Water and Environment Journal
Promoting Sustainable Solutions
CIWEM

Water and Environment Journal. Print ISSN 1747-6585

# Table grapes irrigation with treated municipal wastewater in a Mediterranean environment

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**Keywords**
effluent reuse; fruit quality; microbiological status; mineral analysis.

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doi:10.1111/wej.12656

## Abstract

This study investigated the effect of different water quality regimes [Freshwater (FW), treated wastewater (TW) and alternating FW and TW (FW-TW)] on drip-irrigated table grape yield, quality and microbial contamination. Water and soil samples were analysed. In addition, grape samples were harvested for quantitative and qualitative evaluation. The results showed that the plants irrigated with TW and those irrigated with alternating FW and TW gave 19.57 and 14.95% higher marketable yield, respectively, than plants irrigated with FW. Total soluble sugars, total titratable acidity and sweetness ranged, respectively, between 18.43–20.13, 0.69–0.81% and 21.52–29.19, and were within the desirable levels for table grape harvest. In addition, there was no significant difference in terms of total phenols and mineral composition of berries, leaves, peduncle and pedicels. Finally, table grapes did not present any bacterial contamination which confirm the importance of the adopted irrigation regime for a safe wastewater reuse in agriculture.

## Introduction

Water-Food-Ecosystem nexus is among the crucial issues for the continuity of life on Earth (WHO, 2017). Wastewater is becoming part of the solution required to mitigate the challenges of water scarcity facing the whole world. The treatment and reuse of wastewater would support the 2030 Agenda for Sustainable Development Goals, particularly Target 6.3 that deals with water quality and targets of SDG2 by enhancing agricultural productivity and achieving zero hunger (UN General Assembly, 2015). Worldwide, many studies reported examples of wastewater reuse for the irrigation of table grapes (Petousi *et al*., 2019), olives (Petousi *et al*., 2015) and even vegetables (Christou *et al*., 2017; Farhadkhani *et al*., 2018; Libutti *et al*., 2018; Mehmood *et al*., 2019). It is an interesting option for farmers, however, it could affect the yield and production quality. In addition, the presence of contaminants could harm the environment, as well as the health of farmers and consumers (Petousi *et al*., 2019).

In Lebanon, the Food and Agricultural Organization of the United Nations (FAO) has been working on the development of national guidelines for the wastewater reuse practices (FAO/UTF/LEB/019/LEB, 2011) and the government has been working on the construction of wastewater treatment plants as well as the rehabilitation of the existing systems. However, till now, only few studies have been conducted on the reuse of treated wastewater in irrigation, especially in the Bekaa valley where conventional wastewater treatment plants have started to be supported and operational. A recent study (Mcheik *et al*., 2017), based on case studies from Lebanon and Jordan, pointed out positive effects of treated wastewater reuse in irrigation. Nevertheless, the authors concluded that further investigations are needed in order to adopt adequate management solutions in terms of yield quantity and quality, soil productivity and environment. This study assesses the impact of the treated municipal wastewater reuse in crop irrigation comparing three water quality regimes (freshwater, treated wastewater and alternation of them). The study was performed near the city of Ablah in the Central Bekaa. Commonly, the farmers use freshwater pumped from the aquifer for irrigation. However, in the recent years, they started to get benefits from the treated wastewater released from the local Wastewater Treatment Plant (WWTP). The treated effluent was directly transferred to the farmers to irrigate their fields of table grapes. Hence, this study investigates table grapes production in Ablah village under different water quality regimes. The possible risks to health, the quality of obtained yield and the effect of wastewater irrigation on soil properties are investigated. The tested hypothesis is to determine if it is evident that the selection of the appropriate irrigation strategy (irrigating only with treated effluent or alternating the use of treated effluent and freshwater) would not lead to decreased crop yield, deteriorated grapes quality and degraded local soil.

## Materials and methods

### Experimental site and climate

The experiment was carried out in Ablah village located in the Bekaa valley (37° 16′ N, 14° 25′ E) during the 2017 growing season. The climate of the area is typically Mediterranean, characterized by a hot and dry season from April to October. Table grapes are a common crop grown in the study area. The nearby wastewater treatment plant accomplished a secondary treatment (Conventional Treatment Process through trickling filters + Disinfection by Chlorination) and delivered treated wastewater to the farmers in the study area.

Three farms were selected as experimental sites because they represent the common management conditions of the region in terms of crop, soil and irrigation practices. The response of drip irrigated table grapes grown under three water quality regimes [Freshwater (FW), treated wastewater (TW) and alternating FW and TW (FW-TW)] was assessed. At each farm full irrigation was applied with one of three water quality options. The first farm used FW for irrigation, the second farm irrigated with TW provided from Ablah WWTP while the third one was alternating FW and TW. The aim was to investigate the effect of different water quality regimes on grape yield, quality and microbial contamination as well as on the soil properties. In addition, it is important to understand which irrigation strategy (irrigating only with TW or alternating TW and FW) is to be recommended for table grapes irrigation in Ablah village. The three farms were adjacent to each other and surrounding the WWTP. The location of the WWTP as well as the selected farms are shown in Fig. 1.

