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Reuse of treated municipal wastewater in irrigation: a case study from Lebanon and Jordan

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Abstract

In this study, we present the results of scenarios where secondary-treated municipal wastewater was used for table grapes irrigation in the region of Ablah, Bekaa valley in Lebanon, and fodder crops irrigation (vetch and barley) in the region of Ramtha in Jordan. In Lebanon, we carried out experiments to assess the response of drip-irrigated table grapes grown under two water quality regimes (Freshwater (FW) and treated wastewater (TW) and two water levels (100% of evapotranspiration (ETc) and 75% of ETc). While in Jordan, we carried out experiments to assess the response of drip-irrigated fodder crops considering 4 irrigation levels (Q1: Rain fed; Q2: 80% of ETc; Q3: 100% of ETc; Q4: 120% of ETc) and three crop patterns (C1: Barley 100%; C2: Vetch 100%; C3: Mix 50% barley and 50% vetch). Based on the production and quality components, table grapes were successfully grown on plots that are supplied with TW. Fodder crops were successfully grown using TW with remarkable increase in biomass and grain yield production for the irrigated treatments.

Introduction

Nowadays, the reuse of wastewater in agriculture cannot be practiced in an uncontrolled manner due to the risks that it entails (Balkhair & Ashraf 2016), and under the given conditions, appropriately treated wastewaters could present a resource and an opportunity especially in agriculture sector.

The production of wastewater by human settlements, urban and industrial agglomerations generates a health and ecology issue, particularly in the large cities of the developing countries. Given the projections forecasting the rise in the populations of the developing countries, the increase in per capita water consumption, and the urbanisation processes which will increase the dimensions and the pressures exerted by the large urban agglomerations, the situation is bound to worsen in the near future. However, under given conditions, appropriately treated wastewaters could present a resource and an opportunity. Especially in agriculture, the presence of nutrients (phosphorus, potassium and nitrogen) in the wastewaters renders them suitable for use in fields (Bob 2010).

The use of these wastewaters, however, must always be done within legal limits: the use in agriculture of water with the characteristics of wastewater cannot be practised in an uncontrolled manner, due to the risks that it entails. First of all, there are risks for human health, due to the high concentrations of pathogenic organisms, in addition to the presence of heavy metals which could enter the food chain, and pharmaceutical residues (Balkhair & Ashraf 2016). Notwithstanding the positive presence of natural fertilisers, moreover, the wastewaters can be damaging to the crops; in certain cases, it can lead to a reduction in production or toxicity in the plants. Similarly, in the event of greater salinity, wastewaters can modify the structure of the land, decreasing its productivity; also the aquifers, in the long term, can suffer from the excessive quantities of salt and the presence of nutrients. From the ecological standpoint, if drained in closed water bodies, the irrigation wastewaters can cause eutrophication phenomena in the receiving water body (David 2015).

Despite the increased interest in the effect of irrigation on grape production and quality parameters, very few studies have been reported on table grapes, particularly on the effect of wastewater irrigation. Many studies have demonstrated that deficit and regulated deficit irrigation is a practical and useful technique to improve fruit quality and reduce irrigation application when water availability is limited (Ebel & Proebsting 1993; Fereres & Soriano 2007).

Most of the studies have been performed on deciduous and citrus orchards but very few on table grapes. Among the studies performed on table grapes, Conesa *et al*. 2016 studied the post-veraison deficit irrigation regimes that would enhance berry colouration and health-promoting bioactive compounds in 'Crimson Seedless' table grapes. Another study reported in literature tackled mainly the effect of post-veraison regulated deficit irrigation in production and berry quality of Autumn Royal and Crimson table grape cultivars (Faci *et al*. 2014).

In Jordan, wastewater reuse has been practiced for over the past 34 years (Carr *et al*. 2011) while in Lebanon it is rather a recent practice. Experimental trials on the reuse of wastewater in agriculture have been conducted in Lebanon and Jordan. The trials aimed to investigate the effect of treated wastewater irrigation on table grape production in Lebanon and fodder crops yield in Jordan. The specific challenges for both countries largely depend on adopting appropriate measures aiming at optimising crop yields and quality, maintaining soil productivity and safeguarding the environment.

