The effect of reclaimed wastewater on the quality and growth of grapevines

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ABSTRACT

The effect of the use of treated wastewater on the growth of cabernet sauvignon and merlot grapes from the Guadalupe Valley, Mexico was evaluated. Secondary advanced effluent was used to irrigate the grapevines at a rate of 66 L/vine/week. Wastewater quality results confirmed that all parameters complied with Mexican legislation for crop irrigation as well as reuse in activities in which the public would be in direct or indirect contact with the reclaimed water. Results showed that the number of leaves per shoot and the overall biomass increased in plants irrigated with wastewater and grape production per plant was 20% higher. The concentration of carbohydrates, organic acids and pH were similar in grapes from vines irrigated with wastewater to those irrigated with groundwater. Throughout the experiment, no fecal coliform bacteria were detected in the cultivated grapes. The wastewater caused an increase in the biomass of the grapevines and there was no presence of microbial indicators in the final product so a higher wine production could be achieved without an increase in health risk related problems. If 200 L/s of reclaimed wastewater would be returned to be used for grapevine irrigation in Valle de Guadalupe (the same amount that is currently being sent as drinking water to Ensenada), assuming an irrigation application of 6,000–7.500 m^3/ha/year, approximately 837–1046 hectares (ha) of grapevines could be irrigated. Part of ongoing research includes an economical analysis of the best options for Ensenada and the Valle de Guadalupe in order to establish the optimum volume of water to be returned, the cost of its transportation, as well as the cost of irrigation.

Key words | agriculture irrigation, grapevine growth, wastewater reuse

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INTRODUCTION

More than ninety percent of the wine produced in Mexico is produced in the state of Baja California. This region is arid, with an average annual precipitation of 285 mm and with a heavy relies on the water allocated from the Colorado River. In agricultural regions and cities located away from the Colorado River water allocation, water is obtained via the exploitation of groundwater. This is the case for the Valley of Guadalupe, where the country's two largest wineries are located and from which approximately 6 million cubic meters per year (200 litres per second) of groundwater are extracted to supply drinking water to the city of Ensenada, located 30 km away (Daessle *et al.* 2006). Ensenada has approximately 300,000 habitants and is one of the few Mexican cities that treat 100% of the wastewater collected in its sewer system. Recent studies have demonstrated that the treated wastewater complies entirely with Mexican legislation and can be used for the irrigation of crops as well as for activities in which the public is in direct or indirect contact with the treated wastewater (Mendoza-Espinosa *et al.* 2005). However, currently all wastewater treated in Ensenada is discharged to the ocean, mainly due to the fact that there is some resistance from farmers to use reclaimed wastewater for irrigation, and

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because currently there is no infrastructure to return the reclaimed water to the valley for irrigation. The reuse of wastewater for the irrigation of vinicultures is a relatively new practice in countries like Greece (Sakellariou-Makrantonaki *et al.* 2006). Therefore, in order to help inform farmers and water managers about the pros and cons of reusing treated wastewater for the irrigation of crops, the purpose of the current investigation was to evaluate the effect of the use of treated wastewater on the growth and biochemical composition of cabernet sauvignon and merlot grapes from the Guadalupe Valley.

Mexican legislation for crop irrigation does not establishing maximum allowable levels for BOD5, nitrogen or phosphorous but focuses on microbiological contaminants or indicators like fecal coliforms and nematode eggs (Table 1), and some heavy metals are also included. It has been highlighted that advanced primary treatment followed by disinfection can be a suitable way for treating raw wastewater in Mexico in order to comply with NOM-001-SEMARNAT-1996 without removing N and P (Jimenez, 2005) yet in 2005 only 35% of the country's wastewater received any kind of treatment (CNA 2006). Current Mexican legislation establishes the maximum levels of contaminants in wastewater to be reused for several activities (Table 1).

Table 1 | Types of contaminants and maximum values allowed in Mexican ecological norms for the reuse of treated wastewater.

