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Lesquerella growth and selenium uptake affected by saline irrigation water composition

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Abstract

A greenhouse study was conducted to determine the effects of waters differing in salt composition on growth and selenium (Se) accumulation by lesquerella (*Lesquerella fendleri* Gray S. Wats.). Plants were established by direct seeding into sand cultures and irrigated with solutions containing either (a) Cl^- as the dominant anion or (b) a mixture of salts of SO_4^{2-} and Cl^-. Four treatments of each salinity type were imposed. Electrical conductivities of the irrigation waters were 1.7, 4, 8, and 13 dS m^{-1}. Two months after salinization, Se (1 mg l^{-1}, 12.7 μM) was added to all solutions as Na_2SeO_4. Shoot growth was significantly reduced by increasing Cl-salinity. Regardless of salinity type, concentrations of Ca^{2+}, Mg^{2+}, Cl^-, total-S, and Se were higher in the leaves than the stems, whereas K^+ and Na^+ were higher in the stem. Leaf-Se concentrations were not significantly affected by Cl-based irrigation waters, averaging 503 mg Se kg^{-1} dry wt across salinity levels, whereas leaf-Se decreased consistently and significantly from 218 to 13 mg kg^{-1} as mixed salt salinity increased. The dramatic reduction in Se was attributed to SO_4^{2-}:SeO_4^{2-} competition during plant uptake. The strong Se-accumulating ability of lesquerella suggests that the crop should be further evaluated as a potentially valuable phytoremediator of Se-contaminated soils and waters of low to moderate salinity in areas where the dominant anion in the substrate is Cl^-. Published by Elsevier Science B.V.

Keywords: Drainage water reuse; Ion partitioning; Phytoremediation; Salinity; Sand culture

1. Introduction

In many areas of the world where supplies of good quality water are decreasing, one of the few on-farm water management options available to growers is the reuse of agricultural drainage effluents. This strategy is particularly attractive because significant amounts of good quality water are conserved, and also because the volumes of drainage water that require ultimate disposal are substantially reduced. In the drainage water reuse system proposed for the San Joaquin Valley (SJV) of California, selected crops would be grown and irrigated in sequence, starting with very salt sensitive species, and continuing with increasingly salt tolerant crops. The composition of saline drainage effluents in this region is typically a mixture of

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salts with Na^{+}, SO_4^{2-}, Cl^{-}, Mg^{2+}, and Ca^{2+} predominating in that order on an equivalent basis. These compositions contrast with those generally used in salt tolerance studies where either NaCl or equivalent concentrations of NaCl and $CaCl_2$ are added as salinizing salts.

Saline soils and waters in irrigated agricultural regions are often contaminated with trace elements, such as selenium (Se). Although small concentrations of Se are essential for animal and human nutrition, the optimum range is very narrow. Selenium deficiencies or toxicities can occur outside this range. In parts of the SJV, drainage waters may contain as much as 2 mg Se l^{-1} (Deverel et al., 1994), a concentration that poses a potential health threat to humans, livestock, and wildlife. Classic symptoms of Se toxicity include nervous system dysfunction (e.g. 'blind staggers' in ruminants), skin lesions, and nail necrosis (Mayland, 1994). Plant Se concentrations are influenced by the plant species and by numerous soil factors, including the form and concentration of Se in the soil, soil pH, clay content, soil salinity, and the concentration of competitive ions (e.g. SO_4^{2-}) in the soil solution (Mikkelsen et al., 1989). Selenium in plants and the hazards connected with subsequent bioaccumulation in the food chain have stimulated research to find methods for lowering Se concentrations in soils and waters. One environmentally-acceptable approach is phytoremediation technology, whereby Se-accumulating plant species are grown on problem soils. At harvest, their Se-enriched tissues are removed from the area (Bañuelos et al., 1997b).

Lesquerella fendleri (*Brassicaceae*), a native of the arid and semiarid regions of southwestern United States and Mexico, is a promising new crop whose seed oils contain lesquerolic acid, a valuable raw material for the production of plastics, lubricants, and protective coatings (Thompson and Dierig, 1988). The geographical distribution of this desert mustard suggests that the species may have developed mechanisms for adapting to environmental stresses, such as salinity and drought.

