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Salinity and Alkaline pH in Irrigation Water Affect Marigold Plants: I. Growth and Shoot Dry Weight Partitioning

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***Abstract*. Marigolds are one of the most popular annual ornamental plants; both, the short-stature cultivars (*Tagetes patula* L.) and the taller cultivars (*T. erecta* L.) are used as container plants in landscape and garden settings. *Tagetes erecta* varieties can also make excellent cut and dried flowers for the florists' market. The present study was conducted to evaluate the response of *T. patula* 'French Vanilla' and *T. erecta* 'Flagstaff' and 'Yellow Climax' to irrigation with saline water with and without pH control. Marigold plugs were transplanted into greenhouse sand tanks and established for 1 week under nonsaline conditions. Ten treatments were then applied with electrical conductivities of irrigation water (EC_w) of 2, 4, 6, 8, and 10 dS·m^{-1} and pH levels of 6.4 and 7.8. Growth of all three cultivars decreased in response to irrigation with saline waters at pH 6.4. Compared with the nonsaline controls, 'French Vanilla' exhibited a 20% to 25% decrease in plant height, leaf dry weight (DW), and shoot DW when irrigated with 4 dS·m^{-1} water. However, the number of flowering shoots and the diameter and number of flowers were not significantly affected until the EC_w exceeded 8 dS·m^{-1}. Growth of 'Flagstaff' and 'Yellow Climax' also decreased as EC_w increased. Shoot DW of the tall cultivars decreased by 30% and 24%, respectively, in response to the 4 dS·m^{-1} treatment, but additional salt stress had no further effect on DW production. Marigolds were highly sensitive to high pH. Plants irrigated with nonsaline water with pH at 7.8 exhibited a 50%, 89%, and 84% reduction in shoot DW in 'French Vanilla', 'Flagstaff', and 'Yellow Climax', respectively, compared with plants irrigated with water with pH 6.4. Marigold cultivars were rated as moderately tolerant to salinity because growth was affected when water EC_w exceeded 8 dS·m^{-1}. Salinity tended to reduce internode elongation, resulting in attractive plants. Compactness was not increased as a result of a decrease in DW, resulting in attractive plants, which show great promise as bedding or landscape plants in salt-affected sites provided that the pH of the soil solutions remains acidic. Under our experimental conditions in the sand tank system, the EC_w was essentially equivalent to those of the sand soil solution; however, considering that the EC of the sand soil solution is ≈2.2 times the EC of the saturated soil extract (EC_e), our salinity treatments may be estimated as 0.91, 1.82. 2.73, 3.64, and 4.55 dS·m^{-1}. Thus, the threshold EC_w at which marigold cultivars exhibited acceptable growth, 8 dS·m^{-1}, would be equivalent to EC_e of 3.64 dS·m^{-1}.**

The lack of dependable supplies of good-quality water in many regions has become a concern as the competition among agricultural, urban, industrial, environmental, and recreational groups continues to increase. Members of the nursery and landscape industries are increasingly turning to recycled, often saline, wastewaters as a valuable alternative to the use of fresh water for irrigation. In California, sources of degraded waters available for incorporation in reuse systems include well waters contaminated by intrusion of sea water, drainage effluents from agricultural fields, runoff from greenhouse operations, and municipal wastewater. Development of water reuse practices will benefit the floral and nursery industries in numerous ways: fresh water conservation, nutrient savings, energy conservation, protection of the environment, and a favorable public image (Skimina, 1992). Little information is available to floral and nursery producers, however, on the limits salinity places on the growth, yield, and quality of many ornamental species. Likewise, landscape designers and gardeners have few guidelines for selection of plant species suitable for sites where soils are saline and/or irrigation waters are high in salinity.

Salinity is of concern because of its deleterious effect on plant growth, nutritional balance, and plant and flower marketable quality, including visual injury, flower distortion, and reduced stem length. Plant growth is detrimentally affected by salinity as a result of the disruption of certain physiological processes that lead to reductions in yield and/or quality. Growth, yield, and quality reduction may occur through a decrease in the ability of plants to take up water from the soil solution and the destruction of soil structure (Barrett-Lennard, 2003). In addition, toxicity resulting from excessive concentration of certain ions, principally Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, and HCO_3^- as well as nutritional imbalances (Grattan and Grieve, 1999) may also play important roles in the response of plants in saline environments.

