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Salinity Effects on Four Sunflower Hybrids

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ABSTRACT

Sunflower (Helianthus annuus L.) is becoming an increasingly important source of edible vegetable oil throughout the world because of its high polyunsaturated fatty acid content and no cholesterol. The increasing demand for this oil may promote increased hectarage of sunflower in the western USA, where some soils are saline or have the potential to become so. Since there is little information concerning the response of sunflower grown under saline conditions, a 2-yr field plot study was conducted. Six salinity treatments were imposed on a Holtville silty clay (clayey over loamy, montmorillonitic [calcareous], hyperthermic Typic Torrifluvent) by irrigating with Colorado River water artificially salinized with NaCl and $CaCl_2$ (1:l by weight). Electrical conductivities of the irrigation waters both years were 1.4 (control), 2.0, 3.0, 4.0, 6.0, and 80 dS m^{-1}. Seed yield and oil content of the seed were measured. Relative seed yield of four hybrids was unaffected by soil salinity up to 4.8 dS m^{-1} (electrical conductivity of the saturation extract, EC_e). Each unit increase in salinity above 48 dS m^{-1} reduced yield by 5.0%. These results indicate that sunflower is appropriately classified as moderately tolerant to salinity. Yield reduction was attributed primarily to a reduction in seeds per head. Oil concentration in the seed was relatively unaffected by increased soil salinity up to 10.2 dS m^{-1}. Sunflower appears to be well adapted for growth under moderately saline soil conditions.

SUNFLOWER (Helianthus annuus L.), a New World plant, has been developed into a valuable source of edible oil and meal. In 1992, world production of sunflower oil was about 7.8 million tonnes. As an edible vegetable oil, only soybean [Glycine max (L.) Merr.] and rapeseed-canola (Brassica *napus* L. and ***B.*** *campestris* L.) oil production exceeded that of sunflower (USDA, 1993). In the USA, about 839000 ha of sunflower were harvested in 1992, with oilseed hybrids constituting about 88% of the harvest and nonoilseed hybrids making up the remaining 12%. Most production in the USA is in Minnesota, North Dakota, South Dakota, and Kansas (USDA, 1993). However, with the increasing popularity of edible vegetable oils that, like sunflower, contain high percentages of polyunsaturated fatty acids and low cholesterol, the potential exists for sunflower to become an important crop in many western states, where it is currently grown on a very small hectarage. It has already been shown that sunflower is well adapted to the low desert valley areas of southern California (Lehman et al., 1973) and to the Southern High Plains area of Texas, Oklahoma, and New Mexico (Jones, 1984; Unger, 1986). However, with a possible introduction or increase in hectarage in these and other western states, plantings may be on soils where salinity problems already exist or may develop from the use of saline irrigation water. This field plot study was initiated to predict sunflower seed and oil yield response to salinity.

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MATERIALS AND METHODS

This study was conducted at the Irrigated Desert Research Station, Brawley, CA, on a Holtville silty clay soil. The crops were grown in 6.0- by 6.0-m plots enclosed by acrylic-fortified fiberglass borders that extended 0.75 m into the soil. The tops of the fiberglass borders protruded 0.15 m above the soil level of the plot and were covered with a berm 0.18 m high and 0.60 m wide. Walkways, 1.2 m wide between plots, and good vertical drainage effectively isolated each plot.

Prior to planting, triple superphosphate was mixed into the top 0.25 m of soil at the rate of 73 kg P ha^{-1}. To assure adequate N fertility throughout the experiment. $Ca(NO_3)_2$ was added at the rate of 0.14 kg N ha^{-1} mm^{-1} of water applied at every irrigation. Because the soil contained adequate levels of K, no additional K was added.

The four sunflower hybrids used in this study (452, 465A, 849, and 954) were developed by Sigco/Mycogen Plant Sciences, Breckenridge, MN. Hybrids 452 and 465A are standard oilseed sunflower hybrids containing high levels of linoleic fatty acid, 849 is an oilseed hybrid high in oleic fatty acid, and 954 is a nonoilseed hybrid. All hybrids were planted in level plots on 3 Mar. 1988 and 17 Mar. 1993. Each plot contained four rows of each hybrid. The rows were planted 0.65 m apart, with the seed placed about 80 mm apart within the row. After emergence, the plants were thinned to 0.23 m apart within the row. This provided a population density of about 7 plants m^{-2}.

The experimental design consisted of six treatments replicated three times in a randomized split-plot design, with salinity as main plots and hybrids as subplots. At the time of planting, the

Abbreviations: EC,, electrical conductivity of saturated-soil extract; EC,,, electrical conductivity of irrigation water.

