Indian Journal of Radio & Space Physics
Vol. 27, October 1998, pp. 207-214

Analysis of soil temperature in iso-hyperthermic temperature regime using Fourier technique

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Received 13 April 1998; revised 6 July 1998; accepted 5 August 1998

A study has been conducted using soil climatic data of few stations in Kerala to verify the validity of the general statement regarding periodicity of soil temperature, that all tropical stations show bimodal pattern of soil temperature in the yearly cycle. For some stations the results were found to be true, but for Pilicode and Kottarakara a unimodal pattern was observed. At Kottarakara, it appears that unimodal pattern is due to irrigation used at that place. More data from other places which are influenced only by rain are needed to be examined and analysed to arrive at firm conclusion. However, from a preliminary analysis it is found that out of five stations studied, four show bimodal pattern. Variation of soil temperature with soil moisture also has been presented.

1 Introduction

Soil temperature is an important agrometeorological parameter. The response of soil surface temperature to radiation condition is remarkably well pronounced, especially, on clear days and nights. The amplitude of the soil surface temperature often exceeds that of the air temperature a foot above. In day time it can be very warm, and certainly shows the maximum of the whole vertical temperature profile. The tendency towards extreme temperature ranges in the soil surface leads to some consequences of great importance for the lowest layer of the atmosphere which is known as bio-zone[1]. The steep lapse rate of temperature developed during day time contributes to turbulence, gustiness of the wind and removal of moisture from the soil.

Earth temperature measurements at various depths are very valuable for many purposes, like agricultural meteorology, climatology and study of heat exchange between ground and atmosphere. Extremely high soil temperatures have a harmful effect on roots and may cause destructive lesions on the stems of plants. On the other hand, low temperatures impede the plant mineral nutrient intake and persistently cold soil results in dwarfed growth. The ecological significance of soil temperature is obvious from the fact that an unfavourable value of this parameter during growing season may retard or even ruin the crops.

The magnitude of the diurnal temperature changes will be greater in soil with lower heat capacity[2]. Cooper[3] reported that the root temperature above 33°C drastically decreased the shoot dry weight in maize. Earth temperature and soil moisture are, at present, observed at a relatively small number of stations in some countries. Considering their importance for climatological as well as for agricultural purposes further study is needed in this direction. Soil can greatly affect the use of solar energy and, as a result, can influence both air temperature and soil temperature. This is especially important during drought periods when the dry soil favours high soil temperature and air temperature, thus tending to augment the effect of drought[4]. Rowentree and Bolten[5] studied the simulation of atmospheric response to soil moisture anomalies and reported that dry anomaly in soil moisture reduces evaporation and increases the surface temperature and sensible heat flux. Hunt[6] studied soil hydrology relevant to climatic modelling and discussed the inclusion of soil hydrology in the numerical models of climate. Interaction between boundary layer and soil moisture transport and association of surface potential gradient with the onset of monsoon were studied earlier[7-9]. Pathak *et al.*[10] showed that moisture content of the soil is the basic link between energy budget of the land

Note: A part of this paper was presented at the National Space Science Symposium held at Physical Research Laboratory, Ahmedabad, during 25-28 Nov. 1997.

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surface and hydrological cycle and also found that land surface temperature during September 1991 was negatively correlated with the area averaged total rainfall data over Gujarat. The climatic variation in different months and seasons results in a corresponding variation in soil temperature and soil moisture.

The climate of Kerala is tropical maritime and monsoonal in character. Temperatures and humidities are high throughout the year. The first burst of the south-west monsoon over the Indian subcontinent takes place over Kerala. The three monsoon periods are: south-west monsoon (June-Sep.), north-east monsoon (Oct.-Dec.) and pre-monsoon (Jan.-May)[11].

