

SOME NET-RADIATION AND SOIL THERMAL DIFFUSIVITY MEASUREMENTS FOR THE PORT MORESBY AREA

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ABSTRACT

Measurements of net-radiation and soil heat flux levels for February 1968 are presented and discussed. It is believed these are the first direct measurements of these parameters to be obtained for Papua and New Guinea. By means of two measurements of soil heat flux at differing depths a value is obtained for the thermal diffusivity of the soil. This value is at the low end of the range of values quoted by other workers and needs checking by more direct methods.

INTRODUCTION

FOR Papua and New Guinea, a country dependent on primary production, there are few direct measurements of the physical parameters affecting crop growth. There are records of rainfall, temperature and humidity at some locations but records of evaporation for Port Moresby only. These measurements do not give a complete picture of the agricultural environment. For instance the growth of the plant is highly dependent on the rate of photosynthesis which in turn is influenced by the level and spectral composition of the incoming radiation. Similarly the evapotranspiration rate is strongly dependent on the radiation level. Measurements of radiation, in particular net-radiation, appear to have been neglected although Fitzpatrick (1965) has attempted to estimate the radiation level using standard meteorological data and empirically derived formulae.

During the day radiation reaching the earth's surface is predominantly direct solar radiation with a smaller contribution due to diffuse and scattered radiation from the atmosphere and long-wave radiation from clouds. Of this incident radiation some is reflected and some absorbed into the surface which in turn will be heated and thus re-radiate long-wave radiation back into space. The net-radiation N at any level is defined as the difference between incoming and outgoing radiation levels or as it is usually expressed:

$$N = R_s (1 - \rho) - R_L \quad (1)$$

where R_s is the incoming solar radiation, scattered, diffuse and direct, ρ is the fraction of short-wave radiation reflected from the surface, or more commonly, the albedo and R_L is the outgoing long-wave radiation.

At the surface this net-radiation which is positive or incoming during daylight, is partitioned into several energy dissipating terms. They are:

- (a) the heat flux into the soil, G ;
- (b) the direct flux of heat into the turbulent air over the surface, H ; and
- (c) heat in the form of evaporated water, or latent heat for which we shall use the symbol L .

Symbolically we can write:

$$N = G + H + L \quad (2)$$

Figure 1 shows diagrammatically these terms of the energy balance during daylight.

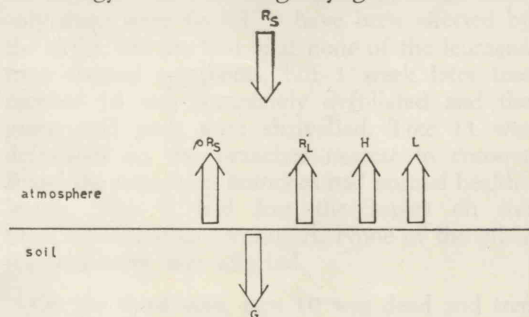


Figure 1.—Diagrammatic representation of energy balance components during daylight.

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The present research programme is aimed at accurate measurements of each of these terms over various surfaces and crops for Papua and New Guinea. Extensive work has been done over temperate grasslands but extrapolation of these results to tropical agriculture is open to question.

EXPERIMENTAL METHODS

Over the period January to March 1968, sensors were installed on a site in the University campus to measure the terms N and G in equation (2) above. The soil was dark cracking clay typical of most of the Waigani Valley floor. Over this was a thin growth of *Axonopus compressus* (Sw.) established not long previously; it was showing a good rate of growth but kept mown so that the overall height was about 1 cm.

The sensors used were a net-radiometer from a design by Funk (1959) and soil heat flux plates from a design by Deacon (1950). These instruments are available commercially and are supplied with a calibration certificate from the CSIRO Division of Meteorological Physics, Melbourne. The net-radiometer was mounted approximately 1.5 m above the surface with a clear view of at least 80 degrees from the vertical all around. The soil heat flux plates were buried in the soil nearby at two depths. This arrangement enables additional information to be obtained on parameters of the soil. Figure 2 illustrates a cross-section of the arrangement.

