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Salinity Tolerance of Crops in Irrigated Agriculture Under Dynamic Conditions

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SALINITY TOLERANCE OF CROPS IN IRRIGATED AGRICULTURE
UNDER DYNAMIC CONDITIONS

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ABSTRACT

One of the limitations of applying crop tolerance to salinity data to field situations is our limited understanding of the interaction of salinity with crop management practices. Three management practices were evaluated in this report: a) changing the irrigation interval (I); b) changing the leaching fraction (L); and c) changing the rate of initial salinization of the soil when saline irrigation water is applied. In addition, some tolerance to salinity function were obtained for five crops for which such information was lacking.

The experiments were conducted in field plots irrigated by either drip or minisprinkler in Bet Dagan and Gilat, Israel, in rhizotron plots in Riverside where drip irrigation was used, and in small plots in Riverside where irrigation water was applied by furrow.

The results may be summarized as follows:

- 1) Data from three crops - eggplant, corn and fescue, grown at three locations - Bet Dagan, Gilat and Riverside, on four soil textures - sandy loam, clay, silt and fine sandy loam showed that yield decline due to increased irrigation water salinity cannot be lowered by reducing the irrigation interval. A unified function of relative yield vs mean root zone salinity could be used for all irrigation intervals, regardless of whether or not irrigation interval had a significant effect on yield.
- 2) Leaching fraction of up to 0.27 improved crop yields regardless of the level of irrigation water salinity. Leaching in addition to reducing soil salinity increased the mean integrated soil water content. Both factors played a part in improving crop yield. It seems to be difficult to avoid subcritical soil water contents when very low leaching fractions are attempted.

3) Applying high leaching rates soon after planting causes rapid soil salinization and, with tall fescue, resulted in about 9% lower yield compared with low leaching. The effect reversed as soil salinity was built-up, due to low leaching. The yield of lettuce was lower with low leaching due to reduced soil water availability despite the lower soil salinity.

4) Crop tolerance to salinity functions were obtained for five crops - turnips, celery, cowpea, asparagus and eggplant as follows, respectively:

$Y/Y_m = 1.0 - 0.09 (EC_e - 0.9)$, $Y/Y_m = 1.0 - 0.06 (EC_e - 1.8)$, $Y/Y_m = 1.0 - 0.12 (EC_e - 4.9)$, $Y/Y_m = 1.0 - 0.2^0 (EC_e - 2.8)$ and $Y/Y_m = 1.0 - 0.06 (EC_e - 1.1)$.

A. INTRODUCTION

The quality of irrigation water is one of the major issues in maintaining crop productivity in irrigated agriculture. Two factors contribute to the prominence of the quality problem: firstly, continuous irrigation is resulting in a steady increase of salt concentration of ground and surface water resources. Secondly, the exploitation of water resources in Israel and in the western U.S., and the need for continued development, encourage the increasing use of brackish water resources. Consequently, effective salinity control measures are becoming acute and solutions are needed urgently to ensure a permanent, viable irrigated agriculture.

A considerable body of information is presently available regarding the tolerance of many crops to salinity (Maas and Hoffman, 1977) and the consequences of using saline water on salt accumulation and distribution in the soil (Bresler et al, 1982). Most of this information on tolerance was obtained under the relatively uniform conditions of the laboratory or field plots. The dynamic and complex nature of salinity under farming conditions and the interactions among the various factors, make the quantitative prediction of the influence of soil salinity on crop yield uncertain. Indeed, in practice, water of poorer quality than would be predicted from controlled observations is successfully used for crop irrigation (Shani Uri, private communication). Recent research findings lend support to these field observations (Bernstein and Francois, 1973).

The difficulties in transferring existing salt tolerance information to field conditions may arise because of differences in environmental or managerial conditions. Plant response to salinity obtained under one set of environmental conditions may be different when temperature (Hoffman et al, 1978), humidity (Hoffman et al, 1971), radiation (Meiri et al, 1982) air pollution (Hoffman

et al, 1975 , ozone concentration) and/or CO₂ concentration (Enoch et al, 1973) are altered. Changing management practices may also alter plant response. The principle managerial practices which may be easily manipulated are irrigation scheduling (quantities and intervals), leaching fractions, irrigation method, fertilizer application, seeding rates and seeding methods.

In addition to the difficulties in the application of existing salt tolerance data, tolerance ratings for crops for which such data are lacking is needed. New data would broaden the choice of crops available to the farmer irrigating with saline water.

The general objective of the research reported herein was to obtain quantitative information for predicting the consequences of using saline water on the yield and quality of crops. The specific objectives were:

- (1) to determine the effect of different irrigation intervals on crop tolerance to salinity;
- (2) to determine the interrelationship between leaching fraction, the level of irrigation water salinity and crop yield;
- (3) to determine the significance of the initial rate of soil salinity build-up on final crop yields, and
- (4) to obtain tolerance to salinity information for some crops for which information was lacking.

The research was carried out in Bet Dagan and Gilat, Israel and in Riverside, California.

B. METHODOLOGY

The methods used, as well as the results and discussion, will be presented according to the four objectives defined above.

(1) Irrigation interval. This problem was investigated both in Israel and the U.S. In Israel, experiments were conducted over a three year period. During the first year, a field experiment was conducted in the coastal plain of Israel, in Bet Dagan, mean August temperature and relative humidity: 25.6°C and 60%; mean winter rainfall 535 mm, on a sandy loam soil (field capacity 27.5%, wilting point 12% by volume); the second year in Bet Dagan on a fine textured grumosol (field capacity 34.0%, wilting point 21% by volume), and the last year at Gilat, in the northern Negev region, mean August temperature 26.8°C and relative humidity 60%, mean annual rainfall 240 mm, on a loess soil (field capacity of 26.0% and wilting point of 11.6% by volume). The test crops were eggplant (Solanum Melongena L. cv Black Amber) during the first two years and sweet corn (Zea Mays, cv Jubilee) during the last year.

The experimental design was split plot with three levels of salinity (five levels during the last year) as main plots and five irrigation intervals (four during the last year) as subplots. The salinity of the irrigation water (EC_e) ranged from 1 to 10 dS/m with irrigation intervals from 2 to 21 days, depending on the crop grown. Plot size was 5x6, 6x8 and 6x9 m; row spacing was 1.0, 2.0 and 0.92 m, and planting density in the row 2, 3 and 8 plants per meter during the first, second and third experiments, respectively.

The eggplant experiments were trickle irrigated. During the first year laterals were set at 0.5 m spacing with 0.5 m between emitters. During the second year two laterals were placed alongside each row 0.4 m apart. The quantities of water applied were equivalent to water loss from USWB screened Class A evaporation pan (8.0, 7.5 and 7.0 mm mean daily evaporation for July, August, September, respectively). The total amount of water applied was 580 mm in 1979 and 424 mm in 1980. Corn was irrigated according to the measured pre-irrigation soil water deficit to 1.20 m depth, except for the

high frequency irrigation where quantities were equivalent to pan evaporation (8.5, 9.5, 9.5 mm mean for May, June, July, respectively). Minisprinklers were used for the irrigation of corn. The Christiansen coefficient for the sprinklers, set at 2x3 m alternate intervals was 0.86. Treatments were initiated when the crop was established (about five weeks after planting).

Fertilizer (220 kg/ha N and 330 kg/ha K for eggplant and 0.062 kg/m³N for corn (120-220 kg/ha depending on the amount of water applied) was added with the irrigation water. A base application of 90 kg/ha N as ammonium sulfate and 110 kg/ha P as superphosphate was also given to corn. The salt solution was made up of equal weights of CaCl₂ and NaCl and injected into the irrigation water with a fertilizer injection pump.

During the growing season pre-irrigation measurements were made of soil water content using a neutron scattering meter and soil metric potential with tensiometers.

In 1979 tensiometers were placed in the small interval treatments at 0.3 and 0.8 m depths and 0.2 m from the trickle line as were neutron access tubes in the large interval treatments. In 1980 access tubes and tensiometers were placed at 0.20 m distance from the plant row to a depth of 0.60 m. In a few treatments (1.5 and 10.5 ds/m water, 3 and 15 day intervals) tensiometers were placed at 0.3 m, 0.6 m and 0.9 m depth; 0.2, 0.4 and 0.6 m distance from the row.

In the corn experiment access tubes and tensiometers were placed next to rows midway between minisprinklers in the large and small interval treatments, respectively. Measurements were made of leaf water potential with pressure chamber, and leaf diffusion resistance with LiCl₂ hygrometer, leaf solute potential by determining sugar and electrolyte concentration in the sap (Shimshi and Livne, 1967), and CO₂ absorption by leaves using C¹⁴

(Shimshi, 1969). Leaf samples were obtained between 11:00 and 14:00 hours. Soil salinity was measured from soil samples two to three times during the season. Salinity sensors were also used in 1979 and 1980. Sensors were placed at 0.6 m and 0.9 m depth at 0.2, 0.4 and 0.6 m from the plant row in 1980.

Eggplant fruit were harvested weekly for 8 weeks during the first year (August 15 - October 3) and 12 weeks during the second year (July 14 - September 29). Eggplant seedlings were planted on June 12 in 1979 and May 25 in 1980. Corn was harvested on July 12, 85 days after seeding.

The experiment in Riverside was conducted in 24 rhizotron plots, 3.0 by 3.0 by 1.5 m deep. The soil was Pachappa fine sandy loam top soil, carefully packed into the plots a year prior to the beginning of this experiment. Treatments were initiated 8 months after planting tall fescue (*Festuca elatior*), in September of 1976. The plots were drained under a constant suction of about 50 kPa through a network of 10 mm in diameter porous ceramic tubes placed at 30 cm spacing 12 cm above the concrete floor of each plot. Two sets of tensiometers and three sets of salinity sensors were installed at four depths, 25, 45, 75 and 120 cm, along a diagonal line across each plot. Two neutron access tubes were installed in each plot.

The experimental design was an incomplete three treatment, factorial design. The treatments were three irrigation intervals (F) (daily, 1/3 (approximately biweekly), and 2/3 (approximately monthly)- soil water depletion in the non-saline treatment). Three levels of salinity in the irrigation water (S) (1, 2.5 and 4 dS/m) and three leaching fractions (L) (0.09, 0.18, 0.27). Only the middle level of all treatments (F, L, S = 1/3, 0.18, 2.5) was replicated four times. The statistical analysis was according to De Baun (1959).

