THE EFFECT OF SOIL TEMPERATURE AND MOISTURE CONTENT ON THE THERMAL PROPERTIES OF ISMAILIA SANDY SOIL UNDER ALFALFA COVER

El-Raies, S.A.A.; Amal M. Abdel Tawab; El-Farghal, W.M. and El-Sisi, S.E.M.

Soil, Water and Environment Agricultural Research Institute,
ARC, Giza, Egypt

ABESTRACT

Fifty one registers (one every week) of soil temperatures in 51 weeks through twelve months from January to December were recorded for every depth. They were recorded for three soil depths (0.05, 0.15, and 0.30m) in sandy soil that covered with alfalfa plants in Ismailia Agriculture Research Station of Ismailia governorate. The total soil temperature registers recorded were (51 observations x 3 depths) 153 readings. One hundred and fifty three soil samples in the same 51 weeks were collected from the same locations of the three depths. The volumetric heat capacity, thermal conductivity and thermal diffusivity were calculated. The obtained results were summarized as follows:

Soil volumetric heat capacity increased with increasing moisture content at the nearest soil surface depth (0.05m) or the deepest one (0.30m). They ranged from 1.345479 to 1.803934, 1.286049 to 1.678707 and from 1.281804 to 1.757947 $MJm^{-3}c^{-1}$ for the three depths 0.05, 0.15 and 0.30m respectively.

Soil thermal conductivity increased with increasing soil moisture content. The values ranged from 1.2603 to 2.2489, 1.23222 to 2.15026 and 1.03913 to $2.18332 Jm^{-1}s^{-1}c^{-1}$, at moisture content ranged from 0.024 to 0.133, 0.010 to 0.103 and 0.009 to $0.122 m^3m^{-3}$ for the abovementioned depths, respectively. However, soil temperature showed a small effect on increasing the thermal conductivity.

Soil thermal diffusivity was affected by soil temperature and soil volumetric moisture content. They ranged from 9.22592E-07 to 13.3223E-07, from 9.10083E-07 to 14.0327E-07 and from 8.1068E-07 to 15.1938E-07 m^2s^{-1} at three depths of 0.05, 0.15 and 0.30m respectively.

Keyword: Soil volumetric heat capacity, Thermal conductivity, Thermal diffusivity.

INTRODUCTION

Thermal conductivity of a soil is a function of the thermal properties of the solid materials, soil texture, pore size distribution, water content, and the temperature of the medium. Heat flow occurs by conduction through the solid particles, through the water present as continuous films on the particles, and through the air in the soil pores. Heat transfer in moist soil also occurs as a result of vapor diffusion. Water vapor molecules diffuse from warm regions where evaporation occurs to cold regions where condensation occurs as a result of vapor pressure gradients caused by temperature differences. **(Sepaskhah and Boersma 1979).**

The thermal properties of a soil at any location are in a constant state of flux due to diurnal and seasonal variations. The thermal characteristics of a soil are influenced by the soil volumetric water content, the volume fraction of air and the volume fraction of the soil solids. These properties are important in every aspect of soil mechanics because they indicate how energy is partitioned in the soil profile. The effect of bulk density, moisture content, salt concentration, and organic matter on the thermal conductivity of some sieved and repacked Jordanian soils was investigated through laboratory studies. Increasing the percentage of soil organic matter decreased thermal conductivity. It was found that the sand had higher values of thermal conductivity than the clay loam for the same salt type and concentrations, **(Abu-Hamdeh and Reeder 2000)**. Dry organic horizons have considerably lower thermal conductivity than wet organic horizons and thus function as good insulators against warm air temperature **(O'Donnell, *et al*, 2009).** Wet organic horizons also dampen the amplitude of seasonal temperature variations through the absorption and release of latent heat during phase transitions **(Romanovsky and Osterkamp, 2000).**

A soil profile describes how energy is dispersed through a cross-sectional slice of the soil from the surface to various depths. The thermal properties, such as thermal conductivity, are related to the temperature of the soil and reflect the heat transfer throughout the soil by radiation, conduction and convection. As one would expect, the temperature variations are hottest at the surface and decrease with depth depending on the thermal characteristics of the soil. **Awadalla (1977)** found that specific heat values decreased from coarse to fine sand then progressively increased in the clay fraction. He attributed the high values of coarse sand fraction to its mineral composition, and added that the volumetric heat capacity increased with increasing soil moisture retention.

The presence of water has a strong influence on the soil thermal properties, including thermal conductivity and soil heat capacity. Thermal conductivity is a measure of the ease with which a soil transmits heat, in that it describes the heat flow in response to a thermal gradient. Water has a high heat capacity in that it takes less heat to raise the soil temperature in a dry soil than in a wet soil. Wet soils conduct heat better than dry soils.

Adjepong (1997) mentioned that the rate of increase of the specific heat capacity with moisture content is found to be high in the clayey soil and low in the sandy soil. He added that in the considered range (0-25%) of moisture content, the specific heat capacities of the soil increase with moisture content. In the case of the sandy soil, the increase is found to be linear over the considered range.

Khalifa (1992) mentioned that the evaporation is very important when using the coupled heat and water flow equations to predict soil temperatures.

Abd El-Dayem (1999) mentioned that the values of both thermal conductivity and thermal diffusivity increased markedly with increasing soil temperature. On the other hand, values of the volumetric heat capacity were not affected with soil temperature.

Accurate estimates of soils thermal conductivity are of prime importance in the numerical simulation of heat transmission through soils. Soil thermal conductivity estimation methods that could easily be incorporated in computer algorithms will have wide application. Factors affecting soil thermal conductivity include moisture, mineral composition and temperature. Moisture content, by far, has the greatest impact upon soil thermal conductivity. As moisture is added to a soil, a thin water film develops which bridges the gaps between the soil particles. This bridging increases the effective contact area between the soil particles, which increases the heat flow and results in higher thermal conductivity. As the voids between the soil particles become completely filled with moisture, the soil thermal conductivity no longer increases with increasing moisture content, **(Penner *et al,* 1975)**.

Soil thermal conductivity also varies with the mineral composition of the soil. For examples, sands with a high quartz content generally have a greater thermal conductivity than sands with high contents of plagioclase feldspar and pyroxene, **(Kersten, 1949)**. **Bora *et al,* (1990)** found that thermal diffusivity of soil was lower near the surface compared with deeper depths.

The objective of the investigation is to calculate thermal properties of sandy soil of Ismailia Agricultural Research Station under a cover of alfalfa plants.

Theoretical consideration:

According to **De Vries (1963)**, **Kimball *et al,* (1976)**, **Fritschen and Gay (1979)** and **Khalifa (1992)**

Volumetric heat capacity (C_v) ($Jm^{-3}c^{-1}$) according (De vries 1963):

$$C_v = \sum_{i=1}^{n} C_i X_i \qquad \left(Jm^{-3}c^{-1}\right)$$

Where; C_i = volumetric heat capacity of the i-th soil constituent

X_i = volume fraction of the i-th soil constituent

Soil volumetric heat capacity was calculated from the sum of the volumetric heat capacities of different components of the soil:

$$C_v = 1.92 X_m + 2.51 X_o + 4.18 X_w$$

Where C_v is the volumetric heat capacity of the soil (MJ m^{-3} c^{-1}); and X_m, X_o, and X_w are the volume fraction of soil mineral, organic matter, and moisture content respectively.

