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Profile and flux measurements over Jowari canopy

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ABSTRACT. An experiment was conducted to test the temperature and temperature difference recorder developed in the institute. With the help of this recorder and a commercial wind speed recorder, a study was carried out to determine the wind and temperature profiles, below and over the Jowari canopy. Diurnal variation of sensible flux is also studied.

1. Introduction

To understand the microclimate of a crop field, knowledge of the temperature, wind and sensible heat fluxes in the crop is necessary. A fair idea of turbulent transfer processes can also be obtained knowing the above parameters inside and outside the canopy. With a view to test out the newly designed temperature profile system, a brief experiment was conducted in the Jowari field near the Central Agricultural Observatory, Pune. In all, 8 days' data was collected starting from 27 October 1977. Further data could not be collected due to the non-availability of the crop field.

2. Site

The site chosen, was near the Central Agricultural Meteorological Observatory, Pune. A fetch to height ratio around 50 was obtained for easterly winds. The data was collected every three hours starting from 6 A.M. The observations were made for an average duration of 5 minutes at the above-mentioned hours. On all the days the winds were easterly.

3. Instrumentation

Winds were recorded using a commercial wind profile instrument. The temperature profile was measured by a system developed in our laboratory. A more detailed account will be given for the temperature profile system which was developed in the institute.

(i) Wind profile

Fig. 1 shows the complete sensing system erected in the crop for measuring winds and temperatures. The wind profile system was supplied by Thornthwaite Associates, USA. The instrumented levels are 10, 30, 70, 150, 230,

310 cm from the ground level. Figs. 2 (a, b) show the chopping assembly along with block diagram of the complete wind measuring system.

In brief, the working of the wind system is as follows:

A light-weight cup anemometer rotates along with its shaft of 8 cm length. At the other end of the shaft a chopper is attached which chops the light falling from a bulb on the photocell. The output of the photocell is fed to a transistorized amplifier and finally to a mechanical counter. There are six mechanical counters corresponding to six levels of observation. There is a parallel recording system available for photographing these outputs. Due to non-availability of polaroid films this facility was not used and all the observations were taken manually. Knowing the average counts, the wind-speeds are determined with an accuracy of 5 cm/sec. Winds at various levels were obtained by referring to the chart giving counts per minute against wind speed (cm/sec) supplied by the manufacturer. This system works on a power supply of 12 volts and draws a current of 1 amp.

(ii) Temperature profile

Temperature and temperature differences were measured at six levels corresponding to levels) mentioned earlier. At the highest level 310 cm, the ambient temperature was measured. At other levels temperature difference was measured with 310 cm level as the reference level. All the observations were taken in a ventilated condition. The tower of this system including the ventilating tubes containing the thermistors was painted with titanium dioxide mixed with white paint. This was done to eliminate the radiation errors. YSI thermistors were used as temperature sensors. These are 3 terminal thermistors sup-
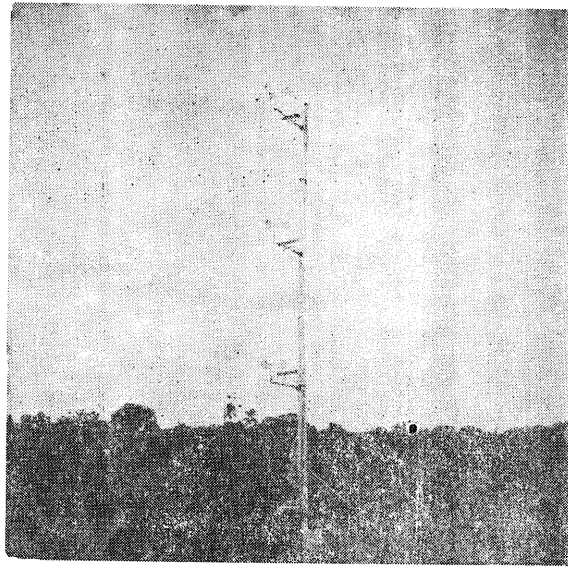
Fig. 1. Complete sensing system erected in the Jowari field near Central Agricultural Meteorological Observatory, Pune.
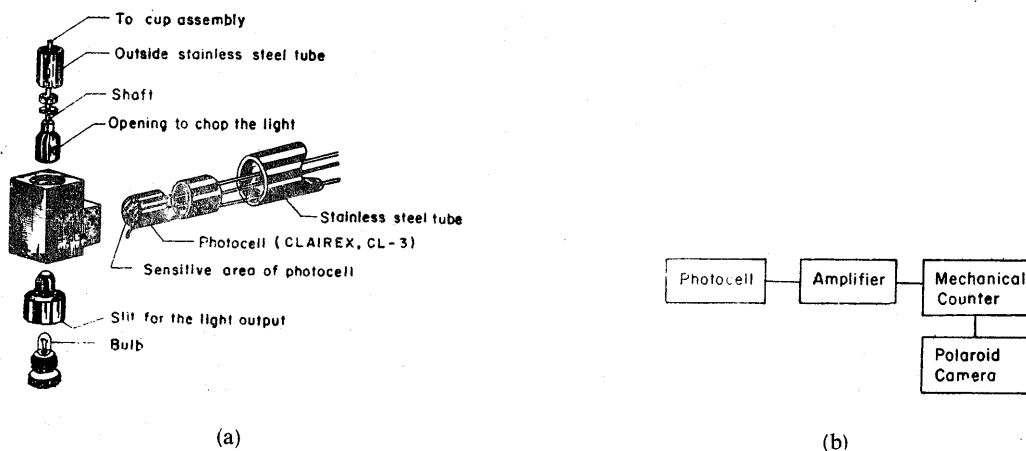

