PRELIMINARY STUDIES ON SUBSOIL TEMPERATURES AT JODHPUR

S. B. KAUSHIK, G. S. SHARMA AND B. G. MOKHASHI

Defence Laboratory, Jodhpur

(*Received* 19 *June* 64 ; *revised* 8 *Sept.* 64)

Diurnal temperature profiles of Jodhpur soil in relation to depth on a few selected days of four different months have been presented. Thermal diffusivity of the soil has been estimated by three different methods and the values, obtained by one of these methods, have been utilized for evaluating the depth of penetration of diurnal temperature wave, which is found to be 50·1 cm on the average. Certain other aspects of surface temperature in relation to ambient temperature, have been discussed.

Pioneering work on subsoil temperatures was carried out at Poona by Ramdas and Dravid[1], Dravid[2] and later on at Waltair by Padmanabhamurty and Subrahmanyam[3,4]. Similar studies in desert are of particular interest to the meteorologist, agronomist and military planner. This paper reports the results of preliminary studies on subsoil temperatures at Jodhpur (Rajasthan) in July '63, Sep. '63, Nov. '63 and Jan. '64. The data collected have been made use of to evaluate the thermal diffusivity of soil by three different methods.

THEORETICAL BACKGROUND

The temperatures attained by surface and subsoil layers are influenced by (*i*) duration and intensity of solar radiation at the place of observation; (*ii*) nature of the soil, particularly its physical characteristics, like colour, porosity, moisture and packing density; (*iii*) convective heat exchange between the ground and the air, and (*iv*) long wave infra-red radiative exchange between the sky and the ground.

The heating of the earth's surface by the sun during the day, followed by cooling during the night, results in a diurnal temperature wave with a time period of 24 hours. Assuming the isothermal layers to be parallel to the surface of the earth, the heat flow will be undirectional, *i.e.* vertically downwards. The Fourier equation in such a case becomes[5]

$$\frac{d\theta}{dt} = h\,\frac{d^2\theta}{dz^2} \tag{1}$$

where θ is the instantaneous temperature at a depth z and h is thermal diffsivity of the soil which for practical purposes is assumed to be independent of depth and time on any particular day.

An approximate solution[6] of equation (1) is given by

$$\theta = \theta_m + A_o e^{-\sqrt{w/2h}\cdot z}\cdot Cos\,(wt - \sqrt{\frac{w}{2h}}\cdot z) \tag{2}$$

where θ_m is the mean temperature assumed to be independent of depth and A_o is the amplitude of the temperature wave at the surface. The solution is based on the assumptions that

$$\theta = \theta_m + A_o\, Cos\, wt, \qquad \text{at } z = 0$$

and

$$\theta = \theta_m \quad , \qquad \text{at } z = \infty$$

It will be appreciated that the first assumption is an over simplification of actual conditions. Further, θ_m is not entirely independent of depth.

It follows from equation (2) that the amplitude A of the temperature wave at any depth z and its velocity of propagation v are given by

$$A = A_o \, e^{-\sqrt{\frac{w}{2h}} \, . z.} \tag{3}$$

$$v = 2\sqrt{\pi h/T} \tag{4}$$

where T denotes the time period of the wave; its value being 24 hours for the diurnal heat wave. Let D be the depth of penetration of the temperature wave at which its amplitude falls to 1% of its surface value. It follows from equation (3) that

$$D = 2 \times 2 \cdot 3 \sqrt{hT/\pi} \tag{5}$$

Thermal diffusivity

Two methods are normally used for obtaining the thermal diffusivity of soil, viz. (*i*) the amplitude method and (*ii*) the lag method. A third method, which is a combination of these two methods, has also been used in the present study.

(*i*) *Amplitude method*: From equation (3) we have

$$\log A = \log A_o - \frac{z}{2 \cdot 3} \sqrt{\pi/hT}$$

Thus log A plotted against z should yield a straight line with slope

$$m_a = - \frac{1}{2 \cdot 3} \sqrt{\pi/hT} \tag{6}$$

whence

$$h = \frac{\pi}{(2 \cdot 3)^2 T} \cdot \frac{1}{m^2{}_a} \tag{7}$$

(*ii*) *Lag method* : The slope (m_p) of the graph between z and T for constant phase of the diurnal temperature wave gives the velocity of wave propagation, which according to equation (4) is

$$m_p = - v = - 2\sqrt{\pi h/T} \tag{8}$$

(minus sign indicates a negative slope)

or $$h = T/4\pi \cdot m^2{}_p \tag{9}$$

(*iii*) *Combination method* : From equations (6) and (8) we get

$$h = 1/4 \cdot 6 \cdot m_p \,/\, m_a \tag{10}$$

PROCEDURE

Soil temperatures at various depths were measured with Casella mercury-in-glass bent bulb thermometers specially designed for soil temperature measurements, while surface temperatures were measured with an ordinary mercury-in-glass thermometer with its bulb covered with a thin layer of soil. The bent bulb thermometers were supported