Table (1):Volumetric heat capacity of soil constituents (Cv)

Constituents	Volumetric Heat Capacity (Cv)
Air (Ca)	1256.3 ($Jm^{-3}c^{-1}$)
Liquid water (Ci)	4187600 ($Jm^{-3}c^{-1}$)
Silt and clay (Cm	1926000 ($Jm^{-3}c^{-1}$)
Organic matter (Com)	2513000 ($Jm^{-3}c^{-1}$)
Quartz (Cq)	1926000 ($Jm^{-3}c^{-1}$)
Gravel (Cg)	1926000 ($Jm^{-3}c^{-1}$)

The thermal conductivity (λ)($Jm^{-1}s^{-1}c^{-1}$)

The thermal conductivity of soil (**De Vries 1963**) is calculated as the weighted average of the conductivities of various soil components:

$$\lambda = \frac{\sum_{i=1}^{n} k_i \lambda_i x_i}{\sum_{i=1}^{n} k_i x_i} \qquad \left(Jm^{-1}s^{-1}c^{-1}\right)$$

where n – number of components, λ_i is the thermal conductivity of each components, and x_i is the volume fraction of each components, and K_i is the ratio of the average temperature gradient, which the previous equation is detailed as follow;

$$\lambda = \frac{K_W \theta \lambda_W + K_a X_a \lambda_{av} + K_q X_q \lambda_q + K_m X_m \lambda_m + K_o X_o \lambda_o + K_g X_g \lambda_g}{K_w \theta + K_a X_a + K_q X_q + K_m X_m + K_o X_o + K_g X_g}$$

Volumes of k_i are calculated for air or water from

$$K_i = (\frac{2}{3})\left[1 + (\frac{\lambda_i}{\lambda_o} - 1) g_i\right]^{-1} + (\frac{1}{3})\left[1 + (\frac{\lambda_i}{\lambda_o} - 1)(1 - 2g_i)\right]^{-1}$$

$$g_i = 0.035 + \left(\frac{0.298}{\varepsilon}\right)\theta \qquad \theta \supset \theta_{wp} \quad \text{(A)}$$

$$g_i = 0.013 + \left(\frac{0.022}{\theta_{wp}} + \frac{0.298}{\varepsilon}\right)\theta \quad \theta \subset \theta_{wp} \quad \text{(B)}$$

Where g_i represents the shape factors for i^{-th} components granules considered as ellipsoids, ε is soil porosity and θ_{wp} is volumetric water content at wilting point.

Table (2): Thermal conductivity λ , ratio of the average temperature gradient through soil granules (Ki) and shape factor of the constituents (except air)

Constituents	**λ (Jm^{-1}s^{-1}c^{-1})**	**Ki**	**g_i**
Air (λav)	0.02513+ λ v	1	Calculate
Water (λw)	0.5737	1	. . . .
Silt+clay (λm)	2.931	0.5223	0.125
Organic matter (λom)	0.2513	1.2608	0.5
Quartz (λq)	8.794	0.2674	0.125
Gravel (λg)	6.3389	0.50395	0.144

Table (3) Atmospheric information

Parameter	**Description**	**Values**
Po	Atmospheric pressure at sea level	101325 Pa
Tlr	Temperature lapse rate	0.0065 Km^{-1}
To	Temperature at sea level	288.15 K
.g	Acceleration due to gravity	9.80665ms^{-2}
M	Molar mass of dry air	0.0289644 kg mol^{-1}
R	Gas constant of water vapor	8.3144 J mol^{-1}K^{-1}
Mw	Molecular weight of water vapor	0.018016 kg mol^{-1}
Z	Elevation for Ismailia	10.2 m

Table (2) showed thermal conductivity of every constituents except for air-filled pores is composed of a part due to normal heat conduction λ_a, and a part due to vapor movement λ_v, it should be calculated the conductivity of water vapor which can be given as described by **De Vries 1963**, and table (3) showed some atmospheric information.

$$\lambda av = \lambda a + \lambda v$$

$$\lambda_v = hLD_{atm}V\beta$$

Where h is the relative humidity of the air filled pores, L is the latent heat of vaporization of water, D_{atm} is the molecular diffusion coefficient of water vapor into air, V is the mass flow factor and β is the derivative of the saturated vapor density with respect to temperature, **(Khalifa, 1992)**.

$$h = \exp\left(\frac{\psi g M_w}{R(T_s + 273.16)}\right)$$

$$L = 3.149(10)^6 - 2.37(10)^3(T_s + 273.16)$$

$$D_{atm} = 2.29 \times 10^{-5}\left(\frac{T_s + 273.16}{273.16}\right)^{1.75}$$

$$P_{sat} = 10^3 \exp\left(6.0035 - \frac{4975.9}{T_s + 273.16}\right)$$

$$P = Po \times \left(1 - \frac{Tlr \times Z}{To}\right)^{\frac{g \times M}{R \times Tlr}}$$

$$V = \frac{P}{\left(P - \left(\frac{hP_{sat}R(T_s + 273.16)}{M_w}\right)\right)}$$

$$\beta = P_{sat}\left(\frac{4975.9}{(T_s + 273.16)^2}\right)$$

Where g, M,R, Tlr, Z and To are shown in table (4), Mw is molecular weight of water vapor (=0.018016 kg mol^{-1}), Psat is saturated vapor density (kg m^{-3}) and P is atmospheric pressure (Pa)

$$\Psi = -\exp\begin{pmatrix} 61.66 - 1832.126 \times \theta + 22524.45 \times \theta^2 - 140527.6 \times \theta^3 \\ + 466504.8 \times \theta^4 - 784028 \times \theta^5 + 522315 \times \theta^6 \end{pmatrix}$$

Thermal diffusivity (α) (m^2s^{-1}):

$$\alpha = \frac{\lambda}{C_v}$$

C_v **= Volumetric heat capacity** $\left(Jm^{-3}c^{-1}\right)$

λ **= Thermal conductivity** $\left(Jm^{-1}s^{-1}c^{-1}\right)$

α **= Thermal diffusivity** $\left(m^2 s^{-1}\right)$

MATERIALS AND METHODS

Fifty one registers (one every week) of soil temperatures in 51 weeks through twelve months from January to December were recorded for every depth. They were recorded for three soil depths (0.05, 0.15, and 0.30m) in a sandy soil that covered with alfalfa plants in Ismailia Agriculture Research Station of Ismailia governorate. Quarter-hour mean temperatures were recorded at data logger with type-T thermocouple probes for the three soil depths. The total registers recorded were (51 observations x 3 depths) 153 observations. One hundred and fifty three soil samples were collected from the same locations of the three depths in the same 51 weeks to determine the soil moisture content. Soil heat properties as ***volumetric heat capacity (VHC or CV)*** (Volumetric heat capacity of the constituents (Cv) Table 1), ***thermal conductivity (Thc or*** λ***)*** (thermal conductivity (λ), ratio of the average temperature gradient through soil granules (Ki) and shape factor of the constituents (except air) Table 2**),** (atmospheric information

Table 3) ***and thermal diffusivity (α)*** were estimated according to **Khalifa (1992)**, **Arshad and Azooz (1996)**, **Don scott (2000), De Vries (1963)** and **Kimball et al (1976)**. Soil properties of the initial soil surface samples (0-30cm) (Table 4) and soil moisture contents for all collected soil samples were determined after **Piper (1950)**, **Page *et al*, (1982)** and **Klute (1986)**.

