Increased Leaching Requirements Allow the Use of Source Water High in Salts for Plant Growth

Kimberly Moore[1], Cristina Burgart[1], Samar Shawaqfeh[2], Luci Fisher[1], and Mica McMillan[1]

KEYWORDS. container production, ornamental plants

ABSTRACT. Growers have different capabilities to alleviate salt stress in the growing substrate. One method to reduce substrate salt levels is to increase the volume of water applied during irrigation. This increases the leaching fraction (LF) which is the volume of water that drains from the growing substrate divided by the volume applied during irrigation. We can determine the leaching requirement (the minimum LF to maintain a desired substrate salt level) using the formula LF = $EC_w/5(EC_e - EC_w)$, where EC_w is the electrical conductivity (EC) of the water and EC_e is the desired EC of the substrate. We tested this formula to see if we could maintain an acceptable substrate EC of 4 $dS{\cdot}m^{-1}$ by modifying the LF for 'Hope' philodendron (*Philodendron selloum*) and 'Tineke' ficus (*Ficus elastica*) irrigated with tap water (EC 0.17 $dS{\cdot}m^{-1}$) or reclaimed wastewater (RWW) from Davie, FL, USA (EC 1.66 $dS{\cdot}m^{-1}$) and RWW from Hollywood, FL, USA (EC 2.93 $dS{\cdot}m^{-1}$). Shoot and root dry weight was greatest for both species with the tap water applied with a 5% LF. Increasing the LF to 15% for Davie RWW and a 55% for Hollywood RWW, produced acceptable growth for 'Hope' philodendron and 'Tineke' ficus. In our second experiment, we monitored the growth of 'Looking Glass' begonia (*Begonia fibrous*), 'Freddie' calathea (*Calathea concinna*), and 'Déjà vu' philodendron (*Philodendron selloum*) irrigated with tap water (EC 0.15 $dS{\cdot}m^{-1}$), salt water (EC 3.49 $dS{\cdot}m^{-1}$), or RWW (EC 3.48 $dS{\cdot}m^{-1}$) with LFs of 28%, 50%, or 65%. 'Looking Glass' begonia and 'Freddie' calathea growth was greater with 65% LF than 28% LF, respectively, for all three water sources. Philodendron growth was not different due to LF. However, philodendron, calathea, and begonia growth was greater with tap water and RWW than with saltwater. Although final leachate EC with saltwater and RWW was around 2 $dS{\cdot}m^{-1}$ using 50% LF, leachate sodium (Na) levels from salt watered plants was higher than for RWW or tap watered plants. We suspect that high Na levels in combination with lower potassium (K) and calcium (Ca) levels in the saltwater solution resulted in poor plant growth. Although the Na levels in leachate from RWW substrates was higher than tap watered substrates, Ca and K levels also were greater. Although we were able to use the salt equation to maintain substrate EC levels ranging from 2 to 4 $dS{\cdot}m^{-1}$, volumes of solution applied were two to three times higher when using RWW or salt water compared with tap water. We suspect that a balance between Na, Ca, and K supported better plant growth with RWW than salt water. However, additional work needs to be done on the benefits of supplemental Ca and K when using water high in salts or Na. This works suggests that in addition to monitoring EC, it also is important to monitor Na, Ca, and K concentrations.

The salt tolerance of a plant can be evaluated by observing changes in plant growth in saline conditions compared with control conditions, with salt-sensitive plants having a greater reduction in growth compared with salt-tolerant plants (Munns, 2022). In addition to the reported plant salt tolerance, growth responses depend on the severity of salt stress (the concentration of salt in the soil solution) and the duration of exposure of the plant roots to salt (Hasegawa et al., 2000; Munns and Tester, 2008; Zhu, 2003).

When salts accumulate in the growing substrate under normal irrigation, this can increase substrate salinity levels. One method of correcting higher substrate salinity levels involves increasing the volume of water applied at each irrigation event (Petersen, 1996). The increased amount of water leaches the salts in the substrate and decreases salinity levels (Petersen, 1996). By measuring the amount of water that drains as a function of the amount of water applied, we can calculate the leaching fraction (LF). Growers can use the following salt balance equation: LF = $EC_w/5(EC_e - EC_w)$, where EC_w is the electrical conductivity (EC) of the water source and EC_e is the desired EC for the substrate to determine the leaching requirement (Petersen, 1996). The leaching requirement is the minimum LF for maintaining a desired EC in the substrate. It is possible to input the EC of any water source into this equation and determine the appropriate leaching requirement (how much water to apply to get a desired amount to drain) to maintain a predetermined substrate EC for that crop. This has potential benefits when using either reclaimed wastewater (RWW) or source water with high salt levels, both of which can have high EC.

