

Response of *Matthiola incana* to Irrigation with Saline Wastewaters

C.M. Grieve,¹ J.A. Poss, and C. Amrhein²

U.S. Department of Agriculture, Agricultural Research Service, George E. Brown, Jr., Salinity Laboratory, 450 West Big Springs Road, Riverside, CA 92507

Additional index words. drainage water reuse, floriculture, ion selectivity, sand culture, stock

Abstract. Two cultivars of *Matthiola incana* (L.) R. Br. ('Cheerful White' and 'Frolic Carmine') were grown in greenhouse sand cultures to determine the effect of salt stress on growth, ion relations, and flower quality. Two types of irrigation waters, differing in ion composition, were prepared to simulate saline wastewaters commonly present in two inland valley locations in California. Solution ICV was typical of saline tailwaters frequently found in the Imperial and Coachella Valleys and contained Cl^- , Na^+ , SO_4^{2-} , Mg^{2+} , Ca^{2+} , predominating in that order. Solution SJV was dominated by Na^+ and SO_4^{2-} and simulated saline drainage effluents often present in the San Joaquin Valley. Five treatments of each salinity type were imposed; each was replicated three times. Electrical conductivities of the irrigation waters (EC_i) were 2.5, 5, 8, 11, and 14 $\text{dS}\cdot\text{m}^{-1}$. Plant heights were determined weekly. Seedlings were sampled for ion analysis 9 weeks after planting. Flowering stems were harvested when about 50% of the florets in the inflorescence were open. Total stem length, weight and diameter, numbers of florets and buds, and inflorescence length were measured at final harvest. All plants remained healthy throughout the experimental period with no visible signs of ion toxicity or deficiency. Although length of the flowering stems decreased with increasing salinity, stems were of marketable quality even at the highest salinity level. Mineral ion composition of the vegetative tissues generally reflected ion concentrations in the irrigation waters. Shoot Mg^{2+} and Cl^- were higher and shoot Na^+ lower in seedlings irrigated with ICV waters than with SJV waters. Shoot P was reduced over control levels once salinity exceeded 11 $\text{dS}\cdot\text{m}^{-1}$. Both cultivars were highly selective for K^+ over Na^+ and selectivity coefficients ($S_{\text{K,Na}}$) increase about 60% as salinity increased from 2.5 to 14 $\text{dS}\cdot\text{m}^{-1}$. This study illustrates that commercially acceptable cut flowers of stock may be produced under irrigation with moderately saline wastewaters.

As quality and quantity of water resources become limited in many parts of the world, new options must be sought to make more efficient use of wastewaters. Because agriculture is the main user of our water supplies, there is strong interest in increasing the efficiency of water use through reuse options. Reuse of wastewaters would preserve greater amounts of high quality water and may also provide a resource for the production of selected high value horticultural crops, including vegetable, flower, herb, and medicinal species.

In California, >300 growers market cut flowers and foliage valued at almost \$366 million annually. These growers produce 60% of all domestically grown, commercially sold cut flowers in the United States (California Cut Flower Commission, 2003). Because many floricultural crops are salt sensitive, growers have traditionally used high-quality waters for irrigation. The availability of these water resources, however, is dwindling through

competition between domestic, ecological and agricultural users. At the same time, the condition of water resources in many areas is deteriorating due to the build-up of salts and other contaminants. Floricultural crop producers must eventually develop innovative ways to manage available waters, including degraded waters, more judiciously. It becomes important, therefore, to identify floral species that will produce a commercially acceptable crop when irrigated with brackish wastewaters. This strategy, together with management practices that avoid salt accumulation in the root media, will provide the grower with an economically and environmentally sound water reuse options.

Several commercially important floral and ornamental crops possess some degree of salt tolerance. Growers have exploited this variability to expand profitable cut flower industries in regions that lack reliable sources of high quality water, e.g., the Netherlands, India, Spain, and Israel. Successes in breeding and selection techniques have been coupled with improved methods of cultivation. As a result of these advances, cut flower crops such as *Limonium*, *Dianthus*, *Gypsophila*, *Helianthus*, *Matthiola*, and *Chrysanthemum* are routinely grown throughout the Negev desert of Israel in fields irrigated with local saline waters (Shillo et al., 2002).