Most horticultural crops are glycophytes (Greenway and Munns, 1980) and range from salt-sensitive to moderately salt-tolerant. Producers of ornamental species are, therefore, reluctant to use water of poor quality for irrigation because they consider floricultural species to be highly sensitive. However, studies have demonstrated that moderately saline waters can be used to irrigate certain ornamental species without compromising economic value (Carter and Grieve, 2008; Friedman et al., 2007; Grieve et al., 2005; Shillo et al., 2002).

Marigold is one of the most important annual ornamental species used in beds or borders of landscape settings and/or as cut flowers (Nau, 1997). Huang and Cox (1988) rated the tall marigold 'First Lady' as moderately tolerant to salinity; plants grown in a peat–perlite medium exhibited symptoms of toxicity only when the electrical conductivity (EC) of a $NaCl + CaCl_2$ solution exceeded 7.9 dS·m^{-1}. However, little is known about the effect of salinity on marigold performance when the pH of the irrigation waters is also high. High pH of irrigation water is associated with high concentrations of HCO_3^- and CO_3^{2-} and eventually alters plant growth by rendering micronutrients (e.g., iron and zinc) insoluble. The present study was designed to compare the growth of three cultivars of marigold in response to irrigation with solutions differing in ionic concentration and pH, imitating the saline conditions of runoff waters typical of those prevalent in the inland valleys of southern California.

Materials and Methods

The experiment was conducted in a greenhouse at the U.S. Salinity Laboratory in Riverside, CA. Climatic conditions were monitored with an automated system at hourly intervals. Daily air temperatures ranged from 21.5 to 28.6 °C (average, 26.5 °C) and night temperatures from 16.4 to 19.3 °C (average, 18.4 °C). Relative humidity ranged from 41.6% to 44.2% (average, 43.4%). Average daily photosynthetically active radiation

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(PAR) was 417.4 μmol·m^{-2}·s^{-1}, whereas noontime average PAR was 860.1 μmol·m^{-2}·s^{-1}.

Seeds of three marigold cultivars (W. Atlee Burpee & Co., Warminister, PA) were seeded on germination trays on 6 Feb. 2007. Plugs of 'French Vanilla' (five plugs) (*Tagetes patula* L.), 'Yellow Climax' (three plugs) (*Tagetes erecta* L.), and 'Flagstaff' (three plugs) (*Tagetes erecta* L.) were transplanted on 8 Mar. 2007 into each of 30 sand tanks containing washed sand with a bulk density of 1.7 mg·m^{-1}. Sand tanks were made of black rigid plastic and had a volume of 360 L (1.2 m × 0.6 m × 0.5 m). Seedlings had one pair of fully expanded leaves and were 5 to 6.5 cm tall. Plants were allowed to establish for 1 week and were flood-irrigated twice daily with a complete nutrient solution having an EC of 2.0 dS·m^{-1} and a pH of 6.4 (± 0.1 or ± 0.2). Solutions of pH 6.4 contained 2.5 meq KNO_3, 1.5 meq KH_2PO_4, 1.0 meq of NH_4NO_3, and 1.4 meq HNO_3 plus the ions shown in Table 1 for the 2.0 dS·m^{-1} treatment and micronutrients as follows: 50 μM iron as sodium ferric diethylenetriamine pentacetate (NaFeDTPA), 23 μM H_3BO_4, 5 μM $MnSO_4$, 0.4 μM $ZnSO_4$, 0.2 μM $CuSO_4$, and 0.1 μM H_2MoO_4. Solutions of pH 7.8 were similar to the one with pH 6.4, but contained 1.75 meq of NH_4NO_3 and no HNO_3. Irrigation had a 5-min duration to saturate the sand and then the solution drained to 765-L subsurface reservoirs for reuse during the next irrigation.

One week after transplant, the irrigation system was changed from flood to an autocompensated drip irrigation system (0.6 L·h^{-1} per dripper; three irrigation lines separated 20 cm with drippers every 20 cm per tank) and experimental treatments were imposed. Irrigation was carried out twice daily and each had a 2-hour duration. Constant EC of irrigation water (EC_w) was maintained by replenishing water lost by evapotranspiration on a regular basis. Saline treatments were prepared to represent concentrations of Colorado River water and from predictions based on appropriate simulations of what the long-term compositions of the waters would be on further concentrations resulting from plant water extraction and evaporation (Suarez and Simunek, 1997). The EC_w treatments were: 2, 4, 6, 8, and 10 dS·m^{-1} and all the solutions had a Ca^{2+}, Mg^{2+}, Na^+, SO_4^{2-}, Cl^- ratio of 1:1:1.6:1:2.6. Table 1 shows target EC_w and ion concentrations in the irrigation waters. Two pH levels, 6.4 and 7.8, were used as previously indicated. The alkaline pH was the normal pH of Riverside tap water (EC_w = 0.6 dS·m^{-1}). Solutions of pH 6.4 were adjusted by acidification with H_2SO_4 every other day. At harvest time, average alkalinity was 0.47 ± 0.05 and 1.82 ± 0.09 meq·L^{-1} for the solutions with pH of 6.4 and 7.8, respectively.

