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RESPONSE OF ORNAMENTAL SUNFLOWER CULTIVARS 'SUNBEAM' AND 'MOONBRIGHT' TO IRRIGATION WITH SALINE WASTEWATERS

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□ *To explore the possibility that saline wastewaters may be used to grow commercially acceptable floriculture crops, a study was initiated to determine the effects of salinity on two pollen-free cultivars of ornamental sunflower (*Helianthus annuus *L.). 'Moonbright' and 'Sunbeam' were grown in greenhouse sand cultures irrigated with waters prepared to simulate wastewaters commonly present in two inland valley regions of California: 1) San Joaquin Valley (SJV) where saline-sodic drainage waters are dominated by sodium (Na^+) and sulfate (SO_4^{2-}) and 2) Coachella Valley (CV) where major ions in tailwaters are Na^+, chloride (Cl^-), SO_4^{2-}, magnesium (Mg^{2+}), calcium (Ca^{2+}), predominating in that order. Ten-day-old seedlings were subjected to five salinity treatments of each water composition, each replicated three times. Electrical conductivities (EC) of the irrigation waters were 2.5, 5, 10, 15, and 20 $dS{\cdot}m^{-1}$. Flowering stems were harvested when about 75% of the ray flowers were nearly horizontal. Stem length and fresh weight, flower and stem diameter were measured. Mineral ion concentrations in upper and lower stems, upper and lower leaves were determined. Sodium was excluded from the young tissues in the upper portions of the shoot and retained in the basal stem tissue. Inasmuch as sunflower is also a strong potassium (K)-accumulator, K^+/Na^+ selectivity coefficients were unusually high in the younger shoot organs. Despite a five-fold increase in substrate Ca^{2+} in both solutions, shoot-Ca decreased as salinity increased and this cation was retained in the older leaves. A few of the lower leaves of plants irrigated with ICV waters at EC = 10 $dS{\cdot}m^{-1}$ and higher, exhibited necrotic margins which were undoubtedly caused by high concentrations of Cl^- in the tissues. Flowering stems produced in all treatments met florist quality standards in terms of diameters for stems (0.5 to 1.5 cm) and blooms (8 to 15 cm). Across treatments, stem lengths ranged from 60 to 175 cm. Both ornamental sunflower cultivars proved to be good candidates for production of marketable flowering stems using moderately saline wastewaters.*

Keywords: floriculture, ion relations, ion selectivity, salinity, sand cultures, water reuse

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INTRODUCTION

Water supplies in many parts of the world are dwindling through a complex system of allocation to and competition among urban, agricultural, industrial, and ecological groups. At the same time, the quality of these water resources is deteriorating due to the build-up of salts and other contaminants. In order to improve water security, new options must be sought to make more judicious reuse of the degraded, often saline, wastewaters for the production of selected agronomic and horticultural crops. Improved guidelines for selection and management of crops suitable for water reuse systems will conserve fresh water supplies, reduce the volume of drainage water requiring disposal, minimize discharge of salts to the environment and optimize land productivity.

Because many high value floricultural crops are believed to be salt sensitive, growers have been reluctant to jeopardize floral quality and economic return by using saline, recycled waters for irrigation. Presently, concerns about environmental, ecological, and regulatory issues associated with the discharge of waters from floricultural operations are growing. Capture, retention, and reuse of degraded waters offer a potential solution inasmuch as many economically-important cut flower crops are, in fact, moderately salt tolerant. Advances in methods of cultivation and management along with successes in breeding and selection techniques have enabled growers to use recycled irrigation waters for production of cut flower crops without loss of yield and quality. *Limonium, Dianthus, Celosia, Gypsophila, Matthiola, Chrysanthemum, Antirrhinum* have been identified as suitable for water reuse systems (Shillo et al., 2002; Carter et al., 2005a; 2005b; Grieve et al., 2006; Friedman et al., 2007; Carter and Grieve, 2008).

Ornamental sunflowers have been produced under irrigation with several sources of recycled waters. Arnold et al. (2003) compared the response of sunflower to irrigation with direct nursery runoff, wetland treated recycled nursery runoff, and municipal tap water with and without the addition of sodium chloride (NaCl). Electrical conductivities of the treatment solutions were as high as 3 $dS{\cdot}m^{-1}$. Secondary treated effluents [electrical conductivity (EC) = 2.9 $dS{\cdot}m^{-1}$] from a domestic sewage treatment facility were used to irrigate sunflowers in the Negev desert of Israel (Friedman et al., 2007). In both studies, all treatments produced high quality, marketable flowering stalks.

