Agropedology, 1998. **8**, 66-72

Seasonal thermal status and heat flow in upland surface soils of Tripura

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Abstract

The seasonal soil temperature and heat flow pattern of soils of ICAR Complex, Tripura were recorded both in the morning and afternoon at the depths of 5, 10, and 20 cm. The soil temperature, in the morning, varied from 22.0 to 28.5°C in *pre-kharif* and *kharif* and from 15.1 to 21°C in *rabi*. It varied in the afternoon from 30.0 to 36.5°C in both *pre-kharif* and *kharif* seasons, but had wider variation in *rabi* season from 23 to 34°C. The volumetric heat capacity and thermal diffusivity showed inverse relation with volumetric moisture, however, there was a little variation found in thermal conductivity with depth. The outward heat flux was more in *pre-kharif* and *rabi* (-0.747 to -2.461 mcal/cm^2/sec) compared to that in *kharif* (-0.223 to -0.843 mcal/cm^2/sec) in 5-10 cm depth. The downward heat flux was also generally observed to be higher in *pre-kharif* and *rabi* (1.991 to 4.477 mcal/cm^2/sec) in 5-10 cm and also in 10-20 cm depth compared to that in *kharif* season (1.084 to 3.382 mcal/cm^2/sec).

Additional keywords: Volumetric heat capacity, thermal diffusivity, thermal conductivity, heat flux.

Introduction

Soil temperature strongly governs both the soil physical processes including evaporation, aeration and rates of chemical reactions and biological processes such as seed germination, seedling emergence and growth, root development and microbial activity. The possibility of actively controlling or modifying the thermal regime requires a thorough knowledge of heat capacity, thermal conductivity and thermal diffusivity. Soil surface temperature conditions can be modified by mulching materials and various tillage treatments. In a sodic soil the ridges were cooler by 1-2°C during day time in the winter and were warmer than flat surface by 1-2°C in the forenoon, 5-6°C in the afternoon hours during the summer (Grewal and Abrol 1990). The present work aims at studying the annual variation in soil thermal regime, effect of moisture on heat capacity, thermal conductivity, diffusivity and seasonal heat flux in the soils of Tripura.

Materials and methods

The observations on soil temperature were recorded during morning (0530 IST) and afternoon (1325 IST) for ten years from 1985-1994 at the soil depths of 5 cm, 10 cm, and 20 cm by the meteorological observatory, ICAR, Tripura using soil thermometers. The texture of the experimental upland soils was sandy loam (Datta *et al.* 1990). The soils had kaolinite as dominant mineral associated with illite with traces of chlorite and quartz (Das *et al.* 1976).

Volumetric heat capacity (VHC) expressed in cal/cm^3/^{0}K was computed from the following equation,

$$VHC = f_m C_m + f_o C_o + f_w C_w \quad ...... (1) \qquad \text{(Hillel, 1980)}$$

where, f_m, f_o and f_w are the volume fractions of soil mineral, air and soil moisture, respectively. The volume fraction of soil solids and pores in the soil of experimental site were found to be 0.58 and 0.42 for 0-5 cm depth, 0.572 and 0.433 for 5-10 cm depth, and 0.56 and 0.44 for 10-20 cm depth. The mineral fraction for those depths were found to be 0.53, 0.52, 0.50, respectively (Datta *et al.* 1990). Where C_m, C_o and C_w are volumetric heat capacities of those fractions.

The volumetric moisture data were measured gravimetrically for the experimental site at depths of 0-5 cm, 5-10 cm, 10-20 cm for four years from 1992-95. The bulk density of these three different layers were 1.42 gcm^{-3}, 1.37 gcm^{-3} and 1.37 gcm^{-3}, respectively. The volume fraction of air was computed from pore fraction and moisture fraction. The volumetric heat capacity was computed for four years from 1992-95. The thermal conductivity for this soil was computed according to Bavel and Hillel (1975, 1976), given by

$$\text{Thermal conducitivity} = \frac{f_w K_w + K_s f_s k_s + K_a f_a k_a}{f_w + K_s f_s + K_a f_a} \qquad \text{..... (2)}$$

Where, K_w, K_a and K_s are the specific thermal conductivity of the soil constituents (water, air, and an average value for the solids, respectively). The values given by Hillel (1980) were used in the present study. The factor K_s is the ratio of thermal conductivity of soil solid relative to the water phase. The factor K_a represents the corresponding ratio for the thermal gradient in the air and water phases. The value of K_s and K_a given by Hillel (1975) were used in the present study. The measured values of volume fractions of water, solid and air (f_w, f_s and f_a as already mentioned) were used in the present study.

