Visual Quality, Gas Exchange, and Yield of Anemone and Ranunculus Irrigated with Saline Water

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SUMMARY. In response to the growing demand for specialty cut flowers, floral crops are increasingly produced in semiarid areas where soil salinity can impact crop timing, reduce stem length, and decrease yield. The goal of this study was to investigate the salinity sensitivity of ‘Carmel’ and ‘Galilee’ anemone (*Anemone coronaria*), and ‘Amandine’ and ‘LaBelle’ ranunculus (*Ranunculus asiaticus*) with respect to physiological characteristics and marketable yield. Nine plants were irrigated weekly for 8 weeks with a nutrient (control) solution with an electrical conductivity (EC) of 0.5 dS·m⁻¹ or saline solutions prepared by adding sodium chloride and calcium chloride dihydrate to a nutrient solution to obtain an EC of 1.5, 2.5, 3.5, 4.5, or 5.5 dS·m⁻¹. Yield was evaluated by dividing stems into marketable and cull grades based on length and bloom quality. At the end of the study, the visual quality of the plants was scored, and gas exchange data were collected using a portable photosynthesis system. Cultivars of each species responded similarly, and marketable yields were low across all treatments, with average marketable yields (mean ± SD) of 1.7 ± 0.6 stems/plant for anemone and 1.2 ± 0.1 stems/plant for ranunculus. Visual quality (0–5 scale, with 0 = dead and 5 = excellent) decreased from 3 to 1 for anemone and 3 to 2 for ranunculus as EC increased from 0.5 to 4.5 dS·m⁻¹ and 0.5 to 5.5 dS·m⁻¹, respectively. Anemone leaf greenness decreased by 48%, stomatal conductance (g_s) decreased by 79%, transpiration (E) decreased by 75%, and net photosynthesis (P_n) decreased by 92% when irrigation solution EC increased from 0.5 to 4.5 dS·m⁻¹. The ranunculus growth index decreased by 17%, leaf greenness decreased by 45%, and E decreased by 23% as irrigation solution EC increased from 0.5 to 5.5 dS·m⁻¹. Both anemone and ranunculus can be considered sensitive to salinity, indicating the importance of careful soil management in cut flower production systems in semiarid areas that are at risk for elevated soil salinity.

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modify vegetative and reproductive growth, and affect key agronomic factors such as crop timing (Grieve et al., 1994), quality (Maas and Grattan, 1999), and yield (Maas and Hoffman, 1977).

For the past three decades, the U.S. cut flower industry has adapted to increases in inexpensive floral imports by focusing on the production of specialty flowers that are difficult to ship long distances and marketing locally grown flowers (Armitage and Laushman, 2003; Kelly, 1991; Stewart, 2007; Yue and Hall, 2010). In Utah and southern Idaho alone, 86 small-scale cut flower farms have been established (Lewis et al., 2021). Production of cut flowers in semiarid areas with high soil salinity and/or low-quality irrigation water faces challenges with cut flower salt sensitivity. Most specialty cut flowers are generally classified as sensitive to soil and irrigation water salinity and, therefore, are avoided as potential crops for saline soils or water reuse systems (Carter and Grieve, 2008). In floral crops specifically, salinity can advance or delay time to harvest, reduce stem length, impact bloom quality, and reduce yield (Carter and Grieve, 2008; Grieve, 2011; Grieve et al., 2008; Shillo et al., 2002). However, some cut flower species are moderately salt tolerant. Limonium (*Limonium* sp.) and stock (*Matthiola incana*) produced marketable stems with no significant decrease in yield when irrigated with water of an EC up to 11.5 and 8.0 dS·m⁻¹, respectively (Carter and Grieve, 2008; Shillo et al., 2002).