We wanted to test this equation to determine if we could maintain desirable substrate EC levels when using irrigation water with high salt concentrations either from saltwater or from RWW. In our first experiment, we compared the growth of 'Hope' philodendron (*Philodendron selloum*) and 'Tineke' ficus (*Ficus elastica*) with tap water and two sources of RWW. In our second experiment, we compared the growth of 'Looking Glass' begonia (*Begonia fibrous),* 'Freddie' calathea (*Calthea concinna*), and 'Déjà vu' philodendron (*Philodendron selloum*) watered with tap water and saltwater. Plants used in both experiments were considered have low to moderate salt tolerance (Broschat and Meerow, 1991).

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
0.5933	$lb/yard^3$	$kg{\cdot}m^{-3}$	1.6856
1	mmho/cm	$dS{\cdot}m^{-1}$	1
28.3495	oz	g	0.0353
7.4892	oz/gal	$g{\cdot}L^{-1}$	0.1335
1	ppm	$mg{\cdot}L^{-1}$	1
(°F − 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Materials and methods

Expt. 1 (using leaching fraction equation). On 2 Feb 2018, rooted liners of 'Hope' philodendron and 'Tineke' ficus (AG 3, Inc., Eustice, FL) were transplanted into 1-gal pots filled with soilless medium (Florida peat, pine bark, and coarse sand; Atlas 3000 mix; Atlas Peat and Soil Inc., Boynton Beach, FL). A 15N–3.9P–10.0K controlled-release fertilizer (Osmocote Plus 15–9–12; 8–9 months; ICL Specialty Fertilizers, Summerville, SC) was incorporated into the growing substrate before planting at a rate of 2.8 lb/yard^3 ($\approx$0.7 g of nitrogen per pot). Plants were watered by hand every other day with tap water or RWW from either Davie, FL, or Hollywood, FL. Substrates did not dry between irrigation events. Pots were arranged in a completely randomized design with five replicates per treatment.

The RWW from Hollywood, FL, was collected from the Southern Regional Wastewater Treatment Facility and had an initial EC of 2.86 dS·m^{-1}. The RWW from Davie, FL, was collected from the Water Reclamation Facility and had an initial EC of 1.68 dS·m^{-1}. The RWW from both facilities was collected in Jan 2018 and stored in sealed 55-gal barrels with lids. Using the salt balance equation, three LFs were calculated to maintain a substrate EC of $\approx$4 dS·m^{-1}. Based on previous work, we know that plants start to decline when EC levels are more than 4 (Moore et al., 2019).

Before starting the experiment, initial pH, EC, nitrate (NO_3), calcium (Ca), potassium (K), and sodium (Na) in each solution were measured (Table 1). We used a combination handheld pH/EC meter (HI98129; Hanna Instruments, Woonsocket, RI) to measure pH and EC, and we used a specific ion probe to measure NO_3, Ca, K, and Na (Acumet XL250; Fisher Scientific, Waltham, MA). The ion-specific electrodes were calibrated before use and a standard curve was performed. After every fifth sample, a standard was performed to check accuracy. After 20 samples, the probes were recalibrated with a standard curve.

Plants were watered by hand every other day with 25 mL tap water (5% LF), 75 mL Davie RWW (15% LF), or 275 mL Hollywood RWW (55% LF). Then, plants were grown for 6 weeks in an open-sided greenhouse exposed to average ambient air temperatures (87.7/71.6 °F day/night) and 73.0% relative humidity at the University of Florida, Fort Lauderdale Research and Education Center, Davie, FL. Weather data were collected by the Florida Automated Weather Network system located 100 ft from the greenhouse.

