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NOTES ON OIL PALM PRODUCTIVITY. IV. CARBON DIOXIDE GRADIENTS AND FLUXES AND EVAPOTRANSPIRATION, ABOVE AND BELOW THE CANOPY

Keywords: photosynthesis, evapotranspiration. micrometeorology, CO_2 and H_2O concentration gradients.

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Continuous measurements of atmospheric CO_2 concentrations made at various heights within and above a mature oil palm canopy showed that concentrations varied widely during the course of a 24-hour period - building up to high levels overnight within the canopy and falling rapidly with the onset ofphotosynthesis in the morning. Measurement of CO_2 fluxes, both within the atmospheric boundary layer above the canopy and within the trunk space, allowed the relative contribution of CO_2 supplied from the above and below-canopy atmosphere to the total canopy CO_2 assimilation to be assessed. Similar assessments of water vapour fluxes provided a measure of the percentage of water lost as evapotranspiration (ET) which was channelled through the palms. Below-canopy CO_2 uptake averaged 18.5% of the above-canopy flux and 15.6% of total flux. Evapotranspiration from the ground (from soil and ground flora) was almost 13% of total evapotranspiration, so that over 87% of ET took place directly from the palm canopy.

INTRODUCTION

Previously, we have determined the evapotranspiration (ET) and CO_2 uptake of oil palm canopies by making gradient or flux measurements within the atmospheric boundary layer above the canopy (Henson, 1993). This is an established approach in micrometeorology but in evaluating CO_2 uptake, it neglects the contribution made by CO_2 emanating from the soil or any decaying surface vegetation. In the case of evapotranspiration, that deduced from above-canopy measurements includes all sources of ET, namely from the main canopy, the soil and any vegetation beneath the canopy, and hence, does not provide a measure of palm transpiration alone. For short vegetation with good ground cover (e.g. grassland) such considerations are unimportant but, clearly, in a tall, multilayered system such as an oil palm stand, they may be of considerable significance. One way of allowing for the contribution of ground sources has been to measure these separately using independent methodology. Measurements of 'soil respiration' in oil palm suggested that the below-canopy CO_2 sources contributed about 15% to the total CO_2 uptake by the canopy (Henson, 1994).

Because the methodology and approaches used for measuring ground and atmospheric CO_2 fluxes have previously differed and because measurements of the two sources were not made concurrently, further investigations relying solely on micrometeorological methods were considered desirable in order to re-evaluate the problem. At the same time, the methodology also made it possible to determine the relative contribution of the main canopy to total evapotranspiration.

MATERIALS AND METHODS

Measurements were made on palms 11 years after planting on a moist coastal site selected for its suitability for making micrometeorological measurements (Henson, 1991a). The site was flat and sufficiently large (94 hectares) to provide adequate fetch to the centrally located instrument mast. At the time of measurement (late 1994), the palms had trunk heights to the lower fronds of nearly five metres and were about 11 metres in height to the top of the canopy. The leaf area index (LAI) was 5.9, giving an estimated fractional transmission of photosynthetically active radiation to the ground of 0.08.

Atmospheric CO_2 concentrations were measured by pumping air through tubing to infrared gas analysers (Licor 6262; Licor Inc., Lincoln, Nebraska, USA) located in a field laboratory. For gradient measurements, the air intakes were located at differing heights within and above the canopy and the samples fed into a solenoid-operated gas switching unit (ADC Ltd., Hoddesdon, Herts, UK) which sequentially routed the air from up to six intakes to a single gas analyser. All tubing was of equal length to equalize lag times. Output from the analyser was recorded every 10 seconds by a datalogger (Delta-T Devices, Burwell, Cambridge, UK), and the data later analysed using BASIC programs.

Direct measurements of flux were made using the eddy correlation (EC) method (Montieth, 1962; Denmead and Bradley, 1989) as described by Henson (1993). Equipment used for this included a three dimensional sonic anemometer (BIRAL Ltd, Bristol, UK) and a fast response gas analyser (Licor Inc, USA). Outputs from the anemometer and gas analyser were recorded in real time using a portable computer. Fluxes were calculated using 'Eddysol' software (University of Edinburgh, UK). Two separate systems were used for simultaneous measurement of fluxes below and above the canopy.

