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Controlled Land Application of Olive Mill Wastewater (OMW): Enhance Soil Indices and Barley Growth Performance in Arid Environments

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Abstract Olive oil industry generates a considerable amount of olive mill wastewater (OMW) each year, which increases the difficulties for successful processing and disposing. A possible and potential alternative is controlled application of OMW into the land. In these two fields' experiments, we investigated a sustainable controlled land application of OMW to enhance soil properties and improve barley production under rainfed conditions. OMW was spread at five application rates (20, 40, 60, 80, and 120 m^3 ha^{-1}) in addition to the control at two sites, Rabba and Ghweer. The physicochemical characterizations of OMW were determined throughout the season. Physicochemical properties of soil were measured after 2 weeks of OMW spreading after planting and after barley harvest. Leaf nutrient content as well as other growth performance has been measured. The results of this study showed no harmful effect of OMW application for all application rates on growth parameters of barley as well as soil properties at both locations. Under all application rates, OMW has increased soil organic matter and nutrient contents, which could reduce the use of chemical fertilizer. There was a significant increase in barley growth in OMW treatments for dry weight (DM) (14 and 22%), biological yield (BYLD) (49 and 34%), grain yield (GYLD) (41 and 47%), and straw yield (SYLD) (55 and 31%) at Rabba and Ghweer sites, respectively. The results exhibited the benefit of controlled application of OMW. However, long-term effect of OMW application needs more study, and local legislative is necessary.

Keywords Barley growth · Controlled spreading · Olive mill wastewater (OMW) · Soil amendments

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1 Introduction

Discarding and handling of olive mill wastewater (OMW) resulted from olive oil industry as a by-product are a serious issue in the producing countries. These countries are having a serious environmental problems initiated by the absence of practicable or cost-effective treatments of olive mill wastewater (OMW) (Mohawesh et al. 2014; Mohawesh et al. 2019; Rusan et al. 2016). The considerably large amount of OMW produced during a short harvesting season (2–3 months) and their high contamination effect exacerbate the problem of their discarding (Belqziz et al. 2016). In addition, the fact that olive industry located in countries that are limited in water resources creates the need for effective handling and recycle of the produced OMW. The distribution of olive mills added more difficulties to treat and handling OMW on-site.

The most common ways of disposing OMW are as follows: storing in evaporation ponds during olive extracting which causes environmental problems and pollution source of shallow ground water, disposing OMW into the sewer system which affects negatively on wastewater treatment plant, and transferring the OMW to the dumping sites with extra high-cost and potential for future point source pollution to the nearby regions. The complex composition of OMW presents significant problems for applicable effluent treatment and disposal technically and economically. Therefore, an alternative and reasonable solution is controlled OMW land spreading (Mohawesh et al. 2014).

In Jordan, there are 131 olive oil mills distributed all around the country (MoA 2018), which generally located close to olive orchards. The olive pomace is used as a fuel for space heating; on the other hand, OMW is discharged to dumping sites without adequate treatment. Olive fruit production is around 200,000 ton/year (MoA 2018). The OMW is generated by these amounts of fruits annually around 200,000 m^3 (MoA 2018) during the harvesting season (2–3 months per year).

According to the Jordanian regulations, the OMW should be disposed into the landfill sites (Rusan et al. 2016; Mohawesh et al. 2019). However, few olive mills are discharging the OMW illegally on soil before reaching the landfill site. This uncontrolled spreading of OMW could pollute the water resources (surface and subsurface), environment, and soil and might decrease land productivity in the disposal area because of the phytotoxic effect of OMW (Albalasmeh et al. 2019). Recently, regulations in Jordan allow a controlled application of OMW to reduce its environmental effect as well as to benefit from the nutrient values of OMW (Ayoub 2017). Moreover, some of the European countries (Cyprus, Greece, Italy, Portugal, and Spain) have issued legislations for controlled spreading of olive mill wastewater (Inglezakis et al. 2012; Mohawesh et al. 2014). As an example, Italy is permitting controlled application of OMW at the rate of 80 m^3 ha^{-1} $year^{-1}$. In this case, if applied at appropriate doses, OMW can be considered as nutrient source for plant growth as well as soil amendment (Magdich et al. 2012). In this context, OMW is considered as a natural fertilizer instead of toxic by-product, which can be disposed without causing harmful effect to crops, soil, and environment if applied at proper dose (Belqziz et al. 2016; Kavvadias et al. 2015; Mohawesh et al. 2014). Moreover, control soilborne plant pathogens (Kotsou et al. 2004) and potential herbicidal activity of OMW (Ghosheh et al. 1999) are considered as an extra added value. However, OMW application on soil might affect its physical, chemical, and biological properties (Albalasmeh et al. 2019; Mohawesh et al. 2014). Several studies showed that using wastewater as irrigation water decreased soil-saturated hydraulic conductivity (Albalasmeh et al. 2019) and increases soil water repellency (Travis et al. 2008) because of grease and oil accumulation in the upper soil horizons. The solute transport and non-equilibrium water flow has been improved because of soil water repellency in structured clay soils. Nevertheless, field experiments for appropriate and controlled OMW spreading/application on soil should be investigated at different regions of diverse climatic conditions. The current study aimed to examine the land application of OMW as soil amendments to improve soil, barley productivity, and to reduce its environmental load under arid and semi-arid conditions.

