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Some aspects of thermal diffusivity for various soil layers in different harmonics

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सार — आयाम अनुपात तथा फेज लैग का उपयोग करते हुए भारत के शुष्क खेती वाले छः स्थानों के पहले तीन हार्मोनिकों की विभिन्न मृदा परतों की तापीय विसरणशीलता (*K*) के मानों का परिकलन किया गया है। सामान्यतः इन सभी हार्मोनिकों का संयुक्त प्रभाव (*K*) का मान बताता है जो कि प्रयोगात्मक मानों से काफी मिलता जुलता है। यह पता लगा है कि सामान्य ताप चालन का सिद्धान्त मृदा माध्यम के लिए उपयुक्त नहीं है। सभी हार्मोनिकों में (*K*) का निम्नतम मान राजामुंदरी में पाया गया है, जबकि पहले दो हार्मोनिकों का उच्चतम मान या तो हिसार में अथवा फिर भुवनेश्वर में तथा तीसरे हार्मोनिक का उच्चतम मान पन्तनगर में देखा गया है। हिसार, पन्तनगर तथा भुवनेश्वर में प्रबल वार्षिक तथा द्विवार्षिक चक्र प्रभावी है जबकि तिमाही चक्र केवल पन्तनगर में प्रभावशाली है।

ABSTRACT. Values of thermal diffusivity (K) in different soil layers for the first three harmonics have been computed for six stations in the dry farming tract of India by using amplitude ratio and phase lag. In general, the combined effect of all these harmonics gives the values of K close to the order of the experimental values. It is found that the theory of simple heat conduction is not applicable to soil medium. While the lowest values of K in all the harmonics are found at Rajahmundry, the highest values are observed at either Hissar or Bhubaneshwar for the first two harmonics and at Pantnagar for the third harmonic. Strong annual and bi-annual cycles dominate at Hissar, Pantnagar and Bhubaneshwar while quarterly cycle is significant only at Pantnagar.

Key words - Thermal diffusivity, Dry farming tract, Amplitude, Phase lag, Harmonics, Heat conduction, Seasonal cycle.

1. Introduction

The manner in which heat flows through the soil is of considerable importance in plant cultural practices in general. Specifically, it affects plant-root activity with respect to the uptake of nutrients, water etc. and in engineering uses of the soils (Marshall and Holmes 1979). Also, the temperatures of the surface of the earth and the soil below it can be represented to any degree of accuracy by a definite number of terms of a Fourier series (Sutton 1953, Lamba and Khambete 1991). As such, the study of amplitudes of phases of the soil temperature waves assumes a lot of significance.

The objective of this study is to compute the values of thermal diffusivity for different soil layers by using two different formulae involving amplitudes and phase angles of the first three harmonics (Krishnan and Kushwaha 1972). These values are first compared layerwise to see whether the theory of simple heat conduction is applicable to soil medium or not. Secondly, how the values (based on amplitudes) for the three harmonics taken together compare with the experimental values and thirdly to determine the periodicity and intensity of different cycles.

2. Data

Six stations, mentioned below alongwith their soil types at observational sites, have been selected in such a way that most of the types of dry farming soil in India are covered (Alexander 1972) :

Pune : Brown to dark brown calcareous soil with varying depth and texture.

Bhubaneshwar : Sandy loam.

Pantnagar : Silty loam, fine texture, brownish colour.

Hissar - Sierozem, calcareous.

TABLE 1

Thermal diffusivity (cm^2/sec) in different soil layers for first three harmonics as computed from amplitudes

