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Salinity Effects on Bud Yield and Vegetative Growth of Artichoke *(Cynara scolymus L.)*

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Abstract. **Globe artichokes recently have been planted in the irrigated desert area of southern California. Soils in this area are, or have the potential to become, highly saline from the application of saline irrigation water. Thus, a 2-year field plot study was conducted. A control and five saline treatments were imposed by irrigation with waters that contained equal weights of NaCl and $CaCl_2$. Bud yield and vegetative growth were measured. For the two years, relative bud yield was unaffected up to a soil salinity of 6.1 $dS{\cdot}m^{-1}$ [electrical conductivity of the saturated soil extract (EC,)]. Each unit increase in salinity above 6.1 $dS{\cdot}m^{-1}$ reduced yield by 11.5%. These results place artichoke in the moderately salt-tolerant category. Yield reduction was attributed primarily to reduced bud weight rather than bud count. Vegetative growth was more tolerant to salt stress than was bud production. Chloride concentration in midrib and blade tissue increased as salinity increased.**

Until recently, globe artichoke production in the United States has been confined to perennial plantings in central Californiacoastal counties, where temperatures are uniformly mild in summer and relatively frost-free in winter. While cultural practices with these perennial plantings have resulted in a harvest season that is generally continuous throughout the year (Ryder et al., 1983), high temperatures during September and October can significantly reduce bud production during November to February.

During this reduced production period in the coastal area, market prices are favorable and a warmer winter climate in the desert has resulted in the recent development of an artichoke industry in these areas. In 199 1, -200 ha of artichokes were grown in the Imperial and Coachella valleys of California (Mayberry and Gonzalez, 1992). Whereas vegetative propagation is mostly used in the central coastal area, artichokes in the south are produced from seed-propagated cultivars.

Artichoke plantings in this arid southern California region may be on soils where salinity problems already exist or may develop from the use of saline irrigation water. While preliminary studies of salt stress on artichoke growth have been conducted with pot culture in the greenhouse (Graifenberg et al., 1993), they provide little information on the effect of salinity in the field where climatic conditions are significantly different. Since salt tolerance data are not available to adequately predict yield responses under field conditions, a 2-year field plot study was initiated to determine the effect of salinity on yield and vegetative growth. A salinity-induced Ca deficiency observed during this study has been previously reported (Francois et al., 1991).

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Materials and Methods

Artichoke seed used in this study was the germplasm breeding line 86-024 released in 1986 by the Agricultural Research Service, U.S. Dept. of Agriculture. Seed of this breeding line is from the fourth generation of a within-line sib pollination of an original cross between an unidentified line from France and an Italian line obtained from V. Rubatzky, Univ. of California, Davis.

Seed were planted 22 Sept. 1986 and 17 Sept. 1987 in 18 level field plots located at the Irrigated Desert Research Station, Brawley, Calif. Each plot (6 x 6 m) contained six rows 0.9 m apart with seed placed 0.15 m apart withineach row. Afterestablishment, the seedlings were thinned to 0.75-m spacing within each row. This plant spacing provided a population of -14,000 plants/ha. Plot soil was a Holtville clay [clayey over loamy, montmorillonitic (calcareous), hyperthermic Typic Torrifluvent]. Each plot was enclosed by acrylic-fortified fiberglass borders that extended 0.75 m into the soil. 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.

Before planting, triple superphosphate was mixed into the top 0.25 m of soil at the rate of 73 kg P/ha. To ensure adequate N fertility throughout the experiment, $Ca(NO_3)_2$ was added at each irrigation at 0.14 kg N/ha per millimeter of water applied. The soil contained adequate levels of K, so no additional K was added.

The design consisted of six treatments replicated three times in a randomized complete-block design. At the time of planting each year, the soil profiles in each plot had been differentially presalinized with the same quality irrigation waters that were to be used throughout the study. To assure good germination, 90 mm of low-salinity water (1.4 $dS{\cdot}m^{-1}$) was applied to all plots before planting to leach salts below the seed bed and also after planting to prevent soil crusting.

