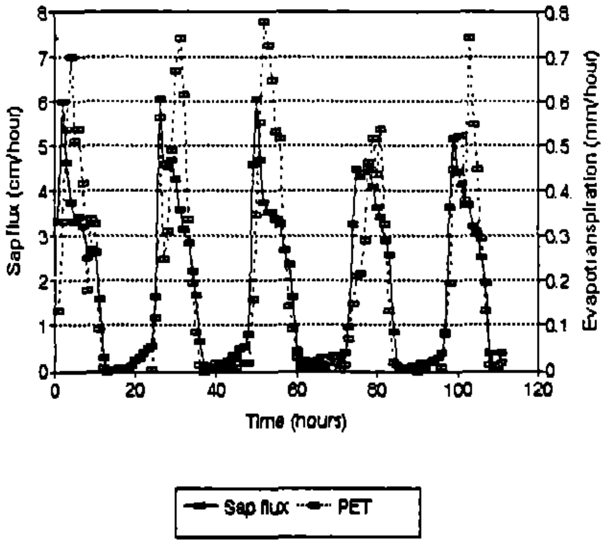
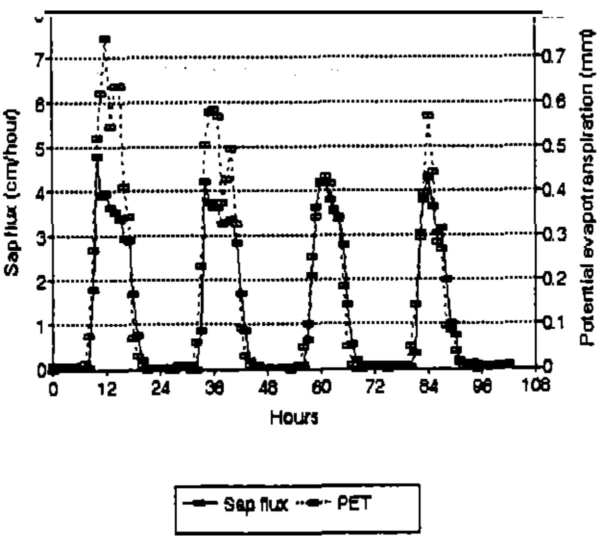
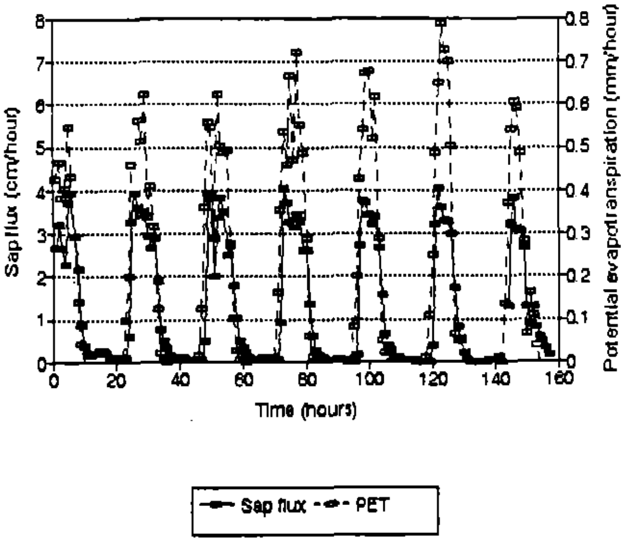

9-14 November 1994

Figure 4. The effect of cutting off the frond above the sap flux probes on the rate of sap flux in the petiole.

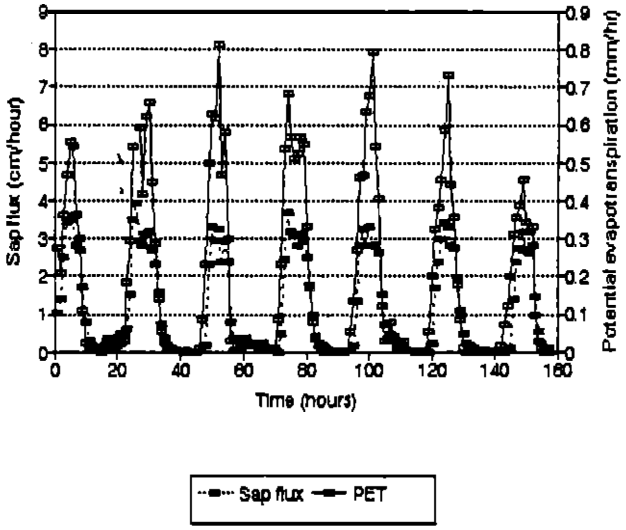
(Figures *5a* to *5f*). This effect was quantified by calculating the ratio between daily cumulative sap flux and daily PE. Ten day averages