Table 1. Ion concentration of irrigation waters prepared to represent concentrations of Colorado River water at varying electrical conductivities (EC_w).

EC_w (dS·m^{-1})	Concn (meq·L^{-1}) Ca^{2+}	Mg^{2+}	Na^+	SO_4^{2-}	Cl^-
2	5.0	5.0	8.0	5.0	13.0
4	7.8	12.1	20.9	13.1	27.5
6	11.4	18.7	32.3	20.0	42.0
8	15.1	25.3	43.6	27.2	57.2
10	18.8	32.6	55.0	34.6	72.5

Shoots were harvested when most of the flower heads were fully opened. Flowers, leaves, and stems were washed twice in deionized water, blotted dry, placed in paper bags, and dried in an oven at 70 °C for 5 d. Measurements recorded for 'Yellow Climax' and 'Flagstaff' included: plant height, and number, length and diameter of flowering shoots, diameter of the terminal flower on each stem, and leaf, flower, and shoot dry weight (DW). Plant height was measured from the base at the plant to the top of the terminal flower, and the diameter was measured on the base of each flowering shoot. Measurements recorded for 'French Vanilla' were: plant height, flower and stem diameter, and leaf, flower, and shoot DW. Compactness of the three cultivars was calculated according to Burnett et al. (2006): compactness (mg·cm^{-1}) = shoot DW (not including inflorescence)/height.

The effect of salinity on vase life of flowering shoots was measured in terms of relative loss of fresh weight (FW). Flowering shoots from 'Yellow Climax' and 'Flagstaff' plants irrigated with water of pH 6.4 and EC_w of 2, 6, and 10 dS·m^{-1} were harvested and weighed in groups of three shoots. Then, one set of shoots, with three replications, was placed in an Erlenmeyer flask with a known volume of deionized water for rehydration, after which the relative FW loss was recorded at 4, 7, 10, and 14 d.

The study was designed as a factorial experiment for each cultivar and set as a completely randomized design with two factors: EC_w and pH of irrigation water. Collected data were analyzed by the analysis of variance procedure and trends using SAS Version 8.2 (SAS Institute, Inc., 2001).

Results

EC and pH of irrigation water significantly affected all plant growth attributes of marigold 'French Vanilla', except for flower DW (Table 2), which was affected only by pH. In plants irrigated with acidic water, the increase in EC_w was associated with a significant linear decrease in plant height, leaf DW, shoot DW, flower diameter, and compactness. In plants irrigated with alkaline water, the decrease in plant height, shoot DW, and compactness was linear, whereas flower DW exhibited a quadratic trend. The pH × EC_w interaction significantly affected plant height and compactness, primarily as a result of the difference in the intercept and slope coefficients (Table 2). The lower slope for plants irrigated with alkaline water indicates that salinity was less detrimental than it was in plants irrigated with acidic water, suggesting a more damaging effect of alkaline pH than EC_w. The significant pH × EC_w interaction for leaf DW was attributable mainly to a nonsignificant trend in plants irrigated with alkaline water (Table 2), stressing the argument that alkaline pH was more detrimental for plant growth. Flower DW was significantly affected by increased irrigation water pH, because plants irrigated with alkaline water had an overall reduction of 56% in DW when compared with plants irrigated with acidic water (Table 2). Flower diameter and shoot DW were significantly affected by EC_w and pH, but the interaction was not significant (Table 2). Averaged across EC_w levels, there was an overall 23% and 49% reduction in flower diameter and shoot DW in plants of 'French Vanilla' irrigated with alkaline water. Shoot DW was unaffected significantly by the pH × EC_w interaction; however, the decrease in DW was linear for both water pH treatments (Table 2).