Weather, crop and soil parameters and management practices, including fertilizers application, were similar at three selected farms. Table grape variety 'Chili' was cultivated at all sites. Soil was of sandy-clay texture and plant density was three times 3 m. Standard cultivation practices were adopted during the crop growing season. Irrigation season started at fruit setting (pea size) on 20 June and stopped on September 10. The vines were harvested on 15 September at commercial maturity.

The main weather parameters were collected from a standard agro-meteorological station located at the experimental station of the Lebanese Agricultural Research Institute (LARI) that is very close to the field trial (at 200 m). The weather regime, in terms of reference evapotranspiration (ETo), precipitation (P), maximum temperature (Tmax), minimum temperature (Tmin) and mean relative humidity (RHmean) during the season 2017 are given in Table 1. In general, overall average minimum and maximum air temperature during the grapevine cycle extending from May to September were 12.9 and 32.9°C. The total precipitation amount from May to September was 6.2 mm with the period July-September without any rain.

### Irrigation system and management

Irrigation was managed on the basis of soil moisture measurements and the soil water balance method and an Excel scheduling tool (Todorovic *et al*., 2006). Reference evapotranspiration was calculated on a daily basis from measured weather data using the FAO Penman-Monteith equation (Allen *et al*., 1998). The management allowable depletion was assumed to be 0.45 of total available water ($P = 0.45$) as suggested in FAO 56 (Allen *et al*., 1998). Irrigation was applied at 100% of crop evapotranspiration (ETc) between fruit set (pea size) and one week prior to harvest.

All the plots were supplied by on-line drippers (discharge rate of 8 L/h, each vine-plant had two drippers corresponding to a total discharge of 16 L/h. The spacing between laterals was 3 m.

Accordingly, the same amount of irrigation water was applied in the three farms corresponding to a total seasonal net amount of 320 mm. The application efficiency was fixed to 0.95 corresponding to the effective (gross) seasonal water application of 337 mm.

### Soil and water: sampling and analysis

In each grape field, soil samples were taken randomly from five locations at two different depths: 0–25 cm and 25–50 cm before the beginning and at the end of the irrigation season. The soil samples were dried and sieved before analysing the physicochemical properties, the presence of micronutrients and trace elements. The electrical conductivity was measured by a conductivity meter and the pH by a pH meter. Sodium (Na) and Potassium oxide ($K_2O$) were measured by a Flame Photometric Detector. Total/Active limestone ($CaCO_3$), Phosphorus pentoxide ($P_2O_5$), Nitrogen (N) and organic matter were determined by titration methods while heavy metals and other micronutrients were detected through atomic absorption spectroscopy.

For irrigation water, the main physicochemical and microbial characteristics of both kinds of water (FW and TW) were monitored. Samples were collected at the start of the irrigation system. Sterile bottles used for the microbiological analysis were stored at 4°C.

Analyses were carried out at the laboratory of the Lebanese Agricultural Research Institute (LARI). Standard methods (APHA, 1998) were used in the laboratory to