Table (4): Some soil properties of the studied soil

Soil properties		Volumetric fraction		Soil properties	
C.sand (%)	63.80	Sand	0.55483	BD (gm^{-3})	1.69
F.sand (%)	23.20	Silt+clay	0.08291	Porosity (%)	39.52
Silt (%)	5.50	OM	0.00676	FC (%)	7.90
Clay (%)	7.50			WP (%)	1.42
O.M (%)	0.52			AW (%)	6.48
$CaCO_3$ (%)	2.55			EC (dSm^{-1})	0.25

RESULTS AND DISCUSSION

1.Volumetric heat capacity:

Effect of volumetric soil moisture content on volumetric heat capacity:

The results revealed that volumetric heat capacity and volumetric moisture content for soil depths of 0-0.05, 0.05-0.15 and 0.15-0.30m through twelve months were more closely related to each other, and take the similar trend.

Data listed in Table (5) revealed the values of ranked ascending soil moisture percent and their effect on volumetric heat capacity, They represented the average matched of every 6 to 8 times moisture content verses the average of volumetric heat capacity for every depth. The values of volumetric heat capacity increased with increasing moisture content. These can be explained that the components of any soil type either of clay, silt, sand or more or less for little of organic matter are constant, but moisture content are changed whatever with period and type of irrigation, percolation, evapotranspiration, cultivated crop, stage of growth or climatic conditions.

Table (5): Volumetric heat capacity ($MJm^{-3}c^{-1}$) versus ranked ascending the soil moisture percent (%)

0-0.05m		0.05-0.15m		0.15-0.30m	
Soil moist.%	CV ($MJm^{-3}c^{-1}$)	Soil moist. %	CV ($MJm^{-3}c^{-1}$)	Soil moist. %	CV ($MJ/m^{-3}c^{-1}$)
1	1.4870	1	1.5205	1	1.5160
2	1.5376	2	1.4985	2	1.4902
3	1.4979	3	1.4899	3	1.5010
4	1.5300	4	1.5228	4	1.5281
5	1.5954	5	1.5990	5	1.5924
6	1.6609	6	1.6702	6	1.6634
7	1.7250			7	1.7579
8	1.7978				

The values in table (6) showed minimum, maximum and average of soil volumetric heat capacity and soil volumetric moisture content. Whereas, volumetric heat capacity ranged from 1.345479 to 1.803934, 1.286049 to 1.678707 and 1.281804 to 1.757947MJm^{-3}c^{-1} for the three successive soil depths respectively.

Table (6). Effect of volumetric soil moisture (m^{3}m^{-3}) on volumetric heat capacity (MJm^{-3}c^{-1}) at the three depths.

Parame -ter	**0-0.05m**		**0.05-0.15m**		**0.15-0.30m**	
	Soil moist.	**CV**	**Soil moist.**	**CV**	**Soil moist.**	**CV**
	m^{3}m^{-3}	**MJm^{-3}c^{-1}**	**m^{3}m^{-3}**	**MJm^{-3}c^{-1}**	**M^{3}m^{-3}**	**MJm^{-3}c^{-1}**
Min	0.0238	1.345479	0.0096	1.286049	0.0086	1.281804
Max	0.1333	1.803934	0.1034	1.678707	0.1224	1.757947
Average	0.0768	1.567395	0.0588	1.492249	0.0523	1.464511

Fig.(1) including the curves of A, B and C concern the three depths explained the role of moisture content on the thermal conductivity and the conformity between each other. Fig. (2) revealed that the volumetric heat capacity of the nearest soil surface depth (0.05m) was higher than those of the other depths until the day of year (DOY) 167, then it behaved as the volumetric heat capacity of the other depths. This trend may be due to climatic conditions or moisture content which was higher at these periods for lowest depth and less for deepest ones. **Adjepoug (1997)** stated that the differences in the rates of increase of specific heat capacity observed for the soil can be attributed to differences in the soil water retention capacity.