The eddy correlation system also provided a measure of sensible heat flux (derived from correlating fluctuations in air temperature with wind vector measurements). The flux of latent heat and hence, evapotranspiration (ET) was obtained by subtracting the sensible heat flux from the available energy. The available energy represents the difference between the net radiation (NR) and the ground heat flux (G). NR was measured above the canopy using a dome net radiometer (REBS, Seattle, USA) and below the canopy using tube net radiometers (Delta-T Devices, Cambs, UK). Heat flux plates (TPD, Delft, The Netherlands) placed just below the soil surface at three positions across an interrow provided a measure of G. Measurements of heat flux were independent of those of CO_2 and were conducted over a longer period.

Potential evapotranspiration (PET) of the canopy was calculated from measurements of air temperature, humidity, windspeed, net radiation and ground heat flux, as described by Henson (1993). All measurements were calculated as hourly averages.

Measurements of soil water potential using tensiometers confirmed the absence of any significant water deficit at the site during the period of study.

RESULTS AND DISCUSSION

CO_2 Concentrations

Although the monthly average concentration of CO_2 in the atmosphere in 1990 was around 355µmol mol^{-1}, rising by around 1.2 µmol mol^{-1} year^{-1} due to man-made emissions (Boden et al., 1992), such data obscure the fact that there may be marked variation diurnally over actively growing vegetation. Continuous monitoring in the present study above and within the closed oil palm canopy revealed regular diurnal variation in CO_2 concentration of as much as 250µmol mol^{-1}, with the lower value of 350µmol mol^{-1} being attained only towards the latter part of the light period (Figure *1*). CO_2 concentrations remained higher for longer on days with low radiation. The build-up of CO_2 concentration overnight was greatest within the canopy. It had previously been observed that in the early years after planting during the development of the oil palm canopy, CO_2 concentrations above the canopy in early morning gradually increased over time as biomass accumulated (Henson, 1991b).

