Study of soil heat-flux in a sugarcane field

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ABSTRACT. Heat-flows into soils were evaluated in the open and in a sugarcane field by using the temperature-gradient method. The measurements were made at the Sugarcane Research Station, Anakapalle (Andhra Pradesh) on four representative days in November and December 1967, and January and February 1968. The magnitude and the diurnal range of heat-flux in the sugarcane field were considerably smaller than those in the open. The times of occurrence of maximum heat-flux were almost the same (about 1200 hrs) in both the open and the sugarcane field. Minimum values of heat-flux, however, occurred in the late evening in the open and at early morning in the cane field, the lag varying from 6 to 10 hours.

1. Introduction

Study of soil heat-flux occupies an important position in the energy budget evaluation of any natural surface. The physical properties of the soil like structure and texture, colour, moisture content etc are known to be important parameters contributing to the nature and quantity of soil heat-flux. Apart from these parameters, the heat-flux is also affected considerably by the surface cover.

2. Experimental

The soil in the sugarcane field was black clay loam while that in the open field close by was brown sandy loam. The sugarcane field was roughly ractangular in shape with sides $65\frac{1}{2}$ metres by $36\frac{1}{2}$ metres. Heights of the canes in the experimental field were 4·10, 4·25, 4·36 and 4·48 metres successively, on the four days of observations reported herein.

The bulk densities of the dry soils determined by the oven method in the present investigation came out to be 1·318 gm/cm³ for the open field and 1·221 gm/cm³ for the sugarcane field. These values are lower than that for a sandy soil at Waltair (1·396 gm/cm³) reported previously by Padmanabhamurty and Subrahmanyam (1961). The density of moist soil was evaluated by using the standard formula —

$$\rho = \frac{\rho_d}{1-W} \tag{1}$$

where, $\rho =$ density of moist soil, $\rho_d =$ density of dry soil, and $W =$ fraction of water by weight in the moist soil.

The moisture content of the soil was determined by taking a number of sugar samples down to a depth of 30 cm, oven-drying and weighing them.

The dry specific heats of both the soils were determined by the method of mixtures. The values obtained were — 0·260 cal/gm/°C for the bare soil and 0·240 cal/gm/°C for the cropped soil. Values ranging from 0·18 to 0·22 cal/gm/°C were reported for dry mineral soils previously (Johnston 1937, Kersten 1949, Smith 1939). The specific heats of moist soil could be evaluated from the standard equation—

$$C = C_w\ W + C_s\ (1-W)$$

where, $C =$ Specific heat of the moist soil, $C_w =$ specific heat of water, $C_s =$ specific heat of the dry soil and $W =$ fraction of water, by dry weight, in the moist soil.

3. Computational

Heat-flux computations in the present investigation were made using the temperature-gradient method described elaborately by Padmanabhamurty and Subrahmanyam (1961). Various other methods of computing the heat-flux were given by Carson and Moses (1963). Soil temperature measurements were made by means of mercury-in-glass bent bulb thermometers buried at 5, 15 and 30 cm below the ground. Surface temperature was measured by means of an ordinary mercury-in-glass thermometer with due precautions about its exposure. Observations were taken every hour continuously for 24 hours on representative days in the four winter months, *viz.*, November and December 1967 and January and February 1968.

On 25 November 1967, the sky was covered (amount 3/10) with patches of cumulus and stratocumulus clouds in the afternoon up to sunset. Rest of the 24-hr period was clear. On 20 December 1967, there were drifting cumulus and strato-

TABLE 1

Thermal properties of the soils

	Moisture content, percentage of dry weight	Moist specific heat (cal/gm/°C)	Moist bulk density (gm/cm³)	Thermal diffusivity (cm²/sec) $\times 10^{-3}$
(a) Brown sandy loam (in the open)				
25 Nov 1967	2·4	0·277	1·353	9·82
20 Dec 1967	9·5	0·330	1·459	8·78
17 Jan 1968	3·6	0·287	1·367	8·78
21 Feb 1968	2·0	0·275	1·348	8·78
(b) Black clay loam (in the crop)				
25 Nov 1967	13·6	0·343	1·413	3·31
20 Dec 1967	19·6	0·389	1·517	4.66
17 Jan 1968	17·9	0·376	1·486	4·66
21 Feb 1968	20·4	0·395	1·534	4·66

cumulus clouds during the day and the sky was even overcast for four hours until mid-night. The morning hours of 21 December were clear; it was thus a partly cloudy day. 17 January 1968, on the other hand, was a completely clear day. On 21 February 1968, the sky was covered with medium and low clouds (amount 1/10 to overcast) throughout the day and night; this too was, therefore, a partly cloudy day.

Heat-flux at the soil surface was computed from the formula —

$$q = - k\rho c \, (\partial\theta/\partial z)_{z=0} \qquad (2)$$

where, k = thermal diffusivity,

ρ = density and

c = specific heat of the soil, and

$(\partial\theta/\partial z)_{z=0}$ = depth variation of temperature in the soil, at the surface.