2 Materials and Methods

2.1 Experimental Sites

The two field trials were done at Rabba research regional center (31° 16′ 43″ N; 35° 44′ 28″ E) and Ghweer research station (31° 9′ 10″ N; 35° 44′ 39″ E), Karak governorate, National Agricultural Research Center (NARC). Karak governorate is one of the most important agricultural regions known for diversity of climatic conditions. Due to this diversity, there are another sub-station connected to Rabba research regional center, Ghweer research station, which is located in different agro-ecological zone in Karak governorate. Average rainfall at Rabba and Ghweer sites was 342.3, 290.1, and 275.9, 235.4 mm for the 2016/2017 and 2017/2018 seasons, respectively. Figures 1 and 2 show the climatic data at both sites for the 2016/2017 and 2017/2018 seasons.

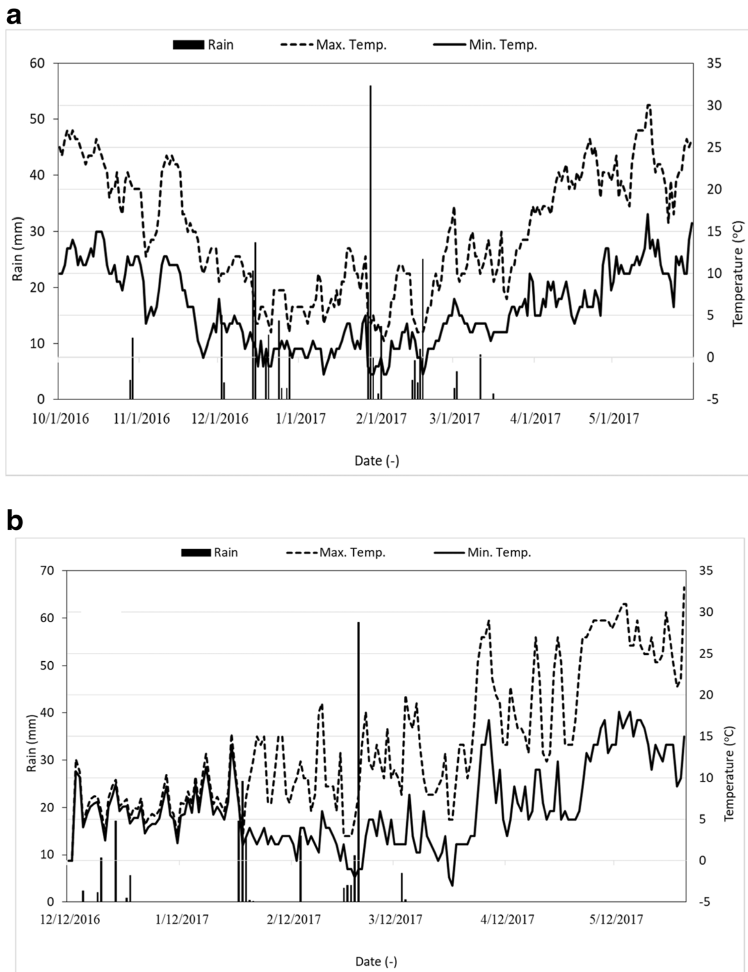

Fig. 1 Meteorological data at (**a**) Rabba and (**b**) Ghweer sites during the 2016/2017 growing season

2.2 Field Experiment Setup and Design

The two field experiments were planted with barley (Rum) (80 kg ha^{-1}) in Rabba and Ghweer research stations/NARC on November 29, 2016, and on December 3rd, 2017, for 2016/2017 and 2017/2018 seasons, respectively. The OMW was applied in six application rates (0 (control), 20, 40, 60, 80, 120 m^3 ha^{-1}) in triplicates on November 20, 2016, and on November 26, 2017, for the two the seasons, respectively. One week after OMW application, soil was prepared for planting. Treatments were arranged using randomized complete block design (RCBD). Recommended agricultural practice was followed during the growing seasons. Each plot was 10 × 2 m, while the area of each block was 150 m^2. Planting row spacing was 25 cm.

2.3 OMW Physicochemical Characterizations

OMW samples were analyzed for COD using a Hach Lange DR2800 spectrophotometer (Hach Lange GmbH, Düsseldorf, Germany) (Mohawesh et al. 2014). BOD_5 was measured using the respirometric OxiTop Control meter (WTW) (Albalasmeh et al. 2019). The OMW electrical conductivity (EC) and alkalinity (pH) were measured using EC and pH meters, respectively (Mohawesh et al. 2019). P was analyzed using a UV-VIS spectrophotometer (Shimadzu UV-1601, Tokyo, Japan) following a vanadate-molybdate method (Olsen and Sommers 1982) whereas sodium (Na) and potassium (K) were analyzed by an atomic absorption spectrometer (Perkin Elmer AAnalyst 300, Shelton, CT-USA) (Chapman and Pratt 1982). Total N was measured following the Kjeldahl procedure

