EFFECT OF OLIVE MILLS WASTEWATER (OMW) ON SOIL THERMAL CONDUCTIVITY

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ABSTRACT

The effect of olive mills Wastewater on soil thermal conductivity of three soils has been investigated under laboratory condition. The soils used were classified as sandy clay, silty clay and clay. The study used the single probe method to determine soil thermal conductivity. Both heating and cooling methods were used to evaluate soil thermal conductivity. Olive mills wastewater (OMW) contains organic matter and, therefore, can be highly beneficial to agricultural soils. However, olive mills wastewater contains oil that may affect soil thermal conductivity, water retention and infiltration rate. Results of this work show that thermal conductivity varies with OMW concentration and soil texture at given moisture content and bulk density. Application of OMW resulted in a decrease in soil thermal conductivity for all soil tested. The thermal conductivity values where higher for sandy clay than silty clay and clayey soil at all OMW concentrations. The decrease in soil thermal conductivity has been observed at all levels of OMW concentration and was significantly different at 60% or higher. Thermal conductivity ranged from 0.89 to 0.71 W/m K for sandy clay soil, from 0.77 to 0.63, and from 0.80 to 0.57 W/m K for clay soil as OMW concentration increased from 20% to 100% at water contents of 0.20 cm^3/cm^3 and bulk density of 1.25 g/cm^3. Finally, graphical and statistical comparisons of thermal conductivity obtained by both methods, heating and cooling, for each soil type are presented. In general, the heating data yield higher thermal conductivities than those obtained from the cooling data.

Keywords: Soil, Thermal conductivity, Organic matter, OMW, Heating

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INTRODUCTION

Olive mill wastewater (OMW) is becoming a critical environmental problem in the Mediterranean region, which accounts for 95% of the world olive oil production. In Jordan, there are over 20 million olive trees planted on an area of 1000 km^2, producing about 180,000 tons of olive fruit, 35 thousand tons of olive oil and 100,000 tons of solid waste annually Ministry of agriculture yearbook 2010. Most of these evergreen trees are grown in the northern part of the kingdom, mostly under rainfed conditions. Olive trees are drought tolerance and have low initial and running cost and protect agricultural high lands from excessive erosion and make good cash revenue in return.

Olive mills process olives for the extraction of olive oil, but they produce olive kernel residue and olive mill effluent wastewater as by products. In the extraction process, two by-products are obtained along with the oil (which accounts for 20% of the total): a solid residue (30% of the total) and a black wastewater (50% of the total) called olive mill wastewater (OMW). Recently, there has been a rising concern regarding the handling and management of wastes of olive mills in Jordan. Olive mills dispose their waste in settlement bonds or nearby valleys. Due to its high organic content, mills solid waste can improve soil properties and productivities. However, no work has been done in Jordan to examine the effect of OMW on soil physical properties.

OMW is characterized by a large phenolic content (Table 1), which is considered to be harmful for plants, hence, an early plant growth inhibitor for different vegetables and source of objectionable odor when contacted with chlorinated waters (formation of chlorinated phenols). OMW has a very high organic content, generally, a BOD of 12 – 63 g/l (Cossu, Blakey and Cannas 1993) and COD of 80-200 g/l (Hayek, Mosa and Halasah 1996). These values are around 200-400 times higher than a typical municipal sewage (Tsonics and Girigeropoulos 1993).

Table 1.
Properties of OME wastewater samples collected from a local olive mill*

Property	
Temperature	25 ºC
pH	4.7
Conductivity	3,500 μ/Ω
Phenols	2.90 g/l
TDS	41.50 g/l
TSS	20.80 g/l
BOD_5	14.50 g/l
COD	35.5 g/l
Volatile Acids	2.75 g/l
Chlorides	0.86 g/l
Density (25 ºC)	0.993 g/l

* Results are shown for wastewater samples after two months of settling.