Irrigation water was applied through a biwall drip irrigation system with emitter spaced 30 cm along each line and 15 cm between lines. The

quantities to be applied were based on the evaporation from a USWB Class A evaporation pan and on the quantity of drainage water. Saline water was prepared in 16 m³ tanks by mixing the desired quantities of NaCl, CaCl₂, MgCl₂ and NaNO₃ with tap water to maintain an SAR value of 2.5 (mol/m³)^{1/2}. The NaNO₃ supplied the equivalent of about 200 kg/ha of N annually.

Rainfall was excluded by covering the plots with reinforced plastic sheeting. The daily irrigation was applied in one to six pulses per day, depending on evapotranspiration. For the third soil water depletion treatment, irrigation interval was from 10-14 days to monthly (17 irrigations annually). For the two-thirds soil water depletion treatment interval ranged from 20-25 days to bimonthly (11 irrigations annually). The rate of water application was the same for all treatments.

Plants were harvested approximately every 16 days during the summer and 3 times during the winter. The grass was cut to 6 cm height. During the season, soil water content was determined weekly, drainage water was collected continuously and analyzed twice weekly, soil water potential was measured with tensiometers and soil salinity was monitored with salinity sensors inserted horizontally into the soil through the rhizotron walls.

At the conclusion of the experiment, roots were sampled at eight depths at two locations of a few representative treatments, using a 900 cm³ core sampler, inserted horizontally through the rhizotron wall.

(2) Leaching fractions. Leaching fractions were studied only in Riverside, in the rhizotron plots. The methodology was described under (1).

(3) Rate of salinity build-up. This objective was investigated in Israel under greenhouse conditions in 1.2 x 2.0 x 0.5 m deep raised plots containing dune sand (volumetric water content 24 hours after irrigation was 8.5%). The

crop, lettuce (*Lactuca sativa* L. cv romana) was seeded on October 25th and gradually thinned to 24 plants per bed (6 plants per 2 m row, 4 rows per bed) until November 20th. The treatments were started on November 27th. The treatments were five levels of irrigation water salinity (1, 2.5, 5.0, 7.5 and 10.0 dS/m) each at two levels of water application, low (twice a week replenishment of 0.7 of E_p as measured in USWB Class A evaporation pan inside the greenhouse), and high (1.6 times the daily E_p). Total pan evaporation for the period November 28 - January 15 was 43 mm. Fertilizer was added with the irrigation water at concentrations of 100, 18, 124 mg/l of N, P and K respectively. Drip irrigation was used with lateral for each lettuce row and five 2-l/h drippers per lateral, giving a total of 20 drippers per plot.

The soil was sampled four times during the season for soil water content and salinity. Soil matric potential was monitored with tensiometers placed at depths of 15 and 45 cm in two replications of each treatment. Plant height was measured twice weekly and physiological parameters (leaf water potential and stomatal conductance) were determined twice during the season. The plots were harvested three times, on December 28th, January 11th and January 17th. The plants were chemically analyzed for Na, K, Ca, Cl, N and P.

(4) Crop tolerance. The tolerance of turnip, celery, cowpeas and asparagus was studied. The experiments were carried out in Riverside in twelve 4.27 x 4.27 m plots that contained Pachappa fine sandy loam soil. All experiments included four levels of salinity and three replications. Saline water was made up by adding equal weights of NaCl, $CaCl_2$ to tapwater.

Cowpea (*Vigna Unguiculata*): A single row of California Blackeye No. 5 cowpea seeds were sown in each of five flat-top beds 0.15 m high and 0.15 m wide,

0.04 m from the bed shoulder. The plants were spaced 0.14 m apart within each row. There was a 0.85 m spacing between bed centers.

Treatments were: $EC_i = 0.8, 3.3, 5.7$ and 10.3 dS/m. Salinization started three weeks after seeding and increased gradually over a three week period. Irrigation water was applied at a rate of 50 mm per week when tensiometers placed at 0.15 m depth in the control treatment showed a reading of - 50 kPa (- 0.5 bar).

Plants were harvested 94 days after seeding. Root distribution within the soil profile was determined by trenching across each plot to a depth of 0.90 m immediately after harvest. These tests were conducted in 1980 and 1981.

Celery (*Apium graveolens* L. var. dulce): Bed shape and planting density was similar to that used for cowpeas. Differential salinization was initiated three weeks after planting (on October 23rd) and was increased stepwise over a two week period until the desired salt levels were achieved. The treatments were: $EC_i = 0.9, 5.7, 10.0, 14.3$ dS/m. A 64 mm depth of saline water was applied approximately every 10 days giving a total application of 640 mm.

Plants were harvested 140 days after transplanting. The middle 20 plants were harvested from each row of 28 plants.

Turnip (*Brassica rapa* L. Rapifera group): Bed shape was similar to that used for cowpeas. The plant spacing within the row was 7.6 cm apart. Soil salinity levels were established prior to planting. Just before planting the top soil was leached with 65 mm of non-saline water and differential salinization was initiated eleven days after planting. Irrigation water was applied once a week. The treatments were: $EC_i = 0.9, 4.1, 6.9$ and 9.4 dS/m.

Asparagus (*Asparagus officinalis* L.): *Asparagus* seedlings were planted in three rows per plot with 137 cm between rows and 30 cm between plants within the row. Differential treatments started seven months after planting and salinization was achieved stepwise in three irrigations. Treatments were: $EC_i = 0.9, 6.6, 13.4$ and 19.5 dS/m. The experiment was conducted over a three year period. Data are reported for the last year harvest only.

C. RESULTS AND DISCUSSION

1. Irrigation interval and salinity

The yield response to salinity at different irrigation intervals may be influenced by two major counteracting processes. As the soil dries between irrigations, the soil solution salt concentration increases, thereby decreasing the soil solute potential (ψ_s) as well as the soil matric potential (ψ_m). As a result, yield reduction due to salinity is expected to be proportionately larger as the irrigation interval is increased, probably beyond some threshold limit. The reduced rate of water uptake due to salinity increase may have a moderating effect on this process. (Shalhevet and Bernstein, 1967; Shalhevet et al 1969.) Shortening the irrigation interval, on the other hand, results in a smaller water application at each irrigation. This causes a larger proportion of the water uptake to be from shallow depths and a higher salt accumulation in the upper root zone due to less leaching of the topsoil (Bernstein and Francois, 1975). Furthermore, the increase in ET when irrigation interval is small results in the addition of larger quantities of salt to the soil and, thus in higher salt content (Bielorai and Levy, 1971). Crops will suffer more from salts accumulated in the upper than the lower part of the root zone (Bernstein and Francois, 1973). The net effect on final yield will depend on the magnitude of the two processes.

There are other factors which may influence crop response under specific circumstances. With perennial crops under low rainfall situations the accumulation of salts at the lower part of the root zone will limit rooting depth, resulting in a need for more frequent irrigation. Under sprinkler irrigation, on the other hand, the higher the frequency the larger the foliar damage to sensitive crops.

The problem is rather complex, and it is not surprising therefore to find reports in the literature showing no interactive effect of salinity and interval (Wadleigh and Ayers, 1945; Bernstein and Francois, 1973), beneficial effect (Ayers et al, 1943; Wadleigh et al, 1946) and detrimental effect (Ayoub, 1977; Bernstein and Francois, 1975) of increasing frequency.

Yield and salinity

Results are presented for three crops - eggplant, sweet corn and tall fescue, from three locations - Bet Dagan, Gilat and Riverside, and four soil textures - sandy loam, clay, loess and fine sandy loam.

The yield data of eggplants, for 1979 and 1980, reported on a relative basis, with the best yield as 100 percent, are presented in Table 1. Analysis of variance showed significant effects of the salinity level on yield in 1979 and 1980, but irrigation interval showed a significant effect only in 1979 when the 16 day irrigation interval caused a decline in yield. The interaction of salinity and interval was significant in 1979 only, showing a smaller effect of salinity at large than at small intervals. Similarly, the effect of interval decreased as salinity increased.

The effect of irrigation water salinity (EC_i) on crop growth is through the salt accumulation in the soil, which is a function of both EC_i and irrigation interval. A more appropriate description of the results may therefore be obtained from a regression analysis rather than an analysis of

Table 1: Effect of irrigation water salinity (EC_i) and irrigation interval on relative fruit yield of eggplant

EC _i dS/m	1979					Mean
	Irrigation interval, days					
	2	5	8	12	16	
	<hr/>					
	%					
1.5	90	95	100	80	78	88a
4.5	86	80	81	76	64	76b
10.0	71	75	72	84	68	74b
	82a	84a	84a	80a	70b	
<hr/>						
	1980					Mean
	Irrigation interval, days					
	3	6	9	12	18	
	<hr/>					
	%					
1.5	100	87	91	91	92	92a
5.0	98	81	85	80	86	86a
10.0	77	54	73	71	69	69b
n.s.	92	74	83	81	83	

Values designated by the same letter are not significantly different at $P = 0.05$ according to Duncan's MRT.

1979	1980
SE salinity = $0.70 \text{ kg/m}^2 \cdot (3.5\%)$	$0.41 \text{ kg/m}^2 \cdot (3.8\%)$
SE interval = $0.46 \text{ kg/m}^2 \cdot (2.3\%)$	$0.45 \text{ kg/m}^2 \cdot (4.1\%)$
100 % yield = 19.8 kg/m^2	10.9 kg/m^2

variance. The regression of total yield as a function of mean soil salinity to a depth of 0.9 m for two years is presented in Figure 1. The linear equations describing the two regressions are:

$$1979: Y = 20.8 - 1.28 EC, \quad r^2 = 0.88$$

$$1980: Y = 10.8 - 0.60 EC, \quad r^2 = 0.70$$

The regression for 1979 does not include the three data points for the 16 day irrigation interval.