About 35 days after planting, when the plants were at the three- to four-leaf stage of growth, differential salination was resumed. Irrigation water salinities were increased stepwise in two increments 14 days apart to achieve the desired salt concentrations. Equal weights of NaCl and $CaCl_2$ were added to Colorado River water to obtain six irrigation waters with electrical conductivities (EC,,) both years of 1.4 (control), 2.0,4.0, 6.0, 8.0, and 10.0 $dS{\cdot}m^{-1}$. During both growing seasons, all plots were irrigated about every 3 to 4 weeks to keep the soil matric potential of the control treatments above -85 $J{\cdot}kg^{-1}$ in the 0.15- to 0.30-m zone. Tensiometers were used to monitor soil matric potential and to guide irrigation frequency. The total amount of irrigation water applied during each growing season was 563 mm in 198687 and 463 mm in 1987-88.

The electrical conductivity of the saturated-soil extract (EC,) was determined on soil samples taken three times each **year** during the growing season. Samples were taken within the plant row in 0.3-m increments to a depth of 0.9 m. The average EC, values over the course of the experiment were 4.6, 6.6, 7.4, 8.7, 10.6, and 11.6 $dS{\cdot}m^{-1}$ in 198687, and 4.4, 5.9, 8.3, 10.4,11.3, and 13.8 $dS{\cdot}m^{-1}$ in 1987-88 for the six treatments.

The mean daytime high for the month preceding the first harvest was 23C in 1987 and 26C in 1988. During the harvest period, the mean highs were 3 1 C in 1987 and 30C in 1988. The cumulative Class A pan evaporation during the same preharvest and harvest periods was 218 and 370 mm in 1987 and 214 and 466 mm in 1988.

Artichokes buds were harvested when their circumference exceeded 250 mm. The first harvests were on 20 Mar. 1987 and 17 Mar. 1988. Subsequent harvests were made at 5- to 6-day intervals for the next 48 days in 1987 and 30 days in 1988. The onset of plant senescence and delayed bud development determined when harvests were discontinued.

At harvest, each artichoke was weighed and its circumference measured. In addition, the outer bracts of each artichoke were removed to determine Ca-deficiency damage to the inner bracts (Francois et al., 1991). If buds exhibited damage, they were weighed separately from the nondamaged buds. Damaged buds were not included in total yield determination.

After all marketable-sized buds were harvested, total vegetative growth from the harvest area was weighed and a subsample dried in a forced-air dryer at 70C to determine water content.

Mature, fully expanded leaves were sampled midway through the 1987 and 1988 harvests. Leaf midribs were removed from the rest of the leaf blade for separate analysis. All sampled material was washed, dried at 70C, and finely ground in a blender. Chloride contents were determined on 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 sampled material were analyzed for Ca, Na, Mg, and K by atomic absorption spectrophotometry.

Results and Discussion

Total bud yield was significantly reduced at soil salinity levels >7.4 dS·m^{-1} in 1987 and 5.9 dS·m^{-1} in 1988 (Table 1). Yields measured at the lower salinities were similar to average commercial yields in the Imperial Valley of Califomiabothyears,i.e., 15.4 t·ha^{-1} (Mayberry and Gonzalez, 1992). However, like most crops, artichoke yields will vary, depending on climate, soil conditions, and cultural practices.

Although the number of buds per plant was significantly affected by increased levels of salinity only in 1988, the higher salinity treatments in both years showed a tendency to produce fewer harvestable buds per plant. This result seems to indicate that bud count may only contribute significantly to yield reduction when soil salinities are higher than those imposed in this study. Since bud circumference was only slightly, although significantly, reduced with increased salinity levels, the reduction in total yield was accounted for primarily by the significant reduction in the weight of individual buds (Table 1).

