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Salt Tolerance of Sunflower and Lettuce in Cultivated and Uncultivated Grass Soil

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We tested two hypotheses: 1) whether a vegetable crop will show greater growth under a given salinity treatment in an uncultivated grass soil than a cultivated soil and 2), if so, whether the greater growth is due to the occasional presence of relatively fresh water in macropores or the interaction between salinity and hypoxia in a soil without significant macropores. A previous study suggested uptake from macropores was significant only for crops with high root water potential (Emerman and Dawson 1997). Hence, in this study, 21 miniature crops were grown in a greenhouse, and the ratio of root dry weight to transpiration rate was measured as a means of ranking crops in terms of root water potential. Based upon the ranking, 'Elf' sunflower (*Helianthus annuus* L.) was chosen as a crop with relatively high root water potential (ratio = (39 ± 7) mg/(g/day)) and 'Tom Thumb' lettuce (*Lactuca sativa* L.) as a crop with relatively low root water potential (ratio = (0.8 ± 0.3) mg/(g/day)). The miniature cultivars of sunflower and lettuce were grown in a greenhouse in undisturbed cores of salinized, cultivated soil and salinized, uncultivated grass soil, and they were given tap water daily at the plant transpiration rate. There was no significant difference between growth in cultivated and uncultivated grass soil. With the addition of tap water, however, lettuce showed no reduction in growth from the no-salt control at NaCl concentration of 4 g/L. At the same NaCl concentration, mortality was 100% without the addition of tap water. It is suggested that daily irrigation with relatively fresh water in salinized soil may be mote successful for crops with low root water potential.

INDEX DESCRIPTORS: *Helianthus annuus, Lactuca sativa,* lettuce, macropore, root water potential, salt tolerance, sunflower, transpiration.

Soil macropores are large (diameter > 1 mm), interconnected pores in soil, such as old root channels, earthworm holes and the boundaries between soil aggregates (Watson and Luxmoore 1986, Emerman 1995). Much research has focused on the role of macropores in the leaching of pesticides and fertilizers (e.g., Larsson and Jarvis 1999 and 2000, Nicholls et al. 2000). This is the fourth in a series of papers that explores the role of macropores in the growth of plants (Emerman and Dawson 1995, 1996, and 1997). Because tillage destroys the connectivity of large pores (Blevins et al. 1984), macropore effects are critical for an understanding of no-tillage agriculture.

Emerman and Dawson (1995) hypothesized that some plants can flourish in saline or contaminated soil due to 1) the existence of macropores and 2) the ability of plant roots to extract water primarily from macropores. Following a rainfall or irrigation event, soil water drains first from macropores and then from pores of ever-decreasing sizes. Macropores tend to be empty except immediately following rainfall. Therefore, macropore water in a saline soil will tend to be less saline because the rainwater that enters macropores is not mixing with any antecedent saline soil water (Emerman and Dawson 1995). It is a common observation that the first drainage of water from a fertilized, macroporous soil following rainfall is relatively fresh water (Thomas and Phillips 1979). The ability of plant roots to extract this relatively fresh water could act as a survival mechanism. Macropore water is highly transient; therefore, plant roots must be able to acclimatize rapidly to changes in the moisture status of the root environment. Plant roots, however, may primarily extract water from large pores due to its higher matric potential. The implication of this hypothesis is that it may be possible to increase crop production on salinized or contaminated land by practicing no-tillage agriculture.

Emerman and Dawson (1995) conducted experiments to determine whether plants primarily extracted macropore water. By irrigating plants in the field and greenhouse with water of a known stable hydrogen isotope composition (δD) and measuring transpiration rates, they calculated the mixing volume of a plant/soil combination: the volume of soil water per plant with which irrigation water mixes before it enters and is transpired by a plant. If plants are extracting water directly from macropores rather than water that has first passed from macropores into micropores, the mixing volume should be small and should be comparable to the volume of xylem water within a small plant because irrigation water would be mixing with very little antecedent soil water before entering the plant. Data from wild strawberry (*Fragaria virginiana* L.) showed mixing volumes of 2–4 cm^3 per plantlet for a variety of soils and pre-irrigation soil water contents. The above mixing volume was comparable with the volume of xylem water of a strawberry plantlet and was three orders of magnitude less than the volume of soil water associated with each plantlet. This argued strongly for water uptake from macropores in these particular experiments.

