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Potassium Fertilization Under Irrigation with Saline and Sodic Waters

A. Meiri, A. Lauchli, S. Fiegenbaum, R. Levy, D.N. Munns

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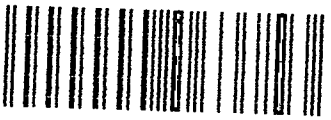

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Potassium Fertilization Under Irrigation With Saline and Sodic Water

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Abstract

A change in the K cycle was foreseen under irrigation with saline sodic water. This study treated the interactions between potassium and sodium salinity from five aspects: (i) the possibility of using K as an antagonist to Na to moderate salinity effects on crops, (ii) the influence of Na salinity on K requirements of the crops, (iii) the influence of Na salinity on K reactions with the soil, (iv) K leaching and movement within the rhizosphere and the entire root-zone, (V) plant influence on the K interactions with the soil under saline conditions.

Nutrient solution experiments were conducted with cotton, peanut, potato and melon. Soil culture experiments were conducted with cotton, on a study quartzipsamment. Rhizosphere work was conducted with barley in three typic xerorthents.

In no case could we indicate a beneficial growth or yield effect when K levels reduced tissue Na levels. On the other hand, K as the main salinity cation was more deleterious than Na to all the tested crops.

Positive growth response to increased K in the medium was found with the salt sensitive Na excluder potato in the range of 5 - 20 mM and with the salt tolerant Na accumulator cotton in the range of < 1 mM. The potato data did not indicate a higher K requirement under saline conditions. The cotton data indicated the possibility of some K sparing under Na salinity.

Sodic saline water in Ca soils increased the K concentrations in the soil solution, in the rhizosphere and soil culture studies. When salinity decreased K uptake as a result of reduced growth rates or competition with Na, the higher K levels in the soil solution were maintained.

The soluble K is only a small fraction of the soils' K. Most of the available K is in the exchange form. In cultivated soil the uptake is a large component of the K balance. Because salinity reduces the uptake, little change in K depletion is expected from increased leaching under saline conditions.

Our data did not indicate a need to modify K fertilization under saline conditions.

Objectives of the original research proposal

The aim of this research was to improve K fertilization management under saline conditions based on better understanding of K-Na interactions in plant and K fertilizers behavior in soils irrigated with saline and sodic water.

Specific objectives were:

1. To study the influence of salinity on K uptake, the partitioning of K and Na in intact seedlings, compartmentation in excised roots, influx, efflux, and release to the xylem of cotton, beans, peanuts and potatoes.

2. To evaluate the influence of salinity, K fertilization, transpiration rate and Na uptake/exclusion on rhizosphere salinity, pH, and levels of K and Na in solution and exchange phase.

3. To study the transport of K through soils as influenced by water quality and leaching fraction (L.F.).

4. To test the possibility of reducing salinity damage to crops through relatively higher levels of K fertilization.

5. To develop K availability criteria under saline conditions based on rhizosphere conditions and soil measurement.

6. To test in the field recommendations for K fertilization for peanuts.

Body of the Report

General Introduction

Agriculture in Israel and southern and western U.S. is now at a turning point. If agriculture is to maintain, or increase, its productivity, new water resources will have to be utilized. By the turn of the century, one half of Israel's irrigation (about 600 million m^3 per year) is expected to be brackish and swage effluent waters. The trend in southern and western U.S. is similar, although a massive switch over to use poor quality water in irrigation will probably occur there somewhat later.

Plant yield decreases with increase in salinity and sodicity. Current management is conducted to control, by leaching, total salinity. Sometimes it is combined with heavy application with gypsum to reduce sodicity hazard. But, there are no recommendations for changes in fertilizer application. In many cases, this approach leaves only a limited choice of crops of high salt tolerance, while crops more sensitive to total salinity, or specifically sensitive to sodium, are eliminated. It was shown that mixed salt solutions have a less deleterious effect than single salt solutions, and that the ratio of K to Na uptake may be very important in response to salinity. There is some evidence in the literature that high concentrations of KCl added to saline growth media, reduced salinity damage.

Irrigation with brackish water, in which the concentration of Ca, Mg and Na are higher than those in water of good quality, cause an increase in K release from exchange sites. It also diminishes the chances of fertilizer K to be absorbed by the soil exchange complex. Thus, larger fractions of the K from natural or fertilizer sources are found in the soils in soluble form, which is more readily available to the roots, but is easily leached out from the root zone, especially as excess leaching for salinity control is required. The faster depletion from natural K resources and the higher mobility of K fertilizers in soil under saline conditions, should modify both K availability index and fertilization management.