2 Data and analysis

Soil temperatures for the periods 1992-1996 have been recorded from four stations, namely, Kariavattom, Vellayani, Arattuvazhi and Kottarakara that come under iso-hyperthermic temperature regime [mean annual soil temperature 22°C or higher and mean summer (June, July and August) and winter (December, January and February) soil temperature differ by less than 5°C at a depth of 50 cm or at lithic or paralithic contact whichever is shallower] and ustic moisture regime[12] (soil moisture control section is dry in some or all parts for 90 or more cumulative days in most years). Stations selected are having different soil types. Table 1 gives latitude, longitude, elevation and soil type of the chosen stations. Kariavattom station is a coconut garden located at the University of Kerala. Kariavattom campus belongs to a typical laterite soil of Kazhakkuttom soil series. Arattuvazhi station is located at the International Centre for Dravadien Linguistics, Thumba. Vellayani station is located at the college of Agriculture, Kerala Agricultural University Campus, Vellayani. The area is under cultivation with mixed crops. Kottarakara station is located in a cultivated area under irrigation. Natural vegetation consists of wild shrubs and grasses. Crops like coconut, arecanut, cassava, bannana, ginger and pepper are extensively grown in the sorrounding areas. Daily soil temperatures for the period 1982-1991 collected from Regional Agricultural Research Station, Pilicode, northern Kerala, also have been studied for comparing the results with southern Kerala. The depths at which the temperatures recorded at Pilicode were 5, 10, 15, 20, 30, 40, 60 and 70 cm from the soil surface. For measuring soil temperatures from southern stations, soil thermometers have been installed at 5, 10, 20, 30 and 50 cm depth from the soil surface. Daily values of soil temperatures recorded at 7.25 a.m. and 2.25 p.m. have been averaged to obtain daily means. Weekly means were worked out for each standard week for the data at 7.25 a.m. and 2.25 p.m. These means were then averaged to obtain normal soil temperature pattern for the 52 standard weeks of the year. Normal weekly mean soil temperatures are subjected to harmonic analysis[13]. The general Fourier series representing mean soil temperature is

$$T = \bar{T} + \sum_{k=1}^{n/2} C_k \{\sin[(360/p)\, kx + \phi_k]\} \qquad \ldots (1)$$

where

$$C_k = (a_k^2 + b_k^2)^{1/2}$$

$$\phi_k = \tan^{-1}(a_k/b_k)$$

Here, C_k is the amplitude of the kth harmonic, ϕ_k the phase angle, T the mean soil temperature, n the number of records (here it is 52), x a time factor varying from 0 to $n-1$ and p the period of the fundamental cycle.

3 Results and discussion

The weekly mean soil temperatures for the yearly cycle for all selected stations except

Table 1—Location of the stations with their soil types

Stations	Latitude (N)	Longitude (E)	Elevation m	Soil type
Kariavattom	8°29′	76°57′	16	Laterite
Vellayani	8°26′	76°59′	8	Red loam (oxisols)
Arattuvazhi	8°29′	76°57′	6	Coastal sandy soil
Kottarakara	9°01′	76°46′	70	Mid-land laterite
Pilicode	12°12′	75°10′	15	Ultisols

Kottarakara and Pilicode show bimodal pattern. This is in agreement with the results of Lamba and Khambete[13]. Kottarakara and Pilicode show unimodal pattern revealing the role of soil moisture in controlling the soil temperature.

Graphs have been drawn for actual soil temperature (observed) and those predicted by first and first two harmonics taken together at all chosen depths. The change in soil temperature pattern due to monsoon is well reflected especially in the upper layers. The combination of the first two harmonics account for the rise in soil temperature during pre-monsoon period, its fall during south-west monsoon period and later, its rise during remaining period of the year. In case of Kottarakara the second peak (rise during N-E monsoon period) is suppressed by the moisture content of the soil. This is in agreement with the results of Oglesby[14]. Soil moisture analysis carried out at selected stations strongly support the above result[2,15]. Results of the study conducted at the southern and northern part of Kerala are described as follows.

3.1 Southern Kerala

Normal weekly mean soil temperatures for the yearly cycle (Figs 1-3) show an increase in March-May period at all depths. The weekly mean soil temperatures at Kariavattom from 5 cm to 30 cm depth for the yearly cycle show bimodal pattern with maximum around 12th-20th and 30th-32nd week. Decrease in soil temperature can be seen at 24th-28th and 40th - 44th week (Fig. 1). Weekly mean soil temperature for Vellayani also shows bimodal pattern for the yearly cycle. The decrease in soil temperature is observed at 24th-28th and 40th - 44th week (Fig.2). The weekly mean soil temperatures at 50 cm depth for Kariavattom, Vellayani, Arattuvazhi and Kottarakara are shown in Fig. 3. All stations except Kottarakara show a fall in soil temperature during the first week of November, while Kottarakara shows gradual increase from October onwards. The unimodal pattern of soil temperature shown in Fig. 3 for Kottarakara reveals the role of soil moisture in controlling the soil temperature.

