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Sub-soil temperature variation and estimation of soil heat flux at Pune

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सार — पुणे में तापमान और उष्णता भण्डार की विभिन्नता के आधार पर प्रत्येक 3 घण्टों के प्रेक्षण का 23 नवम्बर से 8 दिसम्बर 1989 तक के प्रायोगिक आंकड़ों का अध्ययन किया गया है। विभिन्न गहराइयों पर मृदा में तापीय लहरों के नमूनों का प्रभाव, परीक्षण एवं न्यूनतम और अधिकतम ताप का समय देखा गया है। विभिन्न स्तरों पर ताप परास का सैद्धान्तिक परिकलन कर वास्तविक प्रेक्षणों से उसकी तुलना की है। विभिन्न गहराइयों पर उष्णता के संतुलन को प्रस्तुत किया है और उस पर विचार विमर्श किया गया है।

ABSTRACT. Utilising experimental data from 23 November to 8 December 1989, temperature and heat storage variations at Pune have been studied, based on 3 hourly observations. Pattern of penetration of thermal wave within the soil has been examined and time of occurrence of maximum/minimum temperatures discussed for various depths. Temperature ranges in different layers have been theoretically computed and compared with those based on actual observations. Heat balance at various depths has also been presented and discussed.

Key words — Thermal wave, Oscillation period, Heat storage, Diffusivity.

1. Introduction

Soil temperature is of vital significance to plant life and agriculture. It influences germination of seed, functional activities of the roots, rate and duration of plant growth, occurrence and severity of crop diseases etc.

In many cases, soil temperature is of greater ecological significance to plant life than air temperature. Many high altitude locations would certainly be devoid of vegetation were it not for the considerably higher temperature of the soil than that of the air. Study of heat flux is important for understanding the microclimate. Not much information seems to be available on these aspects in India.

In the present study an attempt has been made to examine sub-soil and surface temperature characteristics at Pune.

2. Data

An experiment was conducted at the Central Agromet. Observatory, Pune from 23 November to 8 December 1989 on the black cotton soil. The weather during the period was generally dry and clear, except on 5 December 1989 when 2/3 oktas low and medium clouds were present. The soil temperatures were measured every 3 hours starting from 0530 IST at the surface and at 5, 10, 15, 20 and 30 cm below the ground. Air temperatures were also simultaneously measured at the screen level, *i.e.*, at 122 cm above the soil surface.

The black soil in the study has a bulk density of 1.34 gm/cm^3, field capacity ranging from 32 % to 35% and a wilting point of 18 % to 19%. The soil has the volumetric heat capacity of 3.35×10^3 J/K/kg equivalent to 0.8 cal °C/gm.

3. Results and discussion

3.1. *Diurnal variations*

During the day intense solar radiation is absorbed by the soil which warms the ground surface more than the layers beneath, resulting in temperature gradient between the surface and the sub-soil on one hand, surface and air layers near the ground on the other. Within the soil this cause heat to flow downward as a thermal wave. These waves are a regular feature during clear weather (Fig. 1). Mean pattern of the wave is shown in Fig. 2. Mean air temperature (at 122 cm height) is also shown in the figure for the sake of comparison.

The ground surface starts heating after sunrise at a rate of 3.7°C/hr. Soil at — 5 cm too commences warming after sunrise initially at a rate of $\sim$1° C/hr and attains a maximum of nearly 4°C/hr in noon. At 10 cm and 15 cm thermal wave is seen between 0830 and 1130 IST and 1130 & 1430 IST respectively. Below 15 cm, the peak in soil temperatures is not conspicuous.

An unmistakable progressive phase shift in the time of occurrence of maximum soil temperature is seen. As the wave propogates slowly into the ground, it seems to get damped. There is a tendency for the amplitudes to decrease with depth and at 20 and 30 cm depths the amplitude is practically zero.