Emerman and Dawson (1997) further tested the tendency of plants to primarily extract macropore water by growing 'Mammoth Russian' sunflower (*Helianthus annuus* L.) in split-root chambers in which half of the roots grew in a coarse fritted clay (a macroporous soil) and half of the roots grew in the same fritted clay, which had been ground fine and sieved (a microporous soil). Under different conditions of water stress, the macroporous soil was irrigated with melted snow water (relatively depleted in deuterium) while the microporous soil was irrigated with tap water (relatively enriched in deuterium). By measuring the δD of the sunflower xylem sap, it was possible to deduce from which soil the sunflower roots were extracting water. It was found that sunflower did not primarily extract macropore water under any conditions of water stress, in contradiction to previous work on strawberry (Emerman and Dawson 1995). Emerman and Dawson (1997) explained the results by noting that sunflower has a transpiration rate per plant that remains high even while the soil water potential is decreasing. Therefore, sunflower must have had a greater ability to lower its root water potential so that, by comparison, the difference between the soil water potential of macroporous soil and that of microporous soil was not significant. Based upon the lower per plant transpiration rate of strawberry, especially during soil drying, the root water potential of strawberry was high enough that the plant responded to the higher soil water potential of the macropores. Emerman and Dawson (1997) proposed that crops with a low to moderate transpiration rate per plant (0.01–0.1 L/day) would primarily extract water from macropores while crops with a higher transpiration rate per plant (1–10 L/day) would not. The above argument would not apply to much larger plants, such as trees, which maintain a high transpiration rate per plant due to their large root surface area. Emerman and Dawson (unpubl. data) have tested the above hypothesis by repeating the split-root experiment using white pine (*Pinus strobus* L.) seedlings, plants with a low per plant transpiration rate.

Emerman and Dawson (1996) tested the hypothesis that the presence of soil macropores could increase the growth of plants in saline soil by growing bell pepper (*Capsicum annuum* L. var. *annuum*) in the greenhouse in pots of the same coarse (macroporous) fritted clay and fine (microporous) fritted clay that had been used in the sunflower experiment (Emerman and Dawson 1997). The pots sat in pans of salt (NaCl) water with concentrations of 0, 1, and 2 g/L. Half of the pots were irrigated once a day with tap water and the other half received no tap water. Plants growing in the macroporous soil had greater growth for a given salinity treatment than the plants growing in the microporous soil under both the irrigated and non-irrigated conditions.

The work of Emerman and Dawson (1996) did not directly address questions of tillage because a commercial product was used rather than a field soil, and the microporous "soil" was produced by grinding the fritted clay in a rock grinder, which is a poor simulation of tillage. Therefore, the first objective of this paper was to test the hypothesis that a vegetable crop will show greater growth under a given salinity treatment in an uncultivated grass field soil than a cultivated field soil.

Emerman and Dawson (1996) also left unanswered the question as to whether the greater growth under a given salinity treatment for plants growing in a macroporous soil was either due to the occasional presence of relatively fresh water in macropores or due to the interaction between salinity and hypoxia in a soil without significant macropores under potential waterlogging conditions. Emerman and Dawson (1997) suggested that uptake of relatively fresh water from macropores would be important only when root water potential is high. Therefore, the second objective of this paper was to test the hypothesis that a vegetable crop will show greater growth under a given salinity treatment in an uncultivated grass field soil than a cultivated field soil only when root water potential is high.

METHODS

The objectives of this study were tested by a series of three greenhouse experiments. The first experiment studied 21 small crops grown at the same time and under the same conditions and ranked them in terms of the ratio of root dry weight to per plant transpiration rate. A large ratio implies that a large mass of roots is required to produce a given transpiration rate. We are proposing this ratio as a means of ranking plants in terms of their root water potential so that a higher ratio indicates relatively higher root water potential. Only small crops (e.g., herbs and "baby" vegetables) were studied because we wished to grow these same crops in undisturbed cores of cultivated field soil and uncultivated grass field soil. The results of the first experiment were used to choose two crops: one with very high root water potential, a miniature cultivar of sunflower (*Helianthus annuus* 'Elf'), and one with very low root water potential, a miniature cultivar of lettuce (*Lactuca sativa* 'Tom Thumb'). The first experiment also gave us expected transpiration rates under the conditions of our greenhouse so that excessive watering could be avoided under salinity treatments.

