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Production and ion uptake of *Celosia argentea* irrigated with saline wastewaters

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Abstract

The reuse of saline wastewaters and groundwaters becomes a viable option for the irrigation of salt tolerant floral crops as competition for high quality water increases. A completely randomized design with three replications was used to assess the effects of two water ionic compositions and six salinity levels on the production and mineral accumulation of two cultivars of *Celosia argentea* var. *cristata* (L.) Kuntze under greenhouse conditions. Ionic water compositions mimicked sea water and saline drainage waters of the Imperial and Coachella Valleys of California. Electrical conductivity levels included 2.5 (control), 4.0, 6.0, 8.0, 10.0, and 12.0 dS m^{-1}. Seeds representing the two cultivars ("Chief Rose" and "Chief Gold") were sown in 36 greenhouse sand tanks. Leaf mineral concentrations were determined 1 month from planting for Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, total-S, and total-P. Phenotypic measurements were taken when plants were harvested after flowering. For both cultivars and ionic water compositions, concentrations for Ca^{2+}, K^{+}, and total-P decreased as salinity increased whereas Mg^{2+}, Na^{+}, and Cl^{-} concentrations increased with increasing salinity. Significant two-way interactions were found between water ionic composition and salinity for all mineral concentrations for both cultivars ($P < 0.05$). All phenotypic measurements showed an overall decrease as salinity increased for both cultivars. Based on stem length measurements, "Chief Gold" may be produced for commercial use in saline waters with electrical conductivities of 12 dS m^{-1} in both water compositions. "Chief Rose" may be produced in salinity concentrations up to 10 dS m^{-1} for water compositions similar to the Imperial and Coachella Valleys and up to 8 dS m^{-1} for water

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compositions similar to sea water. Producing cut flowers in saline waters also reduces excessive stem length, which occurs when plants are grown in control treatments.

Keywords: *Celosia argentea*; Cut flowers; Mineral nutrition; Salinity; Wastewater

1. Introduction

Saline wastewaters may provide a valuable water source for the irrigation of selected floriculture crops as water quality and quantity becomes limited and as demand for quality water increases. Historically, the agriculture industry has been one of the primary users of water resources. This is especially true in the floriculture industry where many salt sensitive crops require high quality water for irrigation to eliminate crop failures. In recent years, competition for fresh water has increased between agricultural and urban users due to population growth in many regions of California (Parsons, 2000).

Many cut flower growers are located in coastal areas of California (USA) where ground waters are becoming more saline due to sea water intrusion. Some growers in these areas are opting to sell their land and relocate further inland as coastal real estate values increase, and some are yielding to foreign producers. Inland agricultural soils typically contain higher concentrations of salts due to increased evaporative demand and can pose other limitations on flower production based on microclimate differences associated with the coast. Many of the agricultural crops grown in the inland areas of the Imperial and Coachella Valleys of southeastern California are irrigated with water from the Colorado River. Drainage from agricultural fields in this watershed typically carry salts and nutrients which increase the salinity and eutrophication potential of the water. As competition for quality water continues, the use of saline groundwaters and wastewaters for irrigation, and establishing crops in saline soils, become viable options for producing and sustaining many salt tolerant floriculture crops.

The greenhouse and nursery industries are also facing increasing political and financial pressures due to restrictions on the release of effluents and the cost of improving the quality of local water resources. Specifically, the discharge of effluents from greenhouse and nursery operations has become a critical issue with regard to contamination of rivers, streams, aquifers, and tidal pools since effluents typically contain high concentrations of salts and nutrients. In an attempt to address political, economic, and environmental issues, many growers have begun recycling these waters for use in agricultural systems. Local crop production can save energy and maintain local economic and environmental resources if irrigation and drainage issues are addressed.

Celosia argentea var. *cristata* (L.) Kuntze is a cultivated annual that has become an economically important floral crop. Native to the tropical Americas, *C. argentea* L. (Amaranthaceae) produces a dense spike that is silvery in color. Inflorescences may be cristate, fan-shaped, or brain coral-shaped and red, yellow, or pink in color for cultivated varieties (Gleason and Cronquist, 1991). *Celosia* performs well under full light and warm growing conditions, and can reach heights up to 71 cm. The Amaranthaceae is closely associated with the Chenopodiaceae which contains many species that are salt tolerant.

Given this association, and its ability to withstand particularly warm temperatures, *Celosia* was selected for its potential as a salt tolerant cut flower crop.

The purpose of this investigation was to determine if marketable cut flowers of *C. argentea* var. *cristata* could be produced when grown in saline water. Specifically, the goals of this investigation were to: (1) determine marketability of *C. argentea* ‘‘Chief Rose’’ and ‘‘Chief Gold’’ based on stem length; (2) assess morphological features for each cultivar; and (3) evaluate ion uptake for each variety when exposed to two differing water ionic compositions and six salinity levels.

2. Methods

2.1. Plantings and treatments

A 2 × 6 factorial design with three replications was used to test effects of water composition and salinity (electrical conductivity) on the ion composition and productivity for each of two cultivars of *C. argentea* var. *cristata*. Seeds representing the two cultivars (‘‘Chief Rose’’ and ‘‘Chief Gold’’) were sown in 36 greenhouse sand tanks (1.2 m × 0.6 m × 0.5 m) on 19 June 2003 at the George E. Brown, Jr., Salinity Laboratory in Riverside, CA. A total of six rows were spaced at 17.5 cm in each tank. Each row contained ten wells spaced at 5.0 cm. Three contiguous rows in each tank were planted with ‘‘Chief Rose’’ and the other three with ‘‘Chief Gold’’ with each well containing two seeds. Seedlings were thinned to one per well after emergence on 24 June 2003 resulting in 30 plants for each cultivar per tank.