- To cup assembly
- Outside stainless steel tube
- Shaft
- Opening to chop the light
- Stainless steel tube
- Photocell (CLAIREX, CL-3)
- Sensitive area of photocell
- Slit for the light output
- Bulb

| Photocell | Amplifier | Mechanical Counter |

| Polaroid Camera |

(a)   (b)

Fig. 2. Wind measuring system along with the details of light chopping assembly

plied with linearising resistances. The temperature coefficient for these thermistors (YSI type 44203)* was 38 Ω /°C. The linearity is extremely good. Even the interchangeability of the thermistors is upto an accuracy of 0.15°C. As suggested by the manufacturers all the thermistors were operated at 1.5V.

The governing equations for the YSI thermistors, type 442203 with negative slope is :

$$E_{out} = (-0.0067968 \ E_{in}) \ T + 0.65107 \ E_{in}$$

With E_{in} of 1.52 volts, $T = 20°C$, E_{out} as given by the above equation is 794 millivolts.

The calibrated output was 800 millivolts. This difference was treated as the experimental error. Hence the calibrated chart, indicating temperature *versus* millivolts was used to obtain the temperature readings. Fig. 3 shows the complete circuit of the temperature and temperature difference measuring instrument. All the six thermistors are housed on the tower as shown in Fig. 1. With the help of bandswitch S, thermistor (1) can be compared with other thermistors. Thermistor (1) is at the 310 cm level and other thermistors are positioned at the levels mentioned earlier in descending order. With the switch position in 1 to 5, temperature difference is measured and in the 6th position absolute

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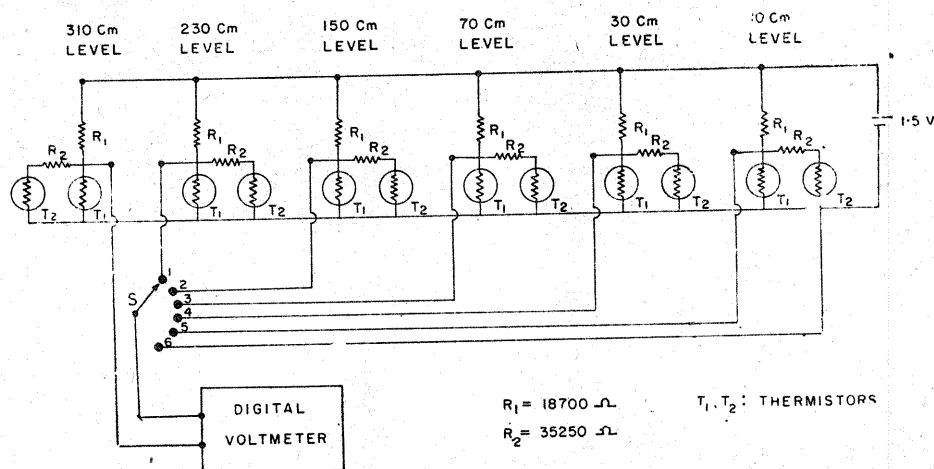*YSI component Division, Ohio, USA.

Fig. 3. Circuit details of temperature and temperature difference measuring circuit

temperature at 310 cm is measured. A differential output of 1 mV corresponds to a temperature difference of 0.1 °C. The temperature and temperature difference outputs are measured on a digital voltmeter.

