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Dilution of olive mill wastewater (OMW) eliminates its phytotoxicity and enhances plant growth and soil fertility

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ABSTRACT

Olive Mill Wastewater (OMW) is phytotoxic and all attempts to treat it are expensive and therefore alternative less expensive treatment techniques should be developed. The objective of this study is to determine whether the dilution of OMW with water improves its suitability for soil application and enhances plant growth without polluting the environment. The following treatments were investigated in a randomized complete block design with four replications in a greenhouse pot experiment: (1) potable water (W); (2) undiluted OMW (100% OMW); (3) diluted OMW at a ratio of $1_{water}:3_{OMW}$ (75% OMW); (4) diluted OMW at a ratio of $1_{water}:1_{OMW}$ (50% OMW); and (5) diluted OMW at a ratio of $3_{water}:1_{OMW}$ (25% OMW). Pots filled with 5 kg air-dry soil and seeded with maize were watered according to the treatments. At the end of the growing period, plant and soil samples were collected for analysis. The results indicated that undiluted OMW reduced plant growth and increased soil salinity. Diluted OMW reduced its phytotoxicity, increased soil organic matter, N, P, and K. However, even diluted OMW increased soil salinity so this should be taken into consideration with continuous OMW application. It was concluded that diluted OMW (25% OMW) eliminated OMW phytotoxicity and enhanced plant growth. Such approach is a practical alternative to the expensive non-affordable by the owners of mills treatments techniques.

Keywords: Olive mill wastewater; Dilution; Maize; Soil properties

1. Introduction

The Mediterranean region is the largest olive oil producer in the world accounting for about 97% of the world oil production [1]. Improving the olive oil processing in this region is of enormous importance for the whole region as well as for each individual country [2]. The process of oil extraction generates annually about 30 million cubic meter of olive mill wastewater (OMW) [3]. The disposal of untreated OMW imposes environmental and health hazards and is considered one of the most serious environmental

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problems faced by most of the Mediterranean countries [4,5]. The major concerns associated with OMW disposal are the high level of the chemical oxygen demand (COD) and the high content of microbial growth-inhibiting compounds, such as phenolic compounds and tannins [6]. OMW has phytotoxic and inhibiting effect on plant growth and an antibacterial effect [5]. Therefore, it cannot be disposed neither directly to the environment nor to the sewage systems [7]. Consequently, OMW must be treated before reuse or before disposal to the environment. All physical, chemical, and biological technologies tested and evaluated for OMW treatment have been proved to be technically effective but unfortunately economically not feasible [8]. In the absence of cost-effective treatment technologies, many countries either discharge it directly into sewer systems, water streams, or conduct a preliminary inefficient treatment through storing in the evaporation ponds where it degrades and releases greenhouse gas emissions [9]. Controlled soil application can constitute an inexpensive and reasonable option for OMW recycling by the farmers and the owners of the olive mills, in particular, in the Mediterranean region where water resources are limited [8].

On the other hand, if OMW was properly treated and managed, it can be beneficial as a source of organic matter (O.M) and nutrients essential to the plants as well as to the fertility of the soil [10] especially in the arid and semi-arid region suffering from scarcity of water and low soil O.M content [11–13]. Several researchers have reported that OMW is rich in nutrients essential for plant growth and contains a high amount of beneficial organic compounds [10,14,15]. These OMW characteristics can enhance the fertility and productivity of the soil of the Mediterranean region that are poor in soil O.M and in fertility level [16]. The high content of organic carbon in the OMW can be used to restore the deficit in soil carbon and combat soil degradation, which consequently enhances the sustainability of the Mediterranean agroecosystems [17–19].