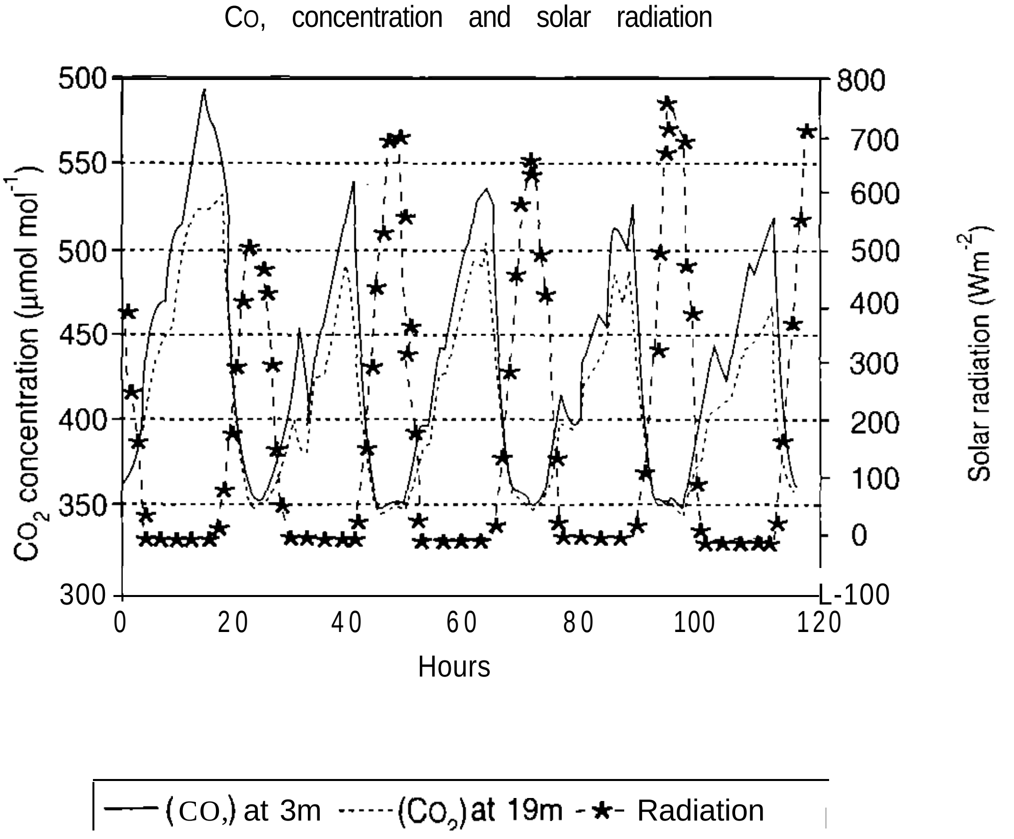

Figure 1. Hourly changes in CO_2 concentration below (3m) and above (19m) the canopy in relation to above-canopy incident solar radiation.