The digital voltmeter, pump and wind-measuring instrument were housed in a wooden box kept 100 metres away from the tower.

4. Data analysis

The major exchange in crop canopies is at the top of the canopies. Thus it is necessary to know the roughness length z_0 and zero displacement length d of the canopy. The size of z_0 for a particular plant canopy specifies its bulk effectiveness as a momentum absorber, while the zero displacement length d can be considered to indicate the mean level at which momentum is absorbed by the individual elements of the plant, i.e., the level of action of the bulk aerodynamic drag on the plant. The relationship between z_0 and h as given by Seginer (1974) is:

$$\ln z_0 = \alpha + \beta \ln h \qquad (1)$$

where z_0 and h are in centimetres. The value of α is about —2.5 and β is about 1. With these values of constants and $h = 117$ cm (average canopy height), z_0 comes out to be ≈ 9 cm. A similar relation between d and h is given by Seginer (1974):

$$d/h = 0\cdot 64 \qquad (2)$$

Using relation (2), $d = 74\cdot 88$ cm.

The Richardson number was estimated following Webb's (1970) method and u_* the friction velocity and θ_* the scaled temperature were calculated as suggested by Businger (1973).

In our study, the first three levels (10, 30, 70 cm) were within the canopy. Other three levels 150, 230 and 310 cm were above the height of canopy.

A geometric height $z = \sqrt{z_6 \cdot z_4}$ for 310 cm and 230 cm was considered for estimating the Richardson number. The Richardson number is given by [for the heights z_6 (310 cm) and z_4 (230 cm)].

$$R_i = \frac{g}{\theta} \cdot \frac{\theta_6 - \theta_4}{(u_6 - u_4)^2} \cdot 10^{-2} \, z \cdot \ln z_6/z_4 \qquad (3)$$

where,

g = acceleration due to gravity, 980 cm/sec²

θ = temperature at 310 cm in degrees Kelvin

z = Geometric height

$\theta_6 - \theta_4$ = temperature difference in °C between 310 and 230 cm levels

$u_6 - u_4$ = wind speed difference in metres/sec between 310 and 230 cm levels.

Using Eqn. (3), Richardson number was estimated for all the days. Mohin-Obukhov length was calculated from Richardson number R_i.