Several studies have shown that soil application of OMW increased crop productivity and enhanced soil fertility [8,20,21]. Plant nutrients such as nitrogen, phosphorus, and potassium increase with soil application of OMW [22]. However, OMW application tends to increase soil salinity [23], which can impose a negative impact on soil physical condition such as soil infiltration rate, aggregate formation and water holding capacity [24]. In contrary, other studies found that soil application of OMW increased soil water-holding capacity, total soil porosity and aggregate stability, while lowered bulk density which was attributed to the effect of the soil compounds provided to the soil with OMW application [19,25].

In Jordan, the olive sector is one of the most important areas of agricultural production. The average annual production of olive fruits in Jordan is about 240,000 tons [26]. The process of oil extraction in Jordan annually produces 25,000 tons of olive oil and generates 200,000 m^3 of OMW [27]. OMW is prohibited to be disposed into the environment to avoid contamination of the soil and water resources. Moreover, Jordanian regulations prohibit discharging OMW into municipal wastewater treatment plants, because its contents may have a toxic effect on micro-organisms [28]. However, OMW in Jordan is not treated but instead it is disposed in dumping sites and sometimes disposed by the owners of olive mills illegally into agricultural lands. Uncontrolled spreading of OMW into agricultural soil not only pollutes the environment and negatively affects the soil fertility and productivity but also is phytotoxic to the crops and prohibits seed germination [29].

Recently, in Jordan, regulations have been issued to allow conditional and controlled direct land application of OMW to avoid costly treatment of OMW. Other countries of the Mediterranean regions have issued somewhat similar conditional OMW land application. However, up to now, there is no solid and scientifically based protocol for proper management of OMW through direct land application. Moreover, much research has been conducted to evaluate the effect of dilution of the municipal wastewater on soil–plant system [11,12,18]. However, researches on dilution of OMW are much fewer and mainly addressed agronomic production parameters or addressed certain soil parameters [5,8,10,16,19]. This study tended to investigate comprehensively the agronomic production, plant and soil quality parameters under semi-arid environment and highly calcareous soils. The specific objective of this study is to evaluate the impact of land application of OMW used as raw and after dilution with potable water on plant growth and on plant and soil quality parameters.

2. Materials and methods

2.1. Materials

A calcareous soil with a low O.M content classified as fine-loamy, mixed, thermic, and calcic Paleargid [30] was collected from the Research Center at Jordan University of Science and Technology and used in this study. The soil was air-dried and sieved through a 5 mm sieve. The soil was analyzed for general characteristics; texture was determined by hydrometer method [31]; soil pH was measured on 1:1 soil:water suspension [32]; electrical conductivity (EC) was measured on 1:1 soil:water extracts [33]; O.M content was determined by the Walkley–Black method [34]; cation exchange capacity (CEC) by the method of Palemio and Rhoades [35]; total nitrogen by Kjeldahl method [36], available phosphorus by extraction with sodium bicarbonate [37]; exchangeable potassium by extraction with 1 M NH_4OAc [38]; $CaCO_3$ by acid neutralization method [39]; and heavy metals (Fe, Zn, Mn, Cu, Cd, Pb) by DTPA extractable microelements [40]; bulk density by the core method [41]. The major characteristics of the soil are presented in Table 1.

2.1.1. Preliminary soil characteristics

The analysis of the soil used in this study indicates that the soil is basic, alkaline and non-saline, poor in O.M, N, P, and basic micronutrients. Available K is considered to be adequate for normal plant growth. The soil texture is silty clay loam with relatively high CEC (Table 1).

2.1.2. Olive mill wastewater (OMW) characteristics

OMW used in this experiment was collected from three-phase olive oil mill in Jordan. The collected OMW was not treated but it was settled in reservoirs. The OMW and potable water used as a source of irrigation water were analyzed for physical and chemical characteristics according to the standard methods described by the American Public Health Association (APHA) [42]. The major characteristics of OMW and potable water are illustrated in Table 2.

