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ORIGINAL RESEARCH

Effect of Olive Mill Wastes on Soil Physicochemical Properties and Maize Yield Under Saline Soil Conditions

Haytham Mohamed Salem [1,2] *, Ali Mohamed Ali[3]

[1]Department of Soil and Water Systems, University of Idaho, Twin Falls Research and Extension Center, P.O. Box 1827, Twin Falls, ID 83303, USA.
[2]Department of Soil and Water Conservation, Desert Research Center, 11753 Cairo, Egypt.
[3]Department of Soil Fertility and Microbiology, Desert Research Center, 11753 Cairo, Egypt.
* Corresponding author: Haytham Mohamed Salem
E-mail: eng_haytham1982@yahoo.com

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ABSTRACT: The addition of olive mill wastes (OMW) to agricultural soils has becoming a common disposal strategy to improve the soil's physical and chemical properties. There is a dearth of information concerning the impact of OMW on soil properties in Egypt's saline soil conditions. Consequently, the aim of this study was to investigate the effects of various types of OMW on soil properties and maize yield in saline soil conditions. This study conducted field experiments in the North Sinai Governorate of Egypt on salt-affected sandy clay loam soil. Different types of OMW were applied at rates of 5 and 10 tons per hectare, either in fresh or compost form, individually or in combination with effective microorganisms (EM-1). The results revealed that the compost from EM-Bokashi and OMW treatment (T_7) at a rate of 10 tons per hectare significantly decreased pH, EC, and ESP values. For instance, application of T_7 significantly decreased EC by 30.6 and 34.8% compared to the fresh OMW treatment (T_3) at a rate of 10 tons per hectare in the soil depths of 0-10 and 10-20 cm, respectively. Moreover, the T_7 treatment significantly decreased soil bulk density by 18.7 and 20% compared to the control treatment (T_1) in the soil depths of 0-10 and 10-20 cm, respectively. However, the differences between T_7 and other treatments were not significant. Furthermore, the application of T_7 significantly increased maize yield by 38.5% compared to T_1. Overall, the best treatment for reducing salinity and bulk density as well as enhancing soil fertility and maize yields was the application of T_7 at a rate of 10 tons per hectare. Therefore, it is desirable to encourage farmers to use the compost of EM-Bokashi and OMW at the rate of 10 tons per hectare as soil amendment in order to enhance soil physicochemical properties and fertility status and to obtain high yields under saline conditions. This practice allows farmers to produce high yields even in saline conditions by improving soil physicochemical properties and fertility status.

KEYWORDS: Soil amendment, effective microorganisms, bokashi, soil properties, maize

1. Introduction

The soil amendment with organic wastes represents a way to increase the soil's fertility (Regni et al., 2017). Among the organic waste materials produced by agricultural and industrial activities, olive mill wastes (OMW) derived from the olive oil extraction process may represent a suitable soil amendment (Brunetti et al., 2005; Camposeo and Vivaldi, 2011; Regni et al., 2017). Increasing waste production in Egypt has increased the problem of how to get rid of it without causing undesirable impacts on the environment and human health. The main use of olive fruits is the extraction of olive oil, and during the production of olive oil, large quantities of waste are generated. The remaining OMW can be used as a good source for increasing soil organic matter

(Walker and Bernal, 2005; Proietti et al., 2015).

The soil spreading of OMW, fresh or after composting process, has received increasing attention in modern sustainable agriculture (Proietti et al., 2015). One of the most important technologies to reuse OMW is to turn such wastes into compost as an effective soil amendment. Assaf et al. (2006) indicated that the use of OMW as soil amendments represents a strategy for the management of the high production of these materials, in which their plant nutrients and organic matter (OM) are returned to the soil without any toxicity impact on the growing plants. Alburquerque et al. (2007) also reported that OMW compost had no toxicity and a relatively high content of organic matter, organic N, K, and lignin contents compared to the other tested organic amendments. Moreover, Paredes et al. (2005) applied OMW in compost form to soil and they did not find any phytotoxic effects on the growing Swiss chard plants. They added that the soil fertility increased with an increase of the application rate of OMW. Hachicha et al. (2006) reached a similar conclusion when they pointed out that the compost of OMW can be used as organic fertilizer for agricultural soils, without any phytotoxic effects. Furthermore, López-Piñeiro et al. (2008) reported that application of OMW to the soil cultivated with olive trees caused significant increases in the soil organic carbon, total N, available P and K, and aggregate stability. This was reflected in the increased production of olive grown in the treated plots.

