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Research Article
Effect of Olive Mill Solid Waste on Soil Physical Properties

Ghaida Abu-Rumman

Deptarment of Civil Engineering, Isra University, Jordan

Abstract

Background and Objective: Addition of organic wastes to agricultural soils is becoming a common practice as a disposal strategy and to improve the physical and chemical soil properties and increase the soil productivity. Amendments of agricultural lands with olive pomace become a common practice in the middle East. However, the olive mills waste contains small fraction of oil which might affects soil water retention and infiltration. The objectives of this study were to investigate changes in soil physical properties resulted from the addition of Olive Mill Solid Waste (OMSW). The properties studied were: Penetration depth, water holding capacity, accumulated intake and bulk density. **Materials and Methods:** The Olive Mill Solid Waste (OMSW) at three rates: 3, 6 and 9% by weight were added to two soils classified as clay (clay 55, silt 25 and sand 20%) and sandy clay (sand 55, clay 40 and silt 5%) soils. A pressure plate apparatus was used to construct soil water retention curves at a pressure varies between 0.30 (Wilting) to 1500 kPa (Saturation). The infiltration tests were performed using FEL5 demonstration infiltration apparatus. **Results:** The application of (OMSW) significantly improved the physical properties of the soils studied relative to untreated soil (control). For clay soil and application rate of 9%, the penetration depth and accumulated water intake were increased 30 and 29%, respectively. The corresponding increases in sandy clay soil were 25 and 32%, respectively. At application rate of 9%, the soil (WHC) increased were 10.3 and 16.5% for clay and sandy clay soils, respectively. Accumulation intake increased as application rate increased; while bulk density decreased as a result of the dilution effect resulting from mixing organic matter with the more dense soil minerals. **Conclusion:** Applications of OMSW increases the organic content of the soil and at the same time reduces its bulk density. The increase in (WHC) at field capacity and wilting point can be attributed to changes in soils textures which resulted from increases in soil organic C. The Water Holding Capacity (WHC), penetration depth and accumulated infiltration increased as (OMSW) application rates increased. The increases in (WHC) depend on soil texture, for fine-textured soils, the increase in (WHC) at wilting point is less than at field capacity. The opposite occurred in coarse-textured soils as a result of sand fraction, significant increase in (WHC) at wilting point rather than at field capacity.

Key words: Soil, organic matter, bulk density, water holding capacity, infiltration, intake, pomace, soil amendments

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Corresponding Author: Ghaida Abu-Rumman, Deptarment of Civil Engineering, Isra University, Jordan

Competing Interest: The author has declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Olive trees cultivation has been connected to life, economy and become a common practice for the Mediterranean countries since ancient times. The beneficial effects on health from the consumption of olives and olive oil have been recognized worldwide. The process of olive oil extraction has been improved over time in terms of production efficiency and product quality. However, the problem of the produced wastes still represents a major concern for the olive oil producing countries.

The two main olive mill waste types are: The solid wastes and the liquid wastes which account for 80% of the total production. Solid wastes are comprised mainly from trees branches, leaves and the mixture of olives skins and pits. Liquid wastes are a mixture of water that has been used in washing the olives and during the extraction process, in addition to the olive juice and residual during separations processes[1,2]. It is estimated that more than 800 million olive trees are cultivated all over the world[3]. Most of these cultivations and productions occur in the Mediterranean region as shown in Fig. 1. The annual production of table olives and olive oil reaches up to 10 and 2000 million tones, respectively. The Olive Mill Waste (OMW) generation reached 30 million tons annually in Mediterranean basin[4,5]. Jordan has 25 million olive trees, which produce 220,000 t of olive annually, 35,000 t of oil and 60,000 t of olive pomace[2,6].

