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Salinity Effects on Asparagus Yield and Vegetative Growth

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Additional index words. *Asparagus officinalis*, salt tolerance, seedling growth, germination, osmotic potential, total soluble solids

Abstract. **The effect of salinity on germination, first-year growth, and spear and fern yield of asparagus (*Asparagus officinalis* L.) was determined in germination dishes, crocks, and field plots, respectively. Saline treatments were imposed by irrigating with water that contained equal weights of NaCl and $CaCl_2$. Spear yield was reduced 2.0% for each unit increase in salinity above 4.1 $dS \cdot m^{-1}$. Yield reduction was attributed primarily to a reduction in individual spear weight. Mature asparagus plants would be considered the most salt-tolerant crop commercially available. Asparagus possessed nearly the same salt tolerance for germination and spear production with soil salinities <7.2 $dS \cdot m^{-1}$. Above 7.2 $dS \cdot m^{-1}$, germination was less salt-tolerant. First-year growth was significantly more salt-sensitive than growth in subsequent years.**

Asparagus (*Asparagus officinalis* L.) has been found growing wild in so many places that its place of origin is doubtful. However, there seems to be a consensus that it originally was native to the eastern Mediterranean seacoast of Europe, North Africa, and Asia (1, 8). Recorded history indicates that it has been cultivated in this region for more than 2000 years. The Roman historian, Marcus Porcus Cata, wrote a full-length discourse on asparagus cultivation in his *De Re Rustica* in about 161 BC (16). Not only was it prized as a food but was valued for its medicinal properties as well. Supposedly it could cure everything from bee stings to heart trouble and toothaches (8).

Asparagus is believed to have been introduced into the United States by the immigration of Huguenots from France in the 1600 and 1700s (16). However, it was not grown commercially until about 1850 to 1860. Today, it has become one of the most important perennial vegetable crops grown in the United States (8).

In the early days of its cultivation in the United States, the application of salt on asparagus fields was nearly universal. Apparently, gardeners believed that since asparagus was native

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to the seacoast, salt was essential for proper growth (14). With few exceptions, the older books on practical gardening recommended the use of salt when growing asparagus (5, 6, 14, 25). These recommendations ranged from 1.0 $kg \cdot m^{-2}$ (25) to a broadcast application 13 mm thick over the entire soil surface (5). Researchers in the early 1900s also reported a beneficial effect with salt application (15, 24). Stalk number, as well as stalk weight, supposedly increased as the amount of salt applied increased. Hunn and Bailey (9) reported no beneficial effect from salt, but still recommended the practice.

In spite of this long historical association of asparagus and salt, reliable salt tolerance data are essentially nonexistent. Therefore, a long-term study was initiated to determine the effect of soil salinity on yield and vegetative growth.

Materials and Methods

The asparagus cultivar used throughout this study was 'U.C. 157', a hybrid released in 1975 that is characterized by early production (18). This cultivar is related to 'Mary Washington', which was introduced into California in the early 1900s (21).

Spear and fern yield. Asparagus seed was germinated in peat pots in the greenhouse in June 1978. Five weeks after planting, when the plants were ≈6 cm tall, selected uniform seedlings were transplanted into twelve 4.27-m^2 flat field plots. Plots contained Pachappa fine sandy loam (mixed, thermic, Mollic Haploxeralf), which had been previously mixed to a 1-m depth to minimize soil heterogeneity. Concrete borders extending 75 cm into the soil, 90-cm-wide walkways between plots, and good vertical drainage effectively isolated each plot. Transplants were placed 30 cm apart in rows 1.37 m apart for a total of 42 plants/plot.