The pH × EC_w interaction was significant for all growth parameters of 'Flagstaff' (Table 3). Plant height was significantly reduced in plants irrigated with acidic or alkaline water. The response was linear and the difference between intercepts and slopes explained the significant interaction. In plants irrigated with alkaline water, the lower slope indicates that height was less affected by increasing EC_w, and the markedly decreased intercept suggests a more detrimental effect of alkaline pH. The remainder of the growth attributes exhibited a similar trend: a linear decrease in plant growth with increasing EC_w in plants irrigated with acidic water, whereas in plants irrigated with alkaline water there was a nonsignificant trend to explain the response to salinity; thus, the slope was not significantly different from zero (Table 3). Like it was observed for 'French Vanilla', this suggests that the primary effect was the result of high pH and that increasing EC_w did not cause further decrease in growth. Averaged across EC_w levels, there was an overall 46% and 82% reduction in flower diameter and shoot DW in plants of 'Flagstaff' irrigated with alkaline water. Salinity decreased vase life of cut flowers of 'Flagstaff' (Fig. 1). Lateral flowering shoots collected from plants when EC_w was 2 and 6 dS·m^{-1} did not exhibit change in FW by Day 4. However, by Day 7, FW markedly decreased. The decrease in FW in shoots collected from plants when EC_w was 10 dS·m^{-1} was noticeable at Day 4, and the decrease continued up to Day 14.

Results in 'Yellow Climax' were very similar to those of 'Flagstaff' (Table 4). There was a significant reduction by increased EC_w in growth of plants irrigated with acidic water following a linear trend. However, in plants irrigated with alkaline water, the trend was not significant, which would explain the significant pH × EC_w interaction. This implies that alkaline pH had a significant effect on plant growth, but increasing EC_w in this type of water caused no further decrease in growth. Averaged across EC_w levels, there was an overall 30% and 76% reduction in flower diameter and shoot DW, respectively, in plants of 'Yellow Climax' irrigated with alkaline water. In general, 'Yellow Climax' plants were more compact compared with 'Flagstaff' (Table 4). Vase life of lateral flowering shoots collected from plants when

Table 2. Effect of electrical conductivity (EC_w) and pH (6.4 or 7.8) of irrigation water on plant growth attributes of marigold *Tagetes patula* 'French Vanilla' at experiment termination.

	Plant ht (cm)		Leaf DW[z] (g)		Flower DW (g)		Shoot DW (g)		Flower diam (mm)		Compactness[y] ($mg \cdot cm^{-1}$)	
EC_w ($dS \cdot m^{-1}$)	pH = 6.4	pH = 7.8	pH = 6.4	pH = 7.8	pH = 6.4	pH = 7.8	pH = 6.4	pH = 7.8	pH = 6.4	pH = 7.8	pH = 6.4	pH = 7.8
2	29.4	22.1	2.16	1.03	2.66	1.23	6.36	3.20	75.3	53.0	125	89
4	23.6	20.4	1.60	0.82	2.31	0.82	5.04	2.21	65.6	54.4	115	68
6	23.0	20.4	1.40	0.84	1.96	0.99	4.31	2.39	66.9	53.7	102	68
8	18.8	17.9	1.18	0.73	2.23	0.76	4.09	1.89	66.2	48.8	99	63
10	20.4	18.4	1.21	0.84	2.21	1.15	4.19	2.49	62.6	48.7	97	73
Trend[x,w,v]	***L	**L	***L	NS	NS	*Q	*L	*L	***L	NS	**L	*L
b_0	28.8 a	22.8 a	2.09 a	—	—	1.65 a	6.12 a	2.95 a	73.5 a	—	126 a	83 a
b_1	–1.2 a	–0.5 a	–0.12 a	—	—	–0.27 c	–0.26 c	–0.09 d	–1.2 b	—	–4 a	–2 c
b_2	—	—	—	—	—	+0.02 c	—		—	—	—	—
ANOVA EC_w	***		***		NS		**		**		**	
pH	***		***		***		***		***		***	
pH × EC_w	*		**		NS		NS		NS		*	

[z]DW = dry weight.
[y]Compactness = (stem DW + leaf DW)/plant height.
[x]L = linear trend; Q = quadratic trend.
[w]NS, *, **, ***, nonsignificant and significant at $P < 0.05$, 0.01, and 0.001, respectively.
[v]a, b, c, d = Significant at $P < 0.001$, 0.001, and 0.05, and nonsignificant, respectively.
ANOVA = analysis of variance.

Table 3. Effect of electrical conductivity (EC_w) and pH (6.4 or 7.8) of irrigation water on plant growth attributes of marigold *Tagetes erecta* 'Flagstaff' at experiment termination.