OMW has also high total solids content. The solids are combination of total suspended solids and total dissolved solids. Moreover, this wastewater is characterized by its brownish black color. The major components in the colored fraction are substances of polymeric nature, derived from several low molecular weight phenolic compounds chemically related to lignin and humid acids Saez et al 1992. The only pretreatment of OMW is the sedimentation process in open ponds to allow the settlement of solids.
OMW contains a substantial amount of oil, which might occupy the macropores and coat soil aggregates, thus, reducing the thickness of water films around soil macro aggregates and retarding the movement of water through soil pores McGill 1971. Accumulation of oil films

around soil aggregates also increase soil liquid contact angle that reduces water infiltration and water flow especially under unsaturated conditions (Letey, Osborn and Pelishek 1962).
Thermal properties affect the microclimate around the plant, and hence affect the plant itself. Germination, seedling emergence and plant growth development are all dependent on soil thermal properties. Soil structure affects plant growth through its influence on soil heat, temperature, air, water, and mechanical impedance to roots. Thermal conductivity is defined as the quantity of heat transferred through a unit area of the conducting body in unit time under a unit temperature gradient. The beneficial and adverse effects of land application of OMW need to be clarified under laboratory and field conditions. Because of the lack of information on the effects of OMW on soil thermal conductivity, the objective of this study is to quantify changes in soil thermal conductivity with application of olive mills wastewater on three different soils.

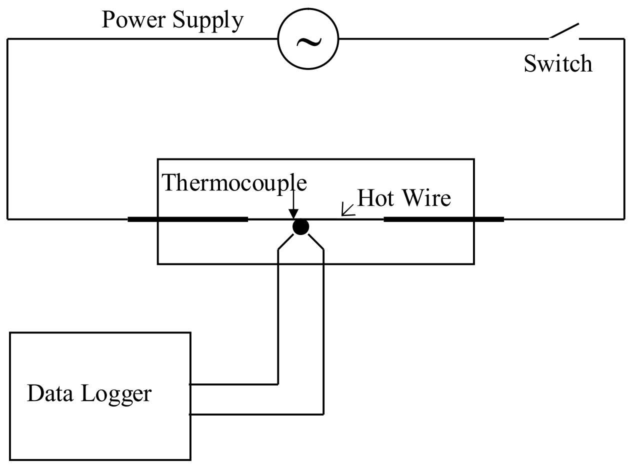
MATERIALS AND METHODS

The experiment was conducted on three types of soils: Sandy clay (55% sand, 5% silt, and 40% clay), silty clay (7% sand, 52% silt, and 41% clay), and clay (20% sand, 25% silt, and 55% clay). Several tests were run for each soil type. These tests were based on different moisture content, packing densities, and different OMW concentration. Distilled water was used in all experiments.
The hot wire method was used to measure the thermal conductivity of soil. In this method, an electrical wire is implanted in the experimental soil sample. A steady current is supplied to the electrical wire and the temperature rise and fall of the heating wire is measured by a thermocouple and recorded during a short heating and cooling interval. Thermal conductivity, K (W K/m), was calculated using the equation given by (Abu-Hamdeh, Al-Jalil, Khdair 2000) and (Abu-Hamdeh, Khdair, Reeder, 2000) :