The maximum yield level in 1979 was twice that in 1980 due to the smaller

FIGURE 1: The regression of absolute yield of eggplant as a function of the electrical conductivity of the soil saturation extract (EC_e) mean 0 - 0.9 m depth of eggplant during two seasons, 1979 - 1980.

row spacing (1 m) used in the first year than in the second (2 m). The rate of change of yield with salinity (the regression coefficient) was also about twice as large in 1979 than in 1980. Consequently, the relation of relative yield to the increase in soil salinity was similar for both years, as can also be seen in Table 1. The equations describing the two lines, in the form suggested by Maas and Hoffman, 1977 were:

$$1979: Y/Y_m = 100 - 6.49 (EC_e - 0.76)$$

$$1980: Y/Y_m = 100 - 6.11 (EC_e - 1.15)$$

For the three points of the 16 day interval in 1979 the equation was:

$$1979: Y/Y_{m_{16}} = 100 - 7.34 (EC_e - 1.72)$$

A laboratory mishap in 1980 resulted in the loss of some of the soil samples collected for EC_e determination. Therefore, yield was plotted for all five interval treatments against the mean EC_e to a depth of 0.9 m of the salvaged samples for each EC_i treatment. The lack of significant effect of interval, the lack of interaction and the subsequent good agreement between the results of the two years justify this approach.

Analyzing all the data together yielded an equation which describes the tolerance of eggplant to salinity:

$$Y/Y_m = 100 - 6.40 (EC_e - 1.1)$$

Both the absolute and relative yield of sweet corn ears and stover fresh weight in relation to the mean electrical conductivity of the soil saturation extract (EC_e) to a depth of 0.9 m for the last two sampling dates (last 40 days of the experiment) are presented in Figure 2. This period represents the maximum vegetative growth and ear formation (Figure 3). The analysis of variance of absolute yield showed highly significant effects of both salinity and irrigation interval, but no interaction with yield decreasing as soil

FIGURE 2: The regression of absolute (Y) and relative (Y/Y_m) yield of corn ears and stover dry matter as a function of soil saturation extract EC_e [mean of two dates of sampling, 20.6 and 26.7 (final) (0 - 0.9 m depth)] for four irrigation intervals.

salinity and irrigation interval increased beyond a threshold level.

As with eggplant, the analysis of variance was performed assuming the salinity to be a constant for all intervals (Table 2). In effect, soil salinity was strongly dependent on interval (see Figure 2), therefore a linear regression of relative yield and a nonlinear regression of absolute yield were done using the actual mean soil salinity values.

Table 2: Relative sweet corn ear and stover dry matter yield as a function of irrigation interval and irrigation water salinity (EC_i)

EC_i dS/m	Irrigation interval, days									
	3	7	14	21	Mean	3	7	14	21	Mean
	ear, %					stover, %				
1.7	100	90	85	75	88	100	100	95	89	96
4.0	98	94	84	77	87	88	88	87	84	87
5.4	86	87	84	69	82	83	79	80	81	81
7.9	70	81	74	62	72	72	72	71	69	71
10.4	66	67	66	56	64	60	67	68	61	64
Mean	84	84	79	67		81	81	80	77	
SE (salinity), %	1.5***					2.4***				
SE (irrigation), %	1.7***					2.6 ns				
100% yield, kg/m ²	2.62					0.75				

ns, *** = statistically not significant and significant at P = 0.001.

For the nonlinear regression, where applicable, we used the NLIN program of Helwiq and Council (1979).

The regression of absolute ear yield as a function of mean $\overline{EC}_e$ shows a linear relationship for the small and large irrigation interval throughout the $\overline{EC}_e$ range studied and threshold values of about 4.6 dS/m for the middle irrigation intervals (Table 3). It is not clear why there is a yield reduction when good irrigation water is used at 7 day irrigation intervals, compared with 4.5 dS/m water. The other data points show no difference in response to salinity

between the 3½ and 7 day irrigation interval treatments. The linear regressions of stover dry weight yield for the two intervals yielded almost identical lines.

Table 3: Parameters for regression equations of ear and stover yield as a function of mean soil salinity to 0.90 m soil depth for four irrigation interval treatments

Irrigation interval days	Intercept kg/m ²	Slope kg/m ² per dS/m	Threshold dS/m	r ²
Ear Yield				
3½	3.38	- 0.219	n	0.95
7	3.90	- 0.301	4.9	0.82
(3½ + 7) [†] adj	3.45	- 0.229	n	0.92
14	3.15	- 0.209	4.4	1.00
21	2.37	- 0.143	n	0.99
relative (all)*	1.22	- 0.068	n	0.80
relative adj	1.24	- 0.075	n	0.87
Stover yield, dry wt.				
3½	0.94	- 0.063	n	0.98
7	0.95	- 0.066	n	0.99
14	0.84	- 0.051	n	0.87
21	0.84	0.060	n	0.99
relative*	1.23	0.079	n	0.93

n = no threshold within the given salinity range.

† = combined analysis excluding low salinity treatment.

* = relative yield with maximum yield of each irrigation interval treatment taken as 1.0.

adj = low salinity - 7 day interval treatment excluded.

Assuming the yield of the low EC_i water at the 7-day interval to be anomolous, the regression for the two treatments combined, excluding this value, yielded a linear equation which was very similar to the 3½ day interval regression. The slope and intercept values of the equations decreased as the irrigation interval increased (Table 3) resulting in a common relative curve for all intervals (Figure 2), described by the equation

$$Y/Y_m = 1.24 - 0.075 EC_e \quad r^2 = 0.87$$

This regression was computed with the maximum yield (Y_m) for the $3\frac{1}{2}$ day interval treatment used to compute the relative yield of the 7-day treatment as well. The resulting regression is similar to the regression of stover dry matter yield

$$Y/Y_m = 1.23 - 0.079 EC_e \quad r^2 = 0.93$$

A threshold value is not indicated within the range of salinities employed in either of the above two relative yield equations. Indeed, Maas and Hoffman (1977) report the following tolerance to salinity equation for sweet corn ear yield, with a threshold value below the lowest $\overline{EC}_e$ of this experiment:

$$Y/Y_m = 1.00 - 0.12 (EC_e - 1.8)$$

It might be expected, therefore, that with lower $\overline{EC}_e$ then the 3 dS/m values found for the control treatment of our experiment, ear yield would have been higher. Indeed, in an adjacent experiment to ours, of irrigation X N fertilizer interaction, using drip irrigation (Sagiv, private communication), the maximum ear yield obtained was 3.3 kg/m², similar to the computed value of 3.1 kg/m² at 1.8 dS/m (the threshold value of Maas and Hoffman, 1977) using our regression equation.

Treatment effects on the rate of vegetative development was noticeable shortly after treatment initiation (Figure 3). The effect of salinity on rate of growth was stronger than the effect of irrigation interval. While the rate of growth declined from 6.4 to 4.0 cm/day as EC_i increased from 1.7 to 10.4 dS/m at the $3\frac{1}{2}$ day interval, the growth declined to 4.7 cm/day as the interval increased to 21 days at the $EC_i = 1.8$ dS/m. These differences corresponded to the effect of the experimental variables on ear and stover yield (Table 2). Despite the differences in plant height, the number of

FIGURE 3: Sweet corn plant growth as a function of time for two levels of irrigation water salinity (EC_i) and four irrigation intervals. Arrows on line indicate time of irrigation.

leaves per plant were about the same (12) in all treatments, and leaf area index was about 5.

It is interesting to note in Figure 3 the increased growth rate after irrigation water was applied to the 14-day interval treatment irrigated with non-saline water. The suppressive effect of salinity on rate of growth of the high salinity treatments obliterated this phenomenon.

Thus, despite the highly significant effect of irrigation interval on yield, the yield response to salinity was independent of interval.

The results obtained with tall fescue in the rhizotron experiment at Riverside support these conclusions (Table 4). The yield of grass irrigated with 4.0 dS/m water, which at low leaching caused a yield reduction of up to 30% (see Table 21), did not benefit from increasing the frequency from 2/3 depletion of available water to daily, despite the much larger fluctuations in soil matric potential in the large, than in the small interval treatment. (Figure 4)

Table 4: The relationship of relative yield (Y/Y_m) and mean soil saturation extract salinity to 1.2 m depth (EC_e) of tall fescue plots to irrigation interval at three levels of irrigation water salinity (EC_i), $Y_m = 1.84 \text{ kg/m}^2$. The mean volumetric soil water content (θ_v) for the three intervals is also reported

EC_i	EC_e dS/m Available Water Depletion			Y/Y_m			Mean
	daily	1/3	2/3	daily	1/3	2/3	
1.0	4.5	3.2	2.8	1.00	0.99	1.00	1.00
2.5	9.5	7.6	8.6	0.98	0.91	0.90	0.93
4.0	14.8	16.0	14.7	0.89	0.86	0.89	0.88
Mean				0.96	0.92	0.99	
Mean θ_v	0.200	0.189	0.175

FIGURE 4: Soil matrix potential at the 45 cm depth for two leaching fractions $L = 0.09$ and 0.27 , two salinity levels $S = 1$ and 4 dS/m and three irrigation intervals $I =$ daily, $1/3$ and $2/3$ soil water depletion.

The results from three different crops, grown in four different soils at three different locations give convincing evidence that except under special circumstances, the deleterious effect of salinity cannot be modified by reducing the irrigation interval.

Yield quality and yield components

Yield differences of eggplant were due to differences in both fruit number and individual fruit weight. Table 5 reports the mean values for the interval and salinity treatments. Salinity resulted in a reduction of both components in both years. Irrigation interval affected fruit number and weight only in those cases where total yield was affected (see Table 1).

Table 5: Effect of irrigation water salinity (EC_i) and irrigation interval on eggplant fruit number, individual fruit size and percent marketable fruit

EC_i dS/m	Fruit Number m^{-2}		Fruit Weight g		Marketable Fruit %	
	1979	1980	1979	1980	1979 ⁺	1980 ⁺
1.5	50	32	387a	311a	40	80
4.5	52	32	346b	296b	48	82
10.0	48	27	366ba	279c	48	82
Interval						
3	50a	33	380a	301	41c	81
6	51a	28	372ab	290	41c	81
9	53a	30	372ab	301	43bc	81
12	51a	30	350c	292	48ab	82
15	46b	31	355bc	291	54a	82

+ Marketable fruit in 1980 excludes only defective fruit while in 1979 it excludes also fruit of unmarketable size.

Values designated by the same letter are not significantly different at $P = 0.05$.

The percent of marketable fruit in 1979 increased with increasing salinity and interval to the extent that the quantity of marketable fruit

was not affected by either stress factor. This was true when commercial standards were the basis for grading. In 1980, when only defective fruit were excluded, the differences in quality were insignificantly small.