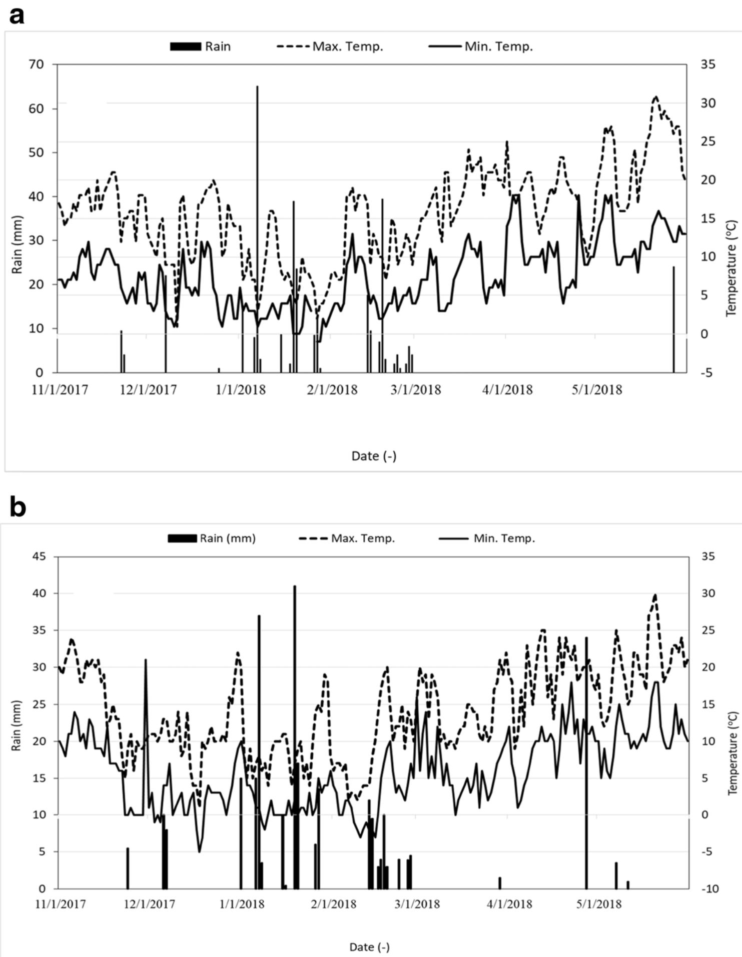

Fig. 2 Meteorological data at (**a**) Rabba and (**b**) Ghweer sites during the 2017/2018 growing season

(Kjeldahle, Gerhardt Co., Ltd., VAPODEST-5, Germany) (Chapman and Pratt 1982). The chemical properties of OMW were analyzed bimonthly. Table 1 presents the general OMW characteristics. It shows that the analyzed parameter values are within the previously published characteristics of Jordanian OMW (Albalasmeh et al. 2019; Al-Khatib et al. 2009; Mohawesh et al. 2019).

2.4 Soil Analysis

Soil samples were collected after 2 weeks of OMW application during 2016/2017 season and after harvesting 2017/2018 season from each treatment from two depths (0–20 cm and 20–40 cm). The soil samples were air-dried and then sieved (< 2 mm) for further physical and chemical soil property analysis. Particle size analysis for soil texture determination was measured using hydrometer method (Klute 1986); pH and EC of the tested soil were measured using pH and EC meters, respectively (Mohawesh et al. 2014); soil organic matter was determined following Walkley and Black method (Walkley and Black 1934); N was measured after Kjeldahl digestion and titration (Chapman and Pratt 1982); total phenols were measured according to Folin Ciocalteau method (Singleton et al. 1999) where the absorbance was measured at 725 nm using a UV-VIS spectrophotometer (Shimadzu UV-1601, Tokyo, Japan). Humification degree (HD) was measured by Borgmark method (Borgmark 2005); after filtration, the absorption was measured at 540 nm. Atomic absorption spectrophotometry (Perkin Elmer, AAnalyst 300) was used to measure available Na, K, and Mg concentrations (Chapman and Pratt 1982) whereas a spectrophotometer was used to measure P concentration (Olsen and Sommers 1982). Water drop penetration time test (WDPT) was used to evaluate soil water repellency

Table 1 Chemical characteristics of olive mill wastewater (OMW)

Parameter	
pH	4.85[a] ± 0.15[b]
EC (dS m^{-1})	8.68 ± 0.11
BOD_5 (ppm)	32,497 ± 1063
COD (ppm)	43,099 ± 3807
Dry matter (%)	8.3 ± 0.39
Oil and fat (%)	0.97 ± 0.09
Phenols (ppm)	1247 ± 58.7
Nitrogen (ppm)	372 ± 25.3
Ca (ppm)	117 ± 23.1
Mg (ppm)	153 ± 33.2
Cl (ppm)	510 ± 34.3
P (ppm)	146 ± 35.2
K (ppm)	968 ± 47.6
Na (ppm)	45.2 ± 6.3
Fe (ppm)	23.9 ± 8.5
Cd (ppm)	nd < 0.009
Pb (ppm)	nd < 0.01

[a]Average values
[b]Standard deviation

(Mohawesh et al. 2014). A few drops of water were retained on the soil surface of each soil sample, and the time required for complete infiltration of each droplet was recorded.