The amplitude and phase angles of soil temperature in respect of first three harmonics are given in Table 2. The mean observed soil temperature (T) decreases as we go down from 5

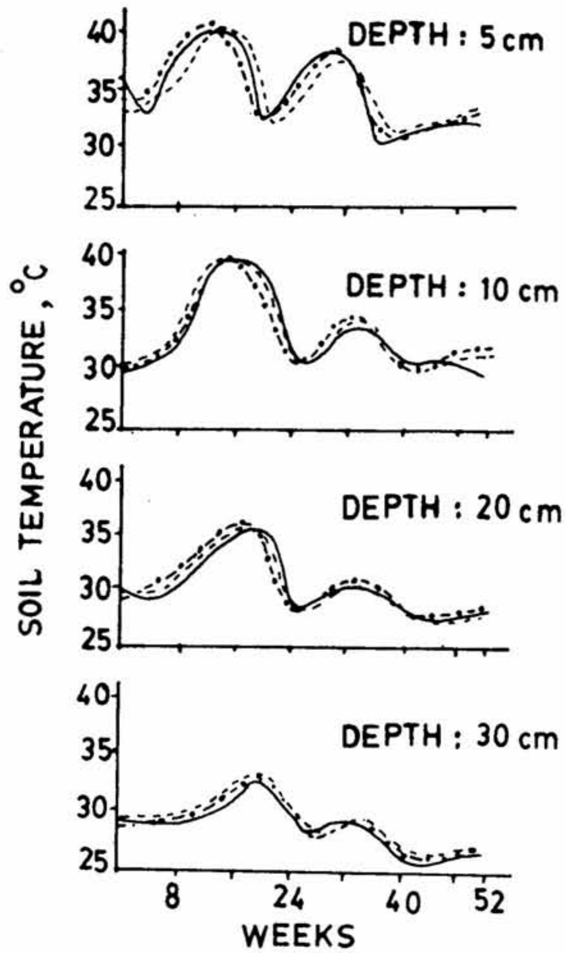

Fig. 1—Normal weekly mean soil temperature and those estimated by first and first two harmonics at Kariavattom (—Mean; —•— I harmonics; ---I & II harmonics)