Contrary to the case of eggplant, the quality of sweet corn was very adversely affected by treatments. Irrigation water salinity of 10.2 dS/m caused the marketable yield (grade A) to be reduced to 24% of the total (Table 6). By comparison, the best treatment (low salinity, 3-day interval) had 84% of grade A ears. The irrigation interval treatments had a less

Table 6: Sweet corn quality characteristics in relation to irrigation water salinity (EC_i) and irrigation interval

EC_i dS/m	Ear No/m ²	Marketable %	Ears ⁺ No/m ²	Cob ⁺ Weight g/unit	Cob ⁺ Length cm	Cob,Net ⁺ Length cm	Kernel ⁺ Height mm
1.8	7.3	70	4.6	263	20.0	17.5	11.5
4.0	7.4	65	4.3	251	19.6	16.6	10.9
5.6	7.1	62	3.9	251	19.6	16.5	11.2
7.9	7.0	40	2.4	227	18.8	15.5	11.0
10.4	7.0	24	1.5	215	18.8	15.3	10.6
SE	0.15ns	3.8***	0.24**	8.0**	0.30**	0.52**	0.34*
Irrigation Interval Days							
3½	7.3	42	3.6	253	19.2	16.6	11.6
7	7.5	56	3.7	247	19.8	16.5	10.6
14	7.2	56	3.6	234	19.0	15.7	11.2
21	6.6	42	2.4	232	19.2	16.5	10.7
SE	0.1**	3.4*	0.21*	7.1***	0.27*	0.47ns	0.30*

+ Marketable ears or cobs (Grade A)

drastic effect on the fraction of marketable yield than the salinity treatments. The total number of ears, on the other hand, was reduced as irrigation interval increased but was not affected by salinity. Cob length and the length of kernel rows on the cob (net length) were reduced by both salinity and irrigation interval, as was kernel height. There was no interaction in the effect of

salinity and irrigation interval on most yield characteristics except the yield of grade A cobs (both weight and number) (Table 7). Increase in EC_i caused a much larger decline in the yield of grade A ears under small than under large irrigation intervals. Likewise, the effect of interval was much stronger where it was increased from $3\frac{1}{2}$ to 21 days when non-saline irrigation water was used than with more saline water.

Table 7: The yield of grade A ears as affected by irrigation water salinity (EC_i) and irrigation interval. Values in parenthesis are relative yield.

EC_i dS/m	Irrigation interval, days			
	$3\frac{1}{2}$	7	14	21
	kg/m ²			
1.7	2.20 (100)	1.79 (100)	1.33 (98)	1.23 (100)
4.0	2.08 (94)	1.58 (88)	1.36 (100)	0.98 (80)
5.6	1.59 (72)	1.58 (88)	1.23 (90)	1.01 (82)
7.9	0.51 (23)	0.91 (51)	1.27 (93)	0.442 (34)
10.4	0.20 (9)	0.57 (32)	0.66 (49)	0.24 (20)

Yield reduction was affected mainly by a reduction in the weight of individual ears. There were 7.8 plants/m² on the average, and each plant bore one ear, as seen in Table 6. The number of ears of marketable size was greatly reduced as the salinity increased and irrigation interval decreased.

There were no significant differences among treatments in the quality characteristics of grade B cobs. The mean values for the whole experiment were: cob weight - 180 g/cob (167 g/cob for the most saline treatment), cob length - 17.3 cm, cob net length - 13.1 cm and kernel height - 9.8 mm. The number of rows per cob were not affected by treatment and were 17.5 and 16.1 for grade A and B respectively.

Crop water and solute potentials, stomatal conductance and ion uptake

The measurements taken in the field of leaf water potential (ψ_w), leaf solute potential (ψ_s) and leaf diffusive conductance of eggplant, generally support the conclusions reached from the crop production data. The reduction in ψ_w due to salinity increase in the high frequency irrigation (0.23 MPa) as well as the reduction due to increased interval in the low salinity treatment (0.24 MPa) were larger than the reductions at the low frequency irrigation (0.06 MPa) and the high salinity (0.17 MPa), respectively. These differences correspond to the differences in yield (Table 1).

Table 8: Pre-irrigation leaf water potential (ψ_w) leaf mass flow permeability (p) leaf diffusive conductance and leaf solute potential (ψ_s) at two levels of irrigation water salinity (EC_i) and two irrigation intervals for eggplant and corn

Irrigation Interval Days	Eggplant EC_i , dS/m					
	1.5	10.0	1.5	10.0	1.5	10.0
	ψ_w , MPa		ψ_s , MPa		k, cm/sec	
2	-0.88±0.06	-1.11±0.05	-1.22	-1.35	0.33±0.02	0.29±0.02
16	-1.12±0.04	-1.28±0.05	-1.34	-1.38	0.33±0.03	0.30±0.02
Irrigation Interval Days	Corn EC_i , dS/m					
	1.5	10.5	1.5	10.5	1.5	10.5
	ψ_w , MPa				p	
3	-1.60±0.19	-1.90±0.25			2.7	1.3
21	-1.89±0.15	-2.15±0.23			1.7	0.5

The mean solute potential (ψ_s) of the sap taken after the last irrigation of the 16-day interval dropped with increasing salinity and irrigation interval (Table 8). Again, the direction of the differences corresponded to differences in yield.

It should be kept in mind that all values of potential are given for a

static situation - a point in time, and not as mean over time.

Stomatal diffusion conductance (k) was not affected by treatments. At the applied levels of salinity and water stress, the stomates remained open ($k = 0.3$ cm/sec).

In the case of corn leaf water potential decreased to the same extent ($\Delta\psi_w = 0.29$ MPa) as either salinity or irrigation interval increased each to the highest values. When both variables increased (high salinity - large interval treatment), there was a further 0.26 MPa reduction in ψ_w . The changes in leaf permeability were in the same direction (Table 8). These differences correspond very closely to differences in yield as reported in Table 2.

Figure 5 shows the change in corn leaf water potential ψ_w and leaf permeability during the day. Early in the morning the ψ_w was high in all treatments but was -0.2 ± 0.005 MPa for the small interval low salinity (control) treatment compared with -0.5 ± 0.01 MPa for the large interval high salinity treatment. ψ_w decreased gradually to the maximum level at noon and remained at about that level until at least 4:00 PM except for the control treatment where it increased to about -0.1 MPa.

Leaf permeability, on the other hand, was low throughout the day in the dry treatment with salinity having only a small effect, but followed the changes in ψ_w in the wet treatment where high salinity caused a substantial reduction (see Table 8).

Irrigation interval had no effect on salt concentration in eggplant. The effect of increasing salinity on the concentration is demonstrated in Table 9, showing an increase in Cl^- in the shoot and fruit, an increase of Ca^{++} in the shoot corresponding to the increased concentration in the irrigation water, but no, or only small, effect on the concentration of the nutrient ions (N, P, K).

The large differences in Na^+ concentration in the irrigation water was

FIGURE 5: Diurnal changes in corn leaf water potential (ψ_w) and mass flow permeability p , for two irrigation intervals (I) and water salinity (EC_i) levels. Bars indicate standard error of measurements.

not reflected in corresponding concentration differences in the plant. Evidently, eggplant excludes the uptake of Na^+ , or at least its translocation from the root to the shoot. It also appears that the high Na^+ concentration had no effect on reducing K^+ concentration as the concentration of Cl^- had no effect on the concentration of N.

Table 9: Ion concentration in the stover and fruit of eggplant (1979) (% on dry weight basis), as influenced by salinity of the irrigation water (EC_i)

EC_i , dS/m	Cl	Ca	Na	K	N	P
			%			
			Stover			
1.5	1.97	2.56	0.11	2.96	5.26	0.51
4.5	2.69	2.76	0.17	2.98	5.18	0.50
10.0	3.15	3.20	0.08	3.40	5.23	0.53
			Fruit			
1.5	0.69	0.15	0.12	3.10	2.65	0.46
4.5	0.86	0.17	0.13	3.07	2.72	0.45
10.0	0.99	0.14	0.13	3.46	2.70	0.45

Ion concentration in the leaves and stems of corn was not influenced by changes in irrigation interval. Irrigation water salinity, however, had a strong effect on the accumulation of Cl, Na and K (Table 10). Chloride and sodium concentration in the leaves tripled as chloride concentration in the irrigation water changed more than ten-fold and Na increased seven-fold. The concentration in the stem was not substantially different from the leaves except at the highest salinity level. Potassium concentration, though not a variable in the experiment, increased as salinity increased, showing no antagonism between Na and K uptake. The preference of corn for K over Na uptake was strong and the concentration ratio (K/Na) at low total salt

concentration was about 50, going down to about 20 at high total salt concentration.

Calcium and magnesium concentration in both leaves and stems was not affected by treatments. The concentration in the leaves of these ions was three times higher than in the stems.

Table 10: Ion concentration in the leaves and stem of corn as influenced by irrigation water salinity

EC _i dS/m	Cl	Na	K	Ca	Mg
g/kg dry matter					
Leaves					
1.7	11.2	0.43	19.4	7.8	5.2
4.0	19.5	0.45	18.7	10.2	5.4
5.6	22.6	0.54	18.3	9.8	5.6
7.9	31.6	0.82	21.6	11.5	6.1
10.4	37.4	1.14	26.4	11.8	5.5
Stems					
1.7	12.7	0.24	17.7	2.6	1.9
4.0	18.3	0.36	19.9	2.7	1.8
5.6	22.5	0.45	24.1	3.1	1.9
7.9	27.3	0.94	27.6	3.3	2.0
10.4	27.9	1.62	28.0	3.7	2.1

Soil salinity matric potential and water balance

Tables 11 and 12 present final soil salinity values for all treatments in 1979 and the rate of salt accumulation as determined with sensors in 1980 for the high salinity small and large interval treatments. The soil salinity values for the corn experiments are given in Table 13 and those for tall fescue have been reported in Table 4. It is clear from the data reported that reducing irrigation interval resulted in most cases in increased mean soil salinity in the main root zone. This undoubtedly was one of the main reasons for the lack of beneficial effect of reduced intervals.

Table 11: Final soil solution electrical conductivity (EC_s)¹, mean of the 0 - 0.9 depth, as a function of irrigation interval and water salinity (EC_i), eggplant 1979. Samples taken 0.2 m from tricklers.