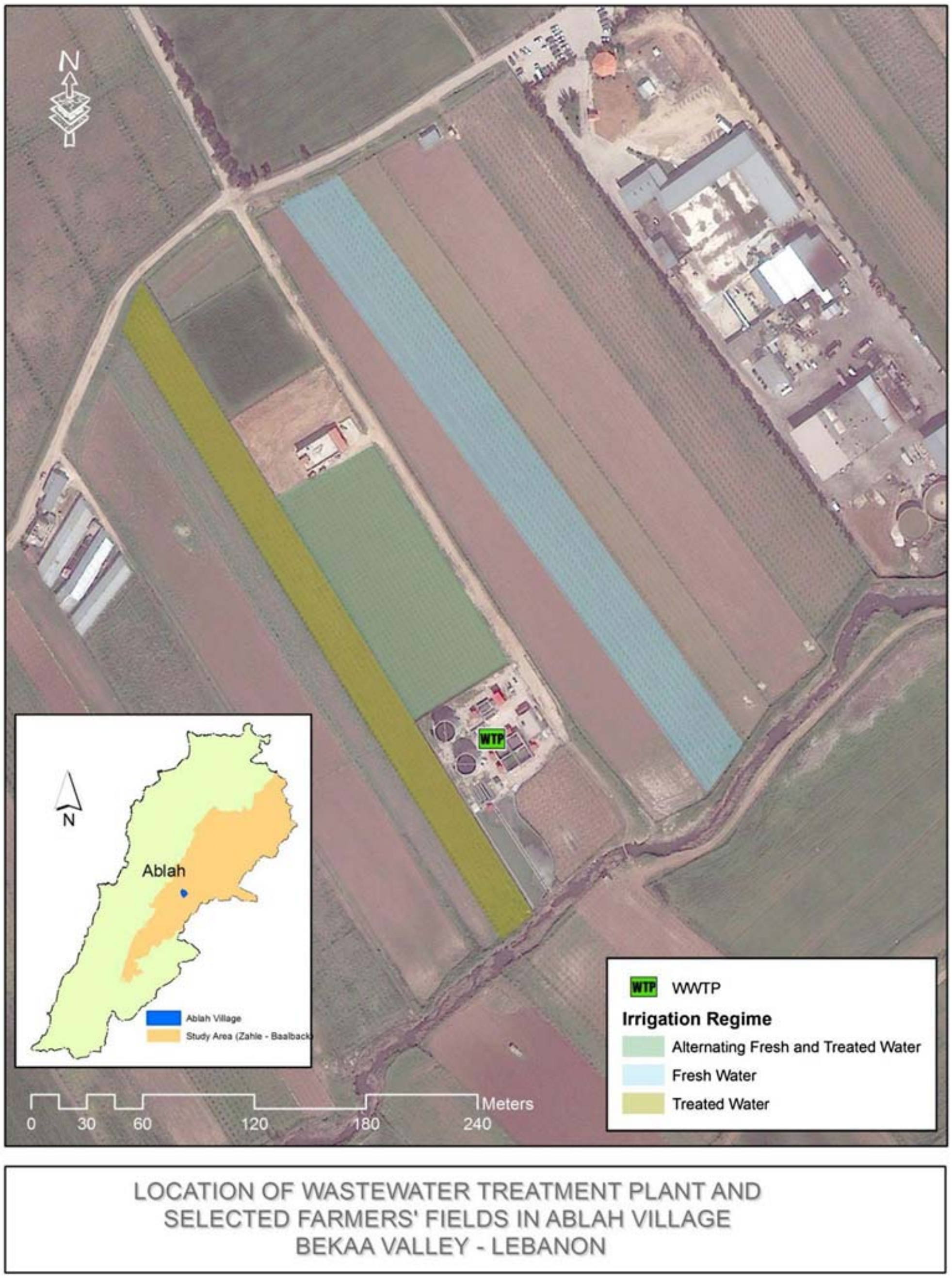


**Fig. 1.** Location of wastewater treatment plant (WWTP) and selected farmers' field in Ablah village Bekaa Valley (Lebanon).

measure the Biochemical Oxygen Demand ($BOD_5$), the total dissolved salts (TDS), electrical conductivity (EC), the pH, etc. The microbiological analysis measured total coliforms (TC), faecal coliforms (FC), Escherichia coli (E. coli) and salmonella. The TC, FC and E. coli were analysed according to standard methods (APHA, 1998) using the membrane filter system; Salmonella were examined according to the methodology described by Giammanco *et al*. (2002). Finally, the samples were also analysed for the presence of trace elements.

## Grape yield, its components and quality determinations

In each field, an area corresponding to 10 rows of vines and 10 vines/row, was used for sampling purpose in order

**Table 1** Monthly climate data for January–September season in 2017 as recorded at the agro-meteorological station

| Month | ETo (mm) | Rain (mm) | Tmax (°C) | Tmin (°C) | RHmean (%) |
|---|---|---|---|---|---|
| January | 70.2 | 119.4 | 10.87 | –0.73 | 78.8 |
| February | 90 | 14.2 | 13.70 | –2.12 | 60.5 |
| March | 114 | 49.4 | 16.15 | 4.01 | 70.8 |
| April | 188.7 | 12 | 22.14 | 5.69 | 54.5 |
| May | 226.2 | 3.8 | 27.69 | 8.98 | 46.9 |
| June | 259.2 | 2.4 | 31.86 | 12.07 | 42 |
| July | 259.8 | 0 | 35.21 | 16.82 | 36 |
| August | 264.9 | 0 | 35.25 | 13.20 | 43.8 |
| September | 100.2 | 0 | 34.44 | 13.67 | 38.7 |
| October | 59.7 | 35.6 | 20.56 | 6.22 | 64.95 |
| November | 50.6 | 1.0 | 18.93 | 2.42 | 63.29 |
| December | 24.23 | 0.2 | 17.37 | 2.83 | 70.23 |

ETo, reference evapotranspiration; Tmax, maximum temperature; Tmin, minimum temperature; RHmean, mean relative humidity.

to determine yield quantity and quality parameters. At harvest, bunches from two randomly selected vines/row (total of 20 vines) were picked and counted in each of the three fields. Yield, mean cluster weight (g) and the number of clusters per vine were determined. In addition, the percentage (%) dry weight of leaves, pedicel and peduncles as well as berries was measured.

For the quality parameters, randomly chosen clusters were taken from each of the three field bulk yield. Grape samples were analysed for pH, total soluble solids (TSS), total titratable acidity (TTA) and total phenols (TP). pH was determined using an analytical bench pH-meter. Berries were crushed manually, the juice was filtered and the sugar content estimated with a digital refractometer (Atago RX-5000). TTA was measured using a 0.1 N NaOH titration solution. Total phenols analysis referred to Folin-Ciocalteu method (Folin and Ciocalteu, 1927). Total phenolic content of the dried grape berries samples were extracted in ethanol solution. The absorbance was measured at 740 nm for total berry phenolics.

## Bacterial contamination

Fruits were harvested from each field and used to measure microbial contamination, mainly the faecal coliform, E. Coli, Staphylococcus aureus, Clostridium perfringens, Listeria monocytogenes and Salmonella. Analyses were performed according to APHA (1998).