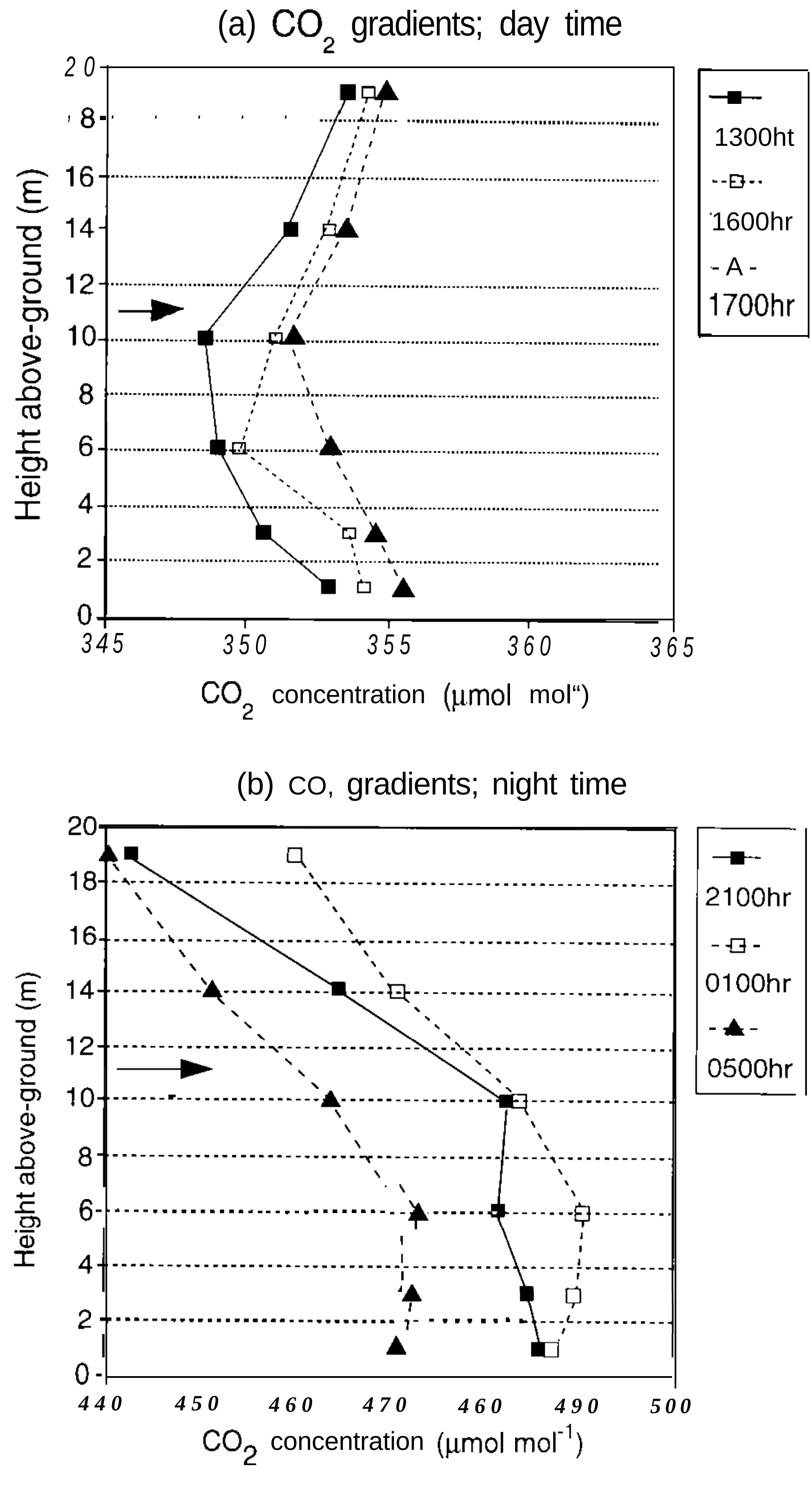

Figure 2. Examples of vertical gradients in CO, concentration within and above the canopy at different times; (a) during daylight and (b) during the night. Note difference in horizontal scales between (a) and (b). Arrows indicate top of canopy.

Examples of vertical gradients of CO_2 concentration are shown in Figure 2. During periods of active photosynthesis, minimum CO_2 concentrations occurred at the 10 metres intake point which corresponded with the upper part of the crown (Figure *2a*). This was likely to have been the most active region of CO_2 uptake by virtue of maximum exposure to radiation and presence of the most active fronds photosynthetically (Corley, 1983; Dufrene, 1989; Dufrene and Saugier, 1993). During the night, concentrations increased due to the absence of CO_2 uptake and the predominance of plant and microbial respiratory activity. The accumulation of CO_2 was greatest within the canopy resulting in concentrations above the canopy decreasing markedly with height (*Figure 2b*).

CO_2 Fluxes

The gradient measurements indicated, as expected, that the palm crowns constituted the strongest sink (region of uptake) for CO_2. From this, it is evident that during daylight hours the direction of CO_2 flux will be towards the canopy, either as a downward flux from the air above it or as an upward flux from the ground. Conventionally, these fluxes are designated as negative and positive respectively but here, for simplicity, they are both treated as positive. The total CO_2 uptake then becomes the sum of the two (positive) fluxes.

Data for cumulative daily uptake of CO_2 from above and below the canopy on days for which complete measurements are available are given in *Table 1.* The variation in total flux was associated with variations in radiation and humidity. The data show that below-ground flux averaged 15.6% of the total, while the total flux was about 19% greater than that measured above the canopy. The mean value of 15.6% for the below-ground flux agrees well with the previous estimate of 14.7% derived from soil respiration and associated measurements (Henson, 1994).

An example of above and below-canopy CO_2 fluxes over 24 hours is presented in Figure 3. It is apparent that the below-canopy fluxes generally followed those above the canopy and that both were related to radiation. However, while the above-canopy flux was slow to increase with radiation in early morning, the lag was partly offset by a surge in below-canopy flux, leading to a positive total flux during all except the first hour of daylight. This surge was observed on four of the five days during which complete flux measurements were made and accounts for the frequently observed morning lag in the rise of the above-canopy flux.

Evapotranspiration

It was previously found (Henson, 1993) that net radiation below the canopy represented only 10% of the above-canopy net radiation while the dry matter of the ground flora was only 5% of that of the palms. Consequently, the proportion of total evapotranspiration taking place below the canopy is likely to be only a minor proportion of the total. Examples of above and below-canopy water vapour fluxes are shown in Figure 4 and totals for all days with complete measurements are given in *Table* 2. These show that below-canopy ET

TABLE 1. CUMULATIVE DAYTIME CO_2 FLUX ABOVE AND BELOW THE CANOPY

Day	CO_2 flux (g m^{-2} day^{-1})			
	above	below	total	% below
Dec 18	12.00	2.03	14.03	14.5
Dec 19	13.47	2.57	16.04	16.0
Dec 20	18.65	3.71	22.36	16.6
Dec 21	15.60	2.77	18.37	15.1
Dec 22	18.73	3.48	22.21	15.7
Mean	15.69	2.91	16.60	15.6