All salinity effects on floriculture crops may not be negative. Salt stress often induces some favorable effects on crop yield, quality, and disease resistance. In some instances, uptake and accumulation of salinizing ions stimulate

growth. Cabrera and Perdomo (2003) observed a positive correlation between relatively high leaf Cl^- concentrations (0.45%) and dry weight in container-grown rose ('Bridal Pink' on *Rosa manetti* rootstock). Flower yield and quality components were unaffected. Salinity imposed early in the life cycle of some cut flower species tends to limit vegetative growth with positive results. For example, reduction of petiole length by salinity may be beneficial in chrysanthemum production where tall cultivars are treated with growth regulators to keep the plants short. Lieth and Burger (1989) found that while plant height was reduced by salinity, developmental timing and inflorescence size were unaffected by stress. The authors suggest that imposition of salinity at appropriate stages of growth would reduce production costs by avoiding the use of growth inhibitors to control stem length.

Application of salinity after some optimum level of vegetative growth has been reached, tends to enhance reproductive growth and often improves crop quality. Shillo et al. (2004) reported that salinity imposed on *Eustoma grandiflorum* during the final stages of vegetative growth resulted in significant increases in numbers of flowers, stem weight and stem diameter. Another benefit of salt treatment was the production of more compact flower clusters, a desirable trait which prevents drooping of *Eustoma* inflorescences. Similar positive effects have been noted with carnation. Salt stress during early reproductive growth resulted in shorter, more robust peduncles with larger inflorescences compared to the nonsaline controls (Baas et al., 1995).

Many stock cultivars appear to be relatively salt tolerant (Heuer and Ravina, 2004). However, wide cultivar differences in sensitivity to chloride have been noted. For example, cultivar 'Ball lilac-lavender' was grown in soil cultures irrigated with a solution containing 5 mM Cl^- (Wigdor et al., 1958). Compared to the Cl^- -free control, this relatively low Cl^- concentration did not reduce stem length, but caused severe leaf tip and interveinal necrosis. In contrast, Lunt et al. (1954) evaluated the salt tolerance of six stock cultivars in soil cultures by comparing plant response to two chloride-dominated irrigation solutions, i.e., $\text{Cl}^- = 85$ mM and $\text{Cl}^- = 171$ mM. Flower quality was not affected and leaf injury was not observed until the Cl^- concentration exceeded 85 mM. Plants grown at the higher salinity were significantly shorter and the basal leaves were chlorotic.

In 2003, California growers produced 24 million stems of stock [*Matthiola incana* (L.) R. Br.] with a retail value of about \$6 million (California Cut Flower Commission, 2003). This greenhouse study was designed to evaluate the effect of saline irrigation waters differing in ion composition on the ion relations, growth and yield of a commercially important cut flower crop.

Materials and Methods

Stock cultivars 'Cheerful White' and 'Frolic Carmine' were grown in greenhouse sand cultures. On 10 Jan. 2003, 20 seeds of each cultivar were planted in each of 30 sand

Received for publication 14 July 2005. Accepted for publication 14 Sept. 2005. The authors are indebted to Phyllis Nash for statistical analyses and to Donald A. Layfield for mineral ion analysis. Seed was donated by Sakata Seed America, Inc., Morgan Hill, Calif. This research was supported in part by a CAL-FED grant, administered by the California Department of Water Resources, Project Manager, Debra Gonzalez.

¹To whom reprint requests should be addressed; e-mail cgrieve@ussl.ars.usda.gov.

²University of California, Department of Environmental Sciences, 214 Science, Laboratory 1 Riverside, CA 92521.

Table 1. Composition of salinizing salts in solutions used to irrigate *Matthiola incana* grown in greenhouse sand cultures. Solution ICV was typical of saline tailwaters frequently found in the Imperial and Coachella Valleys and contained Cl^- , Na^+ , SO_4^{2-} , Mg^{2+} , Ca^{2+} , predominating in that order. Solution SJV was dominated by Na^+ and SO_4^{2-} and simulated saline drainage effluents often present in the San Joaquin Valley.

EC ($\text{dS}\cdot\text{m}^{-1}$)	Salinity type	Salt ($\text{mmol}\cdot\text{L}^{-1}$)				
		Ca^{2+}	Mg^{2+}	Na^+	SO_4^{2-}	Cl^-
2.5	Solution ICV ^z	2.6	3.0	10.6	3.3	13.2
5		4.8	7.7	26.6	8.3	34.8
8		7.6	12.7	43.6	13.6	57.2
11		10.0	17.9	61.0	19.1	80.2
14		13.5	23.5	81.0	25.2	107.0
2.5	Solution SJV ^y	2.6	1.5	13.8	7.0	7.0
5		5.3	4.1	36.4	18.2	17.6
8		8.3	6.6	58.2	29.5	28.2
11		11.5	9.2	80.9	41.1	39.2
14		13.0	12.7	113	54.1	54.6

^zIrrigation water compositions prepared to simulate saline wastewaters commonly present in the Imperial and Coachella Valleys of California.