Plant response to salinity depends not only on the osmotic potential of the external solution, but also on the kinds of salts that contribute to salinity. Data on the salt tolerance of many crops are available (Maas and Grattan, 1999), but in a large percentage of these trials, the experimental irrigation waters are salinized with a single salt, often NaCl, or mixtures of NaCl and calcium chloride ($CaCl_2$). Such solutions do not reflect the ion compositions that are likely to be present in recycled effluents available to growers in

California. Over the past ten years, studies of plant salt tolerance conducted at this Laboratory have used irrigation waters prepared to simulate saline wastewaters found in three agriculturally-productive regions of California, namely the San Joaquin Valley of central CA, the southern inland Coachella Valley, and the coastal areas where seawater intrusion is often a problem. Use of these realistic solution compositions may lead to improved interpretation and prediction of plant performance in areas where these degraded waters are available for irrigation.

This study was initiated to compare growth, yield, quality and ion relations of the pollen-free cultivars of ornamental sunflower, 'Sunbeam' and 'Moonbright', in response to two irrigation waters differing in ion composition, i.e., (1) waters typical of saline-sodic drainage effluents present in the San Joaquin Valley, and (2) saline tailwaters commonly found in the Coachella Valley.

MATERIALS AND METHODS

Sunflower cultivars 'Sunbeam' and 'Moonbright' were grown in greenhouse sand cultures at the U. S. Salinity Laboratory, Riverside, CA, USA. On 13 May 2003, 40 seeds of each cultivar were planted in each of 30 sand tanks to give a planting density of 56 plants m^{-2}. The tanks ($1.2 \times 0.6 \times 0.5$ m deep) contained washed sand having an average bulk density of 1.7 $Mg \cdot m^{-3}$. At saturation the sand had an average volumetric water content of 0.34 $m^3 \cdot m^{-3}$, and 0.1 $m^3 \cdot m^{-3}$ after drainage had nearly ceased. Plants were irrigated twice daily with complete nutrient solution having an EC of 2.5 $dS \cdot m^{-1}$. In addition to the ions shown in Table 1 for this control treatment, the irrigation waters

TABLE 1 Composition of salinizing salts in solutions used to irrigate *Helianthus annuus* cultivars 'Sunbeam' and 'Moonbright' grown in greenhouse sand cultures

Salinity EC (dS m^{-1})	Salinity Type	Ca^{2+}	Mg^{2+}	Na^+	SO_4^{2-}	Cl^-
		mmol L^{-1}				
2.5	Solution CV†	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‡	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	113.0	54.1	54.6

†Irrigation water compositions prepared to simulate saline tailwaters commonly present in the Coachella Valley of California.

‡Irrigation water compositions prepared to simulate saline drainage waters commonly present in the San Joaquin Valley of California.

also contained potassium nitrate (KNO_3; 3 mM), monopotassium phosphate (KH_2PO_4; 0.340 mM) and the following micronutrients (in μM): chelated-iron (Fe) 50, boric acid (H_3BO_3) 23, manganese sulfate ($MnSO_4$) 5, zinc sulfate ($ZnSO_4$) 0.4, copper sulfate ($CuSO_4$) 0.2, and molybdic acid (H_2MoO_4) 0.1 made up with City of Riverside municipal water (EC = 0.6 $dS{\cdot}m^{-1}$). Each irrigation cycle continued for ~15 min, 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 prepared 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 waters would be upon further concentrations by plant-water extractions and by evaporation (Suarez and Simunek, 1997). Fifteen sand tanks were irrigated with solution CV whose composition was prepared to mimic major ion in saline tailwaters found in the Coachella Valley, i.e., chloride (Cl^-), sodium (Na^+), sulfate (SO_4^{2-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), predominating in that order. The remaining fifteen tanks were irrigated with solution SJV which is typical of the saline-sodic effluents commonly present in the western San Joaquin Valley which contain (in order) Na^+, SO_4^{2-}, Cl^-, Mg^{2+}, and Ca^{2+}.