EC_i dS/m	Irrigation interval, days					Mean
	2	5	8	12	16	
	dS/m					
1.5	3.6	4.2	2.6	--	4.0	3.6
4.5	5.8 (5.3) ²	7.8	7.0	7.6	6.6	6.8
10.0	12.0 (11.5) ²	9.2	9.4	7.2	8.0	9.2

1. $EC_s = 2.0 EC_e$

2. Measured in situ with salinity sensors at 0.6 m depth.

Table 12: Changes in soil solution concentration (EC_s) with time at 0.6 m and 0.9 m depth, at three distances from the drip line for irrigation with 10 dS/m water at 3-day intervals and 16-day intervals. Eggplant, 1980 .

Treatment	Distance m	Date							Mean
		31.7	8.8	20.8	26.8	16.9	21.9	30.9	
		dS/m							
		0.6 m depth							
10 dS/m	0	12.4	12.0	12.2	11.1	10.8	10.6	10.4	10.7
3-day	0.2	6.8	7.5	9.6	10.2	10.3	10.0	9.6	10.0
	0.4	3.8	4.4	9.0	10.8	11.2	10.2	10.0	10.5
10 dS/m	0	10.7	7.8	7.8	7.5	-	11.2	10.1	9.5
16-day	0.2	5.6	5.4	5.1	5.1	7.5	7.9	6.5	6.7
	0.4	3.4	5.4	6.0	5.7	8.6	7.9	7.2	7.3
		0.9 m depth							
10 dS/m	0	9.7	9.7	10.7	11.2	11.6	11.5	11.3	
3-day	0.2	4.6	5.0	7.8	8.9	9.4	9.1	9.4	
	0.4	1.2	1.1	3.6	5.9	9.2	9.2	9.5	
10 dS/m	0	5.9	6.5	7.4	6.5	9.9	9.2	8.7	
16-day	0.2	4.5	4.3	4.2	3.7	7.4	7.8	7.4	
	0.4	2.0	1.0	2.0	1.4	6.0	5.7	5.9	

Table 13: Electrical conductivity of the soil saturation extract (EC_e) for corn, mean 0 - 0.9 m for two sampling dates: 20.6.82 and 26.7.82

Irrigation Interval Days	EC_i , dS/m				
	1.7	4.0	5.3	7.9	10.2
3	3.3	4.3	4.8	6.6	7.8
7	3.0	4.6	5.2	6.3	6.8
14	2.9	4.5	4.0	5.8	6.8
21	2.7	3.6	4.0	5.3	6.3

The distribution of salt at the end of the experiment as a function of depth and distance from the drip lateral, presented in Table 14, illustrates the reasonably uniform distribution of salt as a function of the distance from the drip lateral, as long as samples were obtained within the wetting zone. There was some reduction in soil salinity with depth, but except for the surface layer where the values of EC_e were very high, reduction with depth was mild.

The results in Table 12, illustrating a reasonably rapid and uniform salinization of the soil in the eggplant experiments in 1980 and the uniformity demonstrated in Table 14 justify accepting the yield response data as equivalent to eggplant salinity tolerance function obtained under the accepted technique of artificially salinized plots managed to obtained uniform salt distribution.

The soil salinity and pre-irrigation soil water content data (Table 15) together with the moisture characteristic curve, were used to compute the change in total water potential (ψ_w) with time for the large interval treatments of 1979 eggplant experiment. The computation, illustrated in Figure 6, showed that with low salinity water, the pre-irrigation total soil water potential was lower than that with 10 dS/m water. The integrated ψ_w for the two treatments was approximately the same - 0.5 MPa and similar also to the

Table 14: Distribution of saturation extract electrical conductivity (EC_e) at the end of the 1979 and 1980 eggplant seasons as a function of depth and distance from the trickle lateral. Values are given for high salinity short and long interval treatments.

Depth cm	Irrigation interval								Mean	
	2				16					
	Distance from trickle lateral, cm, 1979									
	5	20	35	Mean	5	20	35			
dS/m										
0 - 30	5.2	7.5	6.0	6.4	4.5	7.0	6.0	5.8		
30 - 60	3.6	6.4	4.2	5.0	2.8	3.6	3.3	3.2		
60 - 90	4.2	4.1	3.8	4.1	3.1	2.8	2.9	2.9		
Distance from trickle lateral, cm, 1980										
	0	20	30	40	Mean	0	20	30	40	Mean
dS/m										
0 - 10	9.2	21.4	20.4	21.2	18.0	-	-	10.8	29.7	
10 - 20	8.8	6.7	7.5	6.4	7.4	6.2	6.0	4.1	4.3	5.1
20 - 30	6.2	6.0	5.9	5.7	6.0	4.5	4.2	4.3	4.0	4.2
30 - 40	6.1	5.9	5.3	5.3	5.6					
40 - 50	5.4	4.9	5.0	5.1	5.1					

high salinity high frequency treatments. These differences corresponded to yield differences (Table 1).

Table 15: Preirrigation gravimetric water content distribution in the soil profile (distance of 0.20 m from the trickler) as a function of irrigation water salinity (EC_i) and irrigation interval. Eggplant, 1979.

Depth		Irrigation interval, days					
		12 ¹			16 ²		
m		EC _i , dS/m					
		1.5	4.5	10.0	1.5	4.5	10.0
0	- 0.3	5.6	5.5	7.5	5.0	8.2	9.6
0.3	- 0.6	11.0	9.1	12.7	6.9	9.8	10.0
0.6	- 0.9	14.9	16.1	16.2	14.8	11.0	16.2
0.9	- 1.2	17.1	18.2	18.2	17.6	17.7	17.4
Mean							
0	- 0.9	10.5	10.2	12.1	8.9	9.7	11.9

1. Irrigation given on August 18.

2. Irrigation given on September 13.

FIGURE 6: Calculated change of total soil water potential ψ_w with time between irrigations for eggplant during 1979, for two irrigation intervals (2 and 16 day) and two irrigation water salinity levels (1.5 and 10.0 dS/m).

Similar computation carried out on the 1980 data (Table 12), showed that the pre-irrigation osmotic potential (ψ_s) was - 0.38 MPa (- 0.36 MPa at field capacity), and - 0.35 MPa (- 0.27 MPa at field capacity), for the high salinity 3-day and 16-day interval, respectively. Adding the value of the matric potential (ψ_m) for these two treatments (Table 16), yielded a similar pre-irrigation total soil water potential of - 0.39 MPa for both treatments, as was the yield of these two treatments.

Table 16: Pre-irrigation content (θ_v), matric potential (ψ_m) and relative water uptake (U_p) as a function of soil depth for irrigation with good water and 10 dS/m water at 15 day interval and soil matric potential for 3-day interval with good and saline water.

EC _i dS/m	Irrigation interval, days							
	16						3	
	1.5	10.5		1.5	10.5			
Depth cm	θ_v %	U_p %	ψ_m kPa	θ_v %	U_p %	ψ_m kPa	ψ_m kPa	ψ_m kPa
0 - 30	21.5	56		26.0	50			
30 - 60	25.2	33	-65	26.8	34	-38	-13	- 8
60 - 90	31.1	6	-50	30.9	6	-30	-15	- 5
90 - 120	32.0			31.8				

ET was reduced from 4.5 to 3.4 mm/day as salinity increased to 10 dS/m. Thus, salinity affected both yield and total ET of eggplant (Table 17) in such a way that the water use of efficiency was the same for both the 1.5 and 10.5 dS/m water (0.19 kg/mm).

Both soil salinity and irrigation interval had an influence on the water uptake distribution of corn roots (Table 18). EC_i increase from 1.7 to 10.4 dS/m at the 7-day irrigation interval resulted in a reduction in water uptake

Table 17: Total mean daily evapotranspiration (ET), water use efficiency (WUE), and leaching fraction (LF) for the treatments, irrigated at 16-day intervals using 1.5 and 10.5 dS/m water for the period July 22 - September 29, 1980.

Treatments interval EC _i , dS/m	1.5	16-day 10.5
Total ET, mm	299	224
Mean ET mm/day	4.5	3.4
WUE kg/mm	0.19	0.19
LF	0.30	0.47

from the top 30 cm from 60 to 50% with a corresponding increase in deeper layers. Similarly, water uptake from the top 30 cm soil was reduced to 47% when irrigation interval increased from 7 to 21 days with non-saline water. The corresponding reductions in water uptake of the top layer was smaller at the high level of each of the two experimental variables.

Table 18: Water uptake distribution with depth of sweet corn as influenced by irrigation interval (I) and salt concentration for EC_i of 1.5 and 10.5 dS/m

Depth m	I, days EC _i , dS/m	7			14			21		
		1.7	5.6	10.4	1.7	5.6	10.4	1.7	5.6	10.4
0 - 0.3		60	55	50	52	50	49	47	42	52
0.3 - 0.6		23	25	28	35	33	29	32	29	28
0.6 - 0.9		11	13	16	11	16	18	13	18	15
0.9 - 1.2		6	7	6	2	2	4	6	7	3
1.2 - 1.5		Not Measured						2	3	1

The soil salinity distribution with depth for corn is given in Figure 7 for all treatments for three sampling dates. Since irrigation water was applied on the basis of soil water deficit, no leaching was provided. Consequently, salt accumulation in the soil continued up to the end of the experiment. Salt

FIGURE 7: Distribution with soil depth of saturated extract EC_e on three sampling dates for corn irrigated at five levels of irrigation water salinity (EC_i) and four irrigation intervals (I)

distribution was remarkably uniform (except for the top 0.15 cm of soil) to a depth of 0.90 m, the depth to which water deficit was replenished. Below this depth, salinity dropped abruptly to the original value, showing that very little seepage occurred below the root zone. The mean soil salinity to 0.90 m depth (Table 13) invariably increased with decreasing interval as would be expected.

Irrigation water was applied on the basis of the measured pre-irrigation soil water deficit to field capacity to 0.9 m soil depth. Consequently, the amount of water applied is related to ET. The value for ET given in Table 19 were determined from the difference between the post- and pre-irrigation soil water content and they also include the water uptake after the last irrigation. For these reasons there are some differences between the values of ET and the values of water application. The mean daily ET for the five salinity treatments was 6.5 mm/day with very small differences between the 1.7 and the 10.2 dS/m treatments (6.7 and 6.2 mm/day, respectively). Thus, salinity seemed to have had only a small effect on ET. Only in the 21-day irrigation interval was there a systematic reduction in ET from 6.4 to 4.8 mm/day due to salinity increase.

