THE EXPERIMENT
INTERNATIONAL JOURNAL OF SCIENCE AND TECHNOLOGY

ISSN-2319-2119

RESEARCH ARTICLE

H.SAHRAOUI et al, The Experiment, 2015.,Vol. 30(4), 2002-2011

OLIVE MILL WASTEWATER SPREADING EFFECTS ON HYDRAULIC SOIL PROPERTIES

ABSTRACT

Olive Mill Wastewater (OMW) generated by the olive oil extraction industry is a major environmental problem in the Mediterranean area because of its high organic load and its high content of phytotoxic and antibacterial phenolic substances. To evaluate the effect of OMWapplication on soil water retention and hydraulic conductivity,spreading field experiments were carried out at Sidi Bouali (Tunisia) during four months.Treated soil with50 m^3/haof OMW and one untreatedsoil were compared.Soil water retention was measuredat pressure potentials ranging from-10 to -153000 Cm.Saturated hydraulic conductivitywere determined by the constant headmethod. Olive mill wastewater (OMW) in soil reduced the waterretention for all times and for each pressure potential from -10 Cm to -15300 Cm.OMW increased the saturated hydraulicconductivity on the surface soil on the second month while decreased progressively on the third and fourth month after spreading

.

Key words: Olive Mill Wastewater (OMW), soil, spreading, physical impacts.

INTRODUCTION

The production of olive oil in the Mediterranean region is regularly increasing, and surpasses 30 million m^3 per year (Khoufi et al., 2006). The average Tunisian production is about $22.10^4 m^3$ of olive oil per year and represents one of the most important producers of olive oil in the Mediterranean countries. The extraction of olive oil which is carried out in short periods of time (November to January) generates two by-products, namely solid residues and the olive mill wastewater (OMW).

The OMW characteristics and quantities depend on the olive variety, ripeness, climate and the oil extraction method (Tortosa et al., 2012). There are three olive oil extraction processes: press olive oil extraction, three-phase centrifugal olive oil extraction and two-phase centrifugal olive oil extraction. Three-phase centrifugal olive oil extraction is the most common olive oil extraction process in all Mediterranean countries and produces about 500 and 1.400 l t^{-1} of olives (Sierra et al. 2001; Azbar et al., 2004). Whereas for the traditional system, the amount of OMW ranges between 400 to 500 l t^{-1} of olives (Bonari and Ceccarini 1990).

The production of such a high amount of OMW causes a major environment problem and must be properly managed to avoid the negative environmental impacts associated to their disposal (Mekki et al. 2006;Ouzounidou et al. 2010). OMW are characterized by their high organic load and reaches about 93% by mass (Almomanyand Al-Saket, 1989). Organic matter on OMW are mainly nitrogenous compounds (especially amino acids), tannins, pectins, sugars and polyphenols (Saez et al., 1992), some of these substances are difficult to biodegrade and may exert toxic and inhibitory effects on the microbial activity.Khaleel et al. (1981) has improved that land application of rich organic waste effluents like OMW improve soil structure, increase infiltration rate, hydraulic conductivity and water holding capacity, reduce runoff, and decrease soil erosion.

OMW are characterized by their fertility properties eventually by their richness in different minerals like potassium (K^+), sodium (Na^+) calcium (Ca^{2+}) and phosphorous (PO_4^{2-}) (Salvemini, 1985). Also, OMW are characterized by their adhesive and hydrophobic behavior (Friaa et al., 1986) and their regular application has been shown to increasesoil hydrophobicity (Mahmoud et al., 2010).Bisdom et al. (1993) reported that OMW organic matter and contained residues of oil and greaseform a coating on soil aggregates and pore walls, which may reduce anion diffusion into soil aggregates. Mellouli (1996) has shown that OMW has a beneficial influence on soil aggregation, soil structure stability and hydrodynamic properties of a sandy soil.

