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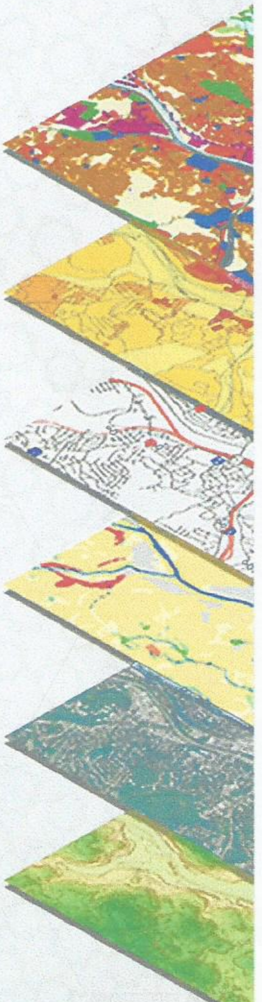

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INFORMATION

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DETERMINATION AND COMPARISON OF THE THERMAL PROPERTIES IN THE SOIL TERRAIN AND IN THE MONOLITH CONDITIONS

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ABSTRACT:

Soil temperature depends on the soil heat relationship (radiation, heat capacity, thermal conductivity, etc.). Heat relations consists heat conduction in the soil and the temperature change caused by heat exchange between the atmosphere and soil. Temperature changes vary depending on the time and soil depth. In this study, soil temperature was measured with a water-proof portable thermal Sensor (Thermochro the iButton DS1921G) in field. The measurements of heat were carried out by placing sensors of the device, called 16 Channel PC-Compatible Elimko 680 Data Logger (Analog/Digital Convertor) that is capable of turning analog signals into digital values and saving on computers, into the 0-0.2-0.5-0.10-0.15-0.20-0.25 and 0.30 m depths of soil column taken from the field by using monolith system. There are 3 lamellar widely used methods in the soil temperature research. We have identified in our study heat transfer in soil by using these methods. Compared calculated thermal diffusivity values with measured values. Their measured and calculated values in the subsurface layers were close to each other while calculated values were lower than measured values in the surface horizon. According to the Surface parameters and statistical approaches of soil temperature at field conditions and monoliths approach; studies with Monolith yielded better results than working in the field.

KEY WORDS: Soil, Modeling, Heat Transfer, Thermal Properties, Monolith,

* Corresponding author.

1. INTRODUCTION

Soil temperature is one the most important factors affecting physical, chemical, and biological characteristics. Soil temperature influences processes such as seed germination, plant growth and development, soil moisture flow and availability to plants, aeration, structure formation, microbiological activity, decomposition of crop residues, availability of plant nutrients, freeze-thaw events. In addition soil temperature have decisive influence on soil formation and processes such as transformation and translocations of matters in soil profile. Thermal diffusivity of soil is the most important heat transmission parameter that represents the temperature change depending on soil heat conductivity and volumetric heat capacity. surface heat balance, the calculation of the thermal conductivity and thermal properties are entirely related to the heat flow in the soil. Soil specific heat capacity (C_m), volumetric heat capacity (C_v), heat conductivity (λ), heat diffuzivity (k) heat balance (Radiation) (R) and damping depth (d) have been studied extensively.

Soil thermal variables such as thermal conductivity, heat capacity, and thermal diffusivity may be measured and/or predicted from other soil variables using mathematical models (Carslaw, 1921; De Vries, 1963; Nerpin and Chudnovskil 1962; Horton 1982; Juri, 1991; Shein, 2005; Mikayilov and Shein 2010). Mathematical models are widely used in predicating soil thermal variables.

The study area is in Cumra, which is located between 37^0-38^0 North latitude and 33^0-34^0 East longitude (Fig.1). Located at 1013 m above sea level, the Cumra region covers approximately 2.330 km^2 plain exhibiting a non-uniform characteristics in terms of topography. Konya, where Cumra region is located within, is one of the most important agricultural areas in Turkey. Due to the favorable ecological aspect of the district, a wide variety of plants can be grown. Most of the soils are level. Cumra covers 7.8% of the agricultural land of Konya. Approximately 70% of the total area of Cumra district is suitable for agriculture (Anonymous, 2014). Cumra and its around, winters are cold and snowy. Summers are hot and dry. Fall and spring months are rainy. Summer temperatures are favorable for cultivation of many agricultural products. While the average temperature increases in summer, humidity decreases. The highest temperature compared to the average of many years of harvest data in July with 39.9°C. The lowest temperature has been measured in February as -26.3°C. The average temperature is 11.4°C. Average rainfall is 318.9 mm and the amount of rainfall in 2013 based on an average of many years is 204.0 mm that shows a significant amount of reduction.

