Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.23612

150 (2019) 73–83
May

Atacama Desert: water resources and reuse of municipal wastewater in irrigation of cut flower aeroponic cultivation system (first laboratory experiments)

Ismael Vera-Puerto[a,b,*], Jorge Olave[a,c], Suzy Tapia[a,c], Wladimir Chávez[a,c]

[a]*Centro de Investigación y Desarrollo en Recursos Hídricos (CIDERH), Vivar 493, 2do Piso, Iquique, Chile, Tel. 56 71 2633188; Fax: 56 71 2203534; emails: ivera@ucm.cl, leovera82@gmail.com (I. Vera-Puerto), jorge.olave@ciderh.cl (J. Olave), vicencio.t.sussy@gmail.com (S. Tapia), wladimir.chavez@ciderh.cl (W. Chávez)*
[b]*Centro de Innovación en Ingeniería Aplicada (CIIA), Departamento de Obras Civiles, Facultad de Ciencias de la Ingeniería, Universidad Católica del Maule, Av. San Miguel 3605, Talca, Chile*
[c]*Universidad Arturo Prat, Casilla 121, Iquique, Chile*

Received 5 April 2018; Accepted 16 December 2018

ABSTRACT

This work aims to evaluate the cultivation of cut flowers irrigated with treated wastewater in a soilless cultivation technique such as aeroponics in arid climates. In addition, information about the state of water resources in the Atacama Desert, focusing on the wastewater management, is showed to explain the context where this study was developed. In this arid environment, two experimental aeroponic units were planted with the cut flower Lily Tresor. For irrigation, municipal wastewater treated by treatment wetlands was used. Moreover, the water resource information of the Atacama Desert was analyzed. Thereby, in the Atacama Desert average annual rainfall is 87 mm/year, and agriculture represents 72% of the total used water (10.29 m^3/s). Furthermore, less than 10% of the treated municipal wastewater is reused despite the treatment coverage close to 100%. Meanwhile, the Lily Tresor was developed under the experimental conditions, but its commercialization would be limited to national markets, because height (stem length) is less than 0.65 m. In this regard, the electrical conductivity (>2,300 µs/cm) in irrigation water and luminosity (>38 klux) were factors that affected the growth of Lily Tresor. Finally, between 10% and 20% of the water for producing Lily Tresor in comparison with other cultivation systems was used. This result shows the efficient water use by the aeroponic cultivation system. Thus, the cut flowers production in soilless cultivation systems such as aeroponics under extreme arid conditions and irrigated with treated municipal wastewater is possible. However, for industrial scaling, improvements in water and luminosity management must be done.

Keywords: Aeroponic cultivation; Cut flower; Lily Tresor; Treatment wetland; Wastewater reuse

1. Introduction

Freshwater availability worldwide is declining, and there is a need for alternative and more efficient use such as reuse of treated municipal wastewater [1]. In many parts of the world, agricultural irrigation using treated municipal wastewater has been practiced for many centuries [2]. In arid areas, such as the Atacama Desert, located in northern Chile, the reuse of treated municipal wastewater is a possibility [3]. In the Atacama Desert and other such arid areas around the world, the scarcity of water (below 1,000 m^3/inhabit-y) is a reality [4]. The use of treated wastewater as a new alternative water source requires the study of different topics. For example, persistence and fate of bacterial indicators is an important topic. In semi-arid areas, *Escherichia coli* has showed limited persistence

---

[*] Corresponding author.

and no relevant accumulation both on the vegetation and in the topsoil irrigated with reclaimed water [5]. However, few studies have been published focusing on treated municipal wastewater reuse that includes irrigation evaluation, cultivation techniques, technical improvements, government models, pathogen behavior, for the Atacama Desert [3,6–10].

Taking this into account, the reclaimed wastewater use in irrigation for the cultivation of cut flowers is an opportunity to the Atacama Desert and other deserts in the world [11,12]. In this regard, floriculture contributes significantly, in economic terms, to the horticultural sector with a worldwide production value of € 37,000 million that involves around 170,000 farms [13]. Despite the production, an important aspect of floriculture is water consumption: it is estimated that 0.1–0.35 m^3 of water are needed to produce 1 kg of plant dry matter, but it can vary with species and variety, cultivation system and plant growing season [13]. Therefore, water consumption could limit the industry potential and development in arid areas. However, cultivation techniques such as aeroponics (soilless cultivation system where the roots developed in the air are subject to an inert medium inside a closed and dark controlled environment saturated with moisture and nutrients) has shown to be efficient in the use of water resources. For example, lettuce culture in soilless cultivation systems uses only 10% of the water in comparison with the traditional soil-based culture [14,15]. Thus, these cultivation techniques would be more efficient in the use of water, with the potential to be a viable alternative for the agricultural development in arid zones. An additional advantage of soilless culture as a mean for root development of plants is the reduction of electrical conductivities (ECs) toxic effects since soils in the Atacama Desert has salinization problems with EC reported up to 65 dS/m [3,16].

Therefore, the aim of this work was to evaluate the cultivation of cut flowers irrigated with treated wastewater in a soilless cultivation technique such as aeroponics in arid climates. In addition, information about the state of water resources in the Atacama Desert, focusing on the wastewater management, is showed to explain the context where this study was developed.

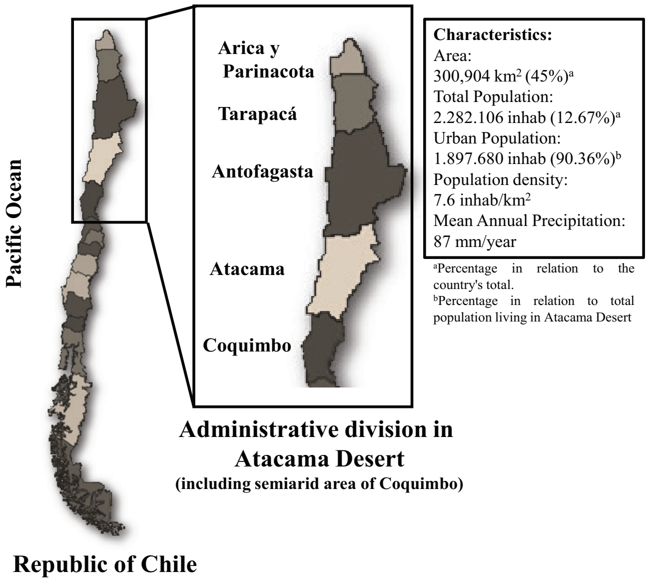
2. Materials and methods

2.1. Water resources into Atacama Desert

The continental Chile is located in South America between latitudes 17°30′S and 56°30′S, with a vast length of more than 4,000 km, bounding on the east by the Andes Mountain Range and on the west by the Pacific Ocean [7,17]. This vast length provides to the country a climatic variability. Thus, in northern Chile and for more than 1,000 km long, is located the Atacama Desert, one of the most arid deserts in the world [18,19]. Fig. 1 shows different characteristics of the Atacama Desert in the Chilean context [20].

In Atacama Desert, the average annual rainfall is only 87 mm/year (Fig. 1). The general relief of the Atacama Desert and longitudinal variations mean that in northern Chile there are areas with rainfall of less than 5 mm/year (costal zones and intermediate depression) and other areas up 250–600 mm/year (The Andes Mountain Range) [17,21]. In this regard, Table 1 shows the availability of water resources by Chilean regions located at Atacama Desert, along with the water use, also including data of local municipal wastewater treatment.