As U.S. specialty cut flower production continues to expand into areas with salinity challenges, screening additional floricultural crops for salt tolerance becomes important from the perspectives of both economic and environmental sustainability. A variety of metrics can be useful for assessing plant responses to salinity, including plant growth, visual quality, leaf greenness,

Soil salinity is a common problem in arid and semiarid environments, with elevated levels of salts naturally occurring in the root zone or accumulating from external sources, such as irrigation water, fertilizers, manures, or composts (Bugbee, 2002; Pitman and Läuchli, 2002; Tanji, 2002). Salinity impacts crops physiologically by altering water and nutrient absorption, membrane permeability, plant metabolism, hormone balance, gas exchange, reactive oxygen species production, and cell elongation and division (Prisco et al., 2016). Collectively, these changes can

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1	mmho/cm	dS·m ⁻¹	1
28.3495	oz	g	0.0353
0.001	ppm	g·L ⁻¹	1000
1	ppm	mg·L ⁻¹	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

and gas exchange measurements (Niu and Cabrera, 2010). The size of leaves, stems, roots, and flowers may be reduced because of salinity stress. Beyond the primary implication of reduced growth decreasing plant productivity, the length and number of stems, and size of blooms are particularly important for cut flowers, making growth index a potentially useful metric for connecting salinity stress to marketability.

Anemone (*Anemone coronaria*) and ranunculus (*Ranunculus asiaticus*) are cool-season perennials belonging to the buttercup family (Ranunculaceae) that are typically cultivated as annuals for cut flower production (De Hertogh, 1996). Valdez-Aguilar et al. (2009) found 'Yellow ASD' and 'Pink CTD' ranunculus to be hypersensitive to salinity, with the number of flowering stems produced per plant decreasing from 2.9 to 0.8 stems/plant and 3.2 to 0.8 stems/plant for each cultivar, respectively, when irrigation solution increased from 2.0 to 6.0 dS·m⁻¹. Irrigation solution salinities less than 2.0 dS·m⁻¹ were not evaluated for ranunculus, allowing the possibility that the salinity tolerance threshold for ranunculus could be less than an EC of 2.0 dS·m⁻¹. To date, research has not been conducted regarding the salinity tolerance of anemone. Therefore, the objective of this study was to evaluate the effect of saline irrigation solutions on physiological characteristics and marketable yield of anemone and ranunculus cut flowers.

Materials and methods

PLANT MATERIALS AND CULTURE. This trial was conducted at the Utah State University Research Greenhouse in Logan, UT (lat. 41°45'28"N, long. 111°48'48"W; elevation, 1409 m). Tubers of 'Carmel' and 'Galilee' anemone (size, 5–6 cm) and tuberous roots of 'Amandine' and 'LaBelle' ranunculus (size, 5–7 cm) were obtained from a commercial supplier (Fred C. Gloeckner and Co., Harrison, NY) on 25 Oct. 2020. For simplicity, both tuberous roots and tubers are referred to as tubers when discussed together. Until the experiment was conducted, tubers were stored in dark conditions at 11 to 13 °C and an average relative humidity of 50% (Cerveny et al., 2011; De Hertogh, 1996).

On 15 Jan. 2021, tubers were soaked in slowly running 15 to 25 °C

tap water for 12 h, and a pump was used to aerate the water once per hour (Cerveny et al., 2012; Wien, 2015). For the last 20 min of soaking, the tubers were drained and submerged in a 0.3% Captan fungicide solution (BONIDE Products, Oriskany, NY), as recommended by the tuber supplier. The tubers were drained and placed in flats filled with a moist soilless growing medium consisting of 68% peatmoss (Canadian sphagnum peatmoss; Sun Gro Horticulture, Agawam, MA), 32% vermiculite (Therm-O-Rock West, Chandler, AZ), 0.48 g·L⁻¹ wetting agent (AquaGro 2000 G; Aquatrols, Paulsboro, NJ), and 1.43 g·L⁻¹ hydrated lime (Mississippi Lime, St. Louis, MO). The flats were stored in a cooler for 2 weeks at 4 °C (Ohkawa, 1986). After cold treatment, on 29 Jan. 2021, the tubers were transplanted into 1-gal injection-molded polypropylene containers (PC1D-4; Nursery Supplies, Orange, CA) filled with soilless growing media of the recipe described and placed in a greenhouse. The day/night temperature in the greenhouse was maintained at 22/18 °C until 25 Mar. 2021, when it was adjusted to 20/16 °C to discourage tuberization (De Hertogh and Le Nard, 1993). Light intensities were recorded hourly using a heated silicon chip pyranometer (SP-230; Apogee Instruments, Logan, UT) mounted to a weather station at the Utah Agricultural Experiment Station's Greenville Research Farm (North Logan), ≈1000 m away from the greenhouse. A light transmission rate of 68% was used when calculating the daily light integral inside the greenhouse, and the daily light integral was (mean ± SD) 25.6 ± 11.5 mol·m⁻²·d⁻¹ from 29 Jan. to 30 Apr. 2021. Supplemental light, measured with a quantum meter (SQ-120, Apogee Instruments), at 153.3 μmol·m⁻²·s⁻¹, was provided using 1000-W high-pressure sodium lamps (Gavita, Vancouver, WA) from 600 to 2200 hR when light intensity inside the greenhouse was less than 500 μmol·m⁻²·s⁻¹.