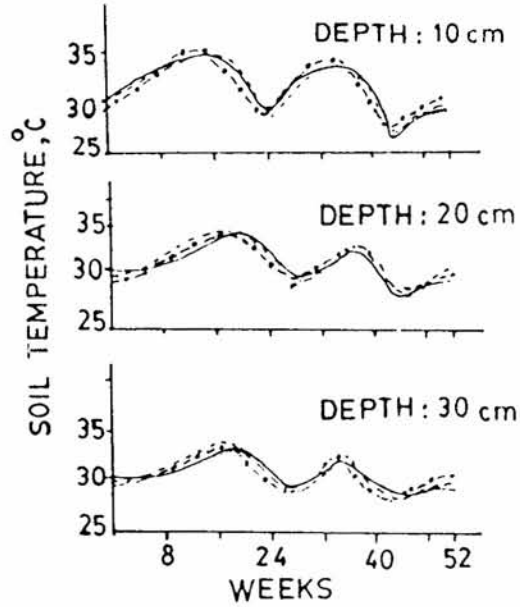

Fig. 2—Same as in Fig. 1, but for Vellayani

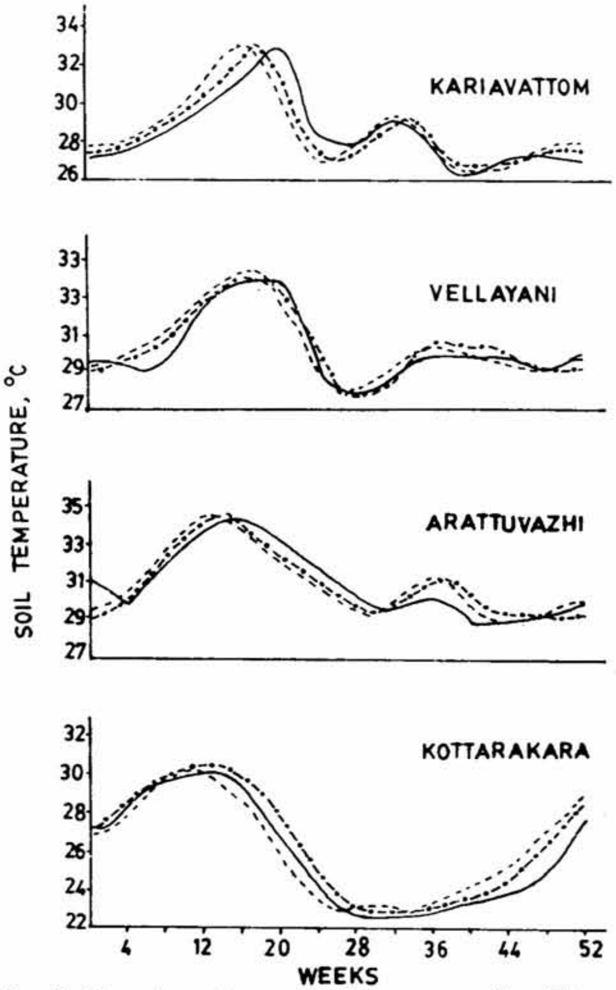

Fig. 3—Normal weekly mean soil temperature for different stations at 50 cm depth (—Mean; —•— I harmonics; ---I & II harmonics)

cm to 50 cm depth for Kariavattom and Vellayani. The amplitude of temperatures at depths 5, 10, 20, 30 and 50 cm decreases with higher order of harmonics. The values have the range 0.9-3.23°C for the first harmonics, 0.65-2.41°C for the second harmonics and 0.55-2.05°C for the third harmonics.

The percentage of variance accounted for the first three harmonics is almost same at all depths under study and amounts to 99% when taken together for each depth (Table 3). The first harmonics explain 50-51% of the total variance at different depths at Kariavattom and Vellayani while II and III harmonics represent 28% and 20% of the total variance, respectively. In case of Kottarakara the first harmonics explain 85% of the total variance and II and III harmonics explain 12% and 2% of the total variance, respectively (Table 3).

Graphs (Figs 1-3) for actual soil temperature and those predicted by I and first two harmonics taken together at 5, 10, 20, 30 and 50 cm depth show that the I harmonics fit the observed data well. The change in soil temperature pattern due to monsoon is well reflected especially in the upper layers. The combination of the first two harmonics accounts for the rise in soil temperature during pre-monsoon period, its fall during south-west monsoon and later its rise during north-east monsoon period. The first peak is observed during

Table 2—Amplitude and phase angles of soil temperature in respect of first three harmonics and observed mean temperature (°C) at selected stations

Depth	I harmonics		II harmonics		III harmonics		Mean observed
cm	Amplitude °C	Phase deg	Amplitude °C	Phase deg	Amplitude °C	Phase deg	temperature °C
				Kariavattom			
5	3.2	305.2	2.4	336.5	2.1	311.1	35.6
10	2.6	304.7	2.0	336.5	1.7	311.1	32.7
20	2.3	297.9	1.7	336.5	1.5	311.1	30.7
30	2.0	316.0	1.5	336.5	1.3	311.1	28.6
50	1.8	322.6	1.3	336.5	1.1	2.2	28.5
				Vellayani			
10	1.2	321.1	0.9	336.4	0.8	36.1	31.2
20	0.9	321.9	0.7	336.4	0.6	36.1	30.8
30	0.9	322.0	0.7	336.4	0.6	36.1	30.3
50	1.0	313.7	0.7	336.3	1.1	2.2	30.4
				Arattuvazhi			
50	1.3	315.3	1.0	336.5	0.8	3.9	31.3
				Kottarakara			
50	3.7	38.4	1.4	354.2	0.5	320.4	25.5

Table 3—Total variance of soil temperature(°C) at various depths and its percentage accounted for by different harmonics at selected stations

Depth	Percentage of variance			
cm	I harmonics	II harmonics	III harmonics	Total
		Kariavattom		
5	50.5	28.6	20.7	99.8
10	50.7	28.5	20.7	99.9
20	50.9	28.3	20.6	99.8
30	51.0	28.3	20.5	99.9
50	51.1	28.1	20.7	99.9
		Vellayani		
10	50.6	28.3	20.8	99.7
20	51.3	28.3	20.2	99.8
30	51.2	28.3	20.4	99.9
50	51.4	28.1	20.7	99.9
		Arattuvazhi		
50	51.1	28.2	20.5	99.8
		Kottarakara		
50	85.5	12.4	1.9	99.9

