Plant and Soil **192:** 277–283, 1997.

Purslane (*Portulaca oleracea* L.): A halophytic crop for drainage water reuse systems

C.M. Grieve and D.L. Suarez
*USDA-ARS, U. S. Salinity Laboratory, Riverside, CA 92507-4617, USA**

Received 3 July 1996. Accepted in revised form 18 March 1997

Key words: leaf areas, salinity, sand cultures, selenium, water use

Abstract

Drainage water reuse systems have been proposed for the west side of the San Joaquin Valley of California in order to reduce the volumes of water requiring disposal. Implementation of this system requires development of a cropping system with successively higher salt tolerance. A major limitation is the need to identify alternate species that will be suitable as the final, most salt tolerant crop in the series. These crops must be productive when irrigated with waters that are typically high in sulfate salinity and may be contaminated with potentially toxic trace elements. This study was initiated to evaluate the interactive effects of sulfate salinity and selenium on biomass production and mineral content of purslane (*Portulaca oleracea*). Plants were grown in greenhouse sand cultures and irrigated four times daily. Treatments consisted of three salinity levels with electrical conductivities (EC_i) of 2.1, 15.2, and 28.5 dS m^{-1}, and two selenium levels, 0 and 2.3 mg L^{-1}. In the initial harvests, shoot dry matter was reduced by 15 to 30% at 15.2 dS m^{-1} and by 80 to 90% at 28.5 dS m^{-1}. Regrowth after clipping above the first node was vigorous and biomass from plants irrigated with 15.2 dS m^{-1} water was nearly double that from the 2 dS m^{-1} treatment. Purslane appears to be an excellent candidate for inclusion in saline drainage water reuse systems. It is (i) highly tolerant of both chloride- and sulfate-dominated salinities, (ii) a moderate selenium accumulator in the sulfate-system, and (iii) a valuable, nutritive vegetable crop for human consumption and for livestock forage.

Introduction

Drainage water reuse has been promoted as an environmentally-sound method for the disposal of saline drainage waters, particularly in the San Joaquin Valley of California (Rhoades, 1989). In the San Joaquin Valley, construction of a master drain to the Sacramento-San Joaquin Delta (discharging to the Pacific Ocean) was halted in 1975 due to funding limitations and concerns over the environmental impact of disposing of this water into the delta (Ohlendorf and Santolo, 1994). Kesterson Reservoir, as the terminal point of the existing drainage system, received drainage water until 1986, when all drainage was halted after embryo deformities in aquatic birds were related to elevated selenium concentrations in the Reservoir (Ohlendorf and Santolo, 1994). Insufficient drainage has resulted in elevated groundwater levels, soil salinization, and the construction of evaporation basins to dispose of drainage water. Presser et al. (1990) estimated that there were 2704 ha of evaporation ponds and that expansion to 13360 ha would be required by the year 2000. Expansion of evaporation ponds has not occurred due to environmental concerns and regulatory restraints, thus the need to reduce drainage volumes remains acute.

The multiple water use approach is advocated to conserve water, to reduce drainage water volume, and to minimize the use of otherwise arable land for the construction of temporary disposal facilities, such as evaporation ponds. In this system, selected crops would be grown and irrigated in sequence starting with very salt sensitive species (melons, onions, almonds) and continuing with increasingly salt tolerant crops (e.g. sweet corn, wheat, cotton, sugar beet). The drainage water becomes progressively more saline

---

* FAX No:19093424963. E-mail:cgrieve@ussl.ars.usda.gov

as each successive crop is irrigated. As conceptually proposed, the sequence ends with irrigation of halophytic species. In addition to the requirement of high potential for sustainability when irrigated with highly saline drainage waters, there is a requirement that the species thrive in the presence of potentially toxic ions such as selenium. Desirable traits for prospective halophytic species for the reuse system are (i) tolerance to highly saline, sodium- and sulfate- dominated drainage water, (ii) accumulation of significant amounts of Se in its tissues so as to limit Se accumulation in the drainage water, and (iii) production of a useful, economically-valuable crop. Several candidates have been proposed to fill this niche in the drainage water reuse system, e.g. *Atriplex* (Watson and O'Leary, 1993); *Medicago*, *Trifolium*, *Leymus*, *Puccinellia* (Parker et al., 1991); *Festuca* (Wu and Huang, 1991).