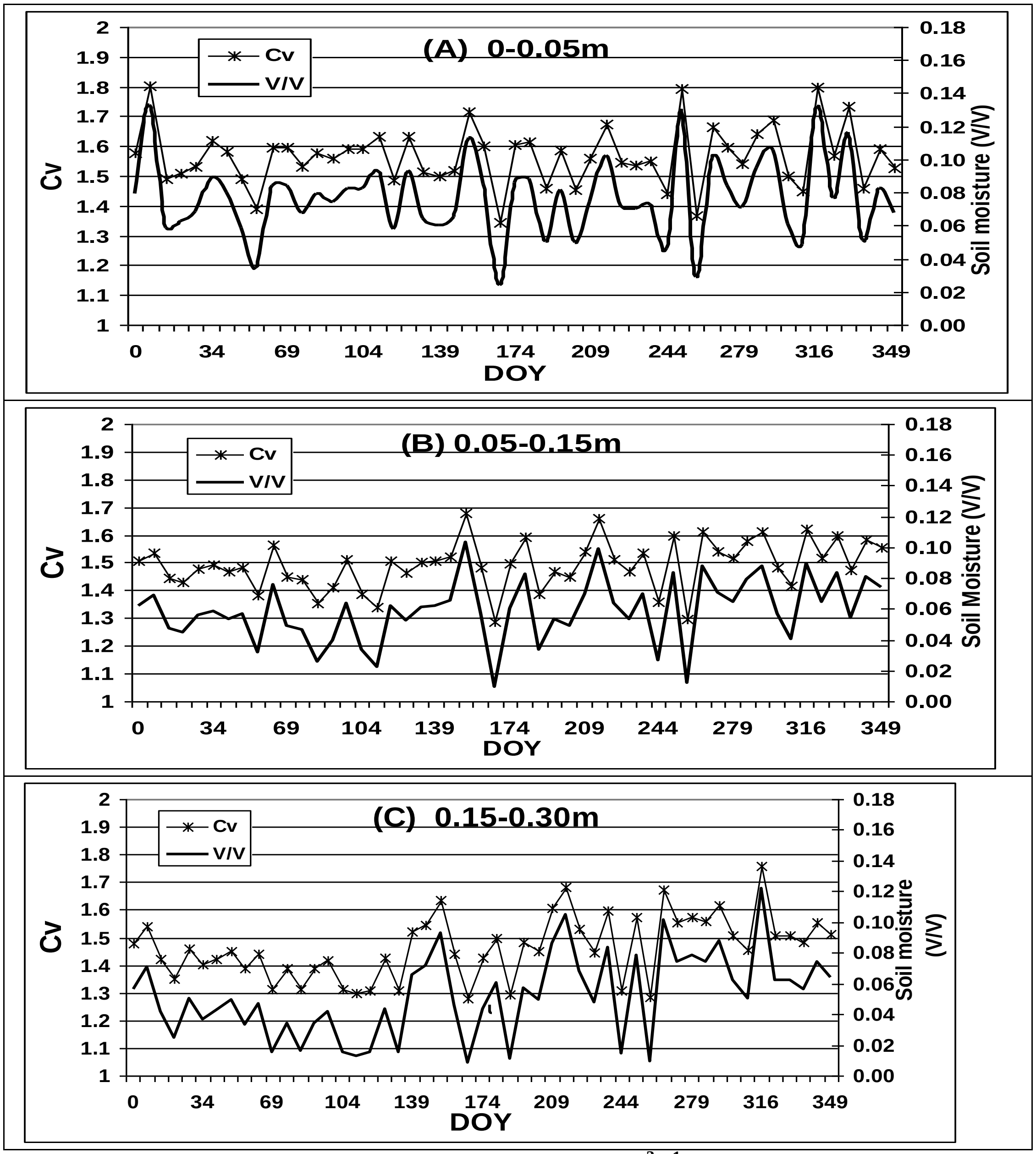

Fig.(1):Soil volumetric heat capacity (CV) ($MJm^{-3}c^{-1}$) and volumetric moisture content (v/v) (m^3m^{-3}) of the three soil depths (A,B and C), (DOY=Day of Year).

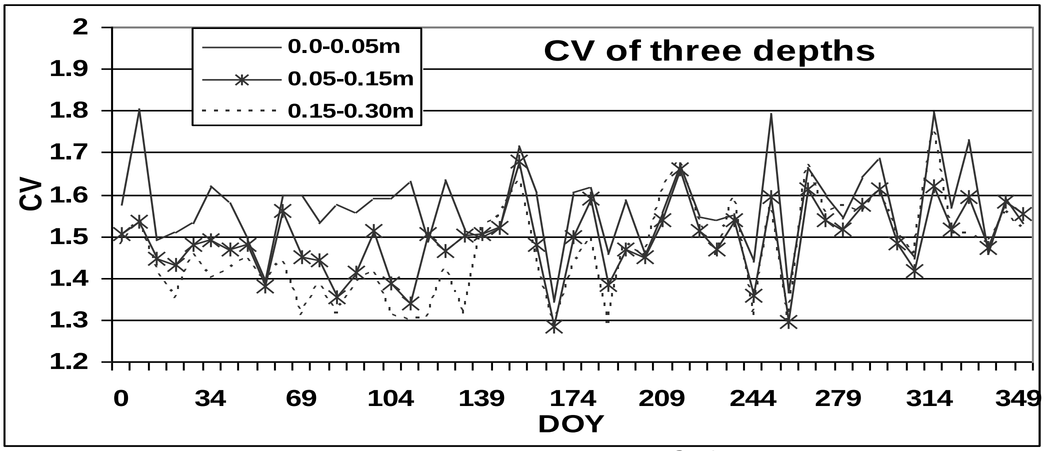

Fig. (2): Soil volumetric heat capacity ($MJm^{-3}c^{-1}$) for three depths at 51 observations, (DOY = Day Of Year).

Regression equation coefficients between soil volumetric heat capacity and volumetric soil moisture content for the three depths were highly positive significant, as well as correlation coefficients were also highly positive significant, (Table 7), which confirmed the abovemention behaved.

Table (7): Regression equation and correlation coefficient of volumetric heat capacity ($MJm^{-3}c^{-1}$) with soil volumetric moisture content (m^3m^{-3}).

Regression equations			Correlation (r) V/V	N
Y	**a + b_1x_1**	**R-Sq**		
Cv 0.05m)	**1.24+ 4.28 V/V**	**97.8****	**0.989****	**51**
Cv(0.15m)	**1.24+ 4.26 V/V**	**93.8****	**0.968****	**51**
Cv(0.30m)	**1.23 + 4.36 V/V**	**94.6****	**0.973****	**51**

2.<u>Thermal conductivity:</u>

Thermal conductivity is an intrinsic property of the soil (or any other substance) that is related to its ability to conduct heat. It may be called “heat flux” or “heat transfer” in that it is related to the movement of heat energy through the soil. The heat moves from an area of high temperature to a cooler area as the heat redistributes itself to reach equilibrium where the heat is evenly distributed through the substance. The increase in the thermal conductivity for added unit of water was different with different temperature, and the rate of increasing was the highest at low water content. This increase is due to the formation of wedges at the points where particles make contact. **O'Donnell *et al.* (2009)** indicate that a strong positive and linear relationship between the thermal conductivity and volumetric water content of soil.

Table (8, 9 and 10) showed the values of soil moisture content determined versus to the moment of soil temperature through depths of 0-0.05, 0.05-0.15 and 0.15-0.30m. Also, they showed the shape factor

(g_i) which was used in the estimation when the moisture contents were more than wilting point (A), and when the moisture contents were less than wilting point (B).

Table (8): Soil moisture content (%) verses the soil temperature (°C) and shape factor (g_i) for the depth of 0-0.05m (DOY=Day Of Year).

DOY	0-0.05m			DOY	0-0.05m			DOY	0-0.05m		
	T (°C)	Soil moist.%	g_i		T (°C)	Soil moist. %	g_i		T (°C)	Soil moist. %	g_i
0	12.62	4.67	A	118	17.90	3.41	A	237	24.72	4.32	A
6	13.30	7.89	A	125	19.06	5.50	A	244	25.25	2.74	A
13	12.05	3.46	A	132	26.24	3.80	A	251	24.74	7.72	A
20	11.55	3.72	A	139	24.49	3.58	A	258	24.55	1.70	A
27	11.67	4.06	A	146	25.57	3.86	A	265	25.07	5.94	A
34	10.46	5.27	A	153	24.61	6.67	A	272	21.26	4.98	A
41	10.53	4.74	A	160	30.30	5.02	A	279	22.63	4.18	A
48	11.58	3.49	A	167	27.27	1.41	B	286	22.86	5.62	A
55	10.95	2.07	A	174	25.15	5.10	A	293	19.56	6.24	A
62	13.34	4.96	A	181	28.98	5.23	A	300	20.42	3.62	A
69	12.08	4.96	A	188	27.57	3.00	A	307	18.58	2.87	A
76	13.27	4.02	A	195	27.44	4.85	A	314	17.06	7.80	A
83	13.08	4.67	A	202	26.49	2.93	A	321	16.06	4.54	A
90	21.95	4.42	A	209	27.22	4.42	A	328	16.55	6.88	A
97	20.54	4.88	A	216	26.37	6.04	A	335	14.47	3.31	A
104	16.44	4.88	A	223	26.25	4.26	A	342	12.72	4.88	A
111	20.46	5.46	A	230	25.08	4.14	A	349	11.89	3.99	A

Table (9): Soil moisture content (%) verses the soil temperature (°C) and shape factor (g_i) for the depth of 0.05-0.15m (DOY=Day Of Year).