Many valorization alternatives were tested to overcome the pollution problems related to OMW. In the recent years some studies have investigated on alternative amendment and fertilization solutions,to benefit from these organic and at the same time it's more environmentally compatible than soil disposal (Paredes et al., 1999; Abu-Zreig and Al-Widyan, 2002; López-Piñeiro et al., 2008; Toscano et al., 2013).

Thus, land application of OMW can be asustainable and cost-effective recycling ofnutrients and organic matter of this effluentto soil (Maftoun and Moshiri, 2008).

Most of the researches on the impact of OMWspreading were performed to assess the impact on soil fertility, on the chemical properties and plant performance (Cabrera et al., 1996); researches on the impact of OMW on soil physics are very few (Mekki et al. 2006).

The main objectives of this study are to investigate the effects of OMW application for four months on selected soil water retention and saturated hydraulic conductivityat field sites.

MATERIAL AND METHODS

Experimental protocol

Characteristics of the OMW used for spreading

The original OMW used in the present study was obtained fromacontinuousolive millneartheexperimental site. The main characteristics of the OMW were: mineral matter: 28.1 %; organic matter: 71.9 %; water content: 95.5 %. Theeffluentusedcontainedan averagerate of7.5% ±1.7 of residueincludingoilresidual, saidactive materialassuggestedbyMellouli(1996).

Experimental design

Field experiments were conducted at SidiBou Ali (Sahel Region–Tunisia). Climate is Mediterranean, characterized by a mild winter, dry hot summer, hightemporal variabilityinterandintra-annual orspatial distribution ofrainfall and anaverage annual temperatureis18 °C (Sakiss et al., 1994). The soil used in this experiment isInceptisolwith a loamy sand textureaccording to Soil Taxonomy-USDA (Soil Survey Staff,1999).The soil used in this experiment is loamy sand, containing 12 % clay, 22 % silt and 66 % sand.The bulk density of the packed soil was 1.3 g/cm^3. The plots did not receive any contribution from OMW previously. The soil sampling was conducted monthly for four months after application (T_1, T_2, T_3, and T_4), at two horizons A and B (0 - 20 cmand 20 - 40 cm respectively).

Soil clods were crushed to pass through a 1 cmsieve before air drying. Air dried soil was further crushed using a mechanical grinder and passed through a 2 mm sieve. Soil aggregates <2 mm in diameter were used in the experiment. Thespreadingwasappliedon parcelsituatedbetweenolives treesarranged 13m×13m.The treatments included:

(1) Untreated soil (control),and

(2) Treated soil amended with 50 m^3/haof OMW.

Physico-chemical characteristics of the soilused in this study were as follows: pH (H_2O) 8.66; EC: 0.63 dS.m^{-1}; organic matter: 0.46 %; N: 0.37 %; P: 6.81 mg.kg^{-1}. The experimental plotwasdividedintonineelementary plotsof 4m^{2}each,distributedinrandomizedblock. Eachparcelisseparatedbyaspace of1 malongthe foursides. The application of OMW as soil amendment was realized in one application.

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Water retention

Soil water retention curve, called pF curves, describes the relationship between soilwater content (θ) and the related soil water tension or soil matrix water potential (h).Soil water retention characterization was established by using three replicates of soilsamples for different tensions, ranging from saturation until thewilting point (-10 cm to -15300cm) using a pressure plate apparatus. Soils were allowed to saturate for 48 h, then they were placed in the pressure chamber and subjected to -10, -50, -100 and -200 cm pressure plate matric potentials (Musy and Soutter 1991; Bousnina and Laouini, 1998). The pressure potentials -614 cm and -15.300 cm (Bousnina and Laouini, 1998) have been achieved through the method of Richards (1947), known as 'Richards pressure chamber '.

The weight of the soil after pressure equilibration at each pressure potential was recorded and the soils were placed in the oven at 105°C. Using the gravimetric water content and bulk density data, volumetric water content at each pressure potential was calculated. Each treatment is replicated in triplicate.The volumetric water contents were obtained by the following equation:

$$\theta = W \times da$$

Where W is the moisture weight (g/g), θ the volumetric moisture (vol/vol) and da is the apparent density of dry soil.