Table 1
Selected chemical and physical properties of original soil

Parameter	Value
pH (1:1 soil: water suspension)	8.18
EC (1:1 soil: water extract (dS m^{-1})	0.61
CEC (cmol kg^{-1})	34.32
O.M (%)	0.72
N (%)	0.01
P (mg kg^{-1})	7.11
K (mg kg^{-1})	452
$CaCO_3$ (%)	13.38
Fe (mg kg^{-1})	3.56
Mn (mg kg^{-1})	5.58
Zn (mg kg^{-1})	1.88
Cu (mg kg^{-1})	1.22
Pb (mg kg^{-1})	0.68
Cd (mg kg^{-1})	0.06
Bulk density (g cm^3)	1.38
Texture class	Silty clay loam

The undiluted OMW is acidic and strongly saline. The total suspended solids were relatively high (1,236 mg l^{-1}), heavily loaded with organic material with COD of 119 g l^{-1}. The levels of major plant nutrients (N, P, and K) were also relatively high which can be valuable sources for plant growth and soil fertility. The total bacterial count in undiluted OMW (100% OMW) was 2.13×10^6 CFU ml^{-1}. OMW contains high phenolic content which is considered toxic to organisms [20] (Table 2).

The settled OMW with and without dilution with potable water were applied to the soil as a source of irrigation water. The following treatments were investigated in a randomized complete block design with four replications in a greenhouse pot experiment: (1) potable water (W); (2) undiluted OMW (100% OMW); (3) diluted OMW at a ratio of $1_{water}:3_{OMW}$ (75% OMW); (4) diluted OMW at a ratio of $1_{water}:1_{OMW}$ (50% OMW); and (5) diluted OMW at a ratio of $3_{water}:1_{OMW}$ (25% OMW).

2.2. Greenhouse pot experiment

Each pot was filled with 5 kg air-dried soil. Three maize seeds per pot were seeded. Pots were watered periodically with undiluted and diluted OMW according to the treatments to maintain approximate field capacity water content. After germination two similar plants were kept per pot. At the end of the growing period, the whole plants were harvested from each pot. The fresh weights were recorded. Then the plant samples were oven-dried at 70˚C for 48 h, and then the oven dry weights were recorded. Plant parts were ground to a fine powder using a laboratory mill with 0.5 mm sieve. The milled plant samples were analyzed

Table 2
Characteristics of water and OMW used for irrigation

Parameters	W	OMW
pH initial	7.8	4.7
EC (dS m^{-1})	0.56	7.6
TSS (mg l^{-1})	10	1,236.2
TP (mg l^{-1})	0.98	1,666.7
COD (g l^{-1})	ND	118.8
N (mg l^{-1})	11.7	96.8
P_2O_5 (mg l^{-1})	34.3	369.5
K_2O (mg l^{-1})	10.9	2,441.8
Total bacterial count (CFU ml^{-1})	–	2.13×10^6

Notes: W = Water (0% OMW); OMW = Olive Mill Wastewater; EC = Electrical conductivity; TP = Total polyphenols; COD = Chemical oxygen demand; TSS = Total suspended solids; CFU = Community forming unit.

for total nitrogen using a modified micro-Kjeldahl digestion procedure [43]. Total P, K, Fe, Mn, Zn, Cu, Pb, and Cd were determined in the dry ash digestion. P was determined using Vanadate–Molybdate–Yellow method, K and Na by flame photometery and Fe, Mn, Zn, Cu, Pb, and Cd by atomic absorption spectroscopy [44]. At the end of the experiment, infiltration rate test was conducted for all treatments using cylinder infiltrometer [45]. Undisturbed soil core was taken to measure the soil bulk density [41]. Representative soil sample was also taken from each pot after thoroughly mixing the soil. Soil samples were sieved through 2 mm sieve and analyzed for the same parameters mentioned above.

At the end of the experiment, analysis of variance (ANOVA) was used to determine the treatment effects. When F ratio was significant a multiple means comparison was performed using Fisher's Least Significance Test (0.05 probability level). Statistical analyses were performed with Systat statistical program [46].

