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# Potassium-salinity interactions in irrigated corn

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**Summary.** Potassium uptake by plants can be affected by high salinity and the Na concentration in the soil solution. There is abundant evidence that Na and the Na/Ca ratio affects K uptake and accumulation within plant cells and organs and that salt tolerance is correlated with selectivity for K uptake over Na. This provides the basis for hypothesis which exists in the literature and was examined in this study, that K application can reduce salinity damage to plants. The main objectives of this study were to: (i) study the effects of salinity and K fertilization interactions on corn yield and nutrient uptake; (ii) test the possibility that salinity damage can be reduced by elevating K fertilization rate; and (iii) study K dynamics in soil as a function of the salinity of the irrigation water, in soils with high and low indigenous potassium. The response of corn (*Zea mays* (L.) cv. 'Jubilee') to K fertilization under saline and non-saline conditions was studied by growing corn in two soil types in a pot experiment. Rates of K application to a 3 kg pot were: 0, 15 and 30 mmol K to the Gilat soil and 7.5, 15 and 30 mmol K to the Nordiya soil as KCl. The desired quantity of K was applied in one dose after seedling emergence. The salinity levels of the irrigation water were 4, 20 and 40 mmol charge $l^{-1}$. The irrigation was applied at least every second day and in excess to avoid water stress and to ensure drainage. Increased salinity in the irrigation water significantly decreased yield in both soils. Potassium significantly increased yield at all salinity levels only in the sandy soil which had a low natural level of K, but there was no difference in the relative yield decrease with salinity increase between the lowest and highest K application rates. Potassium fertilization did not eliminate the deleterious effects of salinity on corn yield despite its beneficial effect of increasing K content and reducing the Na : K ratio in plant tissue. Potassium uptake by plants was the major factor in K dynamic processes. Potassium adsorption, release and fixation were secondary factors while leaching was an insignificant factor in overall K balance under cropping conditions.

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Potassium uptake by plants can be affected by high salinity and the concentration of Na in the soil solution (Helal and Mengel 1979; Khalil et al. 1967). There is abundant evidence that Na and the Na/Ca ratio can affect K uptake and accumulation within plant cells and organs (Ben-Hayyim et al. 1985, 1987; Cramer et al. 1985, 1986; Kent and Lauchli 1985; Lahaye and Epstein 1971; Lynch and Lauchli 1985) and salt tolerance appears to be correlated with selectivity for K uptake over Na (Lauchli and Stelter 1982; Wrona and Epstein 1985). Ben-Hayyim et al. (1987) found that growth of cultured citrus cells in various NaCl and $CaCl_2$ concentrations and composition was a function of internal K independent of NaCl concentration.

A hypothesis that K application can reduce the deleterious effects of salinity on plant development has been proposed (Ben-Hayyim et al. 1987; Kafkafi 1984; Khalil et al. 1967). However, contradictory results on the effect of K fertilization under saline conditions on whole plant and field crops have been reported. These include a reduction in salinity damage to various crops when high concentrations of K are present in growth media (Helal and Mengel 1979; Jeschke and Nassery 1981; Lagerwerff and Eagle 1962) as well as no response to K under salinity or even a negative effect of K nutrition on salt tolerance (Lauter et al. 1988; Lunin and Gallatin 1965).

Irrigation with brackish water, in which the concentrations of Ca, Mg and Na are higher than in good quality water, leads to an increase in K release and desorption (Feigenbaum and Meiri 1988). This K may be more readily available to plant roots, but it is also easily leached down beyond the root zone, especially where excess leaching is required to ameliorate soil salinity (Feigenbaum 1986; Feigenbaum and Meiri 1988; Meiri et al. 1984; Pratt and Laag 1977). The primary chemical reactions governing K transport and availability to plants are exchange with other cations and release or fixation by clay minerals. Potassium fixation by clay minerals and soils has been studied intensively and reviewed by Sparks (1987), but information as to how salinity affects K fixation under cropping is meager. Feigenbaum (1986) using mass balance calculations, reported that unaccounted K, which was assumed to be fixed, increased as a function of salinity in column and field experiments. The dynamics of K reactions in soil while cropped have been studied under nonsaline (Sparks et al. 1980) but not saline conditions.

Thus, under saline and sodic conditions, K fertilization management may need to be modified because of K competition with other cations and especially Na in the plant, and to the effects of salinity on K reactions in soils. Accordingly, the objectives of this study were to: (i) study interactions between K nutrition and water salinity and their effects on corn (*Zea mays* (L.) cv. 'Jubilee') growth and composition; (ii) test the possibility of reducing damage to crops from saline-sodic irrigation by applying higher levels of K; and (iii) study the effects of salinity on reactions of native and applied K in two cropped soils.

## Materials and methods

A corn experiment was conducted in pots at Bet Dagan, Israel (35°E, 31°N, 50 m latitude) in a screen house. Two soils were collected from control plots of fields where irrigation experiments with brackish water are being conducted: a silty loam (loess) soil from the south of Israel – Gilat, and a sandy loam from the Coastal Plain – Nordiya. The basic chemical and physical properties of the soils were determined with standard techniques and are given in Table 1. Sweet corn (*Zea mays* (L.) cv. Jubilee) was sown on May 13, 1987, and emerged after 8 days. Plants were grown in pots containing 3.0 kg of air-dry soil which had been mixed with superphosphate at the rate of 3.0 g pot$^{-1}$. Nitrogen as $Ca(NO_3)_2$ was added to all treatments with the irrigation water, at a concentration of 2 mmol l$^{-1}$ (56 mg N l$^{-1}$), starting at emergence and continuing throughout the growing period. Rates of K application per pot were: 0, 15 and 30 mmol K ($K_0$, $K_{15}$, $K_{30}$) to the Gilat soil and 7.5, 15 and 30 mmol K ($K_{7.5}$, $K_{15}$, $K_{30}$) to the Nordiya soil as KCl. The salinity levels ($S_4$, $S_{20}$ and $S_{40}$) of the irrigation water were 4, 20 and 40 mmol charge l$^{-1}$, respectively, with SAR values of 10 for the two saline treatments. Salts were added as mixtures of $Ca(NO_3)_2$, $CaCl_2$ and NaCl; $S_4$ – 2 mM $Ca(NO_3)_2$, $S_{20}$ – 2 mM $Ca(NO_3)_2$, 0.35 mM $CaCl_2$, 15.3 mM NaCl and $S_{40}$ – 2 mM $Ca(NO_3)_2$, 4.9 mM $CaCl_2$, 25.6 mM NaCl in both soils. The experimental design was a completely randomized block, with nine treatments of three salinity levels and three K application levels for each soil, replicated six times in three blocks.