Salinization commenced on 21 May 2003 when the first true leaves were fully expanded on more than 50% of the seedlings. Salts were added over an eight-day period to avoid osmotic shock to the seedlings. The delay in salinization was based on the assumption that the grower would have a source of good quality water during stand establishment of the crop, and that thereafter, recycled water would be used for irrigation. Five treatments of each salinity type were imposed. Final EC of the irrigation waters were 2.5, 5, 10, 15, and 20 $dS{\cdot}m^{-1}$. The experimental design was two irrigation water types (solutions SJV and CV), five salinity levels, two sunflower cultivars, and three replications. Based on previous studies of the soil-water dynamics in the sand tank system (Wang, 2002), the salinity treatments translate to average rootzone salinities (ECe) of 1.2, 2.3, 4.5, 6.8, and 9.1 $dS{\cdot}m^{-1}$

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

Flowering stems were harvested at maturity, i.e., about 75% of the ray flowers were near horizontal (Ball, 1997). Harvesting commenced on 28 July and continued until 20 August. Parameters measured at final harvest were: leaf number, plant height and weight, diameter of stem and flower. Stem diameters were measured 1 cm above the sand level. Quality of the flowering stems was rated using the standards given by Sloan and Harkness (2006): stem length 60 to 90 cm, stem diameter 0.5 to 1.5 cm, and bloom diameter 8 to 15 cm. Inflorescences were removed and shoots were separated into lower and upper leaves and lower and upper stems. Plant tissues were washed in deionized water, dried in a forced-air oven at 70°C for 72 hr, and ground to pass a 20-mesh screen.

Standard meteorological measurements were made in the greenhouse with a Class I agrometeorological station. Ambient daytime air temperatures in the greenhouse during the experiment ranged from 17.8 to 36.9°C (mean = 27.9°C); nighttime temperatures ranged from 16.5 to 30.6°C (mean = 21.5°C). Relative humidity ranged from 39.5 to 47.9% with a mean of 43.7% during the day and 45.1% during the night.

Total-S, total P, Ca^{2+}, Mg^{2+}, Na^+, potassium (K^+) concentrations in upper and lower leaf and stem segments were determined on nitric-perchloric acid digests of the tissues by inductively coupled plasma- optical emission spectroscopy (ICP-OES). Flowers were not analyzed for ion content. Chloride was determined on nitric-acetic acid extracts by coulometric-amperometric titration. To determine the average ion content (C_{avg}) in total shoot biomass, the concentration of each ion in the each shoot segment was multiplied by the dry weight of that segment:

$$C_{avg} = \Sigma(D_i \times C_i)/D \tag{1}$$

Where D, for example, is the total leaf dry weight (g), D_i is the dry weight of leaves in each segment, and C_i is the concentration of the ion in leaves of each segment (mmol·kg^{-1}). Average ion concentrations in stem segments were calculated in a similar manner. Values from all segments were then summed to give the average concentration of that ion in the biomass of the intact main axis, exclusive of the floral tissues.

Ion selectivity coefficients were calculated from the ratio of specific ions in the plant tissue divided by the ratio of those ions in the irrigation waters (Flowers and Yeo, 1988). 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., Cary, NC, USA).

RESULTS AND DISCUSSION

Growth

Throughout the course of the experiment, both cultivars remained vigorous and healthy, except for marginal leaf scorch on some of the lower leaves, perhaps as a result of mineral ion toxicity. Planting density was higher than recommended (Armitage, 1993) which reduced branching; all plants were single-stemmed.

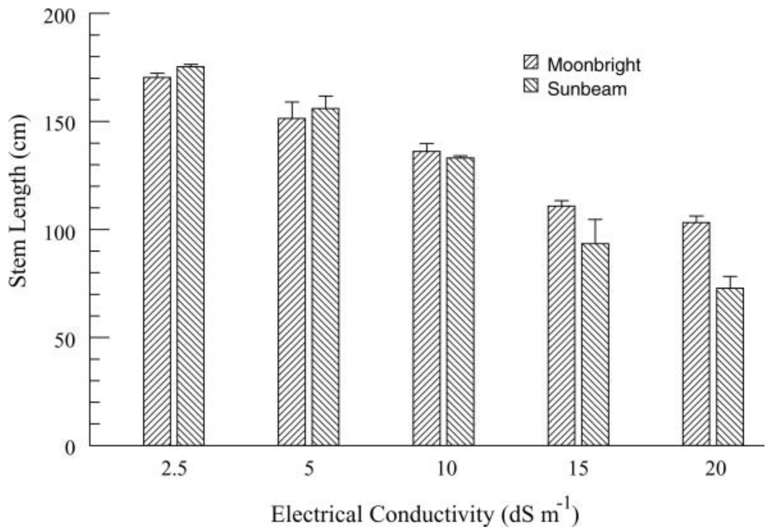

FIGURE 1 Effect of saline irrigation waters on stem length of sunflower cultivars 'Sunbeam' and 'Moonbright'. Irrigation waters were prepared to simulate saline tailwaters commonly present in the Coachella Valley of California. Values are the means of 30 observations ± SE.

