THERMAL PROPERTIES OF AN AGRICULTURAL SITE IN ILE-IFE, NIGERIA.

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Abstract: This study was conducted to determine the soil thermal properties, including the damping depth, at an agricultural teaching and research farm located inside Obafemi Awolowo University, Ile – Ife, Nigeria ($7^0$33'N, $4^0$33'E). The data were collected during the Nigerian Micrometeorological Experiment (NIMEX–1), from February 15 to March 10 2004. Results obtained showed that the damping depth varied between 0.13 m and 0.17 m. The variation of thermal properties with the depth and amount of soil water content has been discussed.

Key words: Damping depth, Soil thermal properties, Soil water content.

1. INTRODUCTION

The temperature of soils is an important physical factor in determining rates of biochemical reactions that occur within them [1]. It is a driving force for crop growth and soil biota [2]. Soil temperature varies in response to changes in the radiant, thermal and latent energy exchange through the soil surface. The effects of these phenomena are propagated into the soil profile by a series of complex transport processes, the rates of which are affected by time-variable and space-variable soil properties [3].

The possibility of actively controlling or modifying the thermal regime requires a thorough knowledge of the processes at play, as well as the soil parameters which govern the rates [4]. The pertinent soil parameters include heat capacity, thermal conductivity, thermal diffusivity and the thermal admittance, etc. (all of which are strongly affected by the amount of water content in the soil [5];[6];[7].

In the upper soil layer (say, surface – 100 cm), the temperature usually decreases with the depths in an exponential manner [8]. The temperature-wave amplitude reaches its maximum (and minimum) at different times for the different depths in the soil.

Thus, the temperature wave amplitude, A, at any depth z, is given as:

$$A = A_s \exp\left(\frac{-z}{d}\right) \qquad (1)$$

where, A_S, is the surface temperature wave amplitude and d the damping depth. The damping depth ,d, of the thermal wave is given by

$$d = \left(\frac{P\alpha}{\pi}\right)^{1/2} \qquad (2)$$

(see [3,8]), where P is the period of the thermal wave (for the diurnal trend, P = 86400s) , and α is the soil thermal diffusivity. The thermal diffusivity of the soil can be determined from the plot of the wave amplitude (on logarithm scale) against the soil depth, z.

The Heat capacity, C , can be obtained from the plot of heat flux change and the difference in layer average temperature with the use of equation (3) [9].

$$\Delta Hg = C\frac{dz}{dt}\Delta\overline{T} \qquad (3)$$

where ΔHg is the change in soil heat flux, dz the layer depth; $\Delta\overline{T}$ is the change of the layer average temperature and dt , the time interval .

The thermal conductivity, K , can be obtained from the relationship given in equation (4)

$$\alpha = K/C \qquad (4)$$

with α being the thermal diffusivity and C the heat capacity.

Nig. J. Pure Appl. Phys. (2005) Vol. 4 pp 71-74. Printed in Nigeria, ISSN 1596-0862. E-mail: njpapfuta@yahoo.com. For rights of reproduction and web access, contact African Journals Online, UK, www.inasp.ajol/journals/njpap

The thermal admittance, μ, is a measure of the ability of a soil surface to accept or release heat and was determined from equation (5)

$$\mu = CK^{-1/2} \qquad (5)$$

Several numerical and empirical methods available use boundary conditions and thermal properties of soil as an alternative for soil temperature prediction [5] ; [10]; [11]. Hence, the objective of this paper is to determine the soil thermal properties that will be useful for such purposes because of its enormous applications to agriculture.

2. MATERIALS AND METHODS

This study was conducted at the Agricultural Teaching and Research Farm situated within the campus of Obafemi Awolowo University, Ile-Ife ($7^0$33'N, $4^0$33'E), Nigeria between 15th of February and 10th of March, 2004. The main project was the Nigerian Micrometeorological Experiment, dubbed the acronym, NIMEX-1, a partnership research project between five institutions, namely the Department of Physics at Obafemi Awolowo University in Ile-Ife; Department of Physics at the University of Ibadan; Department of Meteorology at the Federal University of Technology, Akure; the African Regional Centre for Space Science and Technology Education - English also at the Obafemi Awolowo University and the Department of Micrometeorology at the University of Bayreuth, Germany.

Buried in the soil at three depths (0.05 m, 0.10 m, and 0.30 m) were soil temperature probes and soil heat flux plates (0.02 m later moved to 0.05 m, 0.10 m, and 0.30 m, 1.0 m), and a soil water content reflectometer (model CS615 manufactured by Campbell Scientific).