Table 1. Average electrical conductivities of the saturated-soil extracts (EC.) for two sunflower cropping seasons with a control (1.4 dS m^{-1}) and five levels of irrigation water salinity.

Soil sample depth	ECe					
	Control†	2.0	3.0	4.0	6.0	8.0
m	dS m^{-1}					
	1988					
0-0.3	5.4 ± 0.3‡	5.6 ± 0.3	7.3 ± 0.3	8.5 ± 0.3	10.5 ± 0.4	11.1 ± 0.3
0.3-0.6	5.8 ± 0.5	9.0 ± 0.4	12.4 ± 0.4	13.2 ± 0.5	13.7 ± 0.5	15.1 ± 0.4
0.6-0.9	4.6 ± 0.9	6.3 ± 0.5	10.8 ± 1.0	14.4 ± 0.9	18.1 ± 0.8	18.7 ± 0.4
Avg.	5.2 ± 0.3	7.0 ± 0.3	10.2 ± 0.5	12.1 ± 0.5	14.2 ± 0.3	15.0 ± 0.4
	1993					
0-0.3	5.5 ± 0.7	6.1 ± 0.6	8.4 ± 0.7	8.1 ± 0.5	9.2 ± 0.6	9.0 ± 0.9
0.3-0.6	4.5 ± 0.4	6.6 ± 0.6	7.6 ± 0.5	8.8 ± 0.6	9.2 ± 0.9	10.3 ± 0.6
0.6-0.9	5.1 ± 0.5	5.8 ± 0.5	6.6 ± 0.4	8.2 ± 0.7	7.8 ± 0.5	9.7 ± 0.7
Avg.	5.0 ± 0.4	6.2 ± 0.4	7.5 ± 0.4	8.4 ± 0.6	8.8 ± 0.7	9.7 ± 0.6

† Electrical conductivity of the irrigation water (EC_{iw}), dS m^{-1}; control = 1.4 dS m^{-1}.
‡ Means ± SE of three samples.

soil profiles were still salinized from a previous experiment. To assure good germination, 75 mm of nonsaline water (1.4 dS m^{-1}) was applied to each plot prior to planting, to leach salts from the top 0.15 m of soil; another 50 mm nonsaline irrigation was applied 4 d after planting to prevent soil crusting.

About 3 wk after planting, differential salination was initiated. To allow the plants to adjust osmotically, the salinity in the irrigation water was increased in two steps over a 9-d period, with the first irrigation applied at one-third strength salinity, the second irrigation at two-thirds salinity, and all subsequent irrigations at full strength salinity. The salination of the irrigation water was accomplished by adding equal weight of NaCl and $CaCl_2$ to Colorado River water. In both years of the study, the electrical conductivities of the six irrigation waters (EC_{iw}) were 1.4 (the control: Colorado River water), 2.0, 3.0, 4.0, 6.0, and 8.0 dS m^{-1}. All plots were irrigated about every 2 to 3 wk throughout the study to keep the soil matric potential of the control treatments above -85 J kg^{-1} in the 0.15 to 0.3-m zone. The total amounts of irrigation water applied after planting were 398 mm in 1988 and 367 in 1993. Total rainfall was <5 mm in both growing seasons.

Soil samples were collected from each plot prior to planting and again at 6 and 12 wk after salination. Two soil cores per plot were taken in 0.3-m increments to a depth of 0.9 m. Average EC, for each of the three depths for both years is presented in Table 1.

Monthly mean high temperatures in 1988 ranged from 27°C in March to 34.5°C in May; monthly mean low temperatures for the same period ranged from 8 to 15°C, respectively. During the 1993 growing season, the monthly mean high temperatures were 31°C for March and 34°C for May, with corresponding low temperatures of 11 and 16°C, respectively.

Random height measurements were taken at about monthly intervals. Ten plants per hybrid were measured from the soil surface up to the terminal growth. After head emergence, the measurements were made to the back of the head.

Mature fully expanded leaves were sampled for mineral analysis at the beginning of anthesis in both years. Leaf petioles were removed from leaf blades for separate analysis. The petioles and blades were washed with deionized water, dried at 70°C, and finely ground in a blender. Chloride contents were determined in 0.1 M nitric acid in 1.7 M acetic acid extracts of the leaf material by the Cotlove (1963) coulometric-amperometric titration procedure. Nitric-perchloric acid digests of the ground leaves were analyzed for Na by atomic absorption spectrophotometry.