Sand tanks contained washed sand with an average bulk density of 1.54 Mg m^{-3}, a volumetric water content of 0.34 $m^3\ m^{-3}$ at saturation, and 0.1 $m^3\ m^{-3}$ after the cessation of drainage. Tanks were flood irrigated after planting for ~15 min twice daily until sand was saturated with one of two water ionic compositions made with City of Riverside municipal water. Base nutrient solution for Imperial/Coachella Valleys (ICV) and sea water (SWD) compositions consisted of (in mmol): 2.3 Ca^{2+}, 3.0 Mg^{2+}, 10.5 Na^{+}, 5.0 K^{+}, 3.3 SO_4^{-}, 13.3 Cl^{-}, 5.0 NO_3^{-}, and 0.34 KH_2PO_4. Micronutrient concentrations based on Hoagland’s micronutrient solution were as follows (in μmol) for both water ionic compositions: 100.0 Fe as sodium ferric diethylenetriamine pentacetate (NaFeDTPA), 46.0 H_3BO_3, 10.0 $MnSO_4$, 0.8 $ZnSO_4$, 0.4 $CuSO_4$, and 0.2 H_2MoO_4. Calculations for the base nutrient solutions accounted for ion and mineral concentrations present in the municipal water. These solutions served as control treatments with electrical conductivities (EC_i) of 2.5 dS m^{-1}. Irrigation water was returned from the tanks by gravity to 765 L subsurface reservoirs. Water lost to evapotranspiration was automatically replenished daily to maintain target electrical conductivities in the solutions. Irrigation frequency was reduced to one per day after seedlings emerged.

Treatments were completely randomized and were initiated on 7 July 2003 after the appearance of first leaves. Target EC_i levels for both irrigation water treatments were 2.5, 4.0, 6.0, 8.0, 10.0, and 12.0 dS m^{-1} (Table 1). Salinizing salts for each treatment level were added to subsurface reservoirs in daily increments so that the 12 dS m^{-1} treatment was attained on the fifth day to avoid effects of osmotic shock. Electrical conductivity for water

Table 1
Target concentrations (mM) of salinizing salts in water solutions used to irrigate *Celosia argentea*

EC (dS m^{-1})	Ca^{2+} (mM)	Mg^{2+}	Na^+	K^+	SO_4^{2-}	Cl^-	NO_3^-
Imperial/Coachella Valleys							
2.5	2.3	3.0	10.5	5.0	3.3	13.3	5.0
4.0	3.9	6.1	20.9	5.0	6.6	27.5	5.0
6.0	5.7	9.4	32.3	5.0	10.0	42.0	5.0
8.0	7.6	12.7	43.6	5.0	13.6	57.2	5.0
10.0	9.4	16.3	55.0	5.0	17.3	72.5	5.0
12.0	11.4	19.4	66.9	5.0	20.9	87.8	5.0
Sea water							
2.5	2.3	3.0	10.5	5.0	3.3	13.3	5.0
4.0	2.3	3.0	27.4	5.0	3.3	34.8	5.0
6.0	3.4	3.4	40.5	5.0	3.3	51.3	5.0
8.0	4.6	4.6	55.1	5.0	3.3	69.8	5.0
10.0	5.8	5.8	69.8	5.0	3.3	88.4	5.0
12.0	7.1	7.1	84.3	5.0	3.3	107.0	5.0

in each reservoir was measured weekly with an Orion model 126 conductivity meter (Orion Research, Inc.; Beverly, MA) to confirm target treatment levels. Ion concentrations (Ca^{2+}, Mg^{2+}, Na^+, K^+, total-P, total-S, Cl^-, and NO_3^-) of the irrigation waters were analyzed monthly by inductively coupled plasma optical emission spectrometry (ICPOES) in order to monitor ion concentrations. Chloride was analyzed by coulometric–amperometric titration. The pH levels of irrigation waters were not controlled, but maintained equilibrium at approximately 7.5. An additional 450 mL of micronutrients was added to all reservoirs on 14 July and 2 meq/L KNO_3 on 23 July to maintain target ion levels.

Greenhouse environmental conditions were recorded at a single point above the plant canopy at hourly intervals using an automated system from 19 June to 31 August 2003. Daily air temperatures ranged from 23.1 to 42.2 °C with a mean of 32.3 °C, whereas night temperatures ranged from 21.2 to 34.4 °C with a mean of 23.9 °C. Relative humidity percentages in the day time ranged from 39.2 to 46.4% with a mean of 42.8%. Night time relative humidity values ranged from 41.2 to 47.1% with a mean of 44.6%.

2.2. *Tissue sampling and ion analysis*

On 23 July 2003, plants were harvested from each sand tank for each cultivar for ion analysis. Shoots were collected to provide at least 1.0 g of dried plant material. Fresh vegetative material was weighed, triple washed with deionized water, and dried at 70 °C in a forced air oven for 72 h. Dried plant material was weighed and ground in a Wiley mill to pass a 60-mesh screen. Total S, total P, Ca^{2+}, Mg^{2+}, Na^+, and K^+ were determined with ICPOES using a nitric–perchloric acid digest. Chloride was determined with coulometric–amperometric titration from unfiltered nitric–acetic acid extracts.

Ten plants were randomly harvested for each cultivar in each tank beginning 25 August 2003 after flowering. Plants were measured for stem length (soil line to base of inflorescence), stem weight, stem diameter (7 cm from soil line), inflorescence length, inflorescence weight, and number of leaves.