The Atacama Desert's population is concentrated in urban areas (>90%) with 100,000–300,000 inhabitants located mainly on the shores of the Pacific Ocean [20]. Other important urban areas are settlements depending on mining as the main economic activity: 78% of the companies in Chile engaged in the extraction of different minerals are located at northern [20]. This is reflected in the water consumption (Table 1), where mining uses 14.5% of the total water. On the other hand, agriculture



Characteristics:
Area:
300,904 km^2 (45%)[a]
Total Population:
2.282.106 inhab (12.67%)[a]
Urban Population:
1.897.680 inhab (90.36%)[b]
Population density:
7.6 inhab/km^2
Mean Annual Precipitation:
87 mm/year

[a] Percentage in relation to the country's total.
[b] Percentage in relation to total population living in Atacama Desert

Fig. 1. Atacama Desert in the Chilean Context (DGA [20]).

Table 1
Water resources and their use in Atacama Desert (DGA [20]; SISS [27])

Chilean regions in Atacama Desert	Runoff per capita (m^3/inhabit-year)	Water resources use by economic activity (m^3/s)				Municipal wastewater treatment coverage (%)	Treated municipal wastewater production (m^3/s)
		Agricultural	Drinking water	Industry	Mining		
Arica and Parinacota	725	3.71	0.96	0.25	0	100	1.11
Tarapacá	599	5.21	0.69	1.43	1.54	100	
Antofagasta	47	3.31	1.68	1.29	6.26	100	1.15
Atacama	190	12.03	0.87	0.52	1.9	94.9	0.60
Coquimbo	908	27.19	1.89	0.25	0.71	100	1.09
Average	493.8	10.29	1.22	0.75	2.08	98.98	0.99

uses 72% of the total water employed for economic activities (Table 1). This percentage is similar to global consumption for this sector estimated above 60%, and similar to countries with semi-arid climatic areas, such as Italy (>50%) and Spain (68%) [22]. Therefore, agriculture is the economic activity with the greatest use of water resources in Atacama Desert, and the reclamation of wastewater for irrigation will be important in water resources management. In this regard, Fig. 2 shows the municipal wastewater treatment technologies used in the Atacama Desert and the effluent´s final destination. Table 2 presents a summary of raw municipal wastewater characteristics from three wastewater treatment plants (WWTPs) located in the Atacama Desert. Table 2 values are similar to other raw municipal wastewaters from arid-semiarid climatic areas and other locations in Chile [23–26].

Fig. 2 shows that aerobic systems such as different kinds of the activated sludge (38%) and aerated lagoons (29%) are the most-used municipal wastewater treatment technology in the Atacama Desert. In Chile, more than 60% of its WWTPs are based on aerobic processes [8]. On the other hand, the high participation of marine outfalls stands out (25%), but it highlights even more the amount of water that is poured into the sea (2.52 m^3/s, 64% of the total), and the low amount that is reused (<0.3 m^3/s, 7.37% of the total) (Fig. 2). In the case of reuse, although the treatment coverage is similar to Israel (>90%), in the Atacama Desert, the reuse is below 10%, while Israel reuses over 70% of its treated municipal wastewaters (Fig. 2) [28]. The low reuse in the Atacama Desert could be explained for several reasons. First, the main population centers are located around the Pacific Ocean coast with the consequent Chile's decision to use in coastal urban centers the "marine outfall" disposal technology as the main treatment technology. Second, soils and treated wastewaters have a high salinity (soil, EC above 26.8 dS/m, water, EC above 2 dS/m), explained by the natural geological condition [3,9,16,29]. Finally, the social fear of the wastewater reuse for irrigation along with the lack of information about its benefits lead certainly to a low application of reuse. In this sense, the aim of this work is to produce some cut flowers for ornamental use reducing the risk of the population's rejection applying a cultivation technique which contributes in reducing water consumption up to 90% [15].

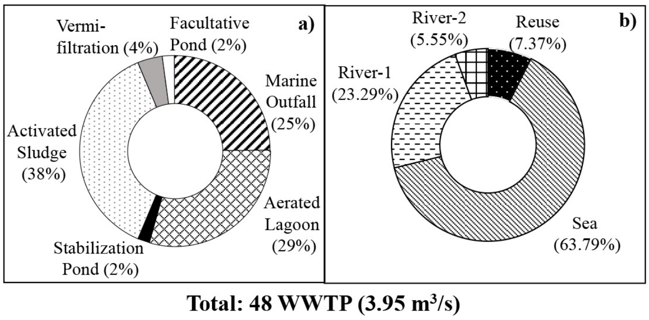


Fig. 2. Municipal wastewater treatment in Atacama Desert. (a) Technologies, (b) final destination (SISS [27]). River-1: streams without dilution capacity; River-2: streams with dilution capacity. WWTP: wastewater treatment plant.

2.2. Mesocosms

2.2.1. Experimental setup

Experimental units (aeroponic beds) A and B were constructed and operated at the CIDERH's Experimental Unit located in Iquique (Chile) on the Atacama Desert coast (latitude, 20°16′15.92″S; Longitude, 70°07′48.57″E). Local rainfall is below 5 mm/year, and the average annual evapotranspiration is above 2,000 mm/year, with an aridity index below 0.05, thus the area where the experimental units were located is classified as "coastal desert with abundant cloudiness" [21,30]. The experimental units are only isolated from the exterior by anti-aphid mesh to protect plants from insects.

Experimental units A and B were built from cubic 96 L plastic tanks (dimensions: 0.60 m × 0.4 m × 0.4 m; length × width × height). Each experimental unit was fitted with eight places to hold planted baskets (plant density: 33 plant/m^2). Each planted basket was slotted with 232.26 cm^3 (height, 8 cm; superior diameter, 8 cm; basal diameter, 6 cm) and were filled with arlite (diameter 8–16 mm). Arlite was employed as support material for the plant´s root system since it allows root's aeration and water retention during and after irrigation. The aerial part of the plant was allowed to develop freely above the experimental unit. The irrigation was carried out with micro jets, fed with a pump per each experimental unit. The experimentation was performed cultivating Lily Tresor, a cut flower plant widely sold in the Chilean market as well as sustainable for soilless culture and salt tolerant (EC, 2.300 μs/cm), conditions commonly found in municipal wastewater of arid environments [3,11,29].

Table 2
Raw municipal wastewater characteristics in Atacama Desert. Data from three WWTP during 2 years

Water quality parameter	*n*	Average ± Standard deviation	Minimum	Maximum
T, °C	82	24.31 ± 2.32	16.50	28.50
pH	82	7.66 ± 0.49	6.59	9.27
BOD_5, mg/L	50	262.22 ± 68.06	87	489
COD, mg/L	50	662.36 ± 217.43	412	1,780
TSS, mg/L	50	240.68 ± 103.75	53	610
TKN, mg/L	38	54.87 ± 31.97	0.9	119
TP, mg/L	38	3.18 ± 4.21	0.2	24
FC, log MPN/100 mL	52	7.46 ± 0.71	3.34	8.20

T: Temperature; BOD_5: 5-d biological oxygen demand; COD: chemical oxygen demand; TSS: total suspended solids; TKN: total Kjeldahl nitrogen; TP: total phosphorus; FC: fecal coliforms; MPN: most probable number.