Materials and methods

Experimental trial in Lebanon

Experimental site and climate

The field experiment was carried out during the growing season in 2015 in Ablah located in the Central Bekaa valley (Lebanon, 37° 16N, 14° 25E) in a vineyard located near the Wastewater Treatment Plant (WWTP) that is serving the village. The WWTP provides a secondary treatment (Conventional Treatment Process/Trickling filters + Disinfection by Chlorination). The plant has a maximum capacity of 2000 m^3 per day and currently receives 800 m^3 per day during the summer time. The plant serves 18.5 ha belonging to 37 beneficiary farmers all of whom are table grape growers. The treated effluent is collected in a reservoir located near the WWTP that was built in 2015 within the framework of ACCBAT project funded by the European Union ENPI CBC MED program 2007–2013, and the reservoir capacity is 15 000 m^3. The stored effluent is then diverted to nearby fields.

The climate of the area is typically Mediterranean, characterised by a hot and dry season from April to October. The main weather parameters were obtained 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 regimes, in terms of reference evapotranspiration (ETo), precipitation (P), maximum temperature (T_{max}), minimum temperature (T_{min}) and mean relative humidity (RH_{mean}) during the season 2015 are given in Table 1.

Table 1 Monthly climate data for the year 2015 as recorded for Ablah region

Month	ETo (mm)	Rain (mm)	T_{max} (°C)	T_{min} (°C)	RHmean (%)
January	28.86	126.70	8.83	−2.22	84.32
February	39.36	128.70	11.51	0.14	81.50
March	78.09	63.90	16.98	3.91	68.76
April	109.42	111.00	19.23	4.20	63.00
May	165.70	33.60	25.86	8.68	51.99
June	182.94	18.00	27.83	8.22	55.00
July	221.48	10.80	33.59	11.45	47.18
August	193.60	0.00	33.53	13.78	47.55
September	145.98	10.00	32.36	13.45	45.09
October	91.17	23.60	26.12	10.39	63.82
November	50.35	24.60	19.43	4.39	65.63
December	32.08	10.40	13.82	−0.67	66.62

In general, overall average air temperature during the grapevine cycle extending from May to September was 20.87°C. The total precipitation amount from May to September was 72.4 mm.

The soil of the study area is sandy clay loam (USDA textural soil classification) with 34.6% clay and 14.7% silt. Field slope is less than 0.1% and total available water holding capacity within the top 1 m of soil profile is 114 mm.

Treatments and agronomic management

The present experiment was carried out to assess the response of drip-irrigated table grapes grown under two water quality regimes [Freshwater (F) and treated wastewater (TW)] and two water levels [100% of crop evapotranspiration (ETc) and 75% of ETc].

The vine growing distance was 3.5 m × 3.5 m according to the standard practices in Ablah region. Standard cultivation practices were adopted during the crop growing seasons. Irrigation season started in July and ended in 25 August 2015 corresponding mainly to the period between fruit setting/pea size and one week after veraison. The vines were harvested at commercial maturity.

In total, the experiment consisted of four treatments with four replicates per treatment: T1: Fresh water/100% irrigated; T2: Fresh water/75% irrigated; T3: Treated water/100% irrigated and T4: Treated water/75% irrigated. Treatments were arranged in a split plot design. Each experimental plot consisted of 4 rows of grapevines and 14 vines/row.

Irrigation management

All the plots were equipped with low polyethylene surface laterals. All the laterals were supplied with on-line drippers (theoretical discharge rate of 8 L h^{-1} at a pressure of 100 kPa), each vine had 2 drippers corresponding to a total of 16 L h^{-1}. The spacing between laterals was 3.5 m. The experiment was equipped with separate reservoirs and head units for the treatments irrigated with fresh water and those irrigated with treated effluent. Filters were manually cleaned.

Irrigation was applied at 100% or 75% of ETc depending on the good treatment, and managed using an Excel-based irrigation tool (Todorovic 2006) that employs meteorological, soil and crop data for a day-by-day estimation of the soil water balance in the effective root zone.

Water sampling and analysis

Concerning irrigation water, the main physical–chemical and microbial characteristics of both kinds of water (F and TW) were monitored.

Standard methods (APHA 1998) were used in the laboratory to measure the biochemical oxygen demand (BOD_5), the total dissolved salts (TDS), electrical conductivity (EC), the pH, etc. The microbiological analysis of total coliforms (TC), faecal coliforms (FC), *Escherichia coli* (*E. coli*) and salmonella was done according to standard methods (APHA 1998). *Salmonella* were examined according to the methodology described by Giammanco *et al*. 2002.

Crop production and microbial contamination of fruits

The effects of the quality of irrigation water on crop production and their interactions were analysed. The analyses measured the marketable yield.