	Plant ht[z] (cm)		Stem length (cm)		Leaf DM[z] (g)		Flower DW (g)		Shoot DW (g)		Flowering stems/plant		Flower diam (mm)		Compactness[y] ($mg \cdot cm^{-1}$)	
EC_w ($dS \cdot m^{-1}$)	6.4	7.8	6.4	7.8	6.4	7.8	6.4	7.8	6.4	7.8	6.4	7.8	6.4	7.8	6.4	7.8
2	72.8	38.9	52.3	20.7	12.8	2.9	31.2	1.6	69.1	7.3	10.9	3.0	87.5	40.2	518	146
4	51.2	34.3	36.2	17.6	6.0	2.4	10.9	1.7	25.9	6.1	6.9	2.6	68.4	31.3	292	128
6	51.1	33.7	32.3	20.0	5.7	2.1	11.2	1.8	24.5	5.6	8.3	1.5	67.5	42.5	261	114
8	57.1	31.1	34.9	15.5	6.8	2.2	18.0	1.8	34.0	5.7	8.7	2.1	74.3	45.0	278	121
10	40.0	29.9	19.4	16.7	4.4	2.3	9.8	1.9	19.4	5.9	6.5	1.6	63.0	35.8	248	137
Trend[x,w,v]	***L	**L	***L	NS	***L	NS	***L	NS	***L	NS	*L	NS	***L	NS	***L	NS
b_0	72.6 a	39.9 a	55.1 a	—	11.9 a	—	26.8 a	—	62.0 a	—	10.3 a	—	85.0 a	—	486 a	—
b_1	–3.0 b	–1.0 b	–3.4 a	—	–0.8 b	—	–1.8 c	—	–4.6 b	—	–0.4 c	—	–2.2 b	—	–28 b	—
ANOVA EC_w	***		***		***		***		***		**		**		**	
pH	***		***		***		***		***		***		***		***	
pH × EC_w	**		**		***		***		***		*		*		**	

[z]DW = dry weight.
[y]Compactness = (stem DW + leaf DW)/plant height.
[x]L = linear trend; Q = quadratic trend.
[w]NS, *, **, ***, nonsignificant and significant at $P < 0.05$, 0.01, and 0.001, respectively.
[v]a, b, c = Significant at $P < 0.001$, 0.001, and 0.05, respectively.
ANOVA = analysis of variance.

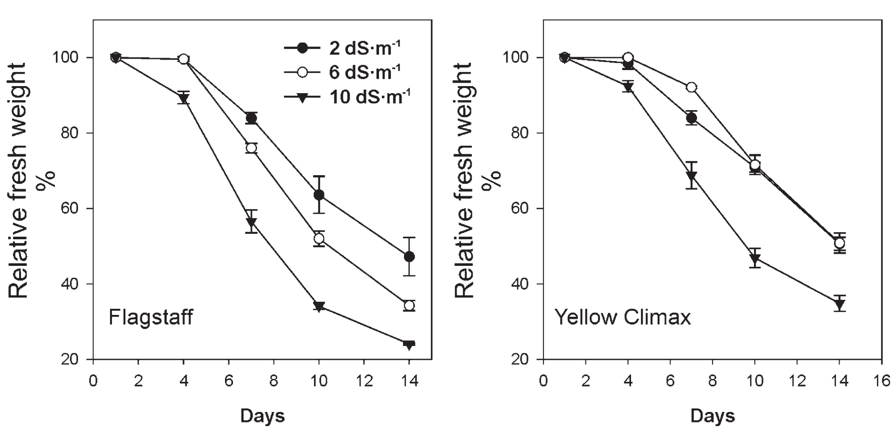

Fig. 1. Relative fresh weight reduction of flowering shoots of marigold *Tagetes erecta* 'Flagstaff' and 'Yellow Climax' as affected by preharvest irrigation water electrical conductivity (2, 6, 10 $dS \cdot m^{-1}$). Bars represent the SE of the mean (n = 3).

EC_w was 2 and 6 $dS \cdot m^{-1}$ showed no decrease by Day 4 (Fig. 1). However, by Day 7, FW was decreased markedly. The decrease in FW of shoots collected from plants irrigated with 10 $dS \cdot m^{-1}$ waters was noticeable even at Day 4, and FW continued to decrease up to Day 14.

Plant DW was partitioned preferentially for flower growth in all three marigold cultivars when irrigation water had an alkaline pH (Fig. 2). Increasing salinity did not affect DW partitioning when irrigation water was acidic. However, when the pH was alkaline, DW was preferentially diverted for stem growth in 'Flagstaff' and 'Yellow Climax'.