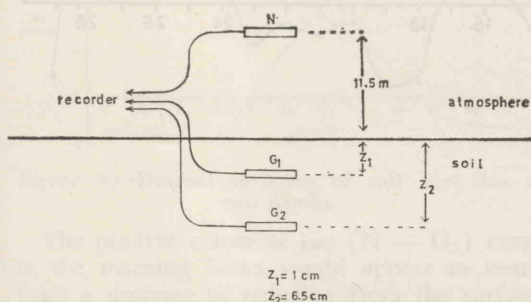


Figure 2.—Cross-section of experimental arrangement of sensors.

A 3-channel potentiometric chart recorder enabled continuous records to be obtained for the quantities N , G_1 , G_2 where the subscripts 1 and 2 denote the heat flux at depths Z_1 and Z_2 , respectively 1 cm and 6.5 cm in this experiment.

RESULTS AND DISCUSSION

Approximately seven weeks of records were obtained but some events, such as power failures and excessive rainfall, rendered some sections unsuitable for analysis. Satisfactory analysis could be carried out for the month of February and data for this period only are presented.

Figures 3 and 4 give the daily average for the 3 parameters and Figures 5 and 6 the hourly average for 24 hour periods over the whole month. Also shown in Figure 5 is the quantity $(N - G_1)$ which from equation (2) is equal to the term $(H + L)$, the total heat flux removed by the atmosphere due to turbulent transfer. This graph shows two points of interest. Firstly a large flux of heat away from the surface which predominantly follows the net-radiation except for a phase-lag of approximately half-hour. At the peak some 86 per cent of the net-radiation level is being removed by this means, the remainder being temporarily stored in the soil for release later in the day. It is a reasonable assumption that the heat stored in the 1 cm of soil above the G_1 flux plate does not introduce an error of more than several per cent in this value though the observed phase-lag is possibly due to this. That the atmospheric heat flux should follow the net-radiation curve so closely is to be expected from the large increase in atmospheric turbulence following instability generated by surface heating.

Secondly we find that in the evening the $(N - G_1)$ term becomes negative from around 1800 to 2300 hours, and then becomes positive again from 2400 hours on through the morning. The negative value indicates that heat is being radiated by long-wave radiation away from the surface at a greater rate than that supplied from the lower soil layers where it was stored during the daylight period. The rate of heat flow to the surface through the soil is determined by the thermal conductivity of the soil whereas long-wave radiation from the surface is a function of surface temperature and cloud cover. In general to satisfy equation (2) both H and L will be negative which in turn implies that the atmosphere is being cooled by contact with the surface and water vapour is condensing on the surface as dew. In view of the high moisture levels in the air and the large value for the latent heat of condensation it is expected that the latter is the more significant.