^yIrrigation water compositions prepared to simulate saline wastewaters commonly present in the San Joaquin Valley of California.

tanks. The tanks ($1.2 \times 0.6 \times 0.5$ m deep) contained washed sand having an average bulk density of $1.7 \text{ Mg}\cdot\text{m}^{-3}$. At saturation the sand had an average volumetric water content of $0.34 \text{ m}^3\cdot\text{m}^{-3}$, and $0.1 \text{ m}^3\cdot\text{m}^{-3}$ after drainage, had nearly ceased. Plants were irrigated three times daily with complete nutrient solution with an electrical conductivity (EC) of $2.5 \text{ dS}\cdot\text{m}^{-1}$. In addition to the ions shown in Table 1 for this nonsaline control treatment, the irrigation waters also contained KNO_3 (3 mM), KH_2PO_4

(0.340 mM) and the following micronutrients (in μM): chelated-Fe 50, H_3BO_3 23, MnSO_4 5, ZnSO_4 0.4, CuSO_4 0.2, and H_2MoO_4 0.1 made up with City of Riverside municipal water ($\text{EC} = 0.6 \text{ dS}\cdot\text{m}^{-1}$). Irrigations were of 15 min duration, which allowed the sand to become completely saturated, after which the solutions drained to 765-L reservoirs for reuse in the next irrigation. Water lost by evaporation was replenished automatically each day to maintain constant ECs in the solutions.

Two irrigation water types were used to simulate typical compositions of saline wastewaters present in two inland valley areas of California and from predictions based on appropriate simulations of what the long-term composition of the water would be upon further concentrations by plant-water extractions and evapotranspiration (Suarez and Simunek, 1997). Fifteen sand tanks were irrigated with solution ICV, whose composition was prepared to mimic major ions in Cl-dominated saline tailwaters found in the Imperial and Coachella Valleys. The remaining 15 sand tanks were irrigated with solution SJV typical of the saline-sodic effluents common to the western San Joaquin Valley (Table 1).

Salinization of the solutions commenced on 27 Jan. 2003 when the first true leaves were fully expanded on >50% of the seedlings. The rationale for delaying salinization was based on the assumption that a source of good-quality water would be available to the grower during stand establishment of the crop, and that thereafter the crop would be irrigated with degraded waters. Salt concentration in the nutrient solution was incrementally increased over 8 d to avoid osmotic shock to the seedlings. Final electrical conductivities (EC) of the irrigation waters were 2.5, 5, 8, 11, and $14 \text{ dS}\cdot\text{m}^{-1}$. The experimental design was two irrigation water types (solutions SJV and

