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Olive Mill Effluent Spreading Effects on Water Retention of Tunisian Sandy Loam Soil

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Abstract

Olive mill effluents (OME) are characterized by their nutrients content and their adhesive and hydrophobic properties. An experiment was carried out at an olive growing area in Tunisia, "Sidi Bou Ali", to identify the impact of spreading over OME on physical soil characteristics. Three treatments were *in situ* monitored, namely T_0 (Control), T_1 (25 m^3/ha) and T_2 (50 m^3/ha), over a period of 4 months. Measurements were conducted monthly corresponding respectively to D_1, D_2, D_3 and D_4. Water retention curves were established by a physical capillary model in porous medium. Results showed that the two applied OME doses induced a decrease in water retention, especially for potential matrixes above pF 2 corresponding to the water available range. No significant differences were found between the treated soil plots T_1 and T_2.

Keywords: Olive mill effluents (OME), spreading, water retention

Abbreviations

OME: olive mill effluent
T_0: Control treatment
T_1: 25 m^3/ha olive mill effluent treatment
T_2: 50 m^3/ha olive mill effluent treatment
D_1: First sampling date
D_2: Second sampling date
D_3: Third sampling date
D_4: Fourth sampling date
P_1: Soil horizon 0 - 20 cm
P_2: Soil horizon 20 - 40 cm

Introduction

Olive mill effluent (OME) is liquid waste produced during olive oil extraction. The quantities and qualities of these effluents vary according to the olive variety, the ripening stage, the climate, and especially on the technology used in olive processing [1-3]. In Mediterranean countries, large amounts of OME are produced per year, which are generated during a few months of the year (November to February). Around 700,000 m^3 of OME is produced in Tunisia per year [4,5]. Pollution by OME is becoming a crucial problem, particularly in the main olive oil producing countries (Spain, Italy, Greece and Tunisia) [6]. This is due to its toxicity, exhibited against microorganism and plant growth. In fact, its higher acidity (pH between 4.5 and 5.2), higher salinity (electrical conductivity between 8 and 16 dS/m), and presence of phenolic compounds [7,8] is believed to contribute to the phytotoxic and antimicrobial nature of these effluents. To get over the pollution problems related to this effluent, many valorization alternatives have been tested by researchers. OME is often used as a soil fertilizer and amendment, since this effluent is rich in organic matter, potassium, phosphorus and magnesium.

Furthermore, OME is characterized by its adhesive and hydrophobic behaviour [9,10]. Experiments conducted by Mellouli [11] have shown that these characteristics have a beneficial influence on soil aggregation, soil structure stability, and hydrodynamic properties of a sandy soil. In addition, water retention at the pressure potential range corresponding to the available water capacity can be reduced by the application of OME. On the other hand, Mellouli [11] and Mellouli *et al*. [9,10] emphasized that the changes of soil physical properties are mainly due to the high organic matter content of the OME and its hydrophobic and bonding property.

The purpose of this work is to to identify the effects of OME spreading on water retention of soil located in the Sidi Bou Ali region and its effect on soil behaviour followed over time.

Materials and methods

Site characterization and experimental approach

For this study, a field experiment was conducted in Sidi Bou Ali (Tunisia). The region of Sidi Bou Ali is part of a semi-arid superior climate level. It is characterized by a temperate climate with mild winters and hot summers. Part of the Tunisian Sahel (coastal area), the region of Sidi Bou Ali is characterized by a large temporal variability inter and intra-annual of rainfall [12]. The OME used in this study was collected from olive mills near the experimental site.

The soil is characterized by sandy loam texture. The soil sampling was conducted monthly for 4 months after spreading (D_1, D_2, D_3 and D_4), at two layers P_1 and P_2 (0 - 20 cm and 20 - 40 cm).