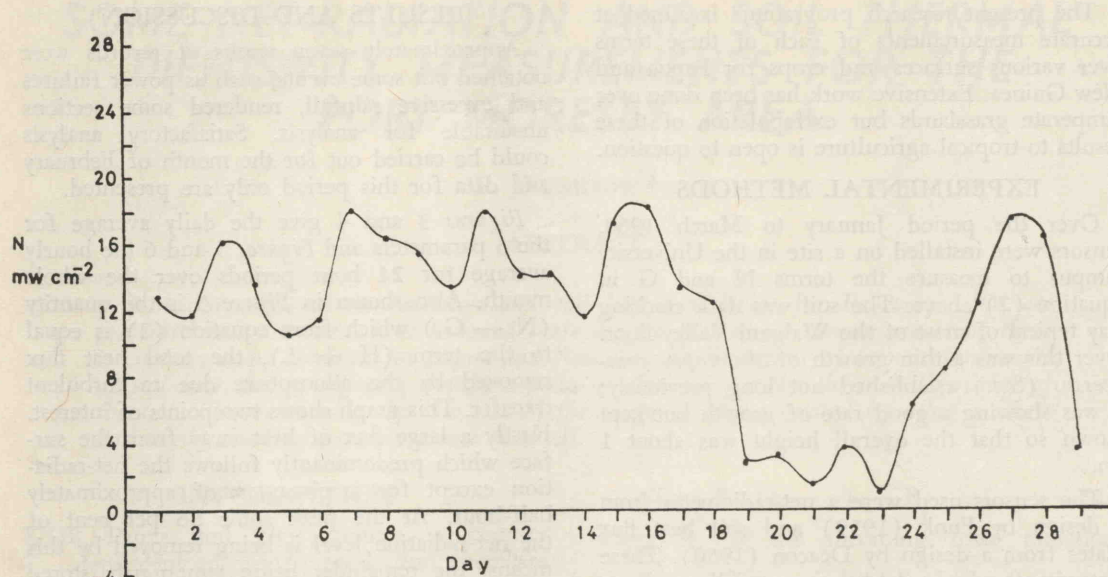


Figure 3.—Daily average values of net-radiation for February 1968.

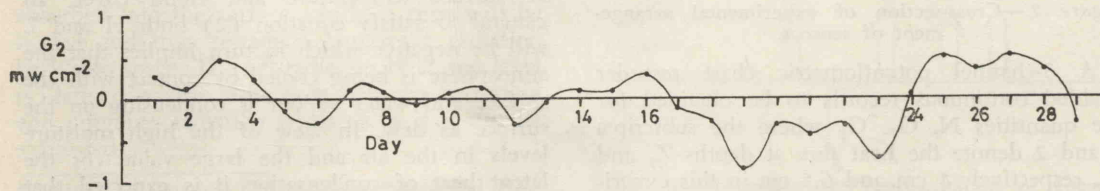
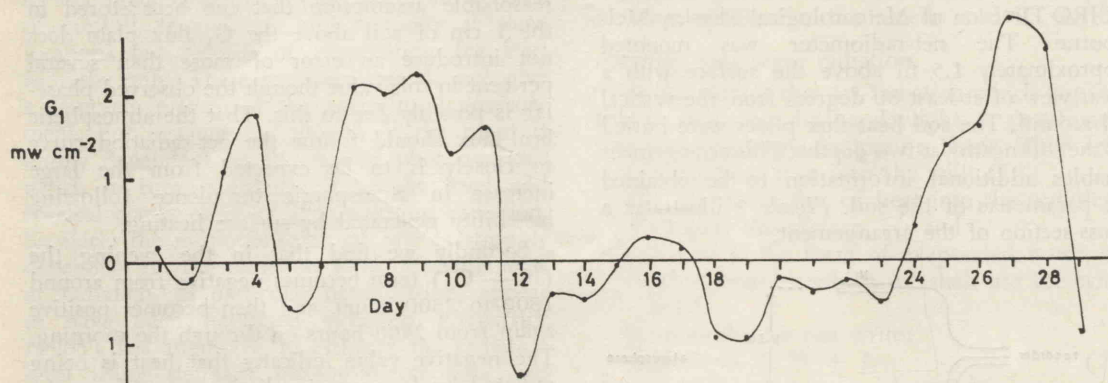


Figure 4.—Daily average values of soil heat flux at two depths for February 1968.

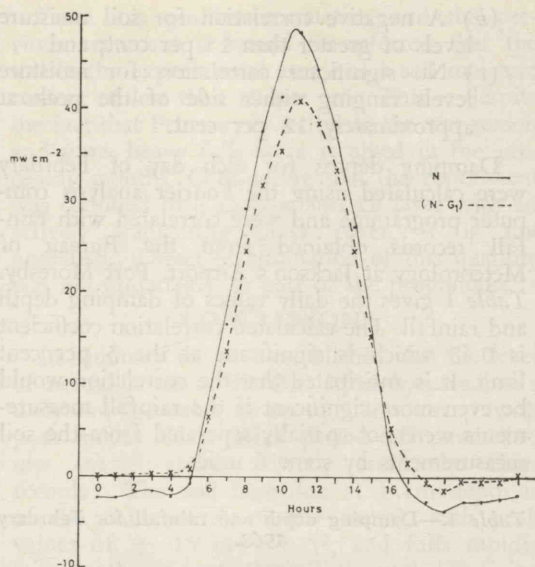


Figure 5.—Diurnal variation of net-radiation and the quantity $(N - G_1)$.