Total yield data for each year were statistically analyzed with a piecewise linear response model (van Genuchten and Hoffman, 1984). The tolerance thresholds (the maximum allowable EC, without a yield decline) and the yield decline above the thresholds were nearly the same for both years. Therefore, the yield data for both years were combined and analyzed. The combined data indicate a threshold of 6.1 dS·m^{-1} and a yield decline of 11.5% for each unit increase in soil salinity above the threshold (Fig. 1). Relative yield (Yr) for any EC, exceeding the threshold of 6.1 dS·m^{-1} can be calculated with the equation in Fig. 1.

Threshold and slope analyses tend to agree generally with those reported by Graifenberg et al. (1993), when artichokes were grown in the greenhouse. Their threshold and slope were 4.9 dS·m^{-1} and 10.7%, respectively.

When Ca-deficient buds, which were not included in the threshold and yield decline analyses, were added to total yield, the tolerance threshold increased to 7.4 dS·m^{-1} and the yield decline per unit increase in salinity decreased to 8.0%. This perceived increase in tolerance was not unexpected because the number of Ca-deficient buds increased significantly each year as salinity increased (Francois et al., 1991). Since these buds were judged to be unmarketable, the higher the soil salinity the greater the number of buds eliminated from final yield analysis.

According to the salt tolerance classification scheme of Maas and Hoffman (1977), artichoke would be classified as moderately tolerant. Thus, artichokes are in a higher tolerance category than most other vegetable crops (Francois and Maas, 1993).

Desert-grown artichokes increase in toughness and decrease in flavor with the onset of warm weather in spring (Mayberry and Gonzalez, 1992). These physiological changes tended to occur earlier in the harvest season with buds on the higher-salinity-treated plants. Not only did the buds become tough and woody, but they were slow to develop to meet harvest criteria.

The combined 2-year data for vegetative dry weight indicate an average threshold of 7.8 dS·m^{-1} and a growth decline of 8.3% for each unit increase in EC, above that threshold (Fig. 1). These data show vegetative growth is more tolerant to salt stress than bud production. An EC, of 7.8 dS·m^{-1}, the threshold for vegetative growth, would show no vegetative reduction but would have reduced bud yield by 20%.

Chloride concentration in the leaves tended

Table 1. Bud vield characteristics of artichokes grown at six salinity levels during two growing seasons.

Soil salinity (EC_e) (dS·m^{-1})	Total bud yield (t·ha^{-1})	Avg bud wt (g)	Bud no./plant	Avg bud circumference (mm)
		1987		
4.6	16.7	211	6.1	289
6.6	16.8	203	6.6	287
7.4	16.1	206	1.3	287
8.7	10.0	190	5.9	282
10.6	9.0	179	6.3	279
11.6	5.3	178	5.4	274
Significance^z	L***	L***	NS	L***
		1988		
4.4	17.1	256	5.2	274
5.9	17.1	234	6.4	275
8.3	13.3	214	5.1	275
10.4	8.5	189	5.2	264
11.3	5.2	180	4.9	258
13.8	4.1	179	4.0	260
Significance^z	L***	L***, Q*	L*	L**

^{z}L = linear; Q = quadratic.

NS, *, **, ***Nonsignificant or significant at P = 0.05,0.01, or 0.005, respectively.