After the corn seedlings emerged, the desired quantity of KCl, was dissolved in 50–100 ml irrigation water and applied to the soil surface. The different salinity treatments were applied 14 days after seeding. The plants were irrigated initially every second day, but as evapotranspiration (ET) increased they were irrigated daily. The quantity of irrigation water for each treatment was estimated to include 100% of plant water uptake plus a 10–20% leaching fraction. "Pot capacity" was determined by adding excess water to pot with soil and weighing it 24 and 48 h after it was put on large container with the same type of soil. The pot capacity was 0.18 and 0.16 w/w for the Gilat and Nordiya soils, respectively. The Nordiya soil which is sandy soil had a similar pot capacity to the Gilat soil due to the high content of smectite type mineral in its clay fraction. Two pots from each treatment were weighed before every irrigation and the required quantity of water was calculated from the difference between "pot capacity" and actual weight minus plant weight. The plant weight was estimated from plant samples assuming an exponential growth rate. Holes in the bottom of the pots allowed the leachate to drain into collection containers throughout the growing period. The quantity of leachate and its ionic composition were determined. Plant tops were sampled four times during the growing period, at 22, 35, 46 and 58 days after seeding. At the last harvest (July 10), the plants were divided into tops (aboveground) and roots (underground). The fresh and oven-dry plant weights (60 °C) were determined. Total K, Na, Mg and Ca in tops and roots was determined in a $HNO_3$ digest, by flame photometry for K and Na, and atomic absorption for Ca and Mg.

After the last harvest the soil in each pot from three blocks was divided into four horizontal layers from the 0–2.5, 2.5–5, 5–8 and 8–11 cm depths. Exchangeable K and Na were extracted from the soils with 1N ammonium acetate. The leachate and saturated paste extracts of the soils were analyzed for: Cl with an anion-specific electrode, K and Na by flame photometry, Ca and Mg by atomic absorption, and electrical conductivity at 25 °C with a conductivity cell.

Statistical analyses of salinity and K application effects on fresh or dry plant matter and Ca, Mg, Na, and K composition of tops were carried out for each sampling date and soil type separately. The SAS ANOVA procedure (SAS 1985) was employed to analyze the complete factorial design involving salinity × K applications in six replicates. Response curves for K yield as a function of soil K were fitted for the two soils together, but separately for each salinity level, with the SAS NLIN procedure (SAS 1985). The following Mitcherlich response curve was used:

$$Y = A(1 - e^{-cX}) \quad (1)$$

where Y is total K yield from a pot (mmol K), X is the amount of applied K plus the native exchangeable K (mmol K (3 kg soil)$^{-1}$), A is the maximum value of Y when X is not limiting (mmol K), and c is a coefficient indicating the effect of K application on K yield ((3 kg soil) (mmol K)$^{-1}$).

## Results

The decline in fresh and dry weights of plant tops for a given K treatment with increasing salinity became significant after 35 days of growth in the two soils (Table 2). Potassium application did not significantly affect dry and fresh weights for any salinity level in the Gilat soil. There was a significant positive fresh yield response to K application in the Nordiya soil for the last two sampling dates, but at the last sampling date there was a significant interaction between K applications and the salinity level of the

**Table 1.** Selected chemical and physical properties of the studied soils

| Soil | Soil Subgroup | $CaCO_3$ (g kg$^{-1}$) | Organic matter (g kg$^{-1}$) | Particle size (g kg$^{-1}$) | | | Texture | pH paste | cmolc kg$^{-1}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sand | Silt | Clay | | | CEC[a] Capacity | EXK[b] K |
| Gilat | Calcic haploxeralf | 203.0 | 9 | 436 | 368 | 196 | 1 | 7.8 | 11.0 | 0.76 |
| Nordiya | Typic rhodoxeralf | 1.4 | 14 | 854 | 48 | 98 | s | 7.5 | 6.25 | 0.19 |