The increase in irrigation interval, on the other hand, resulted in a reduction in mean ET from 7.1 to 5.8 to 4.8 mm/day as irrigation interval increased from 7 to 14 to 21 days. The respective quantities of irrigation water applied were 335,287 and 244 mm (380 mm for the 3½-day interval). This reduction in quantity of water applied seems to be the main cause for the differences in mean soil salinity as reported in Figure 7, rather than the differences in leaching of the top soil between the small and large irrigation intervals. A crude salt balance computation shows that the amount of salt found in the soil at the end of the season was approximately equal to the amount added with the irrigation water plus the amount originally present in the soil.

Table 19: Quantities of water applied and consumed by sweet corn during the season from treatment initiation.

Treatment EC _i dS/m	I days	Water* applied mm	ET Total* mm	ET daily mm/day	ET/E _p
1.5	3½	388	-	8.3 ⁺	1.00
1.7	7	348	355	7.4	0.89
1.6	14	284	279	5.8	0.70
1.9	21	248	262	5.3	0.64
3.8	3½	369	-	7.9 ⁺	0.95
3.8	7	365	325	6.8	0.82
3.9	14	291	260	6.4	0.77
4.3	21	240	256	5.2	0.63
5.1	3½	380	-	8.1 ⁺	0.98
5.5	7	345	356	7.4	0.89
4.9	14	289	219	6.0 ⁺	0.72
5.7	21	254	243	5.0	0.60
7.5	3½	380	-	8.1 ⁺	0.98
8.0	7	301	333	6.9	0.83
7.8	14	288	254	5.3	0.64
8.4	21	254	230	4.7	0.57
9.5	3½	380	-	8.1 ⁺	0.98
10.1	7	318	346	7.2	0.87
10.1	14	266	269	5.6	0.67
11.1	21	224	198	4.0	0.48

* From day 37 to harvest. Approximately 140 mm of normal irrigation water was applied uniformly to all treatments between seeding and day 37.

+ Computed from values of water application.

Figure 8 demonstrates the change in soil salinity in the rhizotron plots at the 0.45 m depth for the monthly and biweekly irrigation intervals. The leaching effect of the single large water application is very apparent and substantiates the results obtained in the field plots in Israel.

Root distribution

The final root distribution of corn as presented in Table 20 shows that salinity stimulated root penetration to lower depth at both the 7-day and the 21-day irrigation intervals, while interval had no effect on root distribution.

FIGURE 8: Time course of soil salinity at 0.45 m depth as a function of irrigation interval (1/3 and 2/3 soil water storage depletion) and leaching fraction (0.09 and 0.27) for irrigation water EC_i of 4 dS/m

These results are surprising, since reducing irrigation interval would be expected to increase root penetration while increased salinity would be expected to decrease root penetration. Since only one location in each treatment was sampled, the results may not be representative of the average conditions in the field.

The root distribution results of tall fescue (Figure 9), showed that reducing the irrigation interval from about once monthly to daily resulted in decreased root concentration throughout the soil profile. Increasing EC_i resulted in increasing root concentration shallow in the soil profile with a corresponding reduction deep in the profile. The same was true when leaching was increased from 0.09 to 0.27.

Table 20: Sweet corn final mean root length (in cm per cm^3 soil volume) at two irrigation intervals (I) and two levels of irrigation water salinity (EC_i). Each value is a mean of 5 samples perpendicular to plant rows.

Depth m	I, days	7		21	
	EC_i , dS/m	1.7	10.4	1.7	10.4
		cm/cm ³			
0 - 0.2		2.5	1.8	1.4	4.0
0.2 - 0.4		1.4	1.8	1.0	2.1
0.4 - 0.6		1.0	0.6	1.4	0.8
0.6 - 0.8		0.3	0.6	1.1	0.9
0.8 - 1.0		0.2	0.5	0.6	1.0
1.0 - 1.2		0.1	0.4	0	0.5

(2) Leaching Fraction

Leaching is the only means by which soil salinity can be maintained at an acceptable level when water of high salinity is used for irrigation. As the salinity of the irrigation water increases and the tolerance of the crop

FIGURE 9: Influence of irrigation interval (I = daily and 2/3 soil water storage depletion), irrigation water salinity (S) and leaching fraction (L) on the density of fescue roots.

to salinity decreases, leaching must be increased to maintain high crop yields. The simplest general expression describing this relationship is $LR = C_i / C_c$ where LR is the leaching requirements C_i is the salt concentration of the irrigation water and C_c is a measure of the salt tolerance of the crop.

Despite the fact that the need for leaching has been recognized for a long time, the leaching requirement (LR) concept is still in controversy. The main ambiguity is in the quantitative evaluation of C_c - the salt tolerance of the crop. Until about ten years ago, the electrical conductivity of the saturation extract, EC_e , at which yield was reduced to 50% of the maximum yield when soil salinity was uniformly distributed with depth (Bernstein, 1964) was accepted as the appropriate value for C_c . More recently, it was shown (Bernstein and Francois, 1973) that salts can accumulate in the lower part of the root zone to values at which alfalfa could no longer extract water, with only a small adverse effect on yield. This finding lead to the suggestion that C_c should be in the EC of the soil water at which no yield is obtained. (extrapolation of the salt tolerance data of Maas and Hoffman (1977) to zero yield). According to this interpretation, the resulting LR values are substantially lower than the values obtained using the 50% yield decrement approach.

Hoffman and van Genuchten (1982) compared a few of the approaches to the calculation of LR and proposed one of their own based on steady state mass balance and the continuity equations, and an exponential water uptake distribution model, using the salt tolerance threshold value for the crop.

The leaching requirements concept is at the foundation of saline water irrigation. The present lack of agreement on the approach for predicting its value makes it imperative that more information will be obtained on the LR for many agricultural crops. Hoffman et al (1970, 1979) have provided information for some crops. The purpose of the present study was to determine whether

irrigation frequency has any effect on the LR for tall fescue and further elucidate on the interrelationship of LR and crop yield.

Yield, soil water content and soil salinity

Table 21 presents the mean annual yield and EC_e over the three year experimental period and all irrigation intervals as a function of the three L and EC_i levels (the differences between the three intervals were not significant, see Table 4). The mean integrated θ_v to a depth of 1.2 m are also reported. Clearly, yield was decreased more by decreasing L from 0.27 to 0.09 than by increasing EC_i from 1.0 to 4.0 dS/m. The strong effect of high leaching on yield was partly due to the decrease in soil salinity (Table 21), but, the effect of L on mean θ_v must have had a substantial effect as well.

Figure 10 illustrates the large differences in the time integrated soil water content distribution among the leaching fraction treatments. The average value of θ_v at the bottom of the lysimeter (outlets) corresponding to L's of 0.09, 0.18 and 0.27 were 0.19, 0.23 and 0.27 m^3/m^3 , respectively. The respective values for the top soil were 0.13, 0.15 and 0.17 m^3/m^3 . The maximum θ_v , measured one day after an irrigation was 0.32 m^3/m^3 . Thus, under low leaching, soil water content was continuously well below field capacity, in a range where plants must have experienced water stress. These results are contrary to calculations using a model presented by van Schilfgaarde et al (1974), where even when L was as low as 0.01, soil moisture was higher than field capacity in a Pachappe soil profile.

If we assume the 21% difference in yield (Table 21) between the low and high L at low EC_i to be due to water stress alone (salinity levels were below threshold salinity), and the 12% yield reduction of the high L to be due to salinity effect, then the two effects combined would result in a 33% yield reduction, similar to the 30% reduction obtained for the low L high

FIGURE 10: Time integrated volumetric soil water content distribution for three leaching fractions (L) and three irrigation intervals (daily, 1/3 and 2/3 soil water depletion).

Table 21: The relationship of Y/Y_m and mean soil EC_e to a depth of 1.2 m for tall fescue plots to the leaching fraction (L) at three levels of irrigation water salinity (EC_i). $Y_m = 2.03 \text{ kg/m}^2$. The mean volumetric soil water contents (θ_v) for the three L treatments for all irrigation frequencies are also reported

EC_i dS/m	EC_e , dS/m			Y/Y_m			Mean
	0.09	0.18	0.27	0.09	0.18	0.27	
1.0	4.4	4.0	2.2	0.79	0.93	1.00	0.91
2.5	11.4	7.9	6.3	0.78	0.81	0.97	0.84
4.0	20.9	12.2	11.0	0.70	0.80	0.88	0.79
Mean				0.76	0.85	0.93	
Mean θ_v	0.158	0.185	0.221				

EC_i treatment. In actual fact, the yield reduction for this treatment should have been larger considering the very high integrated soil water salinity obtained (Table 21). The time integrated soil salinity distribution (Figure 11) indicates a steady state situation achieved with respect to the various L, and can be contrasted with the transient state distribution under corn (Figure 7).

The confounding of the L effect on soil salinity with its effect on soil water content makes it difficult to give a clear interpretation of L. One conclusion which emerges from the above results is that it is difficult, under precise experimental conditions to maintain low L without having a sub-critical soil water content.

Normally under field conditions applying more irrigation water of good quality than needed to satisfy crop water requirements will result in leaching without increase in yield. The water production function reaches a plateau when consumptive use requirements is satisfied. It was also shown by model calculations (see above) that even under low leaching, soil water contents should not drop below critical values to crop growth. The sub-critical soil

FIGURE 11: The distribution with soil depth of the time integrated values of the electrical conductivity of soil water as a function of three leaching fractions (L) and three irrigation water salinities (EC_i).

water contents obtained in this experiment may have resulted from the difficulty to respond in water application to the fluctuation in ET due to periodic harvesting, or from unaccounted water losses. These results lead to the conclusion that new experimental techniques are needed to evaluate leaching fraction effects on yield.