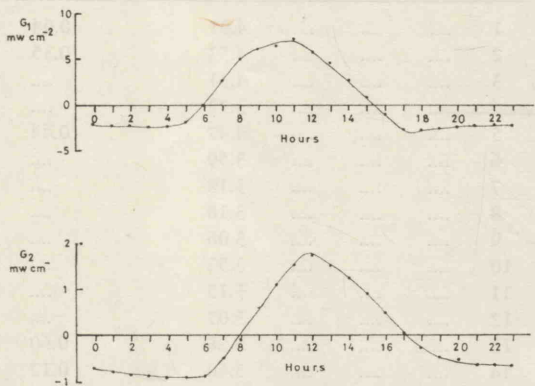


Figure 6.—Diurnal variation of soil heat flux at two depths.

The positive nature of the $(N - G_1)$ curve in the morning hours would appear to result from a decrease in radiation from the surface, due to the lower surface temperature and possibly from thin fog layers, relatively common during this period. The flux of heat through the soil is relatively constant over the night-time period and hence a reduction in N would imply that the heat was being given to the atmosphere either directly by warming or in evaporation.

As yet no direct measurements are available to indicate how the heat may be distributed

between the direct and latent terms. Sellers (1965) gives examples for three different sites and finds large differences in the relative importance of the two terms during the night.

The graphs of G_1 and G_2 in Figure 5 illustrate the typical damping of heat flux and the shift in phase of the peak value with depth, both being due to the low value of thermal conductivity for soil. The theoretical treatment of the damping of a temperature or heat flux wave as it penetrates a layer of soil is well established, e.g., Van Wijk (1966) for the case of a sinusoidal wave. The waveforms G_1 and G_2 are obviously not well defined sinusoids but by using the technique of Fourier analysis we can treat this complex wave as a combination of sinusoids each of which can be treated by the method above.

From the theoretical work we have that the amplitude of any sinusoidal wave shows a decrease with depth usually expressed as:

$$\frac{A_1}{A_2} = \exp \left\{ \frac{Z_2 - Z_1}{D} \right\} \quad (3)$$

where A_1 , A_2 are the amplitudes at depths Z_1 , Z_2 and D is the 'damping depth' for the soil layer. D is defined as the depth in the soil for which amplitude of a sinusoidal temperature wave will be reduced by a factor of 0.368 (approximately one-third).

A computer analysis of the waveforms G_1 and G_2 plotted in Figure 4 gave the sinusoid of period 24 hours, or the fundamental as containing the greatest contribution and a solution for (3) was obtained for this Fourier component only. Lettau (1954) has outlined some of the errors possible in using the amplitude of higher order harmonics in solving for damping depth. The value for D was found to be 4.5 cm. It is readily shown that the damping depth for the annual variation in temperature is approximately 19 times this value, i.e., 85.5 cm.

Extending the theory of propagation of a temperature or heat-flux wave through a soil layer leads to the result that the damping depth parameter is itself expressible in terms of other parameters related to the soil, in particular we have

$$D = \frac{2a}{\Omega}$$

where a is the thermal diffusivity for the soil and Ω is the angular frequency of the temperature sinusoid.

Substituting appropriate values for the diurnal temperature wave we obtain a value for a of $0.8 \times 10^{-3} \text{ cm}^2 \text{ sec}^{-1}$. Quoted values for other soils are 1×10^{-3} for peat and 2 to 5×10^{-3} for clay (Van Wijk 1966), and 1 to 5×10^{-3} (Rose 1966). The figure obtained would appear to be in reasonable agreement.