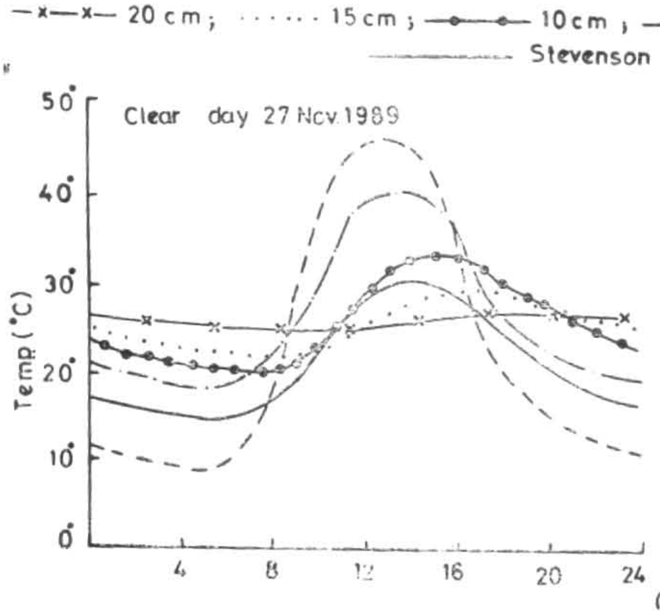

Fig. 1. Diurnal variation of soil temperature for a typical clear day

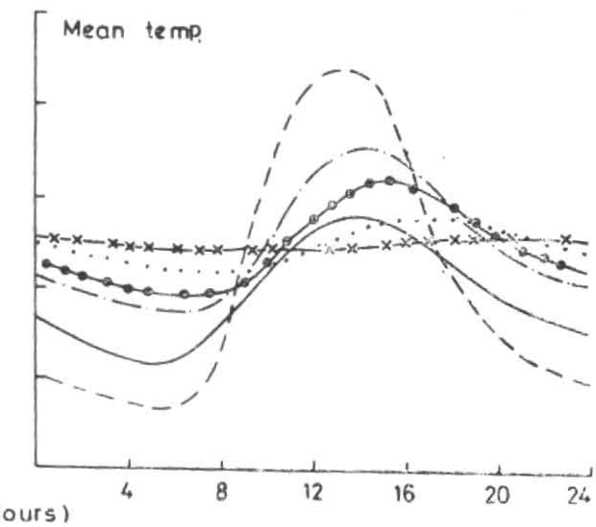

Fig. 2. Diurnal variation of mean soil temperature

TABLE 1

Comparison between theoretically computed temperature range and time lag of maximum temperature with those observed at various depths with respect to ground surface

Soil depth (cm)	Temperature range		Time lag	
	Computed (°C)	Observed (°C)	Computed	Observed
5	20.1	18.2	2 hr 15 min	1 hr 15 min
10	11.0	12.2	4 hr 36 min	2 hr 30 min
15	6.0	6.3	6 hr 54 min	4 hr 15 min
20	3.3	2.1	9 hr 18 min	8 hr 30 min
30	1.0	0.3	13 hr 48 min	11 hr 30 min

Time of occurrence of lowest temperatures at 122 cm and within the soil up to 10 cm, occur about the same time, generally 1-2 hr before sunrise. At deeper depths, they are observed much after sunrise, sometimes 3-4 hr later (Fig. 2).

The period of cooling in layers near the ground, is nearly one and half times that of the warming. However, in deeper depth this factor could be as large as 3.

The diurnal range of soil and air temperature which represents the heat gained due to insolation and penetration and that lost due to conduction and radiation is given in Fig. 3. It is seen that the range decrease exponentially from the surface with depth, but linearly with the height above the soil surface. At the surface it is nearly 37°C while at —5 cm the range is just half that of the surface. It is practically insignificant at —30 cm depth. Parton and Logan (1981) found that the diurnal variation at a short grass prairie site in Pawne (USA) to be less than 2°C at —20 cm depth. The temperature range for any depth Z is given by the equation (Chang 1968):

$$R_Z = R_0 \left| \exp\left\{ -Z \left(\frac{\pi}{K_h P} \right)^{1/2} \right\} \right| \quad (1)$$

where,

R_Z — Temperature range at depth Z,

R_0 — Temperature range at the ground surface,

K_h — Thermal diffusivity of the soil, and

P — Oscillation period.

Thermal diffusivity of soils lie between 10^{-2} and 10^{-3}cm²/sec (Chang 1968). Taking period P as 24 hr and applying Eqn. (1) temperature ranges were worked out for different values of diffusivity ranging from 0.002 to 0.004 at an interval of 0.0005. It was observed that the RMSE was least for K_h —0.0025. This value of K_h is used in the computations. Mean temperature range at various depths are given in Table 1. The computed values of the range appears quite close to the observed ones.