On 16 Mar 2018, when control plants reached a marketable size, aboveground plant growth was harvested by cutting the shoots at the substrate surface. Roots were harvested by shaking the substrate off the roots. Both shoots and roots were dried in an oven at 130 °F for 1 week to measure dry weights. Before harvesting plant material, a final leachate sample was collected using the pour-through method with deionized water (Cavins et al., 2004). Leachate samples were analyzed to determine pH, EC, NO_3 K, Ca, and Na.

Expt. 2 (comparing sources at different volumes). On 4 May 2018, rooted liners of 'Looking Glass' begonia, 'Freddie' calathea, and 'Déjà vu' philodendron (AG 3, Inc.) were transplanted into 1-gal pots filled with soilless medium (Metro-Mix; Sun Gro Horticulture, Agawam, MA). A 15N–3.9P–10K controlled-release fertilizer (Osmocote Plus 15–9–12; 8–9 months) was incorporated into the growing substrate before planting at a rate of 2.8 lb/yard^3 ($\approx$0.7 g of nitrogen per pot). Pots were arranged in a completely randomized design with five replicates per treatment.

Plants were grown in an open-sided greenhouse exposed to ambient air temperatures at the University of Florida Fort Lauderdale Research and Education Center. The average daily temperature and relative humidity were 93.1/79.4 °F day/night and 81.0% relative humidity, respectively, for the duration of the trial. Environmental data were collected by the Florida Automated Weather Network.

Plants were irrigated by hand every other day with RWW, saline water, or tap water (Table 2). Plants received 100, 250, or 350 mL at each irrigation (equivalent to LFs of 28%, 50%, and 65%, respectively) and did not dry between irrigation events. The median LF was determined using the salt balance equation with the goal of maintaining a substrate EC of 2 dS·m^{-1} using RWW and saltwater. We used the same LFs for tap water knowing that the substrate EC would be less than 2 dS·m^{-1}.

The RWW was collected from the Southern Regional Wastewater Treatment Plant in Hollywood, FL, in Apr 2018, and stored in sealed 55-gal barrels with lids. The saline treatment was mixed to have the same EC as the wastewater ($\approx$3.5 dS·m^{-1}). We added 1.5 g·L^{-1} of reagent-grade sodium chloride (NaCl) (Innovating Science, Aldon Corporation, Avon, NY) in tap water. For all three water sources, initial solution pH, EC, NO_3, Ca, K, and Na were measured as described in Expt. 1 (Table 2).

On 15 June 2018, when control plants reached a marketable size, plants were harvested and treated similarly to Expt. 1 before measuring dry weight. Before harvesting the plant material, final leachate samples were collected using the pour-through method with deionized water. Leachate samples were analyzed to determine EC, NO_3, Ca, K, and Na.

Data collection and statistical analysis. These experiments were completely randomized designs with five replicates per treatment. Each experiment was analyzed separately, and all statistical analyses were performed using statistical software (SAS ver. 9.3; SAS Institute Inc., Cary, NC). Nutrient concentrations of five samples of each water source used in Expts. 1 and 2 were analyzed using an analysis of variance (ANOVA), and comparisons were performed using the Tukey-Kramer test. Similarly, differences in plant growth and final leaching nutrient levels in Expts. 1 and 2 were analyzed using an ANOVA; mean separation was performed using the Tukey-Kramer test, and the significance level was α = 0.05. Although we did perform a rate study,

Received for publication 15 Jul 2022. Accepted for publication 26 Sep 2022.

Published online 27 Oct 2022.

[1]University of Florida, Fort Lauderdale Research and Education Center, 3205 College Avenue, Davie, FL 33314, USA

[2]Department of Plant Production and Protection, College of Agriculture Jerash University, 26150 Jerash, Jordan

This research was funded in part by a grant from the Horticulture Research Institute (HRI). This work was also part of a graduate student's research.

K.M. is the corresponding author. E-mail: klock@ufl.edu.

https://doi.org/10.21273/HORTTECH05104-22

Table 1. Expt. 1: Initial solution pH, electrical conductivity (EC), nitrate (NO_3), calcium (Ca), potassium (K), and sodium (Na) levels in tap water or reclaimed wastewater (RWW) from Davie, FL, or Hollywood, FL. The experiment was conducted in Fort Lauderdale, FL, in 2018.