(A) 30 December 1994 to 3 January 1995

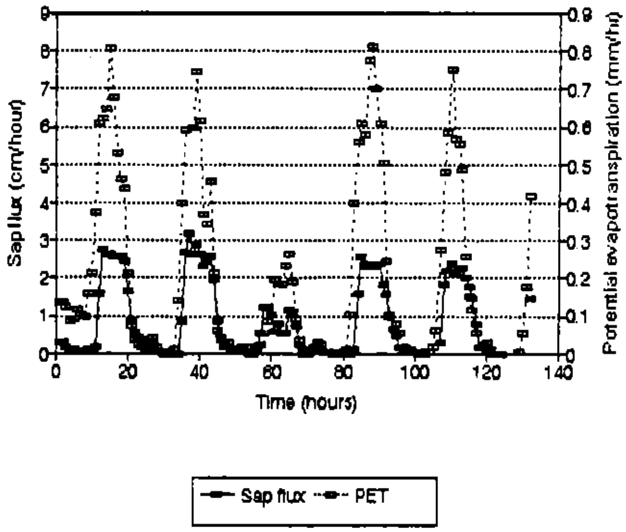

(B) 19-23 February 1995


(C) 28 May to 3 June 1995

(D) 18-24 June 1995



(F) 16-21 July 1995



(E) 2-8 July 1995

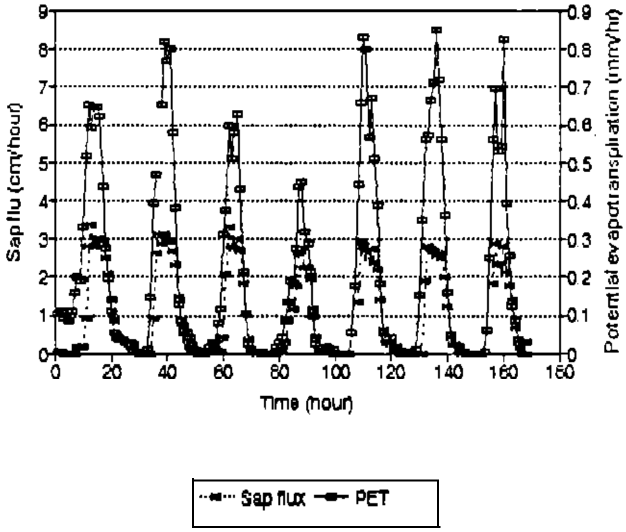


Figure 5. Hourly changes in single frond sap flux rate and in potential evapotranspiration (PET) by the canopy at the inland site on different days after insertion of probes. (A) 11-15 days; (B) 62-65 days; (C) 160-166 days; (D) 181-187 days; (E) 195-201 days; (F) 209-214 days after insertion.

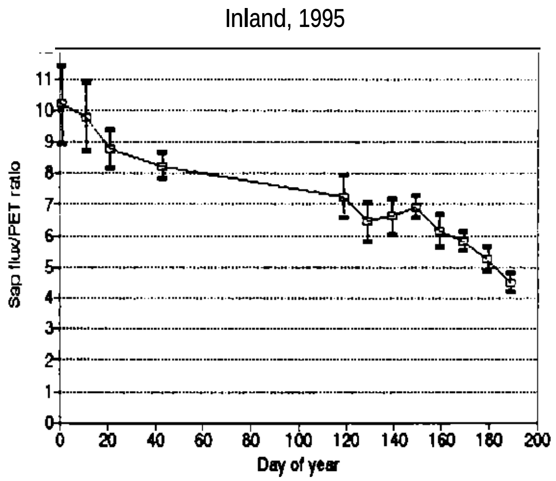


Figure 6. Changes with time in the daily total sap flux (cm / hour) IPE (mm/hour) ratio. Points are ten day means; vertical bars are twice the standard error of the mean.

of these ratios are plotted against time in Figure 6. The decline was probably a response to aging of the frond and to changes in its position within the canopy: older, lower fronds having lower transpiration rates and conductances than younger, upper ones (Squire, 1985; Dufrene, 1989).

Although it was possible to follow patterns of flux rate (u;sap flux density) and their responses to environmental conditions by this technique, total sap flow rates (F) were not determined. F can be calculated from u by multiplying by the cross sectional area of the conducting tissue. However, the diffuse nature of the conducting elements in oil palm renders measurement of the conducting area difficult. While the highest flow rates observed here in fronds were similar to rates found in the trunk by Dufrene (1989), it was calculated that the true flux rates were higher, suggesting that the probes may fail to fully sense localized fast flow occurring in the somewhat sparsely scattered elements. An attempt to 'calibrate' the probes by directly measuring transpiration using detached fronds was not successful. Further work is needed to develop this otherwise very sensitive and useful approach to monitoring palm activity.

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