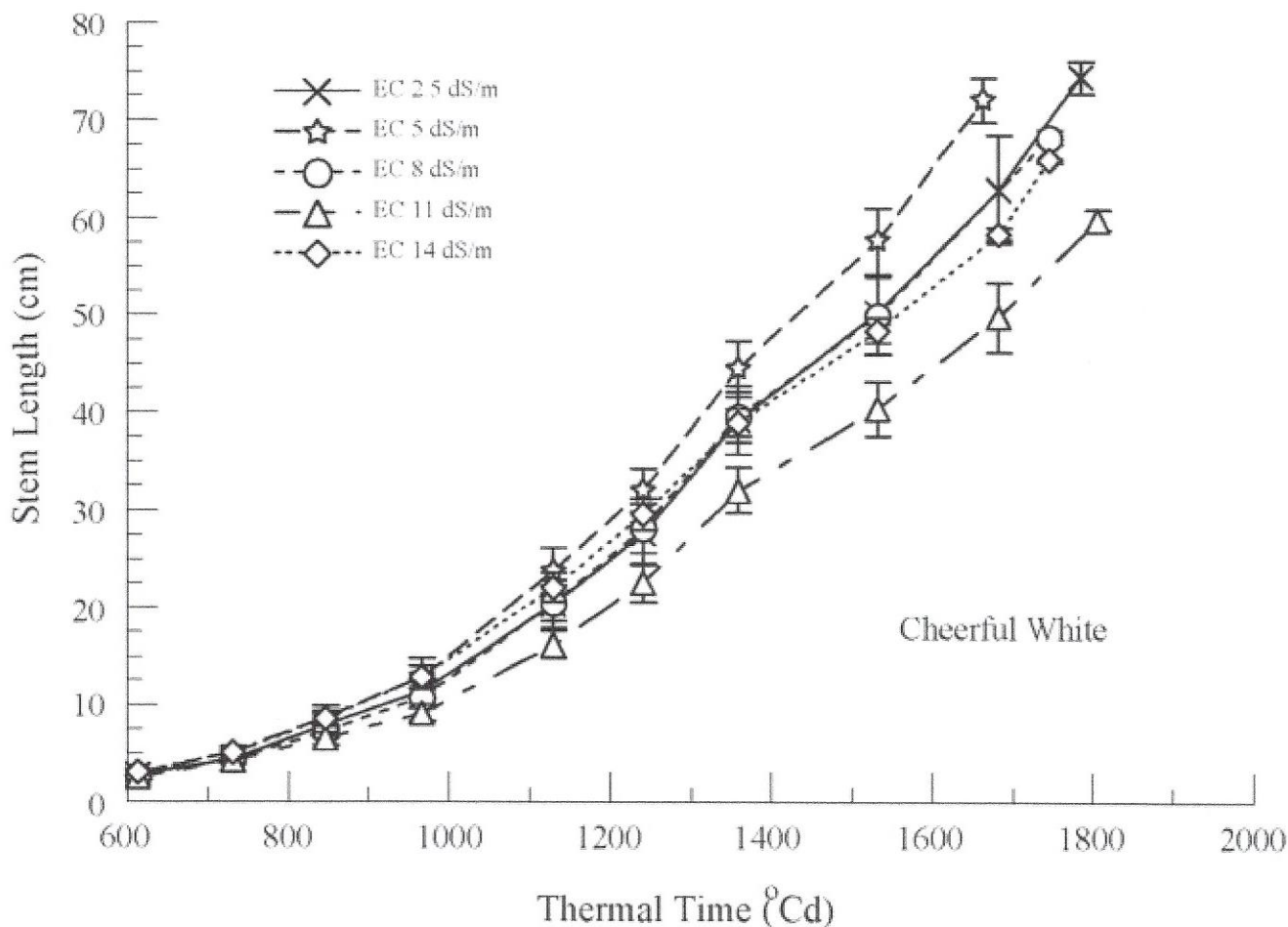


Fig. 1. Stem length of *Matthiola incana* ("Cheerful White") as a function of thermal time after planting. Irrigation waters were prepared to simulate saline wastewaters commonly present in the Imperial and Coachella Valleys of California. Values are the means of 30 observations \pm SE.

ICV), six salinity levels, two stock cultivars, and three replications.

Irrigation waters were analyzed by inductively coupled plasma optical emission spectrometry (ICPOES) four times during the experiment to confirm that target ion concentrations were maintained. Chloride was determined by coulometric-amperometric titration.

Standard meteorological measurements were made in the greenhouse with a Class 1 agrometeorological station. Ambient daytime air temperatures in the greenhouse during the experiment ranged from 8.4 to 36.0 °C (mean = 22.3 °C); nighttime temperatures ranged from 6.6 to 25.5 °C (mean = 14.7 °C). Relative humidity ranged from 42.8% to 47.5% with a mean of 45.4% during the day and 45.7% during the night. Daylength ranged from 10 h 11 min to 13 h 45 min. The pH of the solutions was slightly alkaline and ranged between 7.8 and 8.4.

Shoot vegetative tissues were sampled for mineral ion analysis on 12 Mar. 2003. Samples were weighed, washed in deionized water, dried in a forced-air oven at 70 °C for 72 h, then reweighed, and ground to pass a 60-mesh screen. Total S, total P, Ca²⁺, Mg²⁺, Na⁺, and K⁺ were determined on nitric-perchloric acid digests of the tissues

by ICPOES. Chloride was determined on nitric-acetic acid extracts by coulometric-amperometric titration.

Stems were harvested when about 50% of the flowers in the inflorescence were open (Armitage, 1993). Harvesting began 7 Mar. and continued until 7 May 2003. Plant measurements taken at this time were stem length and weight, inflorescence length, numbers of flowers and buds on the main inflorescence, and diameter of the largest flower in the spike. Stem diameter was measured 5 cm above the sand level.

Ion selectivity coefficients were calculated from the ratio of specific ions in the plant divided by the ratio of those ions in the external medium (Flowers and Yeo, 1985). Daily thermal units (T_u) were calculated from daily maximum (T_{max}) and minimum (T_{min}) air temperatures above a base temperature (T_b) following Hodges (1991): $T_u = [(T_{max} + T_{min})/2]/T_b$, where T_b is assumed to be 0 °C. The sum of T_u provided cumulative thermal units ($\sum T_u$), expressed in degree Celsius days (°C days).

Statistical analyses were performed by analysis of variance with mean comparisons at the 95% level based on Tukey's studentized range test. SAS release version 8.02 was used (SAS Institute, Inc., 2001).

Results and Discussion

Growth and yield. Throughout the course of the present study, both cultivars remained healthy in all treatments with no visible signs of ion toxicities or nutrient deficiencies.