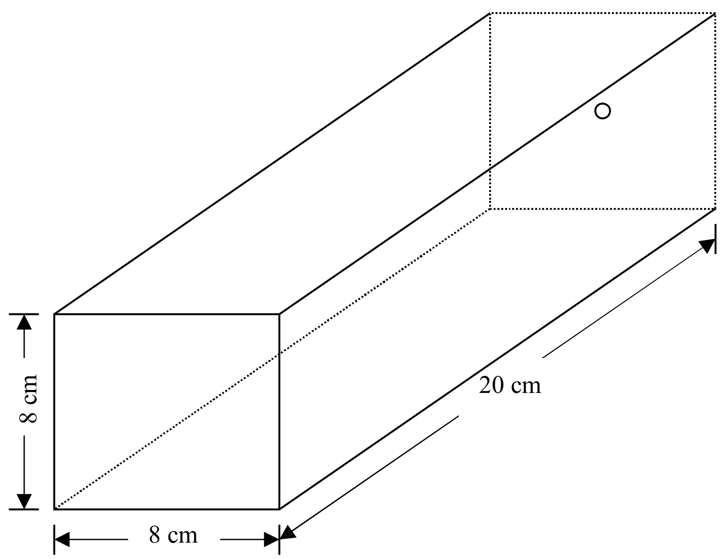
$$K = 0.0796 I^2 R / S \quad (1)$$

where I is the current in the line source (A), R the specific resistance of the wire (Ω/m), and S is the slope of the straight-line portion of the temperature rise versus ln(t) during heating and cooling process (i.e., $S = \Delta T / \Delta \ln(t)$).
The apparatus in this study to measure thermal conductivity of soils is shown in Figure 1. It consists of a rectangular box, 8x8 cm base and 20 cm long made of 0.20 cm thick galvanized steel. An electric wire ran through the center of the box lengthwise and was fastened at both

ends. The wire was connected to a 10 V DC variable power supply unit, which would heat the wire running through the box. A thermocouple was inserted from the side of the box to measure the wire temperature with time. The thermocouple was attached to a data logger, which would record soil temperature at the thermocouple terminals at a specified time intervals.



(a) Top view



(b) Rectangular steel box

Figure 1. Schematic diagram of the experimental apparatus

Oven dried method was used to determine soil moisture content. Soil sample was weighed and dried in an oven at 105 °C for 24 h to determine the initial soil moisture content. The soil sample, which was used to determine thermal conductivity was weighed and then placed in the box. The power supply was then switched on allowing heating of the wire. Temperature of the wire was recorded every 5 seconds to the end of the heating process as shown in Figure 2.

At this stage, the power supply unit is disconnected and cooling process would start immediately. The wire temperature recorded after the battery was disconnected. Temperature of the wire was reordered every 5 seconds until the end of the cooling process. Current was recorded for later use for thermal conductivity calculations. The same procedure was repeated for six OMW concentrations at three different moisture contents of (0.15, 0.20, 0.25 cm^3/cm^3) and three soil densities (1.15, 1.25, 1.35 g/cm^3) for each soil type. Temperature was plotted versus the natural logarithm of the time and slopes of the linear portions of these curves were determined. These values were used to calculate thermal conductivity. Figure 3 shows an example of these plots. On average, these curves became linear after 30 seconds after heat was initiated. The same procedure was repeated for different soil at various levels of OMW for each soil type.

OMW was collected during oil harvesting season of 2010 (October to January) from a number of local olive mills to analyze variation of thermal conductivity with OMW concentration. Samples were stored in tightly sealed plastic containers. The characteristics of the OMW according to standard methods for the examination of water and wastewater Greenberg 1992 are shown in Table 1. These characteristics include: density, conductivity, pH, total suspended solids (TSS), total dissolved solids (TDS), chlorides, phenols, volatile acids, chemical oxygen demand (COD), and biochemical oxygen demand (BOD) as the most widely used parameters of organic pollution applied to both wastewater and surface water.

To eliminate water content as a variable, soil samples were oven dried at 105 °C for 24 h. Soils were screened through a 2 mm sieve. The OMW concentrations used are shown in Table 2, they were obtained by mixing proportion of the OMW solution with distilled water to produce the desired OMW level. Soil samples were mixed with OMW solution in plastic bags. The samples were allowed to equilibrate overnight at room temperature and then placed in a rectangular steel box. The thermocouple temperature was recorded as a function of time following the procedure described earlier and slopes of the temperature versus natural logarithm of the time were obtained. The experiment was repeated three times for each treatment (the box emptied, clean and repacked for each replication).

Table 2.

Olive Mills Effluent (OME)
Concentration % cm^3/cm^3 (distilled water)

Olive Mills Effluent (OME) Concentration % cm3/cm3	Distilled Water %
0	100
20	80
40	60
60	40
80	20
100	0

In general, thermal conductivity increased as soil density and moisture content increased, for the type of soils studied, which is in agreement with the result obtained by Abu-Hamdeh et al 2000, 2001. Therefore, only the results of the effect of OMW on soil thermal conductivity of different soils at a moisture content of 0.20 cm^3/cm^3 and bulk density of 1.25 g/ cm^3 are presented in this paper.