Discussion

Normally, landscapers, growers, and gardeners are reluctant to use water of poor quality for irrigation of landscape areas because ornamental species are considered highly sensitive to high EC_w and alkaline pH. However, some studies have revealed that a number of ornamental plants can grow at high levels of salinity (Grieve et al., 2005; Shillo et al., 2002) and alkalinity (Valdez-Aguilar and Reed, 2007) without substantial loss of quality. Analysis of specific yield components may give vastly different salt tolerance rankings. For example, Devitt and Morris (1987) reported that marigold (*Tagetes patula*) 'Janie Bright Yellow' was very tolerant based on relative plant height,

Table 4. Effect of electrical conductivity (EC_w) and pH (6.4 or 7.8) of irrigation water on plant growth attributes of marigold *Tagetes erecta* ‘Yellow Climax’ at experiment termination.

	Plant ht[z] (cm)		Stem length (cm)		Leaf DM[z] (g)		Flower DW (g)		Shoot DW (g)		Flowering stems/plant		Flower diam (mm)		Compactness[y] ($mg \cdot cm^{-1}$)	
EC_w ($dS \cdot m^{-1}$)	6.4	7.8	6.4	7.8	6.4	7.8	6.4	7.8	6.4	7.8	6.4	7.8	6.4	7.8	6.4	7.8
2	70.2	44.7	48.9	24.1	16.0	4.1	33.6	4.3	78.2	12.8	10.6	3.8	103.4	63.1	635	191
4	55.5	40.8	35.2	22.0	8.5	2.9	16.8	3.0	37.0	8.6	8.7	2.3	90.2	67.5	362	140
6	54.0	42.5	35.1	22.9	8.9	4.3	16.7	4.1	36.5	12.0	8.8	4.4	86.1	66.5	366	190
8	55.7	37.6	37.1	19.8	9.9	2.8	29.6	3.1	53.2	8.2	9.9	2.9	97.2	58.8	422	143
10	46.2	39.4	29.1	22.8	5.4	4.0	14.9	6.3	26.5	14.1	5.4	3.8	89.0	71.9	253	199
Trend[x,w,v]	***L	NS	***L	NS	***L	NS	*L	NS	***L	NS	*L	NS	*L	NS	***L	NS
b_0	70.6 a	—	48.4 a	—	15.6 a	—	29.7 a	—	72.4 a	—	10.8 a	—	99.7 a	—	619 a	—
b_1	–2.4 a	—	–1.9 a	—	–1.0 b	—	–1.2 d	—	–4.4 b	—	–0.3 c	—	–1.1 c	—	–35 b	—
ANOVA EC_w	***		***		***		**		***		NS		NS		**	
pH	***		***		***		***		***		***		***		***	
pH × EC_w	**		***		***		***		***		*		***		***	

[z]DW = dry weight.
[y]Compactness = (stem DW + leaf DW)/plant height.
[x]L = linear trend; Q = quadratic trend.
[w]NS, *, **, ***, nonsignificant and significant at $P < 0.05$, 0.01, and 0.001, respectively.
[v]a, b, c = Significant at $P < 0.001$, 0.001, and 0.05, respectively.
ANOVA = analysis of variance.

