Israel Journal of Plant Sciences *Vol. 59* *2011* *pp. 187–196*
DOI: 10.1560/IJPS.59.2-4.187

***Review*:**

Irrigation of floricultural and nursery crops with saline wastewaters

Catherine M. Grieve
Water Reuse and Remediation Management Unit
U.S. Salinity Laboratory, 450 West Big Springs Road, Riverside, CA 92507, USA

(Received August 8, 2009; accepted in revised form April 16, 2010)

ABSTRACT

Water security has become a major concern throughout the western United States and other arid and semiarid regions worldwide. Uncertainties concerning the allocation and dependability of good quality water have led to increased interest in the use of alternative, non-potable waters for irrigated agriculture. Treated urban effluents, runoff from greenhouse operations, agricultural drainage waters, or naturally-occurring low quality waters are abundant in many arid or semiarid areas. Reuse of these waters for production of floral and nursery crops requires an understanding of plant response to the stress imposed by inorganic salts in the irrigation waters. Such an understanding will allow growers to match specific crops to available water qualities, and further, to institute management practices to sustain quality of the marketable product. This report reviews the results of studies conducted at the U.S. Salinity Laboratory, Riverside, CA, on the effect of saline irrigation waters on yield and quality of ten species of herbaceous cut flower crops. Test crops were: snapdragon (*Antirrhinum majus* L.), celosia (*Celosia argentea* var. *cristata* (L.) Kuntz), sunflower (*Helianthus annuus* (L.)), statice (*Limonium perezii* (Snapf) F.T. Hubb) and *L. sinuatum* (L.) Mill), stock (*Matthiola incana* (L.) R. Br.), ranunculus (*Ranunculus asiatica* L.), marigold (*Tagetes erecta* L. and *T. patula* L.), and zinnia (*Zinnia elegans* Jacq.). Treatment waters were prepared to simulate the inorganic chemistry of recyclable waters available in different areas of California. Guidelines are presented for reuse of degraded water for production of commercially important cut flower crops, and also for selection of crops suitable for salt-affected landscape sites.

Keywords: wastewater, salinity, flowers, nursery crops

INTRODUCTION

Water reuse has a long and well-established history in California (Klotz et al., 1989). For many years, oversight of California water resources was more in line with encouraging, rather than mandating, conservation practices. Since 1928, the California Constitution has prohibited waste or unreasonable water use, encouraged water recycling and reuse projects whenever safe and practical, and, further, prohibited the use of potable water for landscape irrigation when "suitable" reclaimed water was available (Water Education Foundation, 1992). However, once the **federal** Water Pollution Control Acts of 1956 as amended in 1972 were in place, leading California producers of agronomic and horticultural crops concluded that problems of wastewater disposal posed serious implications for their industries. In particular, the floriculture and nursery crop industries responded by instituting extensive water reuse and recycling programs (Skimina, 1980, 1986; M.A. Mellano, personal communication). Benefits from the new and expanding

*Author to whom correspondence should be addressed.
E-mail: catherine.grieve@ars.usda.gov

projects included water conservation, nutrient savings, energy conservation, protection of the environment, and a favorable public image (Skimina, 1992).

The qualities of recycled waters available for irrigation of agricultural crops may range from nonpotable, treated waters containing <400 mg/L soluble salts to severely degraded agricultural drainage effluents containing >8000 mg/L soluble salts. Likewise, agronomic and horticultural crops run the gamut from highly salt-sensitive species to very salt-tolerant, even halophytic species. For agricultural uses, matching water quality to water use is an integral part of water quality management (California Department of Water Resources, 2009).

Numerous publications provide guidelines for predicting the effects of salinity on agronomic and horticultural crop yields (e.g., Maas and Grattan, 1999; Steppuhn et al., 2005a,b). Other sources provide salt tolerance data for woody ornamentals (Maas, 1986; Costello et al., 2003). There are, however, substantial gaps in our knowledgebase on the salt tolerance of cut flower and nursery crops. Therefore, a major challenge in the implementation of wastewater recycling programs is the identification of floriculture crops that are appropriate for the particular water reuse system under consideration, i.e., matching crop yield and quality parameters with appropriate quality of available water resources.

The salt tolerance of floral and nursery crops has been evaluated by many research teams using naturally-occurring saline waters or irrigation waters prepared to simulate recycled or saline water typical of a specific location. Dutch growers frequently employ solutions with compositions adjusted to the average salt composition of surface waters in the western portion of the Netherlands (Sonneveld, 1999). Shillo et al. (2002) used saline solutions mimicking local well waters in the Negev Desert of Israel to determine the effect of salinity on growth and development of cut flower and bulb species. In addition, commercially acceptable scapes of celosia and sunflower were produced under irrigation with secondary-treated effluents available in the Arad area of the Negev (Friedman et al., 2007).

Historically, salt tolerance evaluation studies at our laboratory involved the determination of crop responses to irrigation with chloride-dominated salinity, i.e., a mixture of NaCl and $CaCl_2$. The chloride system, however, does not reflect the composition of waters available for reuse in most areas of California. Therefore, more recently, experiments have been designed to evaluate crop salt tolerance under irrigation with waters prepared to represent degraded waters typical of those commonly present in different agricultural areas of California, such as: (1) the San Joaquin Valley where saline-sodic drainage effluents are typically dominated by Na^+ and SO_4^{2-} (San Joaquin Valley waters, SJVW); (2) the southern inland valleys and coastal regions where recycled imported Colorado River water contains Cl^-, Na^+, SO_4^{2-}, Mg^{2+} and Ca^{2+}, predominating in that order (Concentrations of Colorado River water, CCRW); (3) coastal areas where seawater intrusion to aquifers and groundwaters contribute to salinity (Sea Water dilutions, SWD). In all cases, salt solutions for the studies were prepared to simulate the compositions of these regional wastewaters and increased ionic strengths from predictions based on appropriated simulations of what the long-term composition of the water would be upon further concentrations by plant–water extraction and evaporation (Suarez and Simunek, 1997).