The second experiment measured the growth of 'Elf' sunflower and 'Tom Thumb' lettuce under irrigation with saline water in fritted clay. The salt tolerance of sunflower (Bhatt and Indirakutty 1973, Cheng 1983, Kriedmann and Sands 1984, Ashraf and O'Leary 1995, Ashraf and O'Leary 1996, Ashraf and O'Leary 1997, Francois 1996) and lettuce (Ayers et al. 1951, Osawa 1965, Bernstein et al. 1974, Van den Ende et al. 1975, Shannon 1980, Shannon et al. 1983, Shannon and McCreight 1984, Cramer and Spurr 1986, Pasternak et al. 1986, Russo 1987, Coons et al. 1990, Feigin et al. 1991, Welkie and Miller 1992) has been reported, but it cannot be assumed that their work applies to the miniature cultivars 'Elf' and 'Tom Thumb.'

In the third experiment, sunflower and lettuce were grown in undisturbed cores of cultivated and uncultivated grass soil. The soil cores were flushed with saline water initially and at three-week intervals to maintain a constant soil salinity. Plants received tap water daily at the transpiration rate determined by the first experiment. Tap water was added to assess the ability of crops to benefit from the occasional presence of relatively fresh water in the macropores of the uncultivated grass soil. The third experiment was essentially a simulation of daily irrigation with relatively fresh water of crops growing in salinized soil. In all cases, statistical significance was determined by the t-test ($P < 0.05$).

Root Dry Weight/Transpiration Rate Ratios for Small Crops

Twenty-one miniature cultivars of a wide range of crops were grown in a greenhouse in stainless steel cans of height 12 cm and diameter 7.5 cm (Table 1). The cans were filled with commercial fritted clay (Van Bavel et al. 1978), which was fertilized with Earl May All-Purpose Soluble Plant Food™ (15.00% N, 30.00% P_2O_5, 15.00% K_2O, 0.02% B, 0.07% Cu, 0.15% Fe, 0.05% Mn, 0.0005% Mo, and 0.06% Zn) initially and at three-week intervals. One of the advantages of fritted clay was that it easily separated from plant roots (Van Bavel et al. 1978). Each cultivar was replicated 10 times and there were 30 control cans without plants for a total of 240 cans. Each non-control can received 3 to 10 seeds, depending on seed size. After germination of the plants, all but one healthy plant was removed from each can and the fritted clay was covered with several layers of gravel to reduce evaporation. Once a week the soil in the cans was watered from above with tap water at 0800. The cans were weighed at noon after all drainage had ceased. The cans received no further water until they were weighed again the following day at noon. The per plant transpiration rate was calculated as the weight loss of the can minus the average weight loss by cans without plants. Between measurements of transpiration rate, plants were watered with tap water until water drained freely from the cans. The last watering occurred 52 days after planting. The cans were weighed that day and for the following five days to measure transpiration rate during soil drying. Plants were harvested 57 days after planting. Shoot and root dry weights were measured after drying at 70°C for 72 hrs. Average tap water parameters during the course of the experiments were $[Ca^{+2}] = 15$ mg/L, $[Mg^{+2}] = 17$ mg/L, $[Na^{+2}] = 146$ mg/L, TDS = 578 mg/L, pH = 7.9, EC = 0.926 dS/m (data

Table 1. Small crops ranked according to root dry weight/transpiration rate.