RESULTS AND DISCUSSION

Four parameters were measured in each test for all soil types at different OMEW concentration: wire temperature, time at specified intervals, moisture content and bulk densities. The average of three replicates heating and cooling estimates of thermal conductivity was used in this study.

Figure 2 is an example of plots of measured temperature as a function of time for sandy clay soil at OMW concentration of 60% during heating and cooling process. The figure shows a rapid increase in temperature during the first five minutes of heating, after that temperature variation with time was slow. Cooling process started immediately after power supply was shut off after ten minute of heating. The rate of temperature drop with time during cooling process was slower than the rate of temperature rise during heating process. This might be due to the complicating factors arising from water movement in response to temperature gradients caused by the heating.

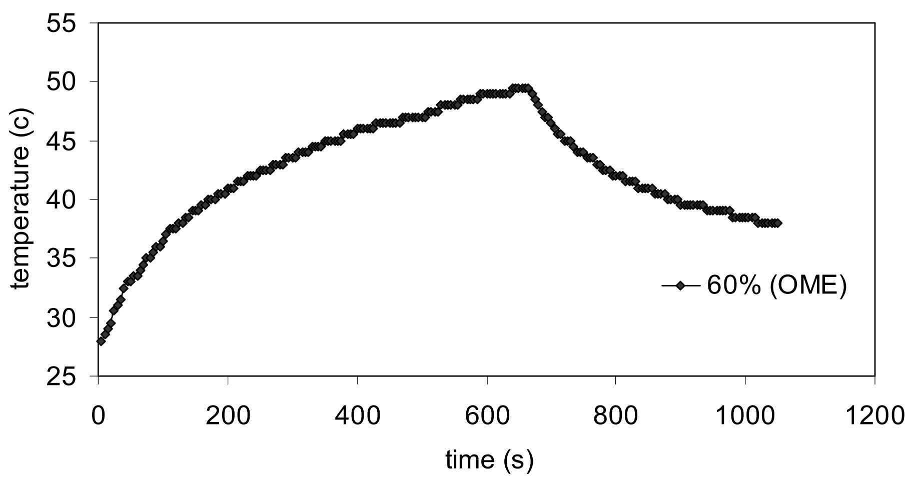


Figure 2. Wire temperature as a function of time during heating and cooling process for sandy clay soil at a moisture content of 20% and bulk density of 1.25 g/cm^3

The characteristic of temperature rise versus the logarithm of time for the clay soil at different OMW concentration is shown in Figure 3. On the other hand, the characteristic of temperature fall versus the logarithm of time for the silty clay soil at different OMW concentration is shown in Figure 4. Slopes of these curves for all tests were determined and used in equation (1) to calculate the thermal conductivity.

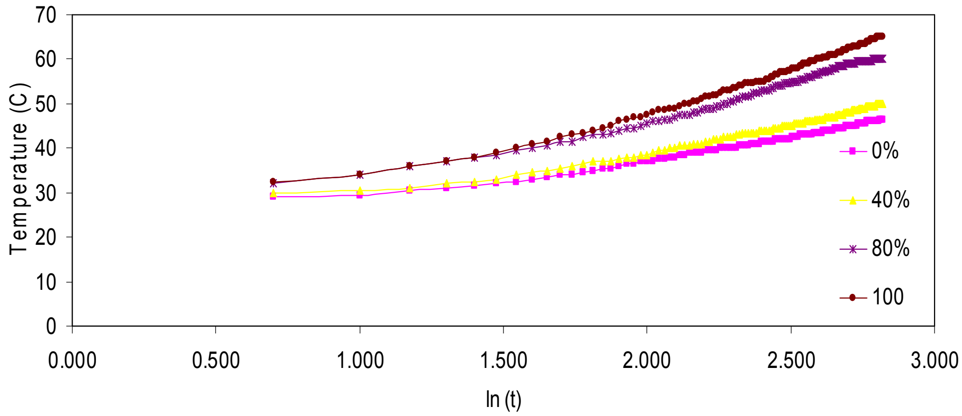


Figure 3. Wire temperature as a function of ln (t) during heating for clay soil at moisture content of 20% and different (OME) concentration