	REUSE ACTIVITY		
	NOM-001-SEMARNAT-1996	**NOM-003-SEMARNAT-1997**	
Parameter (in mg/l unless specified)	**Crop irrigation**	**Direct contact[*] (M. A.)**	**Indirect or occasional contact[†] (M. A.)**
Grease and oils	15 M. A.; 25 D. A.	15	15
Floating material	Non present	Non present	Non present
Total suspended solids	N. A.	20	30
Biochemical oxygen demand	N. A.	20	30
Fecal coliforms (MPN)	1000/100 ml M. A. 2000/100 ml D. A.	240/100 ml	1000/100 ml
Nematode eggs (eggs/l)	≤ 1 restricted irrigation[‡] ≤ 5 non-restricted irrigation[§]	≤ 1	≤ 5

M. A. Monthly average (minimum 2 grab samples; geometric mean for fecal coliforms); D. A. Daily average; N.A. Non applicable

[*] Direct contact: where the general public is exposed directly or in physical contact. Examples: artificial lakes and reservoirs for boating, canoeing and water skiing, ornamental fountains, car washing, irrigation of parks and gardens.

[†] Indirect or occasional contact: where the general public is exposed only indirectly or by incidental physical contact and access is restricted by either physical barriers or security personnel. Examples: highway gardens, central boulevards, ornamental fountains, golf courses, hydrants for fire control, non-recreational artificial reservoirs, cemeteries.

[‡] Restricted irrigation: the use of wastewater for activities such as sowing, cultivation and harvest of agricultural products, except green vegetables and those that are consumed raw.

[§] Unrestricted irrigation: the use of wastewater for activities such as sowing, cultivation and harvest of agricultural products in unlimited form such as fodder, grains, fruits and vegetables.

MATERIALS AND METHODS

The aquifer of the Guadalupe Valley is located 30 km NE off the coastal city of Ensenada between 32°07′–32°02′ North and 116°28′ −116°47 West (Figure 1). The State Public Services Commission (CESPE for its Spanish acronym) is responsible for supplying water to the city from 11 wells located upstream in the Valle de Guadalupe, at an extraction rate of $\sim 200\,\mathrm{l\,s^{-1}}$ ($6\,\mathrm{Mm^3\,y^{-1}}$). Moreover, the aquifer is heavily used to irrigate five large and several small-scale Mexican vineyards, representing the most important wine industry in the country, becoming a worldwide known agro-industry (Daessle *et al.* 2006).

Vines and irrigation

Four-year old rooted grafted vines (*Vitis vinifera* L. cv. cabernet sauvignon and merlot) growing in a commercial vineyard in San Antonio de las Minas, on the western side of the Guadalupe Valley, Baja California, México (32.013°N, 116.643°W) were used in this experiment. Vines were grown in a two-wire trellis system with vine spacing of 1.5 m in east-west oriented rows, with 3 m between rows. Wastewater from a wastewater treatment plant from the city of Ensenada was stored in a 4000 L PTE container and used to irrigate vines. For control purposes, an exact replica of the tank was filled with fresh groundwater, the normal source for the irrigation of vines in the region. Vines ($n = 15$) received 66 L of treated wastewater per week through drip irrigation while control vines received the same amount of groundwater. Irrigation was initiated in mid-May until mid-September of 2006 and no fertilization was applied to the irrigated plot.

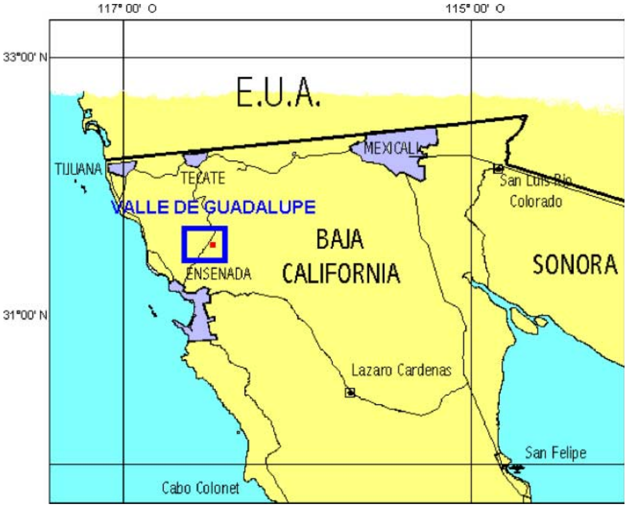

Figure 1 | Study area: Guadalupe Valley and the city of Ensenada.