Stem length of both sunflower cultivars decreased consistently and significantly as salinity increased from 2.5 to 20 dS·m^{-1} regardless of the composition of the irrigation water applied (Figures 1 and 2). This effect, however, was more pronounced for sunflower irrigated with sodium sulfate-dominated waters (SJV) than with CV waters (i.e., 65% and ∼ 40% reduction in stem

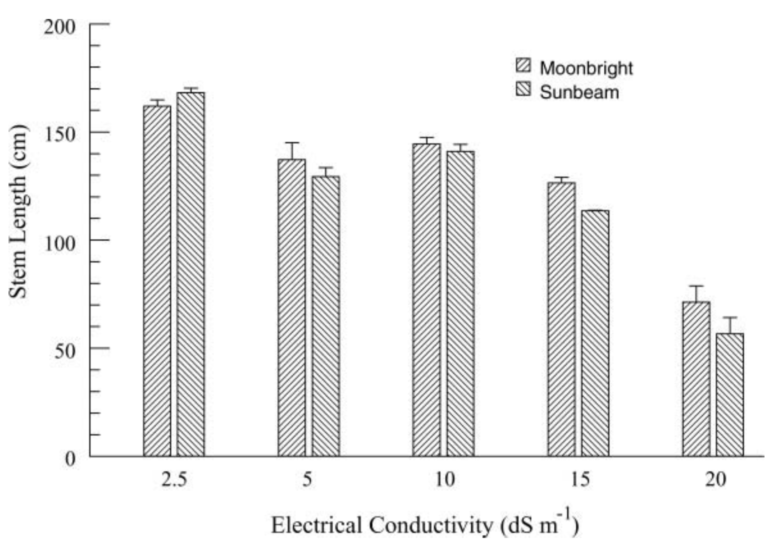

FIGURE 2 Effect of saline irrigation waters on stem length of sunflower cultivars 'Sunbeam' and 'Moonbright'. Irrigation waters were prepared to simulate drainage waters commonly present in the San Joaquin Valley of California. Values are the means of 30 observations ± SE.

length, respectively). Except at the highest salinity levels (e.g., 'Sunbeam' irrigated with waters of either composition, and 'Moonbright' irrigated with SJV waters), stems exceeded the length (60 to 90 cm) preferred by florists (Sloan and Harkness, 2006). Stems, however, can easily be shortened post-harvest and should not detract from overall market value of the crop.

Stems were sturdy and showed no signs of weakness, although stem diameters decreased significantly as salinity increased (Table 2).

In the case of ornamental sunflower, reduction of growth in terms of both fresh weight (Table 2) and stem length appears to be a positive effect of salinity. Inflorescences of many pollenless sunflower cultivars are too large for most market applications and research is underway at the University of Florida to reduce flowers to the size of gerberas and shorten stem length (Dr. E. R. Emino, Department of Environmental Horticulture, University of Florida, personal communication). Growth regulators are often used to curb excessive stem length of sunflower (Ball, 1997). Manipulation of salt stress would avoid the use of these chemicals and also reduce labor costs for pruning to the desired length, without sacrificing other quality parameters. Application of severe salt stress during vegetative growth and subsequent

TABLE 2 Growth parameters of two sunflower cultivars determined at final harvest. Plants were grown in greenhouse sand cultures with two types of irrigation waters and five salinity levels. Solution CV was typical of saline tailwaters frequently found in the Coachella Valley of CA. SJV solutions simulated saline drainage effluents often present in the San Joaquin Valley

	CV		SJV	
EC (dS m^{-1})	Moonbright	Sunbeam	Moonbright	Sunbeam
		Flower Diameter (cm)		
2.5	10.9a†	10.0a	10.4a	12.3a
5.0	10.0a	9.8a	10.3a	11.1ab
10.0	10.1a	10.2a	10.3a	11.5ab
15.0	9.8a	9.6a	10.7a	14.0ab
20.0	9.3a	9.4a	7.9b	7.5b
		Stem Diameter (mm)		
2.5	11.1a	12.3a	10.9a	13.0a
5.0	9.6ab	11.3ab	10.7a	10.8ab
10.0	9.4ab	9.7bc	10.4a	11.1ab
15.0	8.8ab	7.0cd	9.3a	8.5c
20.0	7.8b	5.8d	6.8b	5.2d
		Fresh Weight (g/plant)		
2.5	145a	188a	140a	218a
5.0	111ab	144ab	133a	126b
10.0	95bs	105b	120a	140b
15.0	72bc	54c	99a	86c
20.0	60c	40c	36b	27d

† Within columns and growth parameters, 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.

withdrawal of stress at the initiation of reproductive growth might produce a shorter stem with a flower size which meets florists' standards.