2.5 Plant Analysis

A 1.0 m^2 of plant samples from each treatment from the two experimental sites 2017/2018 season was harvested at two stages (vegetative stage and physiological maturity stage). Plant samples were analyzed for total nitrogen (TN) following the Kjeldahl method (AOAC 1990), P following the sodium bicarbonate method using UV-VIS spectrophotometer (Olsen and Sommers 1982) and K using atomic absorption spectrophotometry (Chapman and Pratt 1982). Leaf chlorophyll content was measured in five randomly plants per plot using the chlorophyll meter (SPAD-502, Minolta, Japan). The average values were presented as SPAD unit. Plant biomass was calculated at the two stages whereas leaf area (LA) was determined following the photoelectric method. Dry matter weight (DM) was measured after drying the plant samples for 48 h at 80 °C. Grain yield (GYLD) was calculated by taking grain yield after threshing. The biological yield (BYLD) was obtained by taking the aboveground total dry matter including seeds. Straw yield (SYLD) was measured from the difference between BYLD and GYLD. Harvest index % (HI) was calculated as the ratio of GYLD divided by the BYLD multiplied by 100. A 1000 kernel weight was measured by weighing 1000 kernels from each plot.

2.6 Statistical Analysis

Significance of difference between the different parameters was evaluated based on one-way analysis of variance (ANOVA) using the SPSS Statistical Software Version 11.5 (SPSS Inc., Chicago). The *t* test was used to compare means at the 0.05 significance level.

3 Results and Discussion

3.1 Soil Analysis

The results presented in Tables 2, 3, 4, and 5 showed a significant effect in many of the measured soil parameters compared with control due to the OMW application. The soil measured chemical parameter concentration increased with the increase in OMW application rate. OMW application rate of 120 m^3 ha^{-1} exhibited the highest soil measured values compared with the other OMW application rates including the control. Soil nutrient and organic matter contents have been increased after applying OMW which have a positive effect on soil properties as well as plant growth performance (Belqziz et al. 2016; Buchmann et al. 2015; Lanza et al. 2017; Mohawesh et al. 2014). After harvest (2017/2018 season), a significant decrease in all measured parameters was recorded compared with measured parameters 2 weeks after planting (2016/2017 season). Because of the poor and infertile soil dominating the region, the high concentrations of nutrient contents in the OMW are considered beneficial to the barley growth. However, there is a potential negative effect due to the rise in osmotic pressure because of salt accumulation after long-term OMW application due to the high EC of the OMW which might not appear in our 2-year study.

Although OMW is acidic (pH = 4.85), it did not decrease the soil pH significantly compared with the control. The results showed insignificant effect after OMW application on soil pH at both depths for both sites after harvesting season, 2017/2018 (Tables 4 and 5). This insignificant effect could be related to the high content of soil calcium carbonate, which increase the

Table 2 Effect of OMW application on soil physiochemical properties after two weeks of application at Rabba site 2016/2017 season

Parameter	Units	Soil depth 0–20 cm					
		Control	10 m^3 ha^{-1}	40 m^3 ha^{-1}	60 m^3 ha^{-1}	80 m^3 ha^{-1}	120 m^3 ha^{-1}
		OMW application rates					
pH (1:2.5 soil:water suspension)		7.84 a*	7.69 ab	7.74 ab	7.77 ab	7.81 ab	7.61 b
EC (1:2.5 soil:water suspension)	dS m^{-1}	0.65 d	0.63 d	0.76 c	0.81 c	0.86 bc	1.10 a
N	%	0.050 c	0.055 bc	0.063 b	0.064 b	0.078 a	0.079 a
P	ppm	4.2 c	4.9 c	8.1 bc	12.3 b	17.1 a	22.1 a
K	ppm	341.8 c	479.0 b	501.2 b	553.4 b	669.8 a	634.2 a
Ca	ppm	163.5 a	185.2 a	176.2 a	185.3 a	191.2 a	188.5 a
Na	ppm	15.3 c	23.3 b	26.2 ba	30.5 a	31.3 a	33.9 a
Mg	ppm	21.5 e	48.6 d	76.2 c	89.7 b	110.2 ab	140.3 a
Phenol	ppm	2.9 c	3.8 c	4.9 c	7.2 b	8.4 b	13.8 a
OM	%	0.58 e	0.89 d	1.57 c	2.01 b	2.19 a	2.25 a
Humification degree (HD, A_{540nm})		0.045 b	0.053a	0.053 a	0.058 a	0.059 a	0.059 a
WDPT	Sec.	3.67 a	3.67 a	3.67 a	3.67 a	3.67 a	3.63 a
Texture class		Clay loam (clay 37.1%, silt 25.7%, sand 37.2%)					
	Soil depth 20–40 cm						
pH (1:2.5 soil:water suspension)		8.03 a	7.76 b	7.74b	7.72 b	7.69 a	7.71 b
EC (1:2.5 soil:water suspension)	dS m^{-1}	0.46 b	0.5 bc	0.52 bc	0.59 bc	0.81 ac	0.83 a
N	%	0.035 b	0.041 b	0.049 ab	0.046 b	0.053 a	0.051 a
P	ppm	3.1 b	2.9 b	3.4 ab	3.4 ab	3.8 a	4.6 a
K	ppm	287.3 c	287.2 c	345.8 bc	384.3 a	247.5 c	401.3 a
Ca	ppm	185.2 a	159.2 a	167.5 a	181.2 a	178.2 a	154.3 a
Na	ppm	18.3 b	20.3 b	21.5 a	20.6 ab	25.2 a	27.8 a
Mg	ppm	15.7 c	33.7 b	37.3 ab	44.0 a	45.0 a	35.7 b
Phenol	ppm	2.6 a	3.2 a	3.2 a	3.7 a	4.2 a	6.8 a
OM	%	0.45 c	0.44 c	0.59 b	0.60 b	0.63 ab	0.71 a
Humification degree (HD, A_{540nm})		0.045 a	0.050 a	0.050 a	0.052 a	0.05 a	0.05 a
WDPT (Sec.)	Sec.	3.33 a	3.33 a	3.33 a	3.67 a	3.37 a	3.67 a
Texture class		Clay (clay 44.5%, silt 31.8%, sand 23.7%)					