DOY	0.05-0.15m			DOY	0.05-0.15m			DOY	0.05-0.15m		
	T (°C)	Soil moist.%	g_i		T (°C)	Soil moist. %	g_i		T (°C)	Soil moist. %	g_i
0	12.32	3.68	A	118	18.08	3.68	A	237	24.65	4.13	A
6	13.27	4.09	A	125	18.43	3.12	A	244	25.15	1.59	A
13	11.72	2.82	A	132	27.12	3.62	A	251	25.62	4.95	A
20	11.55	2.64	A	139	24.73	3.67	A	258	25.18	0.72	B
27	11.91	3.32	A	146	26.86	3.87	A	265	24.77	5.18	A
34	10.43	3.49	A	153	24.68	6.12	A	272	21.15	4.17	A
41	10.12	3.18	A	160	32.96	3.34	A	279	22.73	3.83	A
48	11.83	3.34	A	167	29.65	0.57	B	286	22.83	4.69	A
55	10.94	1.91	A	174	25.89	3.57	A	293	19.60	5.20	A
62	13.31	4.48	A	181	28.56	4.90	A	300	20.38	3.38	A
69	11.97	2.88	A	188	27.52	1.98	A	307	18.33	2.42	A
76	12.77	2.77	A	195	28.07	3.17	A	314	16.91	5.31	A
83	13.28	1.53	A	202	26.75	2.89	A	321	15.92	3.82	A
90	21.94	2.36	A	209	27.15	4.14	A	328	16.29	4.95	A
97	19.73	3.79	A	216	26.10	5.88	A	335	14.23	3.28	A
104	16.50	2.01	A	223	26.90	3.76	A	342	12.47	4.77	A
111	20.58	1.32	B	230	25.35	3.14	A	349	11.62	4.37	A

Table(10):Soil moisture content (%) verses the soil temperature(°C) and shape factor(g_i) for the depth of 0.15-0.30m (DOY=Day Of Year).

DOY	0.15-0.30m			DOY	0.15-0.30m			DOY	0.15-0.30m		
	T (°C)	Soil moist.%	g_i		T (°C)	Soil moist.%			T (°C)	Soil moist.%	g_i
0	12.09	3.32	A	118	17.85	0.89	B	237	25.87	4.94	A
6	13.40	4.17	A	125	18.84	2.55	A	244	26.25	0.85	B
13	13.25	2.46	A	132	23.19	0.90	B	251	26.00	4.64	A
20	12.18	1.47	A	139	22.87	3.90	A	258	25.75	0.56	B
27	12.42	3.00	A	146	23.74	4.23	A	265	25.46	6.02	A
34	11.72	2.19	A	153	22.47	5.50	A	272	22.64	4.37	A
41	10.40	2.50	A	160	26.15	2.75	A	279	23.30	4.62	A
48	13.30	2.92	A	167	25.39	0.51	B	286	23.40	4.40	A
55	12.01	1.99	A	174	25.64	2.56	A	293	21.13	5.21	A
62	13.85	2.79	A	181	27.16	3.56	A	300	21.37	3.69	A
69	13.01	0.92	B	188	27.58	0.66	B	307	20.19	2.98	A
76	13.74	2.02	A	195	27.40	3.38	A	314	18.59	7.24	A
83	14.20	0.97	B	202	27.22	2.91	A	321	17.71	3.68	A
90	18.66	2.02	A	209	27.54	5.09	A	328	17.02	3.70	A
97	16.26	2.45	A	216	26.95	6.19	A	335	15.42	3.34	A
104	17.33	0.92	B	223	27.58	4.02	A	342	14.26	4.39	A
111	19.24	0.75	B	230	26.22	2.85	A	349	13.65	3.78	A

Soil moisture content increased thermal conductivity, and the estimated values showed that thermal conductivity ranged from 1.2603 to 2.2489, 1.23222 to 2.15026 and 1.03913 to 2.18332$Jm^{-1}s^{-1}c^{-1}$, at moisture content ranged from 0.024 to 0.133, 0.010 to 0.103 and 0.009 to 0.122m^3m^{-3}, for the three successive soil depths, respectively (Table 11). **Penner *et al*, (1975)** reported that moisture content, by far, has the greatest impact upon soil thermal conductivity. As moisture is added to a soil, a thin water film develops which bridges the gaps between the soil particles. This bridging increases the effective contact area between the soil particles, which increases the heat flow and results in higher thermal conductivity. As the voids between the soil particles become completely filled with moisture, the soil thermal conductivity no longer increases with increasing moisture content.

Otherwise, soil temperature showed a relatively little effect on thermal conductivity, while the same above range of thermal conductivity had happened at wide range of soil temperature which they were from 10 to 30ºC for the above three depths for all studied days of year (DOY).

Table (12) showed regression equations with highly positive significant coefficients (P**) (n=51) between thermal conductivity ($Jm^{-1}s^{-1}c^{-1}$) with soil volumetric moisture content (m^3m^{-3}) and soil temperature (C). They confirmed the relation between thermal conductivity with temperature and volumetrically moisture content. Also, correlation coefficients were highly positive significant.

Whereas, correlation coefficients of thermal conductivity for the three depths with volumetric moisture content were higher than those with soil temperature which confirmed the important role of moisture that superior the temperature.

Table (11). Effect of volumetric soil moisture content (m^3m^{-3}) on soil thermal conductivity ($Jm^{-1}s^{-1}c^{-1}$) at the three depths.

Parameter	0-0.05m		0.05-0.15m		0.15-0.30m	
	Soil moist.	λ	Soil moist.	λ	Soil moist	λ
	m^3m^{-3}	$Jm^{-1}s^{-1}c^{-1}$	M^3m^{-3}	$Jm^{-1}s^{-1}c^{-1}$	m^3m^{-3}	$Jm^{-1}s^{-1}c^{-1}$
Min.	0.024	1.2603	0.010	1.23222	0.009	1.03913
Max.	0.133	2.2489	0.103	2.15026	0.122	2.18332
Average	0.077	1.8950	0.058	1.74040	0.051	1.69650

Table (12): Regression equations and correlation coefficient of thermal conductivity ($Jm^{-1}s^{-1}c^{-1}$) with soil volumetric moisture content (m^3m^{-3}) and soil temperature (°C)

Regression equations		Correlation (r)		N
$Y = a + b_1x_1 + b_2x_2$	R-Sq	T(°C)	V/V	
Thc (0.05m) = 1.08 + 0.00965 T + 8.28 V/V	73.8%**	0.197ns	0.823**	51
Thc (0.15m) = 0.892 + 0.0144 T + 9.63V/V	70.5%**	0.367**	0.77**	51
Thc (0.30m) = 0.914 + 0.0214 T + 6.88V/V	57.8%**	0.516**	0.668**	51

The previous results were depicted in Fig (3) which showed that soil thermal conductivity was affected by soil temperature as well as the soil moisture (m^3m^{-3}). The figures explain that soil temperature had little symmetrical effect on soil thermal conductivity, while soil moisture content had manifested harmony effect on soil thermal conductivity at the three depths. The same trend was observed from Fig (4) through twelve months from January to December.