2.3. Statistical analyses

A two-way fixed-effects general linear model (GLM) analysis of variance (ANOVA) was performed to determine effects of ionic water composition (ICV or SWD) and salinity (electrical conductivity) treatment on ion composition, stem length, stem weight, stem diameter, inflorescence length, inflorescence weight, leaf number, and ion selectivity for each cultivar. Analyses were performed on replicates of tank means based on 10 plants for each variable. When differences were found, the Bonferroni multiple comparison procedure was performed to determine significant differences between individual means. An α-level of 0.05 with double precision was used for ANOVA. All statistical analyses were performed with Number Cruncher Statistical Systems (NCSS) 2001 (Hintze, 2001).

3. Results

3.1. Ion analyses

Significant two-way interactions were found between water ionic composition and salinity for all ion concentrations for "Chief Rose" including: Ca^{2+} ($F = 6.62$; $P < 0.05$), Mg^{2+} ($F = 24.7$; $P < 0.05$), Na^{+} ($F = 8.74$; $P < 0.05$), Cl^{-} ($F = 8.08$; $P < 0.05$), K^{+} ($F = 5.52$; $P < 0.05$), total-S ($F = 106.52$; $P < 0.05$), and total-P ($F = 65.91$; $P < 0.05$). Similarly, significant two-way interactions between water ionic composition and salinity were also found for all ion concentrations for "Chief Gold" including: Ca^{2+} ($F = 3.95$; $P < 0.05$), Mg^{2+} ($F = 9.53$; $P < 0.05$), Na^{+} ($F = 4.97$; $P < 0.05$), Cl^{-} ($F = 2.99$; $P < 0.05$), total-S ($F = 40.06$; $P < 0.05$), and total-P ($F = 34.42$; $P < 0.05$).

An overall decrease in Ca^{2+} concentration was evident for both water ionic compositions as electrical conductivity increased for both cultivars (Figs. 1a and 2a). Plant Ca^{2+} concentrations were higher, overall, in ICV treatments than SWD treatments for "Chief Rose". Calcium concentrations declined from 507 mmol kg^{-1} dwt in the control to 400 mmol kg^{-1} dwt in 12 dS m^{-1} for ICV treatments and from 462 mmol kg^{-1} dwt in the control to 345 mmol kg^{-1} dwt in 12 dS m^{-1} for SWD treatments (Fig. 1a). For "Chief Gold", Ca^{2+} concentrations for plants exposed to ICV treatments decreased from 509 mmol kg^{-1} dwt in the control to 363 mmol kg^{-1} dwt in 12 dS m^{-1} and from 457 mmol kg^{-1} dwt in the control to 326 mmol kg^{-1} dwt in 12 dS m^{-1} for SWD treatments (Fig. 2a).

An increase in Mg^{2+} was found for both cultivars as electrical conductivity increased (Figs. 1b and 2b). Magnesium concentrations increased in "Chief Rose" from 857 mmol kg^{-1} dwt in the control to 1498 mmol kg^{-1} dwt in 12 dS m^{-1} in ICV. In SWD, concentrations increased from 955 mmol kg^{-1} dwt in the control to 1344 mmol kg^{-1} dwt in 12 dS m^{-1} (Fig. 1b). For "Chief Gold", magnesium concentrations increased from 939 mmol kg^{-1} dwt in the control to 1515 mmol kg^{-1} dwt in 12 dS m^{-1} for ICV and from 1030 mmol kg^{-1} dwt in the control to 1369 mmol kg^{-1} dwt in 12 dS m^{-1} (Fig. 2b).

Sodium concentrations increased as electrical conductivity increased for both cultivars (Figs. 1c and 2c). For "Chief Rose," Na^{+} increased from 216 mmol kg^{-1} dwt in the control to 366 mmol kg^{-1} dwt in 12 dS m^{-1} for ICV and from 187 mmol kg^{-1} dwt in the control to 750 mmol kg^{-1} dwt in 12 dS m^{-1} for SWD (Fig. 1c). Sodium concentrations also