Source[i]	pH	EC ($dS \cdot m^{-1}$)[ii]	NO_3 ($mg \cdot L^{-1}$)[ii]	Ca ($mg \cdot L^{-1}$)[ii]	K ($mg \cdot L^{-1}$)[ii]	Na ($mg \cdot L^{-1}$)[ii]
Tap	7.4 a[iii]	0.17 c	0.17 b	33.1 b	0.02 b	7 c
RWW Davie	6.9 a	1.68 b	23.2 a	206.2 a	23.98 a	262 b
RWW Hollywood	6.9 a	2.86 a	27.1 a	203.7 a	24.64 a	394 a

[i] Water used in this experiment came from the tap or was collected in Jan 2018 from the Water Reclamation Facility in Davie, FL, or from the Southern Regional Wastewater Treatment Facility in Hollywood, FL. All water was stored in 55-gal (208.2 L) barrels with lids.
[ii] Values are averaged for five replicates; 1 $dS \cdot m^{-1}$ = 1 mmho/cm, 1 $mg \cdot L^{-1}$ = 1 ppm.
[iii] Means followed by the same letter within a column are not significantly different according to Tukey's method at α = 0.05.

we used pairwise mean separation instead of a regression analysis because we wanted to observe differences in the water sources and LF.

Results and discussion

Salinity can alter plant growth, development, and nutrient uptake while potentially causing toxicities and eventual plant death. Salts from irrigation water tend to accumulate in small root volumes such as those found in containerized plants (Levitt 1980; Munns, 2002). The quality, volume, and frequency of irrigation can affect the level of accumulation of salts in the growing substrate (Martinez and Clark, 2009; Satti and Lopez, 1994). As the LF increases, the EC of the soil solution should decrease (Ku and Hershey, 1991; Satti and Lopez, 1994). Increasing the LF of the Hollywood RWW to 55% (initial EC of 2.86 $dS \cdot m^{-1}$) produced plants with similar shoot and root dry weights as those of plants watered with Davie RWW (initial EC of 1.68 $dS \cdot m^{-1}$) using an LF of 15%; however, 'Hope' philodendron and 'Tienke' ficus shoot and root dry weights were greatest with tap water applied with a 5% LF (Table 3).

Ideally, when using water high in salts, we want to leach the salts and get the same growth results as those obtained using tap water at 5%. However, we used the LF equation to determine the leaching requirement to maintain substrate EC levels of ≈4 $dS \cdot m^{-1}$ (Table 4). All substrates had EC levels of ≈4, but the final leachate NO_3, Ca, K, and Na levels were greater in substrates irrigated with RWW compared with tap water (Table 4).

The leachate Na levels of the RWW treatments were 453 and 448 $mg \cdot L^{-1}$ with LFs of 15% to 55%. We suspect that the higher concentrations of Na contributed to reductions in growth rather than the higher substrate EC. In previous work, we determined that plants with moderate salt tolerance can tolerate EC and Na levels of 2.1 to 4.2 $dS \cdot m^{-1}$ and 240 to 420 $mg \cdot L^{-1}$ Na, respectively (Moore et al., 2019). Although the growth of philodendron and ficus was lower with RWW, plants were still considered acceptable and saleable. However, we questioned if using an LF of 55% was economical or feasible because we applied ≈6050 mL Hollywood RWW per plant instead of 550 mL tap water per plant.

In Expt. 2, we compared three LFs ranging from 28% to 65% using tap water, RWW, and saltwater. The median LF of 50% was based on the results of the salt equation performed to determine how to maintain a substrate EC of 2 $dS \cdot m^{-1}$ with RWW and saltwater that had an initial EC of 3.5 $dS \cdot m^{-1}$. 'Looking Glass' begonia, 'Freddie' calathea, and 'Déjà vu' philodendron shoot and root dry weights were greater for plants watered with tap water or RWW than for those watered with saltwater (Table 5).