Saline interference to plant growth is divided into osmotic and specific ionic effects. Available quantitative data on plant response to total salinity (Maas and Hoffman, 1977), serving as a basis for irrigation management (Van Schilfgaard, 1974; Shalhevet, 1973), is aimed to control total soil salinity. These data were obtained in many cases using Na and Ca chloride with fertilization recommendations appropriate to non-saline conditions. However, K and the ratio K to Na in salinity stressed plant tissues was recognized to be of major importance. Plant classification for salt tolerance, based on K/Na ratio, was suggested for halophytes (Weissenbock, 1969) and glycophytic and semihalophytic agricultural species (Harmer et al., 1953). High cytoplasmic Na/K ratio appears to cause metabolic damage and salinity may interfere with K uptake (Greenway and Munns, 1980). There is evidence that some of the relatively salt resistance crops, such as

cotton and barley, maintain adequate internal K levels (Läuchli and Stelter, 1982; Lynch et al, 1982). On the other hand, most salt sensitive crops, including legumes, respond to salinity by a drop in internal K concentrations that may reach deficiency levels (Läuchli, 1983; Winter and Läuchli, 1981; Van Steveninck et al., 1982). There is also evidence that high concentrations of KCl in the growth medium reduce salinity damage in beans (Lagerwerff and Eagle, 1961; Melal, 1983).

Crops have developed two strategies as far as Na uptake is concerned. The majority of crops belong to Na excluders, that is these plants tend to exclude Na from transport to the shoot by a variety of mechanisms (Greenway and Munns, 1980; Jeschke, 1982; Läuchli, 1983). For these crops, K is the most important cation in the osmotic regulation (Mengel and Kirkby, 1980). A well known example is the bean plant which excludes Na from the shoot mainly by reabsorption from the xylem vessels in the proximal region of the root (Kramer et al., 1977; Läuchli, 1972, 1983) or along the stem (Jacoby and Ratner, 1974). However, other less well understood transport processes also appear to be involved in the overall strategy of Na exclusion and K/Na selectivity. At K concentrations below about 1mM Na has a small effect on K uptake and affinity to root uptake sites, while Na has a stronger effect on K uptake from high external K concentrations (Epstein et al., 1963). High salinity, even due to the presence of KCl only, reduces K uptake (Meiri, 1973). Potassium uptake rates by whole plants are also controlled by internal K concentration (Glass, 1978). According to Zimmerman (1978) it is cell turgor which ultimately controls K uptake. A few salt resistant crops appear to be Na accumulators and may be able to use Na accumulation in the leaves for osmotic adjustment to salinity (Jennings, 1968; Flowers et al., 1977; Läuchli, 1978; Marshner, 1971). First evidence indicates that cotton belongs to this group (Läuchli and Stelter, 1982). The ratio K/Na has an effect on CO_2 fixation and energy balance of plants under saline conditions (Helah and Mengel, 1981). This energy balance may be an important factor in salt tolerance (Schwartz and Gale, 1981; Meiri et al., 1982). A basic understanding of K and Na uptake, transport and compartmentalization in plants is very important if crop productivity in salt-affected soils is to be improved by K fertilization.

Since soils are the medium for crop growth, K reactions in soil should be investigated, both on the micro scale, the rhizosphere, and the macro scale, K transport in the root zone.

Concentrations of Na and K in the rhizosphere should control plant uptake of these ions, so that it becomes important to find out how they differ from concentrations in the bulk soil solution. Changes in salt and K concentrations in the rhizosphere have been modeled and demonstrated experimentally (Classen and Barber, 1976; Classen et al, 1981; Helah and Sauerbeck, 1981; Hendricks and Jungk, 1981; Sinha and Singh, 1974). However, none of this work has covered saline conditions, salt uptake/exclusion, or growth response by the plant.

Exchange between K and each of the main cations found in the soil has been investigated extensively (Bolt, 1967;Deist and Talibudeen, 1967; Beckett, 1967). There is less information on the simultaneous exchange in soils between several cations. It was found by Levy, Tanji, and Whittig (1983) that in the absence of precipitation reactions and changes in solution pH, the simultaneous exchange between NaÂCaÂMg was governed by the same preference as the exchange between any two of the above cations. It is necessary to study the simultaneous exchange KÂCaÂMgÂNa.