[a] CEC – Cations exchangeable capacity
[b] EXK – Exchangeable K

**Table 2.** Fresh and dry yields of corn tops over time (days after seeding) as affected by K application and salinity

| Treatment | | Fresh weight (g/plant) | | | | Dry weight (g/plant) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Salinity ($mmol_c$/l) | K (mmol/pot) | 22 | 35 | 46 | 58 | 22 | 35 | 46 | 58 |
| | | *Gilat* | | | | | | | |
| 4 | 0.0 | 9.75 | 39.20 | 91.27 | 126.80 | 0.90 | 3.84 | 11.93 | 21.65 |
| 4 | 15.0 | 10.33 | 39.25 | 91.43 | 138.90 | 0.99 | 3.62 | 11.36 | 21.68 |
| 4 | 30.0 | 9.67 | 36.48 | 108.00 | 135.49 | 0.89 | 3.50 | 12.76 | 21.28 |
| 20 | 0.0 | 9.97 | 35.17 | 66.07 | 89.49 | 0.97 | 3.90 | 8.75 | 14.90 |
| 20 | 15.0 | 8.97 | 26.83 | 62.08 | 99.32 | 0.83 | 3.37 | 8.37 | 16.76 |
| 20 | 30.0 | 9.22 | 30.68 | 61.48 | 92.80 | 0.90 | 3.13 | 7.96 | 16.09 |
| 40 | 0.0 | 9.57 | 36.00 | 50.37 | 63.69 | 0.96 | 2.90 | 7.01 | 10.86 |
| 40 | 15.0 | 8.77 | 24.18 | 50.28 | 67.43 | 0.83 | 2.65 | 6.47 | 10.41 |
| 40 | 30.0 | 9.78 | 25.67 | 48.83 | 81.84 | 1.02 | 2.75 | 6.27 | 13.24 |
| Source | df | Probability > F | | | | | | | |
| Block | 2 | 0.46 | 0.11 | 0.442 | 0.123 | 0.47 | 0.33 | 0.235 | 0.268 |
| Salinity | 2 | 0.56 | 0.04 | 0.0001 | 0.0001 | 0.80 | 0.002 | 0.0001 | 0.0001 |
| K | 2 | 0.78 | 0.19 | 0.487 | 0.184 | 0.46 | 0.20 | 0.415 | 0.470 |
| Salinity × K | 4 | 0.69 | 0.76 | 0.200 | 0.615 | 0.23 | 0.87 | 0.68 | 0.381 |
| | | *Nordiya* | | | | | | | |
| 4 | 7.5 | 11.40 | 41.03 | 97.27 | 174.39 a[a] | 0.92 | 4.26 | 12.68 | 27.17 |
| 4 | 15.0 | 11.17 | 48.53 | 101.50 | 204.68 b | 0.95 | 4.70 | 12.63 | 30.81 |
| 4 | 30.0 | 11.38 | 51.48 | 122.97 | 173.27 a | 1.07 | 4.82 | 14.63 | 27.25 |
| 20 | 7.5 | 10.87 | 39.85 | 88.35 | 129.11 b | 1.00 | 4.19 | 11.11 | 19.49 |
| 20 | 15.0 | 11.58 | 42.05 | 95.90 | 139.10 ab | 1.13 | 4.59 | 11.93 | 21.82 |
| 20 | 30.0 | 9.03 | 46.65 | 96.32 | 159.26 a | 0.81 | 4.86 | 11.68 | 23.07 |
| 40 | 7.5 | 8.78 | 29.27 | 69.45 | 110.75 a | 0.86 | 3.19 | 8.73 | 17.20 |
| 40 | 15.0 | 10.12 | 31.13 | 77.38 | 104.84 a | 1.02 | 3.39 | 9.46 | 15.33 |
| 40 | 30.0 | 8.77 | 32.17 | 76.33 | 121.54 a | 0.88 | 3.38 | 9.14 | 17.79 |
| Source | df | Probability > F | | | | | | | |
| Block | 2 | 0.38 | 0.677 | 0.198 | 0.785 | 0.27 | 0.99 | 0.267 | 0.773 |
| Salinity | 2 | 0.018 | 0.0001 | 0.0001 | 0.0001 | 0.55 | 0.0003 | 0.0001 | 0.0001 |
| K | 2 | 0.236 | 0.090 | 0.0033 | 0.0353 | 0.18 | 0.33 | 0.158 | 0.214 |
| Salinity × K | 4 | 0.529 | 0.849 | 0.087 | 0.0012 | 0.12 | 0.98 | 0.32 | 0.03 |

[a] At each salinity level different letters represent significant differences between K treatments at $P \leq 0.05$

irrigation water (Table 2). Hence, at this date, the effects of K applications were analyzed separately for each salinity level. At the last sampling, corn fresh yield increased significantly with K application in $S_{20}$ water, while with $S_4$ water yield increased when K application was increased from 7.5 to 15 mmol $pot^{-1}$ but there was an unexplained decrease of yield due to increase of K application from 15 to 30 mmol $pot^{-1}$. There was no significant effect of K application on yield when $S_{40}$ water was used. Therefore, no generalization can be derived about interaction between salinity and K application from the last harvest in the Nordiya soil.

Bernstein et al. (1974) and Feigin (1985) suggested that the interaction of salinity with soil fertility be analyzed by assessing the slope of relative yield as a function of salinity for a given fertility. With this analysis, the interaction of salinity with fertility is significant if different slopes are observed for the relationship between the relative yield as a function of salinity for different soil fertility levels. For this analysis, the actual electrical conductivity of the soil paste extract ($EC_e$) is preferable to the irrigation water salinity. As expected the soil analyses conducted at the conclusion of the experiment showed that the $EC_e$ increased with increasing salinity level of the irrigation water (Table 3). The highest $EC_e$ values were obtained in the upper soil layer, especially in treatments $S_{20}$ and $S_{40}$ (for detailed data of soil layers see Sparks and Feigenbaum 1990). This phenomenon resulted from water uptake by roots from the upper soil layer where a large fraction of roots developed, while the excess salts were excluded. However, the exact proportion of roots in each layer is not known. Therefore, the average $EC_e$ of the four layers was used for the analysis of relative yield as a function of $EC_e$ (Fig. 1). The decreases in relative yield as a function of the average $EC_e$ in both soils at $K_{7.5}$ or $K_0$ levels were similar or smaller than at $K_{30}$ application treatment (Fig. 1). Thus, there is no positive interaction between salinity and K fertilization as defined above. This analysis also shows that the effect of the actual salinity on relative yield was similar in the two soils.