Agricultural lands in many parts of the Mediterranean region are poor in organic matter, exposed to excessive erosion and progressive degradation processes. Currently, the local practice involves adding fertilizers or untreated animal waste (manure) to improve soil properties and productivity. The concentration of organic load in the solid waste called (pomace or olive cake) from the three-phase olive mills reaches 94% of the dry weight, a fact that is considered beneficial for the cultivations[7]. Amendment of agricultural soils with the OMW has been considered as a disposal practice in addition to improve the physical and chemical soil properties[6,8,9]. Soil application of wet pomace, a lignocelluloses organic material, a by-product of the olive milling process, allows an overall fertility improvement. Soil organic matter and nutrient content increased without altering pH and salinity; moreover, soil structure improved significantly[10]. The germination index, biomass, plant growth and productivity

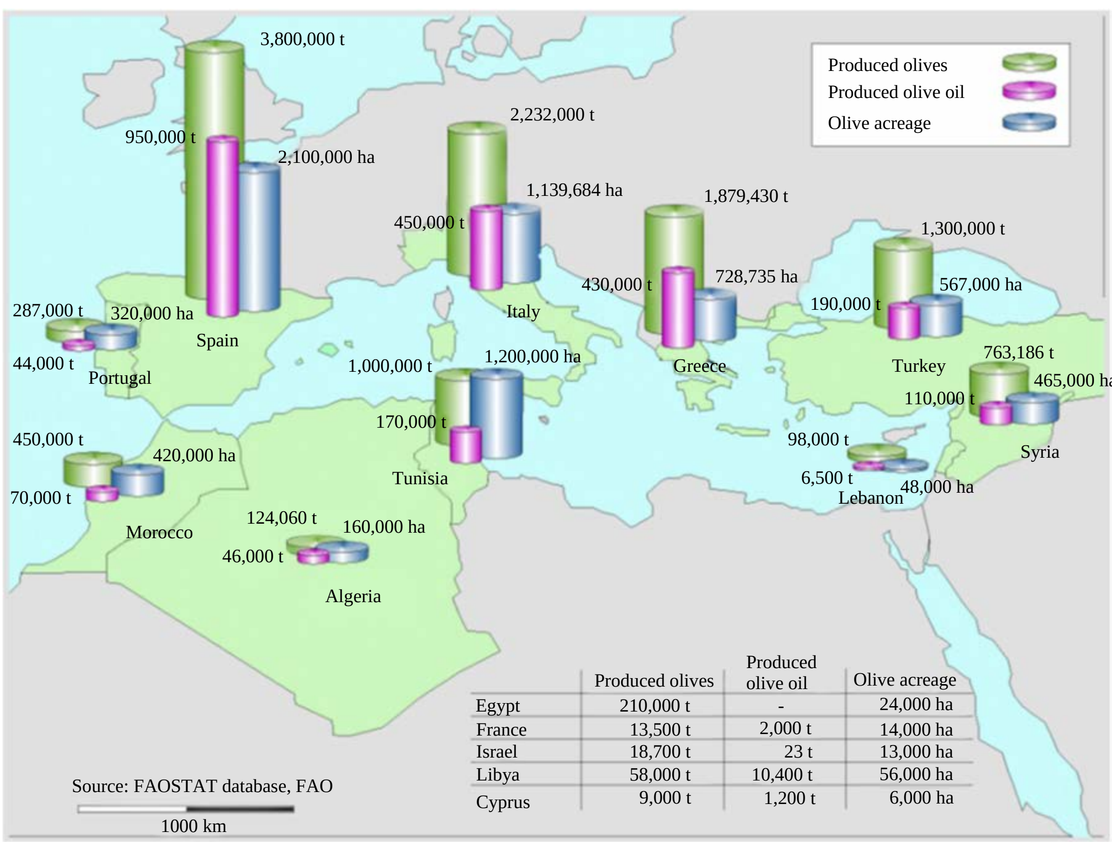

Fig. 1: Olives and olive oil production in the Mediterranean basin

were increased when seeds species were cultivated with treated olive mill waste as reported by Barbera *et al.*[11] and Mekki *et al.*[12]. On the other hand long-term uncontrolled disposal of raw olive Oil Mill Wastes (OMW) on soils may affect soil properties and subsequently enhance the risk for groundwater contamination[13].