Salinity is one of many environmental factors which influence timing of plant development, and the effect is crop-specific. For example, the morphogenesis of wheat is accelerated by salt stress, and those wheat plants under the most severe stress will be the first to mature (Maas and Grieve, 1990). Salinity also induces earliness in tomato, and the response appears to be cultivar-dependent (Cuartero and Fernández-Muñoz, 1999). In contrast, salinity delays rice development, and nonsaline controls reach maturity before the salt stressed plants (Zeng and Shannon, 2000). Production scheduling is critical for the floriculture industry, and numerous techniques are used to control plant development in order to meet specific sales windows (Armitage, 1993; Ball, 1998). However, information on the effect of saline recycled water on timing of developmental events in cut flower or nursery crops is limited.

Not all the effects of salinity on floriculture and nursery crops are adverse. Internode length and/or number generally decrease in response to salt stress. With proper management, salinity becomes an environmentally-friendly alternative to chemical growth regulators by reducing stem length. Under salt stress, stems of tall, rangy plants, such as chrysanthemum, are shortened to a more attractive length, and support is not necessary (Lee and van Iersel, 2008). Salt stress may also increase the number of blooming flowers per inflorescence and prevent stem collapse (Shillo et al., 2002). If aesthetic value remains acceptable, salt-stressed landscape plants will be slower growing, requiring less trimming and maintenance.

The goal of the present project was to develop guidelines for the selection of (1) cut flower and nursery crops that can be economically produced under irrigation with recycled or degraded waters with low to moderate salinity without loss of yield or quality, and (2) species that maintain acceptable aesthetic quality in salt-affected landscape sites.

DESCRIPTION OF THE EXPERIMENTAL CULTIVATION SYSTEMS APPLIED TO THE VARIOUS STUDIES

The experiments were conducted in cultivation tanks filled with washed river sand. The greenhouse tanks were irrigated from storage reservoirs located below the sand-tank facility. After irrigation the drainage water returned to the reservoirs by gravity flow. Water lost by evapotranspiration was replenished daily to maintain constant electrical conductivities in the treatment irrigation waters. Previous studies of the system (Wang, 2002) indicate that the electrical conductivity (ECiw) of the irrigation water is more or less equivalent to that of the soil (or, in this case, sand) water (ECsw), and ECsw is approximately 2.2 times the EC of the saturated soil extract (ECe), the salinity parameter used to characterize salt-tolerance in most studies (Ayers and Westcot, 1985). As an example, for the range of salinity treatments (ECiw = 2.5 to 14 dS m^{-1}) used to determine the salt tolerance of stock cultivars (*Matthiola incana* L.) (described below), the ECe may be estimated as 1.1 to 6.4 dS·m^{-1}. Stock is frequently grown as a field crop in the Coachella Valley of southern California, therefore, these ECe values represent a salinity range over which the crop could be commercially produced using degraded waters available in that area.

Throughout the experiments, treatment solutions were routinely analyzed to confirm that target ion concentrations were maintained. The pH of waters irrigating plants in the greenhouse and outdoor sand cultures was monitored, but generally was not controlled, and reached values as high as 8.4 in some experiments. pH affects the oxidation–reduction equilibrium and solubility as well as the ionic form of several essential plant nutrients (Epstein and Bloom, 2005). Although no visible signs of nutrient toxicity or deficiency have been observed in any of the evaluated cultivars, high pH undoubtedly affected the performance of the crops under investigation (See marigold, *Tagetes* species, below). The high pH levels imposed in our experiments, however, are typical of the levels encountered by crops irrigated with saline-sodic wastewaters available in the San Joaquin Valley (SJV).

For most of our floriculture research, application of saline treatments has routinely been delayed after seeding or transplanting, allowing establishment of the crop under nonsaline conditions. The rationale for this procedure was that winter rains would provide irrigation and leaching of the seed bed, or alternatively, that the grower would have a source of good quality waters during early seedling growth. Neither of these assumptions may be true. Therefore, for selected trials, saline treatments were established in the sand tanks before the seeds were sown or the seedlings were transplanted in the tanks.

SALT TOLERANCE OF SELECTED CROPS

Plant response to saline treatments was determined by analysis of individual yield/quantity/quality components as appropriate for each crop: height of flowering stems, fresh and dry biomass production, flower and stem diameters, flower complexity, numbers of leaves, flowers and branches, internode length, compactness, and in some cases, vase life. Salinity treatments had no effect on color of the flowers or on the symmetry of stems and inflorescences. Plants remained healthy throughout the experiments, showing no visible signs of foliar injury associated with ion toxicity or nutrient deficiency disorders.

Celosia

Celosia argentea var. *cristata* [(L.) O. Kuntze] is popular as a fresh and dried cut flower. It is particularly well-suited for cut-flower production during hot summer months (ASCFG, 2002). The cultivars ‘Chief Red’ and ‘Chief Gold’ were planted in the greenhouse sand tank facility during June 2003 and irrigated with waters differing in ion composition (CCRW vs SWD) with salinity levels ranging from 2.5 to 12 dS m^{-1}.