* Means within a column followed by the same letters are not significantly different at $p < 0.05$

buffering capacity of the soil (Mohawesh et al. 2014). Soil salinity increased significantly after all OMW application rates compared with control. The EC values increased from 0.65 and 0.54 to 1.10 (69%) and 0.91 (69%) at Rabba and Ghweer after the highest OMW application rate (120 m^3 ha^{-1}) at soil depth 0–20 cm, respectively (Tables 2 and 3). However, after harvest, this increase in the EC values was less prominent (Tables 4 and 5), 47 and 18% at Rabba and Ghweer at soil depth 0–20 cm, respectively. The increase in soil EC might be resulted from the amount of nutrients in the OMW. Therefore, the long-term application of OMW might affect the soil salinity. The WDPT exhibited insignificant differences between treatments at both sites and depths. Soil sample water repellency was identified as non-water repellent as WDPT was less than 5 s for all treatments (Tables 2, 3, 4, and5). However, other studies reported that long-term application of OMW enhanced the hydrophobic behavior of the treated soil (Wallach et al. 2005). Moreover, the non-water repellent effect of OMW application in our study could be related to the soil quality indices (low organic and mineral contents) and climate (arid and semi-arid) conditions prevailing at both sites.

OMW application increased OM content significantly from 1.14 to 2.72 and from 0.85 to 2.15% at soil

Table 3 Effect of OMW application on soil physiochemical properties after two weeks of application at Ghweer site 2016/2017 season

Parameter	Units	Soil depth 0–20 cm					
		Control	10 m^3 ha^{-1}	40 m^3 ha^{-1}	60 m^3 ha^{-1}	80 m^3 ha^{-1}	120 m^3 ha^{-1}
		OMW application rates					
pH		7.4 a*	7.39 a	7.35 a	7.38 a	7.37 a	7.32 a
EC	dS m^{-1}	0.54 c	0.55 bc	0.65 bc	0.7 d	0.64 bd	0.91 a
N	%	0.053 c	0.060 c	0.072 b	0.08 b	0.104 a	0.107 a
P	ppm	6.34 c	16.78 b	10.53 bc	24.23 a	25.01 a	27.20 a
K	ppm	288.1 c	295.5 bc	305.6 bc	306.9 b	343.9 a	350.6 a
Ca	ppm	152 b	139.33 b	162 ba	154.33 ba	152.33 ba	171.67 a
Na	ppm	15.58 c	15.93 c	16.05 c	20.47 ba	18.55 bc	24.76 a
Mg	ppm	38.0 c	59.67 b	71 b	74.33 b	95 d	142 a
Phenol	ppm	3.94 c	5.47 c	6.12 bc	7.21 b	7.34 b	11.89 a
OM	%	0.99 c	1.24 c	1.32 c	1.66 b	1.86 b	2.37 a
Humification degree (HD, A_{540nm})		0.050 b	0.051 ab	0.052 a	0.054 a	0.052 a	0.054 a
WDPT (Sec.)		3.00 a	3.00 a	2.67 a	3.33 a	3.00 a	3.33 a
Texture class		Loam (clay 25.2%, silt 48.3%, sand 26.5%)					
		Soil depth 20–40 cm					
pH		7.44 a	7.27 a	7.32 a	7.35 a	7.27 a	7.29 a
EC	dS m^{-1}	0.42 bed	0.44 bc	0.41 b	0.57 ace	0.47 acd	0.63 a
N	%	0.055 b	0.057 b	0.068 b	0.061 b	0.077 b	0.099 a
P	ppm	5.07 a	4.56 a	3.77 a	4.90 a	4.60 a	4.91 a
K	ppm	198.2 c	258.6 b	292.3 a	271 ba	305.2 a	286.9 a
Ca	ppm	125.33 b	154.33 ab	164.33 a	141.33 b	137.67 b	178.33 a
Na	ppm	11.32 a	11.89 a	14.52 a	14.51 a	12.42 a	15.52 a
Mg	ppm	37.33 b	33.33 b	50.67 a	43 ba	50.33 a	57 a
Phenol	ppm	3.49 a	4.79 a	3.76 a	4.34 a	5.25 a	6.64 a
OM	%	0.62 b	0.63 b	0.67 ab	0.7 a	0.73 a	0.79 a
Humification degree (HD, A_{540nm})		0.047 a	0.048 a	0.048 a	0.051 a	0.048 a	0.048 a
WDPT	Sec.	2.67 a	3.00 a	2.33 a	3.00 a	3.33 a	3.33 a
Texture class		Clay loam (clay 30%, silt 40%, sand 30%)					