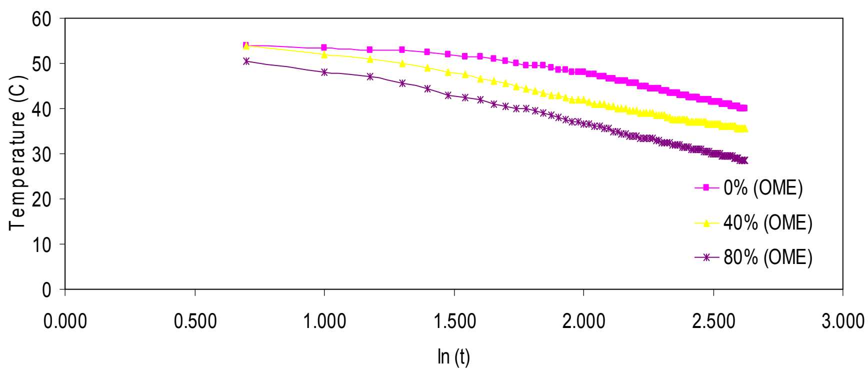


Figure 4. Wire temperature as a function of ln (t) during cooling for silty clay at moisture content of 20% and different (OME) concentration

The average thermal conductivity of three sieved and repacked Jordanian soils as a function of OMW concentration is shown in Figure 5 at a moisture content of 0.20 $cm^3/cm^3$and a bulk density of 1.25 g/cm^3. At various OMW concentrations, sand clay always had a higher thermal conductivity values than other soils. Mineralogical constitutes of the sandy soil may have higher thermal conductivity than those in clay minerals.

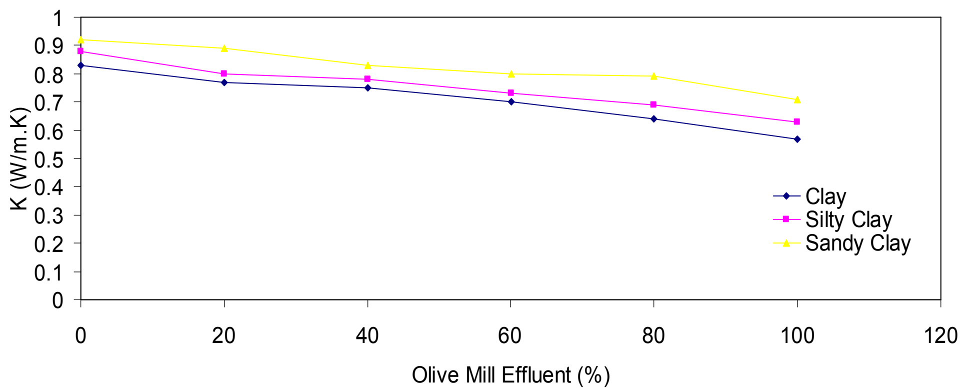


Figure 5. Thermal conductivity as a function of (OME) concentration of sandy clay, silty clay and clay soil at a moisture content of 20%

Thermal conductivity of the three different soils was decreased as OMW concentration increased. Figure 5 shows that thermal conductivity of sand clay soil was reduced from 0.89 W/m.K to 0.71 W/m.K at OMW concentration of 20% and 100%, respectively. This might be a result of increasing the amount of organic matter and minerals as the OMW concentrations increased. Organic matter and mineral solids in OMW were estimated at 4-16% and 2%, respectively. The results give some insight on the relation between the percentage of organic matter content in soil and thermal conductivity. Although, it is expected that thermal conductivity will decrease with an increase in organic matter content, this figure gives an indication of the amount of reduction in thermal conductivity for a given increase in organic matter. For example, thermal conductivity decreased from 0.92 W/m K at 0% OMW (pure distilled water) to 0.71 W/m K at 100% OMW concentration which means a reduction of 23% in the soil's thermal conductivity was observed for an increase of 100% in OMW concentration for sandy clay soil. A constant incremental increase of 20% (from 20% to 100%) in OMW concentration did not yield the same amount of reduction in thermal conductivity. Thermal conductivity decreased in the range of 10% to 30% each time the percentage of OMW increased by 20% for sandy clay soil as shown in Table 3.