Daytime temperatures in the greenhouse range up to 42 ºC. Stem length, diameter, and weight as well as inflorescence weight of both cultivars decreased as salinity increased (Carter et al., 2005b). Although stem diameter decreased from 13 to 7 mm, stems were strong enough to support the inflorescences; staking was not required even under the highest salt level applied. Length of the stems under control conditions (90–110 cm) was excessive for cut-flower commercialization, and reduction of stem length was therefore a positive effect of salt stress. Length and weight of ‘Chief Rose’ inflorescences were higher when the plants were irrigated with CCRW than with SWD (Carter et al., 2005b).

Marketable stems of ‘Chief Gold’ were produced in saline waters with ECiw up to 12 dS m^{-1} regardless of water type. ‘Chief Red’ was slightly less salt tolerant, producing commercially acceptable stems when irrigated with CCRW up to 10 dS m^{-1} and SWD up to 8 dS m^{-1} (Carter et al., 2005b). These results complement those of a recent study conducted by Friedman et al. (2007) who found that growth, yield, and quality components of *C. argentea* cv. *cristata* were not affected by irrigation with secondary treated sewage effluents (ECiw = 2 to 2.3 dS m^{-1}) available in the Arad region of Israel.

Marigold

Both the short-statured French marigold [*Tagetes patula*

(L.)] and the taller African marigold [*T. erecta* (L.)] are versatile annuals highly prized as container plants in landscape and garden settings. *T. erecta* finds a market in the florists' trade, provided the foliage from the lower stems is removed, a practice that decreases marigolds' strong scent which may be objectionable to some people (Ball, 1998).

The salt tolerances of one *T. patula* cultivar ('French Vanilla') and two tall-statured *T. erecta* cultivars ('Yellow Climax' and 'Flagstaff') were evaluated in greenhouse sand cultures irrigated with CCRW (ECiw = 2, 4 6, 8,10 dS m^{-1} and 2 pH levels (6.4 and 7.8). All three cultivars were relatively salt-sensitive. Most yield components were severely reduced by the 10 dS m^{-1} treatment, but no visible symptoms of ion toxicity were apparent. The two evaluated cultivars seem suitable for salt-affected landscape sites, since other than reduction in height, plant appearance was not compromised by salinity. As noted previously by Devitt and Morris (1987), salinity affected marigold yield components differentially. For example, stem diameter, number of flowers, leaf and flower dry mass of 'Yellow Climax' were unaffected by salinity (ECiw = 4 dS · m^{-1}), whereas plant height and shoot biomass were reduced once ECiw exceeded 2 dS m^{-1}. Marigold was also sensitive to high pH, and the combined effects of salinity and pH significantly reduced all yield components (Valdez-Aguilar et al., 2009a).

The marigold cultivars evaluated in this study exhibited a Na^+ exclusion mechanism which effectively limited Na^+ transport to and accumulation in leaf and stem tissues (Valdez-Aguilar et al., 2009b). Sodium concentrations in above-ground tissues ranged from 30 to 50 mmol kg^{-1} across salinity levels, whereas external-Na concentrations increased from 8 to 55 mM as salinity increased. Shoot-Na concentrations in other flower crops, such as celosia and snapdragon (Carter et al., 2005b; Carter and Grieve, 2008), irrigated with waters of the same ion composition and salinity levels, are 8- to 10-fold higher. Control of net Na-transport to shoot tissues is a trait ordinarily associated with salinity tolerance (Hoffman, 1981), but this generalization does not apply to marigold.

Ranunculus

Giant Tecolote Ranunculus (*Ranunculus asiaticus* L.) is grown extensively in home gardens, landscape sites, and for commercial production of cut-flowers and fibrous root propagation. Ranunculus growers in California reported that in the last few growing seasons when reclaimed water was used for crop irrigation, bulb viability had become substandard, although the quality of the flowering stems remained high.

Electrical conductivity of the water used for irrigation was 1.9 dS m^{-1}, pH = 7.8. Information concerning the salt tolerance of ranunculus is, to our knowledge, nonexistent. To fill the gap, a greenhouse sand culture was initiated using ranunculus cultivars 'Pink CTD" and 'Yellow ASD' as test crops, and treatment waters (ECiw = 2, 3, 4, and 6 dS m^{-1}; pH = 6.4 and 7.8). Stem length of both cultivars grown in greenhouse sand cultures irrigated with waters low in salinity and pH were as long as those grown under field conditions (~65 cm). However, once ECiw exceeded 2 dS m^{-1}, height was reduced ~20%, and the number of flowering stems decreased from 3 to 1. Alkaline irrigation waters (pH = 7.8) caused further reductions in yield components, e.g., shoot dry weight, numbers of flower buds per stem, flower diameter. Tuberous root viability was checked in greenhouse sand tanks under nonsaline conditions. Resprouting percentage of these roots decreased as salt applications in the previous year increased (Valdez-Aguilar et al., 2009c). Research is in progress to determine if bulb viability may be caused by nutrient imbalances related to solution pH, or if bulb quality is associated with ion toxicities or deficiencies as has been reported for the "stem topple" of ranunculus, a disorder associated with localized symptoms of Ca^{2+} deficiency (Bernstein et al., 2008).

Snapdragon

Snapdragons (*Antirrhinum majus* L.) are a standard addition to the summer flower bouquet (Ball, 1998). Information on the salt tolerance of the crop is limited, with published tolerance ratings ranging from 'low' (Costello et al., 2003) to 'unknown' (Gilman, 2007).