The additions of the olive-mill waste from a three-phase mill as an organic amendment can improve soil quality and supply nutrient to the plants and crops[14]. Application of wastes to agricultural lands increases the carbon (C) content of the soil. As a result of that soil aggregation increases but bulk density decreases, this increases soil (WHC) and its hydraulic conductivity. The study objectives were to investigate changes in soil physical properties resulted from the addition of (OMSW) at different application rates. The properties studied were: Bulk density, penetration depth, Water Holding Capacity (WHC) at field capacity (around 0.30 kPa) and at wilting point (1500 kPa).

MATERIALS AND METHODS

The effect of Olive Mill Solid Waste (OMSW) addition on soil physical properties was examined for two soils types; namely: Sandy clay and clay. The soils samples were obtained from the top soils surfaces, dried and passed through a 2 mm strainer to remove large residue fragments. The soil moisture was very low (0.8-1.15% w/w) obtained by drying soil samples in oven for 24 h, in addition to low organic content (0.18% w/w) and nitrogen (0.60 g kg^{-1}). The olive mill solid waste (OMSW) as shown in Fig. 2 was collected from a three-phase olive mill, freeze-dried and ground to pass through a 1 mm sieve. Selected chemical and physical characteristics of the soils (soils textures, organic matter, total N and density) are shown in Table 1. Three replicates were performed for each soil sample at three (OMSW) rates namely; 3, 6 and 9% on dry weight basis. For each test OMSW was added to the soil and mixed thoroughly before used.

The characteristics of the (OMSW) are shown in Table 2, which include: Density, moisture content, conductivity, pH, total nitrogen, C/N ratio, N, P, K and ash.

Fig. 2: Olive Mill Solid Waste (OMSW) from three-phase mill

Table 1: Soils classification

Texture	Sandy clay	Clay
Sand (%)	55	20
Silt (%)	5	25
Clay (%)	40	55
Organic Matter (OM) (%)	0.15	0.21
Nitrogen (N) (g kg^{-1})	0.60	0.65
Density (kg m^{-3})	1250	1150

Table 2: Physicochemical properties of olive mill solid waste (OMSW)

Property	Values
Temperature	25°C
Moisture content (fresh weight (%))	70
pH	5.40
Conductivity (dS m^{-1})	4.35
Total nitrogen (g kg^{-1})	12.4
Carbon/Nitrogen (C/N)	32.2
Phosphorus (P) (g kg^{-1})	0.90
Sodium (Na) (g kg^{-1})	0.70
Potassium (K) (g kg^{-1})	0.90
Calcium (Ca) (g kg^{-1})	2.3
Total organic carbon (TOC) (g kg^{-1})	590
Ash (g kg^{-1})	72.4

Soil Water Retention (SWR) curves: The pressure plate apparatus was used to construct Soil Water Retention (SWR) curves at a pressure varies between 0.30 (Wilting) to 1500 kPa (Saturation), according to ASTM D2325-68[15]. Three replicates were conducted for each soil sample, using 70 mm diameter PVC rings. The soil samples were saturated by distilled water. The soil moisture contents were evaluated at different suction pressure, namely; 30, 50, 100, 500, 1000 and 1500 kPa. The SWR curves constructed for each soil represent the averages of the pressure plate tests from all rings.

Infiltration: The infiltration tests[16] were performed using FEL5 Demonstration Infiltration Apparatus-Issue 1. The apparatus has a height of 0.9 m, a width of 0.50 and 0.40 m depth. Soil samples were mixed thoroughly and filled gradually to avoid segregation of soil particles in cylinders up to 380 mm mark in the apparatus. Water discharge was collected by 500 mL beakers placed below the three infiltration cylinders. The initial soil and water surfaces were marked. Each cylinder received equal head of water of 100 mL at the same time. As the wetting frontage advanced, the differences between water and soil surface level were recorded at time intervals of (1, 3, 5, 7, 9, 20, 35, 47, 60, 75, 90, 110, 170, 250 min and after 24 h). The accumulated water intake in the soil was determined using the following Eq. 1-3:

$$I_D = I_W - I_S \quad (1)$$

$$H_D = H_W - H_S \quad (2)$$

$$A_I = I_D - H_D \quad (3)$$

where, I_D is the initial depth, I_W and I_S are the initial water and soil surface heights, respectively, H_D is water depth as time elapsed and H_W and H_S are the heights of water and soil surface, receptively and A_I is the accumulated intake calculated from Eq. 3 after the data collected throughout the tests.

RESULTS AND DISCUSSION

The parameters tested for clay and sandy clay soils at different (OMSW) application rates were: Bulk densities, organic carbon, Soil Water Retention (SWR), infiltration and accumulation. Each test was run in triplicates and their averages were used to estimate the parameter investigated.

The results showed large changes in soils Bulk Densities (BD), Water Holding Capacity (WHC) and infiltration rate as a result of (OMSW) additions. Limited available results showed that waste addition to soil may improve the initial and the steady-state infiltration rate. Others studies showed that water holding capacity, the salinity, the organic carbon content, humus, total nitrogen, phosphate and potassium increased when the spread amounts of organic waste increased.

Soil Water Retention (SWR) curves: Water repulsion by hydrophobic groups of organic molecules which are presented in the waste or formed during waste decomposition temporarily reduces the soil ability to retain water, thus, water available for plants decreases[17,18]. When the concentrations of hydrophobic organic substance in the waste decrease, positive effect on soil water retention is exerted directly due to the organic matter hygroscopicity and indirectly linked to micro porosity improvements[11].

Water holding capacity: Several researchers have reported that Water Holding Capacity (WHC) increased as waste application rates increased at field capacity and wilting

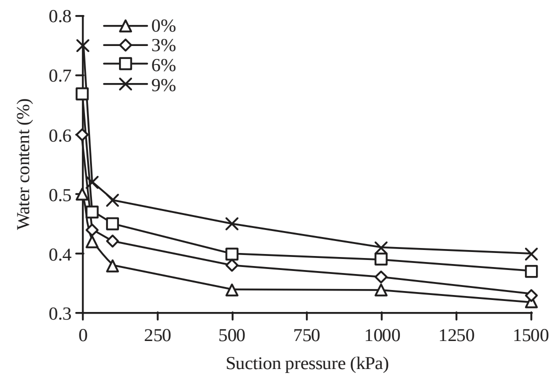

Fig. 3: Water content-suction curves for clay soil as affected by (OMSW) amendments. Values are the means of three replicates

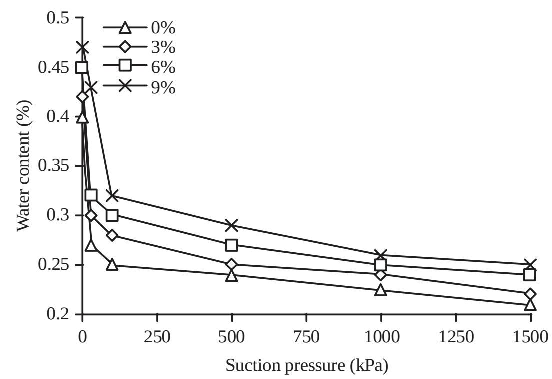

Fig. 4: Water content-suction curves for sand clay soil as affected by (OMSW) amendments. Values are the means of three replicates

holding capacity is affected mainly by pores numbers, size distribution and the soil surface area. Waste application point[19]. Soil water increased soil aggregation; hence total pore space is increased. Also as a result of bulk density decreases, the number of small pores increases and the pore-size distribution is changed, especially for soils with coarse texture. The effective diameter of the pore play an important role in pores drain, so bigger tension is needed to drain small pores relative to large ones. So, the increases in (WHC) at lower tensions say at field capacity may be attributing to the boost in small pores numbers[19].