Experimental design

Two doses of OME were selected for spreading in the field, including 25 (T_1) and 50 (T_2) m^3/ha compared to untreated control (T_0). The choice of doses referred to previously supported studies on OME agronomic impacts. For example, Fiestas Ros de Ursinos *et al*. [1] recommended an optimal dose of 100 m^3/ha for OME containing 1.5 to 4.5 % dry matter, or an average of 3 %. In the present work, the rate of active matter ingredient of OME is 7.5 %. It follows that the quantities to be applied should be between 20 to 60 m^3/ha.

Physical analysis

On the basis of a physical model through the capillary porous medium, the effects of OME on water retention of the soil were studied.

To study the effect of OME on water retention of the soil, pF curves were established. Thus, the humidity at different potentials matrixes was determined as ranging from −10 cm (± to saturation) to −15,300 cm (permanent wilting point). The moisture content of soil at field capacity was determined on samples subjected to a depression of −200 cm.

The potential matrix −614 cm and the permanent wilting point equal to −15300 cm [13,14] were achieved through the method of Richards [15]. The potential matrixes −10, −50, −100 and −200 cm, were made by the method of water column at constant load [14,16]. The model of Van Genuchten [17] was applied for smoothing the curves of water retention θ (h), using the experimental values, with the following equation;

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

where θr and θs are the volumetric water content and residual saturation, and α, m and n are the adjustment coefficients with m = 1 - 1/n [18].

Statistical methods

All analyses were performed in triplicate. The statistical treatment of results was achieved by using the software STATISTICA (V). The results were linked to an analysis of variance to one factor by performing the test of Fisher-Snedecor at the risk threshold of 5 %. It was complemented by multiple comparisons of averages by the LSD test according to Robert Steel [19] and Dagnelie [20].

Results and discussion

OME treatment effect on water retention

Parameters of the equation of Van Genuchten [17,18] (**Table 2** and **4**) were determined with the experimental values of water retention (**Table 1** and **3**). Thus, smooth curve was established by comparing the values of pF depending on the moisture content according to the treatments (T_0, T_1 and T_2) and date (D_1, D_2, D_3 and D_4) after spreading for the 2 horizons (0 - 20 and 20 - 40 cm).

Table 1 Experimental values of moisture (m^3/m^3) desorption in soil treated by surface spreading of OME in situ, mean ± standard deviation of 3 repetitions (P_1).

Date			D1		D2		D3		D4	
h (cm)	**PF**	**T0 (Control)**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
-10	1	**0.593 a* ± 0.0478**	0.558 a ± 0.0108	0.531 a ± 0.0264	0.492 b ± 0.0027	0.491 b ± 0.0127	0.509 ab ± 0.0009	0.498 b ± 0.0182	0.484 b ± 0.0263	0.495 b ± 0.0126
-50	1.7	**0.354 a ± 0.0021**	0.325 ab ± 0.0171	0.311 b ± 0.0242	0.332 a ± 0.0074	0.335 a ± 0.0036	0.326 ab ± 0.0045	0.340 a ± 0.0026	0.325 ab ± 0.0426	0.269 b ± 0.0259
-100	2	**0.284 a ± 0.0092**	0.23 b ± 0.0239	0.218 b ± 0.0157	0.258 a ± 0.0268	0261 a ± 0.0279	0.254 a ± 0.02	0.27 a ± 0.0673	0.252 ab ± 0.0232	0.219 b ± 0.212
-200	2.3	**0.221 a ± 0.0035**	0.2 a ± 0.0308	0.17 b ± 0.021	0.213 ab ± 0.0081	0.192 a ± 0.0198	0.202 a ± 0.0013	0.211 a ± 0.03	0.2 a ± 0.0308	0.135 b ± 0.021
-614	2.79	**0.198 a ± 0.0188**	0.197 a ± 0.0342	0.169 a ± 0.0132	0.149 a ± 0.009	0.142 b ± 0.0112	0.172 a ± 0.0045	0.169 a ± 0.0169	0.158 b ± 0.0136	0.151 b ± 0.0137
-15300	4.18	**0.135 a ± 0.0021**	0.126 a ± 0.0139	0.124 a ± 0.0116	0.116 a ± 0.0051	0.111 b ± 0.0038	0.125 a ± 0.0012	0.126 a ± 0.0110	0.119 b ± 0.0080	0.119 b ± 0.0082

At a given potential matrix for each sampling date separately, the same letter in a line indicates that the averages are not significantly different with the test of Fisher-Snedecor at a probability level of 95 %.