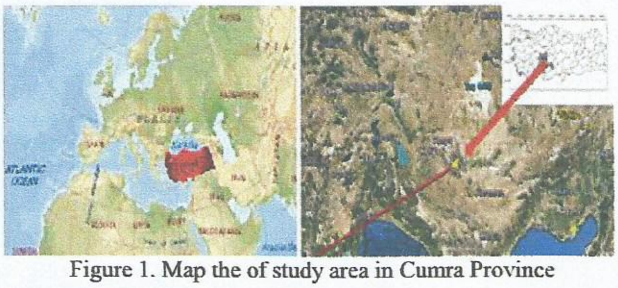

Figure 1. Map the of study area in Cumra Province

The soils of the experimental site are clay loam (CL) in texture. These soils are young alluvial soils with low organic matter content. Horizon boundaries of the soils are faint with slightly wavy structure.

2. MATERIAL AND METHODS

2.1 The studies field conditions

In this study, soil temperature was measured with a water-proof portable thermal Sensor (*Thermochro the iButton DS1921G*) (Fig.2). The sensor registers and stores temperature measurements in its memory. Recorded temperature degrees are stored directly and can be downloaded by users.

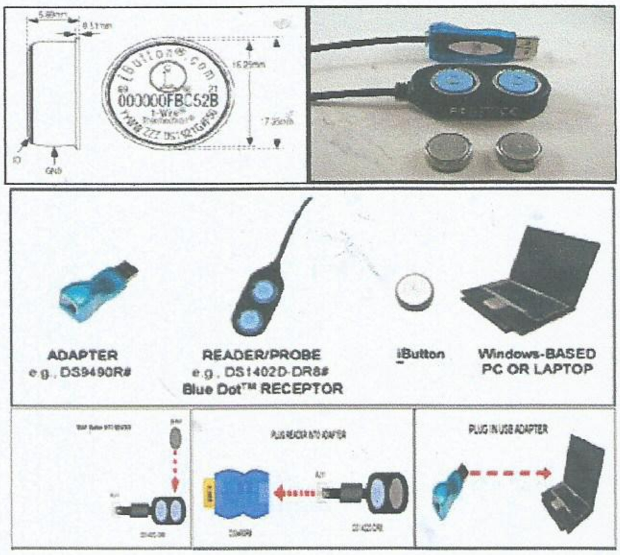

Figure 2. Thermochron iButton DS1921G thermal sensors and schematic diagram of Blue Dot™ receptor & USB adapter

Thermal sensor to be used for recording of temperature measurement sensors in the experiment soil profile opening in the soil profile at respectively 0, 2, 5, 10, 15, 20, and 30 cm depth have been placed in the same plane (Fig. 3).

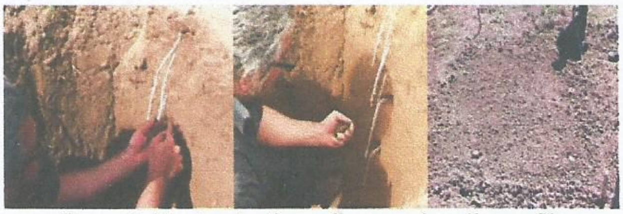

Figure 3. Placing the thermal sensors in soil a profile

2.2 The studies in colon conditions

The measurements of heat were carried out by placing sensors of the device, called 16 Channel PC-Compatible Elimko 680 Data Logger (Analog/Digital Convertor) that is capable of turning analog signals into digital values and saving on computers, into the 0-0.2-0.5-0.10-0.15-0.20-0.25 and 0.30 m depths of soil column taken from the field by using monolith system.

Elimko Data Logger System (EDLS) (Fig. 4 and 5): Data loggers possess both the capacities of storing data obtained thorugh measurements and the data storing capacities that provide flexibility fort the methods used to process the data. After running a proper software, data logger system start obtaining data by means of proper modules and sensors (Konchhar and Burns, 1983).

Figure 4. Experimental setup and photographs used in research.

The convey of the data from the outer source into digital environment is provided by a complex structure including electronic circuits and software. During the constitutiton of the data that received and resulted by computers, sensors compose the most important data transfer system. The physical features, like pressure, heat, light, flow, level, locational change, velocity, acceleration, force, rotation, oscillation and weight, are turned into electric signals and upgraded and transferred to the computer environment in the form of proper numeric structures (Konchhar and Burns, 1983).