The model of van Genuchten (1978 and 1980) was applied for smoothing the curves of water retention θ(h), using the experimental values:

$$\theta = \theta r + (\theta s - \theta r) \times \left[\frac{1}{1 + (\alpha |h|)^n} \right]^m$$

where

m=1 - 1/n for n > 1;

h soil water pressure head (L);

θ volumetric water content of soil ($L^3 L^{-3}$);

θr residual soil water content ($L^3 L^{-3}$);

θs saturated soil water content ($L^3 L^{-3}$);

a fitting parameter in the soil water retention function (L^{-1});

αfitting parameter in the soil water retention function (dimensionless).

Saturated hydraulic conductivity **(K_S)**

The saturated hydraulic conductivities (Ks) of the untreated soil and the same soil treated with OMW were determined using the constant head method. Air-dry soil was packed into the columns to a bulk density of 1.2 g/cm^3.The Ks of the untreated soil and the same soil treated with OMWis determined using Darcy's equation for calculating hydraulic conductivity. Water is pressed through columns, with a cross section (A) and height (L), from below after stabilization of the flow of water. Air-dry soil was packed into the columns.After saturation, they were subjected to a difference (gradient) of hydraulic constants (H). Percolated volumes (V) were recorded for a period (t) and collected in sampling bottles using constant water head. Then, the different values of K_S were determined using Darcy's law:

$$K_s = \frac{V}{A \times t} \times \frac{L}{\Delta H}$$

Unsaturated hydraulic conductivity**K (θ)**

The mathematical model of Mualem (1976), associated with the equation h (θ) of Van Genuchten (1978 and 1980) were used for predicting the unsaturated hydraulic conductivityK (θ):

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$$K(\Theta) = K_s \times \Theta^{0.5} \times \left[\int_0^{\Theta} \frac{1}{h(x)} dx \Big/ \int_0^{1} \frac{1}{h(x)} dx \right]^2 \quad (4)$$

Where h is the pressure head expressed as the function of water dimensionless content as follows:

$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} \quad avec \quad 0 \leq \Theta \leq 1^2 \quad (5)$$

Where s and r indicate saturated and residual values of the soil water content (θ) respectively.

Combining equation (2) for the function h (θ) with equation (4), van Genuchten (1980) obtained the following expression for the hydraulic conductivity:

$$K(\theta) = K_s \times \Theta^{0.5} \times [1 - (1 - \Theta^{1/m})^m]^2 \quad (6)$$

For the treated soil, the value of ks and the parameters of equation (2), α, n and m have yielded analytical expressions of the hydraulic conductivity K(θ) (Equation 6), which were then graphed.

Statistical analysis

All the experiments were performed in triplicate. The data obtained in the analytical determinations were treated statistically using the program SPSS version 20.0 for Windows (.IBM Corp. Released 2012). The differencesbetween the untreated and treated soil werecompared using the Least SignificantDifference (LSD) test at the P≤ 0.05probability level.

RESULTS AND DISCUSSION

Effect of OMW on water retention

Experimental values of water retention on horizons A and B are given in table 1. The differences in water retention, in each treatment, at each pressure potential from -10 to -15300 were on the majority nosignificant (Table. 1).

Table 1 Experimental values of moisture (m^3/m^3) desorption in soil treated by OMW spreading.