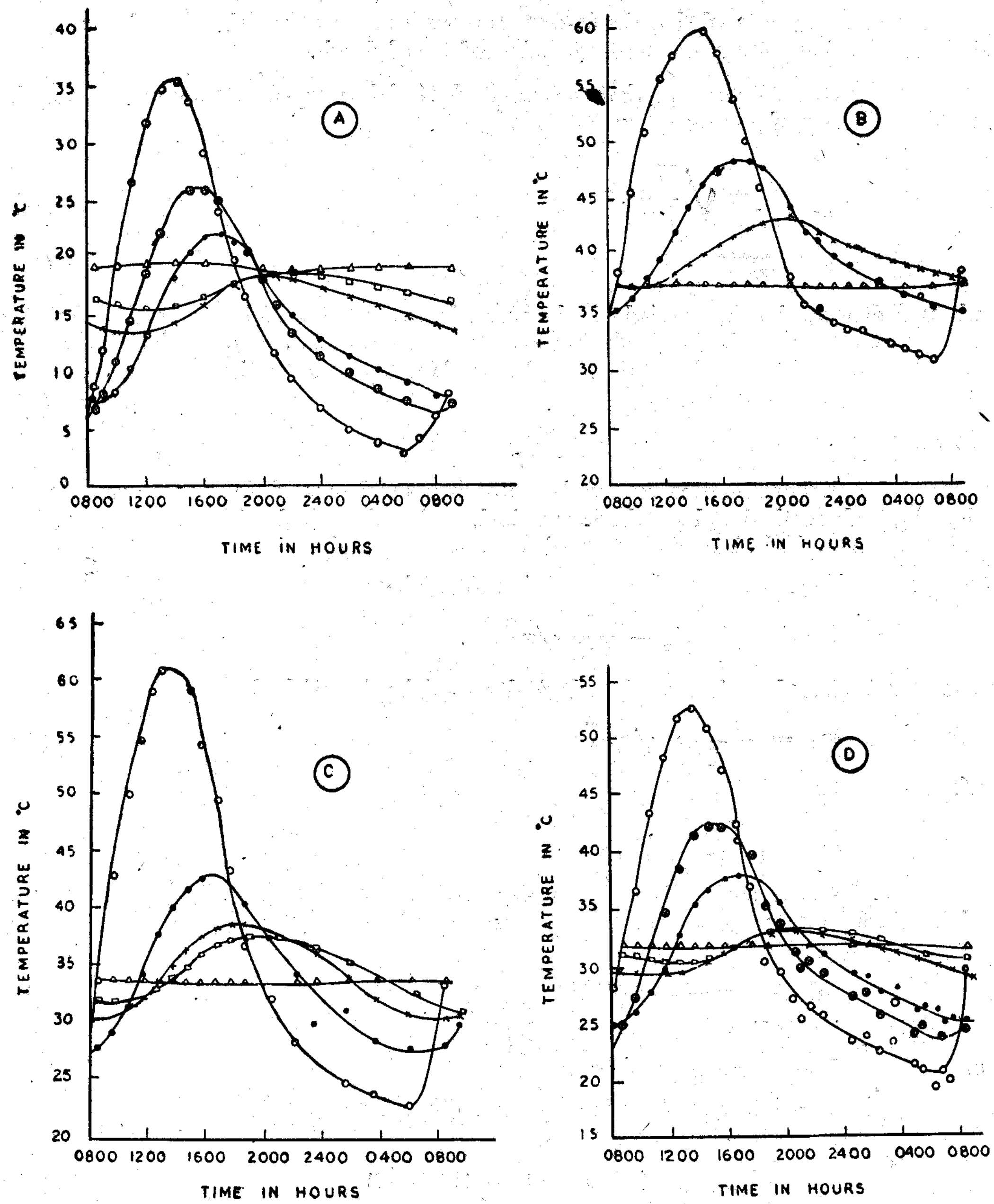

Fig. 1—Diurnal variation of soil temperature at various depths at Jodhpur in four different months.

on angle irons inclined to the vertical and so the effective depth was calculated by multiplying the nominal depth by cosine of the angle of inclination.

Observations were recorded on reasonably clear days. July data were recorded just before the onset of monsoon and September data, a fortnight after the last rainy day of the season. The amplitude for any depth was measured by half the difference between the maximum and minimum temperatures recorded at that depth. In the lag method, the constant phase was taken to correspond with the maximum temperature.