Tall snapdragon cultivars 'Apollo Cinnamon' and 'Monaco Rose' were grown in greenhouse sand cultures and their response to waters differing in ion composition (SWD vs CCRW) was compared. Salinity treatments (2.5, 5, 8, 11, and 14 dS m^{-1}) were initiated when the second true leaves were fully expanded. Identical treatment solutions were also used for a germination experiment, conducted under growth chamber conditions. Seed germination of both cultivars at all salinity levels was over 90% regardless of salinity treatment. Greening of the cotyledons and the apparent vigor of the seedlings suggested that emergence percentage would also be high (Carter and Grieve, 2008).

Salinity slowed developmental events and increased time-to-harvest by as much as 18 days depending on the salinity level and cultivar (Carter and Grieve, 2008). Flowering stems were graded according to the standards developed by the Society of American Florists (Dole and Wilkins, 1999). From lowest to highest, the grades are: "First", "Extra", "Fancy", and "Special". Based on inflorescence height, stem length, and weight, 'Apollo Cinnamon' produced "special" stems under saline irrigation until ECiw exceeded 8 dS m^{-1}, and "fancy" at higher salt levels (11 and 14 dS m^{-1}). 'Monaco Rose' performed even better, with "special" stems produced in all salt treatments regardless of water type (Carter and Grieve, 2008).

The greenhouse experiment, taken together with the germination trial, demonstrates that two snapdragon cultivars are good candidates for water reuse systems. Production under salt stress is expected to be satisfactory whether the crop is direct seeded to presalinized substrates or imposition of salinity is delayed until stand establishment. Choice of the snapdragon cultivars used in the study may be fortuitous; both are moderately salt tolerant. In contrast, both vegetative and reproductive growth of snapdragon cultivar 'Montego Mix' were significantly reduced when the bedding plants were irrigated with NaCl-dominated waters (ECiw = 3 dS m^{-1}) (Arnold et al., 2003).

Statice

Limonium perezii (Stapf) F.T. Hubb and *L. sinuatum* (L.) Mill are rated as halophytic plants, surviving and completing their life cycles in hypersaline waters as high as 56 dS m^{-1} (Aronson, 1989). The salt tolerance of statice was determined in greenhouse sand tanks irrigated with waters of two different compositions (SJVW and CCRW) ranging in salinity from 2 to 30 dS m^{-1} (Grieve et al., 2005). Both species demonstrated salt resistance, but neither species possessed a high degree of salt tolerance as understood by horticulturists or agronomists. The species belong to a special category of halophytes—the miohalophytes, i.e., those plants whose maximum growth occurs at low salinity and decreases steadily as salt stress increases (Flowers et al., 1986; Salisbury, 1995). Evaluated principally by stem length, *L. perezii* (cv. 'Blue Seas') was rated as salt-sensitive (threshold <2.5 dS·m^{-1}); *L. sinuatum* (cv. 'American Beauty') was moderately tolerant (threshold = 6 dS m^{-1}) (Grieve et al., 2005). Newer Japanese *Limonium* hybrids are more salt tolerant than the cultivars we examined. Irrigation water salinity as high as 11.5 dS m^{-1} had little or no effect on yield and flowering stem quality parameters of the Emily series (Shillo et al., 2002).

Limonium perezii was one of the few floriculture crops we seeded in pre-salinized sand tanks (Carter et al., 2005a). Saline irrigation waters as high as 10 dS m^{-1} stimulated both emergence rate and percentage, responses associated with halophytic species. Overall performance and salt tolerance were similar regardless of the time salt treatments were applied (i.e., imposed at planting or delayed until plant establishment). Stem length of plants irrigated with SJV waters were significantly longer than those irrigated with CCR waters until the EC of the solutions exceeded 6 dS m^{-1}, but as salinity increased to 8 and 10 dS m^{-1}, irrigation with CCR waters gave longer stems.

Limonium, a member of the highly stress-tolerant family *Plumbaginaceae*, adapts to salt stress by biosynthesis of a wide range of organic metabolites such as amino acids, quaternary ammonium compounds, organic acids, and nonstructural carbohydrates. The solutes contribute to osmotic balance by facilitating water uptake and retention and also by preserving enzyme activity in the presence of toxic ions (Gagneul et al., 2007). Roots and shoots were sampled from plants in the experiments described above. Organic solutes in the tissues were identified and quantified. Only trace amounts of quaternary ammonium compounds were detected. Major organic osmobalancers were the common sugars (fructose, glucose, sucrose) and sugar alcohols. *Chiro*-inositol, a relatively rare sugar alcohol, was a significant component of the carbohydrate pool, increasing consistently and significantly as salinity increased. To the best of our knowledge, *chiro*-inositol has not previously been detected or characterized in either *L. perezii* or *L. sinuatum* (Liu and Grieve, 2009). The biosynthetic pathway for *chiro*-inositol is relatively simple and offers the potential for improving crop stress tolerance by metabolic engineering.

Stock

Matthiola incana [(L.) R. Br.] is produced as a cut flower field crop in Arizona and California during the winter and early spring months. Stock has been rated as relatively tolerant to chloride-dominated saline irrigation waters, showing no leaf injury or reduction in flower quality provided solution chloride concentration does not exceed 85 mM (Lunt et al., 1954).

Our greenhouse sand culture experiment showed that both 'Cheerful White' and 'Frolic Carmine' produced high quality, marketable flowers when irrigated with SJV and CCR waters at salinity levels 2.5, 5, 8, 11, and 14 dS m^{-1}. Stem lengths and mass were significantly higher in plants irrigated with CCRW where external-Cl concentrations as high as 107 mM. Effect of water type was minimal (Grieve et al., 2006).