For the first year after transplanting, seedlings were irrigated with nonsaline tap water containing 0.5 mM $Ca(NO_3)_2$ and 1.0 mM KNO_3. These two fertilizer salts were added in every irrigation throughout the experiment to ensure adequate N and K fertility. Triple superphosphate at the rate of 73 kg P/ha was mixed into the top 25 cm of soil prior to transplanting. An additional 73 kg P/ha was applied in Jan. 1981 by adding KH_2PO_4 to the irrigation water. Differential salination was initiated in Feb. 1979, at first spear emergence, by applying irrigation waters that contained equal weights of NaCl and $CaCl_2$. To allow the plants to adjust osmotically, the irrigation water salinity (k_{iw}) was increased stepwise over the first three irrigations until the desired salt levels were achieved. The average electrical conductivities of the four treatment waters (k_{iw}) over the 4 years of the experiment were 0.8 (control), 6.5, 13.2, and 19.3 $dS \cdot m^{-1}$ (referenced at 25°C). A 6.5-cm depth of saline irrigation water was applied about every 12 days during the growing season and about once a month during the winter for a yearly application of about 166 cm. Each salinity treatment was replicated three times.

The electrical conductivity of the saturated-soil extract (k_e) was determined on soil samples taken three times each year during the growing season. Samples were taken within the plant row in 30-cm increments to a depth of 120 cm. The average k_e over the course of the experiment were 2.4, 10.0, 14.8, and 20.7 $dS \cdot m^{-1}$. To prevent dilution of the soil salinity during the rainy winter months, a clear plastic tarpaulin was installed over each plot.

Each year, 20-cm-long spears and mature fern were sampled from each plot for elemental analyses. The spears were collected midway through the harvest period, while the fern was sampled in September. The samples were washed, dried at 70°C, and ground in a blender. Chloride was determined by the coulometric–amperometric titration procedure (7). Nitric–perchloric acid digests of the ground tissue was used to determine P by molybdovanadate-yellow colorimetry (11), and Na, Ca, Mg, and K were determined by atomic absorption spectrophotometry.

To allow the plants to become well-established, spears were not harvested until Jan. 1980, at which time the plants were ≈2 years old. Spears were harvested for 30 days in 1980, and for 60 days each year thereafter (20, 21, 26). The average beginning harvest occurred on 24 Jan., with subsequent cuttings every 2 to 4 days throughout the harvest season. Fresh-market asparagus spears are usually cut when 25 to 30 cm long, 5 cm below the soil surface (21). However, in this study, to prevent damage to young spears that had not emerged, all spears were cut when 18 to 20 cm long, at the soil surface. At harvest, the spears were counted, weighed, and graded.

Midway through the harvest period, 10 uniform spears were harvested from each plot for osmotic potential determination of the cellular sap. Immediately after cutting, the spears were quickly frozen with dry ice. At the time the measurements were made, the spears were thawed for 12 min and 2.5 cm of the spear tips was removed and discarded. Cellular sap then was squeezed from the next 4 cm of the spear and the osmotic potential of the sap was determined with a vapor pressure osmometer.

Percent total soluble solids (TSS) was determined on a separate sample of 10 spears per plot. A 4-cm subterminal spear segment comparable to that used for osmotic potential determinations was also used for TSS analysis. The TSS were determined with a refractometer (at 25°C).

To determine vegetative growth, the senescent fern was removed, dried, and weighed in late fall.

Germination. Germination was determined on blotters in 9.5-cm^2 covered plastic germination dishes. The blotters were soaked in the appropriate salt solution and allowed to drip free of excess solution before being placed under and over the seeds. Fifty seeds were placed in each dish, and the dishes then were placed in a germinator that was maintained at a constant 25°C.

The differential salinity levels used (k_{iw}) were 0.0, 4.7, 9.4, 14.3, 18.5, 24.1, 28.2, 32.7, and 37.6 $dS \cdot m^{-1}$. Each solution contained NaCl and $CaCl_2$ in a 1:1 ratio by weight. Each treatment was replicated four times. Counts were made over a 17-day period. Only healthy radicles >1 mm in length were counted. Once a seed germinated, it was removed from the dish and discarded.