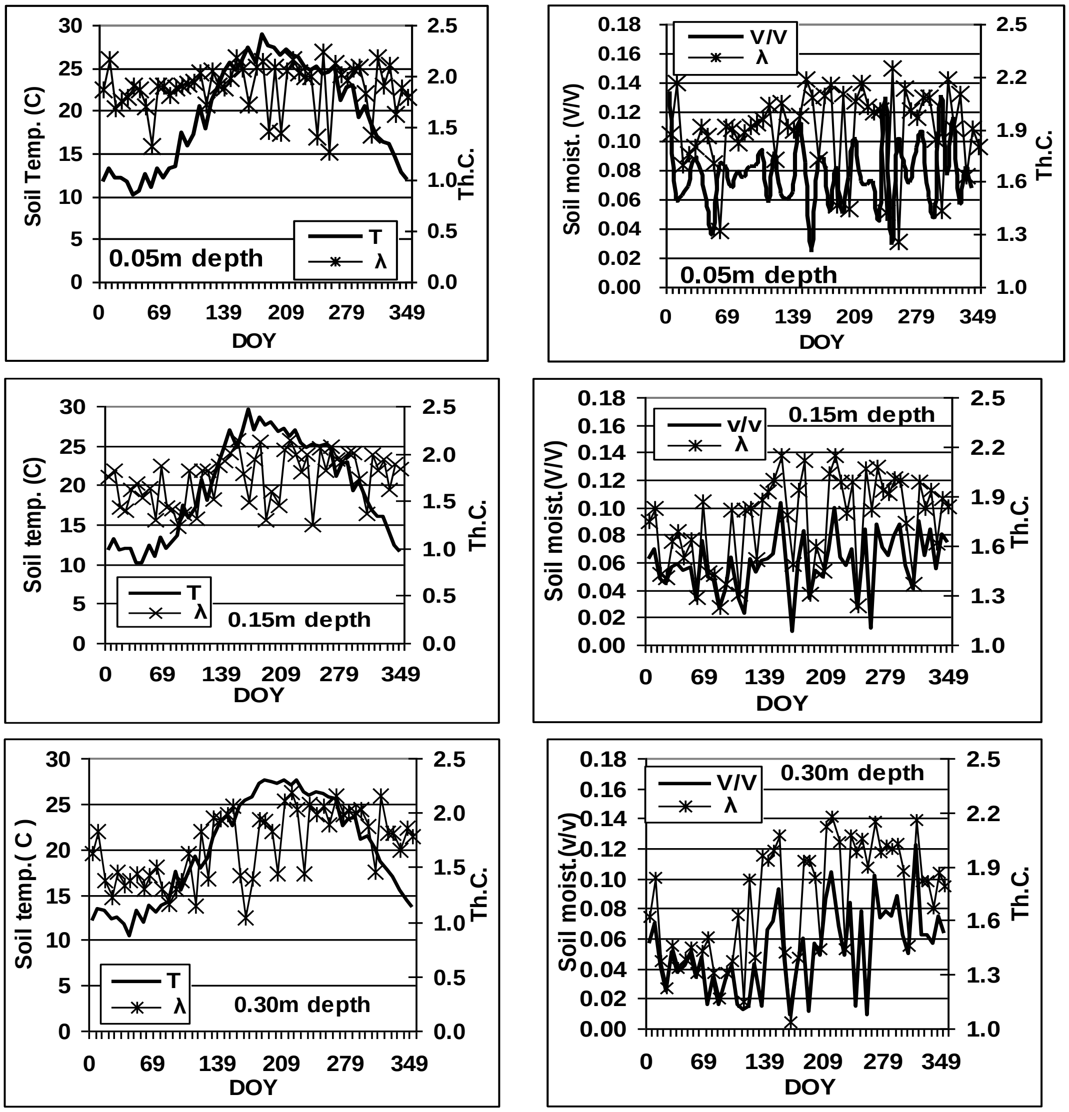

Fig. (3): Thermal conductivity (Th.C.) affected by soil temperature (°C) and soil moisture content (m^3/m^3) through 51 observations at three depths (DOY=Day Of Year).

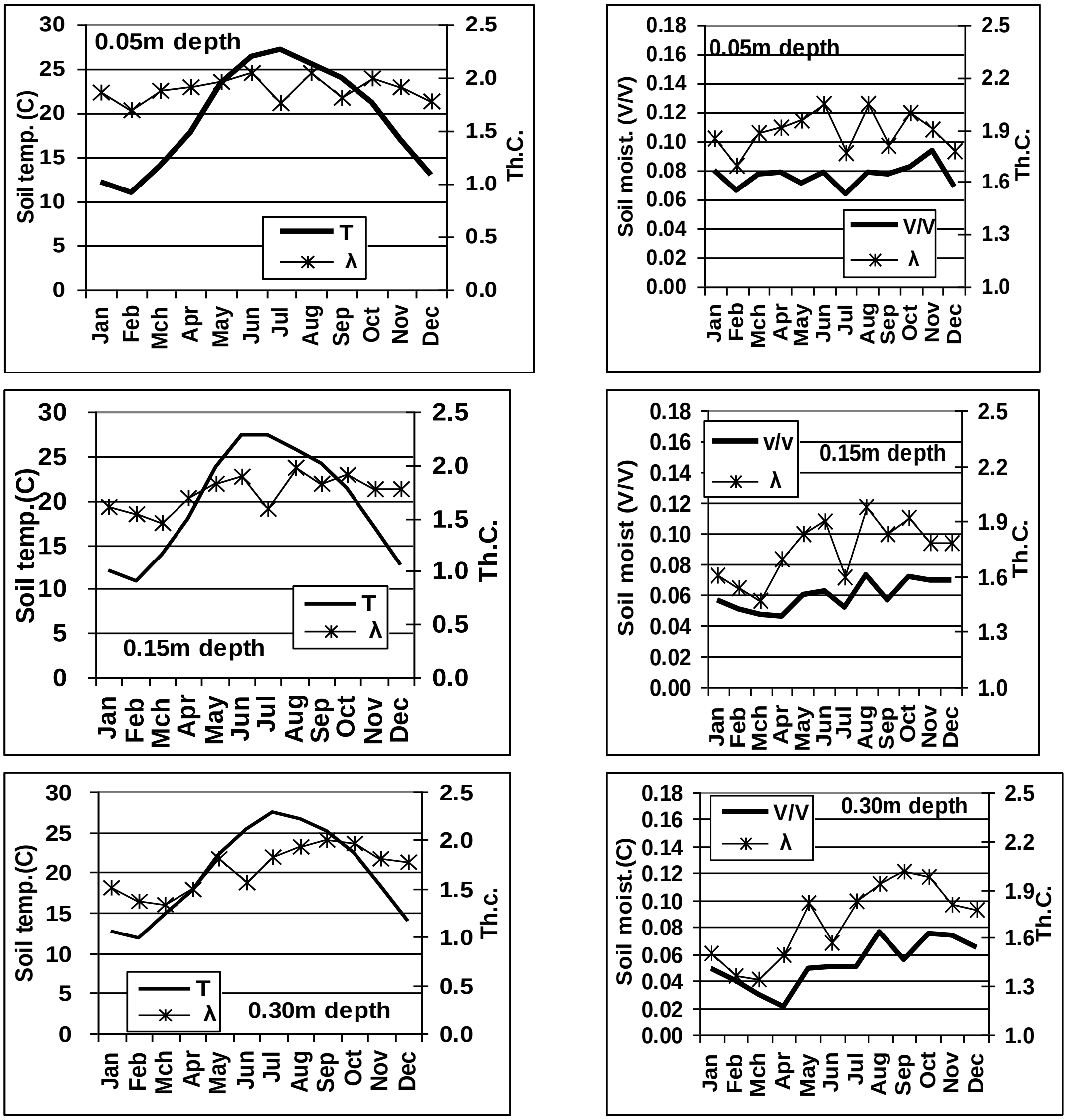

Fig. (4): Thermal conductivity (Th.C.) ($Jm^{-1}s^{-1}c^{-1}$) (affected by soil temperature °C) and soil moisture content (m^3/m^3) through Twelve months from January to December at three depths (DOY=Day Of Year).