Salt tolerance model

The salt tolerance model of Maas and Hoffman (1977) predicts that $Y_r = 100 - 5.3 (\overline{EC}_e - 3.9)$ for tall fescue where $\overline{EC}_e$ is the average electrical conductivity of soil saturation extracts for the crop root zone in units of dS/m. The salt tolerance model is applicable where water is not limiting because L approaches 0.5 in salt tolerance experiments. Thus, this model should bracket the yield versus soil salinity relationship for this experiment because all L treatments were below 0.5 and significant quantities of water were withheld for many treatments. This is demonstrated to be true in Figure 12 where the salt tolerance curve and the relative yield of each treatment are presented as a function of the average electrical conductivity of the soil water ($\overline{EC}_{sw}$). The salt tolerance curve was adjusted assuming $\overline{EC}_{sw} = 2\overline{EC}_e$. The mean of the salt sensor reading through the soil profile, integrated over time, was taken as $\overline{EC}_{sw}$ for each plot because this calculation procedure is used in salt tolerance experiments where soil salinity is relatively uniform with depth. Where water is limiting, as for many of these treatments, this value of $\overline{EC}_{sw}$ may not represent the salinity level to which the crop is responding. Suffice it to say here that if $\overline{EC}_{sw}$ had been calculated based upon water uptake distribution the value for many treatments would be less. If water uptake distribution can be approximated by root density distribution (Figure 8), then $\overline{EC}_{sw}$ would be reduced because of the

FIGURE 12: Relative yield of tall fescue as a function of the average soil salinity for three levels of irrigation water salinity (EC_i) and three leaching fractions (L). The envelope curves depict the salt tolerance of the crop.

large fraction of water uptake shallow in the profile where soil salinity is lowest. If one were to draw curves through the data points based upon L and thus as a function of matric potential, the curves would be similar to those presented by Bresler et al (Figure 75, 1982) for the relative quantity of applied water.

Water balance and water consumptive use

Irrigation (I) and drainage (D), reported as the average depth of water per unit of soil surface area are summarized in Table 22. Annual depth of irrigation ranged from a high of 2630 mm for the control treatment (d , 0.27, 1) to 1280 mm for the treatment (1/3, 0.09, 4). Drainage depths varied in accordance with leaching fraction; averaging 135 mm for 9% leaching, 330 mm for 18% leaching and 620 mm for 27% leaching. The average leaching fractions ($L = D/I$) achieved over the 3-year treatment period were 0.094, 0.176 and 0.263 for the 0.09, 0.18 and 0.27 (L) treatments, respectively.

Crop evapotranspiration (ET), computed as the difference between irrigation and drainage quantities and changes in soil water storage, was influenced by both salinity and leaching fraction. Irrigation interval had a smaller effect. (Table 22). On the average, there was a 21% reduction in ET as leaching fraction was reduced from 0.27 to 0.09, while a salinity increase from 1.0 to 4.0 dS/m resulted in a 17% reduction.

Under minimum leaching with non-saline water, the ratio of ET to pan evaporation (E_p) (annual E_p was 182 cm) was 0.76 for the three frequencies, while for the high leaching the value was 1.02. An accepted ratio for grass under optimal conditions is 0.80, which indicates that the low leaching treatment may have been slightly under-irrigated.

Table 22: Average annual depths of irrigation (I,mm), drainage (D,mm) and evapotranspiration (ET = I-D,mm) for each treatment during the period May, 1978 to May, 1981 rounded to the nearest 5 mm. Relative yield mean for three years of the experiment is also given.

Treatment		Irrigation	Drainage	Evapo-	Relative*
Leaching Fraction	Irrigation Salinity	Depth	Depth	transpiration	Dry Mass Yield
		mm	mm	mm	
DAILY IRRIGATIONS (d)					
0.09	1	1715	120	1595	0.77
	2.5	1565	115	1450	0.83
	4	1370	165	1205	0.82
0.18	1	1950	375	1575	0.91
	4	1815	340	1475	0.81
0.27	1	2630	740	1890	1.00
	2.5	2370	660	1710	0.92
	4	2205	710	1495	0.86
1/3 MOISTURE DEPLETION					
0.09	1	1610	110	1500	0.78
	4	1280	115	1165	0.61
0.18	2.5	1715	335	1380	0.81
	2.5	1910	270	1640	0.77
	2.5	1835	325	1510	0.82
	2.5	2000	290	1710	0.85
0.27	1	2410	665	1745	0.99
	4	2290	645	1645	0.92
2/3 MOISTURE DEPLETION					
0.09	1	1590	165	1425	0.78
	2.5	1370	145	1225	0.73
	4	1410	130	1280	0.75
0.18	1	1970	370	1600	0.94
	4	1755	320	1435	0.78
0.27	1	2515	575	1940	0.96
	2.5	2175	450	1725	0.88
	4	2160	500	1660	0.86

* Differences are significant at $p = 0.0001$.

100% yield = 2.06 kg/m².

(3) The effect of rate of salinity build-up

In most studies of crop salt tolerance, soil salinization began after the crop had been established. Thereafter salinity was increased rapidly in two to three steps to a desired level (see salt tolerance section of this report). Experimentally, such a procedure allows standardization and an unambiguous interpretation of results. In agronomic practice when winter rainfall is significant irrigation water is applied on the basis of crop water requirements, and soil salinization is, therefore, more gradual over the growing season. In order to apply experimental results under field conditions, it is necessary to determine the significance of the initial rate of salinization on final yields.

Yield and yield components

The experiment was conducted in the greenhouse under low evaporation conditions during the winter months using lettuce as a test crop. In order to prevent leaching in the treatments where soil salinization was designed to be slow, the treatments were, in effect, under-irrigated. Thus, the effect of the rate of salinization on yield was such that the slow rate (low water application) resulted in significantly lower yields than the fast rate (Table 23). This was true for other plant characteristics as well (leaf length, leaf number, N and P content). Mean soil salinity, on the other hand (Figure 13) was higher under the fast than the slow salinization. The difference of 1 to 2 dS/m was not large enough to offset the beneficial effect of the high water application.

The effect of soil salinity on yield was small and not statistically significant. The treatments irrigated with water of 1.6 dS/m had a higher yield (by 15%) than the mean of the other treatments. This difference came about because of the large (32%) reduction in yield due to increase in irrigation water salinity from 1.6 to 3.1 dS/m in the slow rate of water

Table 23: Yield and yield component of lettuce as influenced by the daily rate of soil salinization (rapid and slow) and salinity level (last harvest).

Mean EC _i dS/m	Fresh Weight		Leaf Number		Leaf Length		Dry Matter	
	Rapid	Slow	Rapid	Slow	Rapid	Slow	Rapid	Slow
	kg/m ²		cm		cm		%	
1.6	3.37	3.60	36	37	35	35	5.1	5.3
3.1	3.53	2.44	38	32	34	33	5.4	5.9
5.9	3.61	2.54	39	32	34	34	6.1	6.3
7.4	3.11	2.59	35	32	34	33	6.2	6.0
10.4	3.47	2.36	36	32	35	33	6.0	6.3
Mean	3.49	2.70	37	33	34.7	33.6	5.7	6.0
SE rate	0.12**		0.69**		0.25**		N.S.	
SE salt	N.S.		N.S.		N.S.		0.15*	

application and no reduction at all at the high rate of water application (interaction was significant at the 0.05 level of significance, (Table 23)). The reduction in yield was due to both a reduction in the number of leaves and in their size.

Physiological parameters and salt uptake

Leaf water potential, osmotic potential and diffusive conductance were measured at noon on December 13th, ten days after treatment initiation (Table 24). In the more saline treatments there was a distinct reduction of leaf water potential due to the high water application (rapid salinization). This reduction correlated with the increased soil salinity of these treatments (Figure 13). At this stage of plant growth, the effect of the under-irrigation in the slow salinization treatment was not yet noticeable. The reduction in total leaf water potential was not matched by a similar reduction in leaf solute potential, resulting in a reduced turgor potential (Table 24). Leaf stomatal conductance was also reduced slightly as a result of the rapid

FIGURE 13: Changes of soil salinity, EC_e mean 0 - 50 cm, with time in lettuce plots irrigated with three water salinities (5.9, 7.4 and 10.5 dS/m) and two rates of salt build-up, fast (F) and slow (S).

salinization. The increase in EC_e with increase in EC_i also resulted in reduced ψ_w , ψ_s , and diffusive conductance.

Table 24: Leaf water ψ_w , solute ψ_s and turgor ψ_p potentials and leaf diffusive conductance k of lettuce as influenced by irrigation water salinity, and the rate of soil salinization.

EC_i dS/m	Rate of Salinization	ψ_w	ψ_s MPa	ψ_p	k cm/sec
1.6	F	-0.56±0.06	-0.76	0.20	0.20±0.02
1.6	S	-0.55±0.00	-0.77	0.22	0.25±0.02
5.6	F	-0.62±0.06	-0.87	0.25	
6.3	S	-0.63±0.03	-0.84	0.21	
6.8	F	-0.70±0.04	-0.91	0.21	
8.0	S	-0.63±0.03	-0.03	0.26	
10.3	F	-0.77±0.07	-0.90	0.13	0.16±0.03
10.5	S	-0.66±0.06	-0.85	0.19	0.19±0.02

The initial hypothesis that a slow rate of salinization will be beneficial in terms of final crop yield was not confirmed. This was due to the experimental difficulty in maintaining sufficiently high soil moisture content and at the same time keeping leaching to a minimum. The same difficulty was encountered in the leaching fraction experiment in Riverside. Nevertheless, the early measurements of leaf water and osmotic potentials show that the initial increase in soil salinity suppressed the leaf potentials and might have had a detrimental effect on yield, if not for the later water deficit effect.

Support for this hypothesis, though not by design, comes from the fescue experiment conducted in the Riverside rhizotron. The low leaching, high salinity treatment (0.09, 4) had 6-9% better yields during the salination period than the control treatment, while the same treatment showed 34-43% yield reduction during the last year. The slower soil salinization rate of

these treatments was the probable cause for this discrepancy.

Increase in EC_i resulted in increase in Na^+ and Cl^- content in the leaves of lettuce and no change in Ca^{++} content (Table 25). On the other hand, N and P content was reduced with increasing EC_i . Increasing the initial rate of salinization had no effect on final salt concentration, but resulted in a significant increase in N and P content. The better moisture conditions, which resulted in better growth of leaves and probably also roots, was conducive to more efficient nutrient uptake.

Table 25: Mineral concentration in leaves of lettuce at the last harvest as effected by rate of salinization and irrigation water salinity.