Up to this point we have considered calculation of soil parameters only for data averaged for the diurnal cycle over the whole month. We can, just as readily, calculate the damping depth and thermal diffusivity for the soil for each day of the month using the waveforms of G_1 and G_2 obtained for each 24-hour interval. The results will of course not have the reliability of the averaged values but will show day to day fluctuations as a result of the modulation of the thermal diffusivity term by soil water content. A relation between thermal diffusivity and soil moisture for clay soil is shown in Figure 7 after Sellers (1965).

The particular point of interest is not in the absolute values given but in the phenomena of the change of slope of the curve as the water content increases beyond 12 per cent. Hence if we obtain daily values of thermal diffusivity, or damping depth (which differs from it only by a constant factor) and correlate these with rainfall data we would expect one of the following results:

- (a) A positive correlation for soil moisture levels of less than 10 per cent;

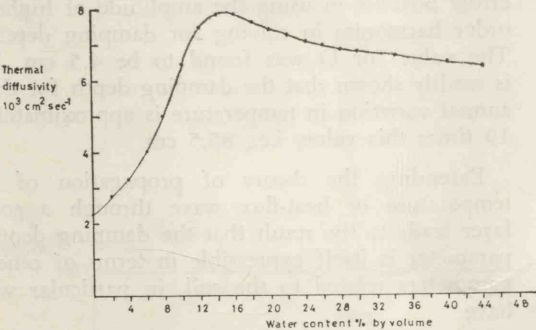


Figure 7.—Thermal diffusivity of clay soil as a function of volumetric fater content, after Sellers (1965).

- (b) A negative correlation for soil moisture levels of greater than 15 per cent; and
- (c) No significant correlation for moisture levels ranging either side of the peak at approximately 12 per cent.

Damping depths for each day of February were calculated using the Fourier analysis computer programme and were correlated with rainfall records obtained from the Bureau of Meteorology at Jackson's Airport, Port Moresby. Table 1 gives the daily values of damping depth and rainfall. The calculated correlation coefficient is 0.45 which is significant at the 5 per cent limit. It is anticipated that the correlation would be even more significant if the rainfall measurements were not spatially separated from the soil measurements by some 6 miles.

Table 1.—Damping depth and rainfall for February 1968.

Day	Damping Depth (cm)			Rainfall (in)
1			4.91	0.04
2			4.53	0.35
3			4.31	....
4			3.22	....
5			4.47	0.44
6			3.59	....
7			3.18	....
8			3.18	....
9			3.06	....
10			3.53	....
11			3.15	....
12			5.07	....
13			5.88	0.60
14			5.40	0.12
15			5.22	0.06
16			4.77	0.07
17			3.91	0.04
18			5.44	0.42
19			6.75	0.26
20			10.21	1.12
21			4.24	0.28
22			5.69	0.52
23			2.71	0.14
24			7.05	0.85
25			5.75	....
26			4.17	....
27			3.84	....
28			3.61	....
29			4.56	....

From this positive correlation and the previous argument it would be inferred that the soil in the experimental area had a soil moisture content of less than 10 per cent. This is despite the fact that February is well into the wet season and some heavy falls were received in the preceding months. Considering that the experiment was confined to a shallow surface layer with an actively transpiring grass cover, it is not unrealistic. Direct determination of this quantity was not undertaken as part of the programme.

CONCLUSIONS

In summary we have established that the level of net-radiation in the Port Moresby area has a daily average value of up to 5 mw cm^{-2} with peak values during this period of about 106 mw cm^{-2} (taken directly from the chart records). The soil heat flux at 1 cm depth is of the order of $\pm 8 \text{ mw cm}^{-2}$, with peak values of $\pm 15 \text{ mw cm}^{-2}$, and falls rapidly with depth owing to the low thermal diffusivity. A value of $0.8 \times 10^{-3} \text{ cm}^2 \text{ sec}^{-1}$ obtained

for the thermal diffusivity is in approximate agreement with that quoted by other workers for clay soils.

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