Plant response to salinity depends not only on the osmotic potential of the substrate but also on the kinds of ions that contribute to salinity. Furthermore, even at isosmotic potentials, plant species differ in their response to the composition of the salinizing medium. Contrasting responses have been reported for two halophytic chenopods. *Chenopodium rubrum* L. grew better with chloride salinity than with the sulfate system (Warne et al., 1990), while *Kochia scoparia* (L.) Schrad., performed better with sulfate-dominated salinity (Curtin et al., 1993). At moderate salinities, sulfate-salinity was generally less growth-limiting to cereal crops than is chloride salinity (Boursier and Läuchli, 1990; Curtin et al., 1993; Khan et al., 1995). In other species, growth in the chloride system led to nutrient imbalances or chloride toxicity with subsequent loss of yield (Mor and Manchanda, 1992).

Purslane (*Portulaca oleracea* L.), a common plant found throughout the United States, is a vigorous colonizer of disturbed, waste habitats. From the yield-response model of Maas and Hoffman (1977), purslane has been rated as salt tolerant with a threshold value, given in terms of the electrical conductivity of saturated-soil extract, EC_e, of 6.3 dS m^{-1} (Kumamoto et al., 1990) and a slope factor 4.8 (C M Grieve, personal observation). Yield was reduced by 50% when EC_e reached 11.5 dS m^{-1} (Kumamoto et al., 1990).

The success of purslane is attributed to its wide geographical, morphological, physiological, and cytological plasticity (Matthews et al., 1993; Zimmerman, 1976). A high degree of polymorphism is demonstrated by its growth habit; and local populations occur as prostrate, semi-erect, or fully-erect types. Purslane has long been a food source for humans and fodder for livestock. It is widely used as a vegetable in various Mediterranean and Central American countries and in the Philippines. Many of the pharmacological properties attributed to purslane in folk medicine may, in fact, be based on the efficacy of some of its constituents which have now been identified by modern phytochemical methods. The shoot is a rich source of ω-3 fatty acids (Kumamoto et al., 1990; Omara-Alwala et al., 1991; Simopoulos and Salem,1986), α-tocopherols, ascorbic acid, β-carotene, and glutathione (Simopoulos et al., 1992). The seeds contain 21% protein and 20% oil of which the major constituents are linoleic (46%) and linolenic (31%) acids (R Kleiman, personal communication).

The unique nutritive qualities of purslane (Simopoulos et al., 1992) as well as its outstanding tolerance to chloride salinity (Kumamoto et al., 1990) make this species a promising halophytic candidate for the drainage water reuse project. Consequently, we evaluated the interactive effects of sulfate-dominated salinity and elevated Se in the irrigation water on biomass production and mineral content in purslane grown in greenhouse sand cultures.

Materials and methods

Purslane seeds, obtained from Valley Seed Service[1], Fresno, CA in 1988, were increased at the US Salinity Laboratory, Riverside, CA in 1988 and 1990. Seeds were planted in trays filled with vermiculite on 21 Dec 1994. Five-week old seedlings were transplanted into 18 sand tanks in a greenhouse. The tanks (1.2 by 0.6 by 0.5 m deep) contained washed sand having an average bulk density of 1.2 Mg m^{-3}. At saturation, the sand had an average volumetric water content of 0.34 m^3 m^{-3}. Each tank contained five rows with 10 seedlings per row. Plants were irrigated four times daily with a nutrient solution consisting of (in mol m^{-3}): 5.0 Ca^{2+},1.25 Mg^{2+}, 15 Na^+, 3 K^+, 6.9 SO_4^{2-}, 7.0 Cl^-, 5.0 NO_3^-, 0.17 KH_2PO_4, 0.050 Fe as sodium ferric diethylenetriamine pentaacetate (NaFeDTPA), 0.023 H_3BO_3, 0.005 $MnSO_4$, 0.0004 $ZnSO_4$, 0.0002 $CuSO_4$, and 0.0001 H_2MoO_4 made up with city of Riverside municipal water. This solution served as the control treatment. Each irrigation was of 15 min duration which allowed the sand to be completely saturated, after which the

