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Rosemary growth and nutrient balance: Leachate fertigation with leachates versus conventional fertigation

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ABSTRACT

The free discharge of drainage water from greenhouse horticultural production to the environment is a current environmental concern due to its capacity to contribute to environmental pollution. This has led to the search of sustainable alternatives for its reuse in the production of other crops. However, before the large-scale use of such horticultural leachates in ornamental plants, the effects of such fertigation treatments on ornamental plants need to be evaluated. Plants of rosemary were grown in pots with a mixture of sphagnum peatmoss and Perlite and subjected to three fertigation treatments: T_0 (a standard nutrient solution or control), T_1 (raw leachates from *Cucumis melo*) and T_2 (a mixture of raw leachates from *C. melo* and tap water 1:1 v/v, over a period of 9 weeks. At the end of the experiment, the growth parameters, color of leaves as well as water and nutrient uptake efficiencies and their losses were assessed for each fertigation treatment. The total dry weight and the water use efficiency of rosemary plants decreased under the fertigation with raw and diluted leachates. In addition, rosemary plants were shorter compared to the control but there were no differences in leaf color between the fertigation treatments. The uptake of N, P and K were affected by the applied fertigation treatments in a different manner. The use of horticultural leachates in the production of ornamental plants (as shown here for melon and rosemary) is feasible and presents a viable option to reduce water and nutrient input in plant production.

1. Introduction

Greenhouse production on the southeastern (SE) Mediterranean coast of Spain is associated with appreciable negative impacts on water resources, especially through nutrient leaching losses resulting in an environmental pollution and aquifer overexploitation (Granados et al., 2013). Reviewing in previous literature, there are many references concerning the release of nutrients (g m^{-2}) in several horticultural crops such as tomato (28 (N), 1 (P), 6 (K)) in a mulching sandy soil and melon (6 (N), 0.03 (P), 7 (K)) and watermelon (16.5 (N), 1.4 (P), 16 (K)) in soilless systems (García-Caparrós et al., 2017a) and in ornamental plants such as *Cordyline fruticose* L. ((1.5 (N), 1.0 (P), 7 (K)) (Plaza, 2013), *Aloe vera* L. Burm, *Kalanchoe blossfeldiana* Poelln and *Gazania splendens* Lem (ranges from 0.5 to 1.5 (N), 0.3 to 0.6 (P) and 2 to 6 (K) (García-Caparrós et al., 2017b) and Rhododendron sp. (1 (N), 0.5 (P)) (Ristvey et al., 2007).

Greenhouse crops in closed hydroponic systems can substantially reduce the pollution of water resources, while contributing to a reduction in water and fertilizer consumption (Carmassi et al., 2005). Nevertheless, nearly all soilless cropping systems in the greenhouses of this area are free-draining, also known as "open", systems that drain directly into underlying soil (Pardossi et al., 2004; Thompson et al., 2013). In these cropping systems, an appreciable proportion of the applied water is drained; drainage fractions are commonly between

Abbreviations: ANOVA, analysis of variance; DW, dry weight; EC, electrical conductivity; FW, fresh weight; H_2O_2, hydrogen peroxide; HPLC, high performance liquid cromatography; LSD, least significant difference; NUE, nitrogen uptake efficiency; PUE, phosphorous uptake efficiency; PAR, photosynthetically active radiation; KUE, potassium uptake efficiency; RH, relative humidity; LWR, relative leaf weight ratio; SWR, relative stem weight ratio; RWR, relative root weight ratio; RGB, red, green and blue; SBC, serial biological concentration; TDW, total dry weight

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20–40% (Schröder and Lieth, 2002). The recirculation of drainage is seldom mainly due to the high investment cost and the frequent replenishment of recirculating nutrient solutions due to the salinity of the groundwater used for irrigation (Magan et al., 2008). Another possible reasons for not recycling water and nutrients in greenhouse production systems include the concern of diseases produced by phytopathogens (Prenafeta-Boldú et al., 2017) and the risk of reduced yields (Grewal et al., 2011).