If $R_i < 0$ $\quad \dfrac{z}{L} = R_i$

$$\therefore L = \frac{z}{R_i} \qquad (4)$$

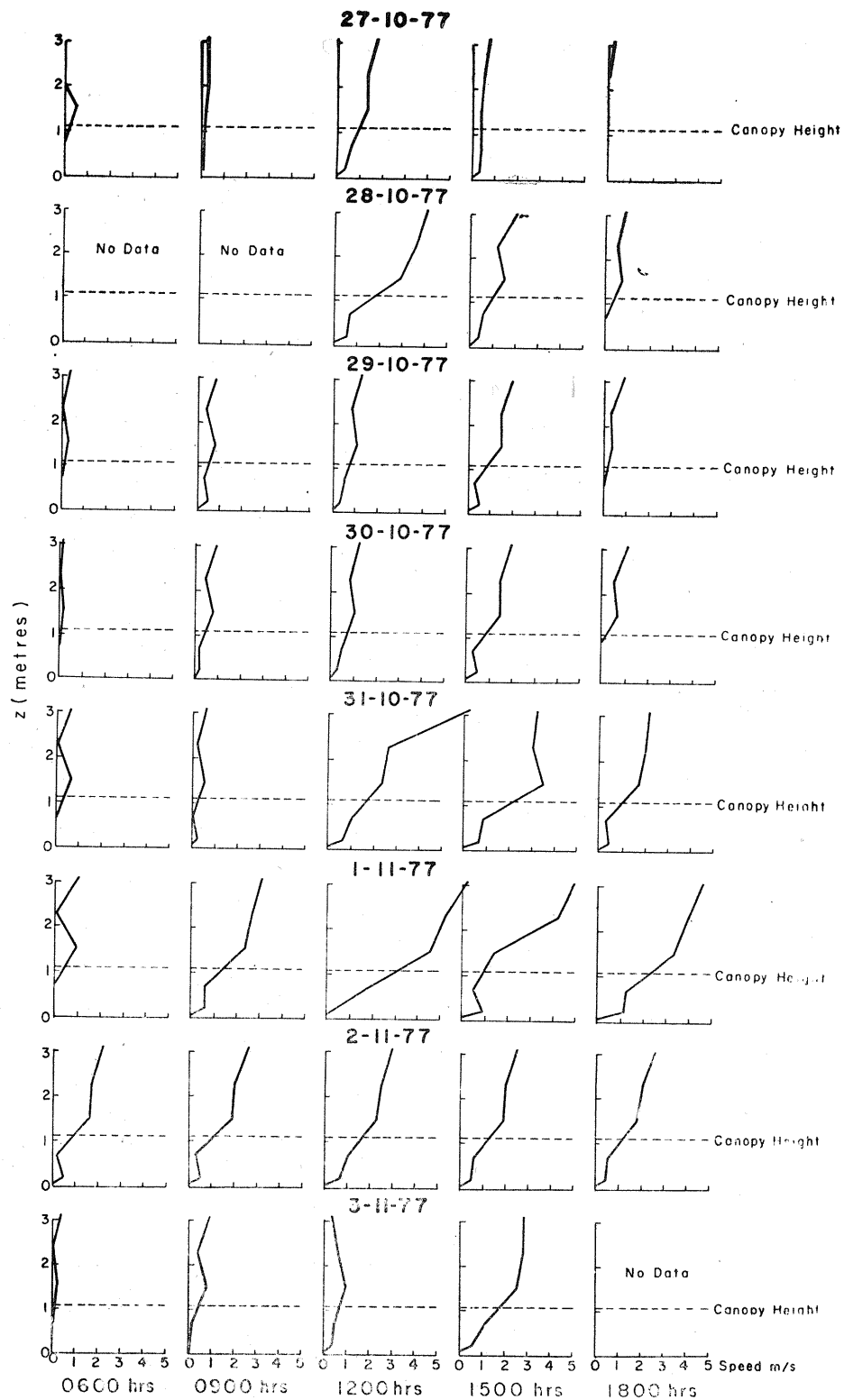K. G. VERNEKAR AND L. K. SADANI

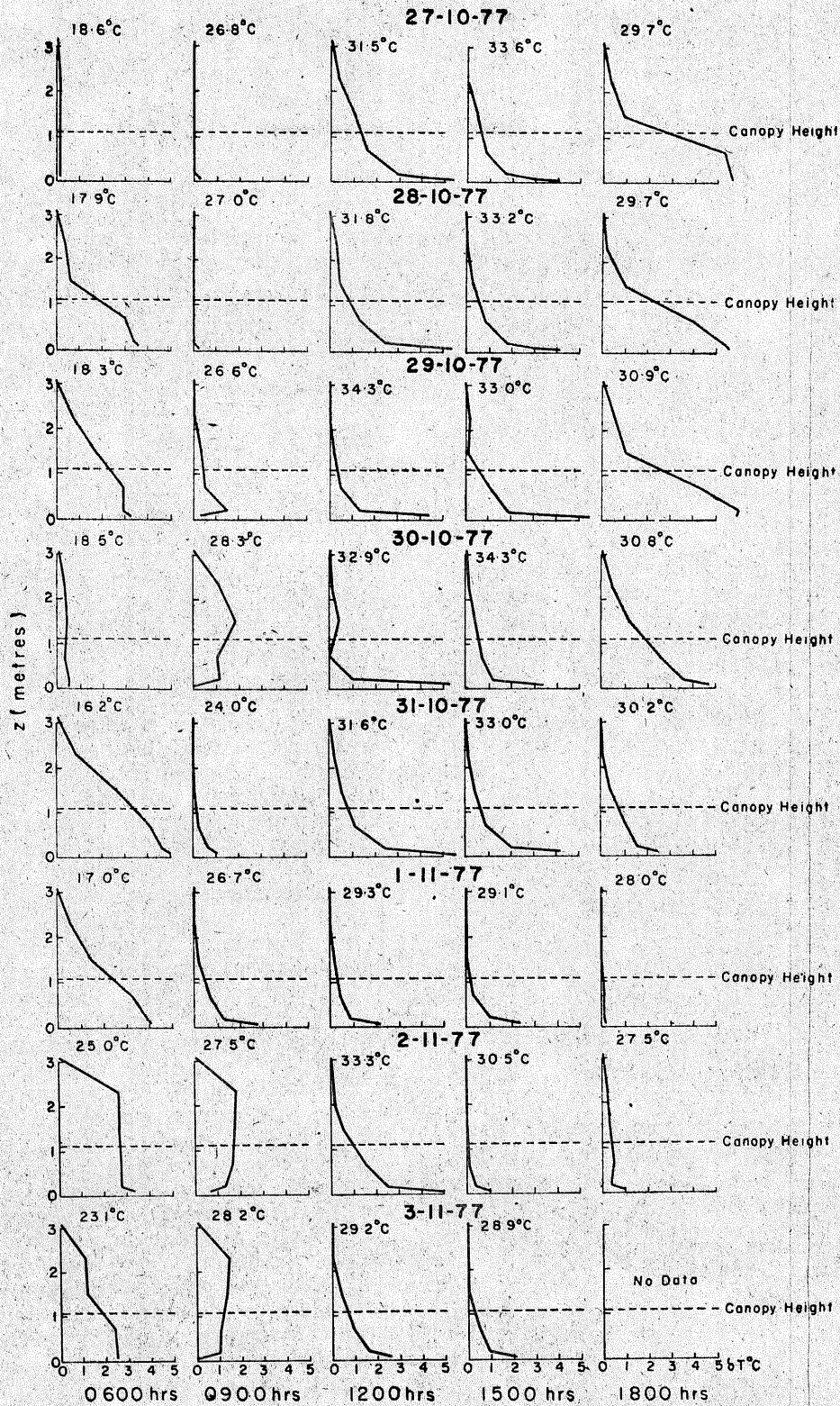Fig. 4.   Wind profiles at an interval of three hours