Dry weights of shoots harvested 6 weeks after application of salinity were not significantly reduced by treatment. Regardless of cultivar, salinity level, or solution ion composition, mean shoot dried weight was 1.6 g/plant (data not shown). However, treatment effects on stem elongation were evident as early as four weeks after salinization (i.e., $\sum T_u = 1425$ °C d). For example, stem lengths of 'Cheerful White' (Fig. 1) and 'Frolic Carmine' (Fig. 2) irrigated with the most saline ICV waters (EC = 14 dS·m⁻¹) were significantly shorter than those under treatment with nonsaline control waters.

Stem length, measured at final harvest, showed the effects of salinity, e.g., length of 'Cheerful White' stems of plants irrigated with ICV waters decreased from 75 to 66 cm as salinity increased from 2.5 to 14 dS·m⁻¹. Stems of 'Frolic Carmine' were significantly shorter than those of 'Cheerful White', ranging from 69 to 62 cm as the EC of ICV irrigation waters increased to 14 dS·m⁻¹. The effect of salinity on plant growth as a function of thermal time under treatment is shown in Fig. 1 ('Cheerful

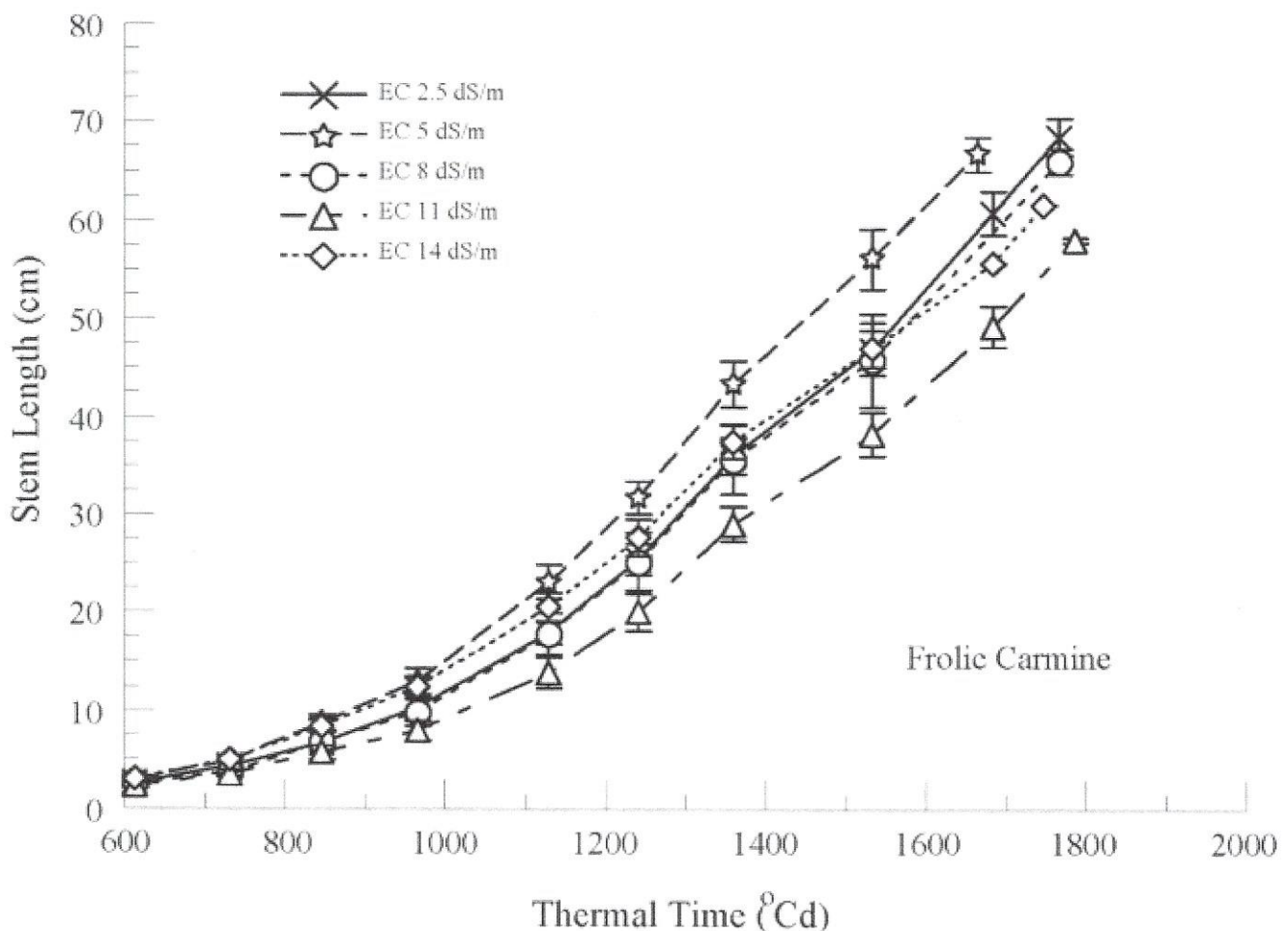


Fig. 2. Stem length of *Matthiola incana* ('Frolic Carmine') as a function of thermal time after planting. Irrigation waters were prepared to simulate saline wastewaters commonly present in the Imperial and Coachella Valleys of California. Values are the means of 30 observations \pm SE.