Few reports are available on the salt tolerance of lesquerella. A two-season field trial was conducted at the Irrigated Desert Research Station, Brawley, CA (Grieve et al., 1997). Six salinity treatments were imposed by adding chloride salts of Na^{+} and Ca^{2+} to Colorado River water. Electrical conductivities of the irrigation waters (EC_i) ranged from 1.4 to 10 dS m^{-1}. Based on combined seed yield for both years, the salt tolerance threshold (the maximum electrical conductivity of the soil extract, EC_e, without a yield reduction) was 6.1 dS m^{-1} and each unit increase above this threshold resulted in a yield decrease of 19%.

Similarly, the response of lesquerella to sodium sulfate-dominated salinity is limited to one trial conducted at the US Salinity Laboratory. In that study, 2-month-old seedlings were transplanted to outdoor sand cultures. Eight salinity levels were imposed with EC_i values ranging from 3 to 24 dS m^{-1}. Solution compositions were prepared in accordance with the model developed by Suarez and Šimůnek (1997) to predict ion composition that would occur in a typical SJV soil using typical drainage waters for irrigation. Shoot biomass production was reduced by 50% when EC_i reached 14.9 dS m^{-1}. Seed yield was significantly higher in the 12 and 15 dS m^{-1} treatments than at the other salinity levels (Grieve et al., 1999).

To the authors' knowledge, no data have been reported on the Se-accumulating capacity of lesquerella. However, various other species of the mustard family, e.g. *Brassica juncea*, *Brassica oleraceae*, *Brassica napus*, show promise for Se-remediation of saline soils and waters (Bañuelos et al., 1997a,b; Terry and Zayed, 1998). In common with other crucifers, lesquerella appears to have an exceptionally high requirement for sulfur (Grieve, unpublished), a character that is generally associated with strong Se-accumulation (Hurd-Karrer, 1938). Therefore, this desert mustard may also be a useful candidate for Se-management. Food chain transfer of Se via the marketable product, its seed oil, would be unlikely as the oil is used for industrial purposes, rather than in products for human or livestock consumption.

The objectives of the current study were: (1) to compare plant growth and ion uptake patterns of lesquerella in response to different saline irrigation water compositions, namely, chloride-dominated salinity and a mixed salt system representative of typical drainage waters present in SJV; (2) to evaluate the effect of different salinity levels and different saline water compositions on Se uptake by lesquerella; and (3) to establish procedures for salt tolerance evaluation of lesquerella in sand cultures, such as direct seeding, irrigation requirements, timing of salt application.

2. Material and methods

This greenhouse study was conducted in sand tanks at the George E. Brown, Jr. Salinity Laboratory, Riverside, CA. The sand tanks ($1.2 \times 0.6 \times 0.5$ m deep) contained washed sand having an average bulk density of 1.4 Mg m^{-3}. At saturation, the sand had an average volumetric water content of 0.34 m^3 m^{-3}. Lesquerella seed used in this study was obtained from plants grown under nonsaline conditions during the 1994–1995 field trial (Grieve et al., 1997).

2.1. Experiment 1

On 23 April 1998, seeds were planted in six rows approximately 50 cm long in each of 12 sand tanks. Six of the tanks were irrigated with saline water of mixed salt composition and six tanks with Cl-dominated water. The solutions were isoosmotic at −0.16 MPa with $EC_i \sim 4$ dS m^{-1} (Table 1). The solutions also contained KNO_3 (3 mM) and the following micronutrients (in μM): KH_2PO_4 170, Fe as sodium ferric diethylenetriamine pentaacetate 50, H_3BO_3 23, $MnSO_4$ 5, $ZnSO_4$ 0.4, $CuSO_4$ 0.2, H_2MoO_4 0.1. The tanks were irrigated twice daily. Each irrigation cycle continued for ~15 min until the sand was completely saturated, after which the solution drained into 765-l reservoirs for reuse in the next irrigation. Water lost by evapotranspiration was replenished automatically each day to maintain constant osmotic potentials in the storage reservoirs.