The soil temperature probes used were a combination of some platinium resistance thermometer (PRT) tranducers and thermocouples while the soil heat flux plates are thermopiles. Both the heat flux plates and the soil thermometers were buried in the ground carefully so that the surrounding soil was left undisturbed. Selection of the thermal properties were based on their relationship to the soil properties and crop growth [11].

All the measurements were controlled by the use of two Campbell CR-10X dataloggers, which sampled the data every 1 second and stored as 1min average values, for the period the experiment lasted. All the soil parameters calculated were compared with the amount of water content in the soil.

3. RESULTS AND DISCUSSIONS

The data in Table 1 show the mean values of the soil thermal properties computed for the experimental site during the observational period for the layers, 5-10 cm and 10-30 cm respectively. The mean value of the heat capacity, C, for the 5 - 10 cm is about three times the value for 10 – 30 cm layer. This difference in the heat capacity value for the two layers is indicative of the different soil layers (texture and compactness). The thermal diffusivity, α, values at the 10 – 30 cm layer, however, are more than doubled that obtained for 5 – 10 cm layer while the thermal conductivity, K, and the thermal admittance, μ values for the 5 – 10 cm layer were higher by a factor of about three and two than in the 10 - 30 cm layer, respectively. These range of values and layer differences in values of properties obtained compared very well with other studies found in literatures (see [12];[13] and [7].

Table 1: Estimated mean values of the thermal properties at the experimental site.

Depth	Statistics	Thermal Diffusivity, α (x10^{-6} m^2s^{-1})	Heat capacity C, (x 10^6 J $m^{-3}K^{-1}$)	Thermal conductivity, K ($Wm^{-1}K^{-1}$)	Thermal admittance, μ ($Jm^{-2}s^{-1/2}K^{-1}$)
5 -10 (cm)	maximum	0.52	1.56	1.64	1.55
	minimum	0.32	0.95	0.68	1.16
	Average	0.44	1.45	1.21	1.34
	Std .dev.	0.06366	0.19069	0.33043	0.14
10 -30 (cm)	Maximum	2.85	0.63	0.58	0.94
	minimum	0.61	0.45	0.28	0.72
	average	1.11	0.54	0.42	0.85
	Std. dev.	0.55607	0.06458	0.12818	0.08075

The value of the damping depth (diurnal) for the site varied between 0.13 and 0.17 m with an average value of 0.15 m.

Figures 1a-d show the day-to-day variation of the thermal properties and the soil water content during the investigation period between 15^{th} of February to 10^{th} of March, 2004. Although the period of observation was a transition period, marked mostly by dry spells with few days of precipitation, the correlation of the thermal properties with the soil wetness were still noticeable.

The heat capacity is positively correlated with the soil wetness (see, fig.1a). For example, between the 25^{th} and 27^{th} of February, the soil water content increased from about 7% to 17% and similarly, the heat capacity rose from about 0.45×10^6 $Jm^{-3}K^{-1}$ to 0.63×10^6 $Jm^{-3}K^{-1}$. Also between 27^{th} and 28^{th} of February, the value of heat capacity reduced from 0.82×10^6 $Jm^{-3}K^{-1}$ to 0.61×10^6 $Jm^{-3}K^{-1}$ when the soil water content reduced from about 16% to 13%. moisture to a certain level and thereafter decline. For instance, between 25^{th} and 26^{th} of February, the soil water increased up to 7% - 15%. Correspondingly, the thermal diffusivity increased from about 0.61×10^{-6} m^2s^{-1} to 1.05×10^{-6} m^2s^{-1}. But the soil water showed further increase to about 17% on the 27^{th} of February, instead the thermal diffusivity decreased to about 0.82×10^{-6} m^2s^{-1}.

