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NOTES ON OIL PALM PRODUCTIVITY. II. AN EMPIRICAL MODEL OF CANOPY PHOTOSYNTHESIS BASED ON RADIATION AND ATMOSPHERIC VAPOUR PRESSURE DEFICIT

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Using data on daytime CO, flux above the canopy determined by eddy correlation, a simple empirical model was devised based on relationships between CO, flux and radiation, and CO, flux and atmospheric vapour pressure deficit. The model satisfactorily predicted above-canopy flux from measurements of these variables using site-specific regression constants. The limitations and practical implications of the model are discussed.

INTRODUCTION

A knowledge of the net uptake of CO_2 by a stand of vegetation over a 24 hour period or longer provides a means of assessing the dry matter production of the stand without the need for destructive sampling or detailed, and often imprecise, measurements on the standing biomass. It also allows direct examination of the influence of various factors on productivity. However, monitoring canopy gas exchange is very demanding, requiring continuous measurements using delicate equipment over extended periods and often under difficult environmental conditions at sites remote from the laboratory. Aside from the possibility of instrument failure, or loss of power supply, there are the needs for calibration checks and other periodic maintenance work which result in interruptions to recording and loss of data. One means of overcoming this last problem is to estimate CO_2 flux using an appropriate model. This report describes a simple model derived from on-site relationships between above-canopy CO;? flux and incoming solar radiation and atmospheric vapour pressure deficit, the two main atmospheric factors known to influence CO_2 uptake by the canopy.

MATERIALS AND METHODS

Measurements of canopy gas exchange were undertaken in oil palm plantings in West

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Malaysia, using an eddy correlation method (Henson, 1993). The site at which the present data were obtained was on an inland soil, and has been described previously (Henson, 1997). The site was sufficiently large (102 hectares) and surrounded by other oil palm plantings of similar age, to provide adequate fetch to the centrally located instrument mast.

Measurements of CO_2 flux began in July 1994 (ninth year after planting) and continued intermittently until February 1995. The canopy had a leaf area index (LAI) of around 4.4.

CO_2 flux was measured 'remotely' using a sampling tube and fast response infra-red gas analyser. Wind vectors were measured with a sonic anemometer, and relative humidity and air temperature with capacitance sensors and/or a dew point hygrometer and thermistors respectively. The latter instruments were protected from direct solar radiation by enclosure in screens. Rotating cup anemometers were used to verify sonic wind speed measurements. Incoming solar radiation was measured using a Kipp solarimeter and/or a silicon cell energy sensor. All *in-situ* instruments were supported at appropriate levels above the canopy on a low profile, galvanised steel mast. Outputs from the CO_2 analyser and sonic anemometer were logged in real time by a portable computer. Other instruments were recorded using a data logger which calculated and stored hourly averages. For fuller details of the instrumentation and methods see Henson (1991a, 1993).

For convenience of presenting the results, the downward flux of CO_2 toward the canopy is taken here as positive and the upward fluxes, which occur in darkness or at light intensities below the light compensation point, as negative; a convention the reverse of that normally employed.

RESULTS AND DISCUSSION

The two most important atmospheric factors known to influence the magnitude of CO_2 flux above stands of vegetation are incoming solar radiation and atmospheric vapour pressure deficit. Temperature is also important but its influence is confounded with, and difficult to distinguish from, the other two factors. Photosynthesis, which dominates daytime gas exchange, is known from seedling and single leaf measurements of oil palm to decline as atmospheric humidity decreases (Smith, 1989; Dufrene, 1989; Henson, 1991b). This was confirmed to be the case also for mature fruiting palms on both a single leaf and on a canopy scale (Henson, 1993, and unpublished results).

Analysis of meteorological data (Henson, 1993) showed that the relationship between whole canopy CO_2 flux and solar radiation (RAD) was generally linear. However, the slope of the response varied, being reduced as atmospheric vapour pressure deficit (VPD) increased.

One means of demonstrating a response to VPD is to normalize CO_2 flux with respect to RAD and plot the resultant values against VPD. The results of plotting normalized cumulative daytime flux against maximum daily VPD are shown in Figure 1. Use of cumulative or mean VPD as an alternative to the maximum did not significantly improve or alter the relationship.