The Salmonella detection protocol consisted of a pre-enrichment stage using a solution of buffered peptone water, which is a nonselective culture medium, to revitalize the microorganism. Then, an inoculum culture was prepared in selenite and cystim medium and incubated at 36 ± 1°C for 48 h. After the incubation period, several cultures were inoculated and incubated in parallel on ss-agar gel to count the number of Salmonella colonies (Giammanco *et al*., 2002).

## Mineral analysis in leaves and fruits

Leaf and grapes samples were collected prior to harvest in accordance with the protocol of Conradie (1994). Grape berries were separated from their pedicel and peduncle and 100 grams of berries were weighed. In addition, each pedicel and peduncle sample were also weighed. All of the samples were dried in oven at 60°C for 48 h and ground with a laboratory blender. Dried powdered samples were digested by adding a concentrated nitric acid using the microwave digestion method (Xing and Yeneman, 1998). Filtrates from each sample were collected in order to analyse their mineral content. Nitrogen was measured by means of a nitrogen analyzer using the methods described by Horneck and Miller (1998). P and K were analysed by means of an ICP-OES spectrometer.

## Statistical analysis

The purpose of this trial was to compare three independent experiments, for this reason the Kruskal–Wallis test by ranks was carried out for different parameters.

The goal of this nonparametric analysis is to compare the mean rank for the three experiments and decide whether the differences are real or because of chance alone. When Kruskal–Wallis tests found significant differences, pairwise Dunn test with Bonferroni corrections were performed. All statistical analyses were carried out by using SAS®UniversityEdition.

# Results

## Water quality

Table 2 shows the seasonal means of the physical–chemical, microbial and metal characteristics of the fresh and the treated water analysed during the trial.

According to the guidelines for interpretation of water quality for irrigation (FAO, 1985), salinity of fresh water was low (0.75 dS/m) while that of treated water was slight to moderate (1.31 dS/m), but it was still suitable for irrigation. The $BOD_5$, with a value of 39 mg/L, was higher than the admissible limits of water category I for treated wastewater reuse proposed by the Lebanese guidelines while the COD value of 50.48 mg/L, was within the limits. Both $BOD_5$ and COD values were within the admissible limits for fresh water. Nitrate content was low in treated effluent (0.3 mg/L) while it was high in fresh water with a mean value of 30.9 mg/L that is very close to the admissible

**Table 2** Fresh water and treated effluent average quality and limit values for the reuse of treated wastewater in Lebanon

| | FW | TW | Environmental limit values for surface water based on MoE Decision 8/1 (MoE, 2001) | Effluent specifications for wastewater reuse in irrigation based on proposed Lebanese guidelines (FAO, 2011) | | |
|---|---|---|---|---|---|---|
| | | | | Water Category I | Water Category II | Water Category III |
| *Physicochemical parameters (mg/L)* | | | | | | |
| pH | 7.31 | 8.29 | 6–9 | 6–9 | 6–9 | 6–9 |
| Electrical conductivity (dS/m) | 0.75 | 1.31 | – | – | – | – |
| COD | 36.00 | 50.48 | 125 | 125 | 250 | 250 |
| $BOD_5$ | 18.00 | 39.00 | 25 | 25 | 100 | 100 |
| Total Suspended Solids | 4.89 | 30.80 | 60 | 60 | 200 | 200 |
| Nitrates | 30.90 | 0.30 | 90 | 30 | 30 | 30 |
| Phosphates | 1.38 | 1.00 | 5 | – | – | – |
| Potassium | 2.10 | 68.70 | – | – | – | – |
| *Pathogens in water* | | | | | | |
| Total Coliform (CFU/100 mL) | 95.00 | 14x10E11 | – | – | – | – |
| Faecal Coliform (CFU/100 mL) | <1 | 20x10E5 | <2000 | <200 | <1000 | – |
| E. coli (CFU/100 mL) | <1 | 20x10E5 | <2000 | <200 | <1000 | – |
| Salmonella | Absence | Present | Absent | Absent | Absent | Absent |
| *Trace metals (mg/L)* | | | | | | |
| Zn | NT | 0.16 | 5 | | | |
| Cu | NT | NT | 0.5 | | | |
| Pb | NT | NT | 0.5 | | | |
| Mn | NT | NT | 1 | | | |
| Ni | NT | NT | 0.5 | | | |
| Cd | NT | 0.0041 | 0.2 | | | |
| Cr | NT | NT | 2 | | | |

FW, freshwater; TW, treated water; COD, chemical oxygen demand; BOD5, Biological oxygen demand.

value of 30 mg/L of water category I. The higher content of nitrates in fresh water is mainly because of the excessive nitrate application in agricultural fields of the region, that unfortunately, end up in groundwater through leaching process. Phosphorus level was most of the time low with a mean value of 1.38 mg/L in fresh water and 1.00 mg/L in treated effluent. Potassium concentration was much higher in treated wastewater (68.7 mg/L) than in freshwater (2.1 mg/L).