[*] Means within a column followed by the same letters are not significantly different at $p < 0.05$

depth 0–20 cm for the application rate of 120 m^3 ha^{-1} at Rabba and Ghweer, respectively, after two seasons of OMW application (Tables 4 and 5). This enhancement in soil nutrients and OM conveyed with an increase in total phenol content. The treated soil showed an increased in the phenol content compared with control; however, this increase was less pronounced after the second season of harvest in comparison with the soil phenol content measured after 2 weeks from the OMW application. Moreover, the phenol content in the (0–20 cm) depth was higher than the (20–40 cm) depth. The phenol content in the treated soil with OMW has been increased directly after application; however, it was decreased afterward, leading to lower concentration of total phenol at the end of the season (Saadi et al. 2013). The phenol might undergo a series of deposition, chemical immobilization in soil-plant continuum, plant uptake, and leaching. The application of OMW significantly affected the amended soil properties at both sites, producing a strong influence after OMW application (Tables 2, 3, 4, and 5). In fact, some soil property values were two- to threefolds higher than in the control in the amended soil treatments especially at the highest application rate (120 m^3 ha^{-1}) treatment. Moreover, statistical analysis showed significant decrease in the treated soils between the 2 weeks after OMW application compared

Table 4 Effect of OMW application on soil physiochemical properties after harvesting at Rabba site 2017/2018 season

Parameter	Units	Soil depth 0–20 cm					
		Control	10 m^3 ha^{-1}	40 m^3 ha^{-1}	60 m^3 ha^{-1}	80 m^3 ha^{-1}	120 m^3 ha^{-1}
		OMW application rates					
pH (1:2.5 soil:water suspension)		7.91 a*	7.89 a	7.84 a	7.86 a	7.84 a	7.79 a
EC (1:2.5 soil:water suspension)	dS m^{-1}	0.49 b	0.54 b	0.61 b	0.59 b	0.74 a	0.72 a
N	%	0.17 b	0.18 b	0.17 b	0.35 a	0.31 a	0.33 a
P	ppm	4.5 d	3.6 d	7.5 bd	15.1 c	20.3 b	25.6 a
K	ppm	291.2 d	356.2 c	345.2 c	421.4 b	524.3 a	463.2 b
Ca	ppm	135.6 c	145.2 b	139.5 bc	165.2 a	171.2 a	159.5 ab
Na	ppm	4.5 d	7.6 c	14.2 ab	11.2 b	15.4 a	17.8 a
Mg	ppm	19.7 d	18.4 d	51.6 c	84.2 a	65.4 b	85.6 a
Phenol	ppm	2.1 b	1.9 b	3.5 ab	4.5 a	5.8 a	4.9 a
OM	%	1.14 c	1.98 b	2.26 b	2.71 a	2.67 a	2.72 a
Humification degree (HD, A_{540nm})		0.09 d	0.17 c	0.25 a	0.21 bc	0.25 a	0.26 a
WDPT	Sec.	2.7 a	3.0 a	3.3 a	3.0 a	2.7 a	3.3 a
Texture class		Clay loam					
		Soil depth 20–40 cm					
pH (1:2.5 soil:water suspension)		7.87 a	7.95 a	7.91 a	7.89 a	7.85 a	7.92 a
EC (1:2.5 soil:water suspension)	dS m^{-1}	0.69 b	0.65 b	0.71 a	0.64 b	0.74 a	0.76 a
N	%	0.15 b	0.14 b	0.16 b	0.24 a	0.23 a	0.25 a
P	ppm	4.2 c	5.6 b	4.6 bc	6.7 a	5.6 b	8.2 a
K	ppm	259.1 c	276.2 c	301.5 b	298.6 b	312.6 b	410.3 a
Ca	ppm	186.99 a	174.07 ab	156.2 c	166.16 b	136.99 d	146.65 c
Na	ppm	8.5 c	10.6 c	14.2 b	10.6 c	23.2 a	19.8 a
Mg	ppm	20.2 dc	17.2 d	17.6 d	25.4 c	35.6 b	50.7 a
Phenol	ppm	3.1 b	2.5 b	3.1 b	4.5 a	3.6 a	4.2 a
OM	%	0.74 c	1.78 b	2.15 a	1.85 b	2.21 a	2.13 a
Humification degree (HD, A_{540nm})		0.11 c	0.13 c	0.18 b	0.25 a	0.19 b	0.26 a
WDPT (Sec.)	Sec.	2.7 a	30 a	2.7 a	3.3 a	3.0 a	3.3 a
Texture class		Clay					

* Means within a column followed by the same letters are not significantly different at $p < 0.05$

with soil properties after harvesting season of 2017/2018. This could be referred to the rainfall leaching effect and plant nutrients uptake during the two growing seasons (Mohawesh et al. 2019).