	Pressure potential (cm)	Untreatedsoil	Treatedsoil T1	T2	T3	T4
Horizon A	-10	**0.593 A* a****	0.531 A b	0.491 A d	0.498 A c	0.495 A c
	-50	**0.354 B a**	0.311 B d	0.335 B c	0.340 B b	0.269 B e
	-100	**0.284 C a**	0.218 C d	0261 C c	0.270 C b	0.219 C d
	-200	**0.221 D a**	0.170 D d	0.192 D c	0.211 D b	0.135 D e
	-614	**0.198 E a**	0.169 D b	0.142 E d	0.169 E b	0.151 E c
	-15300	**0.135 F a**	0.124 E b	0.111 F d	0.126 F b	0.119 F c
Horizon B	-10	**0.552 Aa**	0.505 A a	0.508 A a	0.480 A a	0.440 A b
	-50	**0.389 B a**	0.285 B b	0.305 B b	0.301 B b	0.261 B b
	-100	**0.281 C a**	0.258 C a	0.275 C a	0.270 C a	0.226 C b
	-200	**0.213 D a**	0.194 D a	0.200 D a	0.199 D a	0.161 D b
	-614	**0.193 E a**	0.181 D a	0.181 E a	0.165 E a	0.147 E b
	-15300	**0.141 F a**	0.120 E b	0.125 F a	0.119 F a	0.111 F b

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*For each horizon, the same letter in a column indicates that the means were not significantly different with the test of L.S.D. and T3 Dunnett at a probability level of 95%.
** For each horizon, the same letter in a line indicates that the averages are not significantly different with the test of L.S.D. and T3 Dunnett at a probability level of 95%.
The differences in water retentionbetween the untreated soil and soil amended with OMW for all times and for each pressure potential from -10cm to -15300cm were significant. Even though, the amended soil retained less water compared to the controlsoil. The difference in water retention were not significant at each pressure potential of -614 and -15300 Cm at the first and the third month after the treatment.

After fourth month of treatment, the OMW in the soil significantly reduced water retention at each pressure potential and water retention in the treated soil, at all pressure potentials is reduced by 12% and 16% compared to control.
We obtain a smooth of the curve established by comparing the values of pF depending on the moisture density by treatment and date (T1, T2, T3, and T4) after application for the two horizons (A and B) (Figure, 1 and 2respectively). OMW generate a decrease in water retention of the treated soil, whatever the soil matric potential. Figures 1 and 2 show that treated soil for the effect on the OMW reducing water retention is increasingly important function of the time.

Indeed, retention curves corresponding to the horizon A(Figure 1) show that OMW induced a decrease in water retention for all tensions which is clear at the fourth month after application. Same shapes were observed for the retention curves corresponding to the horizon B(Figure 2) and exhibited a slight decrease on water retention than horizon A.

These decreases in water retention suggest that the hydrophobic group of organic molecules and oily residues presented in the OMW reduced the ability of the soil to retain water.Wallach et al. (2005) confirmed these results and reported that OMW application on soils exhibited the development of hydrophobicity on topsoil. Furthermore, Rasiah et al. (1990) reported that these decreases in water retention attributed that oily residues presented on OMW makessoil constituents hydrophobic and hypothesizedhad succeeded water in the competition for pore space especially macropores. This fact is due essentially to that oil residues of OMWoccupiedthe macropores and coated macroaggregates of the soil,reducing the water film thicknessaround macroaggregates and retardingthe movement of water into and out ofmicroaggregates which decrease the water retention of the soil.

On the same way, Mellouli (1996),after OMW application on laboratory experiments, confirmed that the water retention is generally decrease at the soil surface, where organic matter had accumulated.
Several authors (Mellouli 1996; Mahmoud et al. 2010) indicated that the high organic matter content in OMWimproved the soil water retention capacityand suggested that the organic matter of OMW plays an important role on water retention decrease by its accumulation on topsoil which reduced soil porosity by the loss of larger pores and the increase of finer pores.

The data suggest that both application time and depth (for horizon A and B) play a role in determining the effectiveness of OMW. OMW decreased soil water retention levels in the upper layer of the soil, while at greater depths the application cause slight decrease on water retention. It appears that OMW remains in the upper layers of the soil whereas it movesmore readily through the soil to greater depths (horizon B). However, further research would be necessary to confirm this theory.

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Effect of OMWon hydraulic conductivity K_S

Hydraulic conductivity (K_S) of untreated and treated soil on the two horizons A and B are presented respectivelyinfigures 3 and 4.