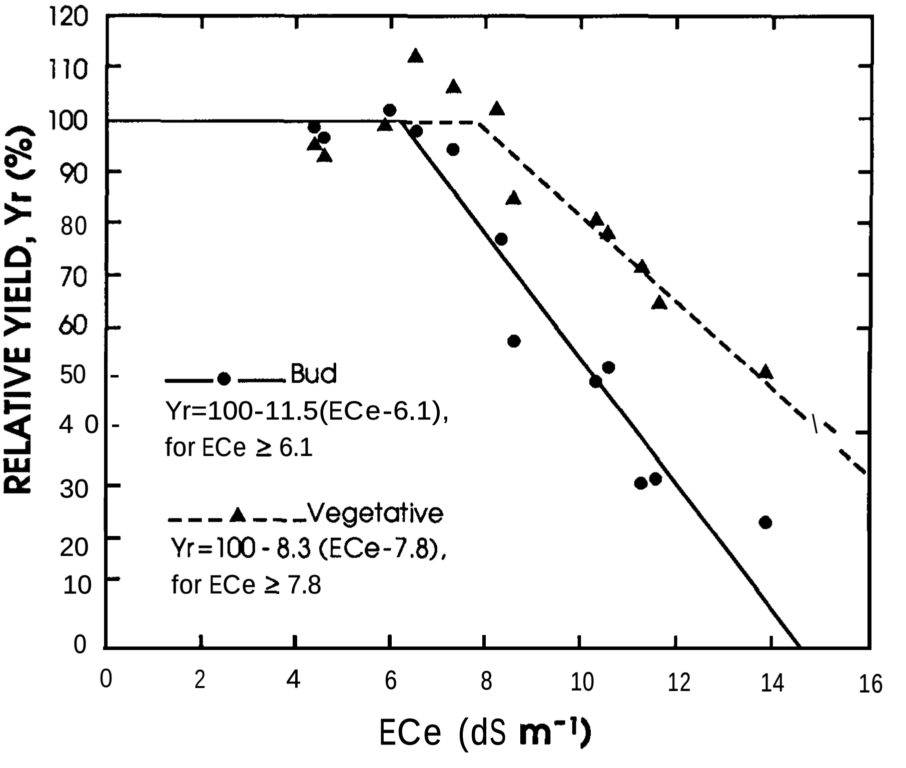

Fig. 1. Relative bud yield and vegetative growth of artichoke as a function of increasing soil salinity.

Table 2. Chloride concentration of leaf blades and midribs from artichokes grown at six salinity levels in 2 years.

Soil salinity (EC_e) ($dS\cdot m^{-1}$)	Cl concn ($mmol\cdot kg^{-1}$ dry wt) Midrib	Blade
	1987	
4.6	1751	1086
6.6	1902	1300
7.4	2057	1310
8.7	1920	1315
10.6	2099	1486
11.6	2072	1462
Significance[y]	L***	L***
	1988	
4.4	1680	1019
5.9	1683	1190
8.3	1692	1320
10.4	1687	1172
11.3	1855	1360
13.8	2094	1346
Significance[y]	L*	L**

[z]$mg\cdot kg^{-1} = mmol\cdot kg^{-1} \times$ atomic weight.
[y]L = linear.
*,**,***Significant at $P \leq 0.05, 0.01$, or 0.005, respectively.

to follow a similar accumulation pattern both years of the study (Table 2). As soil salinity increased, Cl in the midrib and blade tissues increased. Midribs accumulated between 30% to 40% more Cl than did the surrounding blade tissue at all salinity levels. Sodium accumulation was significantly higher in the blades than in the midribs, while Ca was higher in midribs at low salinities and higher in blades at high salinities (data not shown).

Although the plants took up an abundance of Ca under saline conditions, the distribution of Ca within the plant was predominately to the high-transpiring leaves. Calcium concentration in the leaves was 2.5 to 30 times higher than in the low-transpiring inner bracts of the buds. Root pressure, which would normally provide a mechanism for Ca movement to the inner bracts, was severely reduced with increasing soil salinity (Francois et al., 1991). Consequently, with reduced root pressure and low transpiration, a Ca deficiency occurred in the inner bracts of the buds.

Salinity effects on Mg and K content in the leaf blades and midribs have been previously reported (Francois et al., 1991).

This study shows that while artichoke tends to be more salt tolerant than most vegetable crops, the need to maintain low soil salinity levels is essential for maximum yields. When salinity levels become too high, the incidence of Ca deficiency within the bud increases (Francois et al., 1991) and the size of the buds decreases.

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