SALINITY TREATMENTS. A total of 108 ranunculus and 54 anemones were grown in individual pots for 6 weeks before initiating salinity treatments on 10 Mar. 2021. Six salinity treatments were tested on ranunculus that included an irrigation solution at ECs of 0.5 (control), 1.5, 2.5, 3.5, 4.5, and 5.5 dS·m⁻¹. Three salinity treatments—of 0.5 (control), 2.5, and

4.5 dS·m⁻¹ irrigation solution—were used to test anemone because of the limited number of plants available for the study.

The nutrient (control) solution was prepared in a 100-L tank by adding 0.4 g·L⁻¹ 15N–2.2P–12.5K water-soluble fertilizer (Peters Excel 15–5–15 Cal-Mag Special; ICL Specialty Fertilizers, Dublin, OH) to reverse-osmosis water. The saline solutions were prepared with an addition of sodium chloride and calcium chloride dihydrate (Fisher Chemical, Logan, UT) at a molar ratio of 2:1 in the nutrient solution (Niu and Cabrera, 2010). The initial pH of the solutions was adjusted to 6.0 to 6.5 by adding 88% potassium hydroxide pellets or 1 M nitric acid as needed (De Hertogh, 1996). The sodium adsorption ratio and elemental analysis were confirmed by the Utah State University Analytical Laboratory (Table 1). The ECs of the solutions, measured using an EC meter (LAQUA Twin; Horiba, Kyoto, Japan), were 0.59 ± 0.03 (control nutrient solution), 1.44 ± 0.08 (EC 1.5 dS·m⁻¹), 2.45 ± 0.08 (EC 2.5 dS·m⁻¹), 3.53 ± 0.05 (EC 3.5 dS·m⁻¹), 4.49 ± 0.05 (EC 4.5 dS·m⁻¹), and 5.41 ± 0.08 dS·m⁻¹ (EC 5.5 dS·m⁻¹) during the experiment. Salinity treatments were applied once per week for 8 weeks by administering between 0.5 and 1.0 L of solution to each plant to obtain a target leaching fraction of ≈25%. In between treatments, plants were watered with an additional 500 mL of control solution, as necessary, to avoid drought conditions.

DATA COLLECTION. The EC of the leachate of the same two replications per treatment (i.e., 24 ranunculus and 12 anemone plants total) was measured weekly using the PourThru method (Cavins et al., 2008). Flower harvest was carried out daily or every other day as needed from 15 Mar. to 28 Apr. 2021, with each stem assigned a grade based on length and quality. Based on local market preferences and seasonality, straight stems a minimum of 15 cm in length were considered marketable, whereas cull stems were any stems shorter than 15 cm, with excessive curvature, or with visible deformities (A. Harrison, personal communication). A visual score of 0 to 5 was assigned to each plant every 2 weeks and at the end of the experiment based on the guidelines used by Sun et al. (2015). A score of

Table 1. The chemical compositions of a nutrient solution at an electrical conductivity (EC) of 0.5 dS·m⁻¹ (control) and saline solutions at ECs of 1.5, 2.5, 3.5, 4.5, or 5.5 dS·m⁻¹ used to irrigate anemone and ranunculus in a Utah greenhouse in 2021.