---

[1] Mention of company names or products is for the benefit of the reader and does not imply endorsement, guarantee or preferential treatment by the USDA or its agents.

solution drained into 565 L reservoirs for reuse in the next irrigation. Water lost by evapotranspiration was replenished automatically each day to maintain constant osmotic potentials in the solutions. Six days after the seedlings were transplanted, two salinity treatments were imposed with irrigation waters designed to simulate saline drainage water commonly present in the San Joaquin Valley of California, and compositions of increased salinity which would result from further concentration of these drainage waters. Concentrations of the ions were (in mM): 130 Na^+, 60 SO_4^{2-}, 59 Cl^-,15 Mg^{2+}, and 13 Ca^{2+} at moderate salinity, and 275 Na^+, 124 SO_4^{2-}, 120 Cl^-, 31 Mg^{2+}, and 15 Ca^{2+} at high salinity. The calcium concentration in arid lands is restricted by calcite and gypsum precipitation, thus we simulated decreasing Ca^{2+}:Mg^{2+} ratio with increasing salinity, which may reduce plant-available calcium and adversely affect growth of many species (Grattan and Grieve, 1993). Electrical conductivities (EC_i) of the saline treatments were increased to the desired levels by incremental additions of the salts over five consecutive days to avoid osmotic shock in the seedlings. Final EC_i of the irrigation waters were 2.1, 15.2 and 28.5 dS m^{-1}. To test for salinity-selenium interactions, two Se treatments were imposed: 0 and 2.3 mg Se L^{-1}. Selenium was added to the irrigation waters as Na_2SeO_4 when salinization was complete. The concentration of added Se^{2-} is greater than almost all drainage waters in the San Joaquin Valley (Läuchli, 1993). The experiment was a randomized block design with three water qualities, two Se levels, and three replications.

Air temperatures ranged from 23 to 34 °C (mean = 29 °C) during the day and from 16 to 20 °C (mean =18 °C) during the night. Relative humidity ranged from 16 to 87%, with a mean of 37% during the day and 75% during the night.

On days 18, 25, and 31 after the completion of salinization (hereafter designated as harvests 1, 2, and 3), three to five shoots were cut at sand level and weighed. Plants cut at this level did not resprout. Leaf area was measured with a Li-Cor 3000 portable meter (Li-Cor, Lincoln, NE)[1]. Forty-four days after salinization all remaining plants were cut above the first node and weighed. For this harvest (number 4), half of the shoots were separated into leaves and stems; the remainder were left intact. The clipped plants, still irrigated with the treatment solutions, sprouted and grew for twenty-one days before final harvest (number 5). All plant samples were dried in a forced-air oven at 70-75 °C for 96 h, reweighed, and ground.

Sulfate, Ca^{2+}, Mg^{2+}, Na^+, and K^+ were determined on nitric-perchloric acid digests of the plant tissues by inductively coupled plasma optical emission spectrometry (ICPOES). Chloride was determined on nitric-acetic acid extracts by coulometric-amperometric titration. The irrigation waters were analyzed by ICPOES at monthly intervals to confirm that target ion concentrations were maintained. Se^{2-} content of the plants was determined by atomic absorption spectrophotometry-hydride generation after digestion of the sample in HNO_3-H_2O_2.