Table 2 Values of parameters of the relationship θ (h) for P_1, according to the Van Genuchten model (1978 and 1980).

	Dose m^3/ha	θ_s	θ_r	a	n	m	R^2
D_1	0	0.630	0.13	0.053	1.679	0.595	0.992
	25	0.565	0.126	0.064	1.58	0.632	0.964
	50	0.550	0.124	0.054	1.76	0.568	0.968
D_2	0	0.630	0.13	0.053	1.679	0.595	0.992
	25	0.494	0.116	0.039	1.63	0.613	0.997
	50	0.50	0.115	0.023	2.015	0.496	0.999
D_3	0	0.630	0.13	0.053	1.679	0.595	0.992
	25	0.510	0.120	0.053	1.534	0.651	0.986
	50	0.510	0.120	0.030	1.708	0.585	0.994
D_4	0	0.630	0.13	0.053	1.679	0.595	0.992
	25	0.50	0.130	0.034	1.867	0.535	0.998
	50	0.509	0.111	0.048	1.825	0.547	0.988

Table 3 Experimental values of moisture (m^3/m^3) desorption in soil treated by surface spreading of OME in situ, mean ± standard deviation of 3 repetitions (P_2).

Date			D1		D2		D3		D4	
h (cm)	**PF**	**T0 (Control)**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
-10	1	**0.552 a ± 0.0465**	0.53 a ± 0.0247	0.505 a ± 0.0473	0.519 a ± 0.0277	0.508 a ± 0.0535	0.476 a ± 0.0055	0.480 a ± 0.0064	0.449 b ± 0.0175	0.440 b ± 0.025
-50	1,7	**0.389 a ± 0.0282**	0.363 a ± 0.0322	0.285 b ± 0.0321	0.335 b ± 0.0011	0.305 b ± 0.046	0.322 b ± 0.0356	0.301 b ± 0.0921	0.292 b ± 0.0292	0.261 b ± 0.0331
-100	2	**0.281 a ± 0.0175**	0.254 a ± 0.0202	0.258 a ± 0.034	0.307 a ± 0.0475	0.275 a ± 0.0064	0.292 a ± 0.0003	0.270 a ± 0.0752	0.238 b ± 0.0185	0.226 b ± 0.0262
-200	2,3	**0.213 a ± 0.0639**	0.190 a ± 0.0341	0.194 a ± 0.0523	0.230 a ± 0.0374	0.200 a ± 0.0107	0.232 a ± 0.0035	0.199 a ± 0.0292	0.162 b ± 0.009	0.161 b ± 0.0099
-614	2,79	**0.193 a ± 0.0047**	0.198 a ± 0.0146	0.181 a ± 0.0183	0.180 a ± 0.0156	0.181 a ± 0.0031	0.174 ab ± 0.007	0.165 a ± 0.0153	0.156 b ± 0.0126	0.147 b ± 0.0148
-15300	4,18	**0.141 a ± 0.0121**	0.118 b ± 0.0102	0.120 b ± 0.0064	0.129 a ± 0.0112	0.125 a ± 0.0161	0.174 b ± 0.0064	0.119 a ± 0.0094	0.117 b ± 0.0082	0.111 b ± 0.0075

At a given potential matrix for each sampling date separately, the same letter in a line indicates that the averages are not significantly different with the test of Fisher-Snedecor at a probability level of 95 %.

Table 4 Values of parameters of the relationship θ (h) for P_2 according to the Van Genuchten model (1978 and 1980).