3. Results and discussion

3.1. Infiltration rate into the soil

Infiltration rate of diluted and undiluted OMW treatments into the soil just after plant harvest are depicted in Fig. 1. The undiluted OMW prevail the lowest infiltration rate followed by the 75% OMW (lowest dilution) during the first five minutes compared to other treatments that resulted in similar effect on infiltration rate. The highest infiltration rate was obtained by the 25% OMW treatment. The infiltration rate for all treatments decreased with time during the elapsed first 120 min of infiltration run. There were no significant differences among all treatments during the period from 60 min till 120 min. The observed decrease in the infiltration rate could be attributed to the abundant suspended matter in the OMW that might clog the soil pores [47,48]. Further, OMW contains oils that may increase soil hydrophobicity by increasing the contact angle between soil solution and soil solid and therefore reduce infiltration rate and reduce the movement of water through soil pores [49,50]. In the long run and due to the positive effect of OMW on soil organic content, it is expected to improve the soil structure and eventually the soil porosity and infiltration rate [19].

3.2. Plant growth

Plant growth parameters as affected by the undiluted and diluted OMW are shown in Fig. 2. The plant dry weight was the highest with the soil application of the highest dilution of OMW treatment (25% OMW), followed by the control treatment where potable water alone was used (W). The undiluted OMW resulted in the lowest plant dry weight indicating the phytotoxic effect on the plant growth. The relative plant dry weight obtained by the 25% OMW was 23% more than that obtained by the control (W) and three times more than that obtained by the application of undiluted OMW (100% OMW) (Fig. 2). There was a linear relationship between the percentage of OMW and plant dry weight. With each dilution unit (25%) investigated in this study, the dry weight decreased by about 18% (Fig. 3).

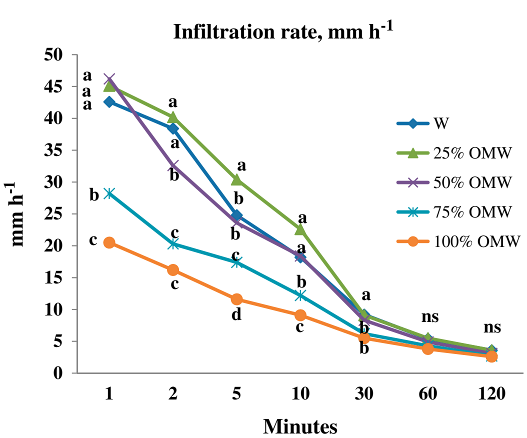

Fig. 1. Infiltration rate of diluted and undiluted OMW into the soil (mm h^{-1}).
Note: Different letters in each treatment indicate significant difference at $p < 0.05$.

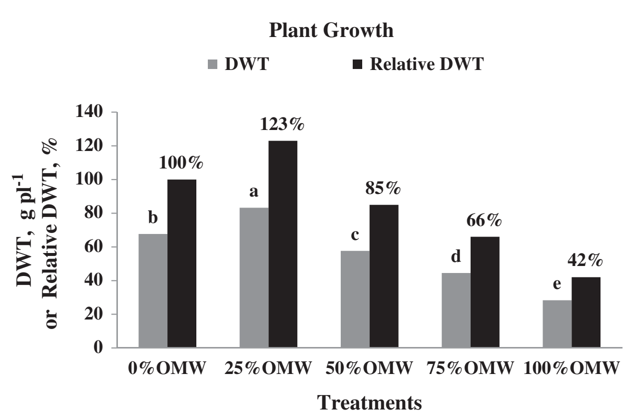

Fig. 2. Plant dry weight as g plant-1 and relative to the control (W).
Note: Different letters in each column indicate significant difference at $p < 0.05$.