First-year growth. Twenty-four glazed ceramic crocks, 48 cm high and 38 cm in diameter, were filled with 82 kg of dry Pachappa fine sandy loam (mixed, thermic, Mollic Haploxeralf) and placed in a greenhouse. Treble superphosphate was mixed into the top 15 cm of soil in each crock for a total application of 73 kg P/ha. Nitrogen and K were added as $Ca(NO_3)_2$ and KNO_3 in each irrigation over the course of the study for a total application of 295 kg N and 400 kg K/ha.

Asparagus seed was planted in each crock on 29 Apr. 1980. On 2 June, when the seedlings were ≈14 cm high, the stand was thinned to five plants per crock. To ensure good germination and a good stand, all crocks were irrigated with nonsaline irrigation water prior to thinning the plants. Differential salination was initiated with the first irrigation after thinning using saline waters that contained equal weights of NaCl and $CaCl_2$. The average electrical conductivities of the six treatment waters (k_{iw}) over the course of the experiment were 0.2, 1.8, 5.0, 9.2, 14.3, and 18.5 $dS \cdot m^{-1}$. Each salinity treatment was replicated

four times. All irrigations were surface-applied in 10-liter increments about every 10 days for a total application of 160 liters/crock for the growing season. Ten-liter irrigations were sufficient to replenish soil water lost by evapotranspiration and provide a 15% leaching fraction of the soil profile with each irrigation. The leaching was essential to prevent an abnormally high accumulation of salt in the soil profile.

The k_e was determined on soil samples taken from each culture three times during the growing season. The average k_e were 1.0, 4.9, 8.2, 13.0, 16.1, and 21.5 $dS \cdot m^{-1}$ for the six salinity treatments.

The mature, senescent fern in each culture was harvested on 2 Dec. 1980, air-dried, and weighed. Twenty-eight days later, the new spears that had emerged after fern removal were harvested, counted, and weighed.

Results and Discussion

Spear and fern yield. During the first harvest year, spear yield was not significantly different among treatments. However, in the second year, a yield reduction pattern associated with increasing salinity levels was established that was maintained throughout the remainder of the study. Salinity did not cause a progressive reduction in plant vigor with each succeeding harvest year.

The effect of salinity on yield of asparagus spears and fern growth over the 4-year study is presented in Table 1. At a k_e of 10.0, 14.8 and 20.7 $dS \cdot m^{-1}$, total spear weight was reduced 10%, 20%, and 35%, respectively. Although significantly reduced, the yield obtained from the high salt treatment (20.7 $dS \cdot m^{-1}$) would still be considered a good yield for asparagus (12). The major parameter contributing to this yield reduction was the decrease in individual spear weight. Although spear number was not significantly affected over the salinity range tested, it did contribute to yield reduction.

The total spear yield data was analyzed statistically with a piece-wise linear response model (NOPT-5) (13, 23). The analysis indicated that the maximum soil salinity without a yield decline (the threshold) was 4.1 $dS \cdot m^{-1}$ (Fig. 1). Each unit increase in k_e greater than the threshold reduced yield by 2.0%. The equation presented in Fig. 1 indicates that a 50% reduction in spear yield would occur at a k_e of 29.1 $dS \cdot m^{-1}$. This value is in contrast to unsubstantiated field observations, which reported a 50% yield reduction at a k_e of 12 $dS \cdot m^{-1}$ (22). The yield response curve does not fall within a single salt tolerance category as established by Maas and Hoffman (13). It extends from the moderately tolerant into the tolerant category. However, since most of the yield response curve falls in the tolerant category (Fig. 1), asparagus is classified as tolerant to salinity. In comparison to all other agricultural crops (13), mature asparagus plants are one of the most salt-tolerant crops commercially grown.

Table 1. Effects of salinity on total yield of asparagus spears and fern growth over a 4-year period.