Emergence started 3 days after seeding. Plants were thinned to ~20 seedlings per row in each of the 12 sand tanks. Additional thinning was planned as the experiment progressed. Commencing 25 days after planting, salts were added in four equal portions over a 10-day period to the Cl-dominated solutions that irrigated three sand tanks and to solutions of mixed salt compositions that irrigated three tanks. These saline solutions were isoosmotic (−0.52 MPa) with $EC_i = \sim 13$ dS m^{-1} (Table 1). The experiment was a randomized block with two salinity types (a Cl-dominated solution and a mixed salt system), two salinity levels ($EC_i = 4$ and 13 dS m^{-1}), and three replications for a total of 12 sand tanks. Immediately after the completion of salinization (28 May 1998), Na_2SeO_4 was added to the solutions to give a Se concentration in all irrigation waters of 2 mg l^{-1} (25.4 μM). Because many of the plants were dead or dying, the experiment was terminated on 1 June 1998. Surviving shoots were harvested and prepared for mineral ion analysis as described for experiment 2.

Table 1
Composition of salinizing salts in solutions used to irrigate lesquerella grown in greenhouse sand cultures

Osmotic potential (MPa)	EC_i (dS m^{-1})	Salinity type	Ca	Mg	Na	SO_4	Cl
			(mM)				
−0.07	1.7	Chloride	2.6	1.5	8.1	1.4	7.0
−0.16	3.8		6.8	1.5	18.9	1.4	29.4
−0.29	7.5		15.1	1.5	36.3	1.4	66.4
−0.52	13.0		26.7	1.5	64.7	1.4	115
−0.07	1.7	Mixed salt	3.1	1.4	6.0	3.9	3.6
−0.16	4.0		5.9	3.3	29.0	14.8	14.1
−0.29	7.4		9.3	7.4	54.7	29.9	27.8
−0.52	12.8		14.2	12.6	100	52.2	49.9

During this experiment greenhouse air temperatures ranged from 14 to 32°C (mean = 25.0°C) during the day and 14–22°C (mean = 18.9°C) during the night. Relative humidity ranged from 44 to 50% with a mean of 46% during the day and 47% during the night.

2.2. Experiment 2

Plant performance in experiment 1 indicated that changes in growing conditions were required, e.g. delaying initiation of salinity, increasing the period for salt addition, decreasing irrigation frequency and amount.

On 10 July 1998 six rows (50 cm long) of lesquerella seeds were sown in 24 greenhouse sand tanks and irrigated with complete nutrient solutions. Twelve tanks were irrigated with Cl-based solutions and 12 tanks with a mixed salt solution. Osmotic potentials for both solutions were -0.07 MPa; $EC_i = 1.7$ dS m^{-1} (Table 1). Micronutrient and KNO_3 concentrations were the same as for experiment 1. Prior to seedling emergence, tanks were irrigated twice daily. For 2 weeks after emergence, plants were irrigated daily, and thereafter, twice weekly. The length of each irrigation was 6 min. Seedlings were thinned to eight plants per row. Salinization commenced 38 days after planting when branching was evident in more than 25% of the plants. Salts were added in five increments over an 18-day period. Compositions of the salinizing salts, osmotic potentials (OP), and electrical conductivities (EC_i) for the treatments are shown in Table 1. Root development was monitored periodically. On 14 September 1998, Na_2SeO_4 was added to each solution so that all sand tanks were irrigated with waters containing 1 mg Se l^{-1} (12.7 μM). The experiment was a completely randomized block with two salinity types, four salinity levels, and three replications.

Daytime air temperatures ranged from 17 to 38°C (mean = 29.3°C); night-time from 17 to 30°C (mean = 22.9°C). Relative humidity ranged from 48 to 41% with a mean of 45% during the day and 45% during the night. The pH of the irrigation waters was uncontrolled, but ranged from 7.8 to 8.0.