For the measurement of heat, a computer connected RS-485 was employed. Thanks to RS, analog values obtained by sensors from 8 different points of soil column were converted into numeric values by using EDLS.

Elimko Data Logger software and Elimko devices having RS-485 Modbus RTU connection protocole are monitored on the same line. To connect this line to the computer, RS-485 / RS-232 or RS-485/USD convertors are utilised.

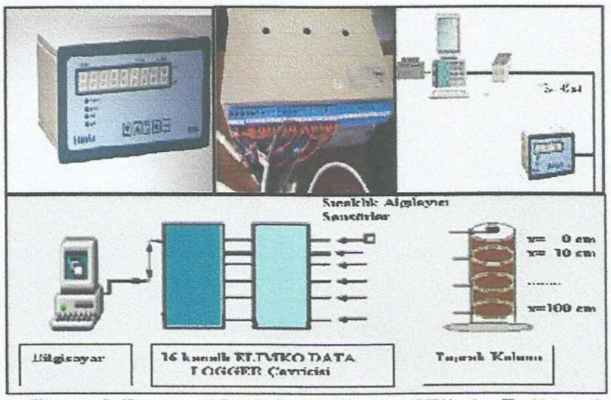

Figure 5. Front and Back Panel Views of Elimko E-680 and Connection Diagrams

Temperature was measured at t = 0, 1, 2,...21, 22, 23 with thermal sensors (*Thermochron* and *Elimko Data Logger System*)

2.3 Calculating thermal diffusivity of soils

One dimensional shape of it which define heat conduction in the semi-homogeneous soil environment heat where there is no source which generate heat and widely used has the following format (Caslaw and Jaeger, 1959; Tikhonov and Samarskiy, 1966; Nerpin and Chudnovskil, 1967; Horton, 1982, Juri, 1991; Shein, 2005; Mikayilov and Shein, 2010).

$$\partial T / \partial t = \kappa \partial^2 T / \partial x^2 \quad (\kappa = \lambda / C_v) \qquad (1)$$

where $T(x,t)-$ the temperature of the soil at the point x (m) at the time moment t (s); $\kappa-$ thermal diffusivity, m^2/s; $\lambda-$ the thermal conductivity, W/(m·°C); $C_v = \rho_b C_m -$ volumetric heat capacity (J/m^3·°C); $\rho_b -$ the soil bulk density (kg/m^3) and C_m – the specific heat capacity (J/kg·°C).

This equation is valid when λ and C_v' is not dependent on space and time and homogeneous soil conditions including water content.

The equation (1) must be solved analytically or numerically to be found of the change of at a given time and depth as a result of various factors time. For this purpose, the equation must be defined and completed with the initial and boundary conditions which including the environmental factors that affect the temperature changing.

Using the Fourier series representation the soil temperature near the surface can be described accurately by (Carslaw, 1921):

$$\begin{aligned} T(0,t) &= \overline{T} + T_a \cos(\omega t + \varepsilon) \\ &= \overline{T} + A\cos(\omega t) + B\sin(\omega t) \end{aligned} \qquad (2)$$

where $\overline{T}-$the average daily temperature of the active soil surface; $T_a = \sqrt{A^2 + B^2}$ – is the variation amplitude of the temperature of the active soil layer; A and $B-$the amplitudes of the harmonic of the temperature wave; $\omega = 2\pi\tau_0$ – the angular daily frequency; $\tau_0-$the temperature wave period (days); $m-$the harmonic number; $\varepsilon-$the phase shift dependent on the time reference point, $\varepsilon = \arctan(-B/A)$ if $A > 0; \varepsilon = \pi - \arctan(B/A)$ if $A < 0$

For determining a parameter used solution of equation (1). The solution of Eq. (1) obtained without the initial (boundary) conditions and with conditions (2) and $T(x \to \infty, t) = \overline{T}$ in dimensionless variables has the following form [Carslaw, 1921):

$$T(y,\tau) = \overline{T} + T_a \cdot e^{-by} \cdot \cos(\overline{\omega}\tau + \varepsilon - by) \qquad (3)$$

where $y = x/L, \tau = \kappa t / L^2$, $b = \sqrt{\overline{\omega}/2}$,$\overline{\omega} = \omega L^2 / \kappa$.

The parameters in Eq. (2) were approximated by methods of method of least squares.

Heat diffusivity parameter (κ) is calculated with below described methods (Carslaw and Jaeger, 1959; De Vries, 1963; Nerpin and Chudnovskil, 1967; Horton, 1982; 1963; Tikhonov and Samarskiy, 1966; Mikayilov and Shein, 2010) based on the solution (2).