Station	I Harmonic			II Harmonic			III Harmonic			Combined effect of I, II & III harmonics		
	5-15cm	15-30 cm ($X10^{-4}$)	5-30 cm	5-15cm	15-30 cm ($X10^{-4}$)	5-30 cm	5-15 cm	15-30 cm ($X10^{-4}$)	5-30 cm	5-15 cm	15-30 cm	5-30 cm
Solapur	1.83	5.66	3.33	1.92	3.54	2.55	0.40	7.84	1.40	$4.15x10^{-4}$	$1.70x10^{-3}$	$7.28x10^{-4}$
Bhubaneshwar	12.80	178.28	40.71	35.94	25.92	29.35	2.05	5.82	3.59	$5.08x10^{-3}$	$2.13x10^{-2}$	$7.37x10^{-3}$
Rajahmundry	1.55	2.42	2.00	1.73	0.73	1.00	0.58	0.13	0.39	$2.86x10^{-4}$	$3.28x10^{-4}$	$3.39x10^{-4}$
Pantnagar	99.48	30.58	45.29	30.90	18.93	22.71	16.82	13.71	14.84	$1.47x10^{-2}$	$6.32x10^{-3}$	8.28x10-3
Hissar	114.60	37.58	54.67	1.07	106.00	50.71	0.49	10.28	1.74	$1.16x10^{-2}$	$1.54x10^{-2}$	$1.07x10^{-2}$
Pune	1.90	57.13	7.32	3.77	9.35	6.18	0.36	2.57	12.00	$6.03x10^{-4}$	$6.90x10^{-3}$	$2.55x10^{-3}$

TABLE 2

Thermal diffusivity (cm^2/sec) in different soil layers for first three harmonics as computed from phase angles

Station	I Harmonic			II Harmonic			III Harmonic			Combined effect of I, II & III harmonics		
	5-15cm	15-30 cm ($X10^{-4}$)	5-30 cm	5-15cm	15-30 cm ($X10^{-4}$)	5-30 cm	5-15 cm	15-30 cm ($X10^{-4}$)	5-30 cm	5-15 cm	15-30 cm	5-30 cm
Solapur	0.78	59.34	3.58	11.15	10.49	10.75	2.35	2.91	2.66	$1.43x10^{-3}$	$7.27x10^{-3}$	$1.69x10^{-3}$
Bhubaneshwar	4.67	30.25	11.56	3355216	2328.0	6700.0	0.61	13.3	2.20	$3.36x10^{-6}$	$2.37x10^{-1}$	$6.71x10^{-1}$
Rajahmundry	0.72	8403.40	4.68	2.76	50.76	40.98	11.03	0.25	0.89	$1.45x10^{-3}$	$8.45x10^{-1}$	$4.65x10^{-3}$
Pantnagar	29.95	58.10	53.27	153.47	49.22	39.64	0.35	6.06	5.57	$1.83x10^{-2}$	$1.43x10^{-2}$	$9.80x10^{-3}$
Hissar	12.52	0.012	0.032	525.27	28.29	9.69	0.51	56.77	4.38	$5.38x10^{-2}$	$8.50x10^{-3}$	$1.41x10^{-3}$
Pune	0.53	225.86	2.90	1.64	3906.9	72.05	0.003	4.68	0.018	$2.17x10^{-4}$	$4.14x10^{-1}$	$7.49x10^{-3}$

Solapur - Medium type, calcareous, blackish brown.

Rajahmundry - Laterite.

The daily values of soil temperature at 5, 15 and 30 cm depths recorded at 0700 and 1400 L.M.T. were averaged to obtain daily means. Weekly means were then worked out for each standard week for the data from 1951 to 1980. These means were then averaged to obtain normal soil temperatures for each of the above mentioned depths for the 52 standard weeks (Lamba and Khambete 1991).

3. Methodology

The above-mentioned normal soil temperature data (N - 52 values) was subjected to Fourier analysis to obtain amplitudes and phase angles for all the $N/2$ (=26) harmonics. The first three out of these harmonics have been considered since they together account for almost 99 percent of variance, *i.e.*, the value of soil temperature obtained by adding the corresponding estimated values of these harmonics at the same depth are a very close approximation to the normal values (Lamba and Khambete 1991).

3.1. *Assumptions*

The following assumptions have been made :

(*i*) Soil is a semi-infinite homogeneous medium,

(*ii*) Soil temperature is a function of time, and

(*iii*) Thermal diffusivity is constant.

It has been shown that the amplitude of temperature fluctuation decreases exponentially with depth Z and there is a shift of $\theta Z \sqrt{\frac{\pi}{PK}}$ in the phase θ where K is the thermal diffusivity and P is the periodic time (Krishnan and Kushwaha 1972, Marshall and Holmes 1979). Using the values of amplitudes and phase variation for different harmonics, two different sets of values of K were obtained. If heat is conducted through the soil in accordance with the above theory of heat conduction, these two values should agree and vice versa (Krishnan and Kushwaha 1972).