Excessive N reduces the quality of flowering stock stems particularly if the nitrogen is applied during flower maturation. Healy (1997) recommends 150 to 200 ppm N during the early stages of growth, and reduction in N level thereafter. Information concerning the combined effects of nitrogen concentration and salinity on stock production is very limited. For this trial, 'Cheerful White' was grown in outdoor lysimeters. The experiment was a 4 × 4 factorial, partially replicated design with four saline irrigation waters (2, 5, 8, and 11 dS m^{-1}) and four N concentrations (35, 50, 75, and 100 ppm). Stock growth and quality components were unaffected by N concentrations in the irrigation waters (Grieve et al., 2008). Salinity (11 dS m^{-1}) delayed time-to-harvest by 6 days. Salinity had little effect on marketability, although length of the flowering stems was reduced from 70 cm under control conditions to 65 cm in response to the 11 dS m^{-1} treatment, regardless of substrate-N level. The study established that N requirements are low for stock over its entire life cycle. Growers could minimize costs by using waters of marginal quality for irrigation and also limit off-site pollution by reducing N inputs (Grieve et al., 2008).

Sunflower

Inflorescences of pollenless sunflowers (*Helianthus annuus* L.) are preferred by florists because they have a longer vase life and are cleaner in arrangements than the cultivars with pollen. However, the flowers are too large for most market applications. Sloan and Harkness (2006) suggest that sunflowers with stem lengths 60–90 cm, stem diameters 0.5–1.5 cm, and bloom diameters 8–15 cm are more acceptable for the florists' trade.

Two sunflower cultivars, 'Moonbright' and 'Sunbeam', were grown in greenhouse sand cultures irrigated with two water types (SJVW and CCRW) and five salinity levels (2, 5, 10, 15, and 20 dS m^{-1}). Plant spacing was 25 cm between rows and 5 cm between plants in a row. Stem length decreased from 175 to 100 cm in response to the most severe salt stress and flower diameter was reduced under irrigation with SJV waters with EC exceeding 15 dS m^{-1}. Treatment with CCRW, however, had no effect on flower diameter over the range of salinities tested. Perhaps application of higher salt concentrations would be more effective in reducing flower diameter and stem length to the size preferred by florists (Grieve and Poss, 2010).

Our results illustrate that sunflower possessed an adaptive mechanism, shared by many glycophytes, that enable plants to survive in a saline environment. One of the processes involved in plant salt tolerance is Na^+ exclusion: the control of Na^+ uptake and the subsequent distribution of Na^+ to plant tissues in order to limit Na^+ accumulation in the shoot (Plett and Møller, 2010). In sunflower, Na^+ was partitioned to the lower stem tissue, thereby minimizing accumulation of this potentially toxic cation in the actively photosynthesizing upper leaves. Sodium accumulation in the upper leaf and upper stem tissues of both sunflower cultivars was very low, ranging from 25 to 30 mmol kg^{-1} regardless of water type or salinity level. Likewise, Na^+ remained low in lower leaf tissue of both cultivars irrigated with CCRW, but increased significantly once the ECiw of SJVW exceeded 15 dS m^{-1} (Grieve and Poss, 2010).

Zinnia

Zinnias (*Zinnia elegans* Jacq.) are heat-tolerant flowers and have been valued as cut flowers and bedding plants for many years. Two zinnia cultivars, 'Giant Salmon Rose' and 'Giant Golden Yellow' (Benary's Series, Johnny's Selected Seeds, Winslow, ME), were grown in greenhouse sand cultures irrigated with two water compositions (CCRW and SWD) and five salinity levels (ECiw = 2, 4, 6, 8, 10 dS m^{-1}). Marketable stems were produced in all treatments. Stem lengths of both cultivars ranged from 95 cm under control conditions to 80 cm in response to the 10 dS m^{-1} CCRW. Salinity effects on inflorescence diameter were small, decreasing from 10 to 9 cm as salinity increased to 10 dS m^{-1}. Harvest date of zinnia was not influenced by salinity (Carter and Grieve, 2009).

The two cultivars evaluated are more salt tolerant than other zinnia cultivars valued as bedding plants. Irrigation with NaCl-dominated waters (ECiw = 3 dS m^{-1}) reduced growth, flowering, and survival of zinnia 'Lilliput Mixed Colors' (Arnold et al., 2003). Similarly, vegetative growth parameters of zinnia 'Peter Pan Flame' were greatly reduced and reproductive growth was completely inhibited in plants irrigated with chloride-dominated waters (ECiw = 4.5 dS m^{-1}) (Devitt and Morris, 1987).

SALT TOLERANCE EVALUATION OF LANDSCAPE PLANTS

Growth suppression by salinity is typically a nonspecific salt response, depending more on osmotic stress created by the total concentration of soluble salts than on the level of specific solutes (Hoffman, 1981). Osmotic stress has an immediate effect on plant growth, slowing the rate of leaf emergence and expansion. The ionic stress phase, which occurs much later, starts when the salt concentrations in the old leaves reach a threshold; the leaves show injury symptoms characteristic of ion toxicity and they die (Munns and Tester, 2008). Under low and moderate salinity, many salt-stressed plants show only the effects of the osmotic phase and are stunted without overt injury symptoms. This general observation describes the response of the floral species evaluated at this laboratory. Stem, internode, and inflorescence lengths, leaf and floret numbers were frequently reduced, but plants remained healthy and attractive.