Average rootzone salinity (k_e) ($dS \cdot m^{-1}$)	Total spear wt ($g \cdot m^{-2}$)	Total spears ($no./m^2$)	Average wt/spear (g)	Total fern wt ($g \cdot m^{-2}$)
2.4	2999	166	18.1	3615
10.0	2708	151	17.9	2714
14.8	2394	158	15.1	2166
20.7	1948	137	14.3	1661
Significance				
Treatment	***	NS	**	***
Linear[z]	***	NS	***	***

[z]Single degree of freedom comparisons.
NS,**,***Nonsignificant and significant at 1% or 0.5% levels, respectively.

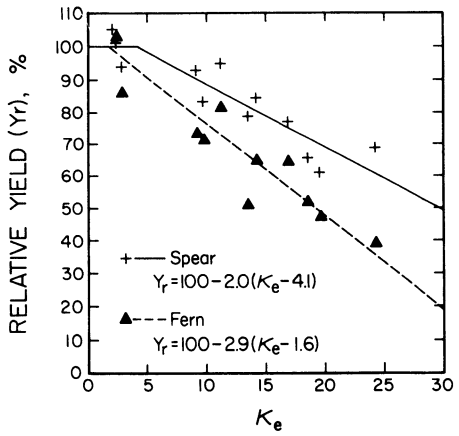

Fig. 1. Relative spear yield and fern growth of mature asparagus plants as a function of increasing soil salinity.

Table 2. Osmotic potential (Ψ_ρ) and total soluble solids (TSS) of cellular sap from asparagus spears grown at four different salinity levels.

Average rootzone soil salinity (k_e) ($dS \cdot m^{-1}$)	OP (MPa)	TSS ($mg \cdot g^{-1}$ fresh wt)
2.4	−1.04	95.6
10.0	−1.14	105.7
14.8	−1.25	108.0
20.7	−1.28	108.6
Significance		
Treatment	***	**
Linear[z]	***	***

[z]Single degree of freedom comparisons.
**, ***Significant at 1% or 0.5% levels, respectively.

Fern yield (Table 1 and Fig. 1) was more sensitive to salinity than spear yield, with a threshold of 1.6 $dS \cdot m^{-1}$ and a yield reduction of 2.9% per unit increase in salinity. A k_e of 29.1 $dS \cdot m^{-1}$, which is estimated to reduce spear yield by 50%, would reduce fern growth by 80%.

Stored carbohydrates, which are produced during fern growth, are used for spear production the following year (17, 20). Consequently, a reduction in fern growth caused by salinity would presumably result in less carbohydrate storage. Therefore, this factor could contribute to the reduction in spear number and weight at harvest.

Cellular sap expressed from the spears showed a significant decrease in osmotic potential ($\Psi\rho$) with increasing levels of salinity (Table 2). A major component of this osmotic adjustment was the increase of total soluble solids (TSS) in the sap. This increase in TSS has been previously reported to occur in carrots (4), tomatoes (10), and muskmelons (19) grown under saline conditions. The capacity of asparagus to adjust osmotically undoubtedly accounts for its salt tolerance, since there is considerable experimental evidence that supports the view that plant growth on saline media is governed primarily by $\Psi\rho$ (2, 3).

Increasing salinity had no physiologically significant effect

Table 3. Elemental composition of asparagus spears and mature fern grown at four soil salinities.

Average rootzone soil salinity (k_e) ($dS \cdot m^{-1}$)	Concn ($mmol \cdot kg^{-1}$ dry wt)[z]					
	Na	Cl	Ca	Mg	K	P
Spears						
2.4	8.0	324	61.5	60.0	914	213
10.0	13.2	342	54.1	47.4	902	210
14.8	18.7	359	57.5	42.7	867	201
20.7	23.6	383	61.9	39.3	892	198
Significance						
Treatment	*	*	NS	***	NS	NS
Linear[y]	***	**	NS	***	NS	NS
Mature fern						
2.4	20.0	356	118	50.6	721	61.2
10.0	20.4	397	127	47.7	706	70.3
14.8	27.0	440	218	44.9	538	56.4
20.7	57.0	389	233	41.1	507	51.1
Significance						
Treatment	NS	NS	*	NS	*	*
Linear[y]	NS	NS	*	NS	**	*