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

Shoot vegetative tissues were sampled on 5 October 1998. Leaves and stems of 12 plants from each tank were separated, then weighed, washed in deionized water, and dried in a forced-air oven at 70°C for 72 h. Tissues were reweighed and ground to pass a 60-mesh screen. Total-S, total-P, Ca^{2+}, Mg^{2+}, Na^+, and K^+ were determined on nitric-perchloric acid digests of the tissues by ICPOES. Chloride was determined on nitric-acetic acid extracts by coulometric-amperometric titration. For tissue Se analysis, the method described by Briggs and Crock (1986) was followed: concentrated nitric acid (20 ml) was added to 2 g dried plant samples contained in digestion tubes, heated at 100° for 2 h, then cooled. Hydrogen peroxide (30%, 10 ml) was added to destroy the organic material. The tubes were cooled and sulfuric acid (36 M, 1 ml) was added. The solutions were cooled, transferred to volumetric flasks, brought to volume with hydrochloric acid (6 M), and heated at 90° for 1 h. Selenium was determined with an atomic absorption spectrophotometer equipped with a hydride generator.

Shoot Se concentrations were calculated from weighted averages of leaf and stem concentrations. Statistical analyses were performed by analysis of variance with mean comparisons at the 95% level based on Tukey's studentized range test. SAS release version 6.12 was used (SAS Institute, Inc., 1996).

3. Results and discussion

3.1. Growth and biomass production

Direct seeding of lesquerella resulted in improved stand establishment and root growth compared to an earlier sand culture study in which seedlings were transplanted to sand from peat-perlite media (Grieve et al., 1999). Based on seedling survival in experiment 1, lesquerella ap-

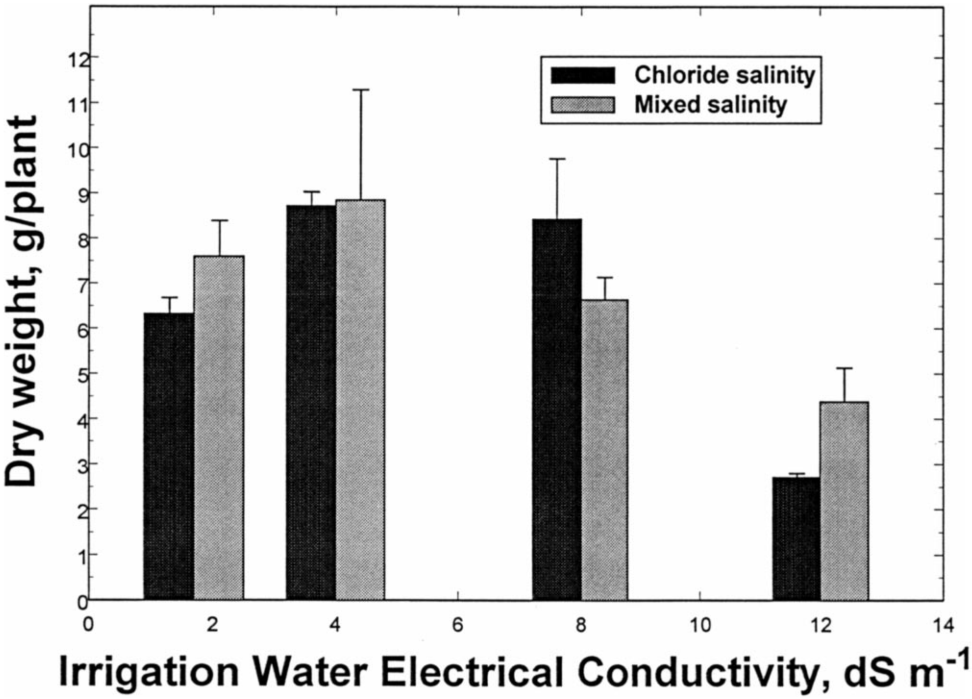

Fig. 1. Lesquerella shoot biomass production as a function of increasing irrigation water salinity. Experiment 2. Values are the means of three replications ± S.D.

peared to be very salt sensitive prior to branching, particularly in response to Cl-salinity. Plant survival 3 days after imposition of salinity (13 dS m^{-1}) was only 50% for plants irrigated with Cl-salinity, but 90% of plants irrigated with mixed salt salinity survived. The reason(s) for the rapid decline and death of the 38-day-old seedlings are unknown at this time, but may have resulted from the interaction of early and rapid application of salt treatments that caused high influx of potentially toxic ions into the shoots, compounded by high greenhouse temperatures, over-irrigation, and possibly Se stress. Due to the salt sensitivity of lesquerella at the seedling stage, it is recommended that low salinity water be used during initial growth until branching is evident. The procedures used for plant growth in experiment 2, along with direct seeding, resulted in marked improvement in plant performance over those observed in both the outdoor sand tank trial (Grieve et al., 1999) and in experiment 1. There were no premature seedling deaths, no evidence of stem cracking, and root morphology appeared normal.