Feacal coliforms, mainly E. Coli, were not present in fresh water, however, they were highly present in the treated effluent and, most of the time, exceeding the limit value of 1000 CF/100 mL proposed by the WHO that is sufficient for the irrigation of all crops. Salmonella was not detected in fresh water; however, it was present in treated wastewater. Metals were not present in fresh water, while in treated water, only zinc and cadmium were detected at concentrations of 0.16 and 0.0041 mg/L, respectively, that do not exceed the environmental limit values for surface water based on MoE Decision 8/1 (MoE, 2001).

Accordingly, the treated water from Ablah is of category II as proposed by the Lebanese guidelines FAO project UTF/LEB/019/LEB (2011) and is suitable for the irrigation of table grapes.

## Yield, its components and grape quality parameters

The arithmetic means of obtained yield, its components and quality parameters of table grape grown under different water quality regimes are given in Fig. 2. In addition, the mean ranks of the Kruskal–Wallis test are given in Table 3.

Overall, the results showed that there was no significant difference in terms of mean cluster weight and number of clusters per vine; however, a significant difference, at $P \leq 0.01$, was obtained in terms of marketable yield. A mean of 30 kg/vine was obtained under TW, while 25 and 29 kg/vine were obtained under FW and under alternating FW and TW, respectively.

pH in the grapes irrigated with FW, TW and alternating FW and TW, did not show any significant difference and the values were 3.72, 3.69 and 3.58, respectively, indicating that harvest occurred at the most appropriate time. Similarly, the concentration of total phenols in leaves, pedicels and berries did not vary between treatments (Table 3). However, there was a significant difference, at $P \leq 0.05$ among treatments in terms of total soluble solids (TSS), total titratable acidity (TTA) and sweetness. The TSS and sweetness were the highest in the FW treatment and the lowest in the

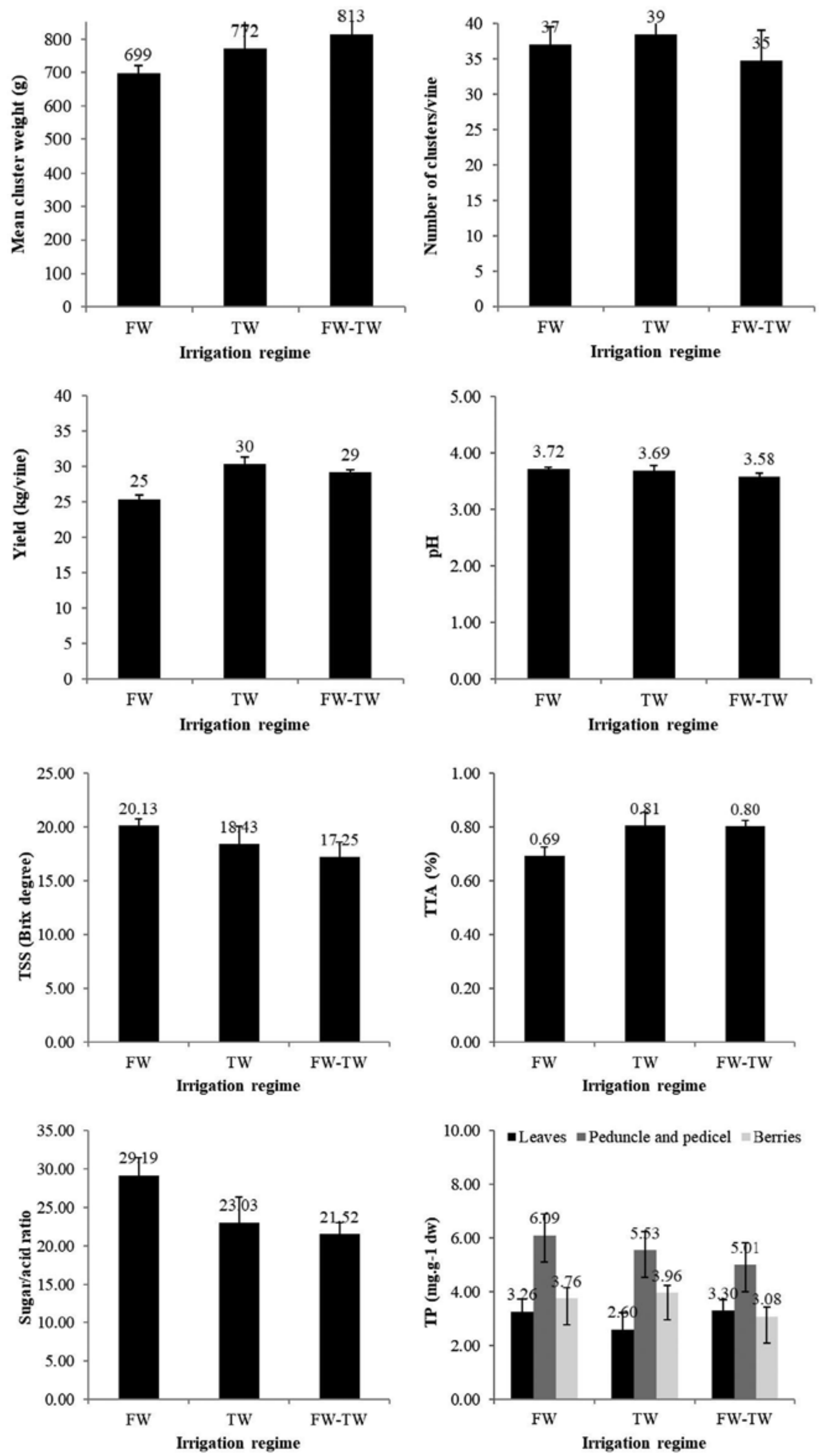


**Fig. 2.** The arithmetic means (*n* = 60) of obtained yield, its components and grape quality parameters grown under different irrigation regimes (FW, fresh water; TW, treated water; FW-TW, alternating fresh and treated water; TSS, total soluble sogars; TTA, total titratable acidity; TP, total phenols).