As a consequence, the study of different management strategies of reusing the drainage water is required in order to reduce the pollution generated by the drainage water. Among these strategies are the sequential reuse or the blending of the drainage (Grattan et al., 2012) with water or nutrient solution. The sequential reuse of the drainage is based on its utilization to grow increasingly salt tolerant crops while concentrating the drainage to a manageable level. This treatment system is known as Serial Biological Concentration (SBC) (Bethune et al., 2004). Blending is based on the combination of two sources of irrigation water to produce irrigation water of suitable quality while increasing the overall irrigation water supply (Grattan and Oster, 2003).

Rosemary (*Rosmarinus officinalis* L., Lamiaceae) is a perennial woody plant species, originating from the Mediterranean region, which currently can be found and cultivated in all continents as aromatic and ornamental plant (Díaz-Maroto et al., 2007). It is a shrub reaching up to 2 m of height with leaves and flowers with a strong characteristic fragrance due to the volatile compounds accumulated in peltate and capitate glandular trichomes (Ribeiro-Santos et al., 2015). Rosemary is well known for its resistance to drought stress (Munné-Bosch et al., 1999) and also for its relative tolerance to salt stress (Tounekti et al., 2008).

There is a little information on the effects of horticultural leachates on the growth of ornamental plants (Plaza et al., 2016, 2017). Similarly, even though there are many studies on the effects of different irrigation conditions or levels of salinity on the growth and nutrient concentrations in rosemary (Nicolás et al., 2008; Zhen et al., 2014; Langroudi and Sedaghathoor, 2012; Tounekti et al., 2011), very little is known about the effects of horticultural leachates on its growth. Therefore, in this trial, a pot experiment with rosemary plants was established in order to determine the effects of the reuse of leachates from melon production on biomass, water and nutrient uptake efficiencies and their losses. Such information can be used for optimizing the rosemary management with horticultural leachates and at the same time the production of horticultural and ornamental crops under different integrated management strategies.

2. Material and methods

2.1. Plant material and experimental conditions

The present study was carried out at the facilities of the University of Almeria (Spain) in two contiguous greenhouses (36°49´N, 2°24´W). One of the greenhouses was a multitunnel greenhouse of 400 m^2 with *Cucumis melo* L. plants (leachates source) whereas the other greenhouse used was a tunnel greenhouse of 150 m^2, where rosemary plants were cultivated.

Melon seedlings ‘Abellan FI’ were grown from 91 days between February and May 2014 into coir grow bag (Pelemix GB1002510 coir grow bag, 100·25·10 cm, L·H·W), with three plants per cultivation unit, a cultivation volume of 25 L and planting density of 1 plant m^{-2} following the recommendations established by Urrestarazu (2004).

Rooted cuttings of rosemary (20 cm high and 1.4 g of dry weight $plant^{-1}$ in average) were obtained from a local nursery and transplanted into 1.5 L polyethylene pots containing a mixture of sphagnum peat-moss and Perlite 80:20 (v/v). Rosemary cultivation started a month after the melon sowing and lasted 9 weeks. The planting density was 12 plants/m^2.

Average day temperature inside the rosemary greenhouse was 20.3 ± 2.3 °C, relative humidity (RH) 64.3 ± 3.5% and photosynthetically active radiation (PAR) 90.5 ± 9.1 μmol m^{-2} s^{-1} (monitored by HOBO SHUTTLE sensors, H 08-004-02).

2.2. Experimental design and treatments

The experiment was focused on the irrigation of rosemary plants with three different fertigation treatments: a standard nutrient solution (Sonneveld and Straver, 1994) namely the control treatment (T_0) and two sequential reuse treatments: one of them was composed of raw leachates from *C. melo* (T_1) and the other was a diluted leachate treatment prepared by blending the raw leachates from *C. melo* with 50% of tap water (T_2). The tap water had the following composition: 1.1, 3.5, 2.0, 1.4 and 2.6 mmol L^{-1} of S, Cl, Ca, Mg and Na, respectively; and EC was 0.9 dS m^{-1}. The plants were irrigated manually with a test tube and 40 mL of the respective solution was poured in each pot every day, totaling 2.5 L pot^{-1} $treatment^{-1}$. The experimental design consisted of three fertigation treatments, four blocks and four plants (pots) per block giving a total of 48 plants of rosemary.