The fresh and dry weights of plants were higher in the Nordiya soil than in the Gilat soil for a given treatment

**Table 3.** Concentration of soluble and exchangeable ions in Gilat and Nordiya soils at last harvest as affected by K application and salinity level

| Treatment | | Soluble ions | | | | | | Exchangeable | |
|---|---|---|---|---|---|---|---|---|---|
| K mmol/pot | salinity $mmol_c\ l^{-1}$ | EC $ds\ m^{-1}$ | Cl mmol/l | K mmol/l | Na mmol/l | Ca mmol/l | Mg mmol/l | K $cmmol\ kg^{-1}$ | Na |
| | | | *Gilat* | | | | | | |
| 0 | 4 | 0.70 | 1.8 | 0.05 | 1.66 | 4.52 | 1.03 | 0.32 | 1.32 |
| 0 | 20 | 5.83 | 62.9 | 0.11 | 47.94 | 9.39 | 2.87 | 0.32 | 2.67 |
| 0 | 40 | 9.03 | 101.8 | 0.18 | 60.51 | 19.93 | 5.19 | 0.37 | 3.18 |
| 15 | 4 | 0.76 | 2.0 | 0.09 | 1.56 | 4.32 | 1.19 | 0.39 | 1.45 |
| 15 | 20 | 4.81 | 50.5 | 0.18 | 40.73 | 5.76 | 1.70 | 0.45 | 3.33 |
| 15 | 40 | 9.51 | 102.1 | 0.43 | 62.57 | 21.09 | 4.75 | 0.57 | 3.14 |
| 30 | 4 | 0.78 | 2.4 | 0.19 | 1.16 | 3.71 | 1.27 | 0.55 | 1.12 |
| 30 | 20 | 5.53 | 57.5 | 0.54 | 45.11 | 7.94 | 2.50 | 0.71 | 2.86 |
| 30 | 40 | 9.27 | 103.3 | 0.95 | 60.94 | 18.90 | 4.68 | 0.78 | 3.36 |
| Source | df | Probability > F | | | | | | | |
| Layer | 3 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| K | 2 | 0.855 | 0.7109 | 0.0001 | 0.6948 | 0.4826 | 0.2014 | 0.0001 | 0.0096 |
| Layer × K | 6 | 0.658 | 0.6246 | 0.0001 | 0.4786 | 0.9678 | 0.4278 | 0.0001 | 0.2631 |
| Salinity | 2 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| Layer × Salinity | 6 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0364 | 0.0001 |
| Salinity × K | 4 | 0.4735 | 0.748 | 0.0001 | 0.4334 | 0.2692 | 0.2934 | 0.0001 | 0.0008 |
| Layer × Salinity × K | 12 | 0.3524 | 0.755 | 0.0001 | 0.5508 | 0.6307 | 0.8951 | 0.1292 | 0.9137 |
| | | | *Nordiya* | | | | | | |
| 7.5 | 4 | 0.68 | 1.4 | 0.08 | 1.47 | 6.59 | 0.28 | 0.18 | 1.26 |
| 7.5 | 20 | 2.64 | 25.8 | 0.06 | 27.26 | 8.09 | 0.24 | 0.14 | 2.51 |
| 7.5 | 40 | 5.02 | 53.3 | 0.08 | 41.83 | 7.0 | 0.34 | 0.15 | 2.42 |
| 15 | 4 | 0.82 | 2.2 | 0.10 | 1.73 | 10.62 | 0.34 | 0.19 | 1.45 |
| 15 | 20 | 2.41 | 22.4 | 0.07 | 24.15 | 4.60 | 0.26 | 0.17 | 2.37 |
| 15 | 40 | 4.82 | 49.7 | 0.11 | 39.17 | 4.59 | 0.40 | 0.16 | 2.39 |
| 30 | 4 | 0.76 | 2.2 | 0.11 | 1.68 | 8.42 | 0.34 | 0.20 | 1.31 |
| 30 | 20 | 2.75 | 24.9 | 0.09 | 27.38 | 15.15 | 0.24 | 0.20 | 2.53 |
| 30 | 40 | 5.38 | 52.8 | 0.28 | 42.83 | 17.37 | 0.45 | 0.28 | 2.44 |
| Source | df | Probability > F | | | | | | | |
| Layer | 3 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| K | 2 | 0.042 | 0.4060 | 0.0001 | 0.0945 | 0.3365 | 0.0585 | 0.0001 | 0.8666 |
| Layer × K | 6 | 0.376 | 0.468 | 0.0001 | 0.0596 | 0.6271 | 0.6215 | 0.0002 | 0.5393 |
| Salinity | 2 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0001 |
| Layer × Salinity | 6 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0364 | 0.0001 |
| Salinity × K | 4 | 0.225 | 0.819 | 0.0001 | 0.5679 | 0.1186 | 0.5935 | 0.0001 | 0.2317 |
| Layer × Salinity × K | 12 | 0.670 | 0.905 | 0.0001 | 0.7162 | 0.7578 | 0.1788 | 0.0830 | 0.9840 |

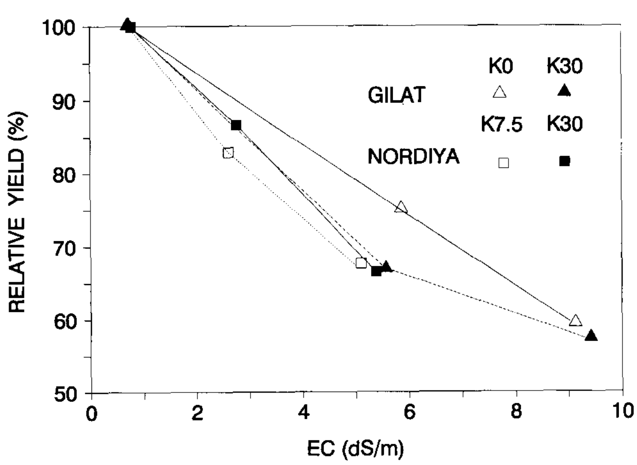


**Fig. 1.** Relative accumulative corn yield as a function of paste electrical conductivity ($EC_e$) for two levels of K in each of the two soils

(Table 2). The soil data at the end of the experiment showed that the effective salinity level of treatments $S_{20}$ and $S_{40}$ was higher in the Gilat soil than in the Nordiya soil (Table 3) because of the less efficient leaching in the Gilat soil. Calculations of the mass balance between total salt input and output showed that the amount of salt loading on the Nordiya soil was 22–48 and 93–120 $mmol_c\ pot^{-1}$ in treatments $S_{20}$ and $S_{40}$, respectively, while for the same treatments in the Gilat soil it was 78–96 and 193–206 $mmol_c\ pot^{-1}$. These differences in salt loading and $EC_e$ can explain the lower