Thermal diffusivity was calculated using the lag method suggested by Johnson and Davies (1927)—

$$k = \frac{(z_2 - z_1)^2}{L^2} \times \frac{T}{4\pi} \qquad (3)$$

where, L=the lag, in seconds, between the times of occurrence of maximum temperature at the depths z_1 and z_2 ; $T = 24$ hours.

Thermal diffusivities by the above method could only be determined for the two clear days — 25 November 1967 and 17 January 1969 — for the two fields. In the heat-flow evaluations the January value of soil thermal diffusivity was also used for December and February as there was not much difference in soil moisture content during these months, particularly in the sugarcane field. The thermal diffusivities are given in Table 1 along with the other physical properties of the soils. The present value of k for dry soil is slightly higher than the average value of $5 \cdot 834 \times 10^{-3}$cm² sec^{-1} for loose sandy soil at Waltair, reported earlier by Subrahmanyam and Subba Rao (1957).

4. Results and Discussions

Fig. 1 shows the hourly variation of soil temperature at different depths in the open field and in the crop on 17 January 1968 — a clear day. The severe damping of the diurnal wave produced by the crop is readily seen from curves. While the diurnal range of soil temperature at the surface was 36°C in the open, it was a mere 7°C in the sugarcane field. The diurnal variation of temperature in the open is quite small at a depth of 30 cm, but in the cropped soil it is imperceptible even at 5-cm depth. While the time of occurrence of surface maximum temperature in the open field is about one hour after the time of maximum incoming solar radiation (i.e., 1200 hr), in the cropped field the lag is about 2 hours. The times of occurrence of minimum surface temperature are, however, the same (about 0600 hr) for both the fields. The progressive phase shift with depth in the occurrence of maxima and minima, especially for the open field, is clear from the graphs. The results compare well with those of Padmanabhamurty and Subrahmanyam (1963).

The hourly marches of soil heat-flux for both the open field and the sugarcane field are shown plotted in Fig. 2. for the four days of measurement. It is seen that both the magnitude and the diurnal variation of heat-flux is much smaller in the cropped field than in the open. This damping is mainly due to the shading effect of the sugarcane crop which was also considerably tall, being above 4 metres during the observational period. Maximum heat-flux values in the open were attained consistently at 1200 hr except on 21 February 1968, when the maximum value occurred 2 hr earlier, i.e., at 1000 hr; this was on account of the general cloudiness obscuring the sun for some time around noon. There appears a gradual shift of the minimum heat-flux epoch in the open to later hours with the advance of the winter season starting from 1700 hr in November to 2000 hr by January; the shift-back of this epoch in February to 1800 hr is presumably due
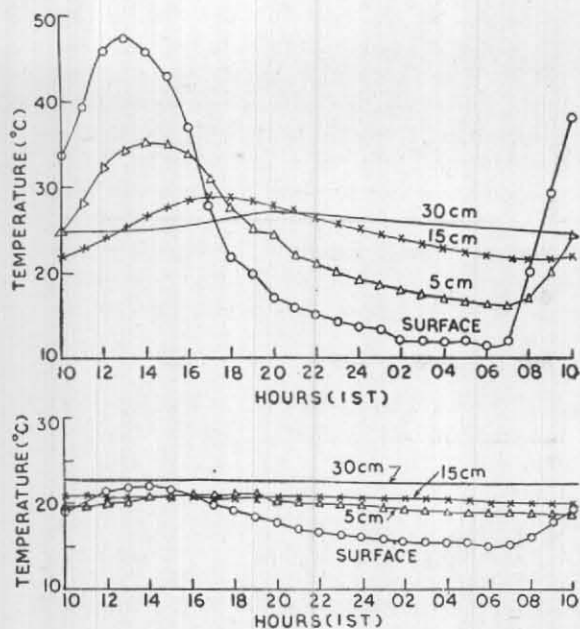
Fig. 1. Hourly variation of soil temperature on 17 Jan 1968
(a) Open field—upper diagram, (b) Sugarcane field —lower diagram
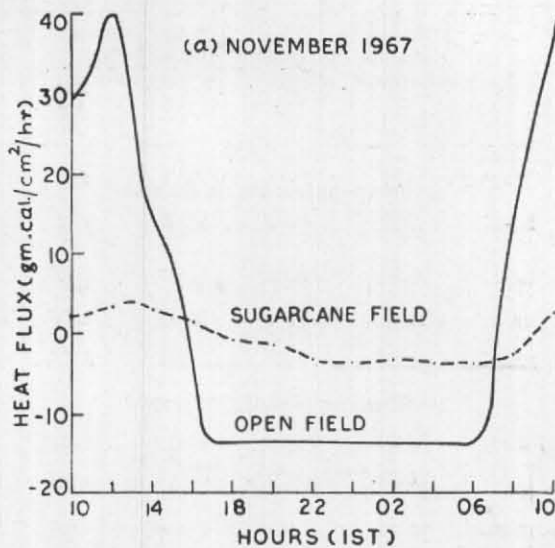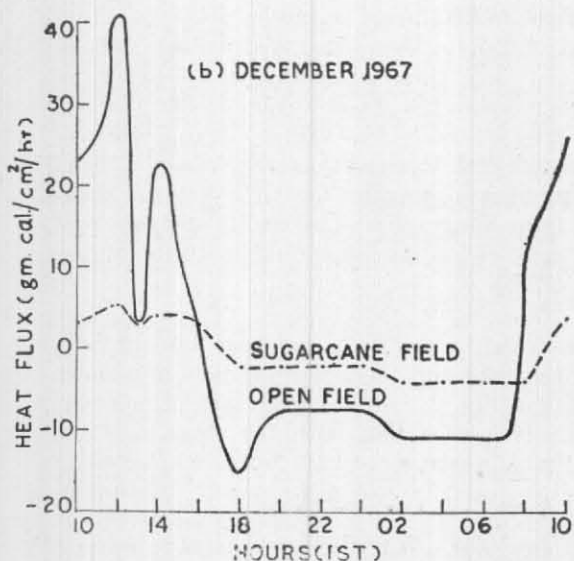
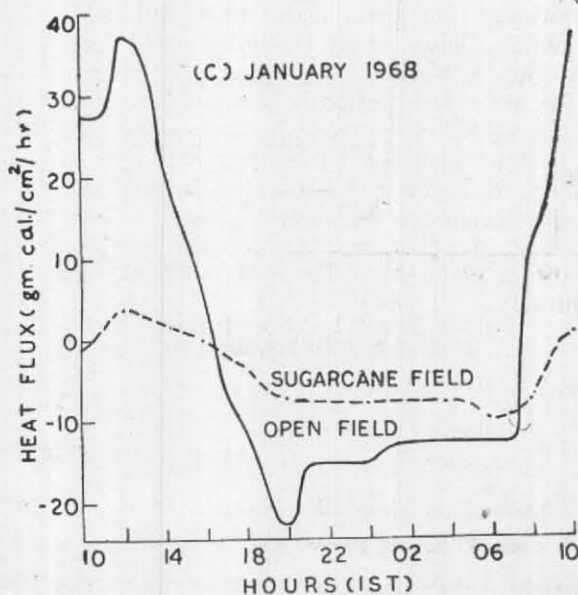Fig. 2(a). November 1967