The application of OMW in composted form enhances some physical properties of coarse-textured soil (sandy loam and loamy sand) like aeration capacity, field capacity, available water content, hydraulic conductivity, and increased soil aggregate stability (Lozano-García et al., 2011). Different studies have observed that the application of OMW represents an inexpensive source of nutrients for the crops that could replace the need for chemical fertilizers (Ayoub et al., 2014; Vella et al., 2016), and can enhance crop yields (Chatzistathis and Koutsos, 2017). In addition, the application of OMW as organic amendments can modify the properties of the soils, and therefore also the environmental behaviour of herbicides (Delgado-Moreno et al., 2017; López-Cabeza et al., 2017; López-Piñeiro et al., 2014).

The microbial inoculant 'Effective Microorganisms' (EM) has been used to promote soil fertility and plant growth in agriculture (Shin et al., 2017). The EM biofertilizer was developed by Teruo Higa at the University of Ryukyus, Okinawa, Japan. EM is a mixture of beneficial microorganisms including up to 80 different species of microorganisms that are considered mutually compatible and coexistent in a liquid culture (Higa, 1998). Several EM-products are commercially available and widely used (Higa, 1998). Products for plant cultivation are EM-1, EM-5, EM-bokashi and EM fermented plant extract. EM-1 is used as a basic material to prepare activated EM (EM-A) by fermentation in water plus molasses. EM-bokashi is an anaerobic fermentation product from solid agricultural byproducts and EM (Higa, 1998).

Bokashi is the growth medium for the microorganisms, and provides a suitable microenvironment for EM in the soil (Shin et al., 2017). EM products have been tested for their effects on soil health, crop yields, and plant protection. Several positive effects of EM application have been reported, enhancing the growth, yield, and quality of crops including bean (Roberti et al., 2015), maize (Xu, 2001), pea (Javaid, 2006), peanut (Yan and Xu, 2002), tomato (Ndona et al., 2011), and wheat (Hu and Qi, 2013).

There is a lack of information concerning the impact of OMW on soil properties in

Egypt's saline soil conditions. Consequently, the aim of this study was to investigate the effects of various types of OMW, whether in fresh or compost form, when applied individually or in combination with effective microorganisms (EM-1), on soil properties and maize yield in saline soil conditions.

2. Materials and methods

2.1. Preparation of compost in Bokashi form and olive mill wastes (OMW)

Bokashi is a Japanese word meaning "organic matter". To make a compost of Bokashi and OMW, we followed the procedure described by Parr et al. (1991). It was prepared in two steps, in the first step, 5 liters of sugarcane molasses + 4 liters of water + 3 kg of rice bran + 3 kg of OMW were mixed well manually with one liter of effective microorganisms (EM-1 [8 ml of EM per liter]) in plastic bags, and the mixture was fermented for 10 days. In the second step, the previously fermented mixture was added to 60 kg of olive mill waste and left for 3 weeks in a dark place. The compost from EM-Bokashi and OMW was ready for use in experimental sites after 3 weeks.

2.2. Preparation of an extended EM solution for composting OMW

The EM extended solution was prepared according to Parr et al. (1991) by mixing (EM-1) with sugarcane molasses and water in a ratio of (1: 5: 14). Therefore, to prepare one ton of composting olive waste with (EM-1) mix 15 L (EM-1) with 75 L (sugarcane molasses) and 210 L of water in a container and kept for fermentation under room temperature for 7 days. On the 8^{th}, day the mixture was ready, giving a nice fermenting smell with a pH of 3.5. Thereafter, the EM extended solution was mixed with OMW and covered with a plastic sheet to ferment in an aerobic condition for 6 weeks. Then it was ready to be used at the experimental site.