Method-1 (Containing heat wave amplitude formulae): The recommended method for the presence of heat diffusivity parameters is developed based on Fourier's 1. law, which expresses steadily decreasing soil temperature amplitude in by depth. In this study κ was calculated by Eq. (4).

$$\kappa_i = \frac{\pi (x_{i+1} - x_i)^2}{\tau_0 \cdot \ln^2 \left[\frac{\Phi_{max}(x_i) - \Phi_{min}(x_i)}{\Phi_{max}(x_{i+1}) - \Phi_{min}(x_{i+1})} \right]} \qquad (4)$$

Where; $\Phi_{min}(x_i)$ and $\Phi_{max}(x_i)-$minimum and maximum temperature in depth x_i; τ_0= period of heat wave (e.g., 24 hours for daily observations).

Method-2 (Arctangent Containing Formula): Based on solution of the thermal conductivity equation, following equation has been developed to calculate heat diffusivity:

$$\kappa = \frac{\pi (x_2 - x_1)^2}{\tau_0 \cdot \arctan^2 \left[\frac{(T_1' - T_3')(T_2'' - T_4'') - (T_2' - T_4')(T_1'' - T_3'')}{(T_1' - T_3')(T_1'' - T_3'') + (T_2' - T_4')(T_2'' - T_4'')} \right]} \tag{5}$$

Method- 3 (Formula Containing Logarithms): Using the assumptions for method-2, Seemann (1979) obtained the following equation:

$$\kappa = \frac{4\pi \cdot (x_2 - x_1)^2}{\tau_0 \cdot \ln^2 \left[\frac{(T_1' - T_3')^2 + (T_2' - T_4')^2}{(T_1'' - T_3'')^2 + (T_2'' - T_4'')^2} \right]} \tag{6}$$

where T_i' and T_i'' are the soil temperatures at the depths $x = x_1$ and $x = x_2$ respectively, at the time moment $t_i = i \cdot \tau_0 / 4 \; (i = 1,2,3,4)$ (for our example τ_0 = 24 h and t_1=6, t_2=12, t_3=18 and t_4=24 hours).

2.4 Evaluation of model performance

Coefficient of determination (R^2) was used to evaluate modeling success. Root mean squared error (RMSE) and mean absolute percentage error (MAPE) were used along with R^2 to evaluate the accuracy of modeling results.

The surface parameters of working area soils $(\bar{T}, T_a, \varepsilon)$ values have been found, being applied of statistically parameter approaches the values on Table (1) are created.

3. RESULTS AND DISCUSSION

The profile descriptions of the soils are given below.

A horizon: 0-24 cm; Dark yellowish brown (10 YR 4/4 moist), silty clay (SiC); weak medium subangular blocky structure; slightly sticky and moderately plastic when moist; common fine vesicular pores; very strongly effervescent with 0.1 M HCl; few, fine roots; abrupt, smooth boundaries

Bw horizon: 24-83 cm; Dark yellowish brown (7.5 YR 4/3 moist), silty clay (SiC); weak, coarse, subangular blocky structure; slightly sticky and slightly plastic when moist; common, fine, tubuler pores; strongly effervescent with 0.1 M HCl; few, very fine roots; very abrupt wavy boundary.

BC horizon: 83- cm; Dark brown (7.5 YR 3/3 moist), silty clay (SiC); weak, fine, subangular blocky structure; slightly sticky and slightly plastic when moist; common fine vesicular pores; very strongly effervescent with 0.1 M HCl; few, very fine roots.

The average sand amount of study area soil is 3.82% , silt is 55.31 % and clay is found a 40.59 %. The amount of silt is 21.21 % between 2-5 µm, 16.45% between 5-10 µm, 16.40 % between 10-50 µm, 1.26 % between 50-250 µm.

Lands of research consists of alluviyal soil. They are lime-rich soils which is moved from the surrounding mountains and hills from the fourth time accumulated in the old lake bed. According to the new genetic classification system they are AC horizon soil as vertisol. The upper horizon of the partially decomposed organic waste is seen mixed with mineral. At C horizons (at bottom) is seen the main material which is dissociated and moved from the environment. The study area soils have a clay loam texture and they are called as heavy clay soils. These soils are young alluvial soils of which organic matter content is very low. Horizon boundaries of the soil shows less obvious and slightly wavy structure.

Determination of *t* heat diffuzivity (κ) in soil is calculated by the above equations. We have identified in our study heat transfer in soil by using these methods. For this, we used data from observing soil temperature changes in the field and in the monolith, is soil column.