	Dose m^3/ha	θ_s	θ_r	a	n	m	R^2
D_1	0	0.60	0.130	0.043	1.708	0.585	0.992
	25	0.554	0.110	0.045	1.607	0.622	0.982
	50	0.540	0.120	0.064	1.626	0.614	0.979
D_2	0	0.60	0.130	0.043	1.708	0.585	0.992
	25	0.540	0.12	0.030	1.696	0.589	0.998
	50	0.550	0.107	0.048	1.539	0.649	0.986
D_3	0	0.60	0.130	0.043	1.708	0.585	0.992
	25	0.480	0.117	0.024	1.705	0.586	0.999
	50	0.485	0.110	0.035	1.616	0.618	0.993
D_4	0	0.60	0.130	0.043	1.708	0.585	0.992
	25	0.470	0.110	0.040	1.774	0.563	0.989
	50	0.460	0.100	0.050	1.690	0.591	0.986

P1 layer

On the basis of the values of water content, the effects of OME spreading and that of the applied tension during the 4 months following spreading are significant (**Table 1**).

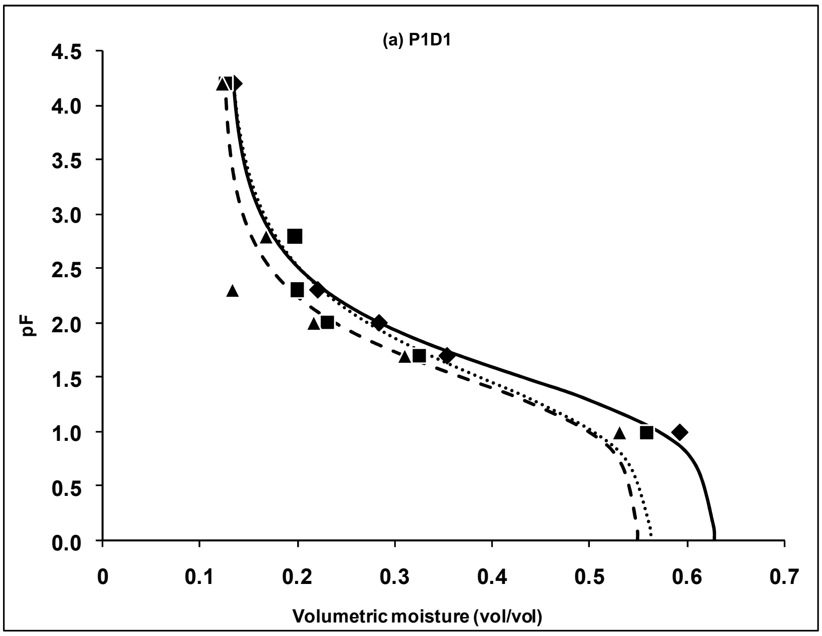
Figure 1 shows that at D_1, there is no difference between the potentials matrixes from pF 4.3 to 2.2 between T_0 and T_1 (no significant difference between the potentials matrixes for −10, −614 and −15,300 cm). Treatment T_2 differs from T_0 and T_1 on the all potentials matrixes while it is in conjunction with different T_1. At D_2, it follows that T_1 and T_2 are generally different from T_0. It is on pF 1.7 that the potential difference was not obtained for T_2. At D_3, no difference was evident for all potentials, except at pF below 2 for T_1 and pF below 1.7 for T_2. At D_4 treatment T_2 were different compared with T_0 for all potentials matrixes (T_2 was significantly different from T_0, and is similar to T_1 for all potentials except at −200 cm).