16th-24th week and second peak is observed around 32nd-36th week. This is in agreement with Lamba and Khambete[13]. In case of Kottarakara the second peak (rise during north-east monsoon period) is suppressed by the moisture content of the soil, because Kottarakara was an irrigated location. This is in agreement with the results of Oglesby[14]. Hence, variation of soil temperature with soil moisture also has been studied for the location, Kariavattom. Fortnightly variations of soil temperature and soil moisture are shown in Fig. 4. It is found that highest temperature and lowest moisture are obtained during pre-monsoon period and lowest temperature and highest moisture content are obtained during south-west monsoon period.

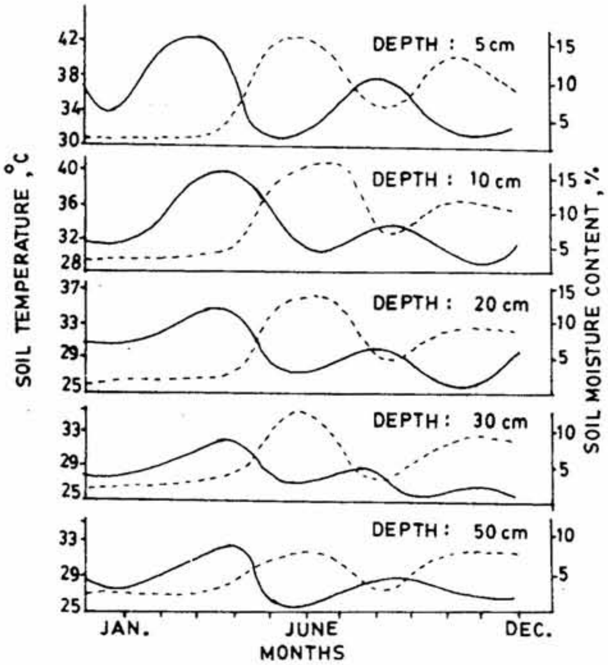

Fig. 4—Variation of soil temperature and soil moisture at different depths for the location Kariavattom (—Soil temperature; ---Soil moisture)

3.2 Northern Kerala

Daily soil temperatures (1982-91) collected from Regional Agricultural Research Station (RARS), Pilicode, northern Kerala, were taken for the study. The depth at which the temperatures recorded were 5, 10, 15, 20, 30, 40, 60 and 70 cm from the soil surface. The experimental site is at 15 m above mean sea level and is well levelled and maintained as barren land without any vegetation.

The weekly mean soil temperature for the annual cycle shows that soil temperature pattern is unimodal with one peak during pre-monsoon period, a fall during 24th-36th week and a gradual increase during the remaining period of the yearly cycle. This is in disagreement with the result of Lamba and Khambete[13]. The amplitude and phase angle obtained are given in Table 4. It is found that for all depths and harmonics the amplitude decreases as one moves from 5 cm to 70 cm depths. The phase angle increases from 5 cm to 15 cm depth for the first harmonic and then decreases. The phase angle obtained for II and III harmonics did not show much variation with depth. Table 4 shows that I harmonics explain 79-90% of the total variance and II and III harmonics explain 8-10% and 0.12-11% of the total variance, respectively. The observed and predicted values of normal weekly mean soil temperatures are given in Fig. 5. It is observed that a gradual rise in soil temperature

Table 4—Amplitude, phase angles and percentage of variance of normal weekly mean soil temperature for different harmonics at Pilicode

Depth	I harmonics			II harmonics			III harmonics		
cm	Amplitude °C	Phase angle deg	Variance %	Amplitude °C	Phase angle deg	Variance %	Amplitude °C	Phase angle deg	Variance %
5	4.1	27.4	80.1	1.4	5.7	9.0	1.5	12.4	10.8
10	3.8	27.5	80.4	1.2	5.4	8.6	1.4	12.4	10.8
15	3.3	28.5	80.2	1.1	5.4	9.0	1.2	12.4	10.6
20	3.2	24.4	80.1	1.1	5.4	9.0	1.2	12.4	10.8
30	3.1	23.3	80.3	1.1	5.4	9.0	1.2	12.4	10.7
40	2.9	24.0	80.2	1.0	5.4	8.9	1.1	12.4	10.8
60	2.8	22.2	79.4	1.0	5.4	8.7	1.0	12.4	10.5
70	2.7	23.3	89.8	1.0	5.4	9.9	1.0	12.4	0.1