Increasing the LF for all three water sources improved begonia and calthea shoot and root dry weights; however, there were no differences in philodendron shoot or root dry weights caused by LF (Table 5). As in Expt. 1, we had to apply greater volumes of solution when using salt of RWW than tap water (2200 mL; 28% LF) compared with 7700 mL (65% LF) of salt or RWW. For all three irrigation sources, the final leachate EC was lower with 65% LF than with 28% LF, but there was no difference in the leachate nutrient concentrations caused by LF (Table 6). The differences in nutrient concentrations were caused by the irrigation source (Table 6). Although we were able to maintain a substrate EC close to 2 $dS \cdot m^{-1}$ in both saltwater and RWW substrates, the leachate Na levels were greater than 400 $mg \cdot L^{-1}$ in saltwater substrates. Although previous work reported acceptable growth with Na levels of ≈420 $mg \cdot L^{-1}$ (Moore et al., 2019), we suspect that lower Ca and K levels in saltwater compared with RWW in combination with high Na contributed to the poor growth of all plants with saltwater (Tables 2, 5, and 6).

With saline concentrations, the uptake of Na may be reduced by the addition of either Ca or K (Deinlein et al., 2014; Muhammed et al., 1987; Zhu,

Table 2. Expt. 2: Initial solution pH, electrical conductivity (EC), nitrate (NO_3), potassium (K), calcium (Ca), and sodium (Na) levels in tap water, reclaimed wastewater (RWW) from Hollywood, FL, and saltwater solution. The experiment was conducted in Fort Lauderdale, FL, in 2018.

Source[i]	pH	EC ($dS \cdot m^{-1}$)[ii]	NO_3 ($mg \cdot L^{-1}$)[ii]	Ca ($mg \cdot L^{-1}$)	K ($mg \cdot L^{-1}$)	Na ($mg \cdot L^{-1}$)
Tap	6.45 a[iii]	0.15 b	0.13 b	33.2 b	0.03 b	6 c
RWW	6.84 a	3.49 a	25.8 a	207.2 a	27.1 a	259 b
Saltwater	6.43 a	3.48 a	0.14 b	34.2 b	0.04 b	328 a

[i] Water used in this experiment came from the tap or was collected in Apr 2018 from the Southern Regional Wastewater Treatment Facility in Hollywood, FL. Saltwater was made by dissolving 1.5 $g \cdot L^{-1}$ (0.20 oz/gal) of sea salt in tap water. All water was stored in 55-gal (208.2 L) barrels with lids.
[ii] Values are averaged for five replicates; 1 $dS \cdot m^{-1}$ = 1 mmho/cm, 1 $mg \cdot L^{-1}$ = 1 ppm.
[iii] Means followed by the same letter within a column are not significantly different according to Tukey's method at α = 0.05.

Table 3. Expt. 1: Final shoot and root dry weights of 'Hope' philodendron and 'Tineke' ficus plants watered with tap water or reclaimed wastewater (RWW) from either Davie, FL, or Hollywood, FL. Based on the initial electrical conductivity (EC) of the water, leaching fractions of 15% for RWW Davie, 55% for RWW Hollywood, and 5% for tap were used. The experiment was conducted in Fort Lauderdale, FL, in 2018.

			Philodendron		Ficus	
Source[i]	Initial solution EC ($dS \cdot m^{-1}$)[ii]	Leaching fraction (%)[iii]	Shoot dry wt (g)[iv]	Root dry wt (g)	Shoot dry wt (g)	Root dry wt (g)
Tap	0.58	5	11.97 a[v]	20.83 a	4.11 a	8.83 a
RWW Davie	1.68	15	10.66 b	14.91 b	3.21 b	4.73 b
RWW Hollywood	2.86	55	10.57 b	14.82 b	3.29 b	4.59 b

[i] Water used in this experiment came from the tap or was collected in Jan 2018 from the Water Reclamation Facility in Davie, FL, or from the Southern Regional Wastewater Treatment Facility in Hollywood, FL. All water was stored in 55-gal (208.2 L) barrels with lids.
[ii] $1\ dS \cdot m^{-1} = 1$ mmho/cm.
[iii] Leaching fractions were determined using the following equation: $LF = EC_w/5(EC_e - EC_w)$, where EC_w is the EC of the water source and EC_e is the desired EC for the substrate. The desired substrate EC was set at $4\ dS \cdot m^{-1}$.
[iv] Values are averaged for five replicates; 1 g = 0.0353 oz.
[v] Means followed by the same letter within a column are not significantly different according to Tukey's method at $\alpha = 0.05$.