Table 3. Mean thermal conductivity of three Jordanian soils as a function of OMW concentration, each value represent the average of three replicates*.

OME Concentration %	Thermal conductivity W/m.K					
	Heating			Cooling		
	Sandy clay	Silty clay	Clay	Sandy clay	Silty clay	Clay
0	0.92 [a]	0.88 [a]	0.83 [a]	0.76 [a]	0.67 [a]	0.63 [a]
20	0.89 [a]	0.80 [b]	0.77 [b]	0.67 [b]	0.62 [b]	0.60 [b]
40	0.81 [b]	0.78 [b]	0.75 [b,c]	0.64 [b]	0.61 [b]	0.57 [b,c]
60	0.8 [b]	0.73 [b,c]	0.70 [b,c]	0.61 [b,c]	0.58 [b]	0.53 [b,c,d]
80	0.79 [b]	0.69 [b,c]	0.64 [b,c,d]	0.56 [b,c]	0.54 [b,c]	0.49 [b,c,d]
100	0.71 [b,c]	0.63 [b,c,d]	0.57 [b,c,d]	0.57 [b,c]	0.52 [b,c]	0.43 [b,c,d,e]

* Means with the same letter indicate insignificant difference at a 10% level.

The maximum thermal conductivity (0.92 W/m K) was observed in sandy clay soil. Clayey soil had a lower thermal conductivity than sandy clay and silty clay at all OMW concentration. Thermal conductivity values reported here were well within the range 0.38 to 1.71 W/m K for sandy clay, and in the range 0.39 to 0.69 W/m K for clay at volumetric moisture content of 10 and 20%, respectively, as reported by Ghuman et al 1985. For the clayey soil, thermal conductivity decrease uniformly with increasing OMW concentration as shown in Figure 5. The low thermal conductivity of the clayey soils is due to the lower bulk density, compared with other soils, and to the lower conductivity of minerals De Vries 1963 constituting the clay particles. Also, the decrease of effective thermal conductivity with decrease in grain size may be explained by the fact that as the grain size decreases, air porosity increases, which means more thermal resistance between particles. This suggests that clayey soil with low thermal conductivities would exhibit larger surface temperature amplitudes, compared with sandy clay or silty clay under equal heat flux densities. This could influence the successful raising of temperature-sensitive crops on the clayey soils in Jordan.

Statistical analysis was performed on the data for each soil type using the statistical analysis software Minitab. The analysis was performed at a significance level of 10%. The null hypothesis was that the mean of the thermal conductivity values was the same for each soil type at different OMW concentration.

Also, a pair t-test was used to test the null hypothesis that thermal conductivity obtained from heating data was not significantly different than thermal conductivity obtained from cooling data. The P-value (one tail) was 0.05, indicating that both heating method and cooling method yield different thermal conductivity values. Table 4 shows comparisons of the average thermal conductivity values obtained using heating and cooling methods at different OMW concentration for sandy clay, silty clay and clay soils.

Table 4.Comparison of mean thermal conductivity of three Jordanian soils as a function of OME concentration obtained by heating and cooling methods, each value represent the average of three replicates*.

OME Concentration %	Thermal conductivity W/m.K					
	Sandy clay		Silty clay		Clay	
	K-Heating	*K*-Cooling	*K*-Heating	*K*-Cooling	*K*-Heating	*K*-Cooling
0	0.92 ^{a}	0.76 ^{b}	0.88 ^{a}	0.67 ^{b}	0.83 ^{a}	0.63 ^{b}
20	0.89 ^{a}	0.67 ^{b}	0.77 ^{a}	0.62 ^{b}	0.80 ^{a}	0.60 ^{b}
40	0.81 ^{a}	0.64 ^{b}	0.75 ^{a}	0.61 ^{b}	0.78 ^{a}	0.57 ^{b}
60	0..8 ^{a}	0.61 ^{b}	0.73 ^{a}	0.58 ^{b}	0.73 ^{a}	0.53 ^{b}
80	0.79 ^{a}	0.56 ^{b}	0.64 ^{a}	0.54 ^{b}	0.69 ^{a}	0.49 ^{b}
100	0.71 ^{a}	0.57 ^{b}	0.63 ^{a}	0.52 ^{b}	0.57 ^{a}	0.43 ^{b}

* Means with the same letter indicate insignificant difference at a 10% level.