The seasonal changes in thermal conductivity were computed for three soil layers of 0-5, 5-10 and 10-20 cm. Thermal diffusivity for different layers were computed by

Thermal Diffusivity (TD) = K/VHC

where, K = thermal conductivity of soil

VHC = volumetric heat capacity of soil

The heat fluxes between 5 cm and 10 cm depth, and 10 cm and 20 cm depth were computed by averaging over four years of computed data for each of the three seasons *pre-kharif*, *kharif* and *rabi*. The months for *pre-kharif* comprises of March and April, *kharif* May to October and *rabi* November to February.

The outgoing heat fluxes during morning (includes upward heat transfer) when minimum soil temperature (0530 IST) occurs and the downward heat fluxes during afternoon (includes the isolation) when maximum soil temperature (1325 IST) occurs, were computed by using the following equation:

Heat flux = $K (T_1 - T_2) / L$

where, T_1 = soil temperature at upper soil layer (°C)

T_2 = soil temperature at lower soil layer (°C)

L = distance between two layers (cm)

K = thermal conductivity of soil (Cal/cm/sec/°K)

Results and discussion

Thermal status of soil surface

The variation of soil temperature for 0-20 cm soil profile between mornings and afternoons over three different seasons in Tripura are presented in figure 1. The soil temperature gradient through different layers established during night became reverse during day time in all the three different seasons, *pre-kharif*, *kharif* and *rabi*. The same reversal thermal gradient was also recorded by Hillel (1980).

Figure 1a showed that morning soil temperature during *pre-kharif* season varied from 22.5°C to 27.0°C as against the afternoon variation of 36.5°C to 30.0°C between 5 and 20 cm soil depths. The observed variations during *kharif* were 25.8°C to 28.5°C for morning and 34.5°C to 30.3°C for afternoon between 5 and 20 cm soil depths (Fig. 1b). But a shift from the normal trend, as recorded in *pre-kharif* and *kharif*, was observed during *rabi* season. The morning soil temperature (Fig. 1c) varied from 15.1°C to 21.0°C between 5 to 20 cm depth and the variation in the afternoon for the same depth was 34°C to 23°C. The temperatures in the *rabi* at 20 cm depth were almost equal to that at 5 cm depth during *pre-kharif* and *kharif* seasons. This may be due to prevalent low ambient temperature during *rabi* season.

It is pertinent to note that the difference between top soil (5 cm depth) and 20 cm depth soil temperature was much higher in *rabi* season than those of *pre-kharif* and *kharif* seasons. This may be due to two reasons, (i) the greater difference between maximum and minimum temperatures, (ii) the longer night length with longer period of heat variation from top soil surface (Grewal and Abrol 1990). The reversal of thermal gradient from day time to night time may be due to the effect that the top soil (0-5 cm) gets warmed up during day time and cooled down during night time through thermal emission. However, the top soil (0-5 cm) is more vulnerable to changes in thermal conditions in the atmosphere, whereas at depths of 20 cm soil temperature remains almost same during morning and afternoon. At greater depths, due to lesser penetration of insulation and less influence of ambient conditions seemed to cause little difference between morning and afternoon temperatures.