**Table 4.** Corn top composition at last harvest as affected by salinity and K application

| Treatment | | mol $kg^{-1}$ (dry wt) | | | | Na/K | Total inorganic cationic charge molc $kg^{-1}$ |
|---|---|---|---|---|---|---|---|
| K (mmol/pot) | Salinity ($mmol_c l^{-1}$) | Ca | Mg | K | Na | | |
| | | *Gilat* | | | | | |
| 0.0 | 4 | 0.13 | 0.15 | 0.37 | 0.02 | 0.04 | 0.95 |
| 15.0 | 4 | 0.13 | 0.13 | 0.53 | 0.01 | 0.02 | 1.06 |
| 30.0 | 4 | 0.11 | 0.10 | 0.60 | 0.01 | 0.02 | 1.03 |
| 0.0 | 20 | 0.15 | 0.18 | 0.49 | 0.28 | 0.57 | 1.43 |
| 15.0 | 20 | 0.14 | 0.17 | 0.63 | 0.23 | 0.36 | 1.40 |
| 30.0 | 20 | 0.14 | 0.13 | 0.74 | 0.29 | 0.39 | 1.57 |
| 0.0 | 40 | 0.19 | 0.19 | 0.52 | 0.47 | 0.91 | 1.75 |
| 15.0 | 40 | 0.19 | 0.18 | 0.69 | 0.40 | 0.58 | 1.83 |
| 30.0 | 40 | 0.17 | 0.14 | 0.79 | 0.47 | 0.60 | 1.88 |
| Source | df | Probability > F | | | | | |
| Block | 2 | 0.761 | 0.64 | 0.15 | 0.273 | 0.160 | 0.750 |
| Salinity | 2 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| K | 2 | 0.265 | 0.0001 | 0.0001 | 0.185 | 0.0012 | 0.0012 |
| Salinity × K | 4 | 0.888 | 0.707 | 0.925 | 0.821 | 0.160 | 0.850 |
| | | *Nordiya* | | | | | |
| 7.5 | 4 | 0.18 | 0.13 | 0.12 | 0.01 | 0.08 | 0.75 |
| 15.0 | 4 | 0.17 | 0.11 | 0.18 | 0.01 | 0.06 | 0.75 |
| 30.0 | 4 | 0.17 | 0.10 | 0.31 | 0.01 | 0.03 | 0.86 |
| 7.5 | 20 | 0.14 | 0.14 | 0.17 | 0.37 | 2.21 | 1.10 |
| 15.0 | 20 | 0.16 | 0.12 | 0.24 | 0.47 | 1.94 | 1.27 |
| 30.0 | 20 | 0.11 | 0.08 | 0.43 | 0.43 | 1.01 | 1.24 |
| 7.5 | 40 | 0.17 | 0.12 | 0.19 | 0.62 | 3.30 | 1.39 |
| 15.0 | 40 | 0.15 | 0.09 | 0.34 | 0.58 | 1.73 | 1.40 |
| 30.0 | 40 | 0.15 | 0.08 | 0.50 | 0.48 | 0.95 | 1.44 |
| Source | df | Probability > F | | | | | |
| Block | 2 | 0.082 | 0.49 | 0.164 | 0.44 | 0.760 | 0.208 |
| Salinity | 2 | 0.0001 | 0.0003 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| K | 2 | 0.0175 | 0.0001 | 0.0001 | 0.196 | 0.0001 | 0.0075 |
| Salinity × K | 4 | 0.017 | 0.105 | 0.0001 | 0.029 | 0.0001 | 0.140 |

yields in the Gilat soil compared with the Nordiya soil at $S_{20}$ and $S_{40}$. However, the fact that plant yield under non-saline conditions ($S_4$) in the loess soil (Gilat) was 30–50% lower than in the sandy loam soil (Nordiya) indicates that soil factors other than K availability and salinity level reduced sweet corn growth in the Gilat soil relative to the Nordiya soil. Such differences in corn and tomato growth between Gilat and two other soils were reported by Bar-Yosef (1986) and related to greater compaction in the leoss soil. Thus, the effect of salinity and K on corn yield was studied in soils that have very different physical characteristics.

The effect of salinity and K application on plant tissue composition was apparent at the second sampling date, 35 days after seeding (Table 4). Potassium concentrations in the plants grown on the Gilat soil were higher than in plants grown on the Nordiya soil for a given K application. This is in agreement with the difference in the initial and final exchangeable K levels in the two soils (Tables 1 and 3). Large differences in soluble and exchangeable K were found in the Nordiya and Gilat soils for identical treatments. In the Gilat soil there was a significant increase in exchangeable and soluble K with increased salinity, but in the Nordiya soil there was no significant effect, or even consistent trend. The highest value of exchangeable K in the upper layer of the Nordiya soil was 0.23 cmol K $kg^{-1}$, while in the Gilat soil the lowest value was 0.30 cmol K $kg^{-1}$ (Fig. 3). Thus, when no K was applied to Gilat soil, its K status at the last harvest was higher than that observed in Nordiya soil at the highest K application. The K concentration of the plant tops was enhanced by increasing the K application rate and the salinity level of the irrigation water (Table 4). The latter effect is in agreement with the results of Lunin and Gallatin (1965) but contradicts the results of Khalil et al. (1967) for cotton. Increasing K contents as well as other nutrient concentrations in corn and sorghum tissue caused by salinity have been reported by Selassie and Wagenet (1981) and by Patel et al. (1975), respectively. This increase in K concentration in the tissue caused by salinity resulted from the sharp reduction in plant weight while K availability was unaffected.