Crop and Variety	Scientific Name	Root Dry Weight/ Transpiration Rate mg/(g/day)
Eggplant 'Bambino Hybrid'	*Solanum melongena* L.	79 ± 8.0[a]
East Indian Lemon Grass	*Cymbopogon flexuosus* (Nees ex Steud.) J. F. Watson	70 ± 20
Bush Bean 'Coco Nain Blanc Precoce'	*Phaseolus vulgaris* L.	48 ± 9.0
Sweet Corn 'Early Sunglow'	*Zea mays* L. subsp. *mays*	40 ± 10
Sunflower 'Elf'	*Helianthus annuus* L.	39 ± 7.0
Pea 'Petit Provencal'	*Pisum sativum* L.	24 ± 7.0
Cowpea 'Brown Crowder'	*Vigna unguiculata* (L.) Walp. subsp. *unguiculata*	19 ± 2.0
Dill 'Fernleaf'	*Anethum graveolens* L.	18 ± 6.0
Summer Squash 'Ronde de Nice'	*Cucurbita pepo* L. subsp. *pepo* var. *pepo*	17 ± 5.0
Carrot 'Parmex'	*Daucus carota* L. subsp. *sativus* (Hoffm.) Arcang. var. *sativus* Hoffm.	11 ± 3.0
Cauliflower 'Snow Crown Hybrid'	*Brassica oleracea* L. var. *botrytis* L.	9.7 ± 0.9
Pac-Choy 'Mei Qing Hybrid'	*Brassica rapa* L. subsp. *chinensis* (L.) Hanelt	8 ± 2.0
Leek 'King Richard'	*Allium porrum* L.	6 ± 1.0
Annual Marjoram	*Origanum majorana* L.	4 ± 2.0
Summer Savory	*Satureja hortensis* L.	3 ± 2.0
Beet 'Baby Spinel'	*Beta vulgaris* L. subsp. *vulgaris*	3 ± 1.0
Onion 'Red Beard'	*Allium cepa* L.	3 ± 1.0
Cumin	*Cuminum cyminum* L.	2.1 ± 0.8
Basil 'Spicy Globe'	*Ocimum basilicum* L.	1.4 ± 0.5
Brussels Winter Chervil	*Anthriscus cerefolium* (L.) Hoffm.	1.3 ± 0.2
Lettuce 'Tom Thumb'	*Lactuca sativa* L.	0.8 ± 0.3

[a]Values are mean ± standard error

supplied by Indianola Water Treatment Facility, Indianola, IA). The above parameters imply a sodium adsorption ratio SAR = 6.13.

Growth of Sunflower and Lettuce under Saline Irrigation in Fritted Clay

'Elf' sunflower and 'Tom Thumb' lettuce plants were grown in the greenhouse in plastic pots of height 9 cm and diameter 10.5 cm. The pots were filled with fritted clay, which was fertilized with Earl May All-Purpose Soluble Plant Food™ initially and at three-week intervals. Each sunflower pot was planted with three seeds and each lettuce pot was planted with 10 seeds. The plants were watered with tap water until 11 days after planting for sunflower and 15 days after planting for lettuce, when all but one healthy plant was removed from each pot and the fritted clay was covered with several layers of gravel. Thereafter, the plants were kept well watered with saline water at concentrations of non-iodized table salt (NaCl) of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 g/L by watering until water drained freely from the pots to prevent a long-term rise in soil salinity. Each salinity treatment was replicated 10 times for each species for a total of 240 pots. Each treatment was made up of a representative set of plants so that the results were not biased by the initial size or health of plants. All plants were harvested 91 days after planting. Shoot and root dry weights were measured after drying at 70°C for 72 hrs. Roots were washed prior to drying. The electrical conductivity (EC) of irrigation water was calculated using the empirical formula of Brady and Weil (2002):

$$\mathrm{EC}\ (\mathrm{dS/m}) = [\mathrm{NaCl}]\ (\mathrm{mg/L})/640 + \mathrm{EC}_{\mathrm{tap}},$$

where $\mathrm{EC}_{\mathrm{tap}}$ is the EC of tap water.

Growth of Sunflower and Lettuce in Salinized, Cultivated Field Soil and Salinized, Uncultivated Grass Field Soil Under Daily Irrigation with Tap Water

One hundred twenty undisturbed cores each of cultivated soil and uncultivated grass soil were collected in October 1999 from the Paul Jacobs Farm in Wapello County, southeastern Iowa (41°7′34″N, 92°20′36″W). The soil was Mahaska silty clay loam (fine, smectic, mesic Aquertic Argiudolls) (Seaholm 1981). The soil cores were collected using the same cans that had been used in the first experiment. The cans were gently tapped into the soil with a rubber mallet over a piece of wood and then dug up with a shovel. The soil cores were collected along lines 18 m in length that were 2.5 m on either side of the line dividing a cultivated from an uncultivated field. The uncultivated field was a grassed waterway that had not been plowed for at least 31 yrs. The cultivated field had been plowed one month previously with a DMI chisel plow to a depth of 30.5–33 cm. The cultivated field was planted with corn (*Zea mays* L. subsp. *mays*) and soybeans (*Glycine max* Merr.) in alternate years.