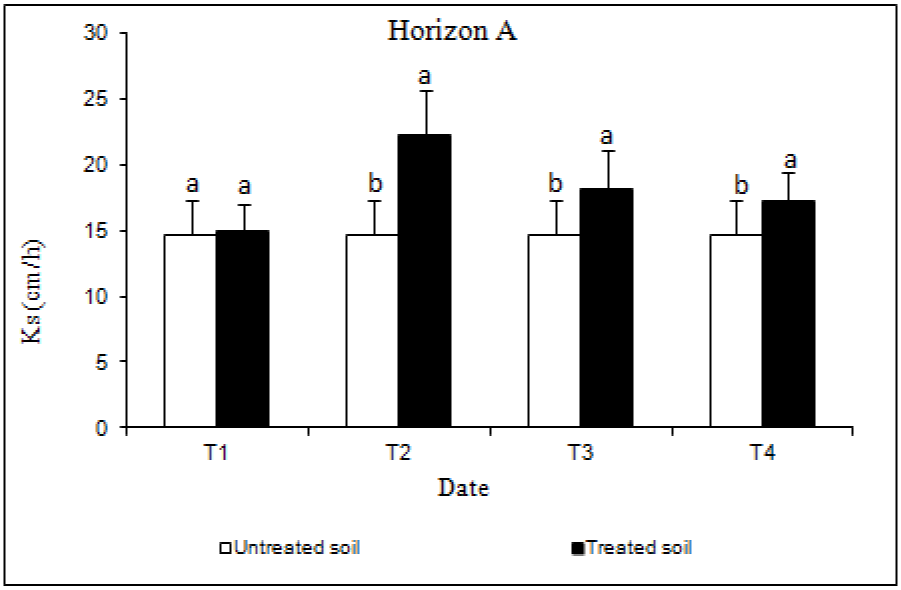

Fig.3OMW effects on saturated hydraulic conductivity (Ks) for T1, T2, T3 and T4 at the horizon A.

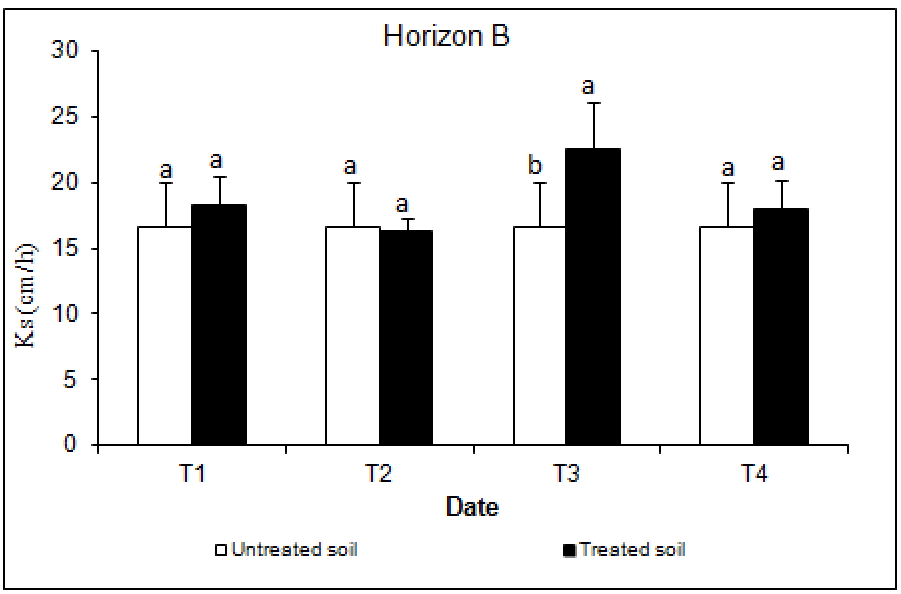

Fig.4OMW effects on saturated hydraulic conductivity (Ks) for T1, T2, T3 and T4 at the horizon B.