Fruits were harvested from each plot and used to measure microbial contamination, mainly faecal coliform, *E. coli* and salmonella. Fruits in 500 g samples were harvested from each plot and used to measure microbial contamination. In the laboratory, 100 g of fruits, including fruit skin and flesh, were homogenised with 900 mL of sterile water by a stomacher. Then, ten-fold dilutions were made within the same medium. Faecal coliform and *E. coli* were measured using membrane filtration techniques (APHA 1998). The *Salmonella* detection was done according to the method of Giammanco *et al*. (2002).

Experimental trial in Jordan

Experimental site and climate

Fodder crops were grown in the field of the National Center for Agricultural Research and Extension (NCARE) located near the Wastewater Treatment Plant (WWTP) that is serving the city. The WWTP provides a secondary treatment (screens, two trains of anaerobic ponds, facultative ponds and maturation ponds, activated sludge & disinfection by chlorination). The plant has a maximum capacity of 5000 m^3 per day and currently receives 4500 m^3 per day. About 110 hectares would benefit from the effluent.

Table 2 Monthly climate data for the year 2015 for Ramtha region

Month	ETo (mm)	Rain (mm)	T_{max} (°C)	T_{min} (°C)	RHmean (%)
January	49.91	65.0	12.15	3.25	72.1
February	62.72	54.3	14.51	4.45	68.0
March	100.75	53.6	18.35	6.30	62.3
April	145.80	11.9	23.67	9.55	53.4
May	201.81	1.2	28.10	12.33	45.1
June	234.30	0.0	31.40	16.21	45.0
July	244.28	0.0	32.75	18.50	50.0
August	219.48	0.00	33.53	13.78	54.5
September	169.80	0.0	31.45	16.55	54.3
October	122.45	6.7	27.25	13.15	53.6
November	78.90	22.9	21.15	8.35	58.2
December	52.70	49.5	15.2	4.01	69.0

The soil of the study area is clay (United States Department of Agriculture (USDA) textural soil classification) with 59.6% clay. The main weather parameters were obtained from a standard agro-meteorological station located at the experimental station of the National Center for Agricultural Research and Extension (NCARE) and are provided in Table 2.

Treatments and agronomic management

Barley and vetch were planted on 12 October 2014. The total area of 23 m × 95 m was used for this experiment (2185 m^2). The size of each plot was 5 m long and 7 m wide. A buffer zone of 1.0 m spacing was designed between plots. A seed rate of 150 kg ha^{-1} was adopted. Each plot received the complex fertiliser N: P: K (20:20:20) at the rate of 60 kg ha^{-1}.

The experiment was laid out in a randomised complete block design (RCBD) with twelve treatments and four replications per treatment considering 4 irrigation levels (Q1: Rain fed; Q2: 80% of ETc; Q3: 100% of ETc; Q4: 120% of ETc) and three crop patterns (C1: Barley 100%; C2: Vetch 100%; C3: Mix, 50% barley and 50% vetch).

Irrigation management

All treatments were irrigated with treated effluent applied at 80%, 100% and 120% of crop evapotranspiration. A drip irrigation system was installed and the head unit included three filtering systems (sand, screen and disc).

The drip system consisted of a mainline with 50 mm diameter which was connected to laterals of 20 mm diameters having inline emitters delivering a discharge of 4 L h^{-1}.

Water sampling and analysis

Water samples were analysed at the NCARE laboratory for the BOD_5, COD and FC. In addition, other physicochemical

Table 3 Fresh water and treated effluent average quality during 2015 and limit values for the reuse of TWW in Lebanon

	Mean value		Limit values for reuse of TW according to proposed Lebanese guidelines (FAO, 2011)		
Parameter	Fresh water (F)	Treated Water (TW)	Category I	Category II	Category III
TSS (mg L^{-1})	12.32	53.44	60	200	200
BOD_5 (mg L^{-1})	8.14	28.22	25	100	100
COD (mg L^{-1})	15.41	155	125	250	250
pH	7.18	8.1	6–9	6–9	6–9
EC (dS m^{-1})	0.786	1.311	3^a	3^a	3^a
TN (mg L^{-1})	13	4	$< 15^b$	$< 15^b$	$< 15^b$
TP (mg L^{-1})	0.51	5.59	$< 10^b$	$< 10^b$	$< 10^b$
FC (CFU/100 mL)	6.00 E +00	1.4 10^7	< 200	< 1000	Non required
E. coli (CFU/100 mL)	<1	<1	< 200	< 1000	Non required
Salmonella (CFU/100 mL)	Absence	Absence	Absent	Absent	Absent

TSS, total suspended solids; BOD5, biochemical oxygen demand at 5 days; COD, chemical oxygen demand; EC, electrical conductivity; TN, total nitrogen; TP, total phosphorus; FC, faecal coliform; *E. coli*, *Escherichia coli*.
[a]Reuse limits for irrigation.
[b]Effluent specifications of WWTP based on MoE decision 8/1, 2001.

parameters were analysed and compared to the 'irrigation water quality in the Jordanian Standards' NO.1766/2014.