3.2 Plant Analysis

Table 6 shows the effect of OMW application on barley nitrogen (N), phosphorus (P), potassium (K), chlorophyll content, and leaf area (LA). The results showed significant effects on all parameters except for chlorophyll content. This could be attributed to the accumulated effect of OMW application over the two seasons. Moreover, the growth of barley was different between both sites. This could be explained by the different soil properties and the amount of rainfall between the two sites and the two seasons (Figs. 1 and 2). The rainfall amount at Rabba site was higher by 20% compared with Ghweer site for 2016/2017 and 2017/2018 seasons (Mohawesh et al. 2019). In addition, the soil properties at Rabba exhibited higher nutrient and water retention compared with soil at Ghweer sites that improved with OMW application (Mohawesh et al. 2014). The results of OMW application had no negative effect on barley growth performance

Table 5 Effect of OMW application on soil physiochemical properties after harvesting at Ghweer site 2017/2018 season

Parameter	Units	Soil depth 0–20 cm					
		Control	10 m^3 ha^{-1}	40 m^3 ha^{-1}	60 m^3 ha^{-1}	80 m^3 ha^{-1}	120 m^3 ha^{-1}
		OMW application rates					
pH		7.78 a*	7.68 a	7.58 a	7.59 a	7.61 a	7.58 a
EC	dS m^{-1}	0.61 b	0.57 b	0.68 a	0.65 a	0.68 a	0.72 a
N	%	0.09 c	0.08 c	0.15 b	0.16 b	0.15 b	0.21 a
P	ppm	6.8 d	10.5 c	18.6 b	10.2 c	19.5 b	30.2 a
K	ppm	214.5 d	3451.2 c	368.4 c	412.8 b	389.4 bc	465.2 a
Ca	ppm	89.5 c	81.5 c	142.3 a	129.6 b	141.2 a	151.2 a
Na	ppm	11.3 b	13.4 b	15.6 ab	13.5 b	17.5 a	18.4 a
Mg	ppm	31.2 d	29.8 d	81.4 b	71.5 bc	64.2 c	147.2 a
Phenol	ppm	2.3 a	3.2 a	1.9 a	4.1 a	3.4 a	2.8 a
OM	%	0.85 c	1.14 c	1.78 ab	1.68 b	1.97 a	2.15 a
Humification degree (HD, A_{540nm})		0.045 a	0.046 a	0.05 a	0.049 a	0.05 a	0.053 a
WDPT (Sec.)		2.7 a	3.0 a	2.7 a	3.3 a	3.3 a	3.0 a
Texture class		Loam					
		Soil depth 20–40 cm					
pH		7.73 a	7.7 a	7.65 a	7.71 a	7.68 a	7.68 a
EC	dS m^{-1}	0.58 b	0.59 b	0.62 b	0.57 b	0.62 ab	0.71 a
N	%	0.06 c	0.09 b	0.11 b	0.15 b	0.14 b	0.23 a
P	ppm	5.2 c	7.5 bc	10.2 b	8.2 b	15.2 a	17.2 a
K	ppm	214.2 d	264.2 bc	231.4 c	239.1 c	268.7 ab	281.3 a
Ca	ppm	124.3 c	119.6 c	134.3 bc	148.7 b	200.7 a	192.5 a
Na	ppm	10.2 bc	8.7 c	12.3 ab	9.7 c	8.6 c	13.5 a
Mg	ppm	35.4 c	31.8 c	29.8 c	51.3 b	60.8 ab	71.5 a
Phenol	ppm	3.1 a	2.4 a	3.5 a	2.9 a	3.1 a	3.9 a
OM	%	0.41 c	0.68 b	0.74 b	0.84 ab	1.01 a	0.98 a
Humification degree (HD, A_{540nm})		0.042 a	0.042 a	0.045 a	0.43 a	0.046 a	0.045 a
WDPT	Sec.	3.0 a	2.7 a	3.3 a	3.3 a	2.7 a	3.3 a
Texture class		Clay loam					

* Means within a column followed by the same letters are not significantly different at $p < 0.05$

even under scarce and uneven distributed rainfall conditions. Our results are inline with the conclusions drawn by Galliou et al. (2018).