2.3. Yield and water use efficiency in melon and rosemary

Eight cultivation units, each containing three melon plants, were randomly selected in the greenhouse and the fresh weight of marketable fruits of melon plants was recorded. Water use efficiency of melon plants represents the fresh weight of fruit per unit of applied water (expressed in kg m^{-3}). The volume of applied irrigation water during the 13 weeks of melon growth was 254.3 L m^{-2} producing 5.5 kg m^{-2} of fresh melon fruit, giving a water use efficiency of 22.1 kg of fresh melon fruit m^{-3} of applied irrigation water.

The water use efficiency in rosemary plants, expressed by grams of fresh weight (FW) per liter of water applied for each treatment was calculated as the difference between plant FW after 9 weeks and the initial plant FW divided by the volume of water applied during the experimental period.

2.4. Monitoring of irrigation and runoff water composition

The samples of nutrient solution applied to melon were collected weekly at the entry point of the greenhouse by collecting water from four of the drippers used to irrigate melon. Leachates were collected randomly from 4 collection trays (one tray per 2 cultivation units). The buckets for collecting nutrient solutions and the trays for collecting drainage were covered with white polyethylene sheeting to reduce incoming radiation thereby minimizing evaporation. Leachates from *C. melo* plants were collected weekly and then used to prepare fertigation treatments for rosemary plants. The leachate fraction obtained from melon production in our experiment was 28%.

To determine the volume of leachate from the rosemary plants, four pots were randomly selected. The leachate of each container was collected weekly by placing a plastic collection bucket under each pot. The buckets were tightly fitted to the pots to prevent evaporation of leachate between collection events and pots were also elevated to prevent them from sitting in the leachate.

Each sample of nutrient solution or leachate was composed by aliquots of 15 mL, filtered through 0.45 μm membrane filters and frozen until nutrient analyses were conducted. In each aliquot, the concentrations of NO_3^--N, $H_2PO_4^-$, and K^+ were determined by high-performance liquid chromatography (HPLC) [model 883 Basic IC Plus, anions ion exchange column model Metrosep A SUPP 4, cations ion exchange column model Metrosep C4 100, IC conductivity detector range (0–15,000 μS cm^{-1}); Metrohm, Herisau, Switzerland)] as described by Csáky and Martínez-Grau (1998). During the experimental growing period, nutrients supplied and leached per plant (in milligrams) were calculated by multiplying the nutrient concentration in the nutrient solution or leachate by their respective applied volume. These values were then used to calculate the nutrients leached per plant in percent (percentages that reflect the fraction of applied nutrient which was leached by the plant during 9 weeks).

2.5. Rosemary plant parameters

At the end of the experiment, the plants of the pots randomly designated for the leachate collection were harvested and the substrate gently washed from the roots. Four plants per treatment were randomly selected to determine the color index in the leaves for Red, Green, and Blue (RGB) pigments as described by Ali et al. (2012). Briefly, the red, green and blue (RGB) values were analyzed using the Epson ES-2000 optical scanner (Seiko Epson Corporation, Suwa, Nagano-ken, Japan) and the images were processed with Adobe Photoshop CS6 (Adobe System Software, Ireland, EU) by averaging the R, G and B values of all the leaf pixels. Plant height from the top edge of the container to the last open leaf of the plant crown was measured and the longest root length was then measured from the crown to the tip of the root.

Plants were then divided into roots, stems, and leaves and washed with distilled water to be subsequently dried with blotting paper. Roots, stems, and leaves were then oven-dried at 60 °C until they reached a constant weight to measure these dry weights (DW). These dry weights were used to calculate several plant parameters as described by Ryser and Lambers (1995) and Correia et al. (2010): relative leaf weight ratio (LWR; leaf DW per unit plant DW), the stem weight ratio (SWR; stem DW per unit plant DW), and the root weight ratio (RWR; root DW per unit plant DW). The total plant dry weight (TDW) was calculated as the DW sum of the leaves, stems, and roots.