	EC (dS·m ⁻¹) ^z					
	0.5	1.5	2.5	3.5	4.5	5.5
Addition to solution ^y						
NaCl (g·L ⁻¹)	—	0.23	0.41	0.64	0.87	1.10
CaCl ₂ ·2H ₂ O (g·L ⁻¹)	—	0.29	0.53	0.82	1.11	1.29
Solution property ^x						
Ca ²⁺ (mg·L ⁻¹)	23.8	108	205	305	400	490
Na ⁺ (mg·L ⁻¹)	2.68	81.7	171	262	346	431
Cl ⁻ (mg·L ⁻¹)	1.22	2.77	603	951	1,450	1,840
K ⁺ (mg·L ⁻¹)	75.4	76.8	85.9	76.7	72.1	76.3
Sodium adsorption ratio	0.13	2.05	3.21	4.06	4.69	5.30
EC (mean ± SE, dS·m ⁻¹)	0.59 ± 0.03	1.44 ± 0.08	2.45 ± 0.08	3.53 ± 0.05	4.49 ± 0.05	5.41 ± 0.08

^zA nutrient solution at an EC of 0.5 dS·m⁻¹ was prepared by adding 0.4 g·L⁻¹ 15N-2.2P-12.5K water-soluble fertilizer to reverse-osmosis water. Sodium chloride (NaCl) and calcium chloride dihydrate (CaCl₂·2H₂O) were added to the nutrient solution to make saline solutions; 1 g·L⁻¹ = 1000 ppm.

^y1 dS·m⁻¹ = 1 mmho/cm.

^xCalcium (Ca²⁺), sodium (Na⁺), chloride (Cl⁻), and potassium (K⁺) ions; 1 mg·L⁻¹ = 1 ppm.

0 = dead, 1 = severe foliar damage (>90% leaves with burnt edges, necrosis, or yellowing), 2 = moderate foliar damage (50% to 90%), 3 = slight foliar damage (10% to 50%), 4 = minimal foliar damage (<10%), and 5 = excellent, without foliar damage. Plant size was not considered when assigning the visual score.

During the study, plants were tested for *Tomato spotted wilt virus*, a widespread plant virus that is responsible for heavy economic losses in both horticultural and floral crops (Parrella et al., 2003). A total of 20.4% of the anemone and 5.6% of the ranunculus plants tested positive for *Tomato spotted wilt virus* and were excluded from statistical analysis. At the end of the experiment, leaf length, two canopy widths, leaf number, and leaf greenness were measured for all living plants. Leaf length and canopy widths were averaged to calculate a growth index [growth index = (leaf length + width 1 + width 2)/3] for each plant. Leaf greenness was measured using a handheld chlorophyll meter (MC-100, Apogee Instruments). Gas exchange measurements were collected at the end of the experiment for all living plants using a portable photosynthesis system (LI-6800; LI-COR Biosciences, Lincoln, NE). After taking all measurements, all plants were harvested and placed in a dryer at 60 °C for 48 h before measuring shoot dry weight. At the end of the study, all tubers were examined visually for an unidentified root rot, with 20.4% of the anemone and 3.7% of the

ranunculus plants affected. All plants with root rot were excluded from data analysis. The pots containing soilless media were left to dry for 10 d to encourage upward movement of salts before EC of the soilless media from the top 5 cm of each pot was measured using the saturated paste method outlined by Gavlak et al. (1994).

EXPERIMENTAL DESIGN AND DATA ANALYSES. The experiment was conducted using a randomized complete block design with nine blocks. Plants were arranged into blocks and placed on different benches in the greenhouse to account for the effects of microclimate and lighting differences within the greenhouse. Each block consisted of 12 ranunculus plants and six anemone plants (i.e., two ranunculus cultivars with six treatments each and two anemone cultivars with three treatments each). Both cultivars for each species responded similarly during the study, so all data were pooled across cultivars before analyses. Analysis of variance was performed for all plant growth and gas exchange parameters, and results were evaluated for statistical significance at $\alpha = 0.05$. Linear and quadratic trend analysis was performed. All statistical analyses were performed using JMP (version 13.2; SAS Institute, Cary, NC).