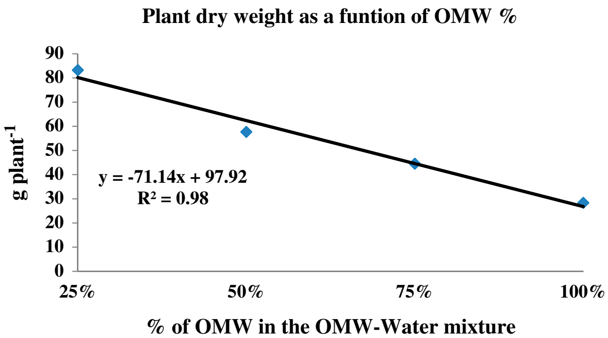

Fig. 3. Relationship between plant dry weight and % OMW in the OMW: water mixture.

These results indicate two findings. The first finding is that inhibiting and phytotoxic effect of OMW can be reduced with dilution of OMW with potable water and at the same time improves the plant growth. The best results obtained with the highest dilution, represented by the 25% OMW treatment, which approximately tripled the plant dry weight. The second finding is that the highest dilution (25% OMW) gave even higher plant dry weight compared to the control treatment (W). This indicates that by diluting the OMW at a ratio of water: OMW of 3:1 (25% OMW), can eliminate the phytotoxicity of undiluted OMW and enhance plant growth. Such plant growth enhancement could be attributed to the beneficial organic substances and essential nutrients provided to the soil with OMW application. The decrease in OMW phytotoxicity following OMW dilution could be attributed to the reduction in the levels of the phenols and other phytotoxic compounds [51]. Several studies have reported the positive response of plant growth to soil OMW application [28,52].

3.3. Plant nutrients content

The plant contents of N, P, and K were the highest for the 25% OMW treatment followed by the W (Table 3). This increase with the 25% OMW treatment compared to the control treatment (W) indicates that the soil is deficient in these nutrients and the OMW provided the soil with these nutrients or enhanced the original unavailable soil nutrients resulting in an increase in their uptake by the plant.

The lowest plant contents of N, P, and K was obtained by the application of the undiluted OMW and tended to increase with dilution of OMW. The higher the dilution was, the higher the contents of plant nutrients. The decreasing trend in plant uptake of nutrients with dilution of OMW followed the trend

Table 3
Plant uptake of macronutrients

Treatments	N (g Plant^{-1})	P (g Plant^{-1})	K (g Plant^{-1})
W	0.99 b	0.17 b	1.38 b
100% OMW	0.48 d	0.06 d	0.44 d
75% OMW	0.66 c	0.08 d	1.04 c
50% OMW	0.98 b	0.11 c	1.48 b
25% OMW	1.74 a	0.26 a	2.14 a

Note: Different letters in each column indicate significant difference at $p < 0.05$.

of the effect of the same treatments on the plant dry weight. Obviously, the lower the dilution of the OMW, the lower the plant dry weight. Although the OMW contains considerable amounts of N, P, and K which simultaneously would be added to the soil upon OMW application [53,54], their uptake by the plant irrigated with undiluted and diluted W remained low due to the low plant dry weight. The enhancements of plant uptake of N, P, and K with OMW application have been reported by several researchers [10,14,22]. The uptake of micronutrients (Fe, Mn, Zn, and Cu) and heavy metals (Cd and Pb) was not affected significantly by all the treatments investigated including the control (Table 4). This agrees with the results obtained by Rinaldi et al. [55] who found that OMW application did not result in heavy metal accumulation in the soil.

3.4. Soil characteristics after plant harvest

Soil pH at the end of the growing period was not affected by the treatments (Table 5). Other researchers have reported a decrease in soil pH with land application of OMW and they attributed such effect to the acidic nature of OMW [56]. However, such change in this study was not observed which could be attributed to the high buffer capacity of calcareous soil used in this study [57].