2.6. Nutrient uptake by rosemary plants

The oven-dried samples were ground to a fine powder in a mill (Grindomix GM 200; Retsch, Haan, Germany) taking care to clean the mill thoroughly between each sample. Each sample was divided in two subsamples. One subsample was used to determine the soluble N-NO_3^- by the previously described HPLC methodology. The other subsample was mineralized with 96% sulfuric acid in the presence of P-free hydrogen peroxide (30% w/v) at 300 °C (humid mineralization) for the determination of organic N (Krom, 1980), total P (Hogue et al., 1970), and K^+ (Lachica et al., 1973) concentration. The total N concentration was calculated as the sum of the organic N and N-NO_3^- concentration. From these determinations and with the DW measured, we calculated the plant nutrient uptake as the difference between final tissue nutrient content after 9 weeks and the initial nutrient content in cuttings at the moment of planting. An initial harvest at the beginning of the experiment gave an average of 26 mg N, 4 mg P, and 44 mg K per plant. These values of nutrient uptake were then used to calculate nutrient uptake efficiencies (percentages that reflect the fraction of applied nutrient accumulated by plant during the 9 weeks).

2.7. Chemical composition of substrate used for rosemary plants

Nutrients available in the substrate were extracted in deionized water, substrate water 1:10 v/v following the methodology proposed by Sonneveld et al. (1974). The mixture was agitated for 1 h and the liquid filtered through 0.45 μm membrane filters. An aliquot of the filtered solution was analyzed by HPLC as described by Csáky and Martínez-Grau (1998). These values were converted to nutrient quantity in the substrate per pot multiplying by the apparent density of the substrate by the pot; and then used to calculate the amount of nutrients retained in the substrate as the difference between the amount of nutrients at the end and at the beginning of the experiment.

Table 1
Chemical composition of the nutrient solutions of each treatment: T_0 – standard nutrient solution, T_1 – raw leachate treatment and T_2 – diluted leachate treatment. EC was expressed in dS m^{-1} and nutrient concentration in mmol L^{-1}. In T_1 and T_2, the values represent means ± standard deviation (n = 4) during 9 weeks.

Parameters	T_0	T_1	T_2
pH	5.78 ± 0.11 b	6.57 ± 0.38 a	6.65 ± 0.29 a
EC	2.01 ± 0.12 b	3.03 ± 0.25 a	2.20 ± 0.22 b
N-NO_3^-	10.05 ± 0.61 a	4.80 ± 0.47 b	2.40 ± 0.25 c
$H_2PO_4^-$	1.45 ± 0.05 a	0.22 ± 0.02 b	0.22 ± 0.02 b
Cl^-	3.45 ± 0.11 c	17.71 ± 1.83 a	14.44 ± 1.47 b
SO_4^{2-}	2.24 ± 0.09 b	4.09 ± 0.42 a	2.48 ± 0.22 b
Ca^{2+}	5.05 ± 0.25 b	8.64 ± 0.78 a	5.56 ± 0.54 b
Mg^{2+}	1.54 ± 0.08 c	3.84 ± 0.34 a	3.05 ± 0.27 b
K^+	4.78 ± 0.20 a	3.32 ± 0.26 b	1.93 ± 0.18 c
Na^+	2.60 ± 0.18 c	5.97 ± 0.46 a	± 0.40 b

Different letters within a row are significantly different at $P < 0.05$ (ANOVA and LSD test).

2.8. Statistical analysis

The experiment had a completely randomized block design, and the values obtained for each plant and each variable were considered as independent replicates. The data were analyzed through one-way analysis of variance (ANOVA) and Fisher's Least Significant Difference (LSD) tests using Statgraphics Centurion XVI.II (Statpoint Technologies, Inc. Warrenton, Virginia, USA) in order to assess the differences between treatments.

3. Results

3.1. Nutrient solution composition

The average chemical composition of the three fertigation treatments supplied to rosemary plants is summarized in Table 1. The irrigation with leachates (T_1 and T_2) showed higher values of pH compared to the control or standard nutrient solution (T_0). The values of pH in leachates were acceptable for the growth of ornamental plants following the recommendations given by Jimenez and Caballero (1990). The irrigation with leachates (T_1 and T_2) showed lower concentrations of N-NO_3^-, $H_2PO_4^-$ and K^+ compared to the control (T_0). The treatment T_1 showed the greatest concentration of Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+} and Na^+ and the highest EC.

3.2. Yield and water use efficiency in rosemary

The volume of applied irrigation water during the 9 weeks of rosemary growing period was the same in all treatments (30 L m^{-2}). Total yield (expressed in g of leaf fresh weight (FW) m^{-2}) in rosemary plants were 140.6 (T_0), 110.3 (T_1) and 89.3 (T_2). The irrigation with leachates reduced the yield in 22% in T_1 and 36% in T_2 compared to the control. The volume of collected leachate was the largest under T_1 and the water use efficiency declined in the leachates treatments (T_1 and T_2) compared to the control (T_0) (Table 2).