Heat capacity and diffusivity

The changes in heat storing parameter, volumetric heat capacity (VHC) and the heat flow parameter, thermal diffusivity (TD) with volumetric moisture content for 0-5 cm, 5-10 cm and 10-20 cm soil depths are presented in figure 2. In all the three layers the VHC increased gradually from 0.32 to 0.60 cal/cm/°K with the increase in moisture from 0.05 to 0.34 cm^{-3}, whereas the thermal conductivity value varied within narrow range of 6.4 to 6.8 mcal/cm/sec/°K for a wider variation in soil moisture. This may be due to presence of higher solid fraction (0.56) with a bulk density of 1.4 gcm^{-3} in sandy soil of Tripura. Hillel (1980) also showed almost constant value of thermal conductivity for loam soil having higher solid fraction of 0.5 and bulk density of 1.33 gcm^{-3}. It may be mentioned that the steady increase in thermal conductivity with increase in soil moisture fraction, takes place below 10% moisture (Fig. 2). This suggested the insignificant role of soil moisture to cause a substantial change in thermal conductivity at higher level of soil moisture specially under coarse textured soil. The higher sensitivity of volumetric heat capacity and lower sensitivity of thermal conductivity with the change in soil moisture under present investigation have led to a gradual decrease in thermal diffusivity (TD) from 22.1×10^{-3} to 10.1×10^{-3} cm^2 sec^{-1}. This finding has good agreement with that of Bavel and Hillel (1975), where the thermal diffusivity (TD) increased significantly with soil moisture increase but below 10% level. This increase was followed by gradual decrease in the values for moisture increase greater than 10 per cent.

Heat flux

The seasonal changes in heat flux and thermal conductivity during morning and afternoon for 5-10 cm and 10-20 cm soil depths are presented in the table 1.

The outward heat flux was highest during rabi season with the range of -1.121 to -2.461 mcal/cm^2/sec for 5-10 cm depth followed by those in *kharif* (-0.223 to -0.843 mcal/