The soil cores were moved to a greenhouse and each soil core was fertilized with Earl May All-Purpose Soluble Plant Food™. Half the cores were planted with three 'Elf' sunflower seeds per core and half with 10 'Tom Thumb' lettuce seeds per core. Eleven days after planting for sunflower and 15 days after planting for lettuce, all but one healthy plant was removed from each can. The soil was covered with several layers of gravel and flushed with 0.5 L of saline water. The soil cores with 'Elf' sunflowers received concentrations of non-iodized table salt (NaCl) of 0, 1.5, and 3 g/L. The soil cores with 'Tom Thumb' lettuce plants received concentrations of table salt (NaCl) of 0, 1, and 2 g/L. The 240 cans were partitioned among two cultivation types, two species and three salinity levels so that each of 12 treatments was replicated 20 times. Each treatment was made up of

Table 2. Mortality and growth of sunflower and lettuce under saline irrigation in fritted clay.

	Salinity (g/L)						
Traits[a]	0	1	2	3	4	5[d]	6[e]
Sunflower							
RDW	380 ± 30[b]	330 ± 60 (0.5)[c]	280 ± 60 (0.2)	190 ± 80 (0.08)	380 ± 60 (0.8)	—	120
SDW	1800 ± 100	1400 ± 200 (0.1)	1200 ± 200 (0.03)	600 ± 200 (0.0006)	900 ± 100 (0.0002)	—	400
TDW	2200 ± 100	1800 ± 300 (0.2)	1400 ± 300 (0.04)	800 ± 200 (0.003)	1300 ± 200 (0.002)	—	600
M	0%	0%	30%	50%	50%	100%	90%
Lettuce							
RDW	84 ± 9	84 ± 9 (1)	80 ± 10 (0.8)	90 ± 10 (0.9)	—	—	—
SDW	510 ± 30	410 ± 70 (0.2)	350 ± 60 (0.03)	550 ± 30 (0.4)	—	—	—
TDW	600 ± 40	500 ± 70 (0.2)	440 ± 60 (0.05)	640 ± 40 (0.5)	—	—	—
M	10%	30%	40%	60%	100%	100%	100%

[a] RDW = Root Dry Weight (mg), SDW = Shoot Dry Weight (mg), TDW = Total Dry Weight (mg), M = Mortality Rate

[b] Values are mean ± standard error

[c] Values in parentheses are P-value based upon the t-test comparison with the no-salt control

[d] Blank spaces (—) indicate no living plants at conclusion of experiment

[e] All plants grown in salinity exceeding 6 g/L had 100% mortality

a representative set of plants so that the results were not biased by the initial size or health of plants. All cans received 15 mL of tap water every morning as sufficient to satisfy the needs of the plant, but not sufficient to leach salt from the soil core. Every three weeks the cans were again flushed with 0.5 L of saline water. The time required to flush each can was recorded as a means of monitoring changes in soil hydraulic conductivity (unpubl. data). The saline water was observed to drain about twice as fast through the uncultivated grass soil as through the cultivated soil throughout the experiment. Ninety-one days after planting, all plants were harvested and shoot dry weights were measured after drying at 70°C for 72 hrs. The experiment was then repeated with the same soil cores with salt concentrations of 0, 4.5, and 6 g/L for sunflower and salt concentrations of 0, 3, and 4 g/L for lettuce.

There was a concern that soil swelling during the course of the experiment could obscure the difference between cultivated and uncultivated grass soil. Mace and Amrhein (2001) showed that the change in water content at matric potential $\psi_m = -22$ kPa (field capacity) could be used as an estimator of soil swelling. In the absence of a pressure chamber, soil swelling was estimated from the drained water content, corresponding to $\psi_m = -(1/2) \times (g = 9.8 \text{ m s}^{-2}) \times (h = 9 \times 10^{-2} \text{ m}) \times (\rho_w = 10^3 \text{ kg m}^{-3}) = -0.44$ kPa, where g was acceleration due to gravity, h was the height of soil, and ρ_w was the density of water. Using the capillary relation between pore diameter and matric potential (Hillel 1980), $\psi_m = -0.44$ kPa corresponded to soil for which all pores with diameter greater than 0.66 mm had drained. After all shoots had been harvested, the soil cans were slowly saturated from below over three days to eliminate air bubbles. The cans were weighed, allowed to drain under gravity for 24 hours, and weighed again. The cans were then dried for 24 hours at 105°C and weighed a final time. Saturated water content and drained water content were calculated assuming a particle density of 2.65 g/cm^3.