3.3. Rosemary plant parameters

Throughout the experiment, there were no mortalities or evident visual damages on rosemary plants in response to the fertigation treatments. However, roots and shoots of fertigated plants with leachates were shorter with respect to the control (T_0). No significant differences were found in the color index (red, green and blue) between all fertigation treatments at the end of the experiment (Table 3A).

Plants fertigated with T_1 and T_2 had lower total dry weight (TDW) than the treatment T_0 mainly due to a decrease in stem and leaf dry

Table 2
Rosemary yield, volume of irrigation water applied, collected leachate and water use efficiency in each fertigation treatment (T_0 – standard nutrient solution, T_1 – raw leachate treatment and T_2 – diluted leachate treatment). Different letters indicate significant differences at $p < 0.05$.

Parameters	T_0	T_1	T_2
Yield (g m^{-2})	140.6 ± 13.5 a	110.3 ± 9.8 b	89.3 ± 8.3 c
Irrigation water applied (L m^{-2})	30	30	30
Leachate (L m^{-2})	5.3 ± 0.3 b	6.4 ± 0.4 a	5.5 ± 0.3 b
Leachate fraction (%)	18	21	18
Water use efficiency (g of FW per L of water applied)	4.7 ± 0.4 a	3.7 ± 0.3 b	3.0 ± 0.3 c

weight (SDW and LDW, respectively). The relative root, stem and leaf ratios (RWR, SWR and LWR) remained unchanged under the different fertigation treatments (Table 3B).

The amount of nutrients applied per plant decreased in plants fertigated with leachates (T_1 and T_2). Plant nitrogen uptake decreased in plants fertigated with leachates (T_1 and T_2). Plant phosphorus uptake did not show a clear response under the decrease of nutrient supplies in the different treatments because plants fertigated with T_1 showed the greatest value. Plant potassium uptake declined significantly in plants fertigated with T_2.

The uptake efficiency of N, P and K showed different trends under different fertigation treatments. The nitrogen uptake efficiency (NUE) declined significantly in plants fertigated with T_2 (5% lower compared with the control), phosphorus uptake efficiency (PUE) showed the highest value in the plants subjected to T_1 (10% higher compared with the control), whilst potassium uptake efficiency (KUE) showed the greatest value in plants fertigated with T_2 (15% higher compared with the control). Nitrogen and phosphorus leached per plant were lower in plants fertigated with leachates (T_1 and T_2) and potassium leached per plant only declined in plants fertigated with T_2. The percentages of nutrient runoff in our experiment were for N (5–8%), P (9–11%) and K (13–26%). As far as nutrients in substrate is concerned, N decreased in plants fertigated with leachates (T_1 and T_2) while P and K remained constant in all treatments (Table 4).

4. Discussion

Considering the results obtained from melon, the leachate fraction of 28% in our experiment was similar to the values of 25–30% that have been commonly reported for free-draining soilless systems in SE Spain (Brañas, 2005; Rodríguez et al., 2014). Total fruit production of melon was 5.5 kg m^{-2} which corresponds to the local commercial production in such system considering the length and timing of the cropping cycles (Contreras et al., 2012; Martínez et al., 2013). The crop water use efficiency reported in this experiment was higher than the range from 4.2 to 9.1 kg m^{-3} reported by Rashidi and Gholami (2008), which can be attributed to better water use efficiency in soilless systems.

As far as fertigation treatments of rosemary plants is concerned, the increase of pH recorded after irrigation with leachates (increase in pH in T_1 and T_2 compared to T_0) was due to the uptake of nitrate by melon and the consequent release of OH^-, as it was found in other similar systems (Mengel and Kirkby, 2001). The decrease of NO_3^-, $H_2PO_4^-$ and K^+ concentrations are the result of the uptake of these ions by melon roots, which is in agreement with the results of Pardossi et al. (2005) and Rouphael et al. (2012). The accumulation of Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+} and Na^+ in the leachate could be due to the high concentrations of these ions in the tap water and the reuse of leachate as reported by Massa et al. (2010).