Flower size was not significantly affected as the EC in CV waters rose from 2.5 to 20 dS·m^{-1}, whereas flower diameters of both cultivars irrigated with SJV waters were reduced once the salinity reached 20 dS·m^{-1} (Table 2). Across salinity levels and cultivars, flower diameters ranged from 8 to 14 cm, well within the size preferred for floral arrangements (Sloan and Harkness, 2006).

Shoot Mineral Ion Concentrations

For this study, flowers were removed; the stalks were cut into four equal sections which were then divided into leaves and stems. Mineral ions were determined in all tissues. The shoot axis was "reassembled" mathematically as described in the Materials and Methods section. Ion concentrations in the intact stem, complete with leaves, are given in Table 3.

Calcium plays a vital nutritional and physiological role in plant metabolism. Under saline conditions, ion imbalances in the substrate or in the plant may adversely affect Ca^{2+} nutrition (Grattan and Grieve, 1999). External levels of Ca^{2+} that are adequate for plant requirements under non-saline conditions may be growth-limiting when the plant is salt-stressed. Regardless of irrigation water composition, Ca^{2+} concentration in the main axis of both sunflower cultivars decreased significantly (Table 3) despite a five-fold increase in substrate-Ca (Table 1). Similar decreases in shoot-Ca have been observed in flowering stems of *Matthiola incana* irrigated with CV and SJV waters (Grieve et al., 2006).

In response to increasing salinity and external-Mg, Mg^{2+} increased in intact shoots of both cultivars regardless of solution composition (Table 3). This response was significant for 'Sunbeam' irrigated with both water types and 'Moonbright' grown with CV waters. Increasing salinity, applied as SJV waters, had no effect on shoot-Mg in 'Moonbright', even though external-Mg increased nearly 10-fold as solution EC rose from 2.5 to 20 dS·m^{-1}.

Shoot Na increased significantly as salinity increased and was higher in plants irrigated with saline-sodic SJV waters than in those irrigated with CV solutions (Table 3), reflecting the relative difference in external-Na concentration (Table 1). Shoot-K in both cultivars tended to decrease as salinity increased, but this effect was significant only with those plants irrigated with solution SJV (Table 3). Regardless of irrigation water composition, shoot-Cl in both cultivars tended to increase only 2-fold or less, although external-Cl rose 7- to 8-fold (Table 3). Patterns of phosphorus accumulation in shoots were inconsistent with no clear trends (Table 3). Total-S increased as salinity and substrate-SO_4 increased and was routinely higher in shoots irrigated

TABLE 3 Effect of increasing salinity on the average ion concentrations in the above-ground main axis (exclusive of floral tissue) of two sunflower (*Helianthus annuus* L.) cultivars. Saline irrigation waters were prepared to simulate ion compositions typical of those present in the Coachella (CV) and San Joaquin (SJV) valleys of California

	Ion concentration (mmol kg^{-1} dry wt)						
EC(dS m^{-1})	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Total-P	Total-S	Cl^{-}
'Sunbeam" Solution CV							
2.5	376ab[†]	213c	19b	1124a	96a	55b	374b
5	436a	297b	44b	1076a	183a	66ab	499b
10	443a	341b	48b	1316a	120a	78ab	885a
15	453a	423a	121a	1045a	172a	90a	991a
20	291b	328b	142a	818a	86a	81a	853a
'Sunbeam' Solution SJV							
2.5	469a	282b	28c	1340a	222a	85c	440b
5	515a	336ab	104bc	1421a	174a	113bc	620ab
10	524a	314ab	104bc	1513a	232a	125b	699a
15	398b	311ab	173b	1354a	198a	121b	774a
20	344b	357a	393a	914a	270a	192a	740a
'Moonbright' Solution CV							
2.5	361ab	142c	23d	1375a	83bc	64c	641c
5	376a	192b	33cd	1370a	168a	74bc	691bc
10	309bc	194b	65bc	1104a	68c	83abc	776abc
15	317abc	262a	99ab	1172a	130ab	98ab	861ab
20	269c	257a	134a	1130a	92bc	106a	954a
'Moonbright' Solution SJV							
2.5	474a	190a	33b	1552a	209a	97b	507b
5	420b	194a	80b	1448ab	142a	99b	561b
10	385b	183a	155ab	1309b	189ab	136ab	686a
15	308c	189a	172ab	1383ab	170ab	139ab	683a
20	247d	210a	279a	990c	195ab	177a	567b