The parameters of the soil surface		field	monolit
Average Temperature of Soil Surface	$\bar{T}$	22.7708	21.6667
Wave Amplitude	T_a	10.6215	11.1119
Phase Angle (Phase Difference)	ε	2.3784	2.3181
Statistical parameters of approximation			
The Coefficient of Determination	R^2	0.8645	0.9066
Root Mean Squared Error (RMSE)	σ	3.26	2.76
Mean Absolute Percentage Error (MAPE)	A, %	13.07	11.39

Table 1. Surface parameters and statistical approaches of soil temperature at field and monoliths conditions

In the consequence of analysis in soil sample, having been found of volumetric water content (θ) and density (ρ_b) in all parcels and all profile layers of soil samples at inception point, volumetric heat capacity has been calculated.

The average particle density of the soil (which refers to field research) has been found as bulk density; ρ_b = 1313.6 kg/m³ and porosity; 49.203%. Volumetric water content of soil sample is calculated as θ=0,3176 m³/m³, and the volumetric heat capacity is calculated as

$$C_v = C_{m,solid\,faz} \cdot \rho_b + C_{v_w} \cdot \theta =$$

$$= 0.20 \frac{cal}{g \cdot {}^\circ C} \cdot 1.3136 \frac{g}{cm^3} + 1 \frac{cal}{cm^3 \cdot {}^\circ C} \cdot 0.3176 \frac{cm^3}{cm^3} =$$

$$= 0.58032 \frac{cal}{cm^3 \cdot {}^\circ C} = 2.429684 \cdot 10^6 \frac{J}{m^3 \cdot {}^\circ C}$$

Similar soil study contained in the monolith have the following results: ρ_b = 1317.2 kg/m³ and porosity; 49.203%. Volumetric water content of soil sample is calculated as θ=0.2109 m³/m³, and the volumetric heat capacity is calculated as; C_v= 1.985799 J/(m³·°C).

The amount of heat that moves a specified distance from a point in a pórous medium is dependent on the rate of delivery of the medium. So another important variable for the thermal phenomena is thermal conductivity. Soil clay content affects the heat conductivity. Widely used units for λ are in the form of cal/cm·sec·°C. The calculated heat conductivity parameter (λ=κ·C_v) are given in Table (2).

The depth of the soil in which damped temperature fluctuations (g) was calculated according to the following formula (Carslaw and Jaeger, 1959)

$$d = \sqrt{\tau_0 \kappa / \pi} \tag{7}$$

Type of methods	Test of Methods	10^{-6}·κ m²/s	λ W/m·°C	d m
Amplitude (4)	field	0,3426	0,8324	0,097
	monolith	0,9493	1,8853	0,162
Arctangent (5)	field	0,5632	1,3684	0,124
	monolith	1,5418	3,0619	0,206
Logarithmic (6)	field	0,3109	0,7554	0,092
	monolith	1,0569	2,0990	0,170

Table 2. The average values of the of soil thermal diffusivity (κ) and thermal conductivity (λ) calculated by various methods

After the determination of the thermal diffusivity by the formula (4) - (6), then by solving (3) calculated values of soil temperature at depths of 2, 5, 10, 15, 20 and 30 cm in the soil terrain and in the monolith conditions.

Comparison of experimental and calculated values shows, the Arctangent method gives the best result for the field soil, and the Amplitude method gives the best result for the soil in the monolith conditions (see Table 3). Table 3 shows the values of the coefficient of determination R^2 between the measured and calculated values of soil temperature

Type of methods	Depths, x, m					
	0,02	0,05	0,10	0,15	0,20	0,30
Field						
(4)	0,8281	0,9294	0,9204	0,9411	0,9211	0,7853
(5)	0,8328	0,9335	0,9333	0,9509	0,9382	0,8275
(6)	0,8051	0,8970	0,8098	0,7746	0,6448	0,3018
Monolith						
(4)	0,7977	0,8986	0,8926	0,8256	0,8286	0,9680
(5)	0,7797	0,8665	0,8149	0,6723	0,6143	0,7514
(6)	0,7934	0,8914	0,8762	0,7926	0,7836	0,9397

Table 3. Results of the statistical analyses. R^2, correlation coefficient

4. CONCLUSIONS

Best results were provided with calculations of logarithmic method. Results which obtained from field studies were more consistent than monolith. In calculations with arctangent methods, adequate are more incompatible according to logaritmic and amplitude models. Generally, adequate decreases with increasing depth in all metods and study fields.

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