Shoot growth

Shoots ($n > 50$) were tagged at the beginning of the experiment using flagging tape. Relative shoot elongation was determined weekly by evaluating shoot length with a measuring tape to the nearest centimetre. Relative shoot growth rate (RGR) was estimated using the following formula

$$RGR(\%) = \frac{(L_1 - L_0)}{L_1} \times \frac{100}{t} \tag{1}$$

where L_1 = final shoot length,
L_0 = initial shoot length
T = time period between L_1 and L_0.

Grape analysis

Sugar concentration in the grapes was evaluated weekly by refractometry. Samples of approximately 30–40 grapes ($n = 3$) were obtained from wastewater and groundwater irrigated vines. The samples were obtained from different sections from the grape-bunch and from both sides of the row, and transported to the laboratory where soluble solids were evaluated with a bench refractometer (LR45302, Fisher Scientific, USA). Titratable acids were determined by titration with 0.1 N NaOH and pH determined using an analytical bench pH-meter.

Water quality

Treated urban wastewater was transported from the El Sauzal wastewater treatment plant (north of the city of Ensenada) to the experimental vineyard. The wastewater treatment plant provides advanced secondary treatment at a rate of approximately 60 L/s and disinfection is reached via chlorination. Treated wastewater was transported via a vehicle with a water tank and subsequently used to fill the 4000 L tank at the vineyard from which the water was used for irrigation. Weekly samples were drawn from the tanks and stored at −20°C until taken to the analytical laboratory where analyses were performed.

Samples were collected on a weekly basis during July and August 2007. Five day biochemical oxygen demand (BOD5), conductivity, grease and oils, pH, turbidity, sedimentable solids, total dissolved solids, total suspended solids (SS) and fecal and total coliforms were analyzed according to *Standard Methods* (APHA 1998). Nematode eggs were analyzed according to the Mexican technique stipulated in NMX-AA-113-SCFI-1999 (SCFI 1999). Nitrate, ammonia and phosphates were analyzed using an auto-analyzer (Skalar SAN-PLUS, Breda, The Netherlands).

RESULTS AND DISCUSSION

Water quality requirements

Wastewater quality results confirmed that all parameters complied with Mexican legislation for crop irrigation (NOM-001-SEMARNAT-1996) as well as for reuse in activities in which the public would be in direct or indirect contact with the reclaimed water (NOM-003-SEMARNAT-1997).

In terms of nutrients concentration, nitrate, ammonia and phosphate levels varied between the treated wastewater and the groundwater (Figure 2). Nitrate concentration in the aquifer water remained relatively constant throughout the experimental period (approx. 13 mg/L). Ammonia and phosphate concentration in the aquifer water was below 1 mg/L throughout the whole experimental period. Large fluctuations of nitrate, ammonia and phosphate were observed for the treated wastewater throughout the experiment. Nitrate levels in the treated wastewater fluctuated from undetectable levels to approximately

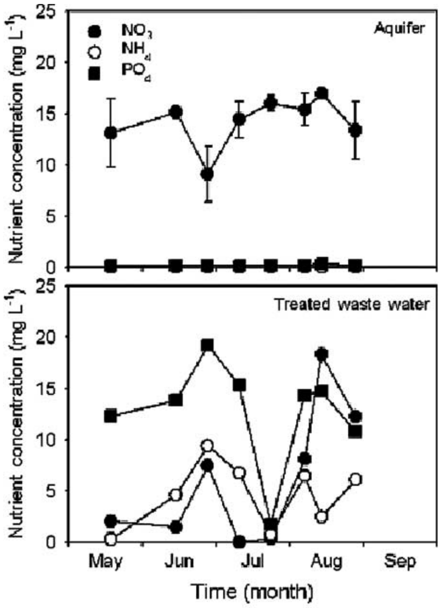

Figure 2 | Ammonia, nitrate and phosphate concentration in the treated wastewater and groundwater used for the irrigation on vines. Error bars indicate standard deviation. Error bars not shown are smaller than symbol size.

18 mg/L while ammonia fluctuated from approximately 1 mg/L to 10 mg/L. Phosphate levels in the treated wastewater fluctuated from approximately 2 to 20 mg/L throughout the irrigation period. In general, wastewater-irrigated vines received 1.5 more nitrogen (on molar bases) and 40-fold more phosphate (on molar bases) than the controls Table 2.