2.3. Experimental site and treatments

The soil in which the experiment was conducted is located at Galbana village, North Sinai Governorate, Egypt (30º 55″ 14′ N, 32º 23″ 31′ E). In this region, the climate is arid; the Emberger's degree of aridity is about 13.6 (Shaheen, 1998). Long-term average rainfall is about 82 mm with high variability, and the rainy season usually extends from October to May (Zahran and Willis, 1992). The mean annual temperature is 20.9 ^{0}C. The monthly relative humidity varies between 68% and 74% with an annual mean of 72%.

Before planting, soil samples from the topsoil (0-30 cm) were collected for analysis.

Table 1. Some soil physical and chemical properties before treatments.

pH [a]	EC [b] (dS m^{-1})	Bulk Density (g cm^{-3})	$CaCO_3$	O.M	Avail. N	Avail. P	Avail.K	Particle size distribution (%)			Textural class
			(%)		mg kg^{-1}			Sand	Silt	Clay	
7.88	10.87	1.56	5.75	0.33	55	9.41	1041	48.2	20.6	31.2	Sand clay loam

[a] pH in saturated soil paste

[b] Electrical conductivity in saturated soil paste extract

Table 2. The properties of the olive mill wastes (OMW) and compost that were employed in the experiment.

Treatments	pH	EC (dS m^{-1})	OM	Total (N)	P	K	Ca	Mg	Fe	Zn	Mn
			(%)						Mg kg^{-1}		
OMW	5.86	0.327	46.64	1.04	0.05	0.53	0.46	0.07	1244	32.78	17.35
Compost of OMW	6.11	0.354	41.78	1.06	0.05	0.56	0.46	0.07	1278	33.21	17.47
Compost of OMW and EM-Bokashi	6.05	0.237	48.64	1.13	0.06	0.61	0.51	0.08	1431	36.11	18.21
OMW + EM	6.08	0.194	44.37	1.02	0.05	0.59	0.48	0.07	1338	35.41	17.34

Note: Effective Microorganisms (EM), EC-electrical conductivity; OM - Organic Matter; N – Nitrogen; P – Phosphorus; K – Potassium; Ca – Calcium; Mg – Magnesium; Fe – Iron; Zn – Zinc; Mn - Manganese

Table 3. Chemical composition of the water used in irrigation.

pH	EC (dS m^{-1})	Soluble cations (meq l^{-1})				Soluble anions (meq l^{-1})			
		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
7.61	1.06	2.73	1.45	0.36	5.98	0.00	4.47	4.16	1.88

The soil of the experimental site is characterized as salt-affected soil with an EC value of 10.8 dS m^{-1} and pH of 7.88 and 0.33 % organic matter content. Such soil has 5.7 % $CaCO_3$ and is sandy clay loam in texture. The most dominant cations in that soil are Na^+; Ca^{2+} and Mg^{2+}, while the Cl^- and SO_4^{2-} are the most dominant anions (Richards, 1954). The exchangeable sodium percentage (ESP) values were calculated according to (Richards, 1954; Gharaibeh et. al., 2021).

The initial soil ESP in the soil was 18.3%, suggesting the presence of sodicity hazards. Table 1 shows some of the soil's physical and chemical properties before treatments.

The experiment consisted of nine treatments. T_1: control (without applying

OMW); T_2: fresh OMW at the rate of 5 ton ha^{-1}; T_3: fresh OMW at the rate of 10 ton ha^{-1}; T_4: compost of OMW at the rate of 5 ton ha^{-1}; T_5: compost of OMW at the rate of 10 ton ha^{-1}; T_6: compost from EM-Bokashi and OMW at the rate of 5 ton ha^{-1}; T_7: compost from EM-Bokashi and OMW at the rate of 10 ton ha^{-1}; T_8: OMW plus the previously prepared (EM-1) at the rate of 5 ton ha^{-1}; and T_9: OMW with the previously prepared (EM-1) at the rate of 10 ton ha^{-1}. The treatments were carried out in a randomized complete block design with four replicates. Table 2 shows some properties of the olive mill wastes used in the experiments.