RESULTS

The ratio of root dry weight to transpiration rate, averaged over the 25 days prior to the cessation of watering, for 21 small crops, varied over two orders of magnitude (Table 1). Lettuce was chosen as a crop with low root water potential because of its low ratio of root weight to transpiration rate. Although eggplant (*Solanum melongena* L.), East Indian lemon grass (*Cymbopogon flexuosus* (Nees ex Steud.) J. F. Watson), bush bean (*Phaseolus vulgaris* L.) and sweet corn had a higher ratio of root weight to transpiration rate, sunflower was chosen as a representative crop with high root water potential because of higher germination rate and lower mortality rate under the conditions of our greenhouse. Also, 'Elf' sunflower was found to have a higher root water potential compared with 'Mammoth Russian' sunflower, which had a lower root water potential (Emerman and Dawson 1997). Unfortunately, Emerman and Dawson (1997) did not measure root dry weights of their plants. The average transpiration rate for the 25 days prior to cessation of watering was 14 ± 1 mL/day for lettuce and 16 ± 1 mL/day for sunflower. Emerman and Dawson (1997) suggested that plants with lower root water potentials would maintain higher transpiration rates under soil drying. However, in this study, attempts to correlate the ratio of root dry weight to transpiration rate with the reduction in transpiration rate under soil drying were unsuccessful.

'Elf' sunflower grown in fritted clay and irrigated with saline water had 100% mortality at salt concentration 5 g/L, only one plant survived at 6 g/L, and mortality was complete at any higher salt concentration (Table 2). 'Tom Thumb' lettuce grown in fritted clay and irrigated with saline water showed complete mortality at salt concentration 4 g/L or higher (Table 2). Because the experiment on growth of sunflower in salinized, cultivated field soil and salinized, uncultivated grass field soil under daily irrigation with tap water was conducted twice under different environmental conditions, growth

Table 3. Mortality and growth of sunflower relative to no-salt control in salinized, uncultivated grass field soil and salinized, cultivated field soil under daily irrigation with tap water.

Traits	Salinity (g/L) 0	1.5	3.0	4.5	6.0
UNCULTIVATED GRASS					
Shoot Dry Weight	1.00 ± 0.04[a]	1.1 ± 0.10 (0.1)[b]	1.1 ± 0.1 (0.3)	0.87 ± 0.07 (0.03)	0.84 ± 0.07 (0.009)
Mortality (%)	0, 5	0	0	5	5
CULTIVATED					
Shoot Dry Weight	1.00 ± 0.04	0.97 ± 0.08 (0.6)	1.0 ± 0.10 (0.6)	0.88 ± 0.06 (0.02)	0.9 ± 0.10 (0.3)
Mortality (%)	0, 0[c]	0	5	0	0

[a] Values for shoot dry weight are mean ± one standard error, relative to the no-salt control.
[b] Values in parentheses are the P-values based upon the t-test comparison with the no-salt control.
[c] Mortality rate is absolute (not relative to no-salt control). The two mortality rates at the no-salt control refer to the two trails.

Table 4. Mortality and growth of lettuce relative to no-salt control in salinized, uncultivated grass field soil and salinized, cultivated field soil under daily irrigation with tap water.

Traits	Salinity (g/L) 0	1	2	3	4
UNCULTIVATED GRASS					
Shoot Dry Weight	1.00 ± 0.05[a]	1.1 ± 0.10 (0.6)[b]	1.1 ± 0.10 (0.4)	1.0 ± 0.20 (0.8)	1.0 ± 0.20 (1)
Mortality (%)	5, 5[c]	0	10	0	0
CULTIVATED					
Shoot Dry Weight	1.0 ± 0.20	0.9 ± 0.40 (0.7)	0.8 ± 0.20 (0.3)	1.5 ± 0.70 (0.3)	1.4 ± 0.70 (0.4)
Mortality (%)	20, 20[c]	10	5	20	30

[a] Values for shoot dry weight are mean ± one standard error, relative to the no-salt control.
[b] Values in parentheses are the P-values based upon the t-test comparison with the no-salt control.
[c] Mortality rate is absolute (not relative to no-salt control). The two mortality rates at the no-salt control refer to the two trials.