2.2.2. Irrigation water

Raw municipal wastewater for feeding treatment wetlands was taken from the local WWTP that serves to 100,000 inhabitants. After filtration by mechanical screening of 10 mm, four treatment wetlands were used to produce the irrigation water. Experimental unit A was irrigated with water composed of a blending of 50% of effluents coming from two treatment wetlands with native plants (*Schoenoplectus americanus*) operated in parallel with hydraulic retention time (HRT) of 3.5 and 7 d. Meanwhile, experimental unit B was irrigated with water composed of a blending of 50% of effluents coming from two treatment wetlands with foreign plants from the Atacama Desert (*Cyperus papyrus*) operated in parallel with HRT of 3.5 and 7 d. The effluents used in this work correspond to months 4 through 7 of the operation of the treatment wetlands. More details about experimental treatment wetland system can be found in Vera et al. [29].

2.2.3. Operation and monitoring strategy

Experimental units A and B were planted in August. The cut flower plants were planted after rhizome was disinfected for fungi and bacteria (rhizome caliber 12–14). The disinfection is necessary because the root zone will be developed under dark and saturated humid environment [31]. During the growth phase, biometric measures such as height (stem length) and stem diameter were measured every week for the plants in the two experimental units (A and B). Height (stem length) was measured from arlite surface to the apex of growth. Stem diameter was measured in the middle of height. In addition, the number of flower buds was counted at the time of harvest. Harvest was made when 50% of the flower buds were pigmented.

In experimental units A and B, the water inside the aeroponic bed was changed every 7 d. This water change was defined according to maximum HRT in the treatment wetlands. A volume of 13 L of treated wastewater was placed into each aeroponic bed on day 0 as water supply for irrigation. The volume was defined according to pump requirements. After 7 d, the remaining water was drained and measured. The aeroponic beds were completely closed to prevent the water evaporation. Previous to water application into aeroponic bed, water quality parameters such as COD, TSS, NH_4^+-N, NO_3^--N, TN, PO_4^{3-}-P, TP and fecal coliforms (FC) were measured in effluents to experimental treatment wetlands [29]. The irrigation was continuous, with application of continuous water during 24 h. The water in the irrigation system was monitored for water quality parameters EC and pH at day 0, 3 and 7. These two water quality parameters were selected because their readings and interpretation are simple and traditionally been employed in reclaimed water projects and guidelines [3,32,33]. Meteorological information (air temperature and relative humidity) was obtained from MeteoChile [34] (Diego Aracena weather station).

2.3. Analytical methods

Water used for irrigation in the experimental units A and B was analyzed for COD, NH_4^+-N, NO_3^--N, TN, PO_4^{3-}-P and TP using a multiparameter photometer for municipal wastewater HANNA HI-83214 and reagents test kits: (a) COD, HI 93754B-25; (b) NH_4^+-N, HI 93764B-25; (c) NO_3^--N, HI 93766–50; (d) TN, HI 93767A-50; (e) PO_4^{3-}-P, HI 93763A-50 and (f) TP, HI 93763B-50. Previous to analysis, the water was filtered (fiberglass filters, 0.45 μm pore size). The determinations correspond to standard adaptation procedures from APHA-AWWA-WEF [35]. TSS measurement was conducted according to procedures in APHA-AWWA-WEF [35]. FC measurement was conducted by multiple tube fermentation according to INN [36]. EC and pH in experimental units A and B were measured by portable multiparameter HANNA HI-9829. Biometric measurements of the cut flower plants were done with tape measure (height) and caliper (stem diameter). The water volume of irrigation (day 0 and 7) was measured by graduated cylinder every 7 d.

2.4. Statistical analysis

All statistical tests were performed using INFOSTAT [37] with a significance level $\alpha = 0.05$. The statistical analysis was used to evaluate differences between: (a) cut flower plant developments, comparison of height and stem diameter between experimental units A and B, taken into account the data at harvest time, (b) pH and EC variations in water used for experimental units A and B at day 0 and, (c) pH and EC variations in water during irrigation at days 0, 3 and 7. For cut flower plant development, pH and EC in water at day 0, the Wilcoxon test was used. Finally, to compare variation in pH and EC during irrigation, the Kruskal–Wallis test was used.

3. Results and discussion

3.1. Development of cut flower plants in aeroponic cultivation

Fig. 3 summarizes the Lily Tresor growth for experimental units A and B. Fig. 3 shows that Lily Tresor's average height (stem length) varied by less than 0.1 m. This height is greater in the experimental unit A, in regards to experimental unit B, but this difference is not significant ($p > 0.05$). Height has been defined as one of the most important aspects of commercial quality for the Lily Tresor [38,39]. The values between 0.5 and 0.6 m of the two experimental units from this work (without a significant difference between them, $p > 0.05$), suggest that flowers have commercial quality for national markets and not for export, because the height must be higher than 0.65 m [31,38]. In addition, the height reached would be lower than the work of Rodríguez-Fuentes et al. [40] for Lily Longiflorum, who for a planting density of 35 plant/m^2 (similar to this study) achieved 0.72 m. However, the height in this work is similar to results of Schiappacasse et al. [39], who for Lily Dreamland and Lily Alhambra, in the control environment without shading, reached a height of 0.59 m.

Regarding to the stem diameter, the two experimental units show similarity with average values between 0.6 and 0.7 cm similar to results of Schiappacasse et al. [39]. On the other hand, each plant had between 4 and 5 floral buttons similar to results of Schiappacasse et al. [39]. According to Auzaque-Rodríguez et al. [38] when a plant has more than 2.5 flowers per individual, the cut flower has marketing characteristics. However, as previously indicated, the Lily Tresor flowers from this work would be limited to national markets due to the height (<0.65 m) [38,39]. Fig. 4 shows the development of Lily Tresor after harvest on day 0 and day 4. Fig. 4 shows a good development of the floral button and its possibility to be sold in the local market.

Other parameters such as proline and nitrate reductase can be useful to evaluate the plant's development when stressful conditions are present during cultivation [41]. Proline is an amino acid that increases in the plant's tissue when plants grow under water deficit, salinity conditions, low temperature and heavy metal exposure [42]. Nitrate reductase is a key enzyme in nitrogen assimilation and its activity gives a good approximation to the nitrogen status into plant´s tissue [43]. Galarce [41] for Lily Tresor cultivation in the Atacama Desert showed in leafs (previous to harvest) average values of 1.66 μmol/gFW-h (fresh weight) and 4.0 μmol NO_2/gFW-h, for proline and nitrate reductase, respectively. Drüge [44] reported proline values between