[z]ppm or $mg \cdot kg^{-1}$ = $mmol \cdot kg^{-1}$ × atomic weight.
[y]Single degree of freedom comparisons.
NS, *, **, ***Nonsignificant or significant at 5%, 1%, or 0.5% levels, respectively.

on the concentration of any of the elements tested (Table 3). The concentration of Na and Cl in the spears increased slightly and Mg decreased with increased soil salinity, while Ca, K, and P were unaffected. In contrast, Ca concentrations increased and K and P concentrations decreased in fern tissue while Na, Cl, and Mg were unaffected by increasing salinity. The analyses clearly show that asparagus tends to restrict Na uptake.

Germination. Soil water salinity (k_{sw}) up to 9.4 $dS \cdot m^{-1}$ had no significant effect on germination (Fig. 2). However, salt levels >9.4 $dS \cdot m^{-1}$ significantly delayed germination and reduced final germination percentage. The data in Fig. 2, when converted to k_e ($k_{sw} = 2k_e$), indicate a germination threshold of 4.2 $dS \cdot m^{-1}$ and a reduction in germination of 1.5% for each unit increase in salinity above the threshold up to a k_e of 7.2 $dS \cdot m^{-1}$. Above 7.2 $dS \cdot m^{-1}$, each unit of salinity reduced germination 6.6%. These data indicate that asparagus possesses nearly the same salt tolerance for germination as for spear production when the soil salinity is <7.2 $dS \cdot m^{-1}$. However, above this salinity, the spear production was affected less by salinity than germination.

First-year growth. Asparagus proved to be much more salt-sensitive during the first year of seedling growth than during either germination or mature stages of growth. The data in Fig. 3 indicate a reduction in growth of 4.5% for each unit increase in salinity beyond the threshold of 0.8 $dS \cdot m^{-1}$. A k_e of 11.9 $dS \cdot m^{-1}$ would reduce first-year fern growth 50%, whereas germination, mature fern growth, and spear yield would be reduced 36%, 30%, and 16%, respectively.

Spear number, which was recorded 28 days after the first-year fern was removed, showed a significant difference between the control (1.0 $dS \cdot m^{-1}$) and all other salinity treatments. Spear weight was not significantly affected except at the two highest salinity concentrations of 16.1 and 21.5 $dS \cdot m^{-1}$. The data indicate that the reduced first-year fern growth, resulting from increased salinity, significantly affects the production of spears

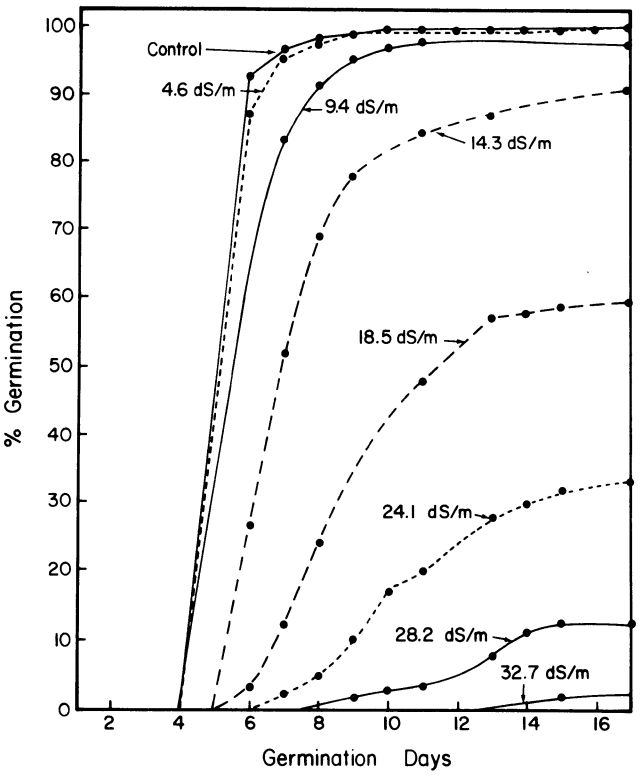

Fig. 2. Germination response of asparagus to increasing salinity levels (k_{sw}). ($k_{sw} = 2k_e$)