Mean EC_i dS/m	Cl		Na		Ca		N		P	
	Rapid	Slow	Rapid	Slow	Rapid	Slow	Rapid	Slow	Rapid	Slow
	meq/kg dry weight									
1.6	847	1037	320	316	453	569	13.8	11.3	1.85	1.41
3.1	1055	950	370	329	430	449	13.1	11.2	1.77	1.42
5.9	990	1222	375	383	595	448	12.2	12.2	1.56	1.36
7.4	1150	1170	396	424	488	588	11.0	11.2	1.26	1.31
10.4	1262	1137	445	455	595	485	11.9	11.5	1.28	1.33
Mean	1064	1103	382	382	521	502	12.4	11.5	1.54	1.37
SE rate	N.S.		N.S.		N.S.		0.22**		0.043**	
SE salt	61.6*		14.9**		N.S.		0.32*		0.068**	

(4) Crop tolerance to salinity studies

The tolerance to salinity of four crops for which insufficient information was available was determined within the framework of this project using standard procedures with one departure - the salinization of the soil profile prior to seeding of turnip, as described in the Material and Method section. The yield results are reported in Table 26. Figure 14 gives the response curve with respect to relative yield. Asparagus was by far the most tolerant and can be

FIGURE 14: Tolerance to salinity of turnip, eggplant, celery, cowpea and asparagus [relative yield (Y/Y_m) in relation to mean electrical conductivity of the soil saturation extract (EC_e)].

considered a very tolerant crop. Turnip turned out to be a sensitive crop, while cowpea and celery are moderately sensitive, with cowpea being somewhat more tolerant on account of its higher threshold value. The 50% yield decrement value of the last two crops was similar (about 9.5 dS/m). Eggplant was quite sensitive to salinity, falling between turnip and celery.

The equations describing the five crops are as follows:

Turnip roots: $Y/Y_m = 1.0 - 0.09 (EC_e - 0.9)$

Eggplant: $Y/Y_m = 1.0 - 0.06 (EC_e - 1.1)$

Celery petiole: $Y/Y_m = 1.0 - 0.06 (EC_e - 1.8)$

Cowpea seed: $Y/Y_m = 1.0 - 0.12 (EC_e - 4.9)$

Asparagus spear: $Y/Y_m = 1.0 - 0.02 (EC_e - 2.8)$

The reduction in top growth of turnip with increased salinity was much lower than root growth. Top growth of cowpea showed greater sensitivity to salinity than seed yield while for asparagus fern development of the last harvest was suppressed to the same extent as spear yield.

Table 26: Growth and yield of turnip, celery, cowpea and asparagus at several soil salinities.

Crop:	Turnip		EC _e dS/m	Celery	EC _e dS/m	Cowpea (1981)		EC _e dS/m	Asparagus (1982)		
Soil Salinity EC _e , dS/m	Fresh root g/m ²	Weight top g/m ²		Plant Weight Trimmed kg/m ²		Dry Weight seed top kg/m ²	Spear weight		Fern weight	Dry weight kg/m ²	
0.9	8.31	6.16	1.8	6.48a	1.1	0.348	0.498	2.9	1.08	1.00	
3.5	6.50	6.39	6.9	4.45b	5.2	0.367	0.317	10.4	0.90	0.77	
5.6	4.41	5.40	11.6	2.73c	6.9	0.292	0.230	17.5	0.79	0.72	
8.3	2.94	4.89	15.2	1.48d	9.5	0.146	0.133	25.2	0.62	0.58	
LSD	1.45	0.84				0.046	0.087				

Turnip - cv Purple-top White Glove; Celery - cv Tall Utah 52-TOR; Cowpea - cv California Blackeye No. 5; Asparagus - cv U.C. 157

Yield quality and yield components

Cowpea

Because mean seed yield was less affected than was plant dry matter, the harvest index of the plants increased with increasing salinity. The change in total yield was due to the reduction in number of pods per plant, while seed weight and number of seeds per pod were affected to a very small degree by salinity (Table 27).

Table 27: Yield components and leaf analysis of cowpea at several soil salinities. 1981 crop season.

EC _e dS/m	Harvest ¹ Index %	Weight per seed g	No. of Pods per plant	No. of Seeds per plant	Na	Cl	Ca	K
					mmol/kg dry weight			
1.1	41.3	0.22	27	6.6	5.8	108	522	736
5.2	53.8	0.23	30	7.2	6.2	216	711	646
6.9	55.8	0.25	23	7.2	6.3	208	744	625
9.5	52.4	0.23	16	6.4	6.7	274	770	544
LDS	8.0	NS	4.4	0.56	NS	72	100	88

1. Harvest index = (seed wt/total shoot wt) x 100.

Celery

Yield reduction was caused by a reduction in petiole size (length, width and thickness), while the number of petioles per plant were not affected by treatments (Table 28).

Increasing salinity above the level of the controls resulted in reducing market quality below the commercially acceptable standards of length, weight and thickness of petiole. Even the control treatment had only 17% of the plants weighing more than the minimum weight of 0.9 kg for most commercially acceptable products. No pith was detected in any of the treatments.

Table 28: Market quality and leaf analysis of celery plants at several soil salinities

EC _e dS/m	Petiole Length cm	Mature Petioles			Na	Cl mmol/kg	Mg dry weight	K	P
		No/plant	Width cm	Thickness cm					
1.8	29.4 a*	8.2a	2.13a	0.64a	592	484	160	926	79.7
6.9	25.2 b	7.7a	1.63b	0.50b	833	2008	94	689	80.4
11.6	20.7 c	7.1a	1.22c	0.39c	939	2106	70	548	95.7
15.2	14.1 d	9.0a	0.86d	0.28d	857	1887	51	654	104.9

* Mean separation within columns by Duncan's MRT 5% level.

Asparagus

The reduction in total spear yield (Table 26) was due to both a reduction in spear number (55.3, 46.7, 49.3 and 41.5 no/m² for the four increasing salinity treatments, respectively), and in average spear weight (19.6, 19.2, 16.1 and 15.0 g, respectively).

Chemical analysis of the plants

Cowpea

Of the three ionic components of the saline growth medium, only chloride concentration in the leaf showed a strong increase with increasing salinity, while sodium was excluded and Ca concentration increased only slightly (Table 27). The concentration of K decreased as salinity increased, while Mg and P were not affected (mean Mg and P concentration were 160 and 117 mmol/kg dry weight).

Celery

There was an increase of chloride and sodium concentration in the leaves as salinity increased from 1.0 to 6.9 dS/m, but further increase in the salinity of the soil had no significant effect on concentration (Table 28). Calcium concentration did not change with treatments (the mean concentration was 892 mmol/kg dry wt). There was a slight increase in P while Mg and K concentrations

decreased with increasing salinity.

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D. Evaluation of the research achievement with respect to the original research proposal

Two general objectives were defined in the original research proposal:

1. To obtain quantitative information for predicting the consequence of using saline water on the yield and quality of crops grown under dynamic field conditions.
2. To develop and test management procedures for minimizing the salinity hazards to crops. Three specific management practices were proposed for testing: irrigation interval, leaching fraction and salinity changes over time.

The results presented in this report apply directly to the objectives as defined above. It was shown that through results of four experiments under a variety of soils, climates and crops, that reduced irrigation interval did not reduce the deleterious effect of salinity on crop development and yield. Thus, the consequences of using saline water cannot be influenced by changing the irrigation interval.

Increasing the leaching fraction, on the other hand, offset yield decline, which resulted from the increased salinity of the irrigation water. The increased yield was due to reduced soil salinity and increased soil water content. Quantitative information was obtained to indicate what level of leaching fraction is required for optimum yield of tall fescue.

The significance of changing the initial rate of salinization on subsequent crop yield was evaluated under limited conditions. The results tentatively showed that reducing the amount of water application (reduced leaching) at the initial period slows down the rate of salt accumulation in the soil, resulting in a smaller reduction in yield than when leaching is provided from the start.

Thus, crop tolerance experiments may have shown a more severe effect of salinity on yield than would be expected under normal agronomic practices.

Tolerance to salinity functions was developed for five crops (turnip, celery, cowpea, asparagus and eggplant) for which information was unavailable.

The results have been published in four reports:

- 1) West, D.W. and Francois, L.E. (1982), Effect of salinity on germination, and yield of cowpea. Irrig. Sci. 3:
- 2) Shalhevet, J., Heuer, Bruria and Meiri, A. (1982), Irrigation interval as a factor in the tolerance to salinity of eggplant. Irrig. Sci. 4:
- 3) Francois, L.E. and West, D.W. (1983), Reduction in yield and market quality of celery caused by soil salinity.
- 4) Heuer, Bruria, Shalhevet, J. and Meiri, A. (1983), The response of eggplant to irrigation with saline water. Hassadeh 63:1058-1060 (in Hebrew).

Five additional papers are under various stages of preparation and should appear within the next year.

- 1) Hoffman, G.J., Jobes, J.A. and Alves, W.J., Response of tall fescue to irrigation water salinity, leaching fraction and irrigation frequency.
- 2) Shalhevet, J., Venten, A. and Meiri, A., Irrigation interval as a factor in the tolerance to salinity of corn.
- 3) Francois, L.E., Salt tolerance of turnip.
- 4) Francois, L.E., Salt tolerance of asparagus.
- 5) Meiri, A., Shalhevet, J. and Heuer, Bruria, Salt tolerance of eggplant.

E. Description and results of cooperation

The cooperation between the research teams in Riverside and Bet Dagan had started sometime before this research project was initiated. The present project tightened this cooperation by initially promoting the common design and rational division of responsibilities for the various aspects of the research, and by the common analysis of the results and presentation of this report.

Most of the cooperation was done by correspondence. However, there were visits by Dr. Hoffman to Israel when the project was proposed and by Dr. Shalhevet when the final report was prepared. Dr. Meiri spent a sabbatical leave at Riverside while this project was in progress.

This cooperative research paved the way to the preparation of additional BARD proposals and to the design of future meetings between the two groups to further the understanding of crop response to salinity and to promote the development of the technology of irrigation with saline water.

F. Benefits to agriculture

As the use of saline water for irrigation is becoming more prevalent, crop and water management recommendations need to be developed or adapted from non-saline water irrigation. The results of this work proved invalid the often made recommendation that irrigation interval employed for non-saline irrigation need to be shortened when saline water is used. Thus, the available information on crop irrigation interval requirements may be used for any quality water. This finding will result in a large saving in labor and water for the saline water user, will save doing additional research, and will prevent yield reductions that may result from unnecessarily increasing irrigation frequency.

The results of the leaching fraction experiment raised doubts regarding the minimum leaching concept presently favored as a guide for determining leaching requirements of crops. The present project showed that minimum leaching may result in yield reduction due to the development of low soil matric potentials. If this finding is supported by further research, it will prevent yield damage resulting from under leaching.

The new tolerance to salinity function for five crops obtained in this project will enable farmers to make rational choices of crops to be used under any specific water quality and will broaden the choice of crops available to the farmer irrigating with saline water.

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