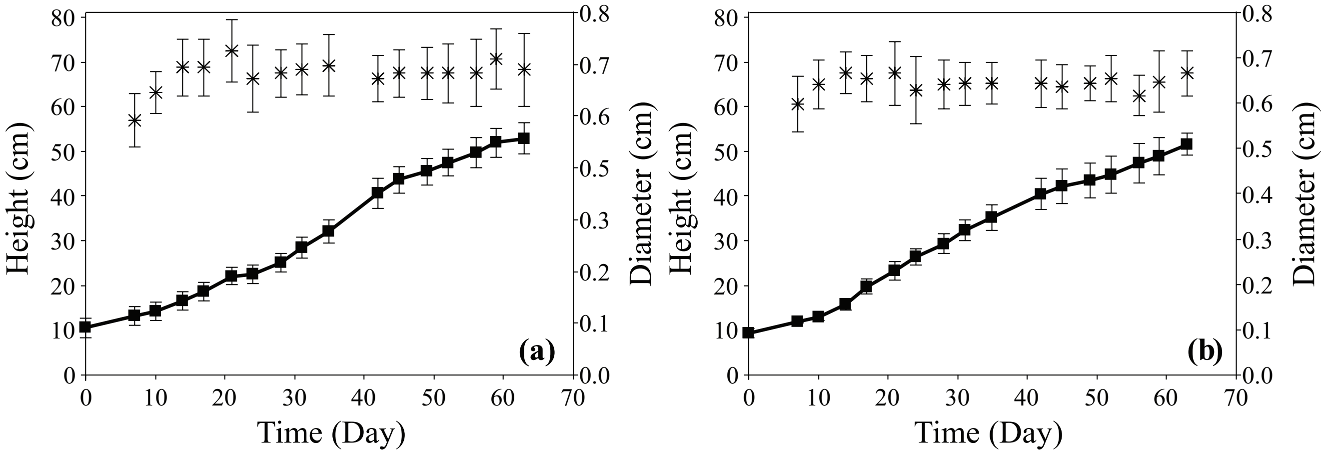


Fig. 3. Growth of Lily Tresor during cultivation time: (a) experimental unit A; (b) experimental unit B. Height (■); diameter (*).

Fig. 4. Lily Tresor after harvest. (a) Day 0; (b) Day 4.

1.1 μmol/gFW and 2.6 μmol/gFW when different substrates for root development of *Chrysanthemum* have been used in a greenhouse (18°C–20°C). Konnerup and Brix [45] showed nitrate reductase values of 22 μmol NO_2/gDW-h (dry weight) when only NO_3 was used as N source for *Canna indica* (ornamental plant) in a growth chamber (20°C–22°C). However, these values are indicative and they have to be carefully taken into account because each plant responds in different ways to stressful cultivation conditions.

3.2. Water quality for reuse and their influence in the development of cut flower plants

Table 3 summarizes the physicochemical characteristics of the effluents to the treatment system based on treatment wetlands. These effluents were used as irrigation water in the experimental units (A and B). In addition, Table 3 includes standards for water use in cultivation irrigation. COD above 170 mg/L showed the principal difference in comparison with the standards in Table 3. TSS, TN and TP effluent concentrations showed similar values to the standards of Table 3. However, they would have restrictions regarding the crop and soil according to indications in Lavrnić et al. [22]. In addition, the NO_3^--N concentration is below 1 mg/L and the NH_4^+-N is above 15 mg/L; therefore, nitrate reductase concentration has not to be expected a problem in plant's tissue. These results show that the treatment wetland system should integrate more treatment stages or recirculation in order to improve the effluent quality. The treatment system improvement is consistent with other studies in arid zones [23,33,46]. Furthermore, although Table 3 shows a reduction between 2 and 3 log units/100 mL of the FC, in order to achieve the effluent's concentration of Table 3, a disinfection process has to be added to the wetland treatment system. On the other hand, the water quality standards in Table 3 have been indicated for traditional agriculture and irrigation methods. However, the cultivation of this work was developed in a non-traditional system such as aeroponics, and in this system, the water was handled with minimal contact to the farmers and crops, and in addition, soil was not used. Therefore, in the future, an evaluation of the standards' applicability included in Table 3 to alternative farming methods such as aeroponics is recommended.

Table 4 shows the pH and EC measurements on day 0, 3 and 7 for irrigation water. Regarding day 0, the average value of pH and EC shows significant differences ($p < 0.05$) between experimental units A and B. In addition, the pH increase of

Table 4
Electrical conductivity (EC) and pH evolution for water used during irrigation in aeroponics crops (average ± standard deviation)

Experimental unit	Day	Water quality parameter	
		pH	Electrical conductivity, μs/cm
A	0	7.5 ± 0.1	2,358.7 ± 62.1
	3	8.0 ± 0.2	2,388.4 ± 369.7
	7	8.3 ± 0.4	2,421.8 ± 300.3
B	0	6.9 ± 0.1	3,481.7 ± 436.8
	3	8.7 ± 0.1	3,203.6 ± 461.6
	7	8.6 + 0.1	3,358.0 ± 551.9

$n = 9$ for each monitored day.

Table 3
Effluent concentrations to treatment wetlands (TWs) used for irrigation in aeroponics crops and water quality standards for irrigation (average ± standard deviation)

Water quality parameter	Effluent for feeding experimental unit A	Effluent for feeding experimental unit B	Treatment goal in effluent to reuse[a]
COD, mg/L	216.5 ± 47.7 (140 – 254)	178.0 ± 35.6 (131 – 218)	<100
TSS, mg/L	58.9 ± 16.0 (32 – 73)	68.1 ± 36.3 (36 – 130)	<10–60
NH_4^+-N, mg/L	55.8 ± 4.2 (52.5 – 63)	19.4 ± 3.7 (14.5 – 24)	–
NO_3^--N, mg/L	0.9 ± 0.7 (0.05 – 2.0)	0.7 ± 0.7 (0.0 – 1.9)	<5.5–50
TN, mg/L	57.2 ± 9.0 (45 – 66.6)	23.7 ± 6.6 (15 – 32)	<5–125
PO_{4-}^{3}-P, mg/L	4.2 ± 2.3 (2.5 – 7.0)	2.2 ± 1.2 (1.1 – 3.5)	–
TP, mg/L	5.4 ± 1.7 (3.8 – 7.3)	2.3 ± 0.7 (1.2 – 3.1)	<0.05–12
FC, log-unit	4.6 ± 0.5 (4.1 – 5.0)	4.2 ± 0.8 (3.3 – 4.8)	<2–4

[a] Treatment goals showed in Norton-Brandão et al. [32] and Lavrnić et al. [22].
$n = 5$ for all parameters except FC (fecal coliforms) with $n = 3$ in experimental unit A and B. Number in parenthesis are minimum and maximum.

up to 0.75 units for average values in the experimental unit A and up to 1.7 units on the experimental unit B, between the day 0, 3 and 7 was observed. These increases were significant ($p < 0.05$) amongst each other. Despite this, the pH falls in a range from 6.0 to 8.0 units recommended for irrigation water, and this range can be extended in the upper limit in regulations focused on reuse (as in this case) until 9.5 [8,32].

The average values of EC (Table 4) from experimental unit A as well as from experimental unit B did not show significant differences ($p > 0.05$) between days 0, 3 and 7. The average values of EC in the experimental unit A are in the range of 1,500–3,000 µs/cm. These EC values let be classified the water for irrigation as "water with adverse effect on most crops" [8]. Meanwhile, the average values of EC in the experimental unit B are in the range of 3,000–7,500 µs/cm. These EC values let be classified the water for irrigation as "water only for salt-tolerant crops" [8]. Therefore, the EC values above 2,300 µs/cm could explain the final height of the plant (<0.65 m) in the two experimental units.