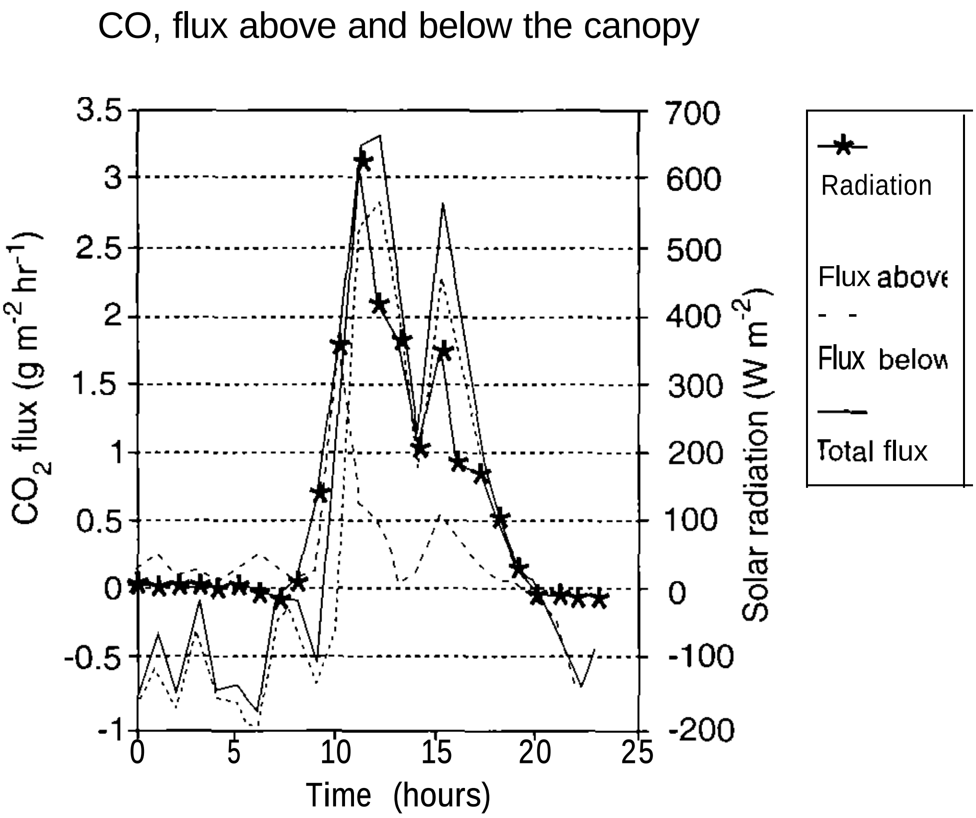

Figure 3. Hourly changes in below-canopy, above-canopy and total CO, flux in relation to above-canopy incident solar radiation, 21 December, 1994.