**Table 3** Results of the Kruskal–Wallis test concerning the yield, its components and the grape quality parameters ($n = 60$)

| Treatment | Mean cluster weight (g) | Number of clusters per vine | Yield (kg/vine) | pH | Total soluble solids (TSS) | Total titratable acidity (TTA) | Sugar/acid ratio (sweetness) | Total phenols (TP) (mg/g dw) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Leaves | Peduncle and pedicels | Berries |
| FW | 4.00 | 6.88 | 2.50 a | 8.63 | 10.00 b | 2.50 a | 10.25 b | 7.25 | 7.38 | 7.5 |
| TW | 7.00 | 7.88 | 10.25 b | 7.63 | 5.88 ab | 8.25 ab | 5.00 ab | 4.00 | 7.00 | 7.5 |
| FW-TW | 8.50 | 4.75 | 6.75 ab | 3.25 | 3.63 a | 8.75 b | 4.25 a | 8.25 | 5.13 | 4.5 |
| Significance | NS | NS | ** | NS | * | * | * | NS | NS | NS |

NS, * and ** Not significant or significant at $P \leq 0.05$ and $P \leq 0.01$, respectively. Means Rank followed by different letter in each column are significantly different according to the Dunn-Bonferroni pairwise comparisons test ($P = 0.05$).

FW, freshwater; TW, treated water; FW-TW, alternating fresh and treated water.

treatment with alternating FW and TW and inversely, the TTA was the lowest under FW.

## Mineral composition of leaves, pedicel and peduncles and berries

Figure 3 shows the average concentrations [g/kg, on dry weight basis (dw)] of nitrogen (N), phosphate ($PO_4$) and potassium (K) minerals in leaves, berries, pedicel and peduncles under different irrigation regimes (FW), (TW) and alternation of (FW) and (TW). In addition, the mean ranks of the Kruskal–Wallis test are given in Table 4.

At harvest, nitrogen was mostly concentrated in leaves, with values of 0.43, 0.41 and 0.51 g/kg, respectively, in the treatments FW, TW and alternating FW and TW. Leaf K concentrations were 0.5, 0.53 and 0.5 g/kg, respectively, in all treatments. Phosphorus was the macronutrient least abundant in leaves with average concentrations of 0.27, 0.24 and 0.30 g/kg, respectively, in the different treatments. Phosphorus and potassium were mostly concentrated in pedicels and peduncles, with average concentrations of $PO_4$ of 0.40, 0.81, 0.47 g/kg, respectively, and 4.26, 4.69, 3.3 g/kg for K, respectively, for all treatments. In addition, the mean ranks of the Kruskal–Wallis test showed that there was no significant difference among treatments.

## Bacterial contamination of table grapes

The bacterial contamination of table grapes grown under different water quality regimes, is provided in Table 5. Pathogenic bacteria such as Salmonella and Listeria monocytogenes were absent on grapes taken from the different fields. In addition, Staphylococcus aureus and Clostridium perfringens were not detected.

## Soil quality

The main characteristics of the soil under FW, TW and alternating FW and TW are given in Table 6. According to the obtained results, there were no major differences between the soil properties at beginning and at the end of irrigation seasons for pH values. Higher electrical conductivity was found in TW in comparison with the other two treatments at the end of the season.

For nitrogen, there is no clear difference that seems to be established between the beginning and end of the season although a decrease in nitrogen concentration was observed at the end of the season for the treatments irrigated with FW and alternating FW and TW. For phosphorus, soil analysis revealed that the element is highly present in soil, exceeding 97.69 ppm at the beginning of the season. In particular, phosphorus concentrations in soil irrigated with FW was 97.69 and 71.29 ppm at the end of the