The EC is a water quality parameter of agriculture importance because it quickly shows the minerals content in irrigation water. EC values above 1,500 µs/cm have an influence on the osmotic pressure of water in the soil (in this case the inert substrate of arlite). Therefore, the respiration process of the plant to extract the water is increased and more energy is used in the process affecting the plant's growth [47]. Authors such as Cassaniti et al. [13] and Wu et al. [48] showed that salinity (measured as EC) is an important factor that affects the growth and development of ornamental plants.

The results of this work do not show significant variation ($p > 0.05$) of the height (stem height), the stem diameter and number of flowers, between the experimental units A and B, despite the EC significant difference ($p > 0.05$) above 1,000 µs/cm in the irrigation water at day 0. In this sense, Al-Ghawanmeh et al. [11] achieved similar results because they showed that variations on EC values below 2,300 µs/cm (lower limit in this work) had no effect on plant's development. Thus, the EC variations in Table 4 could be complementary to the results of Al-Ghawanmeh et al. [11], because treated wastewaters with EC between 2,300 and 3,500 µs/cm could be used interchangeably in the irrigation of Lily's aeroponic cultivation under arid conditions. This is important because EC values between 2,300 and 3,500 µs/cm have already been reported for treated municipal wastewater in the Atacama Desert [3,29] and for other deserts in the world [23,46,49]. However, the irrigation water with EC above 2,300 µs/cm has an effect on the commercial quality of lily's flower (height < 0.65 m, [38,39]) as mentioned earlier.

3.3. Environmental factors and their influence in the development of cut flower plants

Fig. 5 shows a summary of the environmental temperature (T) and the relative humidity (HR) during the development of lily's cultivation in experimental units A and B. The environmental temperature can be considered stable with average values between 14°C and 16°C, and average minimal about 12°C and maximums below 20°C (Fig. 4). According to FIA [31], the ideal environmental temperature for the lily cultivation should be a minimum of 8°C–10°C and maximum of 23°C–25°C. Taking into account these conditions, the lily cultivation of this work had optimal temperature for its development (Fig. 5).

The HR was not controlled for the lily's cultivation because only one anti-aphid mesh was employed to isolate the experimental units A and B from outside. For this reason, the lily's cultivation was subject to the environmental HR of the coastal Atacama Desert. Fig. 5 shows HR minimum, average and maximum, between 55% and 85% during crops' development time (August–October), with a maximum of 15% variation between the weekly average values as inter-weekly. According to CIBF [50], the optimum HR for the lily cultivation should vary between 80% and 85%, keeping it as stable as possible. Thus, Fig. 5 shows HRs below this recommendation. In this sense, for another cut flower cultivation such as rose, the average HR conditions of up to 70%, with daily reductions of up to 40%, did not influence its growth. In addition, after harvesting, these HR conditions did influence the duration of flower in the postharvest (life in a flower pot), with an increase of up to 3 d compared with a cut period with higher relative humidity (HR > 80%) [51]. This result indicates that the HR of this work (below 80%), in some periods (Fig. 5), should not affect the quality of the lily flower. However, postharvest data (life in a flower pot) was not addressed in this work. Therefore, in future works of cut flower cultivation in desert or arid environmental conditions, the study of life in flower pot is recommended to be performed.

On the other hand, an additional environmental factor, solar radiation or the effect of light, which was not studied in this work, could explain lily's growth problems [39]. To evaluate the effect of light, two aspects are important: photoperiod and luminous intensity. Photoperiod has influence on flowering, especially in the amount of flower buttons [31,50]. During the study period (August–October), the photoperiod of the coastal desert of the Atacama has variations between

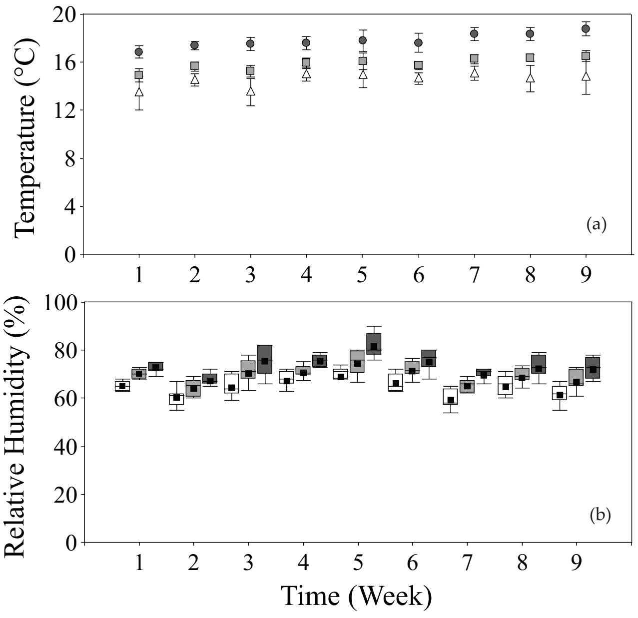


Fig. 5. Evolution of temperature and relative humidity during growth of Lily Tresor. (a) Temperature, minimum (△), average (▣), maximum (●). (b) Relative humidity, minimum (□), average (▣), maximum (▣), mean value (■).

11.5 and 12.5 h [52]. However, the stability in hours and the quantity of flowers buttons, above 2.5 flowers per individual (minimum for lily's commercial quality, [38]), show that the photoperiod was not relevant for the cultivation developed. In this sense, in the coastal Atacama Desert where the crop was developed, the natural photoperiod (11 h in June – 14 h in December [52]) is less oscillating than in temperate zones. Therefore, the photoperiod would be a benefit for the cultivation of Lilies in arid zones taking into account that the main deserts of the planet are located in latitudes similar to the Atacama Desert: in the Northern Hemisphere near to the Tropic of Cancer, and in the Southern Hemisphere near to the Tropic of Capricorn. This advantage stands out because CBIF [50] has suggested the use of artificial light to prolong the photoperiod up to 14 h in the final stage of cultivation (sprouting – visible inflorescence) during spring seasons in temperate zones.

Regarding to the luminous intensity, Schiapaccasse et al. [39] showed for lily's varieties that a shade above 65% could significantly increase ($p < 0.05$) the total height when Lilies are planted in spring (September–December). In this sense, lily plants of this work did not have shade because they were separated from the outside only by anti-aphid mesh. Olave et al. [53] showed that for lily plants developed in the coastal desert of the Atacama, the height increased from 0.38 to 0.69 m when brightness was reduced four times from 38 to 9 klux. Thus, Olave et al. [53] indicated that the luminous intensity would be the most important variable to control, in order to produce lily flowers with commercial quality for export under arid conditions (>0.65 m, [38,39]) such as those from the Atacama Desert, where light intensity can exceed 120 klux [53].