Results and discussion

PLANT GROWTH AND VISUAL QUALITY. Average leaf number (mean ± SD) was 8.5 ± 0.9 for anemone and 14.0 ± 0.6 for ranunculus, with no significant differences observed across

salinity treatments (Table 2). Leaf number is typically determined by the size of the tuber, with larger tubers producing more shoots (Ben-Hod et al., 1989). Consequently, leaf number is likely not a reliable metric of salinity stress for tuberous plants. However, the growth index decreased linearly for ranunculus from 20.0 to 16.6 cm as EC increased from 0.5 to 5.5 dS·m⁻¹ ($P = 0.002$). The growth index for anemone decreased from 21.1 to 18.8 cm as EC increased from 0.5 to 4.5 dS·m⁻¹ but was not affected by salinity significantly. Limited growth is an expected result of salinity stress (Munns and Tester, 2008) and has been observed in other cut flower species in the form of decreased plant height and shoot dry weight (Carter and Grieve, 2008).

The average shoot dry weight was 4.2 ± 0.3 g for anemone and 2.5 ± 0.2 g for ranunculus, with no significant differences observed across treatments. In contrast, Valdez-Aguilar et al. (2009) found that increasing EC from 2 to 3 dS·m⁻¹ induced an 81% decrease in shoot dry weight across ranunculus cultivars, but additional EC increases did not result in additional shoot dry weight reductions. Valdez-Aguilar et al. (2009) initiated irrigation treatments 1 week after transplanting 3-inch-tall seedlings, whereas in our study irrigation treatments began when plants were 6 weeks old and nearly at the flowering stage. Shoot dry weight is a less useful metric for salinity tolerance when irrigation treatments are applied just before flowering, as anemone

Table 2. Leaf number, growth index [(leaf length + width 1 + width 2)/3], shoot dry weight (DW), chlorophyll content index (CCI), stomatal conductance (g_s), transpiration rate (E), and net photosynthetic rate (P_n) of anemone and ranunculus plants after irrigating with a nutrient solution at an electrical conductivity (EC) of 0.5 dS·m⁻¹ or a saline solution at ECs of 1.5, 2.5, 3.5, 4.5, or 5.5 dS·m⁻¹ in a Utah greenhouse in 2021.

Species	EC (dS·m ⁻¹) ^z	Leaves (no.)	Growth index (cm) ^z	Shoot DW (g) ^z	CCI	g_s (mmol·m ⁻² ·s ⁻¹)	E (mmol·m ⁻² ·s ⁻¹)	P_n (μmol·m ⁻² ·s ⁻¹)
Anemone	0.5	7.5	21.8	3.9	9.9	95.1	1.74	6.05
	2.5	9.3	20.0	4.2	6.4	27.1	0.54	1.12
	4.5	8.8	21.0	4.4	5.1	20.4	0.43	0.48
	Linear	NS	NS	NS	NS	*	*	**
	Quadratic	NS	NS	NS	NS	NS	NS	NS
Ranunculus	0.5	13.1	20.0	2.3	23.1	121.6	2.34	6.29
	1.5	14.1	18.6	2.3	15.7	123.8	2.13	3.48
	2.5	14.9	16.2	2.4	16.2	138.0	2.41	4.48
	3.5	13.9	15.9	2.5	16.9	98.9	1.72	2.62
	4.5	14.4	17.4	2.8	12.5	73.4	1.30	4.18
	5.5	13.8	16.6	2.4	12.8	99.8	1.80	4.14
	Linear	NS	**	NS	NS	NS	0.06	NS
	Quadratic	NS	**	NS	NS	NS	NS	NS

^z1 dS·m⁻¹ = 1 mmho/cm, 1 cm = 0.3937 inch, 1 g = 0.0353 oz.

NS, *, **Nonsignificant or significant at $P < 0.05$ or 0.01, respectively.

and ranunculus plants tend not to experience much additional vegetative growth after flowering is initiated (Horovitz, 1985a, 1985b).