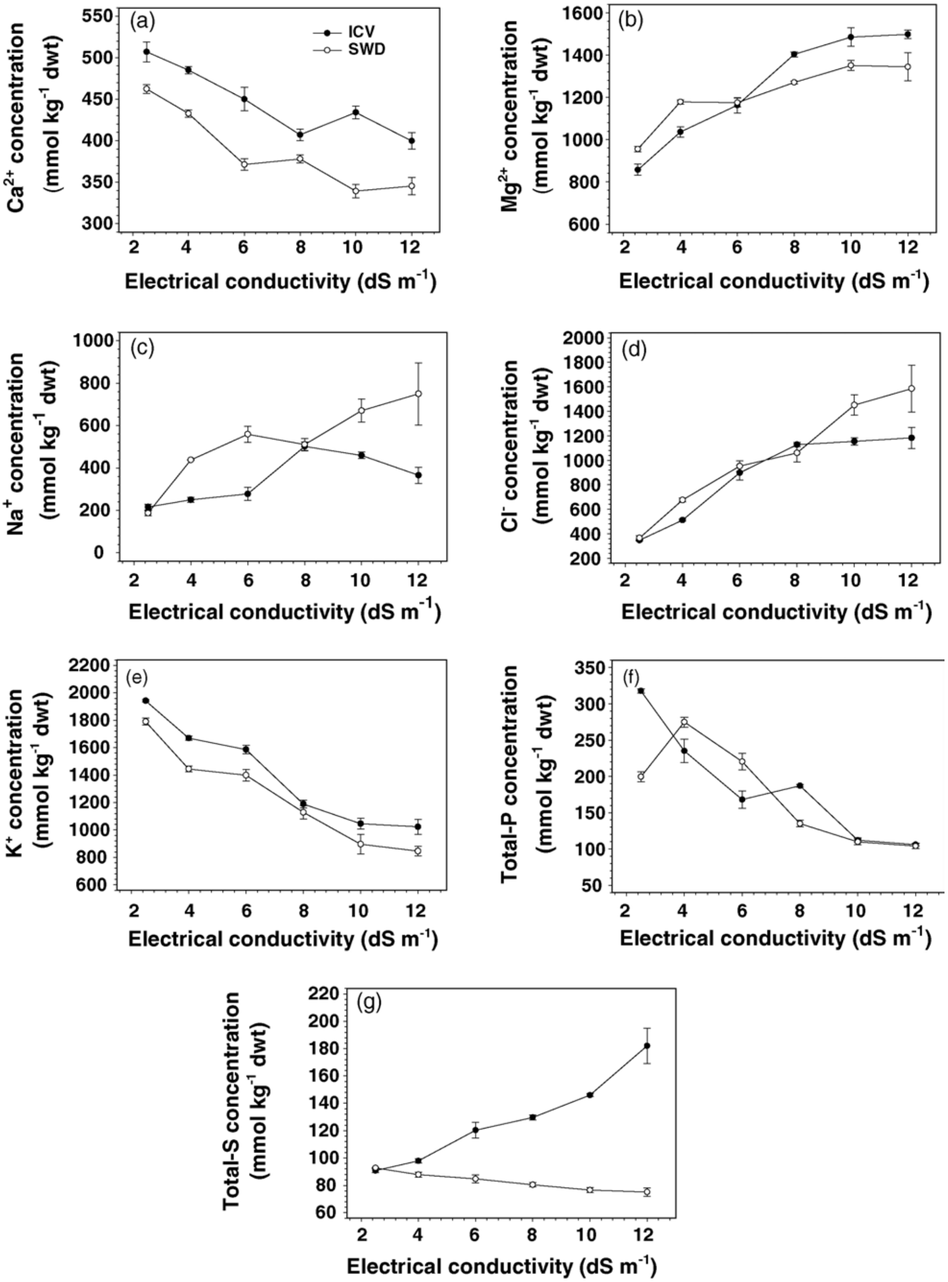

Fig. 1. Ion concentrations (mean ± S.E.) for Ca^{2+} (a), Mg^{2+} (b), Na^{+} (c), Cl^{-} (d), K^{+} (e), total-P (f), and total-S (g) of "Chief Rose" leaves when exposed to six salinity treatments and two water ionic compositions (Imperial/Coachella Valley (ICV) and sea water (SWD)).