Fig.(5) shows the soil thermal conductivity for the three depths at 51 observations. The soil thermal conductivity at depth of 0.05m was higher than at the other depths, until the day of year (DOY) of 167, after that it behaves similar for the other ones. That may be due to the effect of more volumetric moisture content on the thermal conductivity of the first five months of year than the other months.

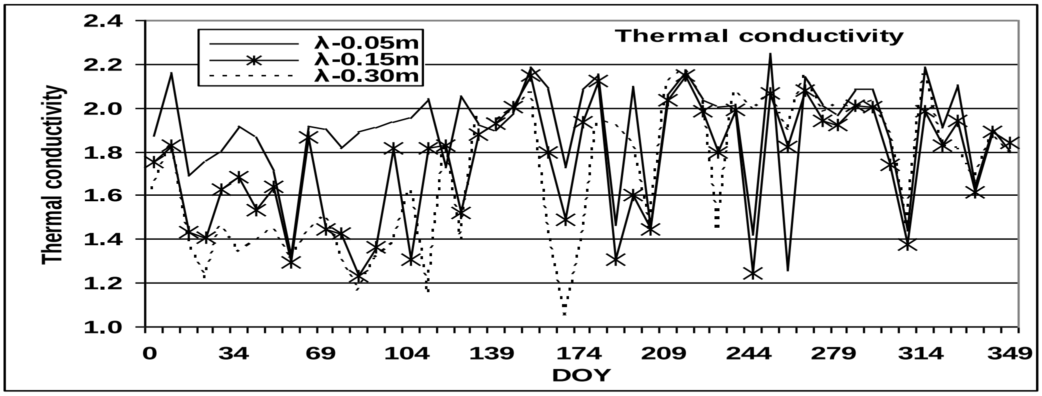

Fig. (5): thermal conductivity for three depths at 51 observations (DOY = Day of Year).

3-<u>Thermal diffusivity(α) (m^2s^{-1}):</u>

Soil thermal diffusivity affected by soil temperature and soil volumetric moisture content similar as volumetric heat capacity and thermal conductivity. They ranged from 9.22592E-07 to 13.3223E-07, from 9.10083E-07 to 14.0327E-07 and from 8.1068E-07 to 15.1938E-07 m^2s^{-1} at the three mentioned depths, respectively (table 13). Soil heat capacity and soil thermal diffusivity increase with increasing soil moisture content **(Guan et al, 2009)**.

Table (13): Minimum, average and maximum values of thermal diffusivity (m^2s^{-1}) and (m^2day^{-1})

Depth (m)		Minimum	Average	Maximum
0-0.05	M^2s^{-1}	9.22592E-07	12.0576E-07	13.3223E-07
	M^2day^{-1}	0.0797	0.1042	0.1151
0.05-0.15	M^2s^{-1}	9.10083E-07	11.6222E-07	14.0327E-07
	M^2day^{-1}	0.0786	0.1004	0.1212
0.15-0.30	M^2s^{-1}	8.1068E-07	11.5473E-07	15.1938E-07
	M^2day^{-1}	0.0700	0.0998	0.133

Fig. (6) shows soil thermal diffusivity at the three depths verses 51 observation. The thermal diffusivity at soil depth of 0-0.05m was higher than other depths until the day of year (DOY) of 167, after that it behaves similar to the other, while at soil depth of 0.15-0.3m it showed scatter differences values than others, started from the above DOY .

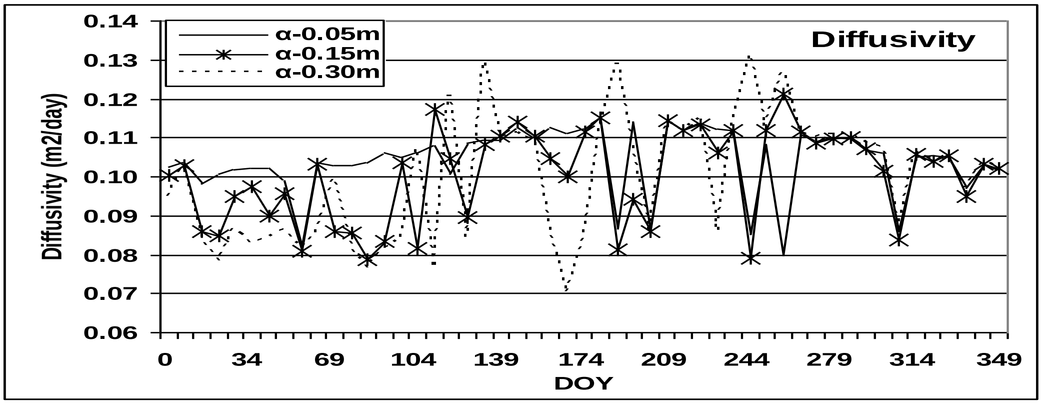

Fig. (6): Soil thermal diffusivity (m^2day^{-1}) for three depths at 51 observation for three soil depths (DOY = Day Of Year).

CONCLUSION

Soil volumetric heat capacity and thermal conductivity considerations are characterized for sandy soil under sprinkler irrigation and specific Ismaili climatologically parameters which undertaken at Ismailia Agricultural Research Station. Volumetric heat capacity of 1.3 to 1.8MJm^{-3}c^{-1} is characterized for sandy soil at moisture content of 0.51 to 7.89% for the same location. A soil temperature increased from 10 to 30ºC at 0-0.30m depth. There are increasing the thermal conductivity values nearly from 1.04 to 2.25Jm^{-1}s^{-1}c^{-1} at the above water content, which temperature decreased with depth followed by thermal conductivity. Volumetric heat capacity and thermal conductivity calculated in sandy soil under similar temperature and water content can manage for suitable plant may cultivated in similar area.

ACKNOWLEDGMENT

The author wish to express his thanks to Prof. Dr. Samia M.S. El-Marsafawy for providing facilities and sincere help during this study.

REFERENCES

Abu-hamdeh, Nidal H. and Reeder, Randall C. (2000). Soil Thermal Conductivity: Effects of Density, Moisture, Salt Concentration, and Organic Matter. Soil Sci. Soc. Ame. J. V.64: (4): 1285-1290

Abd El-Dayem, A.O.A. (1999), The effect of soil temperature and soil moisture on the soil water movement. Ph.D. Sci. Degree of Agric, Fac. Of Agric. Moshtohor, Zagazig University.