Results and discussion

Purslane shoots did not exhibit any visual symptoms of Se toxicity. Results from the first four harvests show that Se frequently had a stimulatory effect on plant growth (Table 1). Shoot dry weights from harvest 4 in the two lowest salinity treatments were 25 to 30% higher in the presence of Se than in its absence.

During the first forty-four days after the initiation of treatments, salinity was inhibitory to shoot growth. Averaged over both Se treatments, salinity-induced reduction in shoot dry matter production ranged from 15 to 30% at 15.2 dS m^{-1} and from 80 to 90% at 28.5 dS m^{-1}. This response to sulfate-dominated salinity in the early harvest is similar to the yield response reported by Kumamoto et al. (1990) for chloride salinity. Analyses of the data sets from both sulfate- and chloride-salinity with a crop response model described by van Genuchten and Hoffman (1984) gave a yield-reduction estimate of 50% when the EC of the irrigation water = 20 dS m^{-1} (approximate EC_e =10.5 dS m^{-1}). Although plants that were harvested at sand level did not regrow, shoots that had been clipped above the first node sprouted and grew vigorously. When shoots were harvested after three weeks of regrowth, the salinity × yield relationship changed dramatically (harvest 5). The halophytic nature of purslane was expressed at this time by a substantial increase in salt tolerance at the lower level of applied salinity. Shoot biomass production in the -Se^{2-} treatment at 15.2 dS m^{-1} was more than two-fold higher than at 2 dS m^{-1} (Table 1). Growth stimulation in response to moderate salinity levels is commonly observed for halophytic species (Flowers et al., 1986). In addition, enhanced plant salt tolerance has been noted with sequential harvests when at least one viable node is left on the decapitated plant. For example, salinity tolerance of the halophyte, Kallar grass (*Diplachne fusca* (L.) Beauv. (syn.

Table 1. Dry matter yield of purslane shoots grown at three levels of sulfate salinity in the presence or absence of selenium in the irrigation waters.

Treatments		Plant shoot[a] Harvest number[b]				
EC (dS m^{-1})	Se (mg L^{-1})	1[c]	2[c]	3[c]	4[d]	5[e]
		(g dry wt/shoot)				
2.1	0	0.348(0.004)	1.14 (0.02)	2.43 (0.04)	3.33(0.32)	1.96(0.06)
2.1	2.3	0.406(0.01)	1.38 (0.03)	2.74 (0.02)	4.82(0.21)	2.54(0.02)
15.2	0	0.306(0.005)	0.95 (0.012)	1.88 (0.01)	3.02(0.06)	5.4 (0.05)
15.2	2.3	0.340(0.004)	0.77 (0.008)	2.09 (0.03)	3.88(0.11)	4.07(0.07)
28.5	0	0.258(0.003)	0.233(0.031)	0.386(0.008)	0.65(0.009)	1.05(0.02)
28.5	2.3	0.248(0.007)	0.269(0.011)	0.372(0.007)	0.45(0.013)	0.75(0.02)

[a] Values are the means of three replications ± s.e.

[b] Harvest dates are given in Materials and methods.

[c] Shoots cut at sand level.

[d] Shoots cut above first node.

[e] Regrowth from harvest 4.

Leptochloa fusca (L.) Kunth) increased after the first cuttings (Mahmood et al., 1995).

In this study purslane completed its life cycle even at the highest salinity level (approximately 350 mM), and the shoots remained free of visible salinity-induced injury or nutrient deficiency symptoms. Fully-expanded blades of plants grown at the two lower levels of salinity were 45 by 18 mm with an area of about 8 cm^2. As salinity increased to 28.5 dS m^{-1}, mean blade area decreased to 3.5 cm^2. In contrast, mean blade area of the weedy, prostrate form of purslane collected on the grounds of the US Salinity Laboratory was 0.9 cm^2.