The effects of adding Olive Mill Solid Waste (OMSW) on Soil Water Retention (SWR) curves for clay soil is shown in Fig. 3, while for sandy clay soils is presented in Fig. 4. The results showed that as the (OMSW) application rates increased, water holding capacity (WHC) increased and this increase is proportional to OMSW application rates. For example, compare to the untreated sample, the increase in WHC were

10, 21 and 31.5% for treated clay soil at application rates of 3, 6 and 9% of (OMSW), respectively. For sandy clay, the corresponding increase was 7.5, 14.8 and 25.9%, respectively. Statistical analysis[20] were carried out using the Minitab 15. The result indicated that at a significant level of 0.05 significant differences existed between the untreated and treated soils at OMSW application rates of (3, 6 and 9%).

The increases in soil (WHC) for the two soils may be as a result of organic content increases as (OMSW) added. For clay soil, the organic content increased by 2.90, 4.5 and 6.35% at (OMSW) application rates of 3, 6 and 9%, respectively. For sandy clay, the corresponding increases were 1.95, 2.75 and 5.20% at application rates of 3, 6 and 9%, respectively. The Available Water Capacity (AWC) for untreated clay soil was 10.50 % increased to 14% for the amended soil, on the other hand sandy clay soil, (AWC) was 4.9% increased to 10% after amendments with OMSW. The Available Water Capacity (AWC) is defined as difference between moisture contents at 30 kPa (filed capacity) and at 1500 kPa (wilting point).

At higher tensions range near the wilting point, most pores are filled with air and the available water is controlled by the pore surface area and water films thickness on these areas. Clayey soils have larger surface area compared to sandy soils; consequently hold more water at higher tensions. The surface area increases as organic matter added, resulting in increased (WHC) at higher tensions. The increases in (WHC) were observed for fine and coarse textured soils at field capacity and wilting point but, increases in fine textured soils were less than coarse textured soils. Such differences in (WHC) increases among different soil classes are also reported in the work of Khaleel *et al*.[19] reviewed the effects of adding organic matter as soil amendment for wide range of soils textures.

Bulk Density (BD): Substantial data is existing related the effects of organic matter addition on soil bulk density indicated a decrease in (BD) with organic additions. This reduction in (BD) can be attributed to the dilution effect resulting from mixing organic matter added with the more dense soil minerals. In agreement with these results, the effect appeared to be more obvious for coarse textured soils than fine textured. This may be tended to reduce soils erosion as a result of soil aggregation improvement[19]. Compared with soil alone, bulk density of clay soil decreased by 11.5, 13.7 and 22.8% as the application (OMSW) rates increased 3, 6 and 9%, respectively.

Infiltration

Penetration depth: The effect of adding (OMSW) on penetration depth is shown in Fig. 5 for clay soil. Figure 5

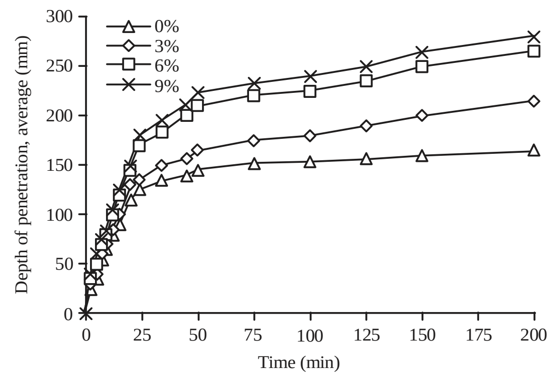

Fig. 5: Effect of (OMSW) application rates on depth of penetration for clay soil. Values are the means of three replicates