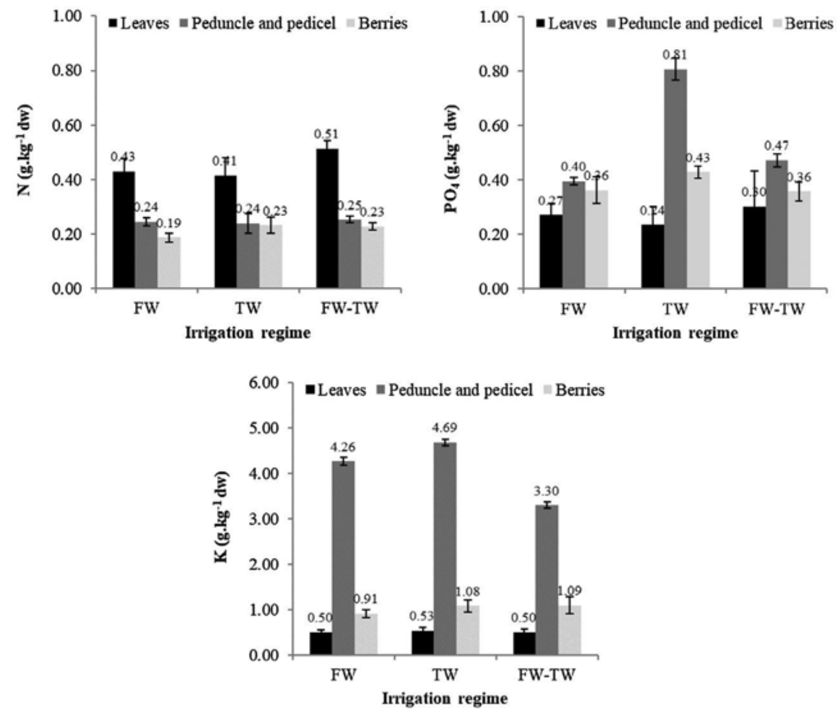


**Fig. 3.** The arithmetic means (*n* = 60) of the main minerals in leaves, pedicel and peduncles and berries under different irrigation regimes.

**Table 4** Results of the Kruskal–Wallis test concerning the Mineral analysis (*n* = 60)

| | N (g/kg d.w.) | | | PO4 (g/kg d.w.) | | | K (g/kg d.w.) | | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment | Leaves | Peduncle and pedicels | Berries | Leaves | Peduncle and pedicels | Berries | Leaves | Peduncle and pedicels | Berries |
| FW | 7.13 | 7.00 | 6.75 | 7.25 | 4.88 | 6.00 | 5.75 | 7.00 | 3.88 |
| TW | 6.25 | 6.50 | 7.00 | 5.25 | 8.88 | 8.00 | 8.38 | 9.00 | 8.13 |
| FW-TW | 6.13 | 6.00 | 5.75 | 7.00 | 5.75 | 5.50 | 5.38 | 3.50 | 7.50 |
| Significance | NS | NS | NS | NS | NS | NS | NS | NS | NS |

NS, * and ** Not significant or significant at $P \leq 0.05$ and $P \leq 0,01$, respectively. Means Rank followed by different letter in each column are significantly different according to the Dunn-Bonferroni pairwise comparisons test ($P = 0.05$).
FW, freshwater; TW, treated water; FW-TW, alternating fresh and treated water.

**Table 5** Bacterial contamination of table grapes grown under different irrigation regimes (*n* = 60)

| | | Grape bacterial contamination | | | | | |
|---|---|---|---|---|---|---|---|
| Farm ID | Treatment | Faecal coliforms (cfu/g) | *E. coli* 44°C (cfu/g) | *S. aureus* 37°C (cfu/g) | *C. perfringens* 37°C (cfu/g) | *Salmonella* sp./25 g (+ or –) | *L. monocytogenes*/25 g (+ or –) |
| 1 | FW | <10 | <10 | <10 | <10 | – | – |
| 2 | TW | <10 | <10 | <10 | <10 | – | – |
| 3 | FW-TW | <10 | <10 | <10 | <10 | – | – |

FW, freshwater; TW, treated water; FW-TW, alternating fresh and treated water.

season while in soil irrigated with TW, the concentrations were 140.56 and 131.90 ppm. In soils where FW was alternated with TW, the phosphorus concentrations were 193.32 and 298.38 ppm.

For potassium, a decrease of this element was found at the end of the season only for treatment irrigated with FW and kept unchanged in soils irrigated with only TW or alternated FW and TW.

**Table 6** Soil characteristics under different irrigation regimes

| | Beginning of the season | | | End of the season | | |
|---|---|---|---|---|---|---|
| | FW | TW | FW-TW | FW | TW | FW-TW |
| pH | 8.81 | 8.44 | 8.04 | 7.74 | 7.16 | 8.09 |
| EC mS/cm | 0.17 | 0.31 | 0.82 | 0.36 | 1.06 | 0.24 |
| N% | 0.18 | 0.15 | 0.36 | 0.06 | 0.17 | 0.09 |
| P2O5 ppm | 97.69 | 140.56 | 193.32 | 71.21 | 131.90 | 298.38 |
| K2O ppm | 454.15 | 649.25 | 699.37 | 283.70 | 574.18 | 720.71 |
| CaO ppm | 2014.59 | 2640.97 | 2400.12 | 3076.03 | 4411.40 | 2932.77 |
| MgO ppm | 1064.35 | 1287.96 | 1102.64 | 1161.56 | 1297.57 | 1198.99 |
| M.O. % | 2.49 | 2.60 | 2.39 | 1.70 | 2.53 | 2.13 |
| Cal T % | 52.01 | 27.42 | 48.28 | 46.13 | 26.49 | 47.14 |
| Cal Ac % | 27.80 | 8.13 | 20.37 | 16.95 | 10.85 | 19.52 |
| Na ppm | 64.35 | 143.13 | 93.13 | 32.38 | 156.82 | 141.78 |

FW, freshwater; TW, treated water; FW-TW, alternating fresh and treated water.