Considering an irrigation rate of 0.4–0.6 ac-ft/ac for a whole season (equivalent to 1,220–1,815 m^3/ha) typical for vines (Weber *et al.* 2006), the treated wastewater would represent an application of 6.10–9.07 kg/ha compared to 1.22–1.81 kg/ha of ammonia for the natural groundwater. In terms of phosphates, the amount applied by the treated wastewater would be 13.4–20.0 kg/ha compared to 1.2–1.8 kg/ha from the groundwater. However, in terms of nitrates, the groundwater represents a higher application (15.85–23.58 kg/ha) when compared to the treated wastewater (12.19–18.14 kg/ha).

Table 2 | Water quality results for treated wastewater and aquifer water used for the irrigation of vines at Guadalupe Valley.

Parameter	Wastewater	Aquifer
Biochemical oxygen demand (BOD5), mg/L	8.1 ± 8.4	<2
Conductivity, μS/cm	1402 ± 542	676 ± 305
Fecal coliforms, MPN/100 mL	3.1 ± 4.6	3.0 ± 4.3
Grease and oils, mg/L	<3	<3
Nematode eggs, eggs/L	0.0 ± 0.0	0.0 ± 0.0
pH	6.8 ± 2.5	7.0 ± 2.6
Turbidity, NTU	3.3 ± 4.3	<1.0
Sedimentable solids, mL/L	<0.1	<0.1
Total coliforms, MPN/100 mL	115.2 ± 2.2	7.5 ± 5.7
Total dissolved solids, mg/L	934 ± 361	558 ± 170
Total suspended solids, mg/L	<5	<5

Other examples of the application of reclaimed water for irrigation is Yountville, located in California's Napa Valley, where recycled water from the Yountville WWTP has been used for the irrigation of hayfields, golf courses and for the irrigation of vines once the wastewater's high nitrogen content and periodically elevated turbidity was controlled. The treatment consist of a 2 MGD (87.6 L/s) plant utilizing trickling filters followed by a contact system that provides aeration, nitrification, and denitrification. The effluent meets Title 22 requirements of less than 2 NTU of turbidity and low 5 mg/L nitrogen requirement desirable for irrigation of the grape vines. The treated wastewater used for the current experiment wouldn't meet Title 22 requirements nor the maximum allowance levels for nitrogen and turbidity.

Plant growth

Relative shoot growth rate (RGR) decreased in both varieties from May toward August (Figure 3). At the start of the irrigation experiments, the RGR was approximately 2.5% d^{-1} for the control cabernet sauvignon plants and the wastewater irrigated vines; for merlot vines the RGR was approximately 1.8% d^{-1}. Shoot growth stopped by the end of June in aquifer irrigated cabernet sauvignon vines while growth was still observed (approx. 0.75% d^{-1}) until the harvest period (mid-August) in wastewater irrigated vines. Relative growth rates were significantly greater ($p < 0.05$) from mid-June until the harvest season in wastewater irrigated vines compared to aquifer irrigated cabernet sauvignon. Similar to cabernet sauvignon vines, RGR for merlot were higher in wastewater irrigated vines compared to the groundwater irrigated vines.

Overall, results confirm that the plants irrigated with treated wastewater grew faster and for a longer period than

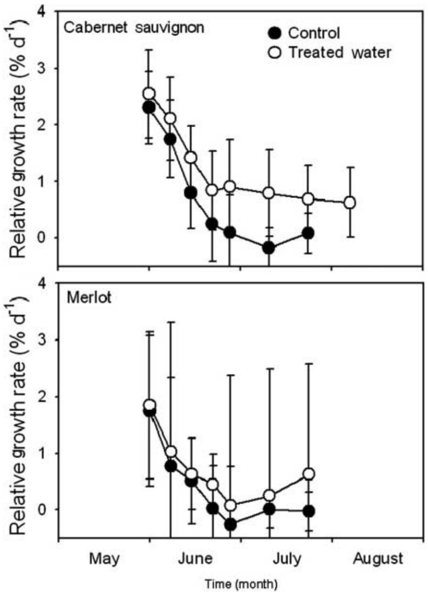

Figure 3 | Relative growth rates (RGR) for cabernet sauvignon and merlot vines irrigated with treated wastewater and groundwater. Error bars indicate standard deviation.

plants irrigated with local groundwater. This can be associated to the higher concentration of total nitrogen (nitrate + ammonia) and phosphates in the treated wastewater, despite the higher levels of nitrate in the groundwater and the higher salinity in the treated wastewater. Due to the fact that salinity affects vines (and plants in general) by osmotic effects and by specific ion effects, currently research in being undertaken in order to calculate these as well as soil characteristics.