Biomass and grain yield production

The effects of the irrigation level and crop pattern on crop production and their interactions were analysed. The analyses measured the biomass and grain yield. Statistical analysis was carried out using the computer package MSTAT-C. Means were compared by analysis of variance (ANOVA) and the least significant difference (LSD) test at $P = 0.05$.

Results and discussion

Experimental trial in Lebanon

Irrigation water quality

Table 3 shows the seasonal means of the physical–chemical and microbial 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 treated water as well as of fresh water is slight to moderate, but it is still suitable for irrigation. The values of the main physical–chemical characteristics, particularly the BOD_5 and the COD were higher than the admissible limits of water category I for treated wastewater reuse proposed by the Lebanese guidelines. However, those values were within the admissible limits for fresh water.

Feacal coliforms 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 World Health Organization (WHO) that is sufficient for the irrigation of all crops. Water contamination by *E. coli* was not noticed. *Salmonella* was not detected. Accordingly, the treated water from Ablah is of category II as proposed by the Lebanese guidelines 'FAO project UTF/LEB/019/LEB'.

Crop production and microbial contamination of fruits

Table 4 reports the production parameters in terms of mean values of marketable yield, Brix degree and titratable acidity for the different treatments.

The treatments under treated effluent gave same yield as the treatments under fresh water irrigation. Obtained yield and other production parameters were not significantly different among the treatments under full as well as under deficit irrigation.

In our study, obtained results of titratable acidity are in agreement with the findings of Conesa *et al*. (2016) who reported that there was no significant difference in titratable acidity among different treatments under deficit irrigation for the table grape variety 'Crimson seedless'. In addition, obtained results on grape production parameters are in agreement with the findings of Faci *et al*. (2014) that found no significant difference among treatments under different deficit irrigation regimes.

Faecal coliforms were not detected on fruits irrigated with FW or TW. It is well known that coliforms are ubiquitous in agricultural environments (Materon 2003). *E. coli* and *Salmonella* contaminations were equally not detected in grape fruits for all the examined irrigation treatments. Results are in accordance with those reported by Vivaldi *et al*. (2013) for nectarines irrigated with treated wastewater. Moreover, Palese *et al*. (2009) found that although *E. coli* content in treated wastewater applied for irrigation of olive groves in Italy was

Table 4 Mean values of grape production and bacteriological parameters

		Fresh water		Treated water		
		T1	T2	T3	T4	ANOVA
Production parameters	Grape yield (Kg vine^{-1})	14.35	14.21	14.13	14.05	ns
	^{o} Brix	19.5	18.6	18.3	18.9	ns
	Titratable acidity (g L^{-1})	3.97	3.95	3.99	3.94	ns
Bacteriological parameters (CFU 100 g^{-1})	Faecal coliforms	<1	<1	<1	<1	
	E. coli	<1	<1	<1	<1	
	Salmonella	Absent	Absent	Absent	Absent	

T1, fresh water/100% irrigated; T2, fresh water/75% irrigated; T3, treated water/100% irrigated and T4, treated water/75% irrigated; ns, no significant effect ($P \leq 0.05$).

Table 5 Average quality of treated effluent during 2015 and limit values for the reuse of TWW in Jordan

		Limit values for the reuse of TW according to Jordanian Standards, NO.1766/2014 Degree of restriction on use		
Parameter	Treated water (TW)	No restriction	Slight to Moderate Restriction	Severe Restriction
Total suspended solids (mg L^{-1})	111.8	<50	50–100	>100
BOD_5 (mg L^{-1})	29.6	<60	110–400	>400
COD (mg L^{-1})	<120	<250	250–1000	>1000
pH	7.56	6–9		
Electrical conductivity (dS m^{-1})	2.69	<1.7	1.7–3	>3
TN (mg L^{-1})	40	<50	50–100	>100
Boron (p.p.m.)	0.35	<0.7	0.7–3	>3
Mn (p.p.m.)	0.048	<0.1	0.1–1.5	>1.5
Pb (p.p.m.)	0.265	>5[a]		
E. coli (CFU/100 mL)	3.10^4	$<10^{6}$[a]		
Salmonella (CFU/100 mL)	Absent	Absent	Absent	Absent