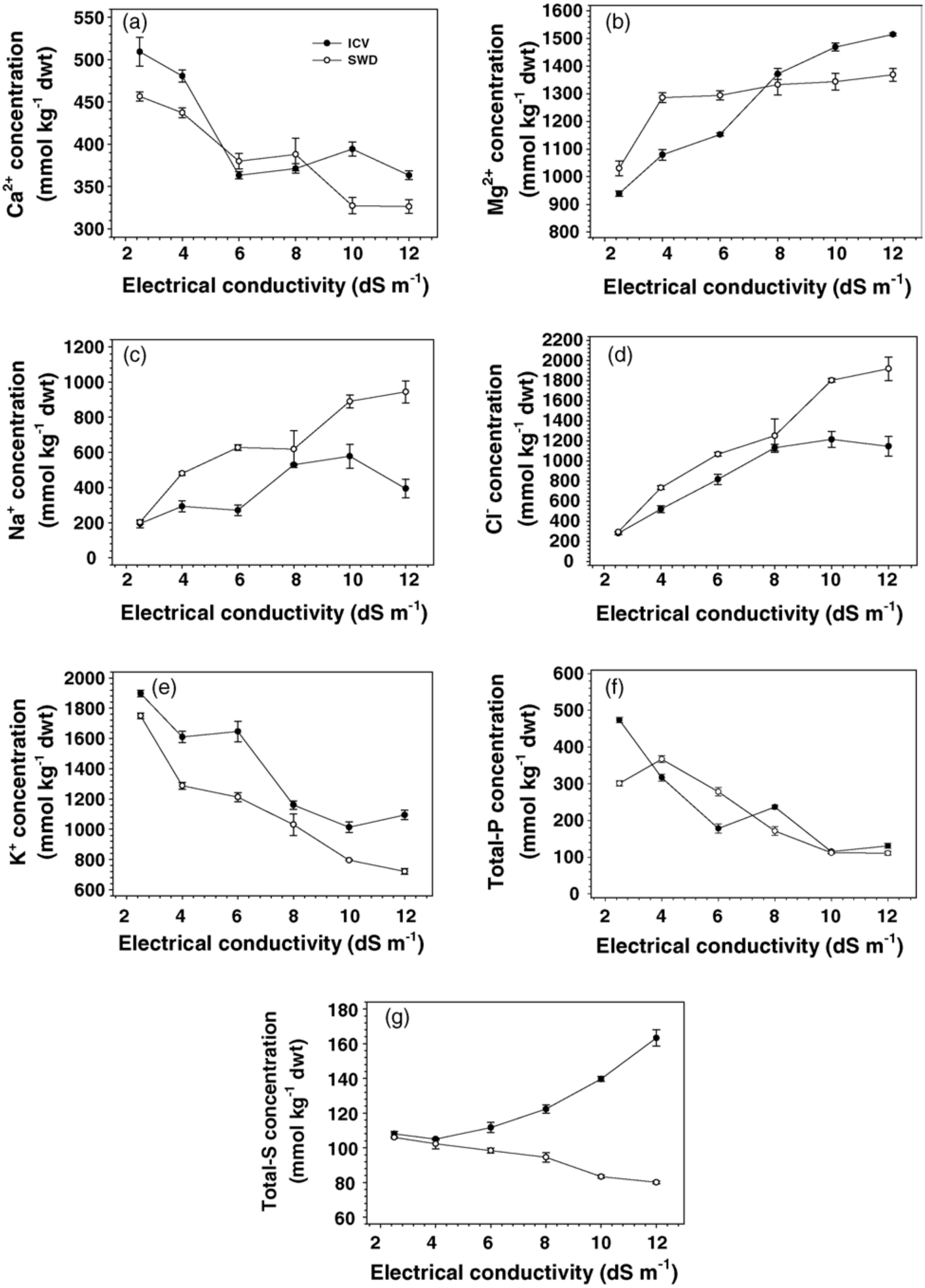

Fig. 2. Ion concentrations (mean ± S.E.) for Ca^{2+} (a), Mg^{2+} (b), Na^{+} (c), Cl^{-} (d), K^{+} (e), total-P (f), and total-S (g) of "Chief Gold" leaves when exposed to six salinity treatments and two water ionic compositions (Imperial/Coachella Valley (ICV) and sea water (SWD)).

increased from 194 mmol kg^{-1} dwt in the control to 394 mmol kg^{-1} dwt in 12 dS m^{-1} for ICV and from 203 mmol kg^{-1} dwt in the control to 944 mmol kg^{-1} dwt in 12 dS m^{-1} for SWD for ‘‘Chief Gold’’ (Fig. 2c).

Chloride concentrations also increased for both cultivars as electrical conductivity increased (Figs. 1d and 2d). Chloride concentrations increased in ‘‘Chief Rose’’ from 348 mmol kg^{-1} dwt in the control to 1183 mmol kg^{-1} dwt in 12 dS m^{-1} in ICV and from 366 mmol kg^{-1} dwt in the control to 1585 mmol kg^{-1} dwt in 12 dS m^{-1} in SWD (Fig. 1d). In ‘‘Chief Gold,’’ Cl$^-$ concentrations ranged from 281 mmol kg^{-1} dwt in the control to

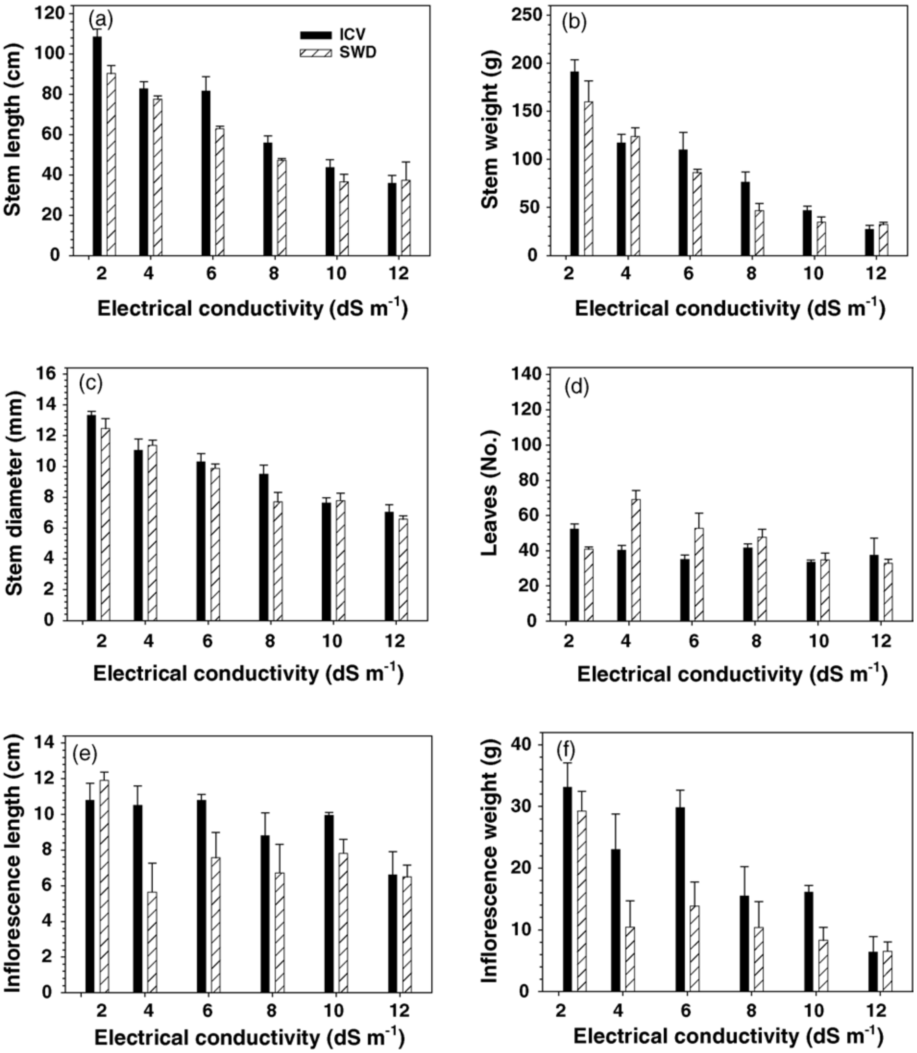

Fig. 3. Phenotypic measurements (mean ± S.E.) for stem length (a), stem weight (b), stem diameter (c), leaf number (d), inflorescence length (e), and inflorescence weight (f) of ‘‘Chief Rose’’ when exposed to six salinity treatments and two water ionic compositions (Imperial/Coachella Valley (ICV) and sea water (SWD)).

1147 mmol kg^{-1} dwt in 12 dS m^{-1} in ICV, and from 294 mmol kg^{-1} dwt in the control to 1919 mmol kg^{-1} dwt in 12 dS m^{-1} in SWD (Fig. 2d).