Under non-saline conditions K fertilization recommendations based on crop requirement and K availability (Mengel and Kirkby, 1980) are basically expressed as a ratio between K to Ca + Mg in the soil solution in the equilibrium with soil(Feigenbaum and Hagin, 1967; Beckett, 1964; Woodruff, 1955; Woodruff, 1960).

Soluble K is in equilibrium with different adsorption sites of the K bearing minerals. The relationship between the different forms of adsorbed K (exchangeable, fixed in the interlayers of clay minerals and for structural K of primary minerals) depends on the mineralogical composition of the different size fractions (Bolt et al., 1963; Carson and Dixon, 1972).

The release of K from different size soil fractions varies because the K bearing soil minerals are at a different stage of weathering (Rich, 1972; Smith et al., 1968). Another soil process to which not enough attention has been paid, is the release of K by dissolution of soil minerals (Gilkes et al., 1973; Pratt and Laag, 1977; Feigenbaum and Shainberg, 1975).

The rate of K release from different K bearing minerals differs by an order of magnitude and is affected both by the total concentration of the solution and by the kind of replacing cation (Gilkes et al., 1973; Feigenbaum et al., 1981; Feigenbaum and Levy, 1977; Feigenbaum and Shainberg, 1975). The K capacity of the soil and the rate of K release from different soil size fractions have to be taken into account in evaluating soil K availability, especially under irrigation with saline and sodic waters.

The high concentrations of Ca and Na found in saline and sodic waters may release more adsorbed K into the soil solution which can be leached from the root zone by the downward movement of the irrigation water. Under normal conditions applied K fertilizers are found in the top soil layer (Munson and Nelson, 1963). In some soils, rainfall of high intensity, or irrigation, moved K slowly downward (Boswell, Anderson,1968; Ganje and page, 1970). The downward movement of the applied K increased with the increase in the salt content of the irrigation water and reached higher depths in the light textured soil (Ganje and Page, 1970; Pratt and Laag, 1977; Meiri and Feigenbaum, 1979).

Salinity could modify K availability index. Equilibrium between various K forms in the soil and soil solution and long distance transport will determine K availability in the root zone.

Considering both soil and plant aspects, different K fertilization management under saline conditions can be foreseen. One aspect is to prevent the development of K deficiency during irrigation with saline waters. The second one is to increase K concentration and to use it as an antagonist to specific Na effects. As soils and cultivars can differ in response a range of soils and crops was tested, using different experimental techniques.

A. The Effect of K/Na Ratio on Growth and Ion Accumulation in Cotton under NaCl Stress

Jeanette C. Papp and André Läuchli

Introduction

Salt tolerance differs between species, between varieties within species, and with developmental age of a plant. The mechanisms by which plants deal with the problems associated with high salinity levels can also vary greatly. Cotton is a fairly salt tolerant Na accumulator (Läuchli and Stelter, 1982). The K^+ ion is a monovalent cation which may be a likely candidate for competition with the Na+ ion. Potassium nutrition can be affected by saline conditions. There is abundant evidence that Na can affect uptake and accumulation of K within the plant (Calahan, 1977; Devitt et al., 1984; Kent and Läuchli, 1985; Lashin and Atanasiu, 1972; Rathert, 1983). In many cases salt tolerance seems to be correlated with K/Na selectivity (Kent and Läuchli, 1985; Läuchli and Stelter, 1982; Watad et al., 1983), and the ability to maintain adequate tissue K levels. There are instances where Na^+ has been shown to substitute for K^+ to some extent at low salinities (Rush and Epstein, 1981; Dibb and Thompson, 1985), while at high salinities the two ions have antagonistic effects. This suggests the possibility that high external K concentration could help block some of the deleterious effects of Na as well as maintaining adequate K levels within the plant in the face of high Na concentrations. Mozafar et al., (1970) found that Na uptake in *Atriplex halimus* was not inhibited by supraoptimal K levels, but Helal (1980) has reported that high K reduces declines in dry weights and carbohydrate contents due to salt-stress in broad beans. Potassium is also important in osmotic adjustment. Additional K may help plants cope with osmotic imbalance associated with salt stress. The objective of this study was to examine the effects of interactions between K nutrition and NaCl salinity on growth and ion levels in cotton (*Gossypium hirsutum*), and to evaluate the feasibility of using K fertilization to alleviate salt stress and improve vegetative growth under high salt conditions.