Table 2. Growth parameters of stock grown determined at final harvest. Plants were grown in greenhouse sand tanks with two types of irrigation waters and five salinity levels. Solution ICV was typical of saline tailwaters frequently found in the Imperial and Coachella Valleys and contained Cl⁻, Na⁺, SO₄²⁻, Mg²⁺, Ca²⁺, predominating in that order. Solution SJV was dominated by Na⁺ and SO₄²⁻ and simulated saline drainage effluents often present in the San Joaquin Valley.

EC (dS·m ⁻¹)	Yield parameter	Cheerful White		Frolic Carmine	
		ICV		SJV	
2.5	Stem length (cm)	75 a ^c	69 a	68 a	62 ab
5		72 a	68 a	70 a	66 a
8		68 bc	66 a	71 a	64 ab
11		60 d	58 b	64 b	61 b
14		66 c	62 b	58 c	53 c
2.2	Stem weight (g)	178 a	135 a	139 b	111 bc
5		180 a	142 a	190 a	154 a
8		158 a	140 a	186 a	147 a
11		130 b	105 b	156 ab	125 b
14		167 a	133 a	128 b	100 c
2.2	Stem diameter (mm)	5.3 a	5.4 ab	5.4 a	5.3 ab
5		5.3 a	5.6 a	5.1 ab	5.5 a
8		5.3 a	5.3 ab	5.1 ab	5.3 ab
11		5.1 ab	5.1 c	5.3 ab	5.2 b
14		5.2 ab	5.3 bc	5.1 ab	5.1 b
2.2	Inflorescence length (cm)	30 a	29 a	30 a	29 a
5		29 a	25 ab	28 ab	27 a
8		26 a	24 ab	25 ab	25 ab
11		22 a	22 b	26 ab	26 a
14		26 a	25 ab	22 b	20 b
2.2	Number of flowers per inflorescence	21 a	20 a	20 a	19 ab
5		22 a	20 a	23 a	22 a
8		20 a	19 a	20 a	19 ab
11		19 a	18 a	20 a	20 ab
14		25 a	21 a	21 a	18 b

^aWithin columns and growth parameter, means followed by a different letter are significantly different at the 0.05 probability level according to Tukey's studentized range test. Values are the means of 30 observations.

White') and Fig. 2 ('Frolic Carmine') irrigated with ICV waters.

Salinity had little effect on weight of the flowering stems, stem diameter, inflorescence length and numbers of flowers per inflorescence. With the exception of inflorescence length of both cultivars irrigated with SJV waters, trends in plant growth components due to treatment were not significant (Table 2).

Stem length of flowers is an important criteria for consumer acceptability. All the flowering stems harvested at 50% bloom in this evaluation trial were well in excess of industry standards for marketability (Barr, 1992) and would quickly reach even more desirable lengths postharvest. In addition, the inflorescences with short internodes and densely packed florets were of superior quality in all treatments.

Shoot ion concentrations and interactions. Calcium status in plants is strongly influenced by the presence by the ionic composition of the external medium. Other salinizing ions in the substrate may reduce Ca²⁺ activity and limit the availability of Ca²⁺ to the plant. (Suarez and Grieve, 1988). Cations such as Na⁺ and Mg²⁺ may displace Ca²⁺ from its extracellular binding sites within plant organs to further disrupt Ca²⁺ acquisition, uptake and transport. Shoot Ca²⁺ decreased significantly as salinity increased, despite a four-fold increase in external Ca²⁺ (Tables 3 and 4). Calcium was strongly accumulated in stock shoots, a trait that is shared by many other members of the family, Brassicaceae, and these concentrations were evidently high enough to prevent physiological disorders commonly associated with salinity-induced Ca²⁺ deficiency (Grattan and Grieve, 1999).

Shoot Mg²⁺ in stock irrigated with saline

ICV increased as salinity increased, but not to the extent that might be anticipated from the nearly 7-fold increase of external Mg²⁺.