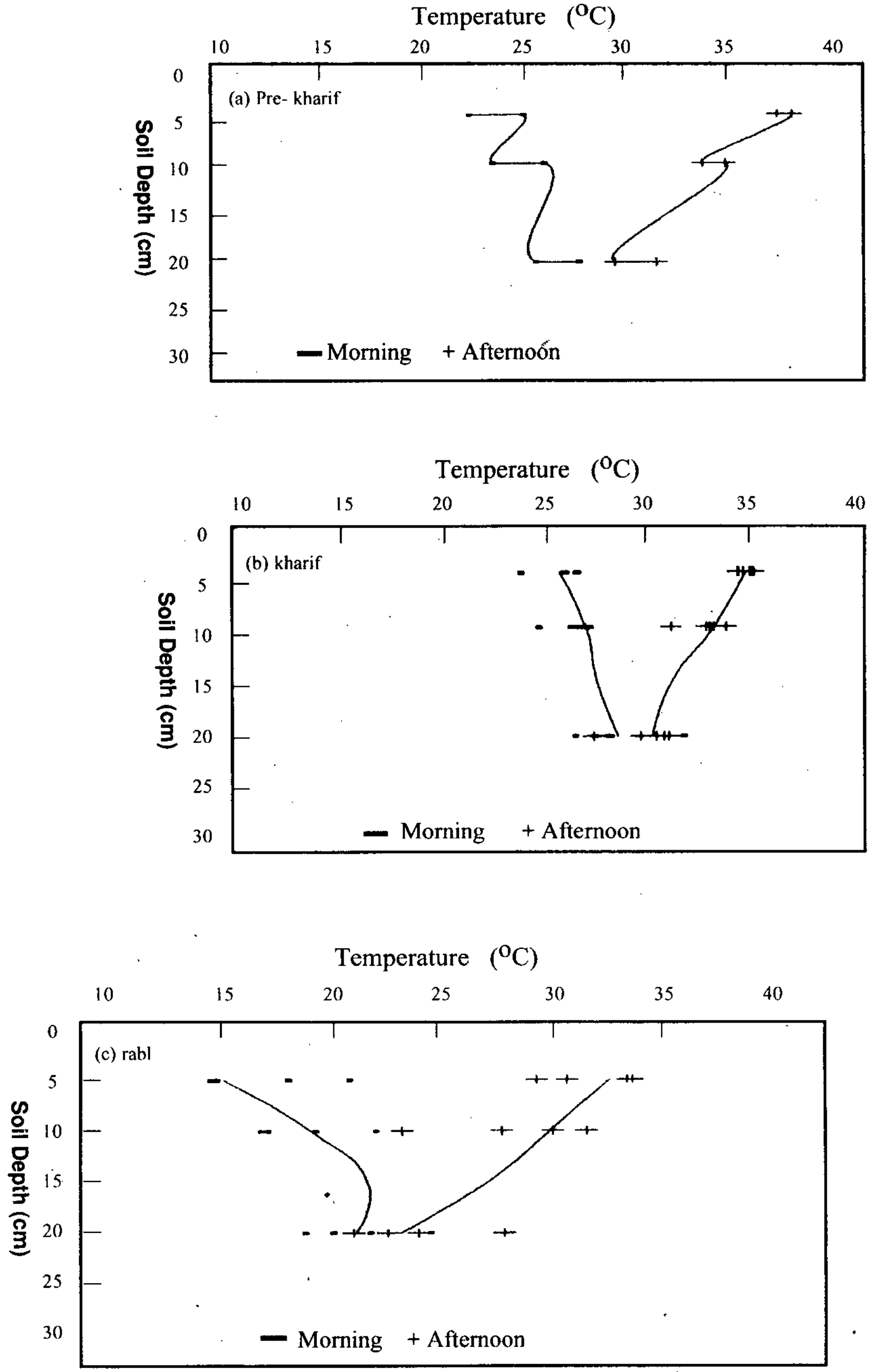

Fig. 1. Soil thermal capacity in upland of Tripura.