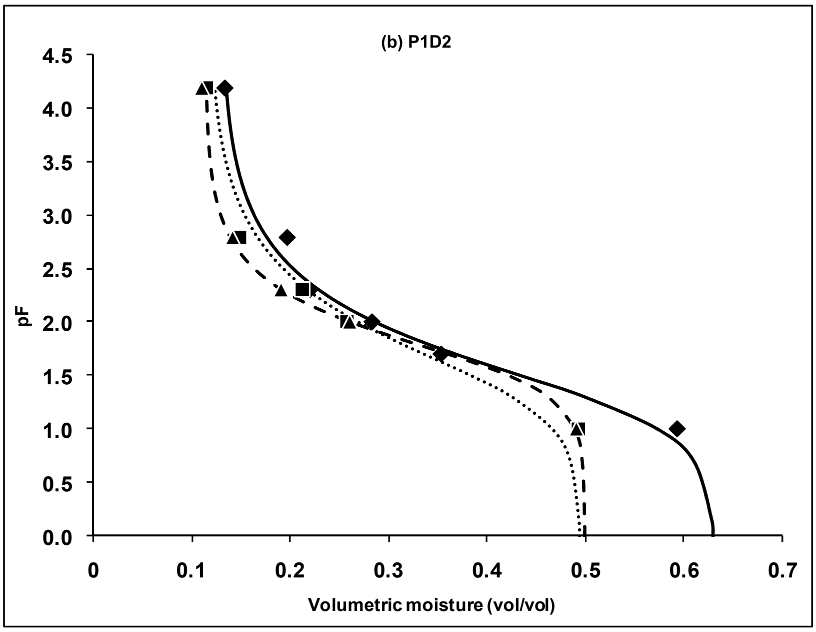
These results confirm that the spreading of OME results in the establishment of a mulch on the topsoil [9-11].

P2 layer

Figure 2 and **Table 3** show that, from almost the potential matrix of pF 4.3 to pF 1.7, a similarity of curves was noted for dates D_1, D_2 and D_3. It was only for the potential matrix of −50 and −15,300 cm that significant differences appeared in the moisture for dates D_1 and D_3. For D_2, no significant differences were found. In contrast, after fourth months post OME spreading (D_4) a significant difference between the control and treatments T_1 and T_2 occurred for each potential matrix, with a similarity between T_1 and T_2.

Overall, it was clear that OME spreading significantly reduced the retention of water for all potentials matrixes after the fourth month, in the surface and in depth. It appears that after the fourth month, the active material of OME (including organic matter and oil) begins to act effectively on the physical characteristics of the soil.


(a) P1D1
pF
Volumetric moisture (vol/vol)


(b) P1D2
pF
Volumetric moisture (vol/vol)