[†] Within columns and cultivars, means followed by a different letter are significantly different at the 0.05 probability level according to Turkey's studentized range test. Values are the means of three replications.

with the high-sulfate SJV waters as compared with those irrigated with CV solutions which contain approximately 50% less SO_4^{2-}.

Ion Partitioning and Ion Interactions

Distribution of mineral ions in sunflower stem and leaf tissues was related to differences in cultivar, tissue age, and treatment. Calcium was accumulated in leaf tissue rather than in the stems and was higher in the older leaves on the lower portion of the axis than in the younger (upper) leaves (Table 4). This finding is consistent with the relative phloem-immobility of Ca^{2+} and its retention in older tissues (Marschner, 1995). Similar age-dependent differences in Ca^{2+} accumulation by sunflower have been previously noted in entire blades (Rivelli et al., 2002) and laminae (Ashraf and O'Leary, 1995)

Regardless of cultivar or irrigation water type, Ca^{2+} decreased in shoot tissues as salinity increased. Plant-Ca status is strongly influenced by the

TABLE 4 Calcium and magnesium concentrations (mmol kg^{-1} dry weight), and selectivity coefficients ($S_{K, Na}$) for leaf and stem segments of sunflower cultivars 'Sunbeam' and 'Moonbright' grown in greenhouse sand cultures irrigated with waters differing in ion composition

	Lower Leaves			Upper Leaves			Lower Stems			Upper Stems		
EC (dSm^{-1})	Ca^{2+}	Mg^{2+}	S_{CaMg}	Ca^{2+}	Mg^{2+}	$S_{Ca,Mg}$	Ca^{2+}	Mg^{2+}	$S_{Ca,Mg}$	Ca^{2+}	Mg^{2+}	$S_{Ca,Mg}$
'Sunbeam' Solution CV												
2	1329ab†	556b	2.8	875a	308b	3.3	158a	168b	1.1	293ab	169d	2.0
5	1645a	867a	3.0	960a	426ab	3.6	151ab	207ab	1.2	306ab	242c	2.0
10	1286ab	774a	2.8	855a	430ab	3.3	167a	257ab	1.1	372ab	289b	2.2
15	1455ab	951a	2.7	755a	480a	2.8	138ab	300b	0.8	402a	411a	1.7
20	1096b	838a	2.3	434b	315ab	2.4	116b	252ab	0.8	264b	339a	1.4
'Sunbeam' Solution SJV												
2	1525a	706a	1.2	907a	382a	1.4	168a	198c	0.5	348bc	227b	0.9
5	1650a	664a	1.9	921a	410a	1.7	181a	268ab	0.5	443a	296a	1.2
10	1649a	800a	1.5	931a	402a	1.6	182a	211bc	0.6	416ab	260b	1.1
15	1305ab	788a	1.3	648b	366a	1.4	149ab	261abc	0.6	367abc	291a	1.0
20	1086b	760a	1.4	484c	346a	1.4	128b	271a	0.5	286c	347a	0.8
'Moonbright' Solution CV												
2	1481b	518a	3.3	967a	230c	4.8	153a	106c	1.7	281a	122c	2.8
5	1722a	591a	4.7	902a	323b	4.5	142	122bc	1.1	267a	178b	2.4
10	1384b	571a	4.1	784a	337b	3.9	112b	116c	1.6	290a	232b	2.1
15	1398b	723a	3.5	771a	420a	1.8	97b	147ab	1.2	265a	332a	1.4
20	956c	649a	2.6	485b	298bc	2.8	99b	168a	1.0	274a	315a	1.5
'Moonbright' Solution SJV												
2	1453a	518a	1.6	1103a	313a	2.0	163a	115a	0.8	372a	179b	1.1
5	1618a	591a	2.1	933b	285a	2.5	151a	133a	0.9	340ab	193b	1.4
10	1507a	571a	1.9	850b	318a	1.9	130ab	92a	1.0	312ab	214b	1.0
15	1105b	723a	1.2	632c	276a	2.3	109bc	104a	0.8	292b	228b	1.0
20	889c	649a	1.3	494c	283a	1.7	84c	112a	0.7	211c	298a	0.7