Materials and Methods

Four experiments were conducted. Plants were germinated on germination paper (experiments 1, 2 and 4) or in sand (experiment 3). During germination they were watered with 0.1 modified Hoagland solution (Epstein, 1972). Seedlings were transplanted into 3 liter pot-mixture pots in experiment 1 or into 10 liter nutrient solution containers in experiments 2 - 4. The basic irrigation or nutrient solution was 0.1 modified Hoagland solution with 1 mM KNO_3 and 4 mM $Ca(NO_3)_2$. In experiment 1 one K level (1 mM) and two NaCl levels (1 and 150 mM) were compared (12 replicates). In experiment 2 (July 1985) three K levels (0.1, 1 and 10 mM) and two NaCl levels (1 and 100 mM) were tested (3 replicates). In experiment 3 (October 1985) two K levels (1 and 10 mM) and two NaCl levels (1 and 100 mM) were tested (6 replicates). In experiment 4 two K levels (1 and 10 mM) and three NaCl levels (1, 75 and 125 mM) were tested (6 replicates). Pots were

arranged in the greenhouse in all the experiments in a completely randomized design. to obtain 0.1 mM K, 0.9 mM of the KNO_3 in the basic solution was replaced with NH_4 NO_3. to obtain 10 mM K, 9 mM KCl was added to the basic solution. Salinization was in 50 mM steps in experiment 1 and in 25 mM steps in experiments 2 - 4. In experiments 2 and 4 the greenhouse was whitewashed to cut down the radiation. The photosynthetically active radiation (PAR) at canopy level at midday was 1200, 1500 and 1200 μmol m^{-2} sec^{-1} in experiments 2, 3 and 4, respectively. Day length, air temperature and relative humidity were not controlled.

Experiment 1 was conducted in late fall of 1984 to evaluate the appropriateness of the Plastochron index PI (Erickson and Michelini, 1957) as a tool in analyzing developmental data on cotton under saline conditions. Then the three following experiments used the PI in the analysis of the data and as a reference for the harvest timing of experiments 3 and 4.

Leaf lengths from base to tip of the lamina were measured every other day in order to determine a Plastochron Index (PI) for each plant, defined as:

$$PI = n + \frac{\ln L(n) - \ln L(ref)}{\ln L(n) - \ln L(n+1)}$$

where n is the serial number of the leaf just longer than the reference length, L(n) is the length of leaf n, L(ref) is the reference length, and L(n + 1) is the length of leaf (n + 1). The reference length is an arbitrary length within the exponential portion of the curve of leaf length versus time (Erickson and Michelini, 1957).

Leaf relative growth rates (RGR) in the exponential growth period (determined from log transformed plots of leaf length versus days as the period when the leaf lengths were less than 40 mm) were calculated using the following approximation:

$$\frac{1}{L} X \frac{dL}{dt} = \frac{d \ln L}{dt} \approx \frac{\Delta \ln L}{\Delta t}$$

where L is leaf length and t is time, and Δ ln L is estimated by linear regression.

Solutions were monitored by electrical conductivity meter, pH meter, and potassium electrode, and amended (in the case of pH, which was maintained at 6.0 ± 0.5) or renewed as necessary (approximately once a week). $Ca(OH)_2$ was used to adjust pH. Leaf lengths were measured and recorded every other day for each plant. Three harvests were made in experiment 2, at 9, 19 and 25 days after final treatments were applied. Harvests were made at night when stomata were closed and fresh weights less affected by differences in transpiration rates. Roots were rinsed twice in distilled water for 15 seconds each time to remove nutrient solution from the root surface. On harvesting samples

were dried, and dry weights recorded. The samples were then extracted at room temperature with 0.5 N HNO_3. Ion levels were determined by atomic absorption and flame emission spectrophotometry. Ion data from this experiment showed no statistically significant differences between ion levels per gram dry weight of tissue for different harvests of the same treatment. Consequently experiments 3 and 4 were each given a single harvest. This made it possible to have more replications of each treatment, allowing a greater degree of certainty in estimation of the true means of population. Harvests were made based on plastochron age of the plants rather than chronological age, that is, each plant was harvested when it reached PI 10, although the day on which this occurred varied as much as a week from plant to plant. Harvest and post-harvest analyses were identical to Experiment 2.