Adjepong, S.K. (1997), Investigation of the variation of the specific heat capacity of three texture types of soil with moisture content. J. App. Sci. and Technology, (Ghana), 2 (1-2):7-12

Arshad, M.A. and Azooz, R.H. (1996), Tillage effects on soil thermal properties in a semiarid cold region. Soil Sci. Soc. Amer. J. 6: (2): 561-567.

Awadalla, S.Y. (1977), Studies on Egyptian calcareous soil "Thermal properties". Ph.D. Thesis . Fac. Agric. Cairo Univ. Egypt.

Bora, E.; Gupta, S.C. and Kosspwsli. J. (1990), Soil temperature predictions from numerical heat flow model using variable constant thermal diffusivity. Soils and Tillage Research, 1: 27-36.

De Vries, D.A. (1963), Thermal properties of soils, in "Physics of Plant Environment", W,R.Van Wijk (Ed.), North Holland, Amsterdam, 382pp.

Don Scott, H. (2000), Soil physics Agricultural and Environmental Applications.(ed.) Iowa State University press/Ames. USA.

Fritschen, I.J. and Gay, L.W. (1979), Environmental instrumentation. Springer-Verlag, NY. Inc. 216pp.

Guan S.; Huang J.; Guo Ni; Jianrong Bi. And Wang G. (2009), Variability of soil moisture and its relationship with surface albedo and soil thermal parameters over the loess plateau. Advances in Atmospheric Sciences, 26 (2):

Kersten, M.S. (1949), Thermal Properties of Soils. Bulletin 28, Engineering Experiment Station University of Minnesota Minneqpolis, MN.

Khalifa, H. El-H. M. (1992), Modeling coupled heat and moisture flow within a bare desert soil. Ph.D. Thesis, Dept. of Soil and Water Sci., Univ. of Arizona, USA.

Kimball, B.A.; Jackson, R.D.; Nakayama, F.S.; Idso, S.B. and Reginato, R.J. (1976), Soil heat flux determination: Temperature gradient method with computed thermal conductivities. J. Soil Sci. Soc. Am., 40: 25-28.

Klute A. (1986), Methods of Soil Analysis. Part1, Physical and Mineralogical Methods, Second edition No. 9 (part1) in the Series of Agronomy.

O'Donnell, J.A.; Romanovsky V.E.; Harden, J.W. and McGuire, A.D. (2009), The effect of moisture content on the thermal conductivity of mass and organic soil horizons from black spruce ecosystems in interior Alaksa. Soil Science, 174 (12): 646-651.

Page, A.L.; Miller, R.H. and Keeney, D.R. (1982), Methods of Soil Analysis Part II. Chemical and Microbiological Properties 2^{nd} ed. Agorn. Madison, Wisconsin. U.S.A.

Penner, E.; Johnston, G.H. and Goodrich, L.E. (1975), Thermal conductivity laboratory studies of some Mackenzie highway soil. Canadian Geotechnical Journal, :12: (3): 271-288.

Piper, C.S. (1950), Soil and Plant Analysis. Inter, Sci. Publ., Inc. N.Y. USA

Romanovsky V.E. and Osterjano T.E. (2000). Effect of unfrozen water on heat and mass transport processes in the active layer and permafrost. Permafr. Periglac. Process, 11: 219-239.

Sepaskhah, A.R. and Boersma, L. (1979), Thermal conductivity of soils as a function of temperature and water content. Soil Sci. Soc. Amer. J. 43 (3): 439-444

تأثير حرارة التربة والمحتوى الرطوبى على الخصائص الحراريه للأراضى الرملية بالأسماعيلية تحت غطاء من البرسيم الحجازى

صادق على احمد الريس، أمال عبد التواب، وليد الفرغلى، صلاح الدين محمد السيسى
معهد بحوث الاراضى والمياة والبيئة – مركز البحوث الزراعية – جيزة

تم تسجيل ٥١ قراءة حرارة التربة خلال ٥١ اسبوع لكل عمق وتم ذلك خلال ثلاثة أعماق هى ٠.٠٥، ٠.١٥ و ٠.٣٠ متر من سطح ارض رملية منزرعة بالبرسيم الحجازى فى محطة البحوث الزراعية بالأسماعيلية بمحافظة الأسماعيلية. وأن مجموع قراءات الحرارة المسجلة هى ٥١ قراءة x٣ أعماق = ١٥٣ قراءة . ايضا تم اخذ ١٥٣ عينة تربة من نفس مكان قراءات الحرارة وخلال نفس ٥١ اسبوع وخلال الأعماق الثلاثة وذلك لتقدير الرطوبة الأرضية. تم حساب السعة الحرارية الحجمية ، التوصيل الحرارى للتربة وكذلك الأنتشار الحرارى بالمعادلات المستخدمة فى ذلك وتحت هذه الظروف. وكانت النتائج كمايلى

تأثرت السعة الحرارية الحجمية بالمحتوى الرطوبى للتربة سواء فى الأعماق القريبة من السطح أو الأكثر عمق وتراوحت القيم للأعماق الثلاثة بين ١.٣٤٥٤٧٩ إلى ١.٨٠٣٩٣٤، بين ١.٢٨٦٠٤٩ إلى ١.٦٧٨٧٠٧ و بين ١.٢٨١٨٠٤ إلى ١.٧٥٧٩٤٧ ميجا جول/متر مكعب/درجة حرارة على الترتيب.

أدى زيادة المحتوى الرطوبى فى التربة الى زيادة التوصيل الحرارى، وان ذلك تراوح بين ١.٢٦٠٣ إلى ٢.٢٤٨٩، ١.٢٣٢٢٢ إلى ٢.١٥٠٢٦ و١.٠٣٩١٣ إلى ٢.١٨٣٣٢ جول/متر/ ثانية/درجة حرارة وذلك عند محتوى رطوبى تراوح بين ٠.٠٢٤ إلى ٠.١٣٣، ٠.٠١٠ إلى ٠.١٠٣ و ٠.٠٠٩ إلى ٠.١٢٢ متر مكعب/متر مكعب، للأعماق ٠.٠٥ ، ٠.١٥ و ٠.٣٠ متر على التوالى. ولكن درجة الحرارة كان لها تأثير قليل نسبياَ على التوصيل الحرارى.

لقد تأثر الأنتشار الحرارى بالتربة بحرارة التربة والمحتوى الرطوبى الحجمى بنفس تأثر الأنتقال الحرارى، وان مدى الأنتشار الحرارى قد تراوح بين ٩.٢٢٥٩٢×١٠-٧ إلى ١٣.٣٢٢٣×١٠-٧، ٩.١٠٠٨٣ X١٠-٧ إلى ١٤.٠٣٢٧×١٠-٧ و٨.١٠٦٨ ×١٠-٧ إلى ١٥.١٩٣٨×١٠-٧ عند الأعماق الثلاثة المذكورة سابقا على التوالى.

وعلى ذلك فلقد أثبتت النتائج ان السعة الحرارية الحجمية والتوصيل الحرارى والأنتشار الحرارى يتأثرون بكل من المحتوى الرطوبى الحجمى وحرارة التربة وأن محتوى الرطوبة الحجمية تلعب دورا هاما فى التوصيل الحرارى وانتشارها خلال قطاع التربة.