The irrigation with leachates resulted in a yield reduction of rosemary plants compared to the control. This yield reduction in both treatments was related to the lowest concentrations of N, P and K in T_1 and T_2, which are essential for plant growth and also it is necessary to highlight that the concentration of Na may reduce the growth due to its toxicity in plants. Nevertheless, Alarcón et al. (2006) reported that the growth of this species was only affected when plants were irrigated with 35.70 mM of NaCl concentration. Although there was a yield reduction under leachate fertigation treatments, ours results under greenhouse conditions showed a higher yield with respect to field conditions (2.5–4 ton ha^{-1}) reported by other researchers (Curioni and Arizio, 2006), mainly due to the higher planting density used in nursery greenhouse which is several times greater than in the open field.

As far as leachate volume is concerned, the increase in T_1 could be due to the increase of EC in the nutrient solution, especially in peat based substrates (Marosz, 2004; Niu and Rodriguez, 2006). Similarly, García-Caparrós et al. (2016a) reported an increase of leachate volume and a decrease in *Lavandula multifida* L. growth under saline conditions. The decline in water use efficiency is related to the decrease of plant fresh weight, as explained previously.

Plants fertigated with leachates were shorter with respect to the control which may be explained by decrease in the concentration of available nutrients in leachates with respect to the full nutrient solution, as explained also by Mengel and Kirkby (2001). However, this result is in disagreement with results obtained by Boyle et al. (1991) and Westervelt (2003) who reported an increase in plant height under low nutrient concentrations. Nevertheless, this morphological response may be interesting to improve the ornamental value of plants, because a reduction in rosemary height has been suggested as a desirable ornamental characteristic by some authors (Han and Kim, 1999; Singh et al., 1999). No changes in color index between leachate fertigation treatments allow the production of marketable plants with horticultural leachates, since in ornamental plants, one of the fundamental quality parameters is leaf color (Ferrante et al., 2015).

Biomass production, expressed as TDW, in plants fertigated with leachates (T_1 and T_2) was 17 and 26% respectively, lower than the control (T_0). These values are far from the acceptable percentage of decrease (45%) proposed by local ornamental growers to produce marketable plants (García-Caparrós et al., 2016b). Therefore, the use of leachates from melon (a horticultural crop) as studied in our trial, is feasible for the cultivation of rosemary (ornamental species) in a controlled environment.

No variations in root, stem and leaf ratios under the different fertigation treatments, suggest that applied treatments did not alter the pattern of dry matter distribution, allowing the production of

Table 3A
Effects of different fertigation treatments (T_0 – standard nutrient solution, T_1 – raw leachate treatment and T_2 – diluted leachate treatment) on plant height and root length (expressed in cm) and color index (RGB) in rosemary plants at the end of the experiment. Values are means ± standard deviation of four plants per treatment. Different letters on the column indicate significant differences at $p < 0.05$.

	Ornamental parameters				
			Color index		
	Plant height	Root length	Red	Green	Green
T_0	29.80 ± 1.63 a	24.63 ± 2.01 a	101.03 ± 1.48 a	108.63 ± 1.57 a	70.23 ± 1.84 a
T_1	25.25 ± 1.50 b	20.03 ± 1.92 b	100.10 ± 1.89 a	110.78 ± 1.25 a	71.95 ± 1.58 a
T2	26.50 ± 1.48 b	19.75 ± 2.01 b	98.90 ± 1.91 a	108.55 ± 1.23 a	70.88 ± 1.49 a

Table 3B
Effects of different fertigation treatments (T_0 – standard nutrient solution, T_1 – raw leachate treatment and T_2 – diluted leachate treatment) on root, stem, leaf and total plant dry weight (RDW, SDW, LDW and TDW, respectively) (g), relative root weight ratio (RWR), stem weight ratio (SWR) and leaf weight ratio (LWR) in rosemary plants at the end of the experiment. Values are means ± standard deviation of four plants per treatment. Different letters on the column indicate significant differences at $p < 0.05$.