†Within columns and solution type, 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 3 replications.

ionic composition of the substrate. Decreases in Ca^{2+} uptake by sunflower may have been due to reactions in the substrate. Competitive ions such as Na^+, K^+, and Mg^{2+} may reduce Ca^{2+} activity in the external solution, limit plant-available Ca^{2+}, and decrease Ca^{2+} uptake and accumulation (Cramer et al. 1985; Grattan and Grieve, 1999; Suarez and Grieve, 1988; Kopittke and Menzies, 2005).

Magnesium was generally higher in sunflower leaf tissues rather than in the stems, and was also higher in the basal portions of the shoot than in the apical sections. Selectivity of Ca^{2+} over Mg^{2+} was consistently higher in shoots irrigated with CV waters than with SJV water even though the Ca^{2+}/Mg^{2+} ratio in SJV solutions was more than twice as high as in the CV waters (Table 1, Table 4). Calcium$^{2+}/Mg^{2+}$ ratio selectivity coefficients in tissues of sunflower shoots irrigation with CV waters indicate the Ca^{2+} was preferentially acquired against a strong Mg^{2+} gradient. However, selectivity values in the lower stems of both cultivars irrigated with SJV waters were low, indicating that Mg^{2+} was preferentially acquired over Ca^{2+}. The Ca^{2+} requirement for the maintenance of structural integrity of these tissues was evidently met as the lower stems of both cultivars appeared robust throughout the experiment.

Sodium distribution among sunflower shoot tissues revealed a mechanism which effectively limited Na^+ accumulation in young, photosynthetically-active leaf tissue by Na-retention in the lower stems. Sodium concentration in the upper leaves of both cultivars averaged $\sim$30 mmol kg^{-1} dry weight, and was insensitive to salinity level and irrigation water composition (Table 5). Sodium concentration in lower leaves and upper stems of 'Moonbright' remained low in plants irrigated with CV waters, but in the lower stem tissue, Na^+ increased significantly as salinity increased. Sodium in the lower leaves of both cultivars increased more than five-fold as the EC of the SJV waters increased from 15 to 20 $dS{\cdot}m^{-1}$. Regardless of irrigation water composition Na^+ concentration in the lower stems of both cultivars increased significantly as salinity increased.

As salinity increased, K^+ concentration in lower leaves and upper stems of 'Sunbeam', was not significantly affected by salinity regardless of irrigation water composition, whereas K^+ in the upper leaves increased significantly and decreased significantly in the lower stems. Potassium concentration in both upper and lower leaf tissues of 'Moonbright' tended to increase in response to salinity and decrease in the lower stem segments. Salinity had no effect on K^+ concentration in the upper stems of either cultivar (Table 5).

Under salinity stress, maintenance of adequate levels of K^+ is essential for plant survival. High levels of external Na^+ may interfere with K^+ acquisition by the roots, disrupt the integrity of root membranes and alter the selectivity of the root system for K^+ over Na^+ (Grattan and Grieve, 1999). Researchers have assumed that the K^+/Na^+ in nonhalophytes should be >1 for normal maintenance of K-mediated metabolic functions (Ashraf, 1992). Ratios of

TABLE 5 Potassium and sodium concentration (mmol kg^{-1} dry weight), and selectivity coefficients ($S_{K, Na}$) for leaf and stem segments of sunflower cultivars 'Sunbeam' and 'Moonbright' grown in greenhouse sand cultures irrigated with waters differing in ion composition