2003). Increased Ca concentrations in the external solution improved rice (*Oryza sativa*) growth because of the role of Ca in reducing root permeability to Na (Muhammed et al., 1987). Similarly, enhanced K nutrition improved tomato (*Solanum lycopersicum*) growth because of the damaging effects of increased NaCl (Al-Karaki, 2000). For

Table 4. Expt. 1: Final leachate solution pH, electrical conductivity (EC), nitrate (NO_3), calcium (Ca), potassium (K), and sodium (Na) levels in tap water or reclaimed wastewater (RWW) from either Davie, FL, or Hollywood, FL. Because there was no difference in nutrient levels measured in leachate collected from 'Hope' philodendron and 'Tineke' ficus, these values were averaged. We used the pour-through method to collect leachate samples after the plants were harvested. The experiment was conducted in Fort Lauderdale, FL, in 2018.

Source[i]	Leaching fraction (%)[ii]	pH	EC ($dS \cdot m^{-1}$)[iii]	NO_3 ($mg \cdot L^{-1}$)[iv]	Ca ($mg \cdot L^{-1}$)	K ($mg \cdot L^{-1}$)	Na ($mg \cdot L^{-1}$)
Tap	5	6.4 a[iii]	3.69 a	285 b	206 b	12.3 a	48 b
RWW Davie	15	6.6 a	3.95 a	375 a	248 a	16.5 a	453 a
RWW Hollywood	55	6.4 a	4.06 a	322 a	269 a	14.1 a	448 a

[i] Water used in this experiment came from the tap or was collected in Jan 2018 from the Water Reclamation Facility in Davie, FL, or from the Southern Regional Wastewater Treatment Facility in Hollywood, FL. All water was stored in 55-gal (208.2 L) barrels with lids.
[ii] Leaching fractions were determined using the following equation: $LF = EC_w/5(EC_e - EC_w)$, where EC_w is the EC of the water source and EC_e is the desired EC for the substrate. The desired substrate was EC was $4\ dS \cdot m^{-1}$.
[iii] Means followed by the same letter within a column are not significantly different according to Tukey's method at $\alpha = 0.05$.
[iv] Values are averaged for 10 replicates; $1\ dS \cdot m^{-1} = 1$ mmho/cm, $1\ mg \cdot L^{-1} = 1$ ppm.

Table 5. Expt. 2: Final shoot and root dry weights of 'Looking Glass' begonia, 'Freddie' calathea, and 'Deja vu' philodendron plants grown in Fort Lauderdale, FL, in 2018, and watered with tap water, saltwater, or reclaimed wastewater (RWW). Plants were watered with leaching fractions of 28%, 50%, or 65%.

Solution[i]	Leaching fraction (%)	Begonia shoot dry wt (g)[ii]	Begonia root dry wt (g)	Calathea shoot dry wt (g)	Calathea root dry wt (g)	Philodendron shoot dry wt (g)	Philodendron root dry wt (g)
Tap	28	10.71 b[iii]	5.58 b	10.14 b	6.33 b	4.87 a	4.96 a
	50	11.24 a	6.04 ab	10.39 a	7.96 a	4.95 a	4.97 a
	65	11.64 a	6.31 a	10.41 a	8.54 a	5.04 a	4.97 a
		11.20 A	**5.98 A**	**10.34 A**	**7.61 A**	**4.95 A**	**4.96 A**
Salt	28	9.99 c	4.67 d	8.19 d	3.77 d	4.07 b	3.90 b
	50	10.09 c	5.17 c	9.33 c	4.81 c	4.17 b	3.97 b
	65	10.46 b	5.16 c	9.51 c	4.93 c	4.29 b	3.98 b
		10.18 B	**5.13 B**	**9.34 B**	**4.83 B**	**4.17 B**	**3.95 B**
RWW	28	10.46 b	5.56 b	10.16 b	6.66 b	4.91 a	4.90 a
	50	11.15 a	6.02 ab	10.29 ab	7.28 a	4.96 a	4.94 a
	65	11.27 a	6.37 a	10.37 a	8.35 a	5.02 a	5.04 a
		10.96 A	**5.98 A**	**10.27 A**	**7.43 A**	**4.96 A**	**4.96 A**

[i] Water used in this experiment came from the tap or was collected in Apr 2018 from the Southern Regional Wastewater Treatment Facility in Hollywood, FL. Saltwater was made by dissolving $1.5\ g \cdot L^{-1}$ (0.20 oz/gal) of sea salt in tap water. All water was stored in 55-gal (208.2 L) barrels with lids.
[ii] 1 g = 0.0353 oz.
[iii] Means followed by the same lowercase or uppercase letter within a column are not significantly different according to Tukey's method at $\alpha = 0.05$. The lowercase letters represent a difference in the water source × leaching fraction treatments (means averaged for five replicates). The uppercase letters in bold represent differences in the water source only (these means are average for 15 replicates).