Visual quality at the end of the experiment decreased from 3 to 1 for anemone and from 3 to 2 for ranunculus as EC increased from 0.5 to 4.5 dS·m⁻¹ and 0.5 to 5.5 dS·m⁻¹, respectively (Fig. 1). The average visual quality scores across all treatments were 2 ± 1 for anemone and 3 ± 1 for ranunculus. In both crops, visual quality scores decreased over time as browning began on the edges of leaves and progressed to the middle of the leaves and stems. Ranunculus plants had greater visual scores than anemones on average because discoloration was more often confined to the edges of the ranunculus leaves, whereas the entirety of the anemone leaves was affected more commonly (Fig. 2). Based on visual quality alone, the irrigation salinity tolerance threshold for both anemone and ranunculus is likely between 0.5 and 2.5 dS·m⁻¹, assuming a leaching fraction of $\approx 20\%$, because significant decreases in visual quality occurred when plants were irrigated with an EC of 2.5 dS·m⁻¹ or more.

LEAF GREENNESS AND GAS EXCHANGE. In anemone, leaf greenness [chlorophyll content index (CCI)] decreased from 9.9 to 5.1 as EC increased from 0.5 to 4.5 dS·m⁻¹ ($P = 0.07$); CCI decreased in ranunculus from 23.1 to 12.8 as EC increased from 0.5 to 5.5 dS·m⁻¹ ($P = 0.05$) (Table 2). In anemone, g_s decreased

from 95.1 to 20.4 mmol·m⁻²·s⁻¹ ($P = 0.03$) and E decreased from 1.74 to 0.43 mmol·m⁻²·s⁻¹ ($P = 0.02$) as EC increased from 0.5 to 4.5 dS·m⁻¹. In ranunculus, g_s decreased from 121.6 to 99.8 mmol·m⁻²·s⁻¹ as EC increased from 0.5 to 5.5 dS·m⁻¹, but this result was not statistically significant. Transpiration decreased from 2.34 to 1.80 mmol·m⁻²·s⁻¹ as EC increased from 0.5 to 5.5 dS·m⁻¹ for ranunculus ($P = 0.06$). Decreased g_s and E , indicative of a water deficit within the plant, are consistent with the expected effects of osmotic stress resulting from salt accumulating in the plant root zone

(Munns and Tester, 2008). Increases in stem length are dependent on cell elongation, a water deficit-sensitive process, making these effects of salinity particularly important for anemone and ranunculus because stem length is linked directly to the economic value of these crops (Dolatkhahi et al., 2020). In anemone, P_n decreased from 6.05 to 0.48 μmol·m⁻²·s⁻¹ as EC increased from 0.5 to 4.5 dS·m⁻¹ ($P = 0.003$). The change in P_n was less pronounced in ranunculus, decreasing from 6.29 to 4.14 μmol·m⁻²·s⁻¹ as EC increased from 0.5 to 5.5 dS·m⁻¹ ($P = 0.18$).

Fig. 1. Visual score of anemone and ranunculus plants after irrigating with a nutrient solution at an electrical conductivity (EC) of 0.5 dS·m⁻¹ or a saline solution at ECs of 1.5, 2.5, 3.5, 4.5, or 5.5 dS·m⁻¹ for eight applications in a Utah greenhouse in 2021. Visual score reference scale: 0, dead; 1, severe foliar damage (>90% leaves with burnt edges, necrosis, and yellowing); 2, moderate foliar damage (50% to 90%); 3, slight foliar damage (10% to 50%); 4, good quality with minimal foliar damage (<10%); 5, excellent without foliar damage. Lowercase letters represent significance differences ($P < 0.05$) among treatments within each species using a Tukey's honestly significant difference test. Vertical bars represent SE; 1 dS·m⁻¹ = 1 mmho/cm.

Fig. 2. Images of (A) anemone and (B) ranunculus plants after irrigating with a nutrient solution at an electrical conductivity (EC) of 0.5 dS·m⁻¹ or a saline solution at ECs of 1.5, 2.5, 3.5, 4.5, or 5.5 dS·m⁻¹ for eight applications in a Utah greenhouse in 2021; 1 dS·m⁻¹ = 1 mmho/cm.

CUT FLOWER BLOOM TIMING AND YIELD. The blooming period lasted 44 d for anemone and 26 d for ranunculus. The ranunculus blooming period was longer than the blooming period of 17 d obtained by Valdez-Aguilar et al. (2009), but low compared with field production with protected cultivation methods, such as the 78 d obtained by Stock et al. (2020) in northern Utah or the 77 d obtained by Bernstein et al. (2018) in Israel. The below-average duration of blooms obtained in our study and by that of Valdez-Aguilar et al. (2009) is likely indicative of salinity stress, as flowering would logically be limited by the reduction in overall plant vigor caused by salt stress (Munns and Tester, 2008).