	Lower Leaves			Upper Leaves			Lower Stems			Upper Stems		
EC (dSm^{-1})	K^+	Na^+	$S_{K,Na}$	K^+	Na^+	$S_{K,Na}$	K^+	Na^+	$S_{K,Na}$	K^+	Na^+	$S_{K,Na}$
'Sunbeam' Solution CV												
2	755a†	21a	125	896b	25a	125	1222ab	20b	206	1152a	14a	290
5	655a	22a	255	814b	23a	310	1216ab	70b	150	1123a	17a	585
10	576a	17a	495	905b	22a	595	1425a	80b	260	1698a	15a	1640
15	614a	19a	650	978ab	23a	875	942ab	235a	80	1490a	24a	1260
20	798a	45a	485	1163a	21a	1480	510b	285a	50	1080a	14a	2240
'Sunbeam' Solution SJV												
2	635a	24b	120	915b	25a	160	1436a	38b	175	1734a	14b	570
5	749a	27b	330	929b	24a	470	1533a	205b	90	1865a	19b	1190
10	770a	21b	990	1007b	26a	750	1646a	210b	155	1946a	14b	2700
15	1013a	39b	700	1170a	25a	1260	1240a	355b	95	1810a	18b	2720
20	996a	230a	160	1189a	25a	1800	497b	800a	25	1390a	105a	490
'Moonbright' Solution CV												
2	899a	29a	100	1065b	24a	160	1327a	26c	162	1758a	15a	370
5	958a	17a	450	1060b	26a	330	1322a	46c	228	1786a	14a	1015
10	1033a	25a	540	1178b	28a	555	815ba	94bc	113	1848a	23a	1045
15	988a	19a	960	1177b	22a	1000	910ab	117a	142	1919a	13a	2705
20	1237a	24a	1270	1466a	26a	1375	745b	240a	74	1687a	15a	2715
'Moonbright' Solution SJV												
2	80c	23b	145	1067c	22a	205	1603a	44c	150	2174a	17a	530
5	940c	21b	500	1119c	22a	560	1388a	130bc	120	2080a	16a	1415
10	1224b	31b	705	1260b	29a	760	992b	258abc	70	2230a	21a	1850
15	1475a	28b	1300	1470a	23a	1570	1035b	300ab	85	2182a	21a	2515
20	1460a	148a	340	1418a	27a	1815	481c	485a	35	1779a	33a	1820

†Within columns and solution type, 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.

K^+/Na^+ in complete sunflower shoots and in most leaf and stem segments in all treatments were well above this critical value. Only in lower stems of 'Sunbeam' irrigated with SJV waters at 20 dS·m^{-1} was the ratio less than 1 (Table 5). Potassium: sodium selectivity coefficients were very high as a result of Na-exclusion by both sunflower cultivars.

Leaves were chlorotic and necrotic on the lower stems of both cultivars irrigated with the most saline ICV waters containing 107 mmol Cl^-·L^{-1}. The damage may have been due to chloride toxicity as Cl^- concentrations in these organs were in excess of 1000 mmol kg^{-1} dry weight (data not shown). Regardless of salinity level, stems contained about twice as much Cl^- as the leaves. The ability of ornamental sunflower to limit Cl-transport to young, photosynthetically-active leaf tissue by retention in stems and older leaves has been previously reported (Rivelli et al., 2002).

Total-S generally increased with increasing salinity and was routinely higher in plants irrigated with the high-sulfate SJV waters. Total-S concentrations were higher in leaves than in the stems (data not shown). Distribution of total-P followed similar trends: the concentration was higher in segments of plants irrigated with SJV waters and was higher in leaf tissue as compared to the stems (data not shown).

CONCLUSIONS

Commercially acceptable, pollen-free sunflowers may be produced using saline solutions with ECs ranging from 2.5 to 20·dS m $^{-1}$. Two water types differing in ion composition were prepared to mimic wastewaters waters in two inland valley areas of California. In all treatments, cultivars 'Sunbeam' and 'Moonbright' met quality standards as determined by stem and bloom diameters. Diameters of the gerbera-sized inflorescences ranged from 14 to 8 cm, a desirable size for general floral arrangements (Sloan and Harkness, 2006). Except for the highest salinity treatment (20 dS·m^{-1}), however, stem length greatly exceeded the standard 60–90 cm preferred by florists. Management strategies whereby salinity applied during the vegetative phase of plant development and partially released at the onset of the reproductive phase may reduce sunflower height and, at the same time, produce an inflorescence that would be commercially acceptable to florists. Irrigation with Cl-dominated waters (solution ICV) with EC = 20 dS m^{-1} caused necrosis of the lower leaves, probably due to Cl-toxicity. Leaf damage should not affect market quality as most of the sunflower foliage is ordinarily removed at harvest (Armitage, 1993).

Sunflowers cultivars, 'Sunbeam' and 'Moonbright', possess two mechanisms which contribute to satisfactory growth under saline conditions: (1) exclusion of Na^{2+} accumulation in young leaf tissue, (2) accumulation of K^+ and Ca^{2+} against a strong concentration gradients of other cations in the external solution.

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