Table 6. Expt. 2: Final leachate, electrical conductivity (EC), nitrate (NO_3), calcium (Ca), potassium (K), and sodium (Na) levels in tap water, saltwater, and reclaimed wastewater (RWW) applied to 'Looking Glass' begonia, 'Freddie' calathea, and 'Deja vu' philodendron plants grown in Fort Lauderdale, FL, in 2018. Plants were watered with leaching fractions of 28%, 50%, or 65%. Because there were no differences in nutrient levels among the begonia, calathea, and philodendron plants, these values were averaged. We used the pour-through method to collect leachate samples after plants were harvested.

Source[i]	Leaching fraction (%)	EC ($dS \cdot m^{-1}$)[ii]	NO_3 ($mg \cdot L^{-1}$)[ii]	Ca ($mg \cdot L^{-1}$)	K ($mg \cdot L^{-1}$)	Na ($mg \cdot L^{-1}$)
Tap	28	0.77 c[iii]	284 b	206 b	13.81 b	47 c
	50	0.66 c	282 b	203 b	13.45 b	46 c
	65	0.56 c	280 b	202 b	12.96 b	41 c
Salt	28	3.02 a	285 a	208 b	14.67 b	495 a
	50	2.21 b	245 a	205 b	14.52 b	457 a
	65	2.14 b	225 ab	202 b	14.04 b	428 a
RWW	28	2.89 a	325 ab	259 a	16.76 a	253 b
	50	2.19 b	321 ab	258 a	15.88 a	232 b
	65	2.02 b	323 ab	249 a	15.29 a	228 b

[i] Water used in this experiment came from the tap or was collected in Apr 2018 from the Southern Regional Wastewater Treatment Facility in Hollywood, FL. Saltwater was made by dissolving 1.5 $g \cdot L^{-1}$ (0.20 oz/gal) of sea salt in tap water. All water was stored in 55-gal (208.2 L) barrels with lids.
[ii] Values are averaged for 15 replicates; 1 $dS \cdot m^{-1}$ = 1 mmho/cm, 1 $mg \cdot L^{-1}$ = 1 ppm.
[iii] Means followed by the same letter within a column are not significantly different according to Tukey's method at α = 0.05.

example, the addition of 4 and 8 mM potassium nitrate [KNO_3 (404.4 and 808.8 $mg \cdot L^{-1}$ KNO_3, respectively)] to 50 mM NaCl (2922 $mg \cdot L^{-1}$ NaCl) resulted in Na:K of 12.5 and 6.3, which resulted in improved tomato growth (Satti and Lopez, 1994). Satti and Lopez (1994) concluded that low K in the nutrient solution was more limiting than Na toxicity and reported that differences in growth were likely caused by added Na rather than added Cl based on their work comparing NaCl, sodium nitrate ($NaNO_3$), and sodium phosphate (NaH_2PO_4).

We suspect that the high Na and low Ca and K contributed to poor growth with saltwater, although the EC was maintained at ≈2 $dS \cdot m^{-1}$ when using the 50% LF. Although we did not kill any of the plants with saltwater, their growth was significantly reduced.

Conclusions

It is well-established that one approach to controlling salinity in substrates is the use of overirrigation to leach salts. The use of the salt balance equation helped us determine the appropriate LF to maintain substrate EC levels within the range of 2 to 4 $dS \cdot m^{-1}$. Increasing the leaching requirement with RWW did produce acceptable-quality plants in both experiments. However, increasing the leaching requirement may not be a feasible practice, especially if our goal is to use RWW in place of freshwater. Applying larger amounts of water to maintain lower substrate EC levels may defeat the purpose. We applied ≈2.5- to 3.5-times more water with RWW or saltwater by increasing the leaching requirement to lower the substrate EC. However, substrate EC was only one component impacting plant growth.