Guidelines for selection of plant species based

Table 1
Floriculture species and cultivars for salt-affected landscape sites. Based on research conducted at the U.S. Salinity Laboratory, irrigation waters salinities (ECiw) or soil salinities (ECe) equal to or less than that given are not expected to compromise the aesthetic value of the crops

Common name	Botanical name	Cultivar	Salinity ECiw (dS/m)	Salinity (ECe) (dS/m)†
snapdragon	*Antirrhinum majus* L.	'Apollo Cinnamon'	14	6.4
		'Monaco Rose'	14	6.4
celosia	*Celosia argentea* var. *cristata* (L.) Kuntz	'Chief Gold'	12	5.5
		'Chief Rose'	12	5.5
sunflower	*Helianthus annuus* L.	'Sunbeam'	20	9.1
		'Moonbright'	20	9.1
statice	*Limonium perezii* (Stapf) F.T. Hubb	'Blue Seas'	30	13.6
	L. sinuatum (L.) Mill	'American Beauty'	30	13.6
stock	*Matthiola incana* (L.) R. Br.	'Cheerful White'	14	6.4
		'Frolic Carmine'	14	6.4
marigold	*Tagetes erecta* L.	'Flagstaff'	4.5	2.0
		'Yellow Climax'	4.5	2.0
	T. patula L.	'French Vanilla'	4.5	2.0
zinnia	*Zinnia elegans* Jacq.	'Giant Golden Yellow'	10	4.5
		'Giant Salmon Rose'	10	4.5

† In the sand tank system at the U.S. Salinity Laboratory. Riverside, CA, electrical conductivity of the irrigation water (ECiw) is equivalent to that of the soil water (ECsw), and ECsw is approximately 2.2 times the EC of the saturated soil extract (ECe).

on sustainability and aesthetic quality are critical for designers of sports field and landscape sites where recycled waters will be used for irrigation (Grieve et al., 2007). In our studies, the range of salinities chosen was generally broad enough to reduce stem length, in some cases more than 50% (e.g., statice), but not enough to reduce aesthetic value. Table 1 lists plant species that should be suitable for landscape sites irrigated with recycled waters. Irrigation waters differing in ion composition caused relatively small differences in plant yield parameters, therefore the quality rating is based on EC only and not on water type. The values given for ECiw and ECe are conservative and represent the minimum stress level expected to cause no reduction in aesthetic quality. Actual plant performance in salt-affected sites, however, depends on a myriad of other factors such as climatic conditions and cultural practices. Choice of cultivar for salt-affected landscape sites is also very important. Wide differences in salt tolerance were evident between some of the species we chose for the series of experiments described herein and the salinity response of the same species, but different cultivars, reported by others, e.g., *Antirrhinum majus* and *Zinnia elegans* (Arnold et al., 2003; Devitt and Morris, 1987).

PRODUCTION OF CUT-FLOWER CROPS WITH DEGRADED WATERS

Water security has become a major concern throughout the United States. In irrigated agricultural areas of the west, producers of agronomic and horticultural crops are faced with water shortages, or with lower quality waters than desired. Alternative waters, such as urban wastewaters, runoff from greenhouse operations, agricultural drainage waters, or other low quality waters are available in many areas. The reuse of these waters for crop irrigation will conserve fresh water resources and reduce contamination of surface and ground waters. Understanding the limitations that degraded waters place on crop performance will help growers balance the need for environmental stewardship against the drive for high quality products (Arnold et al., 2003).

Marketability standards for cut flowers are, in general, rather vague and ill-defined, e.g., "sufficiently long

Table 2
Guidelines for producing selected cut flower species with recycled waters. Based on research conducted at the U.S. Salinity Laboratory, irrigation waters salinities (ECiw) or soil salinities (ECe) equal to or less than that given are expected to produced flowering stems of marketable quality

			Salinity	
Common name	Botanical name	Cultivar	ECiw (dS/m)	(ECe) (dS/m)†
snapdragon	*Antirrhinum majus* L.	'Apollo Cinnamon'	12	5.4
		'Monaco Rose'	12	4.4
celosia	*Celosia argentea* var. *cristata* (L.) Kuntz	'Chief Gold'	10	4.5
		'Chief Rose'	10	4.5
sunflower	*Helianthus annuus* L.	'Sunbeam'	15	6.8
		'Moonbright'	15	6.8
statice	*Limonium perezii* (Stapf) F.T. Hubb	'Blue Seas'	4.0	1.8
	L. sinuatum (L.) Mill	'American Beauty'	7.0	3.2
stock	*Matthiola incana* (L.) R. Br.	'Cheerful White'	12	5.4
		'Frolic Carmine'	12	5.4
ranunculus	*Ranunculus asiatica* L.	'Yellow ASD'	1.5	0.7
		'Pink CTD'	1.5	0.7
marigold	*Tagetes erecta* L.	'Flagstaff'	4.0	1.8
		'Yellow Climax'	4.0	1.8
zinnia	*Zinnia elegans* Jacq.	'Giant Golden Yellow'	8.0	3.6
		'Giant Salmon Rose'	8.0	3.6

†In the sand tank system, electrical conductivity of the irrigation water (ECiw) is equivalent to that of the soil water (ECsw), and ECsw is approximately 2.2 times the EC of the saturated soil extract (ECe).

stems strong enough to carry the flower(s) without bending, appropriately sized flowers, and 'enough' flowers and foliage" (Dole and Wilkins, 1999; Armitage, 1993). One notable exception is the system developed by the Society of American Florists for rating the commercial acceptability of snapdragons (Dole and Wilkins. 1999). The marketability ratings are admittedly very subjective and the decision was made by answering the question "Would we buy this flower?"