RESULTS

Variations in mean diurnal temperature with time, at the surface and various depths are represented graphically in Fig. 1 (A-D) for four months viz., July '63 Sep '63 Nov '63 and Jan '64. The depth of penetration of the temperature wave for the same four months is presented in Fig. 2. The values have been taken from the four sets of curves in Fig. 1.

Thermal diffusivity of soil was evaluated for all the four months by the three methods mentioned before; and the results are presented in Table 1 which also includes the corresponding depth of penetration calculated with the help of equation (5), utilising diffusivity values obtained by the combination method.

TABLE 1

THERMAL DIFFUSIVITY OF SOIL AT JODHPUR AND DEPTH OF PENETRATION OF DIURNAL TEMPERATURE WAVE

Month	Thermal Diffusivity × 10^{-3} Cm.^{2} Sec^{-1}			Depth of Penetration
	Amplitude method	Lag method	Combination method	cm
July 63	4·30	4·60	4·45	51·0
Sep. 63	5·07	8·37	6·51	61·8
Nov. 63	3·04	3·31	3·17	43·0
Jan. 64	3·07	3·66	3·40	44·6
Mean	3·87	4·99	4·38	50·1

The maximum temperature at the soil surface and dry bulb temperatures, for the four months, are given in Table 2, which also shows the times of occurrence of maxima and the time lag of the ambient temperature behind the ground surface temperature.

TABLE 2

MAXIMUM TEMPERATURES OF SOIL SURFACE AND DRY BULB IN RELATION TO THEIR TIME OF OCCURENCE

Month	Max. temp. (°C)		Difference in temp. (°C)	Time occurrence maximum solar temp.		Differences in time hrs.
	Soil	Dry bulb		Soil	Dry bulb	
July 63	59·9	38·5	21·4	1,310	1,635	3·42
Sept. 63	61·2	34·7	26·5	1,243	1,521	2·62
Nov. 63	52·6	33·8	18·8	1,303	1,509	2·10
Jan. 64	35·5	19·3	16·2	1,255	1,441	1·77

DISCUSSION

Fig. 1 shows the variation in diurnal temperature. There is a sharp peak at the surface, about one hour after the solar noon[7], with a progressive flattening of the peak and a gradual shifting of the time of occurrence of the peak with depth.

It will be seen from Table 2 that the maximum soil surface temperature in the four months exceeded the maximum dry bulb temperature by 20·7°C on the average, the range of variation being 16·2°C to 26·5°C. While the mean time of occurrence of the former was 1258 hours (solar time), that of the latter was 1527 hours (solar time), lagging behind the former by about $2\frac{1}{2}$ hours. The variation from month to month in the magnitude and time of occurrence of the maximum soil surface temperature and maximum ambient