It will be seen from what follows that these values of K do not agree and therefore the theory of heat conduction is not applicable to soil medium. The factors in actual soil conditions which might be responsible for the same are porosity, moisture and organic matter content of the soil.

4. Results and discussion

The values of thermal diffusivity in different soil layers for I, II and III harmonics alongwith their consolidated values are presented in Tables 1 & 2.

It is seen that the corresponding values in the two tables do not tally in respect of any of the stations considered. Krishnan and Kushwaha (1972) also showed similar results for Jodhpur station in Rajasthan. Diagreement between the two estimates of thermal diffusivity has also been reported by Lettau (1954), Singer and Brown (1956) and Rider (1957).

Effect of variation in soil moisture is that while thermal conductivity continues to increase with it, thermal diffusivity does not do so since it has an inverse relationship with volumetric heat capacity. Instead, the maxima of thermal diffusivity occurs at medium moisture values probably due to the included effect of vapour phase movement of moisture on heat transfer. Rose (1966) indicated that the bodily movement of moisture through the soil can also transfer large quantities of heat with it. These observations combined with the disagreement of the two estimates of thermal diffusivity, as indicated above, invalidate the application of the theory of heat transfer in soils by thermal conduction alone (Krishnan and Kushwaha 1972, Marshall and Holmes 1979).

Thermal diffusivity depends on thermal conductivity which in turn depends on porosity, moisture and organic matter content of the soil. For the same moisture content, thermal conductivity decreases from coarse of fine-textured soils since the porosity increases. However, in the natural fields, fine-textured soils have a higher water content which greatly increases the thermal conductivity. Also, the organic matter does not transfer heat as readily as mineral soil and lowers the thermal diffusivity (Chang 1964).

For discussion of the results, we shall confine our attention to Table 1. The following observations are made :

At Rajahmundry, thermal diffusivity is lowest for all the harmonics and in almost all the layers. This station has laterite soil which has high porosity and low organic matter content. Both these factors contribute to give low values of thermal diffusivity thereby corroborating the result.

Low values of amplitudes of the harmonics at Rajahmundry also show that no seasonal cycle dominates and, therefore, the values of thermal diffusivity do not undergo any significant variation in any of the three layers under consideration. The amplitudes for the three harmonics at Solapur and Pune also reveal almost the same result. However, the values over the 15-30 cm layer at both these stations possibly show a dominating annual cycle followed by much weaker bi-annual and quarterly cycles. Also, at Pune, the quarterly cycle over the 5-30 cm layer seems to be stronger than the annual and bi-annual cycles. Very high values for the I and II harmonics are observed at Hissar, Pantnagar and Bhubaneshwar while, for the 3rd harmonic, they are accounted for by Pantnagar only. Low to moderate porosity and moderate to high organic matter content of the soils at these stations could be the factors contributing to the high values of diffusivity. These values show that quite strong annual and bi-annual cycles dominate through all the soil layers at these stations except that the bi-annual cycle is 5-15cm layer is quite weak at Bhubaneshwar. Quarterly cycle is quite strong over all the layers at Pantnagar but only over the 15-30 cm layer at Hissar and Bhubaneshwar. This aspect perhaps needs further investigation.

5. Conclusions

Salient features of this study are given below :

(*i*) In 75 percent of the cases, the combined effect of the first three harmonics gives the values of thermal diffusivity close to the order of experimental values.

(*ii*) Theory of heat transfer by thermal conduction alone does not hold in the soil medium.

(*iii*) Lowest values of thermal diffusivity in all the harmonics are found at Rajahmundry, while the highest values are observed at Hissar, Bhubaneshwar and Pantnagar for the first, second and third harmonics respectively.

(*iv*) Strong annual and bi-annual cycles dominate at Hissar and Bhubaneshwar, while quarterly cycle is dominant at Pantnagar. No seasonal cycle dominates at other stations.

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