A decline in K$^+$ was found for both cultivars as electrical conductivity increased (Figs. 1e and 2e). In "Chief Rose," K$^+$ concentrations decreased from 1941 mmol kg^{-1} dwt in the control to 1022 mmol kg^{-1} dwt in 12 dS m^{-1} for ICV. In SWD, concentrations decreased from 1790 mmol kg^{-1} dwt in the control to 845 mmol kg^{-1} dwt in 12 dS m^{-1} (Fig. 1e). Similar results were found for "Chief Gold." Potassium concentrations declined from

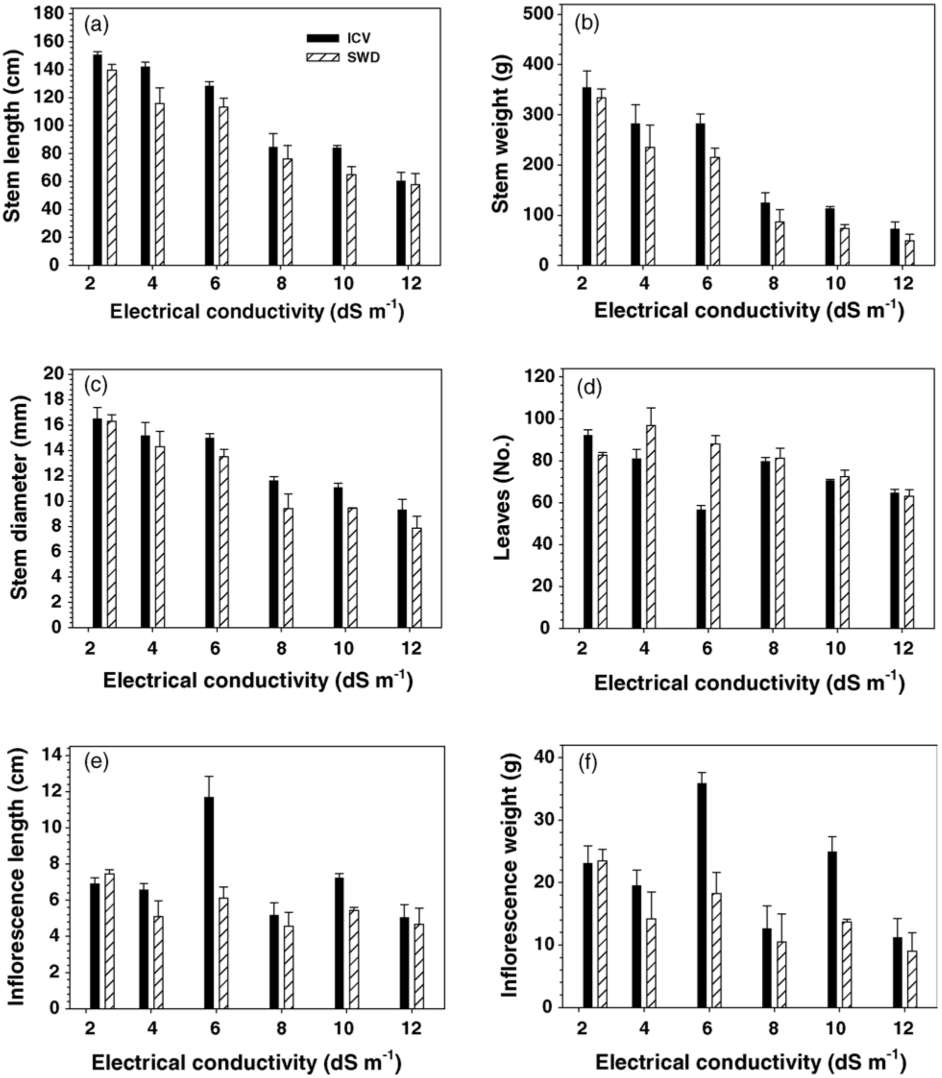

Fig. 4. Phenotypic measurements (mean ± S.E.) for stem length (a), stem weight (b), stem diameter (c), leaf number (d), inflorescence length (e), and inflorescence weight (f) of "Chief Gold" when exposed to six salinity treatments and two water ionic compositions (Imperial/Coachella Valley (ICV) and sea water (SWD)).

1898 mmol kg^{-1} dwt in the control to 1094 mmol kg^{-1} dwt in 12 dS m^{-1} in ICV and from 1750 mmol kg^{-1} dwt in the control to 721 mmol kg^{-1} dwt in 12 dS m^{-1} in SWD (Fig. 2e).

Total-P decreased for both varieties as electrical conductivity increased (Figs. 1f and 2f). Phosphorous concentrations decreased from 318 mmol kg^{-1} dwt in the control to 106 mmol kg^{-1} dwt in 12 dS m^{-1} in ICV and from 199 mmol kg^{-1} dwt in the control to 104 mmol kg^{-1} dwt in 12 dS m^{-1} in SWD for "Chief Rose" (Fig. 1f). For "Chief Gold," total-P concentrations decreased from 474 mmol kg^{-1} dwt in the control to 141 mmol kg^{-1} dwt in 12 dS m^{-1} for ICV and from 301 mmol kg^{-1} dwt in the control to 111 mmol kg^{-1} dwt in 12 dS m^{-1} for SWD (Fig. 2f).

Total-S concentrations in plants differed between the two water treatments for both cultivars (Figs. 1g and 2g). In "Chief Rose," total-S concentrations increased from 91 mmol kg^{-1} dwt in the control to 182 mmol kg^{-1} dwt in 12 dS m^{-1} for ICV, but decreased from 93 mmol kg^{-1} dwt in the control to 75 mmol kg^{-1} dwt in SWD. In "Chief Gold," total-S increased from 108 mmol kg^{-1} dwt in the control to 163 mmol kg^{-1} dwt in 12 dS m^{-1} for ICV, but declined slightly from 106 mmol kg^{-1} dwt in the control to 80 mmol kg^{-1} dwt in 12 dS m^{-1} in SWD (Fig. 2g).