As shown in Table 4, there is significant difference between the average values obtained by heating and by cooling for all soil types studied at all OMW concentration. The thermal conductivity determined using cooling data was smaller than that determined using heating data as shown in Figure 6. One possible reason is the complicating factors arising from water movement in response to temperature gradients caused by heating. Low power inputs were used since lower power inputs are preferable to minimize the effects of heating on soil water movement and hence thermal conductivity.

CONCLUSIONS

Thermal conductivities were investigated for three sieved and repacked Jordanian soils as a function of water content, bulk density, and OMW concentration. Thermal conductivities values varied with soil texture, initial water content, and OMW concentration. Thermal conductivity increased as bulk density and moisture content increased for all soils studied. At given moisture content thermal conductivity values of all soils decreased with increasing OMW concentration. Sandy clay soil had the higher thermal conductivity at any OMW concentration. Sandy clay exhibited slight decreases in thermal conductivity values beyond a certain OMW concentration. Clayey soil generally had lower thermal conductivities than sandy clay and silty clay soil. In general, the heating data yield higher thermal conductivities than those obtained from the cooling data.

REFERENCES

Abu-Hamdeh N.H., Al-Jalil H.F., Khdair A.I. (2000). Thermal conductivity of disturbed soils under laboratory conditions. American Society of Agricultural Engineers. Vol. 43 (4): 855-860.

Abu-Hamdeh N.H., Khdair A.I., Reeder R.C. (2001). A comparison of two methods used to evaluate thermal conductivity for some soils. International Journal of Heat and mass transfer 44: 1073-1078.

Greenberg A. E., L. S. Clesceri, A. D. Eaton, and M. H. Franson, (1992). Standard methods for the examination of water and wastewater, 18th ed., American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC.

Hayek B., M. Mosa, N. Halasah, (1996). An experimental method for treatment of olive oil mills wastewater utilizing upflow anaerobic sludge blanket (UASB) reactor. Proceedings of the Jordanian Chemical Engineering conference II, 2-4 September. pp. 64-84.

Vries De, D. A. (1963). Thermal properties of soils. In *Physics of Plant Environment*, ed. W. R. van Wijk, 210-235. Amsterdam, The Netherlands: North Holland Publishing.

Ghuman. B S and R. Lal 1985. Thermal conductivity, Thermal diffusivity and thermal capacity of some Nigerian soils. Soil Sci. 139 (1985): 74-80.

Saez L, J. Perez, J. Martinez, (1992). Low molecular weight phenolics attenuating during simulated treatment of wastewater from olive oil mills in evaporation ponds, Water Res. 26: 1261-1266.

Letey, J.; Osborn, J.; Pelishek, R. E (1962). The influence of liquid-solid contact angles on water movement is soil. Int.Ass. Sci. Hydrol. Bull 1962, 7(3): 75-81.

McGill, W. B (1971). An introduction to field personnel on the effects of oil spills in soil and some general restoration and cleanup procedures. Alberta Institution of Pedology 1971, Edmonton, Alta, Canada. 19-22.

Ministry of Agriculture (2010). Department of Studies and Statistics. Amman-Jordan.

MINITAB. Minitab Release 15. Minitab Inc. State College. PA. (2005)

Cossu R, N. Blakey, P. Cannas, (1993). Influence of codisposal of municipal solid waste and olive vegetation water on the anaerobic digestion of a sanitary land fill. Water Sci. Tech. 27: 261-271.

Tsonics S.P., S.G. (1993). Girigeropoulos. An aerobic treat ability of olive oil mill wastewater. Water Sci. Tech (28): 35-44.