Treat ments	RDW	SDW	LDW	TDW	RWR	SWR	LWR
T_0	0.61 ± 0.06 a	1.19 ± 0.12 a	2.97 ± 0.25 a	4.77 ± 0.38 a	0.13 ± 0.01 a	0.25 ± 0.02 a	0.63 ± 0.06 a
T_1	0.54 ± 0.05 a	0.96 ± 0.08 b	2.43 ± 0.24 b	3.93 ± 0.35 b	0.14 ± 0.01 a	0.24 ± 0.02 a	0.62 ± 0.05 a
T_2	0.56 ± 0.05 a	0.92 ± 0.09 b	1.94 ± 0.21 c	3.52 ± 0.33 b	0.15 ± 0.01 a	0.26 ± 0.02 a	0.56 ± 0.05 a

marketable rosemary plants. However, other researchers reported a change in the pattern of dry matter distribution in other Lamiaceae species such as *Thymus vulgaris* L. (Cordovilla et al., 2014) and *Lavandula multifida* L. (García-Caparrós et al., 2017c) grown in pots with peat-moss under saline conditions.

From a nutritional point of view, the decrease of nitrogen uptake across fertigation treatments was related to the decrease of nitrogen concentrations in the different solutions used for fertigation as reported also by Masclaux-Daubresse et al. (2010). The increase in phosphorus uptake in T_1 could be related to the increase of EC in T_1 and as a consequence of this increase, there was a rise of phosphorus uptake related to the energy (ATP) required to transport the excess of ions into the vacuoles as explained by Mengel and Kirkby (2001). The decline of potassium uptake in plants fertigated with T_2 was due to the decline of potassium concentrations of the different treatments as suggested Nieves-Cordones et al. (2014) who reported that under low potassium concentrations in the nutrient solution, the uptake of potassium could be decreased as well.

The ranges of N (15–22%), P (4–12%) and K (47–67%) uptake efficiencies observed in this experiment in all treatments were lower than the values for N (35–65%), P (8–28%) and K (77–93%) uptake efficiencies reported by Park et al. (2012) in *Liriodendron tulipifera* L. and *Larix leptolepis* Mill. irrigated with three different fertigation treatments aiming to reduce the nutrient leaching and to improve the nutrient use efficiency. These lower efficiencies could be due to the low concentrations of nutrients present in the fertigation treatments. In addition, it is necessary to highlight that the values of NUE in our experiment may be overestimated as a result of available nutrients in the soilless potting substrate. Similar results were reported by Sandrock et al. (2005) who suggested that N may be mineralized in soilless potting media. Moreover, in soilless media a high percentage of N may be immobilized and denitrified by microorganisms (Scagel, 2003) or volatilized (Rathier and Frink, 1989).

The increase of N and P leachate can be because the organic potting substrates have little NO_3^--N and H_2PO_4–-P retention capacity, especially those that are pine bark or peat based (Marconi and Nelson, 1984). The range of leachate per plant for N (7–17 mg), P (4–12 mg), and K (47–60 mg), were different to those reported by Ristvey et al. (2007) who recorded runoff per plant for N (4–152 mg) and P (2–16 mg) in an experiment with different fertilizer rates being necessary to point out that these results are not directly comparable to ours due to container size and spacing differences.

The percentages of nutrient runoff in our experiment found for N, P and K were lower compared with the data reported by other researchers. Hershey and Paul (1982) reported 12% to 48% of N leached (2.5 g per pot) for potted chrysanthemums irrigated with N solutions of 100–300 mg L^{-1} and Cabrera (2003) reported 16% to 58% of leachate in a N balance of two container-grown ornamental plants irrigated with different N concentrations. Likewise, Pershey and Cregg (2015) also reported ranges from 38 to 57% of P leachate (100 g ha^{-1}) in four conifers (Pinophyta) grown in pots according to different levels of daily water use. Considering the high amount of nutrients discharged to the environment, one sustainable solution could be the use of these leachates for the growth of macrophytes with a high capacity of nutrient removal (García-Caparrós et al., 2016c). Another sustainable solution could be the denitrification processes within constructed wetlands when dealing with horticultural leachates as suggested by Narváez et al. (2011) and White (2013).

The different trends of nutrient concentrations in the substrate disagree with the results found in an experiment with *Rosmarinus officinalis* L. growing in peat fertigated with a water-soluble N, P, K fertilizer (5:1:7.5), where the nutrients in the substrate increased throughout the trial (De Lucia et al., 2013).