shows that the penetration depths at the beginning of the experiment were similar for the treated and untreated soils. This is due to the increase in soil (WHC) as organic matter added, hence the reduction in water advance and penetration in response. The amended soil holds its maximum water capacity, after that it moved down below the wetted zone. Figure 5 shows that penetration depth increased as application rates increased with highest at 9% rates. All amended soils samples reached their maximum water holding capacity after 50 min, while it took untreated sample (control) 60 min. The depths of penetration in the clayey soil after 100 min increased by 17, 46 and 56% at application rates of 3, 6 and 9%, respectively. On the other hand, the corresponding increased in penetration depth for the untreated sample was 150 mm after 200 min from the start as shown in Fig. 5. The increase in penetration depth for the untreated soil after 24 h was not noticeable relative to treated soil as shown in Table 3. On the contrary, the penetration depth after 200 min was 180 mm and reached 215 mm after 24 h, for amended soil with (OMSW) at application rate of 3%. After 200 min, the penetration depths reached 240 mm and 260 mm at application rates of 6 and 9%, respectively. The depths of penetration reached the bottom of the cylinders in less than 24 h.

The effect of (OMSW) addition on penetration depth for sandy clay is illustrated in Fig. 6. The increases in penetration depths for treated clay soil as a function of applications rates of 3, 6 and 9% OMSW were 13.6, 38.5 and 40.5%, respectively. The penetration depth reached the cylinders bottom after 100 min at application rates of 6 and 9%. Similarly, for sandy clay soil, the increased in penetrations depths were proportional to the rate of (OMSW) applications. At application rate of 3%, the penetration depth for sandy clay soil was 270 mm after 24 h. from OMSW relative to 150 mm for the untreated sample. The addition of (OMSW) increased the soil organic content, which favor large soil aggregates formations, hence resulted in larger penetration depth.

Accumulated intake: The cumulative water intake for clay soil was affected by the addition of (OMSW) as shown in Fig. 7, which indicates an increased of the cumulative water increase as the application rates of the OMSW increased. Figure 7 shows that water absorbed by topsoil until reached their capacity and then water started to advance down. It took 50 min to notice the effect of adding 3% of OMSW to the amended clayey soil. The untreated sample reached a maximum water accumulated intake of 65 mL after 50 min

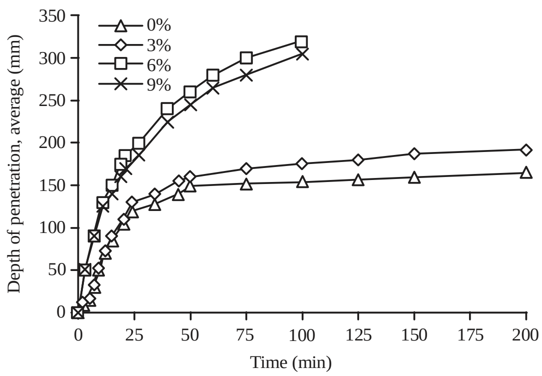

Fig. 6: Effect of (OMSW) application rates on depth of penetration for clay soil. Values are the means of three replicates

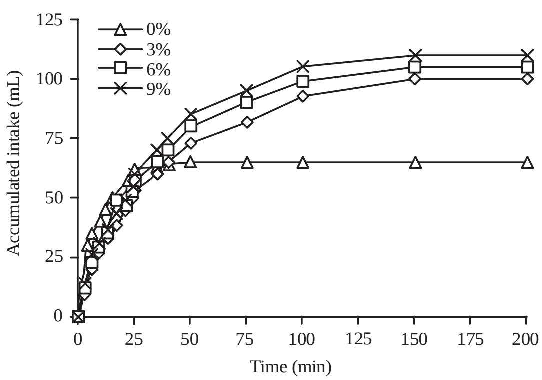

Fig. 7: Effects of OMSW application rates on water accumulated intake (mL) for clay soil. Values are the means of three replicates

and stayed unchanged for 24 h. On the other hand, the treated sample reached a total of 110 mL after 24 h. The addition of organic material to poor structure texture such as the clayey soil, improves its aeration and water infiltration[21]. In addition, the humus portion of waste reduces the stickiness and cohesion of clayey soils[22].