Several cut flowers are well-adapted to growth under alkaline conditions, producing marketable stems when irrigated with saline waters with pH levels as high as 8. Stock, snapdragon, and zinnia, for example, are good candidates for testing under field conditions in areas such as the SJV where soil pH range from neutral to slightly basic (7.0–9.0).

Few guidelines are available for selection of cut flowers species that can be produced suitable for water reuse systems. Table 2 lists guidelines for matching commercially important cut flower crops to irrigation water (ECiw) and soil (ECe) salinities that are expected to produce marketable flowers. Salinity values are conservative, and potential benefits from reuse of degraded waters are dependent on best management practices.

ACKNOWLEDGMENTS

This review highlights research conducted by Drs. Christy T. Carter and Luis A. Valdez-Aguilar while they were post-doctoral research scientists at the U.S. Salinity Laboratory. I am profoundly grateful for their substantial contributions to our floriculture project. Thanks also to Phyllis Nash for providing statistical analyses and to Donald Layfield for mineral ion analyses. Jim Poss provided invaluable technical support; John Draper and Doug Diaz provided technical assistance.

REFERENCES

Armitage, A.M. 1993. Specialty cut flowers. Varsity Press/ Timber Press, Portland, OR, 372 pp.
Arnold, M.A., Lesikar, B.J., McDonald, G.V., Bryan, D.L.,

Gross, A. 2003. Irrigation landscape bedding plants and cut flowers with recycled nursery runoff and constructed werland treated water. J. Environ. Hortic. 21: 89–98.

Aronson, J.A. 1989. HALOPH. A data base of salt tolerant plants of the world. Office of Arid Land Studies, Univ. Arizona, Tucson.

ASCFG. Association of Specialty Cut Flowers Growers. 2002. Cut flowers of the year. www.ascfg.org.

Ayers, R.S., Westcot, D.W. 1985. Water Quality for Agriculture. F. A. O. Irrigation and drainage Paper 29 Rev. 1. F. A. O. UN, Rome. 174 pp.

Ball, V. 1998. Ball Redbook. 16th Edition. Ball Publishing, Batavia, IL.

Bernstein, N., Luria, G., Bruner, M., Nishri, Y., Dori. I., Matan, E., Joffe, M. 2008. Development of “stem-topple” disorder in *Ranunculus asiaticus* is related to localised disturbances in tissue calcium levels. J. Hortic. Sci. Biotechnol. 83: 525–531.

California Department of Water Resources. 2009. Matching water quality to use, Vol. 2. California Water Plan Update, Chapter 16.

Carter, C.T., Grieve, C.M. 2008. Mineral nutrition, growth, and germination of *Antirrhinum majus* L. (snapdragon) when produced under increasingly saline conditions. HortScience 43: 710–718.

Carter, C.T., Grieve, C.M. 2009. Growth and salinity tolerance of *Zinnia elegans* when irrigated with wastewaters from two distinct growing regions in California. HortScience 44: 1083.

Carter, C.T., Grieve, C.M., Poss. J.A. 2005a. Salinity effects on emergence, survival and ion accumulation of *Limonium perezii*. J. Plant Nutr. 28: 1243–1257.

Carter, C.T., Grieve, C.M., Poss, J.A., Suarez, D.L. 2005b. Production and ion uptake of *Celosia argentea* irrigated with saline wastewaters. Sci. Hortic. 106: 381–394.

Costello. L.R., Perry, E.J., Matheny, N.P., Henry, J.M., Geisel, P.M. 2003. Abiotic disorders of landscape plants. A diagnostic guide. University of California Agriculture and Natural Resources. Pub. 3420. 242 pp.

Cuartero, J., Fernández-Muñoz, F. 1999. Tomato and salinity. Sci. Hortic. 78: 83–125.

Devitt, D.A., Morris, R.L. 1987. Morphological response of flowering annuals to salinity. J. Am. Soc. Hortic. Sci. 112: 951–955.

Dole, J.M.,Wilkins, H.F. 1999. Floriculture—principles and species. Prentice Hall, Upper Saddle River, NJ.

Epstein, E., Bloom, A.J. 2005. Mineral nutrition of plants: principles and perspectives. 2nd Edition. Sinauer Associates, Inc., Sunderland, MA.

Flowers, T.J., Hajibagheri, M.A., Clipson, N.J. 1986. Halophytes. Quart. Rev. Biol. 61: 313–337.

Friedman, H., Bernstein, N., Bruner, M., Rot, I., Ben-Noon, Z., Zuriel, A., Zuriel, R., Finkelstein, S., Umiel, N., Hagiladi, A. 2007. Application of secondary-treated effluents for cultivation of sunflower (*Helianthus annuus* L.) and celosia (*Celosia argentea* L.) as cut flowers. Sci. Hortic. 115: 62–69.

Gagneul, D., Aïnouche, A., Duhazé, C., Lugan, R., Larher, F.R., Bouchereau, A. 2007. A reassessment of the function of the so-called compatible solutes in the halophytic Plumbaginaceae *Limonium latifoliun*. Plant Phys. 144: 1598–1611.

Gilman, E.F. 2007. *Antirrhinum majus*, snapdragon. Univ. Florida. Int. Food Agric. Sci. Extension FPS-44. 3 pp.

Grieve, C.M., Poss, J.A. 2010. Response of ornamental sunflower cultivars ‘Sunbeam’ and ‘Moonbright’ to irrigation with saline wastewaters. J. Plant Nutr. In Press.

Grieve, C.M., Poss, J.A., Grattan, S.R., Shouse, P.J., Lieth, J.H., Zeng, L. 2005. Production and mineral nutrition of *Limonium* species irrigated with saline wastewaters. HortScience 40: 654–658.