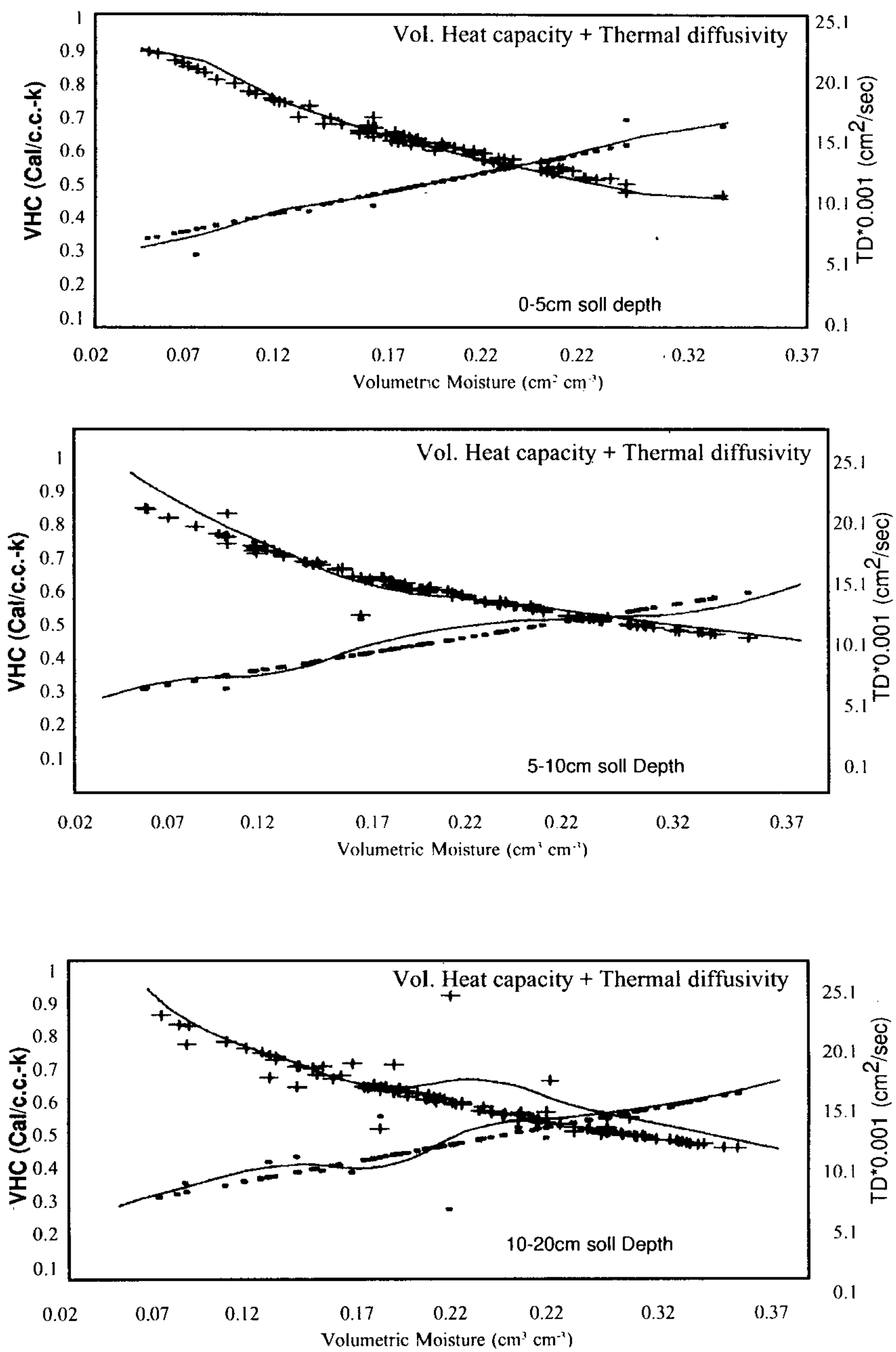

Fig.2. Heat capacity and thermal diffusivity of different soil layers.

cm²/sec) and (-0.747 to -1.407 mcal/cm²/sec) in *pre-kharif*. The same ranking was also found for 10-20 cm soil depth. The outward flux was found to be less in *pre-kharif* and *rabi* season, but higher during *kharif* season. The frequent change in soil moisture in topsoil during *kharif* season might have resulted into greater upward flow of moisture from lower layer which led simultaneously the higher amount of heat transfer from lower level.

Table 1. Seasonal changes in heat flux (averaged for years 1985-1994) and thermal conductivity

Seasons	Heat flux (mcal/cm²/sec) at mean depth of				Thermal conductivity (mcal/cm/sec/°K) at mean depth of	
	5-10 cm layer		10-20 cm layer		5-10 cm layer	10-20 cm layer
	Morning	Afternoon	Morning	Afternoon		
Pre-kharif						
March	-1.407	3.67	-1.265	2.839	6.79	6.696
April	-0.747	4.477	-1.107	2.035	6.79	6.758
Kharif						
May	-0.376	2.106	-0.664	1.689	6.76	6.717
June	-0.661	3.382	-0.680	1.084	6.69	6.639
July	-0.223	1.807	-0.797	1.330	6.58	6.534
August	-0.767	1.647	-0.864	2.033	6.52	6.534
September	-0.524	2.395	-1.078	1.275	6.58	6.532
October	-0.843	2.471	-1.860	2.232	6.55	6.515
Rabi						
November	-1.380	2.868	-1.170	2.325	6.64	6.597
December	-1.918	3.819	-1.836	1.991	6.59	6.567
January	-2.461	3.904	-2.233	3.535	6.66	6.618
February	-1.121	2.343	-1.658	3.165	6.73	6.705
CD at 5%	0.671	1.583	0.619	0.971		

The downward heat flux during afternoon hours in the 5-10 cm soil depth was higher in *pre-kharif* and *rabi* seasons (2.343 to 4.477 mcal/cm²/sec) than in kharif season (2.106 to 3.382 mcal/cm²/sec). The lesser cloud cover coupled with lesser relative humidity in *pre-kharif* and *rabi* seems to have resulted into greater drying and heating up of 5-10 cm depth zone leading to higher heat transfer within that zone. On the other hand, for 10-20 cm depth, the heat transfer was found to be less than that of 5-10 cm soil depth in different seasons. Moreover, the flux showed little variation (1.275 to 2.839 mcal/cm²/sec) except the higher values in January and February having high moisture deficiency. The seasonal changes of downward heat transfer was more in case of top soil (5-10 cm depth) compared to that in 10-20 cm soil depth as indicated by corresponding CD values of 1.583 and 0.970, respectively, at 5% level of significance. The upward heat flux for top soil was little higher compared to that of 10-20 cm layer as indicated by CD values of 0.671 and 0.619 at 5% level.

It can be concluded that for sandy loam soils of Tripura, there was a gradual increase in volumetric heat capacity and decrease in thermal diffusivity with increase in volumetric moisture, but little variation was found in thermal conductivity. The outward heat flux was more in *pre-kharif* and *rabi* (-0.747 to -2.461 mcal/cm²/sec) compared to that in *kharif* (-0.223 to -0.843 mcal/cm²/sec) in 5-10 cm depth. But *kharif* season showed higher outward flux in 10-20 cm depth due to simultaneous transfer of moisture. The downward flux was also generally observed to be higher in *pre-kharif* and *rabi* (2.106 to 4.477 mcal/cm^2/sec) in 5-10 cm and also in 10-20 cm depth compared to that in *kharif* season.

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