Shoot growth of 87-day old plants harvested in experiment 2 was highly variable (Fig. 1). In response to the Cl-system, biomass was significantly reduced once salinity exceeded ~7.5 dS m^{-1} (−0.29 MPa). Shoot dry matter production tended to decrease as mixed salt salinity increased from 1.7 to 13 dS m^{-1}, although the reduction was not significant.

3.2. Shoot-ion relations

In response to both chloride- and mixed salt-salinity, the divalent cations, Ca^{2+} and Mg^{2+}, were partitioned to the leaves (Table 3). The *L. fendleri* ecotype used in this study originated from area of calcareous soils of limestone origin (Dierig et al., 1996). These neutral or alkaline soils contain high amounts of Ca^{2+} and HCO_3^- and are generally warmer, drier, and more permeable to water than, for example, silicaceous soils (Larcher, 1972). Ecotypes differ in their management of Ca^{2+}. Calcicoles, such as lesquerella, are adapted to calcareous soils and generally have a high requirement for Ca^{2+}. Even under nonsaline conditions, leaf-Ca concentrations in lesquerella were 3–4-fold higher than reported for other crucifers, e.g. *B. rapa*, *B. juncea* (Grieve and Shannon, USSL, unpublished), *B. napus* (Francois, 1994). Although Ca^{2+} concentration in the Cl-dominated irrigation waters rose an order of magnitude as salinity increased (Table 1), Ca^{2+} accumulation in neither the seedlings (Table 2) nor the older plants was affected (Table 3). Shoot-Ca in both the seedlings and the older plants tended to decrease with increases in mixed salt salinity despite a 5-fold increase in external Ca^{2+} (Tables 2 and 3). This effect may be attributed to competition of Ca^{2+} with Mg^{2+} and Na^{+} that reduces the availability of external Ca^{2+} (Suarez and Grieve, 1988).

External Mg^{2+} concentration in the Cl-system was constant over the salinity range, and Mg^{2+} decreased in both leaf and stem tissue. Salinity had no effect on shoot-Mg in plants irrigated with mixed salt solutions, although external Mg^{2+} increased from 1.4 to 12.6 mM. At low salinity (1.7 dS m^{-1}) lesquerella shoots accumulated about twice as much Mg^{2+} from the mixed salt system as from the Cl-system, although external Mg^{2+} was the same in both treatments.

Sodium concentrations in lesquerella were considerably lower than reported in other salt-stressed crucifers. Canola (*B. napus*), irrigated with Cl-dominated saline waters ($EC_i = 6$ dS m^{-1}), accumulated 900 mmol Na kg^{-1} dry wt in leaf tissue (Francois, 1994). Leaf-Na concentration in mustard greens (*B. rapa*), irrigated with mixed salt waters ($EC_i = 7$ dS m^{-1}) was ~ 1600 mmol kg^{-1} (Grieve and Shannon, USSL, unpublished). Shoots of *B. carinata* and *Eruca sativa* grown in sand cultures salinized with 100 mM NaCl accumulated over 1000 mmol Na^{+} kg^{-1} (Ashraf and Noor, 1993). Lesquerella apparently has the ability to exclude Na^{+} from the leaves by retention in stem, and perhaps, root tissue. However, once irrigation water salinity exceeded ~ 7.5 dS m^{-1} and external Na^{+} exceeded ~ 40 mM, the Na^{+} retention capacity of the lower organs of lesquerella apparently became saturated and the mechanism(s) for controlling Na^{+} distribution to the shoot were less effective. Increases in salinity and substrate-Na then resulted in significant increases in leaf-Na accumulation (Table 3), and decreases in biomass (Fig. 1). Results from a field trial in Brawley, CA also illustrate the Na-exclusion capability of lesquerella (Grieve et al., 1997).