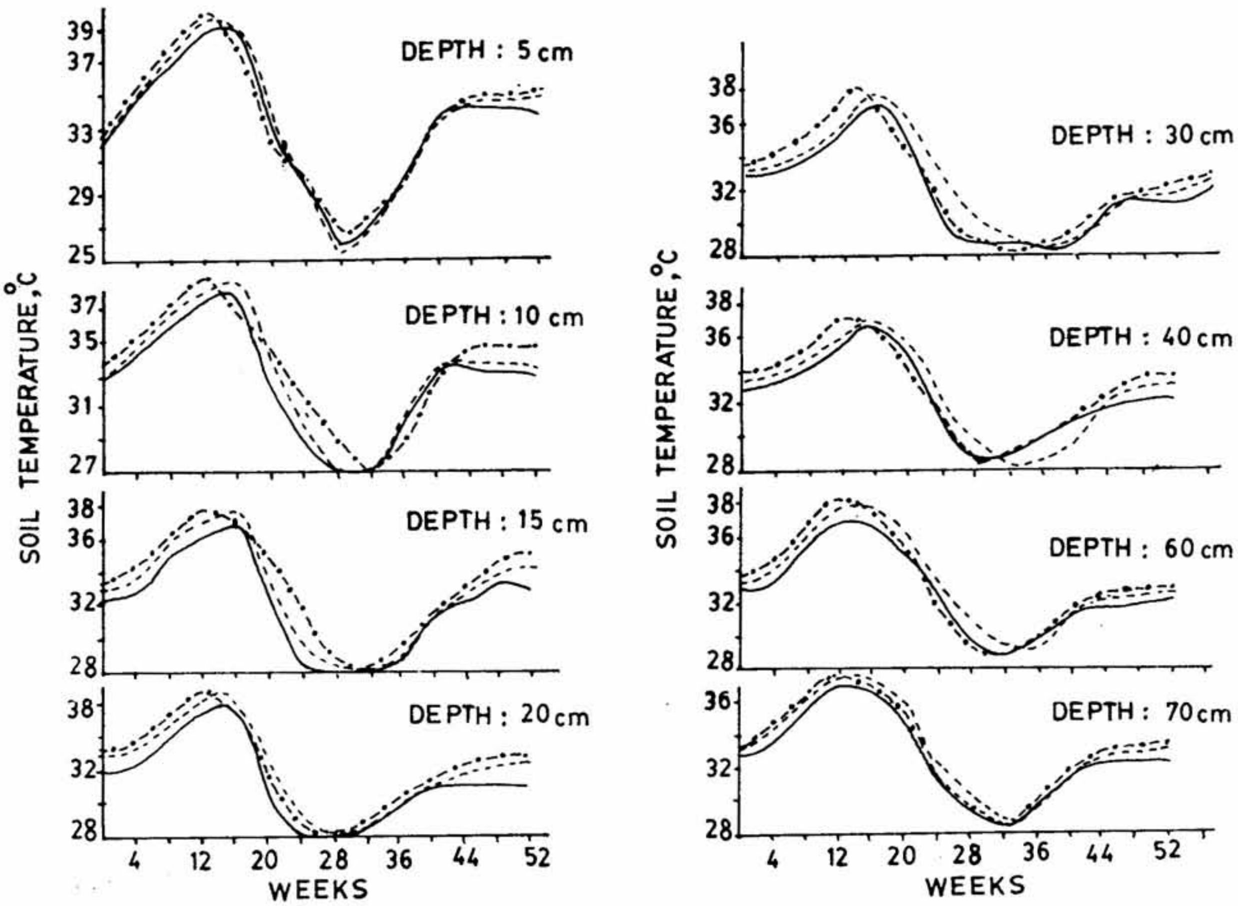

Fig. 5—Normal weekly mean soil temperature (observed) and those estimated by first and first two harmonics at Pilicode [—Mean (observed); ---I harmonics; —•—•— I & II harmonics]

Table 5—Mean temperatures (maximum and minimum) and rainfall at Pilicode during the study period (1982-91)