The impact of increasing salinity on marketable and total yield was insignificant for both species tested (Fig. 3). Cut flower yield in tuberous species, such as anemone and ranunculus, is generally considered a factor of tuber size and environmental factors—mainly, temperature, light, and moisture (De Hertogh and Le Nard, 1993). Anemone and ranunculus prefer a day/night temperature range of 12 to 16/7 to 10°C (Armitage and Laushman, 2003; De Hertogh, 1996), but the greenhouse temperature in our study was maintained at 20/16°C because the space was shared with

other crops. However, this temperature range is representative of field conditions in late spring along Utah's Wasatch Front, where daytime temperatures averaged 20 ± 5°C and nighttime temperatures averaged 13 ± 4°C in May 2021 for Murray, UT (Utah Climate Center, 2021). Total yields ranged from one to two stems per plant for ranunculus and two to three stems per plant for anemone, whereas marketable yields ranged from one to two stems per plant for both species. Ranunculus marketable yields are consistent with the one to three stems per plant obtained by Valdez-Aguilar et al. (2009), but total yields are low compared with the three to five total stems per plant obtained in a field production trial by Wien (2015), and the 9 to 15 total stems/plant predicted by the tuber supplier for tubers of the 5- to 7-cm size used in our study (Fred C. Gloeckner and Co.). Similarly, marketable anemone yields were low compared with the average four stems per plant obtained by Bernstein et al.

Fig. 3. Total yield in stems per plant of (A) anemone and (B) ranunculus after irrigating with a nutrient solution at an electrical conductivity (EC) of 0.5 dS·m⁻¹ or saline solution at ECs of 1.5, 2.5, 3.5, 4.5, or 5.5 dS·m⁻¹ for eight applications in a Utah greenhouse in 2021. The total yield is the sum of the marketable yield (black bars) and cull yield (white bars). Based on local market preferences and seasonality, straight stems a minimum of 15 cm (5.9 inches) in length were considered marketable whereas cull stems were any stems shorter than 15 cm, with excessive curvature, or with visible deformities (A. Harrison, personal communication). Vertical bars represent SE; 1 dS·m⁻¹ = 1 mmho/cm.

(2018), and total yields were low compared with the potential 13 to 15 stems per plant described by breeders (Laura and Allavena, 2007). The total yields for both species, across all salinity treatments, are likely less than the yields obtained in the aforementioned studies with tubers of the same size because of the above-optimal greenhouse temperatures. The percentage of cull blooms was 30% $\pm$ 18% for anemone, which is consistent with the 25% obtained by Bernstein et al. (2018), and the result of noticeable discoloration on the blooms that prevented stems from being marketable regardless of stem length. The percentage of cull blooms was much less, at 4% $\pm$ 4%, for ranunculus. Valdez-Aguilar et al. (2009) did not report any ranunculus cull blooms in their study, but categorized blooms as marketable based only on stem length, without considering bloom quality.

LEACHATE AND SUBSTRATE EC. For each salinity treatment, leachate and substrate EC were not noticeably different across species; therefore, data were averaged across species. The average leaching fraction across eight applications was 21.36% $\pm$ 8.86%, and leachate ECs were greater than the EC of the irrigation solution in all treatments, including the control (Fig. 4). Leachate EC of control plants ranged from 0.57 to 1.67 dS·m⁻¹, and the ECs of the leachate from treatments increased from 1.42 to 2.08, 1.94 to 3.28, 2.62 to 5.19, 2.72 to 5.57, and 3.47 to 7.25 dS·m⁻¹ after eight applications of saline solutions with an EC of 1.5, 2.5, 3.5, 4.5, and 5.5 dS·m⁻¹, respectively. Substrate EC at the end of the experiment increased with increasing salinity of irrigation solution, from 1.06 $\pm$ 0.60 dS·m⁻¹ for the control to 9.11 $\pm$ 1.96 dS·m⁻¹ for EC 5.5 dS·m⁻¹ (Table 3). The increase in leachate EC over time and increased substrate EC compared with irrigation solution EC are consistent with previous observations that irrigation with saline water leads to accumulation of salts in the plant rhizosphere (Ayers and Westcot, 1985; Paudel et al., 2019; Wu et al., 2016). The observed accumulation of salts in the substrate likely accounts for the decreased visual quality, CCI, and *E* in both species, as well as decreased *g_s* and *P_n* in anemone and decreased growth in ranunculus.