Potassium was also higher in lesquerella stems than in the leaves. Leaf-K concentrations were 2–3 times lower than in other crucifers, e.g. *B. juncea* (Ashraf, 1992), *B. napus* (Francois, 1994). Researchers have assumed that the K^{+}:Na^{+} ratio in nonhalophytes should be > 1 for normal functioning of K-mediated metabolic processes (Ashraf, 1994). Judged by this criterion, K^{+} nutri-

Table 2
Ion concentration in shoots of lesquerella seedlings grown in greenhouse sand cultures*

EC_i (dS m^{-1})	Shoot ion concentration (mmol kg^{-1} dw)						Se (mg kg^{-1} dw)
	Ca	Mg	Na	K	Cl	S	
Chloride salinity							
4.1	1813a**	253a	165b	725a	689b	911a	1236a
13.1	1906a	206b	539a	431b	2064a	559b	548b
Mixed salt salinity							
4.2	1462a	357b	272b	781a	364b	732a	662a
13.6	1169b	449a	987a	438b	869a	594b	20.6b

* Saline irrigation waters were supplemented with selenium (2 mg l^{-1}, 25.4 μM). Experiment 1. Values are the means of three replications.

** Within columns and salinity type, means followed by a different letter are significantly different at the 0.05 probability level according to Tukey's Studentized Range Test.

Table 3
Mineral composition of leaves and stems of lesquerella grown in the greenhouse*

EC_i ($dS\ m^{-1}$)	Ca	Mg	Na	K	S	Cl	Se ($mg\ kg^{-1}$ dw)
	($mmol\ kg^{-1}$ dw)						
Chloride salinity — leaves							
1.7	1493a**	281a	23.6b	542a	396ab	243c	475a
3.8	1778a	244a	53.4b	618a	561a	519cb	704a
7.5	1805a	167b	63.7b	465a	443ab	803b	488a
13.0	1903a	171b	683a	496a	277b 2387a	345a	
Chloride salinity — stems							
1.7	639a	116a	46.7b	847a	320ab	70.6b	215ab
3.8	733a	116a	57.1b	786a	363a	161b	277a
7.5	789a	89.5a	177b	745a	332ab	362b	169ab
13.0	879a	95.1a	1063a	383b	284b	1315a	138b
Mixed salt salinity — leaves							
1.7	1516a	564a	30.8c	568a	486a	118c	218a
4.0	1509a	504a	71.3bc	648a	521a	220cb	129b
7.4	1285a	559a	152b	599a	524a	344ba	30.8c
12.8	1251a	498a	328a	518a	543a	433a	12.9c
Mixed salt salinity — stems							
1.7	669a	169a	52.4c	907a	304a	29.1c	62.7a
4.0	580ab	158a	182c	867a	338a	67.4cb	17.7a
7.4	532ab	149a	383b	680ab	306a	108b	9.0b
12.8	468b	154a	750a	487b	351a	190a	8.1b

* Saline irrigation waters of different compositions were supplemented with selenium (1 mg l^{-1}; 12.7 μM). Experiment 2. Values are the means of three replications.

** Within columns, salinity type, and plant parts, means followed by a different letter are significantly different at the 0.05 probability level according to Tukey's Studentized Range Test.

tion was adequate in lesquerella shoots irrigated with Cl-dominated solutions until the salinity exceeded 7.5 dS m^{-1}, whereupon the K^+:Na^+ ratio then fell to 0.59. In response to mixed salt salinity, however, the K^+:Na^+ ratio in the shoots was maintained at 1 or above in all treatments.

Lesquerella has a high requirement for sulfur as is typical for many cruciferous plants. Total-S in lesquerella shoots was greater than in *Brassicas* grown in sand cultures and irrigated with mixed salt solutions of identical composition (Grieve and Shannon, USSL, unpublished). The uptake of SO_4^{2-} from the mixed salt system was apparently closely regulated inasmuch as the increase of external SO_4^{2-} from 3.9 to 52.2 mM in the mixed salt system had no effect on total-S in either leaves or stems (Table 3). In Cl-dominated irrigation waters with constant SO_4^{2-} concentrations, total S in both leaf and stem tissue was variable, but tended to decrease with increasing salinity.