Salinity significantly affected ion concentrations and distribution within the shoots (Table 2). As salinity increased, shoot-Ca^{2+} and K^+ decreased while Na^+ and Mg^{2+} increased. Cation levels in the tissues reflected the relative concentrations of these cations in the irrigation waters. As substrate Na^+/Ca^{2+} ratio increased from 3 to 18, Na^+/Ca^{2+} in the shoots increased from 2 to 30 (Table 3). Shoot Mg^{2+}/Ca^{2+} increased about four-fold as salinity increased. Both K^+/Na^+ and K^+/Mg^{2+} in shoot tissue decreased as K^+ concentration in the substrate remained constant while external Na^+ and Mg^{2+} increased. The ability of purslane to accumulate K^+ relative to Na^+ in the shoot was reflected in the K^+/Na^+ selectivity coefficients (Table 3). At 15.2 dS m^{-1}, $S_{K,Na}$ was about 40% higher than in the control treatment. At the highest salinity level, the presence of Se reduced the ability of the plant to exclude Na^+ and $S_{K,Na}$ did not differ from the value calculated for the + Se, 2 dS m^{-1} treatment. Calcium and Mg^{2+} were preferentially accumulated in leaves, while stem-K^+ concentrations were higher than in the leaves. Stem tissue accumulated relatively low levels of Ca^{2+} which were further depressed as salinity increased. Salinity-induced Ca^{2+} deficiency may be involved in the reduced growth of plants irrigated with waters at 28.5 dS m^{-1}. In this treatment, high external Na^+ and Mg^{2+} concentrations undoubtedly limit plant-available Ca^{2+} (Suarez and Grieve, 1988). At all salinity levels, stem-Ca^{2+} was about 10% of that in the leaves. Sulfur was preferentially accumulated in the leaves, rather than in stem tissue. The effect of supplemental Se on sulfate uptake was not consistent.

Several plant species have been screened for their potential as bioremediators of Se-containing saline soils (Banuelos and Meek, 1990; Banuelos et al., 1993; Parker et al., 1991). Under saline conditions, selenium uptake and accumulation by plants is profoundly affected by the major anions that are present in the substrate, particularly in view of the well-documented competition between sulfate and selenate (Läuchli, 1993). Sulfate salinity inhibits Se accumulation appreciably more than chloride salinity. In chloride-saline cultures supplemented with 3 mg L^{-1} Se, shoot-Se in tall fescue was about 1200 μg Se g dry wt^{-1}. However, in response to sulfate salinity, Se accumulation was reduced nearly two orders of magnitude (14 μg Se g^{-1}) (Wu and Huang, 1991). Alfalfa accumulated Se to a greater extent from solutions salinized with chloride than from sulfate-dominated substrates (Mikkelsen et al., 1988). Selenium uptake is also influenced by its concentration in the substrate. In a chloride system (EC_i = 15 dS m^{-1}), Se concentration in shoots of wild

Table 2. Mineral composition of purslane grown for forty-five days at three levels of sulfate salinity in the presence or absence of selenium in the irrigation waters