The Mitcherlich response curve has been intensively used to express nutrient yield as a function of the nutrient applied. Exchangeable K has often been used to assess the availability of K to plants (Fixen and Ludwick 1983;

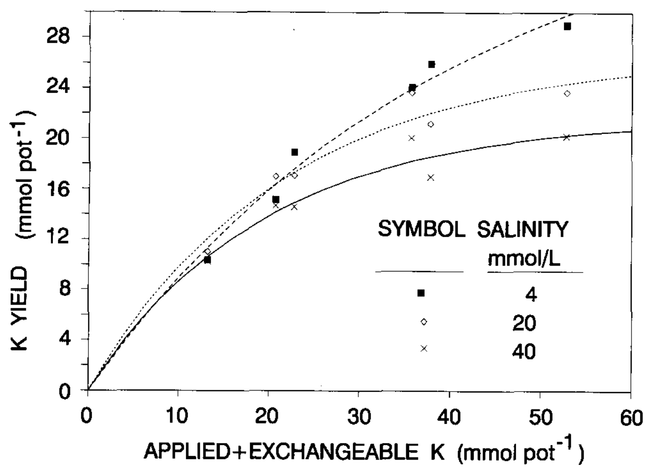


**Fig. 2.** Total K uptake by plants per pot as a function of the sum of initial exchangeable K plus applied K. The curves were calculated with Eq. (1) and the parameters for each curve are given in Table 5

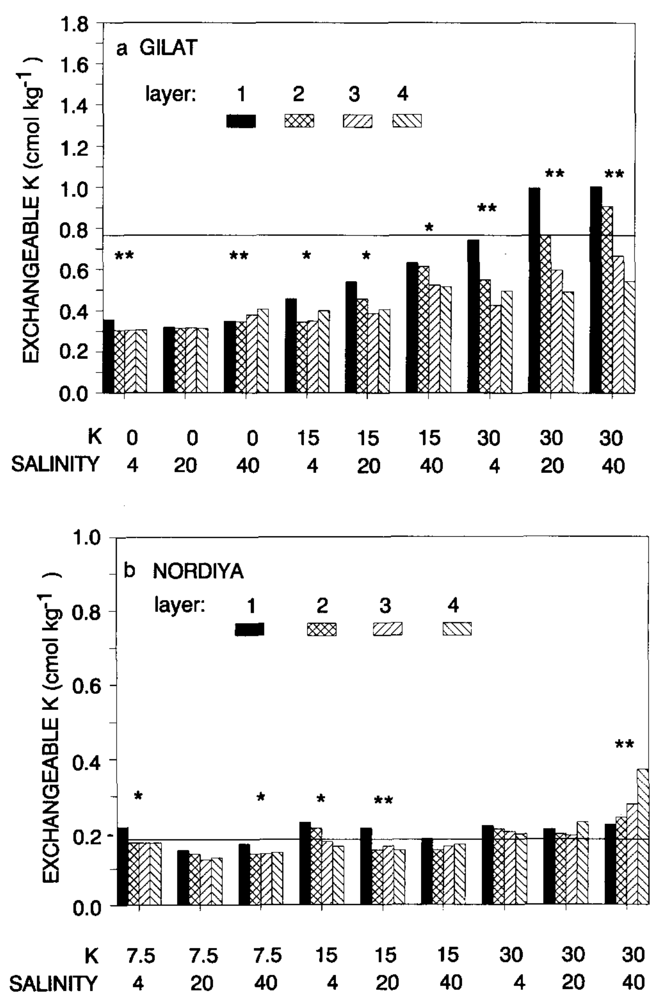


**Fig. 3a, b.** Exchangeable K distribution in the soil layers at the last harvest affected by K application, salinity and plant growth; the horizontal line represents the initial exchangeable K; * and ** represent significant differences between layers at $P \leq 0.05$ and $P \leq 0.01$, respectively, for each treatment

Halvin et al. 1984; Ndiaye and Yost 1989). Potassium yield (total uptake by plants in each pot) could be described as a function of applied plus exchangeable K for both soils together (using Eq. 1), and for each salinity level (Fig. 2). The total uptake of K by the plant was reduced by increasing salinity, and the gap between salinity levels increased as the quantity of applied plus exchangeable K increased. The estimated A values from Eq. (1) shows that increasing salinity of irrigation water from 4 to 40 $mmol_c\,l^{-1}$ significantly reduced the maximum K uptake from 40.9 to 21.7 (Table 5). On the other hand, this increase in salinity doubled the estimated c parameter from 0.0053 to 0.0106. For values of exchangeable plus applied K lower than 13.2 mmol $pot^{-1}$, the difference in total K uptake between salinity levels was insignificant because the quantity of K was the limiting factor for K yield.

Under saline conditions (treatments $S_{20}$, $S_{40}$), K, Ca and Mg concentrations in the plant tissue decreased with time, while the Na concentration increased, indicating a cumulative effect of salinity on Na content in the plants (data not presented). Increasing the salinity level enhanced Na concentration in the plant tops for all levels of applied K and for both soils (Table 4). Soluble Na in the soil paste was a function of salinity in both soils but was unaffected by K application (Table 3). It was much higher in the paste than in the irrigation solution and was higher in the Gilat soil than in the Nordiya soil, especially in the upper soil layer. In the Nordiya soil, there was an interaction between K application and salinity effects on Na concentration in the plant tops. Increasing K application caused a significant reduction in tissue Na at the high salinity treatment (Table 4). For the Gilat soil, K application did not affect Na concentration in the plant tops. The Na : K molar concentration ratio in the plant tops, which has been considered an important factor in assessing the effect of sodic-saline water on plant growth (Lauchli and Stelter 1982), was increased with salinity (treatments $S_{20}$ and $S_{40}$) by a factor of 10 to 50 relative to non-saline conditions ($S_4$). In both soils, the application of K reduced this ratio by a factor of 2 to 4 for all salinity treatments.