3.3. Selenium relations

Selenium uptake and accumulation by plants may be profoundly affected by the concentration of major anions (e.g. SO_4^{2-}, Cl^-) often present in saline drainage waters (Mikkelsen et al., 1989). Root transport of SO_4^{2-} and SeO_4^{2-} by many crop species is mediated by a common cell membrane carrier and the anions compete for the binding sites on this carrier. As a result of this antagonism, Se uptake is inhibited to a greater extent by external SO_4^{2-} than by Cl^- (Läuchli, 1993; Marschner, 1995). Comparison of the response of lesquerella to the two salinity types illustrates this competitive inhibition. As Cl-salinity increased from 4 to 13 dS m^{-1}, Se concentration in the seedlings decreased by 55%, whereas seedling-Se decreased 30-fold as mixed salt salinity increased (Table 2).

Selenium is generally highest in actively growing aerial organs where S-protein synthesis is high (Arvy, 1993). Selenium distribution in lesquerella followed a similar pattern, and its concentration was higher in leaves than stems, regardless of salinity type or level (Table 3). Chloride-dominated salinity did not significantly affect Se accumulation in leaves (mean = 503 mg kg^{-1}), whereas stem-Se was variable. Compared to other crucifers, lesquerella accumulated unusually high concentrations of Se from Cl-based solutions containing 1 mg Se l^{-1} and a constant SO_4^{2-}:SeO_4^{2-} ratio of 110. For example, leaf tissues of *B. oleracea* accumulated 552 mg Se kg^{-1} from a nonsaline substrate containing 3 mg Se L^{-1} (Kopsell and Randle, 1999). Wild mustard (*B. juncea*) accumulated 97 mg Se kg^{-1} from a Cl-based saline substrate (10 dS m^{-1}) supplemented with 2 mg Se l^{-1} (Bañuelos et al., 1990).

In contrast to the response to Cl-salinity, Se uptake by lesquerella decreased markedly with increases in mixed salt salinity. As EC_i increased from 1.7 to 13 dS m^{-1} and external SO_4^{2-}:SeO_4^{2-} ratio increased from 307 to 4110, leaf-Se decreased 17-fold as SO_4^{2-}:SeO_4^{2-} ratio in the tissue increased from 2500 to 42 000. At salinity levels above 1.7 dS m^{-1}, the plant SO_4^{2-}:SeO_4^{2-} ratio was approximately constant at 10 times that in solution. This ratio provides a convenient assessment of the Se uptake potential of a plant species in the presence of elevated SO_4^{2-}.

The preliminary data from experiment 2 demonstrate that lesquerella has great potential for Se-remediation of moderately saline soils, provided the dominant anion in the substrate is Cl^-. For example, shoot biomass was partitioned 60% to leaf tissue and 40% to the stems (Data not presented). Calculations based on weight and Se concentration (Table 3) in organs of plants irrigated with Cl-dominated waters with an (EC_i = 7.5 dS m^{-1}) give a mean Se concentration in the entire shoot of 360 mmol kg^{-1} dry wt. With a dry matter yield of 8 g $shoot^{-1}$ (Fig. 1), each plant would contain 2.9 mg Se. At the recommended planting density of 1 000 000 lesquerella plants ha^{-1} (Brahim et al., 1996), it was calculated that the crop would remove 3 kg Se ha^{-1} $year^{-1}$ if the substrate Se concentration were 1 mg l^{-1}. This estimate is well in excess of the minimum target (1 kg Se ha^{-1} $year^{-1}$) for economically feasible management of Se-contaminated sites as proposed by Parker and Page (1994). It is unlikely, however, that lesquerella would be a useful candidate for removing Se from saline soils or waters when the major anion in the substrate is SO_4^{2-}, as is the case in the SJV. However, not all Se-containing soils have high SO_4^{2-} concentrations, and industrial effluents from sources such as electric utilities aqueous discharges, oil refinery wastewaters, and coal fly ash, are not necessarily high in salinity nor in SO_4-salts (Bañuelos et al., 1996). In these selected sites, lesquerella may be an effective crop for Se-phytoremediation.

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