For example, the substrate EC for salt-watered plants with a 50% LF was ≈2 $dS \cdot m^{-1}$, but plant growth was significantly reduced. In this case, we suspect that high Na levels in combination with lower K and Ca levels in saltwater contributed to poor growth compared with RWW. Based on our work, we suggest that, in addition to monitoring EC levels, users should monitor Na, Ca, and K levels. The use of soil amendments that add Ca and K might improve growth when using water high in Na that can be found in some RWW and saline water sources. Further research of adding K and/or Ca to alleviate the effects of higher Na levels in saline water and RWW is necessary.

References

Al-Karaki, G.N. 2000. Growth, sodium, and potassium uptake and translocation in salt stressed tomato. J. Plant Nutr. 23:369–379, https://doi.org/10.1080/01904160009382023.

Broschat, T. and A.W. Meerow. 1991. Betrock's reference guide to Florida landscape plants. Betrock Information Systems Inc., Hollywood, FL.

Cavins, T., B. Whipker, and W. Fonteno. 2004. Established calibration curves for comparing pour-through and saturated media extract nutrient values. HortScience 39:1635–1639, https://doi.org/10.21273/HORTSCI.39.7.1635.

Deinlein, U., A.B. Stephan, T. Horie, W. Luo, G. Xu, and J.I. Schroeder. 2014. Plant salt-tolerance mechanisms. Trends Plant Sci. 19:371–378, https://doi.org/10.1016/j.tplants.2014.02.001.

Hasegawa, P.M., R.A. Bressan, J.K. Zhu, and H.J. Bohnert. 2000. Plant cellular and molecular responses to high salinity. Annu. Rev. Plant Physiol. Plant Mol. Biol. 51: 463–499, https://doi.org/10.1146/annurev.arplant.51.1.463.

Ku, C.S.M. and D.R. Hershey. 1991. Leachate electrical conductivity and growth of potted poinsettia with leaching fractions of 0 to 0.4. J. Amer. Soc. Hort. Sci. 116:802–806, https://doi.org/10.21273/JASHS.116.5.802.

Levitt, J. 1980. Responses of plants to environmental stresses. Vol. II. Water, radiation, salt, and other stresses. Academic Press, New York, NY.

Martinez, C. and M. Clark. 2009. Using reclaimed water for landscape irrigation. Univ Florida, Inst Food Agr Sci, Florida Coope Ext Serv AE44900. https://edis.ifas.ufl.edu/pdffiles/AE/AE44900.pdf. [accessed 4 Jul 2022].

Moore, K.A., C. Wasjbrot, C. Burgart, and L. Fisher. 2019. A test method to evaluate salt tolerance of ornamentals. HortTechnology 29:434–437, https://doi.org/10.21273/HORTTECH04365-19.

Munns, R. 2002. Comparative physiology of salt and water stress. Plant Cell Environ. 25:239–250, https://doi.org/10.1046/j.0016-8025.2001.00808.x.

Munns, R. and M. Tester. 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant Biol. 59:651–681, https://doi.org/10.1146/annurev.arplant.59.032607.092911.

Muhammed, S., M. Akbar, and H.U. Neue. 1987. Effect of Na/Ca and Na/K ratios in saline culture solution on the growth and mineral nutrition of rice (*Oryza sativa* L.). Plant Soil 104:57–62. https://www.jstor.org/stable/42936850. [accessed 26 Sep 2022].

Petersen, F.H. 1996. Water testing and interpretation, p 31–49. In: D.W. Reed (ed.). Water, media, and nutrition for greenhouse crops. Ball Publ, Bataivia, IL.

Satti, S.M.E. and M. Lopez. 1994. Effect of increasing potassium levels for alleviating sodium chloride stress on the growth and yield of tomato. Commun. Soil Sci. Plant Anal. 25:2807–2823, https://doi.org/10.1080/00103629409369227.

Zhu, J.K. 2003. Regulation of ion homeostasis under salt stress. Curr. Opin. Plant Biol. 6:441–445, https://doi.org/10.1016/S1369-5266(03)00085-2.