Plant harvest began on 3 June 1988 and 11 June 1993. Because of differences in maturity between hybrids, the harvest extended over a 7-d period in both years. To determine seed yield of each hybrid, a 3.6-m' area was harvested from the center of each plot. Seed heads were hand-harvested, weighed, and threshed. The seed was then cleaned and weighed. At harvest, 10 additional seed heads of each hybrid were threshed and cleaned to determine seed number per head.

Seed analysis for oil was conducted by Sigco/Mycogen Plant Sciences, Breckenridge, MN. Oil contents were determined on samples of whole seed with an Oxford 4000 NMR Spectrometer' (Oxford Instr., Oxon, England).

RESULTS AND DISCUSSION

When salination began each year, the plants in all treatments had approximately four fully developed leaves. This indicates that the pretreatment soil profiles had little effect on seedling growth and development. Height measurements taken 4 wk after salination showed that plants of all hybrids in the high-salt plots were about 50% shorter than control plants. This early height differential remained generally constant through the remaining developmental stages of growth. Hang and Evans (1985) and Unger (1983) have reported a similar height reduction for water-stressed sunflower.

Reduction in plant height was accompanied by a significant reduction in leaf number with increasing salinity levels (data not shown). As early as 30 d after salination, plants of all hybrids treated with the highest salinity had 1 to 2 leaves less than the controls. This reduction in leaf number was more pronounced at anthesis, with final leaf number on control plants averaging 25 to 26 leaves, and 20 to 21 leaves on high-salt plants. This reduction in leaf number has also been shown to occur when sunflower is subjected to soil water deficits (Marc and Palmer, 1976).

While increasing salinity stress significantly reduced leaf initiation, the time of flower initiation among salinity treatments was unaffected, with anthesis occurring on all treatments within 1 to 2 d of each other. This is in contrast to most plant species, where salinity generally accelerates flower initiation (Francois, 1982; Francois and Bernstein, 1964; Francois et al., 1986). This insensitivity has also been reported to occur when sunflower is subjected to temperature and water stresses (Marc and Palmer, 1976). Consequently, it appears that flower initiation in sunflower

[1] Reference to specific products is made for identification purposes only and does not imply endorsement by the author, the USDA-ARS, or cooperating agencies of the U.S. government.

Table 2. Average seed yield and yield parameters of four sunflower hybrids (452, 465A, 849, and 954) grown at Brawley, CA, with six soil salinity levels in 1988 and 1993.

		452			465A			849			954		
Soil salinity (EC_e)	df	Seed yield	Seeds per head‡	100-seed wt.	Seed yield	Seeds per head	100-seed wt.	Seed yield	Seeds per head	100-seed wt.	Seed yield	Seeds per head	100-seed wt.
dS m^{-1}		g m^{-2}	no.	g	g m^{-2}	no.	g	g m^{-2}	no.	g	g m^{-2}	no.	g
							1988						
5.2 (control)		237	877	4.05	324	911	3.32	326	986	3.32	406	396	9.17
7.0		199	782	3.81	288	912	3.42	294	778	3.21	301	375	8.78
10.2		182	775	3.52	246	688	3.39	246	781	3.01	231	320	7.90
12.1		176	680	3.88	181	792	3.46	222	739	3.14	221	311	8.70
14.2		150	619	3.62	187	701	3.39	211	582	3.61	187	302	8.15
15.0		141	606	3.49	148	628	3.21	156	546	3.15	167	246	1.75
							1993						
5.0 (control)		298	1307	3.48	300	1197	3.61	295	1209	3.90	348	562	9.56
6.2		273	1179	3.17	294	1256	3.59	299	1126	3.92	322	526	9.58
7.5		262	1043	3.51	283	1214	3.60	313	1036	3.95	313	539	8.33
8.4		236	1077	3.44	288	1202	3.41	247	1008	3.65	284	556	8.47
8.8		231	1098	3.22	231	1003	3.25	248	993	3.62	257	525	7.78
9.7		208	1030	3.10	222	985	3.13	221	986	3.35	224	466	7.19
							Analysis of variance, mean squares						
Source							1988						
Salinity	5	3.62†	33.75†	0.15†	14.01†	43.32†	0.02	11.11†	75.73†	0.13†	23.39†	8.71†	0.93*
Linear	1	17.08†	159.11†	0.39†	66.97†	168.94†	0.01	52.64†	329.55†	0.01	106.90†	39.95†	2.88†
Quadratic	1	0.04	0.51	0.02	0.07	0.52	0.07	0.04	1.03	0.16†	6.22†	0.02	0.07
Error	10	0.22	3.41	0.01	0.37	4.91	0.05	1.02	10.27	0.01	0.14	0.57	0.20
							1993						
Salinity	5	3.14†	32.87†	0.16	3.45*	41.18†	0.13	4.07†	23.79†	0.16†	6.23†	3.51	2.72*
Linear	1	15.35†	129.56†	0.46*	11.96†	113.25†	0.46*	13.32†	112.04†	0.58†	28.61†	7.65*	12.22†
Quadratic	1	0.13	18.84	0.24	2.16	54.29†	0.12	4.01**	6.49	0.21**	1.78	2.94	0.39
Error	10	0.35	3.90	0.05	0.84	3.34	0.09	0.39	2.34	0.02	0.55	1.41	0.69