Fig. 5. Temperature profiles at an interval of three hours. The temperature at 310 cm level is shown in each profile.
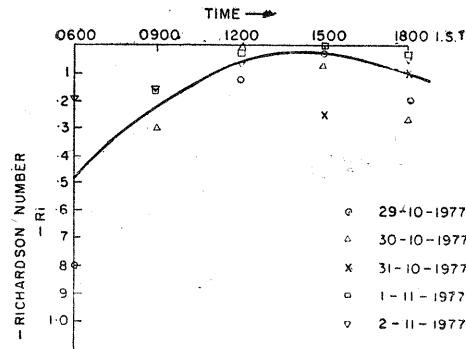
Fig. 6. Variation of stability in terms of Richardson
        number (at 2.3 metres height) over the jowari
        canopy

This relation holds goods for all the days of our observation u_*, the friction velocity was calculated knowing z/L and du/dz :

$$u_* = k.z.\frac{du}{dz} \cdot \left(1 - 16\frac{z}{L}\right)^{1/4} \tag{5}$$

where du/dz is wind gradient between z_6 and z_4, k the Von Karman constant $= 0.41$ and z the geometric mean height between z_6 and z_4 levels. Random check and comparison was made for calculating u_* according to the Businger (1973) equation:

$$u = \frac{u_*}{k}\left\{\ln\frac{z}{z_0} - \psi\right\} \tag{6}$$

where, ψ is given as:

$\psi = 2\ln(1 + \chi/2) + \ln(1 + \chi^2/2) - z\tan^{-1}\chi + \pi/2$

$\chi = (1 - 16\,z/L)^{1/4}$ for $L < 0$

$\chi = (-5).z\,(z/L)$ for $L > 0$

where, $k = 0.41$

   $z_0 = 9.02$ cm

   $z = $ level of interest

The values calculated from Eqn. (6) were consistently differing from u_* calculated from Eqn. (5) by 5 per cent. Hence the use of simpler Eqn. (5) was made to calculate u_* .

Using an equation similar to (5), θ_* scaling temperature was calculated as :

$$\theta_* = k.z.\frac{d\theta}{dz} \cdot (1 - 16\,z/L)^{1/2} \tag{7}$$

where $d\theta/dz$ is the temperature gradient between z_6 and z_4, z the geometric mean height. Finally the sensible heat fluxes were calculated in terms of u_* and θ_*:

$$H = -\rho\,c_p u_* \theta_* \text{ (watts/cm}^2) \tag{8}$$

where, $\rho = $ the density of air 1.25×10^{-3} gm/cm³

   $c_p = $ specific heat of air at constant pressure

   $= 0.2 \times 4.1$ Joules/gm/ °C.