For the two horizons, Ks increased significantly for the treated soil compared with the untreated soilon the second, for the horizon A (from 14.64Cm/h for the untreated soil to 22.24 Cm/h for treated soil). For the third and fourth

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month after OMW spreading, significant differences was showed between the two treatments, but we noted a quantitative decrease of hydraulic conductivity compared to the second month.

From the experimental values of water retention on horizon A and B, parameters of the equation of Van Genuchten (1978 and 1980) were determined (Table 2).

Table 2 Values of parameters of the relationship θ(h) for horizon A and B according to the Van Genuchten model (1978 and 1980).

			θ_s	θ_r	a	N	m	R^2
A	**Untreatedsoil**		0.630	0.130	0.053	1.679	0.595	0.992
	Treatedsoil	T1	0.550	0.124	0.054	1.760	0.568	0.968
		T2	0.500	0.115	0.023	2.015	0.496	0.999
		T3	0.510	0.120	0.030	1.708	0.585	0.994
		T4	0.509	0.111	0.048	1.825	0.547	0.988
B			θ_s	θ_r	a	n	m	R^2
	Untreatedsoil		0.600	0.130	0.043	1.708	0.585	0.992
	Treatedsoil	T1	0.540	0.120	0.064	1.626	0.614	0.979
		T2	0.550	0.107	0.048	1.539	0.649	0.986
		T3	0.485	0.110	0.035	1.616	0.618	0.993
		T4	0.460	0.100	0.050	1.690	0.591	0.986

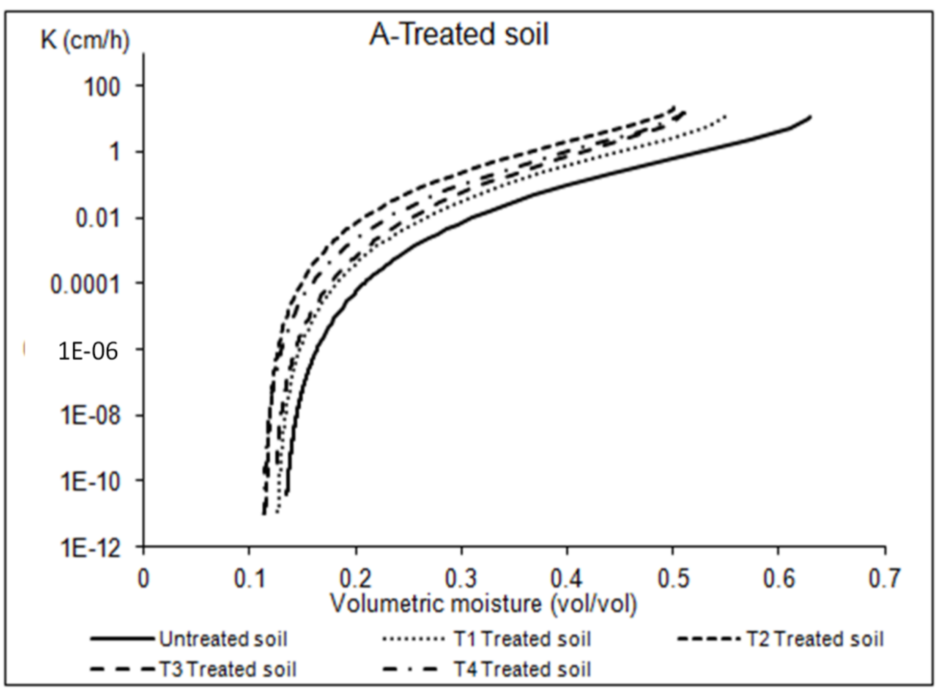

Fig.5 OMW effects on hydraulic conductivity K(θ)for T1, T2, T3 and T4 at the horizon A.