On the other hand, the soil salinity (EC) increased drastically by the application of undiluted and diluted OMW (Table 5). The highest increase in soil EC was obtained by the undiluted OMW (100% OMW) and then the EC increased with decreasing dilution of the OMW. The increase in EC with OMW application is obviously attributed to the high salt concentration in the OMW that would accumulate in the soil with continuous application. Abid and Sayadi [58] has reported an increase in soil electrical conductivity following OMW application. The continuous buildup of salts in the soil surface with long-term application of OMW may adversely affect seed germination, seedling

Table 4
Plant uptake of micronutrients and heavy metals

Treatments	Fe (mg Plant^{-1})	Mn (mg Plant^{-1})	Zn (mg Plant^{-1})	Cu (mg Plant^{-1})	Cd (mg Plant^{-1})	Pb (mg Plant^{-1})
W	3.68	1.86	0.39	0.02	0.05	0.17
100% OMW	1.74	1.61	0.27	0.03	0.02	0.08
75% OMW	1.72	1.64	0.21	0.03	0.07	0.08
50% OMW	1.95	1.72	0.22	0.02	0.14	0.09
25% OMW	1.81	1.92	0.25	0.02	0.16	0.11
$LSD_{.05}$	NS	NS	NS	NS	NS	NS

Note: Different letters in each column indicate significant difference at $p < 0.05$.

Table 5
Soil characteristics after plant harvest

Treatments	pH	EC (dS m^{-1})	O.M (%)	TP (%)	BD (g cm^{3})
W	7.87 a	0.98 d	1.21 d	0.11 e	1.22 a
100% OMW	7.70 a	5.88 a	2.10 a	20.67 a	1.09 b
75% OMW	7.87 a	4.88 b	1.96 a	15.95 b	1.09 b
50% OMW	7.90 a	3.22 c	1.83 ab	10.31 c	1.2 a
25% OMW	7.87 a	2.83 c	1.65 bc	5.09 d	1.2 a

Notes: EC = Electrical conductivity; O.M = Organic matter; TP = Total polyphenols and BD = Bulk density. Different letters in each column indicate significant difference at $p < 0.05$.

establishment and plant growth, and may also deteriorate soil productivity. Therefore, this should be considered in managing soil application of OMW especially when OMW will be used for long-term application [12]. Since these salts are water soluble, potential leaching beyond the rooting systems is possible [59].

The soil contents of both O.M and total polyphenols were the highest for the undiluted than by diluted OMW compared to soil irrigated by potable water. Other studies reported an increase in soil O.M as well as in phenolic compounds with soil application of OMW [5,22,58,60,61]. Such increase in soil O.M tends to enhance soil fertility level [19,62]. Besides, the 100% OMW and 75% OMW treatments decreased the soil bulk density, which tend to enhance soil structure and soil aggregation [61].

3.5. Soil nutrients after plant harvest

Soil N, P, K, Ca, Mg, and Na drastically increased with undiluted and diluted OMW application in comparison with the control treatments where water was applied. The highest values for all these nutrients were obtained when undiluted OMW was applied (Table 6). The increase in soil N, P, and K contents with OMW application can be attributed to their high content in the OMW used. Such enrichment of the soil with O.M and macronutrients would improve the soil fertility and productivity levels. Positive effect of OMW on soil fertility level has been reported by other studies [5,62,63]. Increasing soil content of N, P, and K with OMW application to the soil has been reported in other studies [5,22,52].

The soil contents of the soil DTPA-extractable Fe, Mn, Zn, and Cu after crop harvest were not affected significantly by the application of neither undiluted nor diluted OMW (Table 7). This could be attributed to their very low concentrations in the OMW. In addition, fine textured soils have the capacity to treat OMW and retain considerable amount of micronutrients and heavy metals rendering them not bioavailable that is commonly measured by DTPA extraction [57]. However, continuous application of OMW may lead to the accumulation of certain nutrients in the soil to levels high enough to cause nutrient imbalance; therefore, one should take this into consideration before determining the rate of application [57].