Time lags of maximum thermal cycle within the soil has also been attempted. Theoretically, according to Chang (1968), the cycle can be expressed by :

$$t_2 - t_1 = \frac{Z_2 - Z_1}{2} \left(\frac{P}{K_h \pi} \right)^{1/2} \quad (2)$$

where, t_2 and t_1 are the times of occurrence of maximum temperature at depths Z_2 and Z_1 respectively. The actual time lags with respect to its occurrence at the surface, alongwith the computed lags are also shown in Table 1. It appears that attainment of the maximum temperature gets delayed practically linearly up to 10 cm depth. It is about 4 hr at — 15 cm, 9 hr at — 20 cm and 12 hr at —30 cm (*cf* Decker 1955).

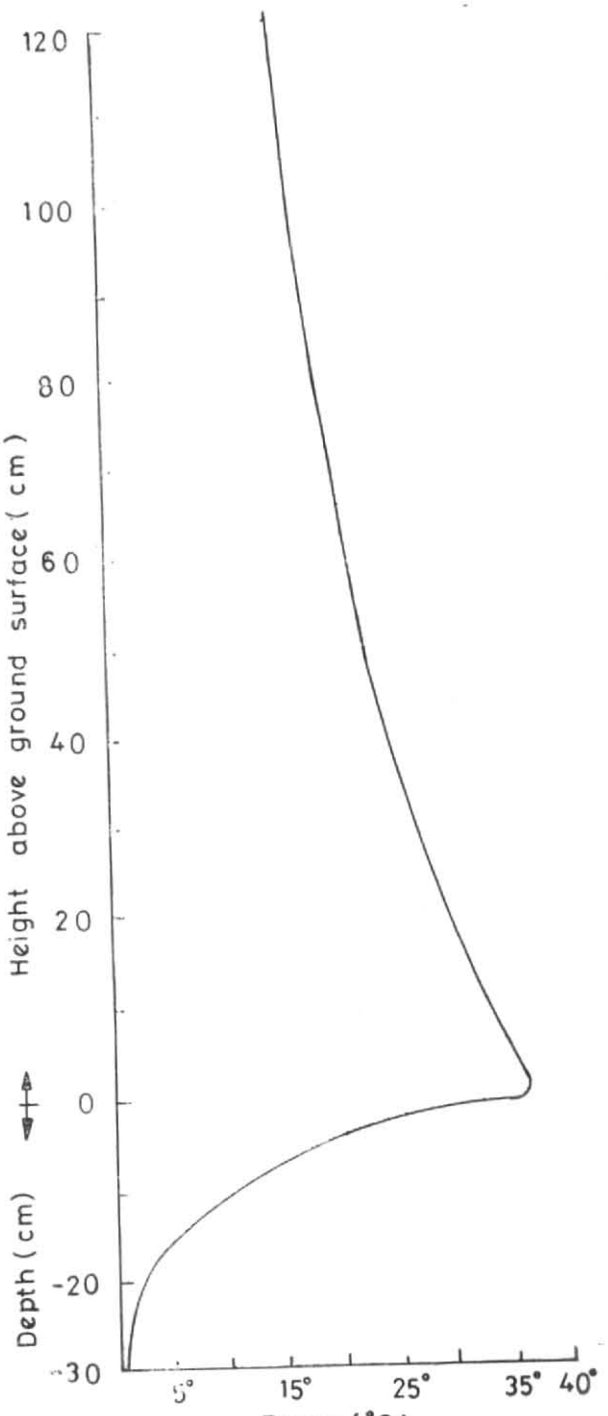

Fig. 3. The diurnal range of soil temperature and air temperature

Results for minimum temperature were similar to that for maximum temperature and hence not been discussed.