Treatments		Plant tissue[a]						
EC$_i$ (dS m^{-1})	Se (mg l^{-1})	Ca	Mg	Na	K	S	Cl	Se
		(mmoles kg^{-1} dry wt)						(mg kg^{-1} dry wt)
Whole shoot								
2.1	0	324 (4.3)	578 (8.7)	666 (1.4)	2410 (17)	65.3 (0.90)	443 (2.8)	na[b]
2.1	2.3	281 (2.1)	460 (5.0)	496 (2.1)	2420 (26)	66.8 (0.27)	410 (0.96)	8.98 (0.07)
15.2	0	171 (1.4)	739 (1.4)	1970 (10)	1560 (31)	97.8 (1.90)	527 (9.9)	na
15.2	2.3	172 (2.2)	744 (3.7)	2106 (8)	1613 (5)	80.1 (0.23)	461 (3.3)	4.08 (0.07)
28.5	0	98.5 (0.56)	825 (4.5)	3133 (5)	1067 (2)	99.4 (0.65)	887 (21.2)	na
28.5	2.3	102 (1.0)	977 (0.4)	3120 (2)	890 (6)	73.1 (0.58)	687 (1.6)	4.03 (0.05)
Leaves								
2.1	0	933 (8.0)	1276 (3)	845 (5.9)	1390 (4)	82.2 (0.44)	453 (6.6)	na
2.1	2.3	1013 (1)	1349 (3)	765 (7.4)	1640 (17)	98.8 (0.41)	513 (4.2)	14.09 (0.08)
15.2	0	457 (1.5)	1891 (5)	2760 (10)	705 (7.1)	343 (4.5)	545 (5.3)	na
15.2	2.3	562 (0.9)	1656 (2)	2720 (11)	847 (4.6)	346 (3.3)	516 (4.0)	9.10 (0.06)
28.5	0	206 (0.2)	1390 (11)	3990 (8)	592 (1.0)	493 (3.9)	1000 (7.7)	na
28.5	2.3	175 (1.3)	1410 (17)	3880 (13)	629 (2.9)	489 (0.8)	862 (6.2)	7.43 (0.03)
Stems								
2.1	0	124 (1.5)	231 (1.0)	896 (3.2)	3650 (15)	38.0 (0.20)	571 (4.1)	na
2.1	2.3	90.2 (0.54)	191 (2.5)	614 (4.5)	3444 (1)	36.0 (0.33)	585 (3.8)	7.38 (0.05)
15.2	0	41.5 (0.53)	373 (2.4)	2640 (19)	2410 (33)	105 (1.5)	673 (2.7)	na
15.2	2.3	43.3 (0.34)	385 (2.1)	2510 (14)	2480 (1)	116 (1.1)	588 (3.7)	3.69 (0.02)
28.5	0	18.8 (0.20)	368 (1.9)	3980 (19)	1950 (10)	148 (1.2)	860 (5.5)	na
28.5	2.3	21.1 (0.12)	548 (4.2)	4240 (24)	1350 (12)	179 (1.6)	1113 (0.1)	2.43 (0.01)

[a] Values are the means of three replications ± s.e.
[b] Not applicable.

Table 3. The effect of sulfate salinity with or without supplemental selenium on ion and K/Na selectivity ratios in purslane shoots [a,b]

Treatments		Na/Ca	K/Na	Mg/Ca	K/Mg	$S_{K,Na}$[c]
EC$_i$ (dS m^{-1})	Se (mg l^{-1})					
2.1	0	2.08 (0.03)	3.61 (0.028)	1.78 (0.13)	4.24 (0.103)	18.1 (0.14)
2.1	2.3	1.78 (0.02)	4.88 (0.073)	1.66 (0.007)	5.26 (0.108)	24.4 (0.36)
15.2	0	11.5 (0.05)	0.794 (0.0213)	4.34 (0.047)	2.12 (0.006)	34.7 (1.02)
15.2	2.3	12.3 (0.10)	0.766 (0.0052)	4.34 (0.060)	2.14 (0.006)	33.2 (0.22)
28.5	0	31.7 (0.48)	0.349 (0.0071)	8.58 (0.053)	1.30 (0.007)	32.0 (0.65)
28.5	2.3	30.8 (0.30)	0.286 (0.0025)	9.36 (0.111)	0.92 (0.008)	26.2 (0.23)

[a] Harvested forty-four days after the initiation of salinization.
[b] Values are the means of three replications ± s.e.
[c] $S_{K,Na}$ = (K content/[K] medium):(Na content/[Na] medium).

mustard (*Brassica juncea* L.) was about 50 mg Se kg dry wt^{-1} when substrate-Se was 2 mg L^{-1} and 1300 mg Se kg dry wt^{-1} as external Se increased to 15 mg L^{-1} (Banuelos et al., 1990).