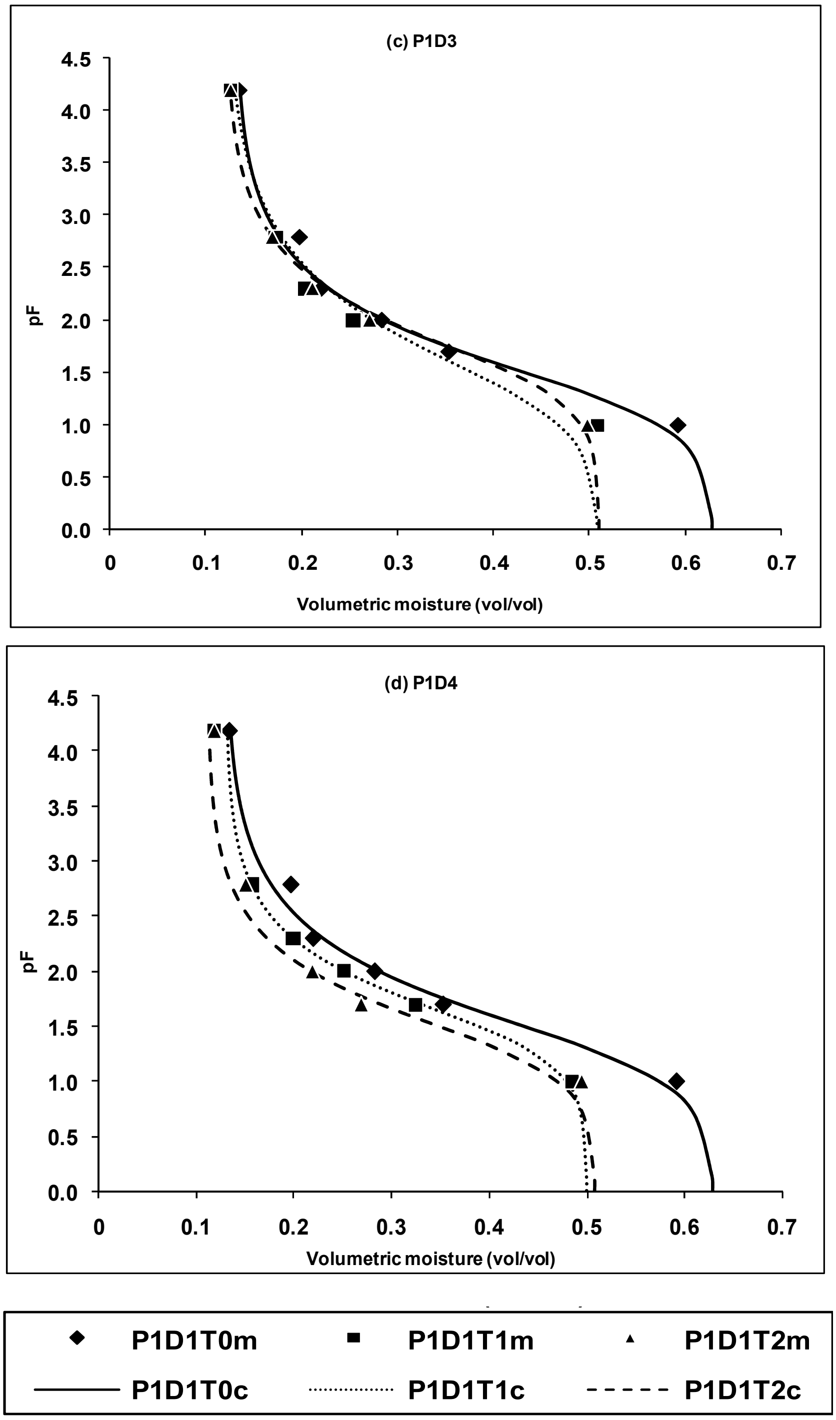
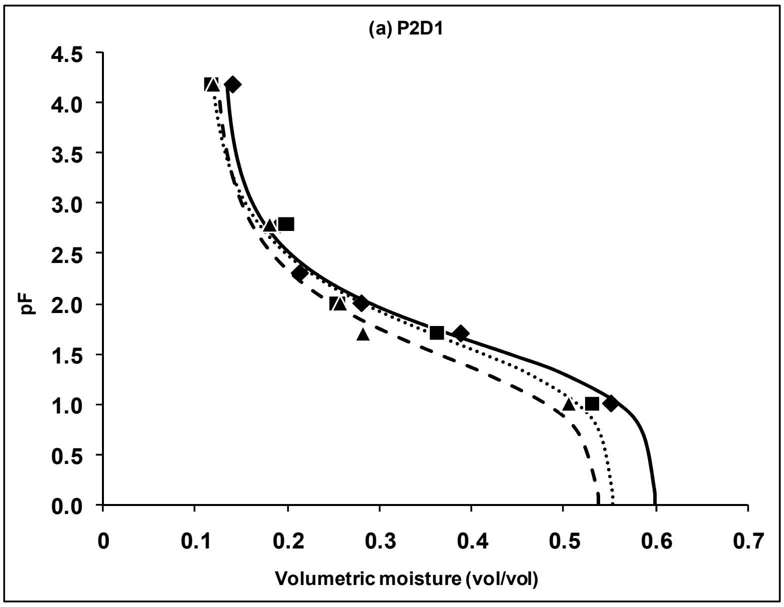
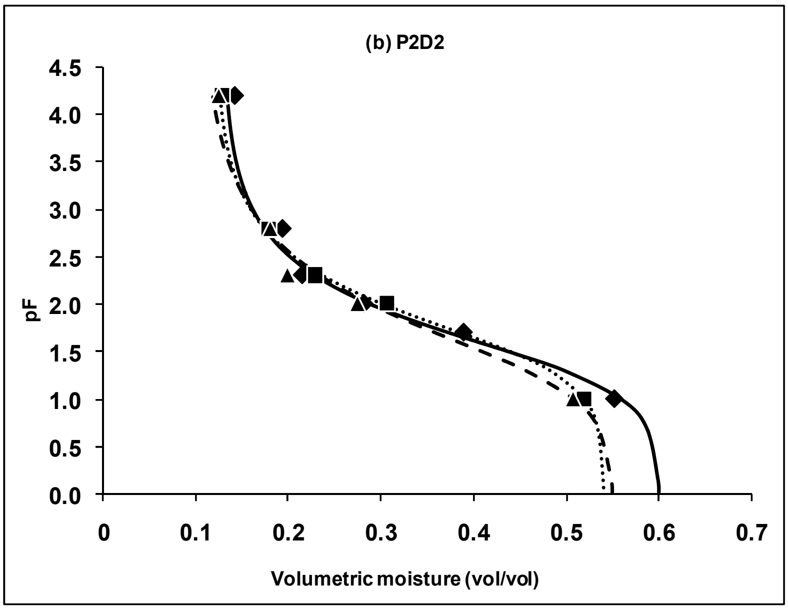