was calculated relative to the appropriate no-salt control at the time of the experiment (Table 3). Mortality rates were absolute, not relative to a no-salt control (Table 3). The reduction in sunflower growth became statistically significant at salt concentrations greater than or equal to 4.5 g/L. The only exception was the relative sunflower growth in cultivated soil at salt concentration 6 g/L. Relative sunflower growth was significantly greater in salinized field soil under daily irrigation with tap water than in fritted clay under saline irrigation at a given salt concentration (compare Table 2 with Table 3). In the range of salt concentration 4.5–6 g/L, sunflower growth was reduced by 10–16% with mortality rates in the range 0–5%. Sunflowers grown in fritted clay under saline irrigation in the same range of salt concentrations, however, experienced 75–100% mortality (mortality rates were interpolated between salt concentrations 4–5 g/L in Table 2). At no salt concentration was the difference between relative growth of sunflower in cultivated and uncultivated grass soil statistically significant.

The growth of lettuce in salinized, cultivated field soil and salinized, uncultivated grass field soil under daily irrigation with tap water was also calculated relative to the appropriate no-salt control (Table 4). Mortality rates were absolute (Table 4). No reduction in lettuce growth was observed in the salt concentration range 0–4 g/L. By contrast, mortality of lettuce was 100% when grown in fritted clay under saline irrigation at salt concentration 4 g/L (Table 2). At no salt concentration was the difference between relative growth of lettuce in cultivated and uncultivated grass soil statistically significant.

DISCUSSION

Only Kriedmann and Sands (1984) have reported root and shoot dry weights of sunflower for growth affected by varying concentrations of NaCl. Results for 'Elf' sunflower compared with results from Kriedmann and Sands (1984) for 'Grey Stripe' sunflower grown in nutrient solution suggest that 'Grey Stripe' sunflower is markedly more salt-tolerant than 'Elf' sunflower (Fig. 1). Ashraf and O'Leary (1995, 1996, and 1997) have shown that there are both salt-sensitive and salt-tolerant cultivars of sunflower.

The yield response function for shoot fresh weight as a function of EC averaged across eight lettuce cultivars was calculated by Maas and Grattan (1999) from data obtained by Ayers et al. (1951), Osawa (1965) and Bernstein et al. (1974) (Fig. 2). Although significant differences are known to exist among salt tolerances of lettuce cultivars (Shannon 1980, Shannon and McCreight 1984, Shannon et al.

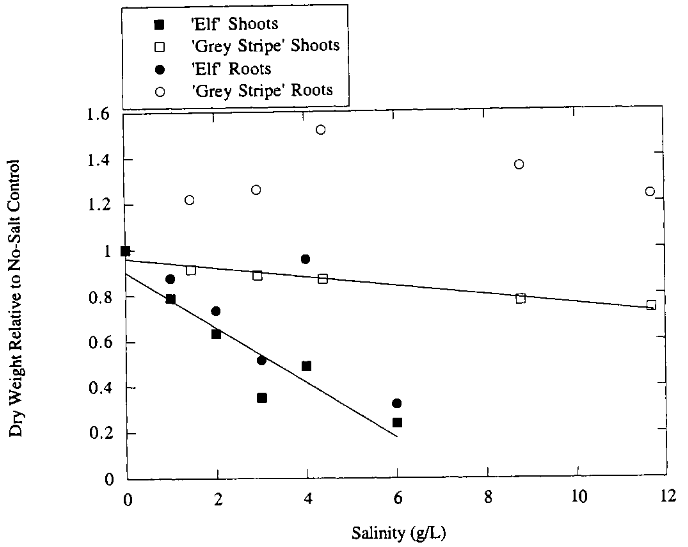

Fig. 1. Shoot and root dry weights relative to no-salt control vs. salinity for 'Elf' sunflower grown in fritted clay (this study) and 'Grey Stripe' sunflower grown in nutrient solution (Kriedmann and Sands 1984). Straight lines show best linear fits to shoot dry weights. 'Grey Stripe' sunflower is significantly more salt-tolerant than the miniature cultivar 'Elf' sunflower.