Maize was planted on May 28, 2021. The recommended rates of P and K fertilizers were applied before cultivation at the rates of 60 kg of P_2O_5 and 80 kg of K_2O, respectively. Furthermore, N fertilizer was applied in four equal portions (i.e., 20, 35, 50, and 65 days after planting) in the form of ammonium nitrate (33.5%) at a rate of 100 kg of N. A sprinkler irrigation system was used to irrigate the experiment. The chemical composition of the water used in irrigation is shown in Table (3). Plants were harvested at maturity, and the grain yield was recorded and analyzed according to Snedecor and Cochran (1967). Soil samples were taken with a cylindrical core at depths of 0-10, 10-20 cm. The core samples were immediately weighed and then dried at 105 ^{0}C for 24 h. Soil bulk density was measured according to Blake (1965). Different soil samples were taken at harvesting time from the experimental plots at two depths (0-10) and (10-20) cm and prepared for the determination of EC and pH using methods described by (Richards, 1954).

2.4. Statistical analyses

Treatment effects on measured variables were tested by analysis of variance (ANOVA), and comparisons among treatment means were performed using the least significant difference (LSD) at $p < 0.05$. The statistical procedures were carried out using SPSS version 19 (SPSS Inc., Chicago, Illinois, USA).

3. Results

3.1. Effect of different treatments on pH, EC, and ESP.

The data in figure 1 shows the effect of different treatments on soil pH and EC (Electrical conductivity) in soil depths of (0-10 and 10-20 cm). Apparently, the EC and pH of the studied soil were relatively higher in all soil layers of the untreated soil (control). On the other hand, opposite trends were obtained for the studied parameters in the case of applying OMW. i.e., the application of such wastes resulted in significantly reduced soil EC, pH, and ESP values.

For instance, application of T_7 significantly decreased EC by 30.6 and 34.8% compared to the fresh OMW treatment (T_3) at a rate of 10 tons per hectare in soil depths of 0-10 and 10-20 cm, respectively. Mekki et al. (2009) found that soil EC values were proportional to the volume of supplied OMW. Walker and Bernal (2008) studied the effects of OMW compost on the soil chemical properties of highly saline agricultural soil, and found that such materials did not significantly change the soil electrical conductivity through the decomposition of the applied wastes. However, our results are consistent also with those obtained in previous short-term studies (López-Piñeiro et al., 2008).