*,**,t Significant at the 0.05, 0.01, and 0.005 levels of probability, respectively.
‡ To obtain actual values for seed per head, multiply reported values by 10'.

may be regulated more by the age of the plant than by the various stresses encountered.

Seed yield obtained from the control plots (5.2 dS m^{-1} in 1988; 5.0 dS m^{-1} in 1993) for all four hybrids exceeded those reported for the same hybrids in field performance trials in 1988 and 1993 by Sigco Research in the Upper Midwest of the USA (Sigco/Mycogen Plant Sciences, 1988, 1993). In these upper-midwestem trials, hybrids 452,465A, 849, and 954 averaged 206, 212, 175, and 208 g m^{-2}, respectively. The higher yields obtained in this current study, and in earlier field performance trials at the University of California Imperial Valley Field Station (Lehman et al., 1973), show that sunflower is well adapted to the low desert areas of California.

Seed yield of all hybrids was significantly reduced by increasing levels of salinity in both harvest years (Table 2). This reduction was attributed primarily to a reduction in seeds per head and secondarily to an inconsistent reduction in seed index (weight of 100 seeds). Head size, which was unaffected in 1993, was significantly reduced in 1988 when soil salinity exceeded 10.2 dS m^{-1} (data not shown). However, reduction in head size only partially explains the reduction in seeds per head. Since the reduction in seeds per head also occurred at soil salinities < 10.2 dS m^{-1} in both years, it appears that flower and/or seed abortion may have occurred as well.

The seed yield data for each hybrid for individual years were statistically analyzed with a piecewise linear response model (Maas and Hoffman, 1977; van Genuchten and Hoffman, 1984). The data indicate that the hybrid thresholds (i.e., the maximum allowable EC, without a yield decline) were nearly the same in both years. Therefore, the seed yield data for all hybrids in both years were combined and analyzed. The combined data indicate a threshold of 4.8 dS m^{-1}, with a 5.0% reduction in seed yield for each unit increase in salinity above the threshold (Fig. 1). Relative yield, Y_r, for any EC, exceeding the threshold of 4.8 dS m^{-1} can be calculated with the formula presented in Fig. 1. According to the salt tolerance categories established by Maas and Hoffman (1977), seed yield of

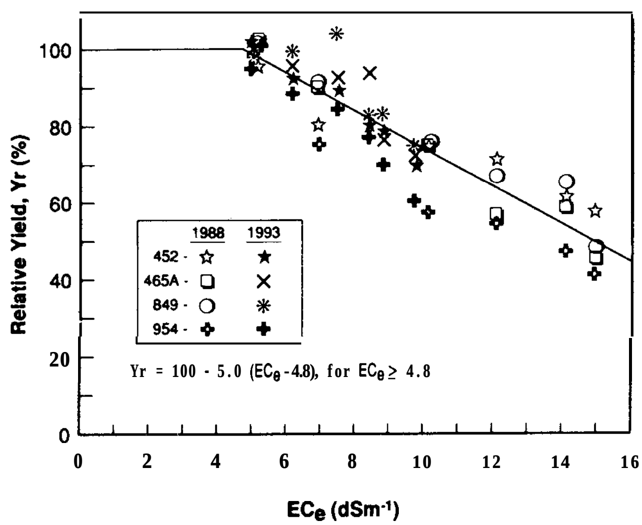

Fig. 1. Relative seed yield of four sunflower hybrids grown at Brawley, CA, in 1988 and 1993 as a function of increasing soil salinity.

Table 3. Oil percentage of three oilseed sunflower hybrids (425,465A, and 849) grown at Brawley, CA, at six salinity levels in 1988.