3.4. Water consumption in the production of cut flower lily

Fig. 6 shows the water consumption expressed as the percentage of water used for irrigation in each experimental unit. For the cultivation of lilies, it has been established that the highest water consumption occurs during the growth of roots (first 3 weeks), and later, during the formation of flower buds (3 weeks before cutting) [31]. Taking this into account, the water consumption shows variations regarding to FIA [31] (Fig. 6). In the first 4 weeks, the water consumption is stable around 5%–15% with a small increment of 5%–15% in week 5. This difference with FIA [31] could be explained by the values of EC (>2,300 μs/cm) that affected the growth (<0.60 m), which caused less water to be used for a normal export height (>0.65 m, [38,39]). Furthermore, the water consumption increases in week 5, at the same time that a greater pronouncement of growth rate can be found in Fig. 3 (day 30 to 45, weeks 5 and 6 of growth) in the two experimental units, reaffirming that a greater growth, a greater water consumption. In the case of the last 3 weeks, Fig. 6 shows that the water consumption increases by almost 20% during the last 2 weeks in agreement with FIA [31].

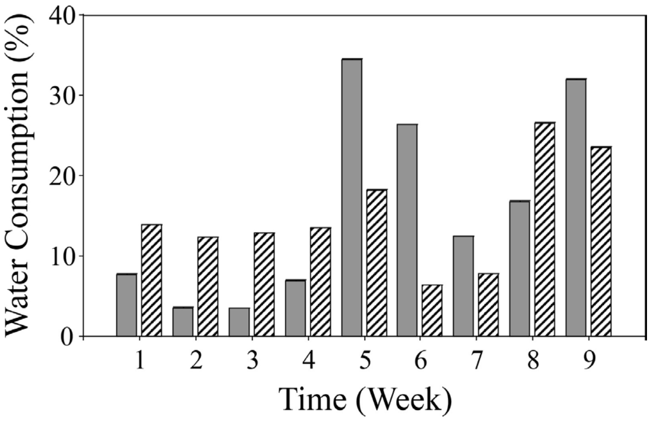


Fig. 6. Evolution of water consumption for irrigation of Lily Tresor expressed as percentage of total water applied into each experimental unit at day 0 of each week. Experimental unit A (■); experimental unit B (▨).

According to Fig. 6, the production of one lily flower requires between 1.71 L/plant (experimental unit B) and 2.35 L/plant (experimental unit A) for the cultivation period of 65 d (Fig. 3). The difference of 0.64 L/plant between experimental units A and B is explained by average EC increase in irrigation water (Table 4), because the water consumption in soilless cultivation systems is reduced when EC in water for irrigation increases [54,55]. However, weeks 1, 2, 3 and 4 had different behavior. This particular behavior can be explained because according to FIA [31], in this period, the roots are developed, and EC differences of 1,000 μs/cm (Table 4) could have influenced on its development, and therefore, in the water consumption. For the rest of growing time, with exception of week 8, the water consumption followed the expected behavior: at higher EC, lower water consumption. The difference in water consumption for week 8 could be explained by differences in the flower buds development between the experimental units [31], but this work cannot give conclusions about that, because biometric measures were not taken on them.

The water consumptions of this work were above 50% higher than the water use efficiency reported by Safi et al. [49], who achieved a water consumption between 0.70 and 1.11 L/plant in an arid environment and a lily cultivation system in the soil, when effluents from a WWTP are reused for irrigation. This difference could be explained by the difference in the water salinity but mainly in the irrigation way. Safi et al. [49] reported an EC of 2,002 μs/cm, whereas in this study, the EC values were always above 2,300 μs/cm. However, a mathematical relationship between EC and water consumption to produce one lily flower cannot be established in this work, because more data would be necessary. Despite that, this work can be conclusive regarding EC influence during the first 3 weeks of growth, because a difference up to 9% in the water consumption can be found between the two experimental units.

Another difference with Safi et al. [49] was the irrigation way. Safi et al. [49] adjusted the daily amount of irrigation water to the values of the evaporation tank class A, while in this study, irrigation was performed continuously during 24 h. Al-Ghawanmeh et al. [11] for a soilless cultivation system at pilot scale under desert conditions achieved an average water use of 13.5 L/m^2 d (plant density, 25 plant/m^2, estimated) for the different treatments (EC in water below 2,300 μs/cm; irrigation frequency, three times per day). Therefore, a water consumption of 0.54 L/plant-d was estimated and for the total experiment time (40 d) it was necessary to use 21.6 L/plant. Thus Al-Ghawanmeh et al. [11] showed that irrigation optimization is a topic to be studied for aeroponic cultivation systems in arid conditions because their results are not in agreement to Safi et al. [49]. In addition, the water consumption achieved in this work (1.71–2.35 L/plant) is only 10% of those 21.6 L/plant of the study of Al-Ghawanmeh et al. [11]. Therefore, the irrigation optimization in aeroponic cultivations would be an important aspect to be evaluated in future studies of this cultivation system in desert conditions, and probably, this will be the most important factor in water consumption to produce one lily flower.

Additionally, the water consumptions in this work could be compared with CIBF [50]. CIBF [50] shows for dry conditions (environmental conditions assimilated to the desert or arid environments) that the water consumption can reach up to 9 L/m^2 d, in planting densities of 55 plants/m^2, hence 0.163 L/plant could be required daily, and for a growth time of 65 d (Fig. 3), the water necessity would be 10.6 L to produce one lily flower. Therefore, the water consumption reported in this work is only 20% of the 10.6 L, suggesting that the aeroponic cultivation system would be more efficient in water use. Thus the results are in agreement with Treftz and Omaye [15], who for soilless cultivation system of lettuce achieved a reduction of up to 90% in the water consumption. Despite this, the results of this work will need scaling and irrigation optimization needs to be more conclusive regarding to water use.

Finally, the cut flower aeroponic cultivation system has several advantages for reclaimed water projects when it is compared with traditional cultivation techniques [56]: (a) protection of public health because water during cultivation has a minimal contact with farmers and cut flowers are an ornamental product, (b) prevention in damage to soils and groundwater because the cultivation system is waterproof to prevent percolation, and (c) reduction in water consumption because for the production of one cut flower only 10%–20% of water is used. However, the aeroponic cultivation system has some disadvantages to be taken into account in reclaimed water projects [57,58]: (a) the necessity of advanced equipment such as high-pressure pumps, atomization nozzles, EC and pH measuring devices, temperature, light intensity and humidity sensors and timers to control the system, increasing the construction costs for large-scale production, (b) the farmers must need a specific proficiency level to operate the system, (c) the grower must have the information about the appropriate quantity of required nutrient for plant growth in the system; and (d) mister spray heads may also have a tendency to clog and not produce mist when needed.

4. Conclusions

- The water resources in the Atacama Desert such as other arid areas in the world are scarce. However, only 10% of the treated municipal wastewater is reused, despite a treatment coverage of close to 100%. This situation was explained by multiple factors, among which the high disposition stands out (2.52 m^3/s, 64% of the total) of municipal wastewater through marine outfalls to the sea.
- Lily Tresor as a cut flower could be cultivated under the arid condition of the Atacama Desert. However, its quality would only be for national markets because height (<0.65 m) is the biometric factor that would limit its commercialization to international markets.
- The EC (>2,300 μs/cm), and to a greater extent, the luminous intensity (>38 klux), are responsible for the smaller height (stem length) of Lily Tresor.
- The aeroponic cultivation system showed to be efficient on the water use with consumptions from 10% to 20% for producing Lily Tresor in comparison with other cultivation systems. Despite this, the water use can be further optimized when scaling the implementation of aeroponic crops to produce Lily Tresor cut flowers.
- For industrial scaling in arid conditions such as those of the Atacama Desert, control over water quality and light intensity management is recommended, if improvements in height are wanted in the Lily Tresor. This would allow its commercialization in international markets.