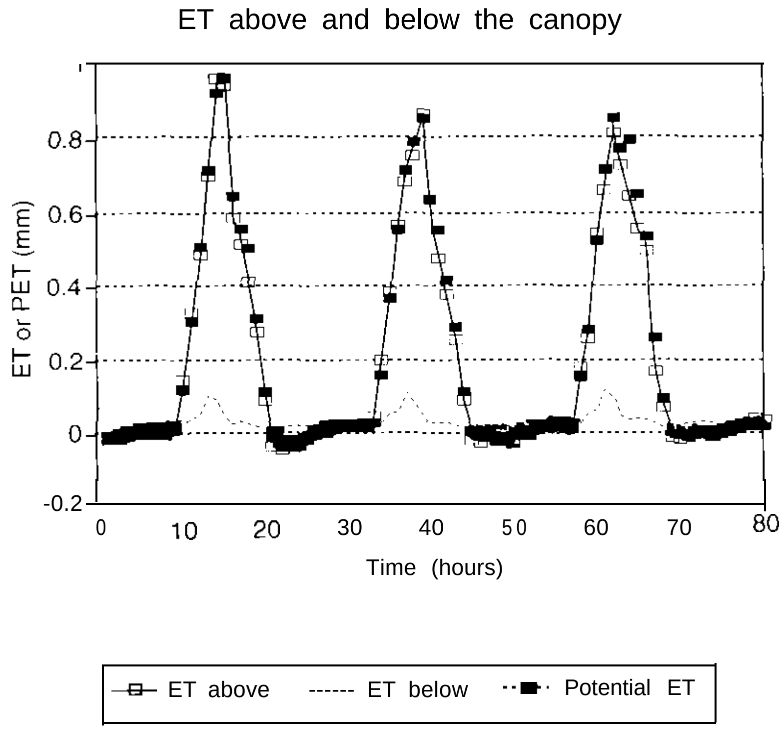

Figure 4. Hourly changes in total (above-canopy) and below-canopy evapotranspiration in relation to potential ET, 23 to 25 December, 1994.

TABLE 2. DAILY EVAPOTRANSPIRATION (ET) ABOVE AND BELOW THE CANOPY IN RELATION TO POTENTIAL ET (PET)

Day	PET (above)	ET above	ET below	ET below/above
	mm day[-1]			
Oct 22	3.29	2.51	0.30	0.120
Oct 25	3.54	2.84	0.36	0.127
Dec 18	2.56	2.74	0.46	0.168
Dec 19	2.73	2.90	0.37	0.128
Dec 20	5.09	5.14	0.54	0.105
Dec 21	4.35	4.38	0.41	0.094
Dec 22	3.17	2.67	0.37	0.139
Dec 23	5.49	5.28	0.61	0.116
Dec 24	5.34	5.13	0.65	0.127
Dec 25	5.43	4.85	0.66	0.136
Mean	4.10	3.84	0.47	0.126

averaged 13% of the total leaving some 87% of the water evaporated to he channelled from or through the palms. Squire (1985) previously estimated that evaporation from hare (moist) soil below an oil palm canopy at noon (LAI = 5.3) was 16% of total ET but lower transmission of radiation at other times of day would have led to the mean value over the day being lower than this.

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REFERENCES

BODEN, T A; SEPANSKI, R J and STOSS; F W (eds.) (1992). *Trends '91: A Compendium of Data on Global Change - Highlights*. ORNIJ CDIAC-049. Carbon Dioxide Information Analysis Centre, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 80 pp.

CORLEY, R H V (1983). Photosynthesis and age of oil palm leaves. *Photosynthetica, 17:* 97-100.

DENMEAD, 0 T and BRADLEY, E F (1989). Eddy-correlation measurement of the CO, flux in plant canopies. In Fourth Australasian Conference on Heat and Mass Transfer. Christchurch, New Zealand. p.183-92.

DUFRENE, E (1989). Photosynthese, consommation en eau et modelisation de la production chez le palmier a huile (*Elaeis* guineensis Jacq.). Doctorate thesis, Universite de Paris-Sud d'Orsay. 154 pp.

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.

HENSON, I E (1991a). Potential use of micrometeorological methods for assessing CO, exchanges and evapotranspiration by oil palm canopies. In Second National Seminar on Agrometeorology. Malaysian Meteorological Service, Petaling Jaya. p.45-68.

HENSON, I E (1991b). Age-related changes in stomata1 and photosynthetic characteristics of leaves of oil palm (*Elaeis* guineensis Jacq.). *Elaeis, 3: 336-348.*

HENSON, I E (1993). Carbon assimilation, water use and energy balance of an oil palm plantation assessed using micrometeorological techniques. Paper presented at 1993 PORIM International Palm Oil Congress - Update and Vision (Agriculture). Kuala Lumpur, 20-25 September, 1993.

HENSON, I E (1994). Estimating ground CO, flux and its components in a stand of oil palm. *PORIM Bulletin, 28*:1-12.

MONTIETH, J L (1962). Measurement and interpretation of carbon dioxide fluxes in the field. ***Netherlands Journal of Agricultural Science. 10: 334-346.***

SQUIRE, G R (1985). Techniques in environmental physiology of oil palm. 3. Evapotranspiration. ***PORIM Bulletin, 11: P-12.***