Under sulfate salinity purslane is a relatively weak Se accumulator. Shoots of plants grown in the lowest salinity treatment accumulated 14 mg Se kg dry wt^{-1} within 15 days after Se was added to the irrigation water (data not shown). Shoot-Se generally decreased in subsequent harvests probably due to dilution by plant growth (Table 2). Selenium levels were highest in the leaves, and the concentration in all tissues tended to decrease with increasing salinity. The amount of Se accumulated by purslane irrigated with the sulfate-dominated saline waters containing 2.3 mg L^{-1} Se does not present a dietary hazard to humans, but does serve to meet the dietary requirements of this essential micronutrient. One serving of purslane (100 g fw) grown with high salinity-high Se drainage water would provide about 50 μg Se, slightly below the dietary allowance for adults (55 to 70 μg/day) recommended by the National Research Council (1989).

Purslane exhibited vigorous growth under saline conditions. For example, for the 3 week period of plant regrowth ending April 17 (harvest 5), estimated fresh weight yield was 139 t ha^{-1} (7.35 t ha^{-1} oven dry weight) for the 15 dS m^{-1} treatment. We estimate a water consumption use of 35 cm for this interval (based on the yield- ET relations given by Power et al., 1961, and Hanks et al., 1969), corresponding to 3,500 m^3 ha^{-1} for this cutting. A detailed field study is necessary before annual water consumption can be determined, but these data indicate high biomass production and high water use under saline conditions. Purslane appears ideal as a salt-tolerant crop to be used at the end of a drainage reuse system to reduce drainage water volume. With present average drainage water salinity of 10 dS m^{-1}, the potential exists to concentrate this water to greater than 30 dS m^{-1}, corresponding to a volume reduction of more than 3 fold.

Purslane, a high value speciality crop, appears particularly well suited for cropping with highly saline drainage water, with either chloride- or sulfate-based salinity and in the presence of elevated selenium concentrations.

References

Banuelos G S, Cardon G E, Phene D J, Wu L, Akohoue S and Zambrzuski S 1993 Soil boron and selenium removal by three plant species. Plant Soil 148, 253–263.

Banuelos G S and Meek D W 1990 Accumulation of selenium in plants grown on selenium-treated soil. J. Environ. Qual. 19, 772–777.

Banuelos G S, Meek D W and Hoffman G J 1990 The influence of selenium, salinity, and boron on selenium uptake on wild mustard. Plant Soil 127, 201–206.

Boursier P and Läuchli A 1990 Growth responses and mineral nutrient relations of salt-stressed sorghum. Crop Sci. 30, 161–174.

Curtin D, Steppuhn H R and Selles F 1993 Plant responses to sulfate and chloride salinity: Growth and ionic relations. Soil Sci. Soc. Am. J. 57, 1304–1310.

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

Grattan S R and Grieve C M 1993 Mineral nutrient acquisition and response by plants grown in saline environments *In* Handbook of Plant and Crop Stress. Ed. M Pessarakli. pp 203–225. Marcel Dekker, Inc., New York.

Hanks R J, Gardner H R and Florian R L 1969 Plant growth-evapotranspiration relations for several crops grown in the Central Great Plains. Agron. J. 61, 30–34.

Khan A H, Ashraf M Y, Naqvi S S M, Khanzada B and Ali M 1995 Growth, ion and solute contents of sorghum grown under NaCl and Na_2SO_4 salinity stress. Acta Physiol. Plant. 17, 261–268.

Kumamoto J, Scora R W, Clerx W A, Matsumura W A, Layfield D and Grieve C M 1990 Purslane: A potential new vegetable crop rich in omega-3 fatty acid with a controllable sodium chloride content. Proceedings of the First International Conference on New Industrial Crops and Products, Riverside CA. Eds. H H Naqvi, A Estilai and I P Ting. pp 229–233. Univ. of Arizona, Tucson, AZ.