## Discussion

In this study, it was evident that the selection of the appropriate irrigation strategy did not lead neither to a decreased crop yield, nor to a deterioration of the grapes quality. Moreover, the local soil was not affected.

In fact, the plants irrigated with TW and those irrigated with alternating FW and TW gave 19.57 and 14.95% higher marketable yield, respectively, than plants irrigated with local groundwater (Fig. 2). This can be associated with the higher concentration of potassium in the TW (Tak *et al*., 2013), despite the higher salinity in the treated wastewater. The results are in agreement with the findings of Petousi *et al*. (2019), and Mendoza-Espinosa *et al*. (2008) who reported a 20% greater grape production per plant in plants irrigated with wastewater.

The quality of grapes is in agreement with the findings of Petousi *et al*. (2019) who reported that higher production rate under treated wastewater irrigation had resulted in a lower °Brix. It should be noted that obtained values for TSS, TTA and sweetness ranged, respectively, between 18.43–20.13, 0.69–0.81% and 21.52–29.19 in all treatments. Generally, sugar levels ranging between 18 and 24 °Brix are desirable, and acid levels generally should fall between 0.6–0.8% at harvest. Accordingly, these results showed that the biochemical characteristics of grapes irrigated with wastewaters were equally good indicating that the quality of final product was not modified by applying treated wastewater. The results are in agreement with those reported by Petousi *et al*. (2019) that mentioned that the application of treated wastewater had no significant effect on the mineral concentration in grape juice.

In this study, the mineral anlysis was not influenced by the irrigation strategy. Nitrogen forms part of several cell constituents, such as proteins, nucleic acids and chlorophyll, which justifies its relative greater presence in the leaves (Hawkesford *et al*., 2012). Nitrogen can also be lost through volatilization directly from canopy to the atmosphere, in particular at the end of the growing season (Wetselaar and Farquhar, 1980; Eichert and Fernández, 2012). In vine leaves, P usually decreases over the growing season (Benito *et al*., 2013). Studies have shown that berries are the major sink for K after the initiation of berry growth (Poni *et al*., 2003; Mullins *et al*., 2007). However, pedicels and peduncles contained the highest K concentrated tissues of the vine. The berries presented a moderately high K concentration. The findings are in agreement with Arrobas *et al*. (2014). The most plausible explanation for the high K concentration in the pedicel and peduncles is the role of the nutrient in the transportation of photosynthates from leaf to berry (Mpelasoka *et al*., 2003; Hawkesford *et al*., 2012). Potassium is characterized by high mobility in plants at all levels, within individual cells or in long-distance transport via the xylem and phloem (Mpelasoka *et al*., 2003). For K, it is not only important to consider the amount of nutrient removed in fruit, but also the amount of K naturally available in the soil, because soils can supply considerable amounts of K.

The bacterial analysis showed that the grapes were safe for human consumption. Mendoza-Espinosa *et al*. (2008) also reported that faecal and total coliforms were not present in the Cabernet Sauvignon and Merlot grapevines irrigated with reclaimed wastewater in Mexico. These results pointed out that the best agricultural practices, such as the adoption of drip irrigation, would guarantee human health and safe cultivation with respect to pathogens risk when using treated wastewater. In addition, it is important to highlight the fact that the surface placement of drip emitters may have the advantage of reducing bacteria by exposure to ultraviolet light.

The soil test results (short-term) were in agreement with those found by Petousi *et al*. (2015) who observed in an olive grove that there is no significant effect of nitrogen in soil for the first 2 years of wastewater application. Plant uptake or movement of nitrogen from the soil may be the reason for no significant accumulation of nitrogen in the soil (Heidarpour *et al*., 2007). Petousi *et al*. (2015) also found an increase in phosphorus in soil of olive groves after 3 years of irrigation with treated wastewater, while Bedbabis *et al*. (2010) found an increase of those elements in soil of olive groves irrigated with treated wastewater after a period of 19 months. Moreover, Petousi *et al*. (2015) also observed that there is no significant effect of potassium in soil for the first 2 years of wastewater application. Finally, Levy *et al*. (2014) confirmed that the soil properties are not always dictated by those of the irrigation water. Therefore, the effect of wastewater irrigation on soil quality should be studied after several years of irrigation with treated effluent in order to study the long-term effect on soil.

## Conclusion

**(1)** This study assessed the feasibility of using treated municipal wastewater for table grapes production in Ablah village, central Bekaa valley, Lebanon.

**(2)** The results have revealed that the application of treated wastewater for the irrigation enhanced the yield of table grapes and kept unchanged the quality of fruits.

**(3)** The study has confirmed the validity of using drip irrigation practice which is essential to prevent bacterial contamination on fruits and to protect human health.

**(4)** Moreover, it reduces the risk of contamination with faecal coliforms and salmonella.

**(5)** The results have confirmed that there was no negative effects on the soil properties.

**(6)** However, the trial should be replicated in order to endorse the results obtained in this study and to investigate the long-term effects of treated wastewater reuse on soil properties, ecosystem and human health.

**(7)** This is essential to promote a safe reuse of treated wastewater in crop irrigation in Lebanon and other countries of Middle East and North Africa region.

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