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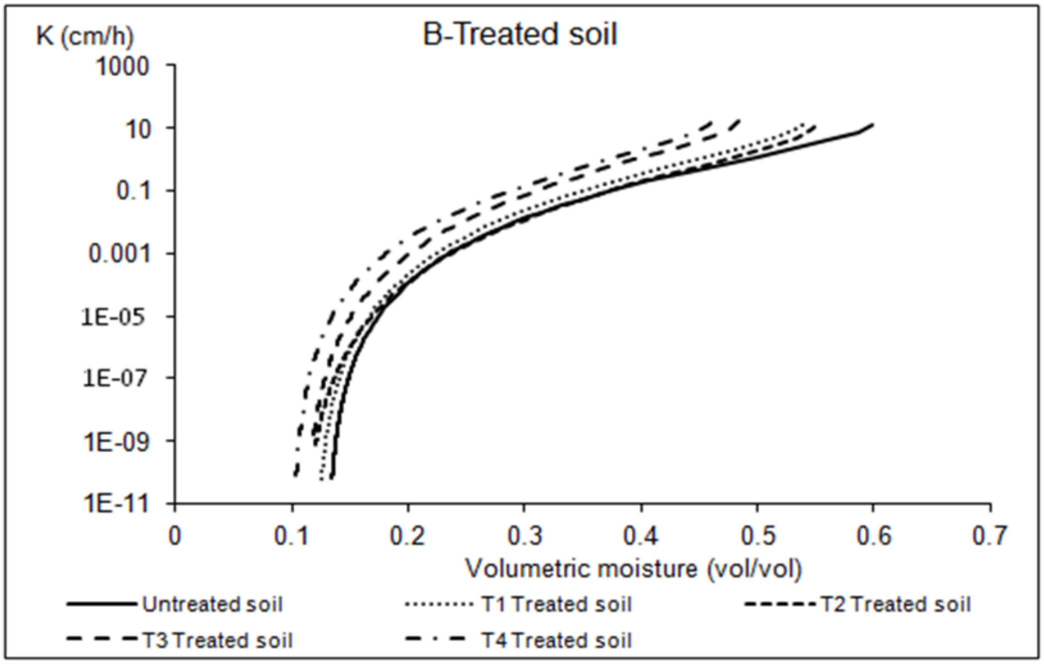

Fig.5 OMW effects on hydraulic conductivity K(θ)for T1, T2, T3 and T4 at the horizon B.

Studies of Papini et al. (2000) confirmed that the hydraulic conductivity (K_S) increased after OMW application, and attributed it to the biological decomposition of the fatty substances presented on OMW. We hypothesizedin the study that fatty substances were gradually decomposed from the second month after OMW spreading, and thus hydraulic conductivity decreased with the decomposition of these substances. Mahmoud et al. (2012) found that the soil hydraulic conductivity decreased with long term OMW application.For horizon B, hydraulic conductivity increases significantly only on the third month (increased from 16.67 Cm/h for the untreated soil to 22.53 Cm/h for treated soil), whereasdecreased on the fourth month where no significant difference was shown between untreated soil and treated soil.

CONCLUSION

This study investigated the effects of OMW application onselected soil water retention and hydraulic conductivity.The spreading of OMW for fourmonths has been shown tohave distinct effects on the properties of soil physics. Water retention decreased with OMW application whereas hydraulic conductivity increased after the second month of spreading on soil surface and decrease gradually with time.These modifications are consequence of hydrophobic compounds and organic matter generally presented on OMW whichbinds the soil particles.

ACKNOWLEDGEMENTS

Authors appreciate the valuable comments by anonymous reviewers, which helped us to improve the manuscript.

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H.SAHRAOUI[1]*, S.KANZARI[1], M.HACHICHA[1],H.J.MELLOULI[2]

[1]Institut National de Recherches en Génie Rural, Eaux et Forêts, Rue HédiKarray, 2049 Ariana, Tunisia

[2]Institut National de la Recherche Agronomique de Tunisie, Rue HédiKarray, 2049 Ariana, Tunisia