Läuchli A 1993 Selenium in plants: Uptake, functions, and environmental toxicity. Bot. Acta 106, 455–468.

Maas E V and Hoffman G J 1977 Crop salt tolerance - current assessment. J. Irrig. Drainage. ASCE 103 (IR2), 115–134.

Mahmood K, Vanderdeelen J and Baert L 1995 Phosphorus uptake by Kallar grass (*Leptochloa fusca* L.) from different depths in saline and non-saline soil. Eur. J. Agron. 4, 245–251.

Matthews J F, Ketron D W and Zane S F 1993 The biology and taxonomy of *Portulaca oleracea* L. (Portulacaceae) complex in North America. Rhodora 95,166–183.

Mikkelsen R L, Haghnia G H, Page A L and Bingham F T 1988 The influence of selenium, salinity, and boron on alfalfa tissue composition and yield. J. Environ. Qual. 17, 85–88.

Mor R P and Manchanda H R 1992 Influence of phosphorus on the tolerance of table pea to chloride and sulfate salinity in a sandy soil. Arid Land Res. Rehab. 6, 41–52.

National Research Council 1989 Recommended Dietary Allowances. 10th Edition. National Academy of Sciences, Washington, DC.

Ohlendorf H M and Santolo G M 1994 Kesterson reservoir-past, present, and future: An Ecological risk assessment. *In* Selenium in the Environment. Eds. W T Frankenberger and S Benson. Chap 4, pp 69–117. Marcel Dekker, Inc., New York.

Omara-Alwala T R, Mebrahtu T, Prior D E and Ezekwe M O 1991 Omega-three fatty acids in purslane (*Portulaca oleracea*) tissues. JAOCS 68, 198–199.

Parker D R, Page A L and Thomason D N 1991 Salinity and boron tolerances of candidate plants for the removal of selenium from soils. J. Environ. Qual. 20, 157–164.

Power J F, Grunes D L and Reichmann G A 1961 The influence of phosphorus fertilization and moisture on growth and nutrient absorption by spring wheat: I. Plant growth, N uptake, and moisture use. Soil Sci. Soc. Am. J. 25, 207–210.

Presser T, Swain W C, Tidball R R and Severson R C 1990 Geologic sources, mobilization, and transport of selenium from the California coast ranges to the western San Joaquin Valley: A reconnaissance study. US Geol. Surv. Invest. Report 90–4070.

Rhoades J D 1989 Intercepting, isolating, and reusing dranage waters for irrigation to conserve water and protect water quality. Agric. Water Manage. 16, 37–52.

Simopoulos A P, Norman H A, Gillaspy J E and Duke J A 1992 Common purslane: a source of omega-3 fatty acids and antioxidants. J. Am. Coll. Nutr. 11, 374–382.

Simopoulos A P and Salem N Jr 1986 Purslane: a terrestial source of ω-3 fatty acids.N. Engl. J. Med 15, 833.

Suarez D and Grieve C M 1988 Predicting cation ratios in corn from saline solution composition. J. Exp. Bot. 39, 605–612.

Van Genuchten M Th and Hoffman G J 1984 Analysis of crop salt tolerance data. *In* Soil Salinity Under Irrigation. Ecological Studies Vol. 51. Eds. I Shainberg and J Shalhavet. pp 258–271. Springer Verlag. Berlin.

Warne P, Guy R D, Rollins L and Reid D M 1990 The effects of sodium sulphate and sodium chloride on growth, morphology, photosynthesis, and water use efficiency of *Chenopodium rubrum*. Can. J. Bot. 68, 999–1006.

Wu L and Huang Z Z 1991 Chloride and sulfate salinity effects on selenium accumulation by tall fescue. Crop Sci. 31, 114–118.

Zimmerman C A 1976 Growth characteristics of weediness in *Portulaca oleracea* L. Ecology 57, 964–974.

Section editor: T J Flowers