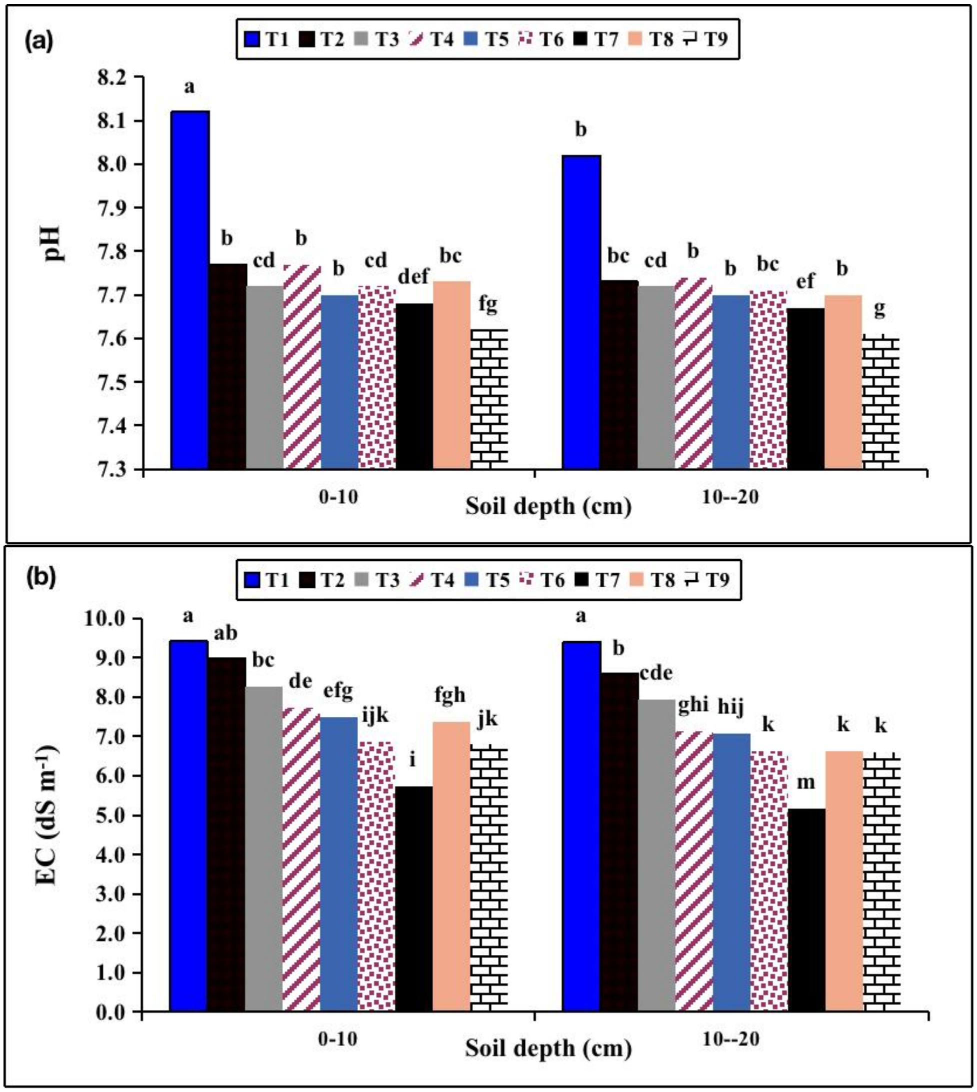

Figure 1. Effect of different treatments on soil (a) pH and (b) EC (Electrical conductivity) in soil depths of (0-10 and 10-20 cm). T_1: Control; T_2: Fresh OMW (5 ton ha^{-1}); T^3: Fresh OMW (10 ton ha^{-1}); T_4: OMW compost (5 ton ha^{-1}); T_5: OMW compost (10 ton ha^{-1}); T_6: Compost of EM-Bokashi and OMW (5 ton ha^{-1}); T_7: Compost of EM-Bokashi and OMW (10 ton ha^{-1}); T_8: EM + OMW (5 ton ha^{-1}); and T_9: EM + OMW (10 ton ha^{-1}). Different letters indicate significant differences at $p < 0.05$ according to the LSD test.

The reduction in soil salinity in our study could be explained as follows: the application of OMW increased the capacity of the soil to hold water, and hence, more soluble salts became prone to being leached out by the following irrigation of the deeper soil layers. This was reflected in decreasing soil EC values and the concentrations of soluble ions. The pH values were significantly decreased with different magnitudes in accordance with the application rate of OMW and/or soil depth. The lowest values of pH were recorded under T_9 and T_7 while the highest values were observed unter T_1. In other words, T_7 significantly decreased pH by 5.4 and 4.3% compared to T_1 (control) in soil depths of 0-

10 and 10-20 cm, respectively.Tang and Yu (1999) suggested that the direction and the magnitude of pH change depend on the concentration of organic anions in the OMW, initial soil pH and the degree of residue decomposition. Xu et al. (2006) reported that pH of soil was changed with applications of different rates of plant residues. pH of the OMW residue is around 6, therefore its application rate is important to regulate soil pH. The highest rate of decrement in the values of such parameters was achieved with the combined treatment of T_7. The positive effect of such treatment on reducing soil pH values may be due to the organic and inorganic acids formed during the decomposition of OMW by soil microorganisms which are able to produce acid in amounts enough to lower the soil pH. In this respect, López-Piñeiro et al. (2008) found that at the highest rates of applied OMW, the pH values were decreased by 0.12 and 0.17 units. Also, Valarini et al. (2003) reported that organic matter and EM-microorganism incorporation significantly decreased pH values in all treatments compared with the control. Walker et al. (2008) pointed out that the reduction in soil pH values was attributed to the acidic nature due to the oxidation reactions of the applied olive mill wastes in the soil.