Grieve, C.M., Poss, J.A., Amrhein, C. 2006. Response of *Matthiola incana* to irrigation with saline wastewaters. HortScience 41: 119–123.

Grieve, C.M., Wu, S., Grattan, S.R., Harivandi, A. 2007. Tolerance of plants to salinity and to specific ions. In: Tanji, K., ed. Managing salinity of recycled water for landscape irrigation: a comprehensive literature review. National Water Research Institute. Chapter 5, pp. V1–V60. CD-ROM available: trusso@nwri-usa.org.

Grieve, C.M., Poss, J.A., Carter, C.T., Shouse, P.J 2008. Modeling growth of *Matthiola incana* in response to saline wastewaters differing in nitrogen level. HortScience 1787–1793.

Healy, W. 1997. Stock as a cut flower. In: Ball, V., ed. Ball Redbook. 16th edition. Ball Publishing. Batavia, IL.

Hoffman, G.J. 1981. Alleviating salinity stress. In: Arkin, G.F., Taylor, H.M., eds. Modifying the root environment to reduce crop stress. Am. Soc. Agric. Eng. Monograph 4. ASAE, St. Joseph, MI. Chapter 9.

Klotz, E., Lawton, H., Hall, J., 1989. A history of citrus in the Riverside area. Riverside Museum Press. Riverside, CA.

Lee, M.K., van Iersel, M.K. 2008. Sodium chloride effects on the growth, morphology, and physiology of chrysanthemum (*Chrysanthemum* × *morifolium*). HortScience 43: 1888–1891.

Liu, X., Grieve, C.M. 2009. Accumulation of chiro-inositol and other non-structural carbohydrates in *Limonium* species in response to saline irrigation waters. J. Am. Soc. Hortic. Sci. 134: 329–336.

Lunt, O.R., Kofranek, A.M., Hart, S.A. 1954. Tolerance of six stock (*Matthiola incana*) varieties to saline conditions. Proc. Am. Soc. Hortic. Sci. 64: 431–436.

Maas, E.V. 1986. Salt tolerance of plants. Appl. Agric. Res. 1: 12–26.

Maas, E.V., Grieve, C.M. 1990. Spike and leaf development in salt-stressed wheat. Crop Sci. 30: 1309–1313.

Maas, E.V., Grattan, S.R. 1999. Crop yields as affected by salinity. In: Skaags, R.W., van Schilfgaarde, J., eds. Agricultural Drainage. Agron. Monogr. 38. ASA-CSSA-SSSA. Madison, WI, pp. 615–657.

Munns, R., Tester, M. 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant Biol. 59: 651–681.

Plett, D.C., Møller, I.S. 2010. Na^+ transport in glycophytic plants: what we know and would like to know. Plant Cell Environ. 33: 612–626.

Salisbury, F.B. 1995. Units, symbols, terminology for plant physiology. Utah State Univ. Logan, UT.
Shillo, R., Ding, M., Pasternak, D., Zaccai, M. 2002. Cultivation of cut flower and bulb species with saline water. Sci. Hortic. 92: 41–54.
Skimina, C.A. 1980. Salt tolerance of ornamentals. Proc. Intl. Propag. Soc. 30: 113–118.
Skimina, C.A. 1986. Recycling irrigation runoff on container ornamentals. HortScience 21: 32–34.
Skimina, C.A. 1992. Recycling water, nutrients and waste in the nursery industry. HortScience 27: 968–971.
Sloan, R.C., Harkness, S.S. 2006. Field evaluation of pollen-free sunflower cultivars for cut flower production. HortTechnology 16: 324–327.
Sonneveld, C., Baas, R., Nijssen, M.C., deHoog, J. 1999. Salt tolerance of flower crops grown in soilless culture. J. Plant Nutr. 22: 1033–1048.
Steppuhn, H., van Genuchten, M. Th., Grieve, C.M. 2005a. Root-zone salinity: 1. Selecting a product-yield index and response function for crop tolerance. Crop Sci. 45: 209–220.
Steppuhn, H., van Genuchten, M. Th., Grieve, C.M. 2005b. Root-zone salinity: II. Indices for tolerance in agricultural crops. Crop Sci. 45: 221–232.
Suarez, D.L., Simunek J. 1997. UNSATCHEM: unsaturated water and solute transport model with equilibrium and kinetic chemistry. Soil Sci. Soc. Am. J. 61: 1633–1646.
Valdez-Aguilar, L.A., Grieve, C.M., Poss, J.A. 2009a. Salinity and alkaline pH of irrigation water affect marigold plants. I. Growth and shoot dry mass partitioning. HortScience. 44: 1719–1725.
Valdez-Aguilar, L.A., Grieve, C.M., Poss, J.A., Layfield, D.A. 2009b. Combination of salinity and alkalinity in irrigation water affect marigold plants: II. Mineral ion relations. HortScience. 44: 1726–1735.
Valdez-Aguilar, L.A., Grieve, C.M., Poss, J.A., Mellano, M.A. 2009c. Hypersensitivity of *Ranunculus asiaticus* to salinity and alkaline pH in irrigation water in sand cultures. HortScience. 44: 138–144.
Wang, D. 2002. Dynamics of soil water and temperatures in above ground sand cultures used for screening plant salt tolerance. Soil Sci. Soc. Am. J. 61: 1384–1491.
Water Education Foundation. 1992. Layperson's guide to Water recycling and reuse. 16 pp.
Zeng, L., Shannon, M.C. 2000. Salinity effects on seedling growth and yield components in rice. Crop Sci. 40: 996–1003.