An even more striking response in shoot Mg occurred in response to irrigation with saline SJV waters. An 8-fold increase in substrate-Mg

Table 3. Effect of increasing salinity on shoot ion concentrations in two *Matthiola incana* (L.) R. Br. cultivars in response saline irrigation waters with ion compositions typical of those present in the Imperial and Coachella Valleys of California (Solution A).

EC (dS·m ⁻¹)	Ion concn (mmol·kg ⁻¹ dry wt)						
	Ca	Mg	Na	K	P	S	Cl
Cheerful White							
2	359 a ^c	193 b	539 d	1174 a	422 a	216 b	159 c
5	524 a	233 ab	985 c	1035 b	413 a	229 ab	326 bc
8	431 b	258 a	1252 b	949 b	433 a	218 b	448 abc
11	460 b	282 a	1477 a	807 c	446 a	206 b	617 ab
14	420 b	224 ab	1594 a	754 c	288 b	251 a	721 a
Frolic Carmine							
2	536 a	180 c	644 d	1125 a	353 a	199 b	182 d
5	530 a	224 b	1058 c	940 b	351 a	217 b	377 cd
8	442 b	251 ab	1343 b	849 bc	369 a	204 b	492 bc
11	435 b	264 a	1566 ab	770 c	355 a	210 b	710 ab
14	378 b	235 ab	1727 a	654 d	202 b	243 a	916 a

^aWithin columns and cultivars, means followed by a different letter are significantly different at the 0.05 probability level according to Tukey's studentized range test. Values are the means of three replications.

Table 4. Effect of increasing salinity on shoot-ion concentrations in two *Matthiola incana* (L.) R. Br. cultivars in response saline irrigation waters with ion compositions typical of those present in the San Joaquin Valley of California (Solution B).

EC (dS·m ⁻¹)	Ion concn (mmol·kg ⁻¹ dry wt)						
	Ca	Mg	Na	K	P	S	Cl
Cheerful White							
2.5	670 a ^c	163 a	822 d	1047 a	503 a	230 b	172 c
5	534 b	148 a	1263 c	921 b	372 bc	251 ab	233 c
8	475 bc	150 a	1506 bc	800 bc	378 bc	223 b	286 bc
11	406 c	167 a	1627 b	715 cd	328 c	240 ab	405 ab
14	437 c	156 a	2068 a	645 d	440 ab	266 a	474 a
Frolic Carmine							
2.5	657 a	136 a	857 e	1024 a	434 a	223 b	171 c
5	506 b	131 a	1234 d	868 b	294 c	234 ab	242 b
8	434 bc	132 a	1464 c	791 b	308 bc	211 c	273 b
11	441 bc	133 a	1803 b	643 c	315 bc	237 ab	416 a
14	408 c	140 a	2138 a	569 c	357 b	244 a	407 a

^aWithin columns and cultivars, means followed by a different letter are significantly different at the 0.05 probability level according to Tukey's studentized range test. Values are the means of three replications.

did not significantly affect Mg^{2+} concentrations in the shoots (Tables 3 and 4).

Sodium concentrations in SJV waters were higher than in ICV waters (Table 1), therefore it is not surprising that shoot Na^+ levels in plants irrigated with the two water types are significantly different (Tables 3 and 4). Sodium in the shoots of both cultivars increased significantly as salinity increased.

Under salinity stress, maintenance of adequate levels of K^+ is essential for plant survival. Potassium is the inorganic plant solute present in highest concentration in plant cells (Marschner, 1995). Under saline conditions, K^+ makes a major contribution towards lowering the osmotic potential in root cells, a prerequisite for controlling solute transport and water balance. Potassium concentration in stock seedlings decreased significantly as salinity increased from 2.5 to 14 $dS \cdot m^{-1}$. High levels of external Na^+ not only interfere with K^+ acquisition by the roots, but also may disrupt the integrity of root membranes and alter the selectivity of the root system for K^+ over Na^+ (Grattan and Grieve, 1999). External K^+ concentration was constant in this study, whereas Na^+ increased across salinity treatments. As a result, shoot K of both stock cultivars decreased significantly as salinity increased and the ratio of K^+/Na^+ in the external solution decreased. Stock appeared to be highly selective for acquisition of K^+ over Na^+ . Selectivity coefficients ($S_{K,Na}$) increased about 60% as salinity increased from 2.5 to 14 $dS \cdot m^{-1}$ (data not shown). As salinity increased over the range of ICV treatments, values for 'Cheerful White' increased from 7.7 to 12.7, and from 5.9 to 10.0 when SJV waters were used.