Soil salinity (EC_e)	df	Oil percentage 452	465A	849
dS m^{-1}		g kg^{-1}		
5.2 (control)		41.3	38.4	31.1
7.0		41.4	39.0	37.8
10.2		40.1	38.7	38.0
12.1		39.9	38.9	38.1
14.2		39.7	38.7	39.2
15.0		39.0	31.7	38.6
Source		Analysis of variance, mean squares		
Treatment	5	2.73†	0.65	0.94
Linear	1	12.68†	0.46	3.20*
Quadratic	1	0.02	1.61	0.29
Error	IO	0.30	1.18	0.6

*,† Significant at the 0.05 and 0.005 probability levels, respectively.

sunflower should be classified as moderately tolerant of salinity. This places sunflower in the same tolerance category as soybean (Maas and Hoffman, 1977) and safflower (Carthamus *tinctorius* L.) (Francois and Bernstein, 1964), two other major edible oil crops. Although the threshold for all three species is nearly identical, the rate of yield decline above the threshold is much greater for soybean and safflower. Unlike seed yield, oil concentration of hybrids 465A and 849 was not significantly affected by salinity (Table 3). However, the third oilseed hybrid, 452, showed a small but significant reduction in oil concentration once soil salinity was ≥ 10.2 dS m^{-1}. Mean oil content from control plots in 1988 was about 3.0% lower than was reported from field performance trials conducted in the upper-midwestern USA using the same hybrids (Sigco/Mycogen Plant Sciences, 1988, 1993). The difference in oil content may have been the result of different environmental factors at the two locations, especially temperature. Although the reported effects of temperature on oil content have been variable (Anderson et al., 1978; Harris et al., 1978; Unger and Thompson, 1982), the relatively high average temperature of about 34°C during seed development and maturation in our study could account for the lower oil content.

Chloride concentration in the leaves tended to follow a similar accumulation pattern both years of the study (Table 4). As soil salinity increased, Cl in both the petiole and blade tissue increased. Regardless of salinity level, petioles accumulated about twice as much Cl as the blades. Compared with Cl, Na was largely excluded from both tissues and its concentration only increased slightly even at the highest salinity treatment (data not shown). The leaf tissues at all treatment levels indicate that, like safflower (Francois and Bernstein, 1964), sunflower tends to be a Na excluder.

The results of this study indicate that sunflower is moderately tolerant to soil salinity. Therefore, it can be grown successfully on most agricultural soils, as long as the EC, does not exceed 4.8 dS m^{-1}. Absolute yields will vary, depending on climate, soil conditions, and cultural practices. The oil content of the seed, for which the crop is most often grown, shows little response to increased soil salinity.

Table 4. Average chloride composition of blades (B) and petioles (P) of four sunflower hybrids (452,465A, 849, and 954) grown at Brawley, CA. in l988 and 1993 at six levels of salinitv.

Soil salinity (EC_e)	df	Cl composition 452 B	452 P	465A B	465A P	849 B	849 P	954 B	954 P
dS m^{-1}		mmol Cl kg^{-1} dry wt.							
				1988					
5.2		480	980	457	1081	502	977	570	1136
7.0		598	1202	576	1196	600	1245	616	1335
10.2		703	1525	578	1472	667	1402	609	1617
12.1		672	1473	619	1375	811	1640	740	1662
14.2		796	1636	726	1744	675	1701	830	1834
15.0		769	1625	700	1523	629	1617		1862
				1993					
5.0		578	992	582	1049	606	1146	473	796
6.2		545	1049	604	1121	564	1262	617	1041
1.5		656	1259	668	1315	664	1426	693	1254
8.4		703	1343	723	1374	753	1472	709	1261
8.8		711	1276	699	1353	729	1582	821	1395
9.7		770	1399	762	1435	750	1688	837	1535
				Analysis of variance, mean squares‡					
Source				1988					
Salinity	5	40.75†	205.67†	28.30	169.69†	30.97†	235.59†	31.06†	245.60†
Linear	1	182.19†	930.11†	124.68†	679.13†	57.34-l	1070.62†	123.40†	1200.25†
Quadratic	1	4.81	62.31*	0.01	8.72	65.60†	61.11**	1.76	16.32
Error	IO	2.08	1.73	9.11	5.69	4.32	6.96	1.71	22.87
				1993					
Salinity	5	21.84*	79.76†	14.49	70.70	19.14*	120.12†	54.84-l	206.73†
Linear	1	96.77†	369.47†	68.96*	336.95†	76.18†	590.639	259.02†	1001.92†
Quadratic	1	4.50	1.85	0.34	3.55	0.93	2.38	1.59	2.36
Error	10	4.17	5.95	11.28	24.37	3.66	15.28	3.69	4.88

*,† Significant at the 0.05 and 0.005 probability levels, respectively.
‡ For all mean squares, actual values = reported values multiplied by 10^3.

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