3.2. *Soil heat flux*

The heat storage Q (cal/cm²) between the soil depth Z_2 and Z_1 is given by

$$Q = \int_{Z_1}^{Z_2} C(Z)\, T(Z)\, dZ \qquad (3)$$

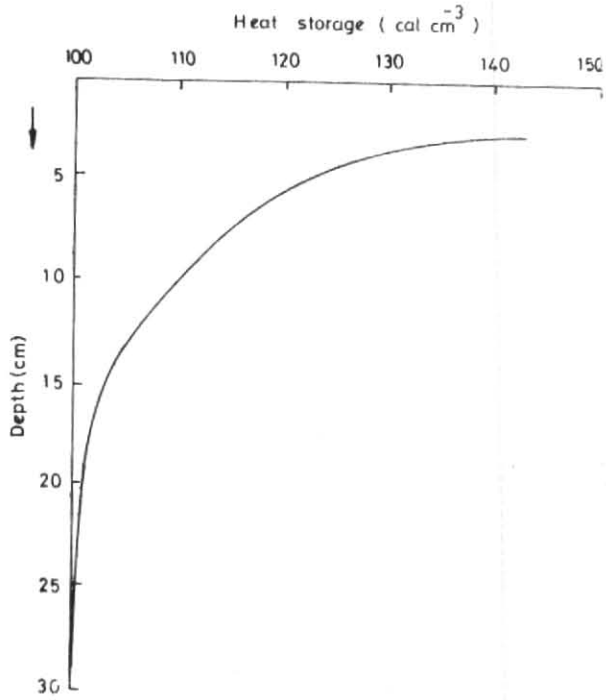

Fig. 4. Mean soil heat storage during day time

where, $C(Z)$ is the volumetric heat capacity in cal/cm³/°C at depth Z, $T(Z)$ is the temperature (°C) at depth Z.

The above equation can be simplified as

$$Q = \overline{C}\, \overline{T} \triangle Z \qquad (4)$$

where the operator (—) represents average value for a depth $\triangle Z$.

Based on 3 hourly observations mean picture of the soil heat storage for day time observations (0830 to 1730 IST) is illustrated in Fig. 4. The analysis reveal that maximum difference between any two layers did not exceed 5 cal/cm². It did not also show any systematic pattern with depth.

Fig. 4 shows that the radiation absorbed from the sun decreases exponentially with depth. Beyond —20 cm, the soil does not seem to be much affected by the diurnal variations. In the top layer the heat stored is nearly 14 times that at 15 to 20 cm depth while that in 5 to 10 cm layer, it is 13% more than in 15 to 20 cm depths. In the adjoining layers, *i.e.,* 10 to 15 cm and 15 to 20 cm depths, the heat gained during day in the former, is about 4% more than that in the latter.

Changes (G) in the heat storage, Q_2 and Q_1 between times t_2 and t_1 respectively is given by :

$$G = (Q_2 - Q_1) / (t_2 - t_1) \qquad (5)$$

The soil heat budget calculated from Eqn. (5) is given in Table 2. Heat entering any layer is unequivocally matched by the heat dissipated. Maximum rate of heat gained is 0.39 cal/cm²/min in the top (0–5 cm depth) layer. Soil generally gains heat up to 15 cm depth from

TABLE 2

Soil heat budget (cal cm^{-2} min^{-1})

Soil depth	Rate of change of heat between hours							
	0530-0830	0830-1130	1130-1430	1430-1730	1730-2030	2030-2330	2330-0230	0230-0530
Screen - Surface	0.19	0.35	0.05	—0.23	—0.20	—0.07	—0.05	—0.04
Surface -5 cm	0.04	0.39	0.07	—0.26	—0.19	—0.08	—0.04	0.07
5-10 cm	0.03	0.20	0.10	—0.06	—0.13	—0.07	—0.04	—0.03
10-15 cm	0.00	0.10	0.09	—0.01	—0.07	—0.05	—0.03	—0.03
15-20 cm	0.00	0.03	0.04	0.02	—0.02	—0.03	—0.02	—0.02
20-30 cm	0.00	0.00	0.02	0.02	0.00	0.00	—0.02	—0.02

near about sunrise to 1430 IST and losses during the rest of the day. The deeper layer, *i.e.*, 15 cm to 30 cm gains heat between 1130 & 1730 IST but losses it after midnight. Thus the thermal properties of the deeper layer appears independent of the diurnal exchange. The layer up to 15 cm depth can as such be called the "surface layer of the soil" (Ramdas and Mallik 1939) analogous to surface layer of the atmosphere.

4. Conclusions

The following broad conclusions emerge from the analysis :

(*i*) The thermal wave penetrate the sub-soil layers consequent to the surface solar heating. The amplitude of this wave decreases with soil depth.

(*ii*) The maximum temperature within 10 cm of soil are attained in the afternoon. At deeper layers it is realised only towards midnight.

(*iii*) The lowest temperature in the top layers occur 1-2 hr before sunrise but at deeper depth, 3-4 hr after the sunrise.

(*iv*) Heat stored in the soil decreases exponentially with depth.

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