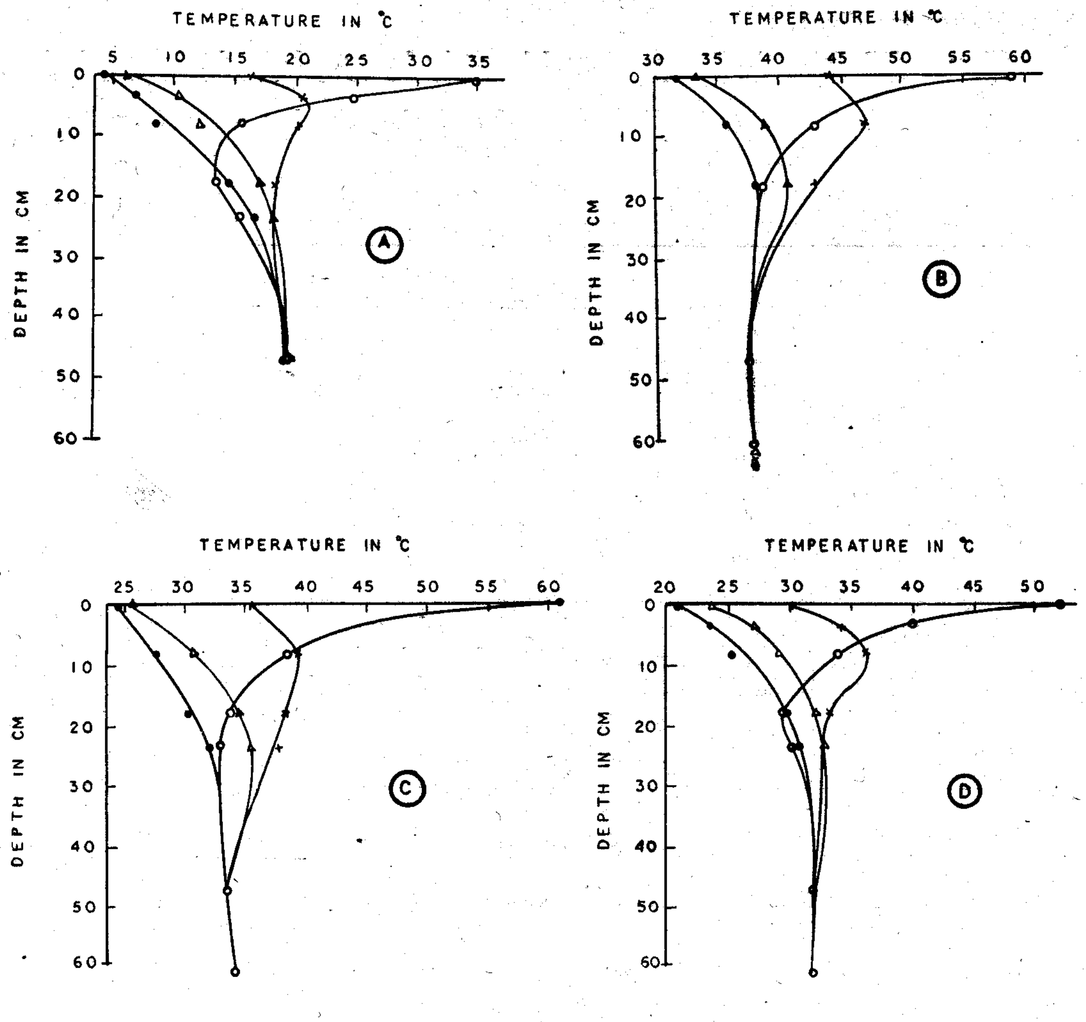

Fig. 2—Temperature as a function of depth at selected hours for the four months.

temperature depends on the relative importance of the various components of the radiation balance of the soil. These components have a diurnal and seasonal variation and are influenced by several climatic parameters, as for example duration of sunshine, cloudiness, turbidity of the atmosphere, albedo of the terrain, humidity, and so on.

Fig. 2 indicates almost exponential decrement of the amplitude of the temperature wave with depth and also gives a rough idea of the depth of penetration. Reliable estimate of the depth of pene ation can, however, be obatained from equation (5) with known values of thermal diffusivity.

Table 1 indicates that the three methods for estimating diffusivity yield somewhat different values, the amplitude method giving the lowest figure and the lag method giving the highest figure. The combination method gives a value which is the geometric mean of the values obtained by the other two methods. The differences are likely to be due to the approximate nature of the solution of the Fourier equation. It is, however, interesting to note that there is a sufficiently close agreement among the values obtained by the three methods in all months, except in September. This may be due to large gradients of moisture concentration with depth in the postmonsoon period, while the solution is based on assumed uniformity of moisture distribution which is nearly true for other months in Rajasthan. The mean diffusivities for the four months as given by the three methods are $3 \cdot 87 \times 10^{-3}$, $4 \cdot 99 \times 10^{-3}$ and $4 \cdot 38 \times 10^{-3}$ cm^2 sec^{-1} respectively. The average value of diffusivity at Waltair as reported by Padmanabhamurty and Subrahmanyam[5], is $6 \cdot 134 \times 10^{-3}$ cm^2 sec^{-1}, according to the amplitude method, which is somewhat higher than the corresponding value at Jodhpur, presumably because of the higher moisture content of soil at Waltair, which is a coastal station.

Depth of penetration of the diurnal temperature wave at Jodhpur is 50·1 cm on the average (range : 43·0 to 61·8 cm). The highest value is in September, corresponding to the highest moisture content of soil shortly after the cessation of rains.

The findings of this preliminary study do not justify drawing any definite conclusion for which detailed observations throughout the year, preferably with autographic instruments, are necessary. The results, however appear to be quite representative of the typical desert soil.

ACKNOWLEDGEMENTS

Thanks are due to Dr. V. Ranganathan, Deputy Chief Scientist, Research & Development Organisation, Ministry of Defence and Dr. H. Nath, Director, Defence Laboratory, Jodhpur for their kind encouragement and keen interest in the work. The authors are specially, indebted to Shri N. C. Majumdar for his constant guidance and helpful discussions.

REFERENCES

1. RAMDAS, L.A. & DRAVID, R.K., *Proc. nat. Inst. Sci. India,* **2** (1936), 131.
2. DRAVID, R.K., *Ind. J. Agric. Sci.*, **10** (1940), 352.
3. PADMANABHAMURTY, B. & SUBRAHMANYAM, V.P., *India J. Met. Geophys,* **12** (1961), 261.
4. ————, *ibid,* **14** (1963), 339.
5. JACOB, M., "Heat Transfer" (John Wiley and Sons. Inc., New York) 1949, p. 292.
6. DE VRIES, D.A., "*Proc. Symp. UNESCO, Canberra,*" 1958, p. 109.
7. SUTTON, O.G., "Micrometeorology" (McGraw Hill Book Company Inc. New York) 1953, p. 197.