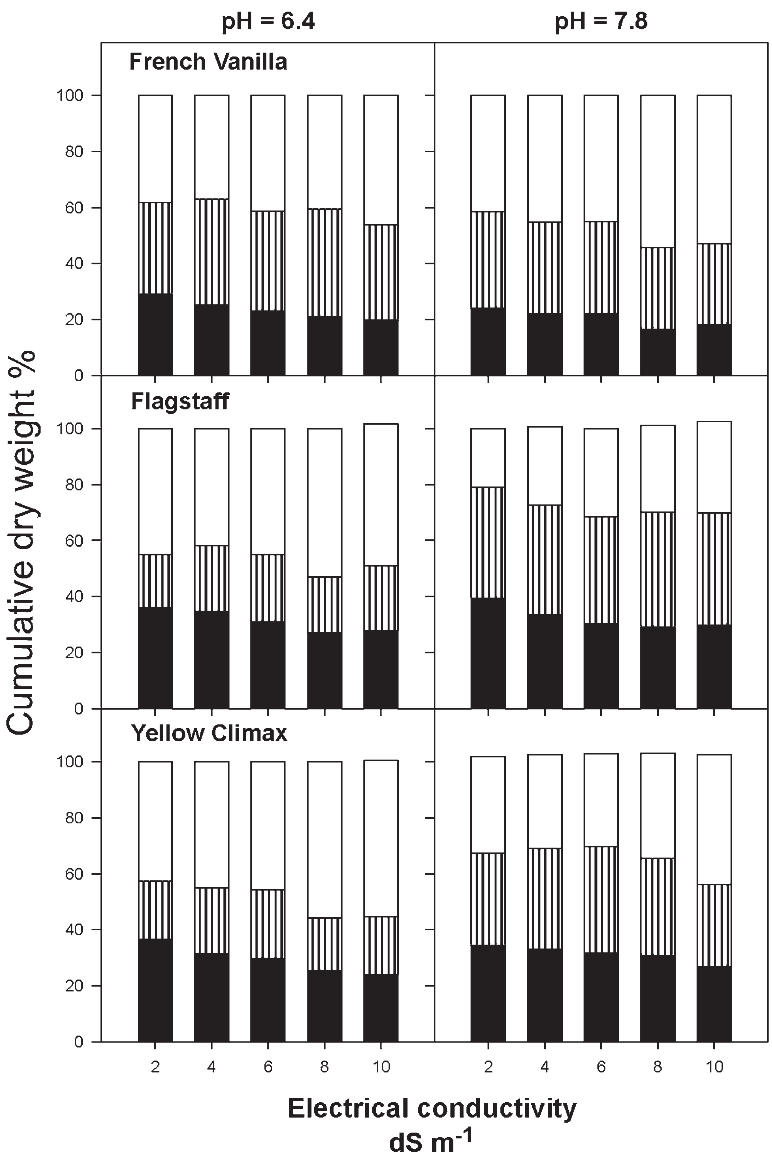

Fig. 2. Dry weight partitioning in shoots of marigold *Tagetes patula* ‘French Vanilla’ and *Tagetes erecta* ‘Flagstaff’ and ‘Yellow Climax’ as affected by electrical conductivities and pH of irrigation water. Black column = root dry weight proportion; crossed column = shoot dry weight; white column = leaf dry weight.

on relative DW, and on relative maximum flower diameter, but very sensitive based on the relative number of flowers. In the present study, results indicate that the growth of three marigold cultivars was decreased by increasing EC_w, probably in response to limited cell expansion resulting from osmotic stress (Munns and Tester, 2008). However, this finding does not necessarily imply that the use of poor-quality water for irrigation should be ruled out for both *Tagetes* species, because salt-induced reduction of growth components are not necessarily limiting factors. Ornamentals are generally acceptable for landscape applications if, compared with a premium-grade plant, the plant is slightly shorter. Users would undoubtedly be willing to include such species in problem, salt-affected sites provided the overall health of the plant is not compromised, stems are robust, colors of leaves and flowers remain true, and there is no visible leaf or flower injury resulting from salinity. However, the major criterion for species selection in problem sites is sustainability of aesthetic value throughout the growing season. ‘French Vanilla’ exhibited a linear decrease in plant height, leaf DW, and shoot DW when plants were irrigated with increasing EC_w. However, despite the significant growth decrease, flower DW was not significantly affected, whereas flower diameter was marginally decreased at the highest EC_w evaluated. Additionally, plant compactness was decreased only by 21% at maximum EC_w. Thus, if growers, gardeners, and landscapers would consider such a growth reduction acceptable, ‘French Vanilla’ would be a candidate for use of moderately saline waters, particularly because compactness and aesthetic value remained high (Fig. 3).

Quality of flowers was more compromised in ‘Flagstaff’ because flower diameter and stem length of cut flowers were comparatively more affected than in ‘Yellow Climax’. Production of flowering stems was also affected by increasing EC_w, but the effect was similar in both cultivars. Postharvest

Fig. 3. Marigold *Tagetes patula* 'French Vanilla' plants at experiment termination. From left to right, plants irrigated with water with electrical conductivities of 2, 4, 6, 8, and 10 dS·m^{-1}, respectively. Top plants were irrigated with water of pH 6.4 and bottom plants with water of pH 7.8.

quality of cut flowers of both cultivars was also reduced by Day 7 when EC_w was 6 and 10 dS·m^{-1}; however, in 'Yellow Climax', quality of harvested flowers of plants irrigated with EC_w 6 dS·m^{-1} was similar to that of control plants, suggesting a higher tolerance.

The reduced growth of 'Flagstaff' and 'Yellow Climax' plants irrigated with water with EC_w 8 to 10 dS·m^{-1} makes these cultivars potentially useful for landscape purposes, because the aesthetic value was unaffected despite the reduction in plant height and decreased plant compactness (Figs. 4 and 5). The nonsignificant effect on the number of flowering shoots and the diameter of flowers when EC_w was 8 dS·m^{-1} contributed to the maintenance of the aesthetic quality of these cultivars, because high salinity was not related to changes in DW allocation or to a 10% increase in DW diverted for flower growth at the expense of stem DW accumulation. Hunter and Wu (2005) reported similar results in grass species.