Figure 1 Effect of OME spreading on the retention of water for the date D_1 (a), D_2 (b), D_3 (c) and D_4 (d) at the horizon P_1.

a) The symbols correspond to experimental values (m) and the lines represent the curves predicted by the model of van Genuchten (c)


(a) P2D1
pF
Volumetric moisture (vol/vol)


(b) P2D2
pF
Volumetric moisture (vol/vol)

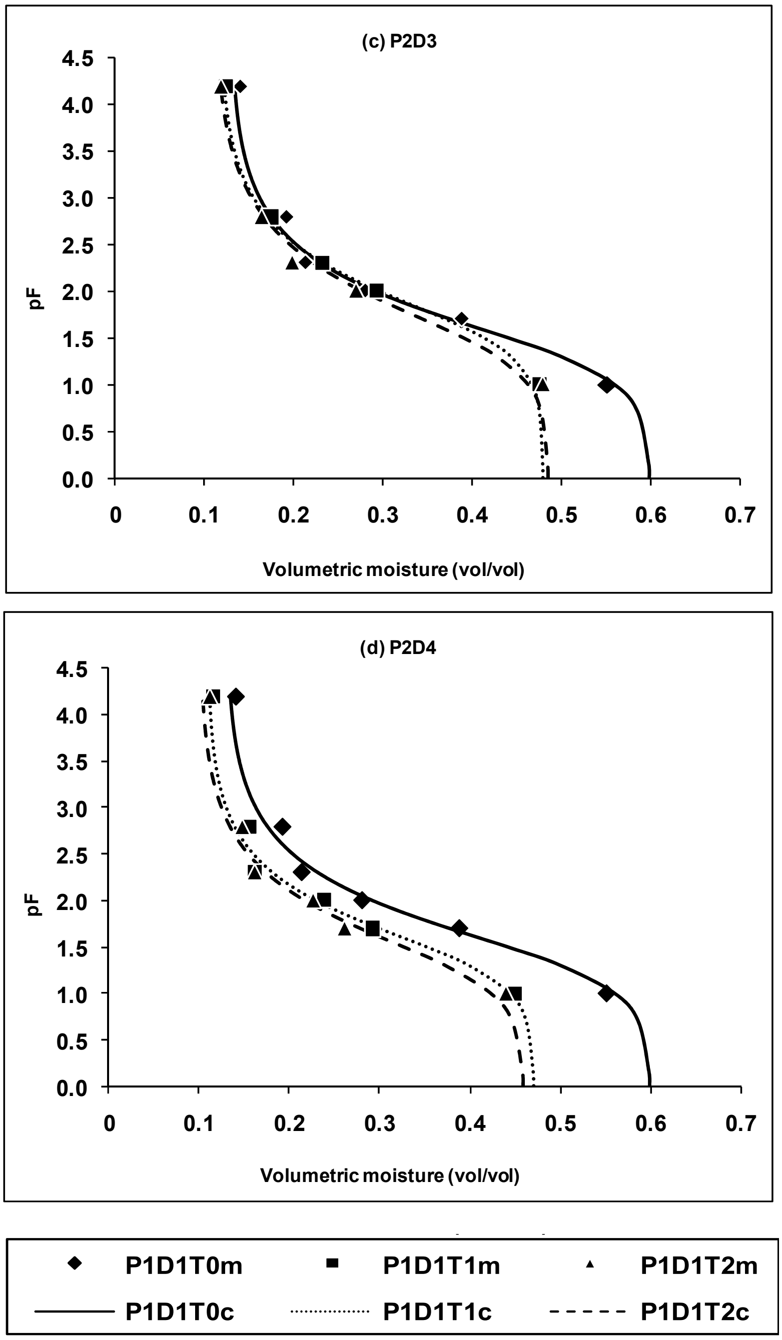


Figure 2 Effect of OME spreading on the retention of water for the date D_1 (a), D_2 (b), D_3 (c) and D_4 (d) at the horizon P_2.

a) The symbols correspond to experimental values (m) and the lines represent the curves predicted by the model of van Genuchten (c)

Discussion

The reduction in retention at P_2 confirms the migration process of OME from the surface P_1 to P_2. Furthermore, significant changes of water retention at P_1 confirm the effect of OME by improving aggregation, and the implications on the hydrodynamic characteristics of soil are shown by [11]. These results indicate that soil texture, homogeneous along its profile, has acquired a new hydrodynamic behaviour that can be simulated in stratified soil. In cases where the effect of migration of OME would be negligible in the P_2 horizon, the soil can be simulated in two layers; the first is of a coarser texture than the latter. Otherwise, and since the effect of OME is more significant in the topsoil P_1 at the level of the underlying P_2, the soil would behave like a multi layered soil (3 layers) increasing in fine texture from the topsoil.

In both cases, it results in a change in the movement of water by capillary action, as the topsoil is a barrier reducing the water transfer to the atmosphere. Thus, referring to the concepts of soil physics [21,22], the work of Modaihsh *et al*. [23] and Bousnina [24] on the benefit of a mulch of sand on a finer textured soil to reduce evaporation from bare soil, and especially the work of Hillel and Talpaz [25], it can be concluded that the layer surface could act as a mulch that modifies the behaviour of water in the soil profile and reduces water loss by evaporation.

The results of this work on the physical effects of OME on the field showed that the spreading of this effluent did not have negative environmental impacts on agricultural land. In general, the study has confirmed the effects of their hydrophobic and binding characteristics and reached the following conclusions;