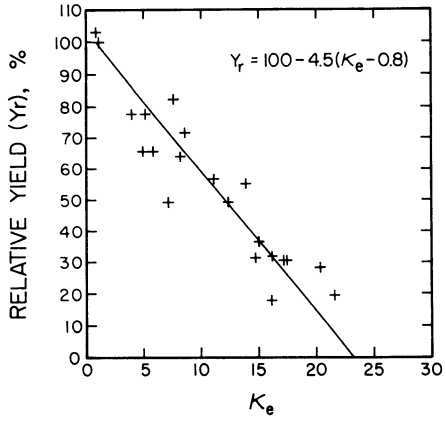

Fig. 3. Relative fern growth of first-year asparagus plants as a function of increasing soil salinity.

the second year. Apparently, the reduced fern growth during the first year severely reduced the stored carbohydrates needed for spear production the following year.

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Effect of Soil Management and Calcium Nitrate Fertilization on the Availability of Soil Nitrate and Cations in an Eastern Apple Orchard

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Additional index words. *Malus domestica*, nitrogen, N accumulation, soil pH, magnesium, manganese, leaf analysis

Abstract. **Four annual applications of $Ca(NO_3)_2$ were made to 'Golden Delicious' and 'Delicious' apple trees beginning in the second leaf at rates of 0.5 to 8 times the recommended rate (45 g/tree per year of age) in each of three soil management systems: cultivated, herbicide, and mowed sod. Soil samples were collected in Mar. and July 1983 (fifth leaf) to a 120-cm depth at the tree drip line. July samples were analyzed for available Ca, Mg, K, Mn, percentage of base saturation, NO_3-N, and soil pH (0.01 M $CaCl_2$); March samples only for NO_3-N. The sod system had the highest soil pH, Ca level, and percentage of base saturation; the herbicide had the lowest, and the cultivated treatment was intermediate. The rate of $Ca(NO_3)_2$ had no measurable effect on these values except in the surface pH levels (0–30 cm), where sod was unaffected but the cultivated and herbicide systems had a significant reduction in pH with increasing levels of $Ca(NO_3)_2$. Soil Mn availability and leaf Mn increased with increasing $Ca(NO_3)_2$ levels in association with the decreasing pH levels. Available soil Mg and leaf Mg decreased with increasing $Ca(NO_3)_2$ due to Ca displacement of soil Mg on the cation exchange complex. Leaf Ca was unaffected by $Ca(NO_3)_2$ rate or the soil management system. During the growing season (Mar.–July 1983), the herbicide system accumulated significantly more of the applied $Ca(NO_3)_2$ than the cultivated or sod systems. No yield response and minimal leaf N response suggested differences in NO_3 accumulation were due to variation in leaching due to the soil management systems.**

The predominant apple cultivars in the eastern United States exhibit physiological disorders due to low Ca (2, 4, 19). Disorders such as corking, bitter pit, scald, and internal breakdown have been moderated or reduced by $CaCl_2$ sprays and dips and liming of the orchard (5, 7, 13, 15, 20). In addition, $Ca(NO_3)_2$ has been recommended as a readily available source of Ca and N (3, 14). Nutrient solution and greenhouse studies have demonstrated that leaf and fruit Ca levels can be increased by increasing the availability of Ca (11, 17). In a field study, $Ca(NO_3)_2$ fertilizer increased Ca availability and uptake in apple (6). However, in other field studies, no response to $Ca(NO_3)_2$ was measured (13, 16). Calcium nitrate lacks the acidifying potential of NH_4-N fertilizers, but it can increase the pH of some soils (1).

Soil management systems interact with fertilizer source and rate to influence nutrient availability. It is important to under-

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