Acknowledgements

This work was supported by CONICYT/REGIONAL/CIDERH/R09I1001. The authors wish to express their gratitude to Sergio Fuentes, Renzo Aravena and Isabel Tello from Aguas del Altiplano for their notable help and support. Also, Christian Santander and Mauricio Rojas from CIDERH, Camila Jorquera from the Universidad de Tarapacá, and Nathaly Verdejo from the Universidad Técnica Federico Santa María, for their notable help during construction and experiment's implementation. Finally, to the Universidad Católica del Maule for supporting the Research Fellowship of Luis Rojas from Civil Engineering Program who helped during the last part of the manuscript preparation.

References

[1] A. Gross, M. Sklarz, A. Yakirevich, M. Soares, Small scale recirculating vertical flow constructed wetland (RVFCW) for the treatment and reuse of wastewater, Water Sci. Technol., 58 (2008) 487–494.
[2] T. Asano, Urban water recycling, Water Sci. Technol., 51 (2005) 83–89.
[3] L. Cáceres, J. Delatorre, F. De la Riva, V. Monardes, Greening of arid cities by residual water reuse: a multidisciplinary project in northern Chile, Ambio, 32 (2003) 264–268.
[4] N. Hammouri, J. Adamowski, M. Freiwan, S. Prasher, Climate change impacts on surface water resources in arid and semi-arid regions: a case study in northern Jordan, Acta Geod. Geophys., 52 (2017) 141–156.
[5] P. Vergine, R. Saliba, C. Salerno, G. Laera, G. Berardi, A. Pollice, Fate of the fecal indicator Escherichia coli in irrigation with partially treated wastewater, Water Res., 85 (2015) 66–73.
[6] L. Cáceres, E. Gruttner, R. Contreras, Water Recycling in Arid Regions, Ambio, 21 (1992) 138–144.
[7] F. Suárez, J. Muñoz, B. Fernández, J. Dorsaz, C. Hunter, C. Karavitis, J. Gironás, Integrated water resource management and energy requirements for water supply in the Copiapó River Basin, Chile, Water, 6 (2014) 2590–2613.
[8] I. Vera, C. Jorquera, D. López, G. Vidal, Humedales construidos para tratamiento y reúso de aguas servidas en Chile : reflexiones, Tecnol. y Ciencias del Agua, 7 (2016) 19–35.
[9] I. Vera, M. Rojas, W. Chávez, B. Arriaza, Evaluación de materiales filtrantes para el reúso en agricultura de aguas residuales tratadas provenientes de zonas áridas, Cienc. e Ing. Neogranadina, 26 (2016) 5–19.
[10] P. Stathatou, E. Kampragou, H. Grigoropoulou, D. Assimacopoulos, C. Karavitis, J. Gironás, Creating an enabling environment for WR&R implementation, Water Sci. Technol., 76 (2017) 1555–1564.
[11] K. Al-Ghawanmeh, N. Bani Hani, A. Al-Hammouri, N. Karam, Effect of irrigation with nutrient solutions mixed with treated