In both soils, Mg concentration in the plant tops declined significantly with the application of potassium (Table 4). This decline may have been caused by antagonistic effects of K on Mg uptake by corn plants or from enhanced displacement and leaching of Mg from the soil due to application of K. The soil analyses data (Table 3) show no significant effect of K application on soluble Mg in soil pastes. Thus, it seems that reduction in the concentration of Mg in the plant is due to the antagonistic effects of K on Mg uptake which agrees with published data (Arnon 1975). The Mg concentration in plant tops was lower in the Nordiya soil than in the Gilat soil but even the lowest values were above those of the deficient range (Arnon 1975). However, the decline in Mg uptake that was due to K application might have reduced plant response to K application. In the Gilat soil, increasing salinity from $S_4$ to $S_{40}$ increased Mg concentration in the soil paste four to five fold (Table 3). The Mg concentration in plant tops from the Gilat soil was enhanced by salinity (Table 4) in agreement with the soil data. The

**Table 5.** Statistical analysis of parameters used in Fig. 2 for the following equation: $Y=A(1-e^{-CX})$ where Y is K yield (mmol pot$^{-1}$), X is the sum of initial exchangeable K and applied K, A is the maximal K uptake per pot (mmol pot$^{-1}$), and C is a parameter (pot mmol$^{-1}$)

| Salinity ($mmol_c\ l^{-1}$): | 4 | | 20 | | 40 | |
|---|---|---|---|---|---|---|
| Parameter: | A | C | A | C | A | C |
| Parameter value: | 40.9 | 0.025 | 26.8 | 0.045 | 21.7 | 0.051 |
| St. error of the parameter estimate: | 5.50 | 0.0053 | 2.27 | 0.0087 | 1.86 | 0.0106 |
| T-test: | 7.44* | 4.72* | 11.81* | 5.17* | 11.67* | 4.81* |
| St. error of the estimate: | 1.24 | | 1.35 | | 1.29 | |

effect of salinity on Mg content in the plant tops was small relative to the effect of K application.

In the Gilat soil, a 50% increase in the concentration of Ca in plant tops was due to increases in salinity from $S_4$ to $S_{40}$, regardless of K application (Table 4). In the Nordiya soil, there was an interaction between salinity and K application on Ca concentration in plant tops and even the trend of the effect of salinity that was observed was dependent on K application.

The sum of K, Ca, Mg and Na charge concentration ($mmol_c\ kg^{-1}$, on a dry matter basis) increased slightly due to the application of K (Table 4). Thus the effect of K on Mg uptake can be explained on the basis of the balance among K, Mg and Ca in the corn plants (Arnon 1975). This total charge concentration increased by 50 to 100% as salinity in the irrigation water increased from 4 to 20 and from 4 to 40 $mmol_c\ l^{-1}$, respectively. The effect of increasing water salinity on the sum of cation charge was greater in the Gilat soil which corresponds to the higher EC values in the Gilat soil paste than the Nordiya soil paste (Table 3).

The plant growth, K concentration in plant tops and K yield data show that K application was effective in enhancing uptake and concentration of K in the plant tissue from both soils. The response of plant growth to K application in Nordiya soil indicates that K was a limiting factor in this soil but not in the Gilat soil, which contains higher concentrations of K. However, one of the objectives of this study was to test the hypothesis that salinity, especially high concentrations of Na, reduces uptake and concentration of K in plant tissue. In such a case, larger quantities of applied K would reduce the damage from saline-sodic irrigation water.

In both soils, increasing the salinity level from $S_4$ to $S_{40}$ increased K concentration in the plants by 30 to 90% (Table 2), indicating that the retarded plant growth caused by salinity did not result from K deficiency. Therefore, the data in the present study did not support this hypothesis.

With low and medium K application treatments in the Gilat soil, the exchangeable K levels in the soil dropped below the initial values after growing corn. The effect of plant growth on soil exchangeable K levels was greater in the loess soil (Gilat). Even though there was no yield response to K application in the Gilat soil, there was a significant effect of K application on maintenance of exchangeable K levels in the soil (Fig. 3). In most treatments, higher exchangeable K levels were found in the upper soil layers than in the lower layers after growing plants, and the difference between soil layers increased with K application. These data indicate that downward movement of K was very limited under cropping, which agrees with the drainage data (Table 6). The only exception was the application rate of 30 mmol K pot$^{-1}$ at $S_{40}$ in the Nordiya soil. With this treatment, the combination of high K application with relatively low plant uptake of K, resulted in a buildup of an exchangeable K gradient throughout the profile and downward movement of K was enhanced (Fig. 3).

The total amount of K leached from the soil increased with K application and with salinity level and was affected by soil type (Table 6). In both soils less than 5% of the initial K (exchangeable plus applied) was leached from the pot, except for treatment $K_{30}S_{40}$ of the Nordiya soil where 14% of the applied K was leached. The effect of increasing salinity from 4 to 40 $mmol_c\ l^{-1}$ on K leaching from the Nordiya soil (treatment $K_{30}$) was mainly in reducing K uptake by the plants from 24 to 20 mmol K per pot. In the Gilat soil only 1.3 mmol K pot$^{-1}$ was leached from the $K_{30}S_{40}$ treatment. On the other hand, 0.1–0.2 mmol K pot$^{-1}$ was leached from the Nordiya soil with treatments $K_{7.5}$ and $K_{15}$ while 0.3 to 0.4 mmol K was leached from the control of the Gilat soil, depending on salinity level. The difference between the Nordiya and Gilat soils is due to the larger K buffer ability of the latter soil. Thus, when no K was applied to the Gilat soil, native K was leached out of the soil, and when a large quantity of K was applied, the leached K was much smaller than in the Nordiya soil, due to adsorption processes.