3.2. Phenotypic analyses

Overall, stem length, stem weight, stem diameter, number of leaves, inflorescence length, and inflorescence weight tended to decrease as salinity (electrical conductivity) increased for both cultivars (Figs. 3 and 4). A significant two-way interaction between water ionic composition and salinity (electrical conductivity) was found for number of leaves for "Chief Rose" (Table 2). Water ionic composition was significant for stem

Table 2
F-ratios of a two-way analysis of variance (ANOVA) for phenotypic characters of "Chief Rose" and "Chief Gold" varieties of *Celosia argentea* by water ionic composition (*W*) and salinity (*S*)

Variable	*W*	*S*	$W \times S$
Chief Rose			
Stem length	13.79^{***}	63.21^{**}	1.58^{ns}
Stem weight	5.51^{*}	54.13^{**}	1.27^{ns}
Stem diameter	3.48^{ns}	44.45^{**}	1.25^{ns}
Leaf number	5.39^{*}	5.52^{***}	5.19^{**}
Inflorescence length	9.23^{**}	4.52^{**}	1.97^{ns}
Inflorescence weight	13.44^{***}	11.73^{**}	1.37^{ns}
Chief Gold			
Stem length	12.98^{***}	54.54^{**}	0.79^{ns}
Stem weight	8.26^{**}	45.4^{**}	0.25^{ns}
Stem diameter	8.64^{**}	31.83^{**}	0.39^{ns}
Leaf number	9.55^{**}	14.15^{**}	7.78^{**}
Inflorescence length	16.81^{**}	11.09^{**}	5.32^{***}
Inflorescence weight	13.72^{***}	9.71^{**}	2.61^{ns}

ns: not significant.
* $P < 0.05$.
** $P < 0.01$
*** $P < 0.001$.

length, stem weight, number of leaves, inflorescence length, and inflorescence weight for "Chief Rose" (Table 2). Salinity (electrical conductivity) was significant for stem length, stem weight, stem diameter, number of leaves, inflorescence length, and inflorescence weight for "Chief Rose" (Table 2).

Significant two-way interactions between water ionic composition and salinity were found for number of leaves and inflorescence length for "Chief Gold" (Table 2). Water ionic composition was significant for stem length, stem weight, stem diameter, number of leaves, inflorescence length, and inflorescence weight (Table 2). Salinity was significant for stem length, stem weight, stem diameter, number of leaves, inflorescence length, and inflorescence weight (Table 2).

4. Discussion

4.1. Ion analyses

An overall decrease in Ca^{2+} was found in leaves exposed to both water ionic compositions as salinity increased, and concentrations were lower in plants exposed to SWD when compared to those exposed to ICV. This can be attributed to the decreased ability of root membranes to discriminate between Ca^{2+} and Na^+ as Na^+ increases in treatment waters (Suarez and Grieve, 1988). It is reasonable to believe that lower Ca^{2+} concentrations in plants exposed to SWD are due to the higher Na^+ content in SWD treatment waters than in ICV, thereby having a greater inhibitory effect on the uptake of Ca^{2+} in both varieties.

Magnesium increased in plant tissues as salinity increased in the treatment solutions for both varieties. Calcium can outcompete Mg^{2+} for binding sites on the root plasma membrane when Ca^{2+} concentrations are high in solution (Marschner, 1995). The Mg^{2+}:Ca^{2+} ratio in the treatment solutions varied from 1.3:1 to 1.7:1 with increasing salinity for ICV and 1:1 for SWD. The increase of Mg^{2+} concentrations in plant tissues, especially in those exposed to ICV treatments, can be attributed to the relatively higher Mg^{2+} in treatment solutions with respect to Ca^{2+} and to the overall increase in Mg^{2+} in solutions as salinity increases. However, plants would more than likely accumulate higher amounts of calcium than magnesium if these floral crops were produced under field conditions. Yet it is unlikely that a magnesium deficiency would result, especially in coastal or desert soils of southern California, since magnesium is rarely a limiting factor to plant growth in soils (Salisbury and Ross, 1992) and because magnesium deficiencies have been reported to occur mostly in areas with high rainfall and in acidic, sandy soils (Embleton, 1966). Alternatively, Mg^{2+}:Ca^{2+} in sea water approximates 5:1 (Grattan and Grieve, 1999b), but in fresh water wells where sea water has intruded the ratio decreases towards 1:1 (unpublished data, Salinity Laboratory). It is reasonable to expect that these species would not demonstrate adverse reactions (magnesium toxicities or calcium deficiencies) when irrigated with water from wells where sea water intrusion is occurring.

Potassium concentrations decreased in plant tissues for both varieties as salinity increased. Since K^+ concentrations remained constant across all treatment solutions, decreases in K^+ can be attributed to an increase in Na^+ in the treatment solutions. As Na^+

increases in solution, it replaces essential nutrients and competes with K^+ for binding sites in the plant (Maathuis and Amtmann, 1999; Tester and Davenport, 2003; Subbarao et al., 2003). Na^+ was also greater in plant tissues exposed to SWD when compared to ICV as the Na^+ concentration was greatest in SWD treatment solutions.