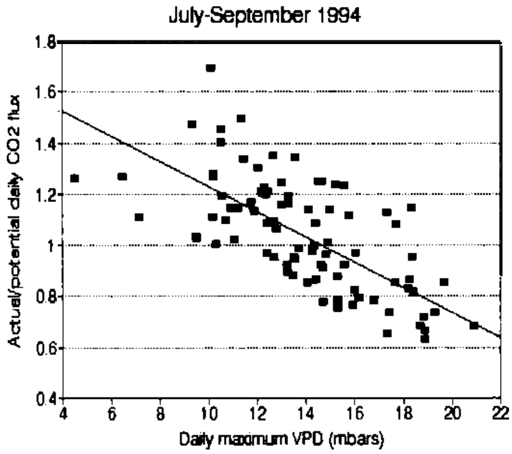

*Figure 1. The relationship between the ratio of actual/'potential' daily cumulative CO, flux and the daily maximum VPD during July to September 1994. 'Potential' CO_2 flux was calculated hourly from solar radiation, where CO_2 flux (g/m²/hour) = 0.005 * RAD (W/m²). The line of best fit is shown, r=0.64; P=<0.001.*

A simple empirical model based on the above relationships takes the form:

$$CO_2\ flux1 = [(VPD * a) + b] * (RAD * c) \quad (1)$$

where a,b and c are site-specific constants derived by regression analysis.

The relationships deduced at the inland site using the above equation are shown in *Figure 2*.

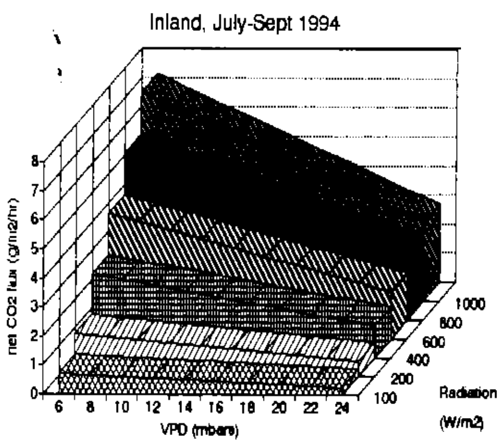

Figure 2. Relationships between above-canopy CO_2 flux, solar radiation and vapour pressure deficit, derived from measurements made from July to September 1994.

Because the relation with RAD cannot take account of the magnitude of negative CO_2 fluxes (respiration) which occurs in the dark, a further regression was performed. This related the measured hourly fluxes to fluxes derived from Equation 1 to give a second estimate:

$$CO_2\ flux2 = [CO_2\ flux1 * d] - e \qquad (2)$$

Because measured night-time fluxes were frequently erratic and considered to underestimate the extent of the true negative CO_2 flux, the constant e in Equation 2 was fixed at a value which assumed the rate of dark respiration to be constant at $-1.0 g/m^2/hour$.

Figure 3 shows an example of changes in measured CO_2 flux and modelled flux over several days at the inland site. With the exception of night hours, measured and modelled data agree closely (Figure 4). Daytime totals for the (positive) CO_2 flux are given in *Table 1*.

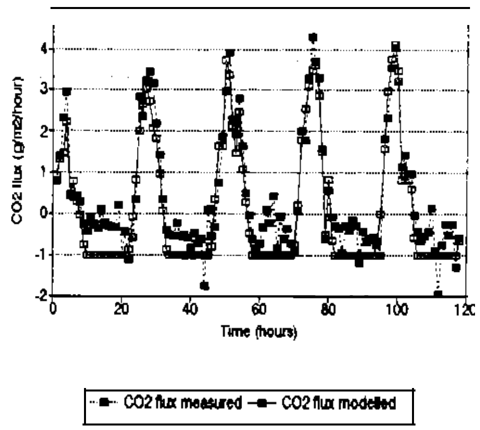

Figure 3. Comparison of hourly changes in measured and modelled CO_2 flux; 30 September to 5 October. 1994.

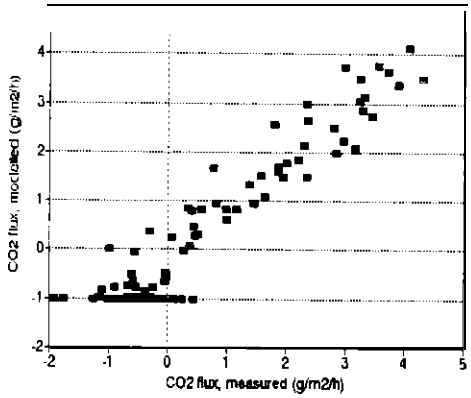

Figure 4. Relationship between hourly measured and modelled values of CO_2 flux; $r=0.95$; $P<0.001$.

TABLE 1. MEASURED AND MODELLED DAILY CUMULATIVE DAYTIME CO_2 FLUX OVER A FOUR DAY PERIOD AT THE INLAND SITE (September 1994)

	Day of month				Total
	12	13	14	15	
	(g $CO_2/m^2/day$)				
Measured flux	27.31	29.25	26.25	24.99	107.8
Modelled flux	31.85	28.33	24.73	24.57	109.5

The good fit of the modelled results suggests that it should be possible to determine flux over considerable periods from measurements of RAD and VPD alone. However, in the long term, further relationships need to be built into the model such as the response to changes in leaf area index, ground CO_2 flux and soil water deficits. More data are required for this purpose. The other need is for a more precise evaluation of dark CO_2 fluxes which is especially crucial for the overall carbon balance.

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