To complete the nutrient balance, the total nutrients applied were determined as the difference between the nutrient supplies per plant and the nutrient uptake per plant plus nutrient leached and nutrient retained in the substrate. Unaccounted N, P and K showed the same trends, declining across the fertigation treatments, whereas the unaccounted nutrient loss, expressed in percentage (unaccounted nutrient per nutrient supplies), showed different trends, since concentrations of N and P remained unchanged across the treatments and K declined across the different fertigation treatments.

5. Conclusions

The reuse of melon leachates has no detrimental effects on color index, relative root weight ratio, stem weight ratio and leaf weight ratio in rosemary plants. However, rosemary plants fertigated with raw and

Table 4
Nutrient balance of rosemary plants under different fertigation treatments (T_0 – standard nutrient solution, T_1 – raw leachate treatment and T_2 – diluted leachate treatment). Values are means ± standard deviation of four plants per treatment. Different letters on the column indicate significant differences at $p < 0.05$.

	Treatments	Nutrient supplied per plant (mg)	Plant nutrient uptake (mg)	Nutrient Uptake Efficiency (%)	Nutrient leached per plant (mg)	Nutrient leachates (%)	Substrate (mg)	Unaccounted nutrient (mg)	Unaccounted loss (%)
N	T0	325.8 ± 34.3 a	63.8 ± 5.7 a	19.6 ± 2.0 a	16.7 ± 1.7 a	5.1 ± 0.5 b	26.1 ± 2.7 a	219.2 ± 22.1 a	65.2 ± 6.8 a
	T1	164.4 ± 16.2 b	36.7 ± 3.4 b	22.3 ± 2.3 a	9.0 ± 0.8 b	5.5 ± 0.5 b	13.4 ± 1.4 b	105.5 ± 10.7 b	64.1 ± 6.3 a
	T2	82.2 ± 8.0 c	12.2 ± 1.3 c	14.8 ± 1.6 b	6.8 ± 0.7 c	8.3 ± 0.8 a	8.1 ± 0.01 c	55.3 ± 5.4 c	67.4 ± 6.4 a
P	T0	108.7 ± 9.9 a	10.7 ± 0.9 b	9.8 ± 0.9 c	12.1 ± 1.1 a	11.1 ± 1.3 a	0.1 ± 0.01 a	85.9 ± 8.7 a	79.1 ± 7.8 a
	T1	65.2 ± 6.3 b	13.2 ± 1.1 a	20.2 ± 2.1 a	7.1 ± 0.7 b	10.9 ± 1.1 a	0.1 ± 0.01 a	46.9 ± 4.6 b	73.9 ± 6.9 a
	T2	44.6 ± 4.7 c	5.5 ± 0.6 c	12.3 ± 1.4 b	3.9 ± 0.4 c	8.7 ± 0.9 b	0.1 ± 0.01 a	35.2 ± 3.8 c	78.9 ± 8.0 a
K	T0	465.6 ± 44.3 a	119.3 ± 12.1 a	25.6 ± 2.3 c	59.7 ± 6.0 a	12.8 ± 1.3 c	0.4 ± 0.03 a	286.3 ± 29.5 a	61.5 ± 6.2 a
	T1	317.6 ± 30.7 b	108.4 ± 10.7 a	34.1 ± 3.2 b	67.2 ± 6.8 a	21.2 ± 1.9 b	0.4 ± 0.04 a	141.6 ± 14.9 b	44.6 ± 4.9 b
	T2	184.7 ± 18.7 c	73.9 ± 7.7 b	42.0 ± 4.2 a	47.3 ± 4.4 b	25.8 ± 2.4 a	0.4 ± 0.03 a	63.5 ± 6.4 c	34.4 ± 3.4 c

diluted leachates had significantly shorter roots and had lower total dry weight and water use efficiency than the control, but the percentage of decrease are acceptable to produce marketable plants. Plant nutrient uptake was affected showing different trends between nutrients studied. Nitrogen and phosphorus leached per plant and unaccounted nutrients were lower in plants fertigated with leachates compared to the control. These results suggest the importance of comprehensive studies of the impact of the use of horticultural leachates in ornamental plants production (application of serial biological concentration) to help the growers and gardeners to save water and nutrients and protect the environment.

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