A significant increase in barley growth was exhibited in the OMW treatment compared with control for dry weight (DM) (14 and 22%), BYLD (49 and 34%), GYLD (41 and 47%), and SYLD (55 and 31%) at Rabba and Ghweer sites, respectively, for the 120 m^3 ha^{-1} treatment (Table 7). The GYLD and SYLD enhancements after OMW application can be related to the improvements in soil organic matter and the nutrient contents (Belqziz et al. 2016; Brunetti et al. 2007; Mohawesh et al. 2014). The increase in soil organic matter enhanced soil structure and soil hydraulic properties such as water holding capacity, which leads to an increase in soil water content (Mohawesh et al. 2014). This study exhibited that barley growth performance improved with OMW application with no harmful impact on soil and plant that might result in reducing the requirement of using chemical fertilizer (Belqziz et al. 2016). The yield of barley was higher in the amended soils compared with the control treatment. The increase of BYLD and GYLD is mainly attributed to the higher nutrient contents supplied by OMW

Table 6 Barley leaves' elemental and morphological measured properties at Rabba and Ghweer sites 2017/2018 season

Parameter	Units	Rabba					
		Control	10 m^3 ha^{-1}	40 m^3 ha^{-1}	60 m^3 ha^{-1}	80 m^3 ha^{-1}	120 m^3 ha^{-1}
		OMW application rates					
Chlorophyll	mg g^{-1} $_{fw}$	48.1a*	50.8a	50.0a	49.8a	48.1a	51.7a
K	ppm	3547e	4217 cd	3879d	47521b	5014a	4962a
P	ppm	201d	185d	287c	394ab	375b	426 a
N	%	1.57c	1.81b	1.94b	2.13ab	2.23a	2.21a
LA	cm^{-2}	5.0b	5.6b	6.5ab	8.1a	7.9a	7.7a
		Ghweer					
Chlorophyll	mg g^{-1} $_{fw}$	50.4a	47.3a	47.1a	45.8a	51.0a	46.9a
K	ppm	5124c	4879d	5147c	4997c	5642a	5421b
P	ppm	547b	498c	468c	587ab	614a	648a
N	%	2.34a	2.42a	1.78c	1.45d	2.13bc	2.31a
LA	cm^{-2}	1.86b	1.89b	1.88b	1.9b	2.19a	2.18a

* Means within a column followed by the same letters are not significantly different at $p < 0.05$

application (Belqziz et al. 2016). The increasing of yields with increasing soil salinity and major plant nutrient (N, P, K) after OMW application approves that OMW is beneficial for providing nutrients for plant growth. OMW spreading on soil showed no visual damage because of OMW application up to 120 m^3 ha^{-1} application rate.

4 Conclusion

The results achieved from this field experiments showed that there is no harmful effect of OMW application at both sites for all application rates compared with the control on the tested soil properties and barley growth performance indicators. However, OMW characteristics

Table 7 Barley biomass and yield at Rabba and Ghweer sites 2017/2018 season

OMW application rates	DM/1st cut (kg ha^{-1})	BYLD (kg ha^{-1})	GYLD (kg ha^{-1})	SYLD (kg ha^{-1})	HI%	500kw (g)	1000kw (g)
Rabba							
20 m^3 ha^{-1}	966.7 a*	2600.0 d	1133.3 c	1466.7 c	43.5 a	27.5	55.0 a
40 m^3 ha^{-1}	1000.0 a	3066.7 c	1300.0 b	1766.7 b	42.0 a	24.8	49.6 b
60 m^3 ha^{-1}	1033.3 a	3400.0 b	1500.0 a	1900.0 b	43.5 a	25.6	51.2 b
80 m^3 ha^{-1}	1100.0 a	3933.3 a	1633.3 a	2300.0 a	41.7 a	26.1	52.2 ab
120 m^3 ha^{-1}	1100.0 a	3866.7 a	1600.0 a	2266.7 a	41.3 a	24.8	49.7 b
Control	966.7 a	2600.0 d	1133.3 c	1466.7 c	43.5 a	26.5	53.1 a
Ghweer							
20 m^3 ha^{-1}	1033.3 b	2153.3 b	343.3 b	1810.0 b	15.8 c	19.60	39.2 a
40 m^3 ha^{-1}	966.7 bc	1933.3 c	383.3 b	1550.0 c	20.0 a	18.00	36.0 a
60 m^3 ha^{-1}	1033.3 b	2253.3 b	348.3 b	1905.0 b	16.7 b	19.10	38.2 a
80 m^3 ha^{-1}	1000.0 b	2936.7 a	520.0 a	2416.7 a	17.9 b	19.30	38.7 a
120 m^3 ha^{-1}	1100.0 a	2793.3 a	385.0 b	2408.3 a	13.5 c	19.50	39.1 a
Control	900.0 c	2196.7 b	355.0 b	1841.7 b	15.9 c	18.00	36.0 a

DM1/1st cut, dry matter first cut; *BYLD*, biological yield; *GYLD*, grain yield; *SYLD*, straw yield; *HI*, harvest index; *1000kw*, 1000 kernel weight

* Means within a column followed by the same letters are not significantly different at $p < 0.05$

as well as soil properties should be considered in managing OMW land application. All applied rates of OMW increased soil nutrient contents and organic matter, which could result in a reduction of chemical fertilizer uses. The OMW application significantly increased OM, N, P, K, and HI at Rabba and Ghweer after two seasons of OMW application. A significant improvement of barley growth has been noticed in treated soil with OMW at both sites. In Jordan, field studies of OMW land spreading under rainfed conditions are inadequate. Hence, this study illustrates the practicality of controlled OMW application on soil, which indicated by enhanced soil properties and plant growth parameters. Finally, appropriate rate of OMW application and continuous monitoring for soil and plant growth parameters is mandatory to confirm the positive and harmless effect of long-term OMW application.

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