3.6. Soil micro-organisms

The total bacterial count in the undiluted OMW was 2.13×10^6 CFU ml^{-1}. The total bacterial count in the soil irrigated with potable water was $4.52 \times 10^6 \pm 6.14 \times 10^5$ CFU ml^{-1}, while in the soil irrigated with the undiluted OMW (100% OMW) was

Table 6
Soil macronutrients and secondary nutrients after plants harvest

Treatments	N (%)	Olsen-P (mg kg^{-1})	K (mg kg^{-1})	Ca (meq L^{-1})	Mg (meq L^{-1})	Na (meq L^{-1})
W	0.09 b	8.83 d	631 d	3.47 e	3.13 e	2.96 d
100% OMW	0.12 a	82.50 a	2,926 a	23.73 a	22.70 a	8.10 a
75% OMW	0.12 a	64.23 b	2,558 b	17.70 b	16.73 b	7.59 a
50% OMW	0.11 a	54.53 bc	2,290 b	11.23 d	13.10 c	6.31 b
25% OMW	0.12 a	28.23 c	1,664 c	12.77 cd	8.27 d	5.03 c

Note: Different letters in each column indicate significant difference at $p < 0.05$.

Table 7
Soil DTPA-extractable micronutrients after plants harvest

Treatments	DTPA Fe (mg kg^{-1})	DTPA Mn (mg kg^{-1})	DTPA Zn (mg kg^{-1})	DTPA Cu (mg kg^{-1})
W	1.50 b	3.10 d	0.88 d	1.49 a
100% OMW	3.12 a	83.40 a	2.45 a	1.30 a
75% OMW	3.69 a	65.27 b	2.40 a	2.10 a
50% OMW	4.34 a	27.70 c	2.50 a	1.87 a
25% OMW	2.86 a	22.77 c	1.93 b	1.56 a

Note: Different letters in each column indicate significant difference at $p < 0.05$.

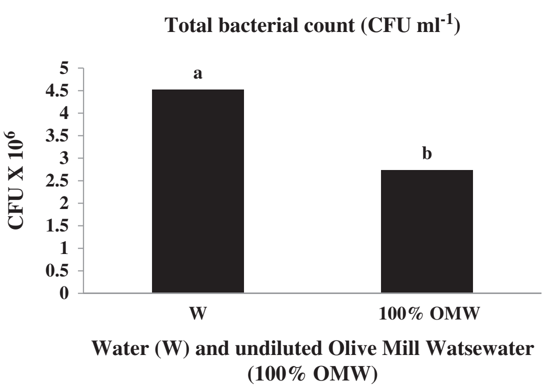

Fig. 4. Total bacterial count (CFU ml^{-1}).
Note: Different letters in each column indicate significant difference at $p < 0.05$.

$2.74 \times 10^6 \pm 4.79 \times 10^5$ CFU ml^{-1} (Fig. 4). This indicates the toxic effect of OMW on soil micro-organisms [5]. Sidari et al. [51] have reported that addition of raw OMW to the soil reduced the numbers of bacteria and actinomycetes in the soil. Similar findings were obtained by other researchers [5,64].

4. Conclusions

Based on the results obtained from this study, it can be concluded that soil application of undiluted OMW had a phytotoxic and prohibiting effect on plant growth and soil micro-organisms. On the other hand, due to the high levels of O.M, phenols and nutrients in the OMW, the soil fertility was improved following soil application of OMW. Dilution of OMW with potable water at water to OMW ratio of 3:1 (25% OMW) is recommended before soil application to eliminate its phytotoxicity and to enhance plant growth. Such dilution can be adopted without any further treatment as an inexpensive technology before application. Finally, the enhancement of soil O.M, N, P, and K which improve soil fertility is of particular importance for the poor soils of the arid and semi-arid region. Thus, OMW in this region has the potential to be used as an organic soil amendment.

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