TSS, total suspended solids; BOD5, biochemical oxygen demand at 5 days; COD, chemical oxygen demand; EC, electrical conductivity; TN, total nitrogen; *E. coli*, *Escherichia coli*.
aEffluent specifications of WWTPs Based on Jordanian Standards NO.1766/2014.

often over the limits, the hygienic quality of soil and fruits was preserved. Petousi *et al*. (2015) reported no contamination with *E. coli* on olive fruits. According to WHO guidelines, orchard wastewater irrigation should be stopped 2 weeks before harvest and no fruit should be picked up off the ground (WHO 2006a). For table grapes, the harvesting period in the Bekaa valley, Lebanon begins at mid-September while irrigation stops at the end of August. Hence, at least there is a period of 2 weeks before harvest, thereby reducing the risk for contamination.

Experimental trial in Jordan

Irrigation water quality

Table 5 shows the seasonal means of the physical-chemical and microbial characteristics of the treated water analysed during the trial.

According to the guidelines on irrigation water quality in the Jordanian Standards NO.1766/2014, the salinity of treated effluent, with average value of 2.69 dS m^{-1}.shows a slight to moderate degree of restriction on use in irrigation. Generally, fodder crops are sensitive to salinity during seed germination and early growth stages while they are tolerant during later growth stages (Guy 2013).

The average seasonal value of total suspended solids confirms that a severe degree of restriction on the use of the treated water should be considered, as given in the Jordanian Standards NO.1766/2014.

The Total Nitrogen (TN) value, which is 40 p.p.m., is considered within the limits and no restriction on the use of water in irrigation should be adopted.

Trace elements such as Mn and Pb were not detected in the treated effluent. All the samples showed less than 60 mg L^{-1} as BOD and less than 120 mg L^{-1} as COD and they are within the limits. Water contamination by *E. coli* was noticed

Table 6 Mean value of total yield and grain yield production for the different treatments of the experiment

		Treatment	Total yield Kg ha^{-1}	Grain yield Kg ha^{-1}	
Barley	Rainfed	Q1C1	4,825d	2,442c	
	80% ETc	Q2C1	6,731c	3,208b	
	100% ETc	Q3C1	8,156b	3,923a	
	120% ETc	Q4C1	956.9a	4,188a	
Vetch	Rainfed	Q1C2	2,442c	1,131d	
	80% ETc	Q2C2	3,208b	1,579c	
	100% ETc	Q3C2	3,923a	1,920b	
	120% ETc	Q4C2	4,188a	2,131a	
Mix (50%				**Vetch**	**Barley**
Barley + 50%	Rainfed	Q1C3	3,781c	1,599c	1,202b
Vetch)	80% ETc	Q2C3	4,981b	1,922b	1.574a
	100% ETc	Q3C3	6,900a	2,812a	1,593a
	120% ETc	Q4C3	6,638a	3,2848a	9,325b

Statistical analysis was carried out using the computer package MSTAT-C. Means were compared by ANOVA and the LSD test at $P = 0.05$.

and it is recommended to stop irrigation at least 3 days before harvesting (Jordanian Standards NO.1766/2014). *Salmonella* was not detected.

Biomass and grain yield production

The biomass and grain yield production were affected in response to total water amount (Table 6). The highest total yields were observed for the treatments under 120% ETc as compared to the other treatments, while the lowest total yields were observed for rainfed treatments.

Due to irregular and insufficient rainfall, there was severe scarcity of water throughout the year, and especially during summer, wells dried up frequently and the irrigation and table water declined, leading to increased crop water demand in a short period and thus influencing crop failures and drought (Suhas *et al*. 2009).

Conclusion

(1) Land application of municipal waste water is common in many regions of the world. One approach to evaluating the suitability of reclaimed waste water is to consider it the same as any other freshwater source and appraise its suitability for irrigation using some reference criteria. When such criteria are applied there will be no serious potential agronomic or public health problem in Lebanon and Jordan using the effluent water especially in the treatment plants of Ramtha and Ablah.

(2) Wastewater use for agriculture is an emerging priority for water-stressed countries and low-income countries. As water scarcity grows, investment in wastewater treatment and related irrigation systems are becoming more viable. To encourage such investments, governments should establish enabling policies, establish a clear regulatory framework, and develop a strategy and action plan for moving from unplanned to planned wastewater use for irrigation.

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