For both varieties, chloride concentrations in plant tissues also increased with increasing salinity and were higher in plants exposed to SWD than in ICV. Higher concentrations of Cl^- were present in SWD treatment waters with respect to ICV. Cl^- concentrations in plants treated with ICV also reached an asymptote around 8 dS m^{-1}. This can be tied to the respective total-S concentrations in treatment waters. Plants have a selective preference for $SO_4{}^{2-}$ when compared with Cl^- (White and Broadley, 2001). As total-S increased in ICV treatment waters, total-S increased in plant tissues and Cl^- remained relatively constant above 8 dS m^{-1} in both varieties, thereby indicating selectivity for $SO_4{}^{2-}$. Plants treated in SWD showed increasing Cl^- concentrations when their respective total-S concentrations in treatment waters were held constant. Grieve et al. (2001) found similar responses with a study of nine leafy vegetables. They found that *Beta vulgaris* (Swiss chard), *Cichorium endivia* (curly endive), and *Cichorium intybus* (radicchio) showed an increase in total-S uptake as substrate salinity increased, but Cl^- concentrations in leaves did not differ significantly. $SO_4{}^{2-}$ concentrations for the substrate solutions in their investigation ranged from 10.9 mol m^{-3} at 3.0 dS m^{-1} to 93.5 mol m^{-3} at 23 dS m^{-1}.

Total-P decreased as salinity increased for both varieties. Decreases in total-P in plant tissues have been linked with increases in salinity and, in particular, for Ca^{2+} concentrations in the substrate (Papadopoulous and Rendig, 1983; Sharpley et al., 1992; Grattan and Grieve, 1999a). This can be attributed to the formation of calcium phosphate as the concentration of Ca^{2+} increases in the substrate solution, making P unavailable to the plant (Sharpley et al., 1992; Grattan and Grieve, 1999a). In a study including different agricultural crops, Champagnol (1979) found conflicting results for P uptake depending on the species. As substrate salinity increased, total-P concentrations decreased in tomatoes, barley, and onions, yet it increased in sesame, sorghum, and corn. Overall, similar results for ion uptake were found by Carter et al. (in press) in an investigation of *Limonium perezii* where plants were exposed to ICV and the sulphate dominated waters of the San Joaquin Valley (SJV) in California.

4.2. Marketability

The ability to produce high quality flowers with an adequate stem length is of utmost importance for any flower grower. Barr (1992) suggested that the commercial standard for stem length for cut flowers in general is 41 cm (16 in.). Our results show that marketability based on stem length is possible for both "Chief Rose" and "Chief Gold" under saline conditions. In fact, saline waters may be used to control for excessive stem lengths which occurs when plants are produced in the highest quality water (control) and even in moderate salinities. In this sense, saline irrigation water functions as a natural alternative to growth regulators (used by many growers to shorten plant height) and encourages the use of saline wastewaters in place of high quality water. In a study of cut chrysanthemum exposed to increasing soil moisture tensions, Lieth and Burger (1989) found that chrysanthemums had relatively shorter stems, but inflorescence size and timing remained unaffected. The cut flowers produced were still marketable based on inflorescence size and stem length even though overall stem lengths were reduced. This investigation shows that ‘‘Chief Gold’’ may be produced for commercial use in saline waters with electrical conductivities of 12 dS m^{-1} in both water compositions. ‘‘Chief Rose’’ may be produced in salinity concentrations up to 10 dS m^{-1} for water compositions similar to the Imperial and Coachella Valleys (areas that have a higher concentration of sulphates) and up to 8 dS m^{-1} for water compositions similar to sea water (compositions dominated by sodium and chloride). It is still important to consider plants with stems under 41 cm for production for local markets as longer stemmed plants are required for shipping longer distances. Armitage (1993) reported that the average stem lengths for ‘‘Chief Gold’’ and ‘‘Chief Rose’’ were 54.7 cm (22.6 in.) and 36.6 cm (14.4 in.), respectively, when produced in the field under ideal conditions. Devitt and Morris (1987) found that plant height for *C. argentea* L. ‘‘Apricot Brandy’’ ranged from 39 cm in 0.8 dS m^{-1} to 20.4 cm in 4.5 dS m^{-1} under greenhouse conditions. Salinity treatments in their investigation were based on a 2:1 equivalent-weight basis using $CaCl_2$ and NaCl.

Devitt and Morris (1987) found inflorescence lengths for ‘‘Apricot Brandy’’ to range from 4.1 cm in 0.8 dS m^{-1} to 2.3 cm in 4.5 dS m^{-1}. Inflorescence lengths in our study remained above 5.1 cm for all treatments for both varieties. Overall reductions in stem weight, leaf number, and inflorescence weight also provide an added benefit to growers in that shipping weights are reduced. Devitt and Morris (1987) also found the number of leaves per plant decreased from 115.7 in 0.8 dS m^{-1} to 59.2 in 4.5 dS m^{-1}.

5. Conclusions

Saline waters that are dominated by sulphate and chloride salts may be used to produce *C. argentea* L. (‘‘Chief Rose’’ and ‘‘Chief Gold’’) commercially. ‘‘Chief Gold’’ may be produced in saline waters with electrical conductivities of 12 dS m^{-1} in both water compositions. ‘‘Chief Rose’’ may be produced in salinity concentrations up to 10 dS m^{-1} for water compositions similar to the Imperial and Coachella Valleys and up to 8 dS m^{-1} for water compositions similar to sea water. Higher salinities may be used, if plants are being produced for local markets where longer stems may not be as necessary as they are when shipping over long distances. Other morphological features including inflorescence length and weight, leaf number, stem weight, and stem diameter tended to show an overall decrease as salinity increased. Both varieties showed similar responses in the uptake of ions. Overall, concentrations for Ca^{2+}, K^+, and total-P decreased as salinity increased, whereas Mg^{2+}, Na^+, and Cl^- concentrations increased with increasing salinity. Mineral uptake within plant tissues can be directly related to the compositions of the substrate solutions.

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