Month	Parameters		
	Rainfall mm	T_{max} °C	T_{min} °C
Jan.	9.2	32.5	19.0
Feb.	0.0	31.0	17.0
Mar.	97.3	32.8	23.7
Apr.	91.8	33.5	25.5
May	194.7	33.5	26.1
June	339.6	29.1	23.3
July	417.9	29.5	23.5
Aug.	245.9	30.2	23.5
Sep.	145.2	29.9	22.8
Oct.	140.0	29.2	22.0
Nov.	170.8	32.1	22.3
Dec.	1.8	32.9	19.6

during pre-monsoon, a fall during south-west monsoon and, later, a rise during north-east monsoon are well represented by the first and first two harmonics taken together. The results obtained show that all tropical stations do not show bimodal pattern of soil temperature in the yearly cycle, which is in disagreement with the results of Lamba and Khambete[13].

The gradual rise in soil temperature and air temperature during north-east monsoon period may be due to the fact that north-east monsoon is not significant at the northern region of Kerala because of its geographical position. Maximum and minimum temperatures (T_{max} and T_{min}) given in Table 5 for the period 1982-1991 also show unimodal pattern.The results of another study on sub-soil temperature and air temperature for one disastrous drought year (1982-83)and normal rainfall year(1983-84) over Pilicode again support these results[15] (Fig. 6). Soil temperatures at different depths and air temperature (maximum and minimum) are shown in Fig. 6. Air temperatures [maximum (b) and minimum (b_1)] also show unimodal pattern with one peak during pre-monsoon period. The only difference observed was that the temperatures observed in sub-soil and air during drought year were higher than those of normal rainfall year.

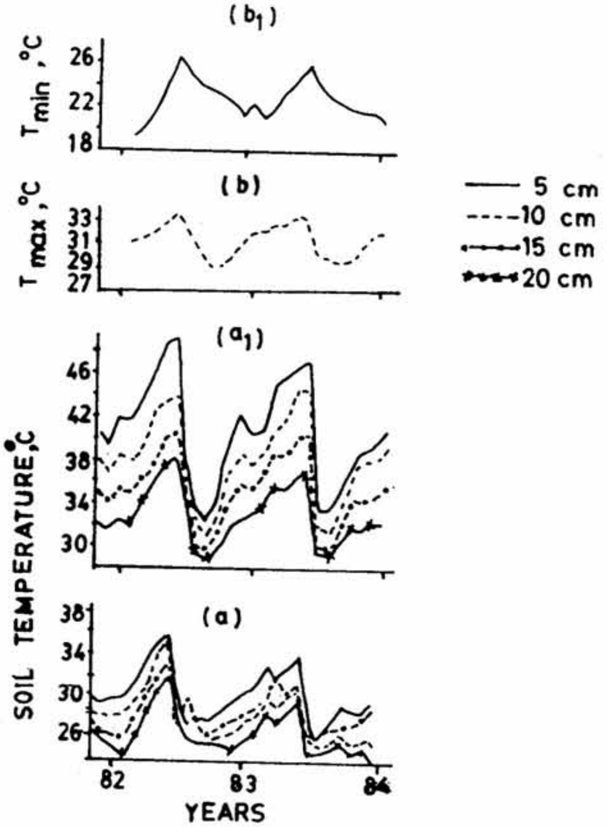

Fig. 6—Soil temperature and air temperature pattern at Pilicode during one disastrous drought year(1982-83) and one normal rainfall year (1983-84) [(a) at 7.25 a.m and (a_1) at 2.25 p.m.]

4 Summary

Soil temperatures and their maxima / minima at different depths and at any time can be estimated on the basis of their annual periodicity with the help of harmonics computed by Fourier technique. All stations except Kottarakara and Pilicode show bimodal pattern of soil temperature in the yearly cycle. Air temperature for Pilicode also shows unimodal pattern in the yearly cycle. In case of Pilicode, the gradual rise in soil temperature and air temperature during north-east monsoon is due to the fact that north-east monsoon is not significant at northern region of Kerala. Soil moisture has much influence in controlling the soil temperature at a region. The study reveals that not all tropical stations show bimodal pattern.

Acknowledgements

The authors are highly thankful to the Director, Regional Agricultural Research Station, Pilicode, for providing the data required for this work. The authors are grateful to the anonymous referees for their useful suggestions to improve the quality of the paper.

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