Fig. 2(b). December 1967

Fig. 2(c). January 1968

Fig. 2(a-c). Diurnal heat-flux into the soil at Anakapalle

again to the general clouqiness prevailing through-
out that day. Maximum heat-flux in the sugar-
cane field also seems to lag some what behind
the open due to the insulating effect mentioned
earlier. Interestingly, the minimum heat-flux
values in the crop appear to occur late in the
night or early hours of the morning; this feature
too is probably the consequence of the crop acting
as a biological medium of high heat capacity.

Table 2 shows the net soil heat-flux both for
the open field and for the sugarcane field. It is
interesting to see that while the net flux for the
open field is positive, for the cropped field the
values are negative except in February when the
net flux was slightly positive. The largest negative
net flux of -25 gm cal/cm^2/day occurred on
17-18 January 1968, an extremely clear day.
Similarly, the lowest positive net flow occurred

TABLE 2

Net diurnal heat flow (gm cal/cm²/day)

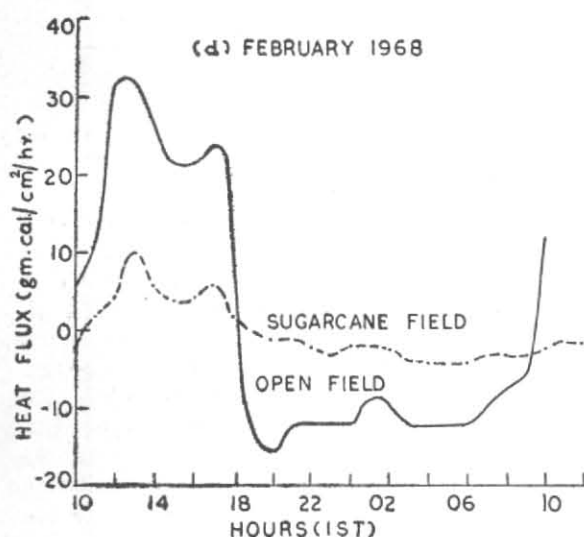|	Open field			Sugarcane field			State of sky
	Positive flow	Negative flow	Net flow	Positive flow	Negative flow	Net flow	
25–26 Nov 1967	51·8	48·9	2·9	5·3	10·0	—4·7	Clear
20–21 Dec 1967	40·4	35·3	5·1	6·9	10·5	—3·6	Partly cloudy
17–18 Jan 1968	49·5	49·1	0·4	3·0	28·3	—25·3	Clear
21–22 Feb 1968	46·1	39·0	7·1	10·3	9·7	0·6	Partly cloudy

Fig. 2(d). Diurnal heat flux into the soil
at Anakapalle for February 1968

in the open on the same day. These observations lead to the conclusion that in the cropped environment the soil loses energy to the crop on a daily basis, whereas the bare soil in the open field seems to gain energy in small quantities even in the cool seaons.

5. Acknowledgement

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