(i) A decrease in water retention in the 2 horizons, with a greater importance in the surface horizon, was noticed during all the dates of the experiment, starting from spreading the OME over the soil.

(ii) The changes of soil physical properties were particularly more pronounced in the surface than the underling horizon. These indicate that consistent texture throughout its profile, has acquired a new hydrodynamic behaviour that can be simulated to a stratified soil, with layers of texture, becoming finer from its surface. The topsoil plays the role of a hydrophobic mulch modifying, the behaviour of water in the soil profile, and reducing water loss through evaporation. This is a sought-after attribute for water conservation, especially under rainy conditions in arid and semi-arid environments.

(iii) The OME hydrophobicity, transmitted to the soil by a reduction in its retention, resulted in association with the severity, leading to an intensification of the infiltration process. Also, the stimulation of the infiltration process allows a better distribution of water depth in the soil. It can be concluded that the soil surface becomes immune to the conditions of evaporative environment.

Conclusions

The valorisation of OME and its use as water for irrigation in agriculture is an attractive prospect for Mediterranean countries in which water resources are scarce. For this reason, agronomic spreading of OME effects on soil physical properties was investigated.

From this field experiment on OME spreading, some beneficial conclusions were derived. The OME spreading showed a favourable effect by decreasing evaporation losses. This is due essentially to the decrease in water retention, especially in the topsoil. It is well established that OME hydrophobicity and adhesivity were responsible for these soil physical change properties that lead to a layered soil, from a texture coarser in the topsoil to a fine texture. Although the data indicated that physical properties were changed, considerably more research would be needed to determine the duration of these changes over a time period of 1 or more crop seasons.

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