Substrate EC was about double the irrigation solution EC for all

Fig. 4. Electrical conductivity (EC) of leachate solution collected after irrigating anemone and ranunculus plants with a nutrient solution at an EC of 0.5 dS·m⁻¹ or a saline solution at an EC of 1.5, 2.5, 3.5, 4.5, or 5.5 dS·m⁻¹ in a Utah greenhouse in 2021. The nutrient solution was prepared by adding 0.4 g·L⁻¹ (400 ppm) 15N–2.2P–12.5K water-soluble fertilizer to reverse-osmosis water. Sodium chloride and calcium chloride dihydrate were added to the nutrient solution to make the saline solutions. Vertical bars represent the SE of eight measurements, four plants per treatment per species; 1 dS·m⁻¹ = 1 mmho/cm.

treatments, including the control. According to Ayers and Westcot (1985), a leaching fraction of 20% should result in a soil EC 1.3 times greater than the irrigation solution EC, with the calculated soil EC value representing an average of the entire root zone. In this case, measured substrate EC values represented the top portion of soilless media after drying and upward movement of salts occurred, so

Table 3. Average electrical conductivity (EC) of the soilless media from each irrigation solution treatment after eight treatments on anemone and ranunculus in a Utah greenhouse in 2021. Saturated soil paste technique (Gavlak et al., 1994) was used for determining the substrate EC and results were pooled across cultivars and species.

EC	Substrate EC (mean $\pm$ SE) (dS·m ⁻¹) ^z
0.5	1.06 $\pm$ 0.15
1.5	2.60 $\pm$ 0.21
2.5	4.94 $\pm$ 0.66
3.5	7.66 $\pm$ 0.85
4.5	9.72 $\pm$ 0.44
5.5	9.11 $\pm$ 0.69
Linear	***
Quadratic	NS

^z1 dS·m⁻¹ = 1 mmho/cm.

NS, ***Nonsignificant or significant at *P* < 0.001, respectively.

it is logical that substrate EC values were consistently greater than would be predicted by the literature for most soils. In soil tests of 33 small, urban farms across Utah's Wasatch Front, soil EC ranged from 0.93 to 5.80 dS·m⁻¹, with an average EC of 2.51 $\pm$ 1.17 dS·m⁻¹ (M. Stock, unpublished data). The soil EC range encountered in Utah indicates that the substrate ECs to which anemone and ranunculus plants were subjected in our study are representative of both current and potential field conditions, because soil EC values across the Wasatch Front appear to be increasing gradually.

Conclusion

After eight irrigation treatments, the EC of soilless media for all treatments and the control was about double the EC of the irrigation solution. As a result of this increasing salinity in the root zone, ranunculus visual quality, growth, leaf greenness, and *E* decreased as irrigation solution EC increased from 0.5 to 5.5 dS·m⁻¹, which is consistent with the findings of Valdez-Aguilar et al. (2009) that ranunculus is sensitive to salinity stress. Similarly, anemone visual quality, leaf greenness, *g_s*, *E*, and *P_n* decreased as the irrigation solution EC increased from 0.5 to 4.5 dS·m⁻¹. Based on visual quality alone, the irrigation

salinity tolerance threshold for both anemone and ranunculus is likely between 0.5 and 2.5 dS·m⁻¹, because significant decreases in visual quality occurred when plants were irrigated with an EC of 2.5 dS·m⁻¹ and more. The soil salinity tolerance threshold is likely higher, within the range of 1 to 5 dS·m⁻¹ that resulted in the substrate after eight treatments with irrigation solution between 0.5 and 2.5 dS·m⁻¹. Based on our findings, both anemone and ranunculus can be considered sensitive to salinity, making these cut flowers poor choices in production systems with a risk of elevated soil salinity.

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