Grape evaluation

Sugar content in the grapes from control and wastewater irrigated vines was similar from veraison to the harvest period (Figure 4, $P < 0.05$). In general, merlot grapes matured at a faster rate than cabernet sauvignon grapes. Similarly, pH and the concentration of titratable solids did not vary between treatments (data not shown). These results suggest that the biochemical characteristics of grapes irrigated with wastewaters are not modified. The similar behavior of grape characteristics between treatments is important to assure grape-growers that the quality of their products will not be modified by applying treated wastewater to their crops. Furthermore, the number of leaves per shoot and the overall biomass increased in plants irrigated with wastewater. Grape production per plant was 20% higher in plants irrigated with wastewater.

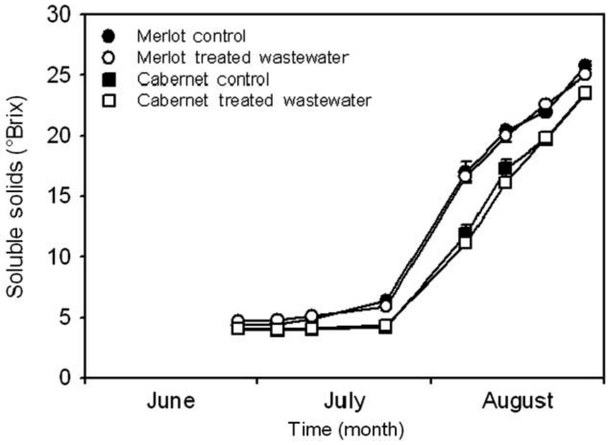

Figure 4 | Soluble solid content in the grapes of merlot and cabernet sauvignon grapes irrigated with groundwater and wastewater. Error bars indicate standard deviation. Error bars not shown are smaller than symbol size.

Fecal and total coliforms were not present in Cabernet sauvignon and Merlot samples; in all cases, levels were < 18 MPN/100 g. According to the Mexican norm dealing with sanitation in food to be served to the public (NOM-093-SSA1-1994), the maximum permissible level allowed for raw vegetable or fruit is 100 MPN/100 g so the grapes in the present study fully comply with the norm. This finding highlights the fact that proper handling of fresh produce is essential to reduce health risks particularly when treated wastewater is reused for the irrigation of the produce.

Water demand implications

The reuse of wastewater could help reduce the current rate of groundwater extraction from the aquifer. If 200 litres per second of reclaimed wastewater would be returned to be used for grapevine irrigation in Valle de Guadalupe (the same amount that is currently being sent as drinking water to Ensenada), assuming an irrigation application of 6,000–7.500 m^3/ha/year, around 837–1046 hectares (ha) of grapevines could be irrigated. Moreover, the wastewater caused an increase in the biomass of the grapevines and there was no presence of microbial indicators in the final product so a higher wine production could be achieved without an increase in health risk related problems. Therefore, reclaimed water could be safely used for the irrigation of vineyards in the Guadalupe Valley. Part of ongoing research includes an economical analysis of the best options for Ensenada and the Valle de Guadalupe in order to establish the optimum volume of water to be returned, the cost of its transportation as well as the cost of irrigation.

CONCLUSIONS

The application of 9.4 L/d of advanced secondary effluent for the irrigation of cabernet sauvignon and merlot vines at the Guadalupe Valley, Mexico proved to enhance the relative growth rate (RGR) of the plants. In general, wastewater-irrigated vines received 1.5 more nitrogen (on molar bases) and 40-fold more phosphate (on molar bases) than the controls. The higher salinity of the wastewater (934 vs 558 mg/L) did not appear to produce and adverse effect on the growth of vines. The crops irrigated with treated wastewater achieved greater growth and for a longer period of time. Further research on geological, soil and meteorological parameters must be undertaken in order to optimize and protect humans and the environment.

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