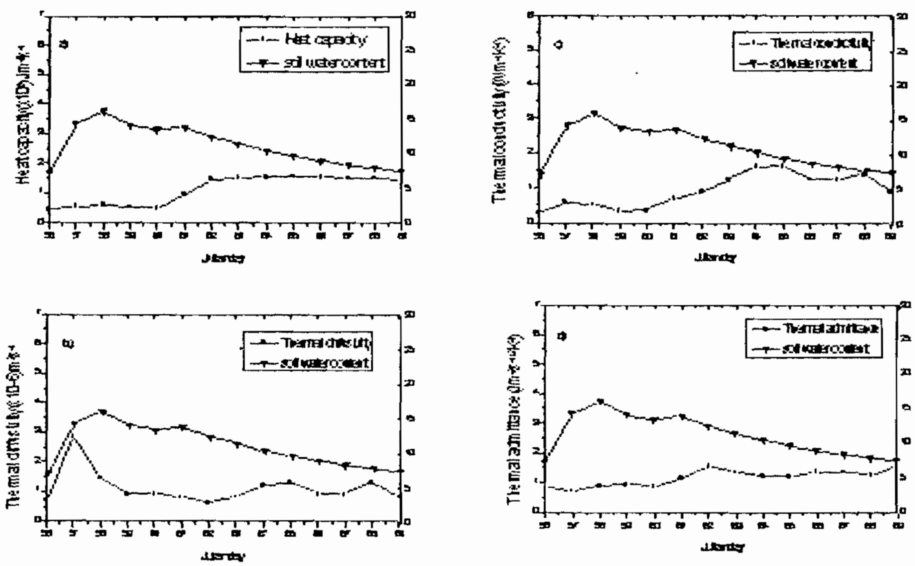

Fig. 1a-d. Variation of soil thermal properties with the soil moisturee content during the observation period from Julian day 56 -69

It can be observed from fig.1c that the soil thermal conductivity is also a varying property with the soil moisture content. Between 25^{th} and 27^{th} of February, the soil water increased from about 7% to 15%, while the conductivity initially increased from 0.28 $Wm^{-1}K^{-1}$ to 0.58 $Wm^{-1}K^{-1}$ and later reduced to about 0.33 $Wm^{-1}K^{-1}$ on the 28^{th} of February when the soil water content was about 13%. Also on the 6^{th} and 8^{th} of March when the soil water content values were approximately 10% and 8%, the thermal conductivity values were 1.64 $Wm^{-1}K^{-1}$ and 1.24 $Wm^{-1}K^{-1}$ respectively. The thermal conductivity is more sensitive to the soil moisture than the thermal diffusivity.

In fig. 1d the day–to-day variation of thermal admittance with soil moisture content is shown. The thermal admittance varied significantly with the moisture content. On the 3rd and 4^{th} of March, for example, the soil water content were 13% and 11% respectively. The obtained values of the thermal admittance decreased from 1.55 $J\ m^{-2}\ s^{-1/2}\ K^{-1}$ to 1.36 $J\ m^{-2}\ s^{-1/2}\ K^{-1}$. Also, between 26^{th} and 27^{th} of February the thermal admittance value increased from 0.72 $Jm^{-2}\ s^{-1/2}K^{-1}$ to 0.88 $Jm^{-2}\ s^{-1/2}K^{-1}$ when the soil water increased from 15% to 17%.

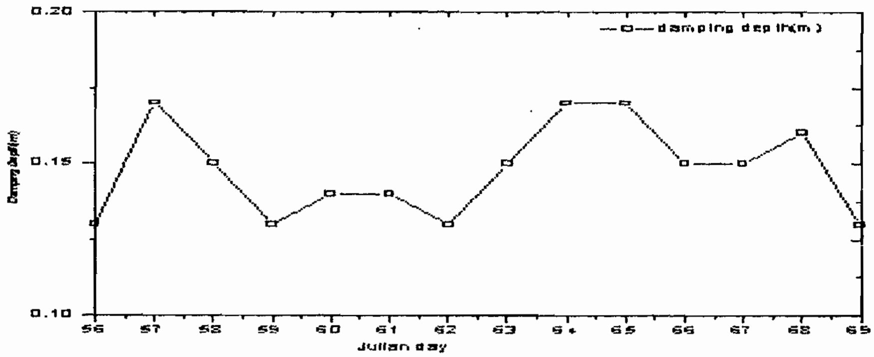

Fig 2: Day-to-day variation of damping depth during the period of observation

In Fig.2 the day-to-day variation of the damping depth is shown. It can be noticed from this plot that the damping depth varied on a daily basis and thus not a constant value for a particular location and day. The maximum value of 0.17m was obtained on 26th of February, 4th and 5th of March, while a minimum of 0.13m was obtained on 25th of February, 3rd and 10th of March.
This difference was probably due to changes in soil conditions as well as the difference in net radiation values for these days.

4. CONCLUSION

The day-by-day study variation of the soil thermal properties with the soil moisture content for this particular location is consistent with studies in literatures ([12]; [11]).

The knowledge of soil thermal properties and the damping depth value obtained from this study will be of great importance in soil temperature prediction and modeling of surface energy budget ([11]; [14]), for this location.

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