Shoot P tended to decrease with increasing salinity (Tables 3 and 4). Stock appears to have a higher P requirement, and to acquire P from the external solution more efficiently, than other cruciferous species. For example, shoot P concentrations were 2- to 4-fold higher in 'Cheerful White' irrigated with SJV waters than in *Brassica* species (e.g., *B. juncea* and *B.*

rapa) grown in sand cultures and irrigated with waters of the same composition and salinity levels (Grieve et al., 2001).

Total S in shoots of both cultivars significantly increased with salinity (Tables 3 and 4). A comparison of S accumulation in shoots grown with waters differing in external SO_4^{2-} suggests that stock may possess a mechanism for limiting S uptake. For example, the concentration of total S in shoots of 'Cheerful White' (i.e., 251 $mmol \cdot kg^{-1}$) irrigated with ICV saline solutions containing 25 $mmol \cdot L^{-1}$ SO_4^{2-} was not significantly different from the concentration in shoots (i.e., 266 $mmol \cdot kg^{-1}$) irrigated with SJV waters containing twice as much SO_4^{2-} (i.e., 54 $mmol \cdot L^{-1}$). Likewise, total S in 'Frolic Carmine' was not influenced by SO_4^{2-} concentration in the most saline treatment (14 $dS \cdot m^{-1}$). Plant response to solutions differing in dominant anion concentration warrants further investigation.

Chloride in stock shoots increased significantly as salinity increased. ICV waters generally contain twice as much Cl as SJV water and this difference in external Cl was reflected in shoot Cl concentrations (Tables 3 and 4).

Conclusion

The results of this study clearly demonstrate that stock is relatively salt tolerant and that this important cut-flower crop may be produced under saline irrigation without loss of quality nor reduction of marketability.

Literature Cited

Armitage, A.M. 1993. Speciality cut flowers. Varsity Press—Timber Press, Portland, Ore.
Baas, R., M.C. Nijssen, T.J.M. van den Berg, and M.G. Warmenhoven. 1995. Yield and quality of carnation (*Dianthus caryophyllus* L.) and gerbera (*Gerbera jamesonii* L.) in a closed nutrient system as affected by sodium chloride. *Scientia Hort.* 61:273–284.

Barr, C. 1992. The kindest cuts of all: How to evaluate new crops. *Greenhouse Manager* 11:82–84.
Cabrera, R.I. and P. Perdomo. 2003. Reassessing the salinity tolerance of greenhouse roses under soilless production conditions. *HortScience* 38:533–536.
California Cut Flower Commission. 2003. cfc@ccfc.org.
Flowers, T.J. and A.R. Yeo. 1988. Ion relations of salt tolerance, p. 392–416. In: D. A. Baker and J. L. Hall (eds.). Solute transport in plant cells and tissues. John Wiley & Sons, New York.
Grattan S.R. and C.M. Grieve. 1999. Salinity mineral nutrient relations in horticultural crops. *Scientia Hort.* 78:127–157.
Grieve, C.M., M.C. Shannon, and J.A. Poss. 2001. Mineral nutrition of leafy vegetable crops irrigated with saline drainage water. *J. Veg. Crop Prod.* 7:37–47.
Heuer, B. and I. Ravina. 2004. Growth and development of stock (*Matthiola incana*) under salinity. *Austral. J. Agr. Res.* 55:907–910.
Hodges, T. 1991. Predicting crop phenology. CRC Press, Boca Raton, Fla.
Lieth, H.J. and D.W. Burger. 1989. Growth of chrysanthemum using an irrigation system controlled by soil moisture tension. *J. Amer. Soc. Hort. Sci.* 114:387–392.
Lunt, O.R., A.M. Kofranek, and S.A. Hart. 1954. Tolerance of six stock (*Matthiola incana*) varieties to saline conditions. *Proc. Amer. Soc. Hort. Sci.* 64:431–436.
Marschner, H. 1995. Mineral nutrition of higher plants. Academic Press, New York.
SAS Institute, Inc. 2001. SAS/STAT software. Changes and enhancements through release 8.02. SAS Inst., Cary, N.C.
Shillo, R., M. Ding, D. Pasternak, and M. Zaccari. 2002. Cultivation of cut flower and bulb species with saline water. *Scientia Hort.* 92:41–54.
Suarez, D.D. and C.M. Grieve. 1988. Predicting cation ratios in corn from saline solution composition. *J. Expt. Bot* 39:605–612.
Suarez, D.L. and J. Simunek. 1997. UNSATCHEM: Unsaturated water and solute transport model with equilibrium and kinetic chemistry. *Soil Sci. Soc. Amer. J.* 61:1633–1646.
Wigdor, S., R.F. Stinson, and W.W. McCall. 1958. Chloride toxicity of flowering stock and sweet peas. *Mich. Agr. Expt. Sta. Qrtly. Bul.* 40:468–476.