Figure 2 shows the effect of different treatments on ESP in soil depths of (0-10 and 10-20 cm). The ESP values of the control (T1) were 14.08 and 13.24%, while the ESP values of T7 were 9.29 and 9.34% in soil depths of 0-10 and 10-20 cm, respectively. ESP values decreased with increasing OMW application rates. Such results are in agreement with the results of Qadir et al. (2001) and Valarini et al. (2003).They reported that the addition of organic wastes to saline soils can accelerate the leaching of Na^+, decrease the ESP and EC, and the increase water infiltration rate. The lowest values of ESP were recorded under T_7 and there were significant differences between T_7 and T_1 in all soil layers

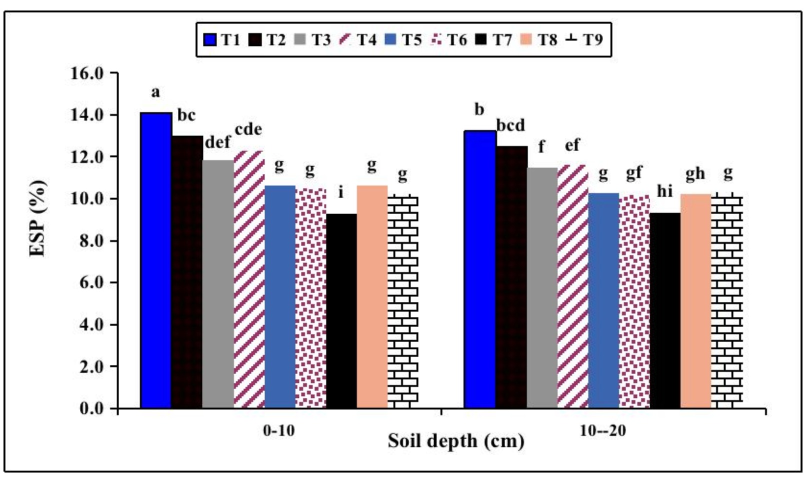

Figure 2. Effect of different treatments on the exchangeable sodium percentage (ESP) in soil depths of (0-10 and 10-20 cm). Different letters indicate significant differences at $p < 0.05$ according to the LSD test.

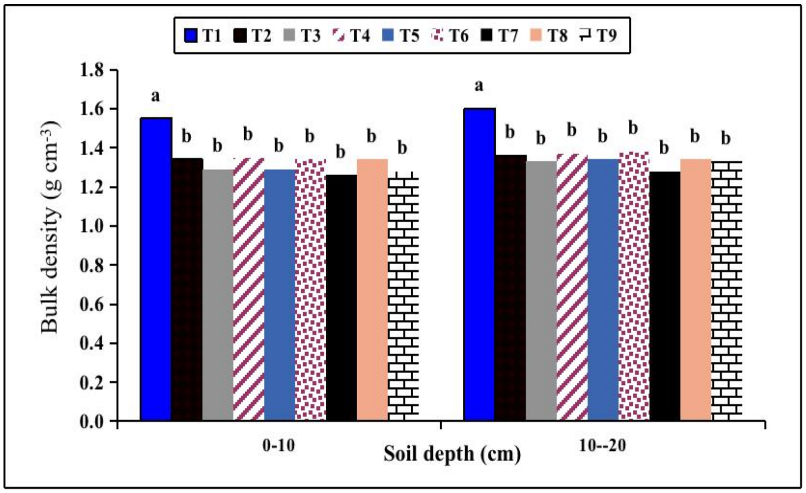

Figure 3. Effect of different treatments on soil bulk density in soil depths of (0-10 and 10-20 cm). Different letters indicate significant differences at $p < 0.05$ according to the LSD test.