wastewater on Asiatic lily “Brunello” grown in a closed soilless culture, Acta Agric. Slov., 1 (2017) 29–42.
[12] D. Bizari, J. Cardoso, Reuse water and urban horticulture: alliance towards more sustainable cities, Hortic. Bras., 34 (2016) 311–317.
[13] C. Cassaniti, D. Romano, T. Flowers, In: I. García-Gariazábal, R. Abrahao, The Response of Ornamental Plants to Saline Irrigation Water, Irrigation-Water Management, Pollution and Alternative Strategies, InTech, Rijeka, 2012, pp. 131–158.
[14] T. Buckseth, A. Sharma, K. Pandey, B. Singh, R. Muthuraj, Methods of pre-basic seed potato production with special reference to aeroponics—a review, Sci. Hortic., 204 (2016) 79–87.
[15] C. Treftz, S. Omaye, Hydroponics: potential for augmenting sustainable food production in non-arable regions, Nutr. Food Sci., 46 (2016) 672–684.
[16] Y. Tapia, O. Diaz, C. Pizarro, R. Segura, M. Vines, G. Zúñiga, E. Moreno-Jiménez, *Atriplex atacamensis* and *Atriplex halimus* resist As contamination in Pre-Andean soils (northern Chile), Sci. Total Environ., 450–451 (2013) 188–196.
[17] R. Valdés-Pineda, R. Pizarro, P. García-Chevesich, J. Valdés, C. Olivares, M. Vera, F. Balocchi, F. Pérez, C. Vallejos, R. Fuentes, A. Abarza, B. Helwig, Water governance in Chile: availability, management and climate change, J. Hydrol., 519 (2014) 2538–2567.
[18] D. Aitken, D. Rivera, A. Godoy-Faúndez, E. Holzapfel, Water scarcity and the impact of the mining and agricultural sectors in Chile, Sustainability, 8 (2016) 1–18.
[19] R. Jayne, R. Pollyea, J. Dodd, E. Olson, S. Swanson, Spatial and temporal constraints on regional-scale groundwater flow in the Pampa del Tamarugal Basin, Atacama Desert, Chile, Hydrogeol. J., 24 (2016) 1921–1937.
[20] Dirección General de Aguas (DGA), Atlas del Agua, Chile (In Spanish), Ministerio de Obras Públicas, Santiago, 2016.
[21] P. Cereceda, H. Larrain, P. Osses, M. Farías, I. Egaña, The climate of the coast and fog zone in the Tarapacá Region, Atacama Desert, Chile, Atmos. Res., 87 (2008) 301–311.
[22] S. Lavrnić, M. Zapater-Pereyra, M. Mancini, Water scarcity and wastewater reuse standards in southern Europe: focus on agriculture, Water Air Soil Pollut., 228 (2017) 2–12.
[23] A. Albalawneh, T. Chang, C. Chou, S. Naoum, Efficiency of a horizontal sub-surface flow constructed wetland treatment system in an arid area, Water, 8 (2016) 1–14.
[24] F. Araya, I. Vera, K. Sáez, G. Vidal, Effects of aeration and natural zeolite on ammonium removal during the treatment of sewage by mesocosm-scale constructed wetlands, Environ. Technol., 37 (2016) 1811–1820.
[25] L. Vera, G. Martel, M. Márquez, Two years monitoring of the natural system for wastewater reclamation in Santa Lucía, Gran Canaria Island, Ecol. Eng., 50 (2013) 21–30.
[26] I. Vera, F. Araya, E. Andrés, K. Sáez, G. Vidal, Enhanced phosphorus removal from sewage in mesocosm-scale constructed wetland using zeolite as medium and artificial aeration, Environ. Technol., 35 (2014) 1639–1649.
[27] Superintendecia de Servicios Sanitarios (SISS), Informe de Gestión de Sector Sanitario 2014, Gobierno de Chile, 2015. Available at: http://www.siss.gob.cl/577/articles-11844_inf_gest.pdf.
[28] B. Jiménez, Irrigation in Developing Countries Using Wastewater, Int. Rev. Environ. Strateg., 6 (2006) 229–250.
[29] I. Vera, N. Verdejo, W. Chávez, C. Jorquera, and J. Olave, Influence of hydraulic retention time and plant species on performance of mesocosm subsurface constructed wetlands during municipal wastewater treatment in super-arid areas, J. Environ. Sci. Health Part A, 51 (2016) 105–113.
[30] E. Lictevout, C.Mass, D. Córdoba, V. Herrera, R. Payano, J. Rodríguez, J. Aguilera, P. Beltrán, Water Resources Region of Tarapacá. Diagnosis and systematization of the information (In Spanish), Editorial Universidad Arturo Prat, Iquique, 2013.
[31] Fundación para la Innovación Agraria (FIA), Handbook for Cut Flower Production in V Region (Chile) (In Spanish), Fundación para la Innovación Agraria, Santiago, 2007.
[32] D. Norton-Brandão, S. Scherrenberg, J. van Lier, Reclamation of used urban waters for irrigation purposes – a review of treatment technologies, J. Environ. Manage., 122 (2013) 85–98.
[33] M. Travis, N. Weisbrod, A. Gross, Decentralized wetland-based treatment of oil-rich farm wastewater for reuse in an arid environment, Ecol. Eng., 39 (2012) 81–89.
[34] Dirección Meteorológica de Chile (MeteoChile), Productos Climatológicos Actuales e Históricos: Estación Diego Aracena (In Spanish), 2014. Available at: http://164.77.222.61/climatologia/., 2017.
[35] American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF), Standard Methods for the Examination of Water and Wastewater, 20th Edition, APHA American Public Health Association, Washington, 1998.
[36] Instituto Nacional de Normalización (INN), NCh 2313/23 of. 95 Aguas Residuales Métodos de Análisis Parte 23: Determinación de Coliformes Fecales en medio A-1 (In Spanish), 1995.
[37] J. Di Rienzo, F. Casanoves, M. Balzarini, L. Gonzalez, M. Tablada, C. Robledo, InfoStat Versión 2011, Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Argentina. Available at: http://www. infostat.com.ar., 2011.
[38] O. Auzaque-Rodríguez, H. Balaguera-López, J. Álvarez-Herrera, G. Fischer, Efecto de la vernalización de bulbos reutilizados sobre la calidad de la flor de lirio (Lilium sp.) en la Sabana de Bogotá, Agron. Colomb., 27 (2009) 65–71.
[39] F. Schiappacasse, G. Carrasco, F. Carrasco, Effect of four shading levels on flower stem and bulb quality of two lilies (Lilium spp.) cultivars (In Spanish), Agric. Técnica, 66 (2006) 352–359.
[40] H. Rodríguez-Fuentes, J. Vidales-Contreras, K. Acuña-Askar, J. Aranda-Ruíz, M. Jiménez, J. Rodríguez-Ortíz, Growth, mineral uptake and stem elongation of lillium spp. as a function of plant density, Acta Hortic., 843 (2009) 81–88.
[41] M. Galarce, Evaluacion agronómica de lilium (lilium sp.) en un sistema de cultivo sin suelo regados con agua residual urbana proveniente de lagunas aireadas en la comuna de Alto Hospicio, Región de Tarapacá, Chile (In Spanish), Agronomist engineer thesis, Arturo Prat University, Iquique, 2018.
[42] S. Hayat, Q. Hayat, M. Nasser, A. Shafi, J. Pichtel, A. Ahmad, Role of proline under changing environments, Plant Signal. Behav., 7 (2012) 1456–1466.
[43] S. Yanagisawa, Transcription factors involved in controlling the expression of nitrate reductase genes in higher plants, Plant Sci., 229 (2014) 167–171.
[44] U. Drüge, Proline level in leaves and yield of cuttings and flowers of chrysanthemum as influenced by different root zone conditions, Sci. Hortic., 68 (1997) 171–180.
[45] D. Konnerup, H. Brix, Nitrogen nutrition of *Canna indica*: effects of ammonium versus nitrate on growth, biomass allocation, photosynthesis, nitrate reductase activity and N uptake rates, Aquat. Bot., 92 (2010) 142–148.
[46] Y. Tencer, G. Idan, M. Strom, U. Nusinow, D. Banet, E. Cohen, P. Schröder, O. Shelef, S. Rachmilevitch, I. Soares, A. Gross, A. Golan-Goldhirsh, Establishment of a constructed wetland in extreme dryland, Environ. Sci. Pollut. Res., 16 (2009) 862–875.
[47] V. Lazarova, A. Bahri, Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass, CRC Press, Boca Ratón, 2004.
[48] S. Wu, Y. Sun, G. Niu, Morphological and Physiological Responses of Nine Ornamental Species to Saline Irrigation Water, HortScience, 51 (2016) 285–290.
[49] M. Safi, A. Bulad, A. Blawenah, I. Bashabsheh, Flower yield and quality of Lilium aziatische Irrigated with different types of water, Int. J. Agric. Biol., 9 (2007) 264–266.
[50] Centro Internacional de Bulbos de Flor (CIBF), El cultivo del lilium: flor cortada y cultivo en maceta (In Spanish), Centro Internacional de Bulbos de Flores, Holanda, 1980.
[51] B. In, J. Lim, Potential vase life of cut roses: Seasonal variation and relationships with growth conditions, phenotypes, and gene expressions, Postharvest Biol. Technol., 135 (2018) 93–103.
[52] Servicio Hidrográfico y Oceanográfico de la Armada (SHOA), Luz y oscuridad (In Spanish), Gobierno de Chile, 2017. Available at: http://www.shoa.cl/php/luzyobscuridad.php?idioma=es.
[53] J. Olave, B. Torres, W. Chávez, O. González, Producción de Lilium bajo invernadero en un sistema aeropónico recirculante con agua residual urbana tratada en el desierto de Atacama (In Spanish), Editorial Universidad Arturo Prat, Iquique, 2016.

[54] J. Santos, H.R. Gheyi, D. Filho, F. Soares, N. Dias, Efficiency of water use in sunflower grown in hydroponic system under saline stress, Engenharia Agrícola, 33 (2013) 718–729.

[55] R. Lira, E. Silva, G. Silva, H. Soares, L. Willadino, Growth, water consumption and mineral composition of watercress under hydroponic system with brackish water, Hortic. Bras., 36 (2018) 13–19.

[56] N. Ait-Mouheb, A. Bahri, B. Thayer, B. Benyahia, G. Bourrié, B. Cherki, N. Condom, R. Declercq, A. Gunes, M. Héran, N. Kitir, B. Molle, D. Patureau, A. Pollice, A. Rapaport, P. Renault, K. Riahi, B. Romagny, T. Sari, C. Sinfort, J. Steyer, S. Talozi, B. Topcuoglu, M. Turan, N. Wéry, E. Yıldırım, J. Harmand, The reuse of reclaimed water for irrigation around the Mediterranean Rim: a step towards a more virtuous cycle?, Reg. Environ. Change, 18 (2018) 693–705.

[57] P. Gopinath, P. Vethamoni, M. Gomathi, Aeroponics Soilless Cultivation System for Vegetable Crops, Chem. Sci. Rev. Lett., 6 (2017) 838–849.

[58] I. Lakhiar, J. Gao, T. Syed, F. Chandio, Modern plant cultivation technologies in agriculture under controlled environment: a review on aeroponics, J. Plant Interact., 13 (2018) 338–352.