'Yellow Climax' exhibited similar trends as 'Flagstaff' but appears to be more salt-tolerant. Shoot DW decreased by 24% and plant height decreased by 21% when EC_w was 8 dS·m^{-1}. In addition, the total number of flowering shoots produced and flower diameter were not decreased significantly when EC_w was lower than 8 dS·m^{-1}, suggesting that

Fig. 4. Marigold *Tagetes erecta* 'Flagstaff' plants at experiment termination. From left to right, plants irrigated with water with electrical conductivities of 2, 4, 6, 8, and 10 dS·m^{-1}, respectively. Top plants were irrigated with water of pH 6.4 and bottom plants with water of pH 7.8.

Fig. 5. Marigold *Tagetes erecta* 'Yellow Climax' plants at experiment termination. From left to right, plants irrigated with water with electrical conductivities of 2, 4, 6, 8, and 10 $dS \cdot m^{-1}$, respectively. Top plants were irrigated with water of pH 6.4 and bottom plants with water of pH 7.8.

flower production and quality are not severely affected. In addition, 'Yellow Climax' produced attractive cut flowers with acceptable vase life of the flowering stems from plants grown in the 6 $dS \cdot m^{-1}$ treatment

Huang and Cox (1988) reported that marigold 'First Lady' exhibited toxicity symptoms when EC_w was higher than 7.9 $dS \cdot m^{-1}$, a finding that is in close agreement with the results of the present study. However, they reported chlorotic young leaves and bronzing and marginal necrosis on mature leaves, becoming apparent 2 weeks after the beginning of irrigation with high EC_w; in our study, we detected the presence of marginal chlorosis only on older leaves of plants irrigated with saline water of EC_w higher than 8 $dS \cdot m^{-1}$. Younger leaves remained healthy throughout the course of the experiment, contributing to the maintenance of the landscape value. The fact that shoot growth was decreased even at low EC_w suggests that cell expansion of marigold was decreased as a result of osmotic stress; however, that increasing EC_w up to 8 $dS \cdot m^{-1}$ did not cause a significant additional decrease in growth suggests the possibility of tolerance to ionic stress resulting from exclusion or compartmentalization of toxic ions (Munns and Tester, 2008).

Lower-quality plants of the three cultivars were obtained under irrigation with high pH waters as a result of extensive necrosis of mature leaves and significant reduction in all growth attributes, which decreased overall quality (Figs. 3–5). However, we suggest that these plants may still be acceptable in areas in which available water for landscape irrigation has a combination of high EC_w and alkaline pH. Plants irrigated with alkaline water did not exhibit any response to increasing EC_w, except for plant height in 'Flagstaff', suggesting that the combined pH plus EC_w effects were nonadditive and that high pH is more detrimental for plant growth than salinity. Therefore, to irrigate marigold with degraded waters, it may be necessary to prevent a rise in soil solution pH.

In conclusion, marigold 'French Vanilla', 'Flagstaff', and 'Yellow Climax' may be used as bedding plants and 'Yellow Climax' as specialty cut flower production as well as in landscape sites when EC_w is lower than 8 $dS \cdot m^{-1}$ with minimal effects on plant quality. Although quality of marigold flowering stems was reduced as a result of their sensitivity to treatment irrigation waters, all three cultivars will produce acceptable plants in landscape sites where high salinity and high pH co-occur as dual stress factors. It is important to consider that under our experimental conditions in the sand tank system, sand waterholding capacity, and intervals between irrigations, the salinity of irrigation waters was essentially equivalent to that of the sand soil solution. Previous studies (Wang, 2002) indicate that soil–water dynamics in the river sand used is similar to that found in field soils and that the EC of the sand soil solution is ≈2.2 times the EC of the saturated soil extract (EC_e), the salinity parameter used to characterize salt tolerance in most studies (Ayers and Westcot, 1985). Therefore, our salinity treatments (EC_w) may be estimated as 0.91, 1.82. 2.73, 3.64, and 4.55 $dS \cdot m^{-1}$ expressed as EC_e, representing a range of values the crop could encounter in landscape or nursery settings. Thus, the threshold EC_w at which marigold cultivars exhibited acceptable growth (8 $dS \cdot m^{-1}$) would be equivalent to EC_e of 3.64 $dS \cdot m^{-1}$.

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