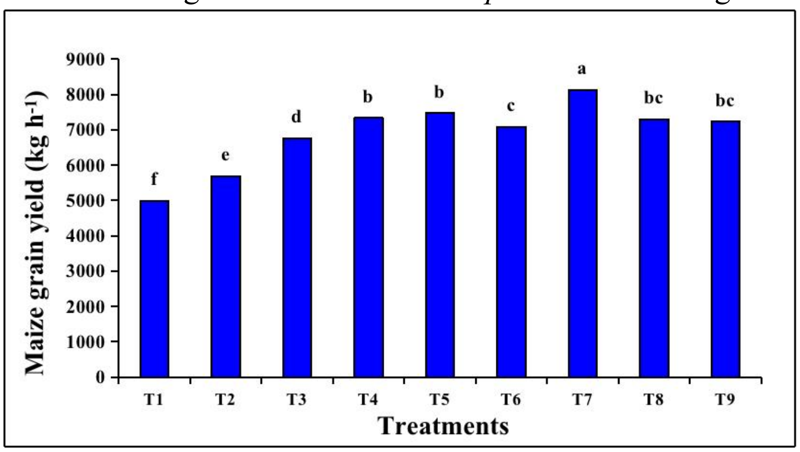

Figure 4. Effect of different treatments on maize grain yield. Different letters indicate significant differences at $p < 0.05$ according to the LSD test.

3.2. Effect of different treatments on bulk density

Data in Figure 3 shows the effect of different treatments on soil bulk density in soil depths of (0-10 and 10-20 cm). Evidently, the OMW application significantly decreased the soil bulk density compared to the control at all soil depths. For instance, T_7 significantly decreased soil bulk density by 18.7 and 20% compared to T_1 (control) in soil depths of 0-10 and 10-20 cm, respectively. The lowest values of soil bulk densities were observed under T_7 and T_9. However, the differences among all OMW treatments were not significant. This reduction in soil bulk density can be attributed to the dilution effect resulting from mixing organic matter (OM) added with the more dense soil minerals. This may be due to the higher initial content of organic carbon in the applied OMW (Table 2).

The OM can accelerate the leaching of Na+, decrease the ESP and electrical conductivity, and increase water infiltration rate as well as the water-holding capacity and aggregate stability (Lax et al., 1994; Qadir et al., 2001; Lakhdar et al., 2010). This is of the greatest importance in arid and semi-arid conditions where agricultural soils are poor in OM content. These results are in agreement with (Karim et al., 1992; Hussain et al., 1999) who concluded that the soil bulk density was sharply reduced by the addition of olive composting wastes.

3.3. Effect of different treatments on maize grain yield.

The data presented in Figure 4 shows a significant increase in maize yield with different magnitudes depending upon the type and/or rate of applied OMW. Mixing the compost of OMW at rate of 10 ton ha-1 with EM-Bokashi (T7) increased maize yield by 38.5, 30, 16.9, 9.7, 8.6, 12.7, 10.3 and 11% compared to T1, T2, T3, T4, T5, T6, T8, and T9, respectively. The differences in maize yield between T8 and T9 and between T3 and T4 were not significant. Kavdır et al. (2009) found a similar positive effect of OMW compost on maize growth, where maize development was greater in compost treatments compared to those in control. However, it was found that compost of OMW might reduce phytotoxicity compared to fresh one (Pages et al., 1984). Therefore, it is good enough to mix such wastes with saline soil to ensure better distribution of the organic manure and to obtain a high quantity and quality of the growing maize plants.

4. Conclusion

Composting serves as a viable alternative method for managing solid waste generated from olive oil production. While direct use of OMW has been associated with negative effects, findings of the current study suggest that the application of compost derived from olive solid waste can have a positive impact on various soil properties. These include a reduction in the soil EC, pH levels, ESP, as well as a decrease in the soil bulk density. It is important to note that the extent of these improvements varied depending on the specific treatment and the type and/or rate of waste applied. Notably, the application of compost derived from a combination of EM-Bokashi and OMW, at a rate of 10 ton ha^{-1}, resulted in significant improvement in soil physicochemical properties and enhanced availability of essential nutrients for plant growth. This, in turn, led to a substantial increase in maize grain yield. This sustainable approach to waste management aligns with the principles of environmental stewardship and resource conservation.

Conflicts of Interest: The authors declare no conflict of interest.

Authors Contributions: H.M., Salem conceived the main idea, designed the experiment, and wrote the manuscript. A.M., Ali helped in data collection, data analysis and revising the manuscript.

Data availability statement: Data available upon request from the authors.

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