   $u_* = $ friction velocity, a variable (cm/sec)

   $\theta_* = $ scaled temperature, a variable (°C)

5. Discussion

Figs. 4 and 5 show wind and temperature profiles for all the days starting from 27 Oct 77 to 3 Nov 77. The wind speeds (m/s) are plotted against the height (metres) at different observational times. Temperature differences are plotted against the height. The actual temperature at the 310 cm level is indicated in each graph. The temperature differences are positive with respect to 310 cm level. The canopy height is also shown in all the graphs. Fig. 6 shows the stability in the form of Richardson number R_i plotted against the time. Richardson number is negative indicating an unstable condition prevailing over the canopy. Considering Fig. 4 the wind profile increases above the canopy as expected. Bache et al. (1977) has made similar studies over cotton canopy. Bache gives the definition of an aerodynamic crop height as the height of the point of inflection between the 'in-canopy' and 'above-canopy' wind profiles. In our study, it is found that aerodynamic height is the point of inflection between the 'in-canopy' and 'above-canopy' wind profiles. In Bache's study the aerodynamic crop height is within 15 cm of the actual crop height. In the present study the aerodynamic height variation is quite large. On most of the days it is less than the actual crop height by 40-50 cm.

Uchigima (1976) has given a good account of the turbulent transfer of heat and water vapour within rice and maize canopies. In rice
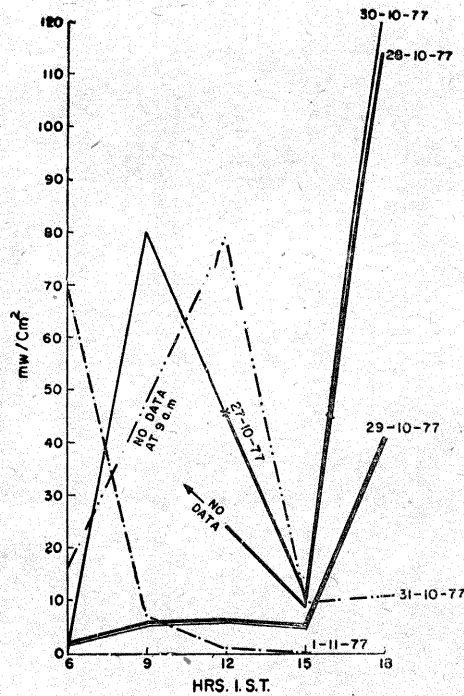
Fig. 7.   Variation of sensible heat flux $(\rho c_p \, u_* \theta_*)$ with time

and maize canopies the temperature and vapour pressure decrease monotonically with the crop height from the ground leading to an upward heat flux through the crop. Similar trend of temperature profile was observed in the Jowari canopy. Maximum temperature difference occurs between the top (310 cm) and the lowest (10 cm) levels. Comparing the wind profiles and temperature profiles it is seen that temperature difference between above canopy and below canopy is reduced whenever there is a high wind. Thus on 29 October 1977 the winds were of smaller order and the temperature difference between 310 and 10 cm levels was round 5°C, whereas on 31 October 1977 and 1 November 1977 winds were higher corresponding to smaller temperature difference $\simeq$ 2°C between the same two levels.

As stated earlier on most of the days an unstable condition prevailed over the canopy. This may be a combined effect of wind and temperature gradients (leading to a -ve Richardson number). The other reason may be that the canopy acts like a source of heat energy (Thom 1976). This source of heat may exist inside the canopy because of various conditions prevailing inside the canopy such as soil temperature, inside canopy temperature, winds and most important is the eddy diffusivity.

Fig. 6 shows the stability at 2.3 metres in the form of gradient Richardson number (R_i) plotted against the time. It is seen that all through the day an unstable condition prevailed leading to an upward sensible heat flux. Fig. 7 shows this sensible heat flux variation with time over the canopy. The variation follows a general trend of incoming radiation which is maximum at the local noon. The sensible flux also closely follows the same trend. The maximum is around local 1400 hr. As seen in Fig. 7 there is a slight deviation from the general variation of the flux at 1500 and 1800 hr. A minimum flux is observed at 1500 hr. This may be due to the stable conditions prevailing at 1500 hr (Fig. 6), but the increase at 1800 hr is due to the increased foliage activities. Shortly after the noon, in the canopy, the stomata of the leaf closes and there is an increase of leaf temperature. It is observed that the sunlit leaf is 5°-10° C warmer than the surrounding air (Oke 1978). The increase of flux at 1800 hr may be due to the flux emitted by the leaves of the canopy.

6. Conclusion

In Jowari canopy during harvesting period considerable amount of temperature gradients are observed leading to a good amount of upward sensible heat flux. The foliage activity is also predominant towards the production of heat flux in the evening hours. A detailed experiment taking simultaneous observations of the leaf temperature as well as canopy temperature will give more information of these problems.

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