Using the quantity of applied K, the initial and final extractable K levels, the accumulation of K in the leachate, and the plant uptake of K data, one can determine a mass balance for K in the two soils using the following equation:

$$\delta K = K_F + MASS\,(EXK_i - EXK_f) - KUP - K_D \qquad (2)$$

where $\delta K$ is the amount of K released (−) or fixed (+) by the soil (mmol K), $K_F$ is the quantity of applied K (mmol K pot$^{-1}$), MASS is the soil mass in a pot (kg pot$^{-1}$), $EXK_i$ is the initial exchangeable K (mmol K kg$^{-1}$ soil), $EXK_f$ is the final exchangeable K (mmol K kg$^{-1}$ soil), KUP is the total uptake of K by plant tops and roots (mmol K), and $K_D$ is the total amount of K accumulated in the drainage (mmol K).

**Table 6.** Mass balance of K in pot as affected by K application and salinity of the irrigation water

| Treatment | | Exchangeable (mmol K pot$^{-1}$) | | | | mmol K pot$^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|
| Salinity mmol$_c$ l$^{-1}$ | K mmol K pot$^{-1}$ | Initial | Final | | | K Drainage | K Uptake[a] | δK[b] |
| | *Gilat* | | | | | | | |
| 4 | 0.0 | 22.8 | 9.52 | | | 0.27 | 20.7 | −7.7 a[c] |
| 20 | 0.0 | 22.8 | 9.48 | | | 0.31 | 18.5 | −5.5 ab |
| 40 | 0.0 | 22.8 | 11.12 | | | 0.42 | 15.8 | −4.6 b |
| 4 | 15.0 | 22.8 | 11.60 | | | 0.51 | 28.6 | −2.9 a |
| 20 | 15.0 | 22.8 | 13.40 | | | 0.71 | 22.9 | 0.8 ab |
| 40 | 15.0 | 22.8 | 17.10 | | | 0.99 | 18.5 | 1.1 b |
| 4 | 30.0 | 22.8 | 16.60 | | | 0.72 | 31.5 | 4.0 a |
| 20 | 30.0 | 22.8 | 21.40 | | | 1.18 | 25.6 | 4.6 a |
| 40 | 30.0 | 22.8 | 23.40 | | | 1.35 | 22.1 | 6.0 b |
| Source | | df | PR > F | Source | df | PR > F | PR > F | PR > F |
| Layer | | 3 | 0.0001 | Block | 2 | 0.200 | 0.362 | 0.39 |
| K | | 2 | 0.0001 | Salinity | 2 | 0.0001 | 0.0015 | 0.0001 |
| K × Layer | | 6 | 0.0001 | K | 2 | 0.0001 | 0.0008 | 0.0001 |
| Salinity | | 2 | 0.0001 | Salinity × K | 4 | 0.043 | 0.3787 | 0.54 |
| Salinity × Layer | | 6 | 0.0364 | | | | | |
| K × Salinity | | 4 | 0.0001 | | | | | |
| K × Salinity × Layer | | 12 | 0.1292 | | | | | |
| | *Nordiya* | | | | | | | |
| 4 | 7.5 | 5.7 | 5.40 | | | 0.08 | 11.1 | −3.4 a |
| 20 | 7.5 | 5.7 | 4.07 | | | 0.11 | 11.5 | −2.5 a |
| 40 | 7.5 | 5.7 | 4.42 | | | 0.11 | 10.8 | −2.1 a |
| 4 | 15.0 | 5.7 | 5.78 | | | 0.09 | 16.2 | −1.4 ab |
| 20 | 15.0 | 5.7 | 5.10 | | | 0.16 | 18.0 | −2.5 a |
| 40 | 15.0 | 5.7 | 4.95 | | | 0.16 | 15.6 | −0.0 b |
| 4 | 30.0 | 5.7 | 6.12 | | | 0.09 | 25.9 | 3.6 a |
| 20 | 30.0 | 5.7 | 6.12 | | | 0.93 | 25.3 | 3.4 a |
| 40 | 30.0 | 5.7 | 8.30 | | | 4.01 | 21.5 | 1.9 a |
| Source | | df | PR > F | Source | df | PR > F | PR > F | PR > F |
| Layer | | 3 | 0.0112 | Block | 2 | 0.036 | 0.7943 | 0.57 |
| K | | 2 | 0.0001 | Salinity | 2 | 0.0001 | 0.0001 | 0.25 |
| K × Layer | | 6 | 0.0002 | K | 2 | 0.0001 | 0.0001 | 0.0001 |
| Salinity | | 2 | 0.0002 | Salinity × K | 4 | 0.0001 | 0.0001 | 0.035 |
| Salinity × Layer | | 6 | 0.0013 | | | | | |
| K × Salinity | | 4 | 0.0001 | | | | | |
| K × Salinity × Layer | | 12 | 0.0830 | | | | | |

[a] K uptake by plant tops and roots in four samples.
[b] δK = Initial exchangeable K + Applied K − Final exchangeable K − Drainage K − K Uptake
[c] At each K level different letters represent significant difference between salinity treatments at $P \leq 0.05$

In both soils, K was released at the lowest K application, and K was probably fixed when 30 mmol K was applied (Table 6). With the medium fertilization treatments, small amounts of fixation and release were observed. The effect of K application on K release and fixation phenomena is in agreement with others' findings (Feigenbaum 1986; Page et al. 1967; Pratt and Goulben 1957).

The salinity level significantly affected the δK value in the Gilat soil; increasing salinity decreased K release from the low fertilization treatments and increased the δK value (fixation) from the highest fertilization treatment. In the Nordiya soil there was an interaction between the effect of salinity and K application, however, there was no clear trend of salinity effect on K release and fixation in this soil. No satisfactory explanation for the effect of salinity on apparent K fixation in the Gilat soil was found.

## Conclusions

From these studies one can draw the following conclusions: (i) potassium fertilization did not eliminate the deleterious effects of salinity on corn yield despite its effect on increasing K content in the plant and reducing the Na : K ratio in the plant tissue; (ii) increasing salinity did not reduce K concentration in the plant dry matter; (iii) under cropping conditions in pots, K uptake by plants was a major factor in soil K dynamics, while K sorption, release and fixation were secondary factors. Leaching was an insignificant factor in the overall K balance in contrast to the situation in uncropped pots.

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