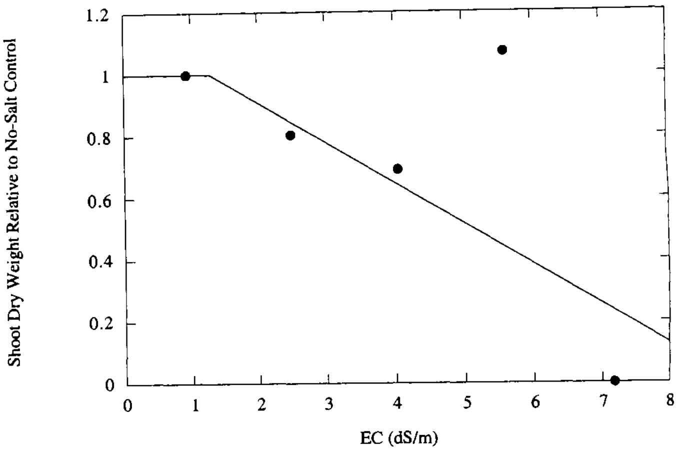

Fig. 2. Shoot dry weight relative to the no-salt control for 'Tom Thumb' lettuce grown in fritted clay (solid circles) and the average yield response function for lettuce shoot fresh weight relative to the no-salt control (Maas and Grattan 1999) (solid line) as a function of electrical conductivity (EC). The salt tolerance of the miniature cultivar 'Tom Thumb' lettuce is very similar to the average salt tolerance for lettuce. The exceptional point at EC = 5.6 dS/m is represented by only four lettuce plants due to the 60% mortality at that salinity.

1983), the salt tolerance of the miniature cultivar 'Tom Thumb' was similar to an average for lettuce (Fig. 2). The only exceptional point occurred at salinity 3 g/L (EC = 5.6 dS/m), which was represented by only four lettuce plants due to the 60% mortality that occurred at that salinity.

The significant result of this study was that increased growth in uncultivated grass soil was not observed. No significant differences were detected either in comparing the growth of sunflower (high root water potential) in cultivated and uncultivated grass soil or in comparing the growth of lettuce (low root water potential) in cultivated and uncultivated grass soil. Increased growth was reported in comparing the growth of bell pepper in fritted clay with growth in fritted clay that had been treated by grinding and sieving (Emerman and Dawson 1996). Grinding and sieving is seemingly a more radical transformation than tillage. Although tillage destroys the connectivity of macropores, it does not affect soil texture. Another possible explanation for the lack of difference in growth between plants grown in cultivated and uncultivated grass soil was that soil swelling due to irrigation with water with high SAR may have altered soil structure and obscured differences between cultivated and uncultivated grass soil (Bohn et al. 1985). However, significant soil swelling should have caused observable changes in the time required to flush each can with saline water, but no changes were observed. The time required to flush each can was not related to salinity treatment. Moreover, significant soil swelling should have caused an increase in drained water content as salinity was increased. Drained water content did not increase with an increase in salinity for either the cultivated soil or uncultivated grass soil over the salinity range of this experiment (Table 5).

There was, however, a significant difference between the response of 'Tom Thumb' lettuce grown in salinized soil under daily irrigation with tap water and the response of 'Elf' sunflower grown under the same conditions, regardless of tillage status. Tap water supplied daily at the transpiration rate did improve the growth of sunflower at a given soil salinity. However, the reduction in growth in saline soil compared with the no-salt control was statistically significant. On the other hand, under the same conditions, lettuce showed no reduction in growth from the no-salt control even at salt concentrations at which lettuce showed complete mortality without the addition of tap water. The tentative conclusion was that crops with low root water potential grown in salinized soil responded significantly better to daily irrigation with relatively fresh water than did crops with high root water potential. Crops with low root water potential may have a superior ability to rapidly extract a small

Table 5. Drained water content (cm^3 H_2O/cm^3 soil) of cultivated and uncultivated grass soil as a function of salinity.

Treatment	Salinity (g/L)				
	0	3	4	4.5	6
Cultivated	0.51 ± 0.01[a]	0.53 ± 0.01 (0.4)[b]	0.52 ± 0.02 (0.9)	0.50 ± 0.02 (0.5)	0.50 ± 0.02 (0.5)
Uncultivated grass	0.46 ± 0.01	0.47 ± 0.01 (0.5)	0.46 ± 0.02 (0.7)	0.49 ± 0.02 (0.1)	0.48 ± 0.01 (0.08)

[a] Drained water content refers to water content at matric potential $\Psi_m = -0.44$ kPa. Values for drained water content are mean ± one standard error.

[b] Value in parentheses is the P-value based upon the t-test comparison with the no-salt control.

amount of relatively fresh water before it mixes with the ambient saline soil water solution. This may provide some clues as to which crops will respond best to daily irrigation with relatively fresh water in salinized soil.

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