The (OMSW) is a coarse filament and granular in shape which might change soil physical properties by working as a bulking material. The effect of adding (OMSW) to sandy clay on accumulated intake is illustrated in Fig. 8. Figure 8 showed that for the first 50 min, there was little difference between the treated and untreated soils at application rate of 3% of (OMSW), later difference begin to appear indicating that increases in the accumulated intake take place, while the untreated sample stopped absorbing water after 150 min. For example, the average accumulated intake was 70 mL after 150 min for sand clay soil treated with 3% OMSW as shown in Table 3, while for the untreated soil it reached 63 mL after 24 h. Figure 8 shows the increases in water accumulated intake were 12, 35 and 38% at application rates of 3, 6 and 9% of (OMSW). The highest was 110 mL after 100 min at application rates of 6 and 9%, respectively. Different responses between the two soils may be attributed to differences between their structures. The clay soil contained 54% clay, whereas sand clay contained 25% clay. Generally, clay soil has less water intake and penetration than sand clay[10,11,19] confirming the outcomes achieved in this study.

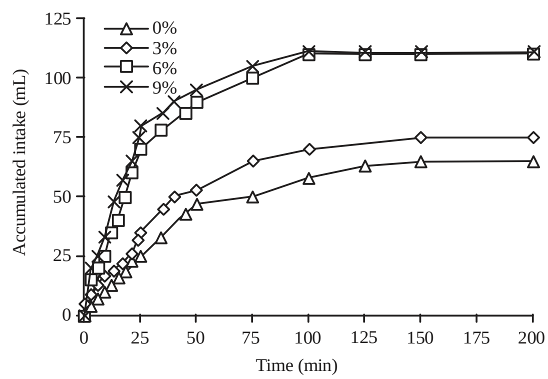

Fig. 8: Effect of (OMSW) application rates on accumulated intake (mL) for sand clay soil. Values are the means of three replicates

Table 3: Penetration depth and accumulated intake with (time)

	Clay (%)				Sandy clay (%)			
Parameters	0	3	6	9	0	3	6	9
Penetration depth (mm)	165[a] (24 h)	215[b] (24 h)	300[c] (24 h)	320[c] (24 h)	185[a] (24 h)	270[b] (24 h)	320[c] (100 min)	305[b] (100 min)
Accumulated intake (mL)	65[a] (24 h)	93[b] (24 h)	105[b] (150 m)	110[c] (150 m)	63[a] (24 h)	70[b] (150)	110[c] (100 m)	111[c] (100 m)

Values with the same letter were not significantly different at $\alpha = 0.05$

CONCLUSION

The effects of adding (OMSW) on soil physical properties were investigated for sieved and repacked clay and sandy clay soils. The study showed that Olive Mill Solid Waste (OMSW) can be used as soil amendment due to its enhancement of the physical properties of soil. The Water Holding Capacity (WHC) and penetration depth increased as (OMSW) application rates increased for the studied soils. The same conclusion applied to the accumulated infiltration. The increases in WHC as application rates increases at field capacity and witling depend on soil texture such as the reduction in bulk density. The increase in WHC for fine-textured soils at wilting point is less than at field capacity. As a result of sand fraction in the coarse-textured soils, the opposite occurred resulted in significant boost in WHC at wilting point rather than at field capacity. Due to desertification, soils in semi-arid and arid regions are poor in organic matter and fertility, addition of (OMSW) increases its organic content and fertility.

SIGNIFICANT STATEMENTS

The Olive Mill Solid Waste (OMSW) can be used as soil amendment due to its enhancement of the physical and chemical properties of the soil. Soils in semi-arid and arid regions are poor in organic matter and fertility due to desertification. The addition of (OMSW) increases its organic content and fertility. The Water Holding Capacity (WHC), penetration depth and accumulated infiltration increased as (OMSW) application rates increased. The increases in (WHC) at field capacity and witling depend on soil texture. For fine-textured soils, the increase in (WHC) at wilting point is less than at field capacity. As a result of sand fraction, the opposite occurred in coarse-textured soils, significant increase in (WHC) at wilting point rather than at field capacity.

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