Statistical Analysis

The data proved to be normally distributed, hence the untransformed data were analyzed by analysis of variance (ANOVA). Pairwise comparisons between treatments were obtained using Fisher's protected least significant difference test (PLSD). To test for interactions between the two treatment variables, potassium and sodium, a two-way factorial ANOVA was used.

Results

Growth data

The leaf extension data indicate that cotton follows the mode of growth required for the application of a Plastochron Index. Plotting length on a logarithmic scale versus days for a typical leaf (Fig. A1) shows that cotton follows the specified growth pattern: an early phase of exponential growth followed by a gradual slowing and finally virtual cessation of growth. Thus it is suitable for analysis by Plastochron Index. The Plastochron Index is often useful, as many parameters show less variability when plotted against PI, a developmental scale, than against chronological age. An example of this relationship is shown in Fig. A2, where length of leaf five for several plants is plotted against both scales.

Differences in the response to treatments between experiments were small; therefore, in most cases the data of only one experiment are shown in full.

Plotting PI vs. days after salinization (Fig. A3) shows that the rate of progression of the Plastochron Index, or the rate of leaf initiation, declines with increasing sodium concentration. 15 days after salinization the low sodium treatments had approximately two more leaves than the high sodium treatments in every experiment. However, according to Fisher's PLSD test there was no significant effect on the Plastochron Index due to potassium level in any of the experiments.

Leaf relative growth rates (RGR) were calculated for Experiments 3 and 4 pooling the data for leaves four, five and six, chosen as representative leaves with sufficient data points to allow reasonable confidence in the estimation of the linear regression. The results show that increases in external sodium correlate with a decline in RGR relative to the control, although differences between 75 mM and 125 mM were not significant (Fig. A4). Increasing external potassium level showed somewhat larger RGR's at all salt levels, but this effect was not significant at the 95% confidence level.

In all experiments leaf size as dry weight (Fig. A5) or leaf area (Fig. A5B) declined with increasing sodium concentration. Both parameters were not significantly affected at the 95% significance level in the youngest and oldest leaves. Significant differences showed up at the intermediate ages, primarily in leaves three, four and five in both parameters, and leaf six only in leaf area. Weight reductions compared to controls average 18% at 100 mM NaCl (experiment 3) and 35% at the high sodium levels in experiment 4. Leaf areas declined with increasing sodium concentration on average 30% in experiment 3 and 32% in experiment 4. Potassium levels had no effect on dry weight or leaf area at the 95% significance level, again with the exception of weight of leaf six at the 1 mM K, 75 mM Na treatment, which had a higher dry weight than leaf six at the 10 mM K, 75 mM Na treatment. Two factor analysis of variance found no potassium-sodium interaction for either experiment at the 95% significance level.

Table A1. Effect of K/Na ratio on root dry weights and root fresh weight: dry weight ratios (FW/DW). Means, n = 6. Means followed by the same letters are not significantly different at the 95% level according to Fisher's PLSD.

	Treatment (K and Na in nutrient solution, mM)			
Experiment 3:	1K, 1Na	10K, 1Na	1K, 100Na	10K, 100Na
Dry Weight (mg)	1420 a	1565 a	1771 ab	2182 b
FW / DW	16.23 a	16.19 a	13.47 b	13.60 b

	Treatment (K and Na in nutrient solution, mM)					
Experiment 4:	1K, 1Na	10K, 1Na	1K, 75Na	10K, 75Na	1K, 125 Na	10 K, 125Na
Dry Weight (mg)	1535 a	1280 a	1378 a	1370 a	1216 a	1330 a
FW / DW	16.58 a	17.74 ab	17.72 ab	18.92 b	15.87 a	16.98 ab

Root dry weights were not significantly affected by potassium level or by potassium-sodium interaction in either experiment 3 or 4 (Table A1). Root dry weights increased with increasing sodium concentration in experiment 3. In experiment 4, while differences were not significant, the trend seems to be in the opposite direction.

Leaf fresh to dry weight ratios were affected by leaf serial number as well as by treatment. Both the oldest and youngest leaves of every treatment had lower fresh to dry weight ratios than the intermediate aged leaves, except for experiment 4, treatment 1 mM K, 125 mM Na (Fig. A5C). High sodium treatments had higher fresh to dry weight ratios compared to those of the control in both experiments in leaves older than leaf six, and in experiment 4 the 125 mM Na treatments had higher fresh to dry weight ratios than the 75 mM treatments at both potassium levels in leaves older than leaf five (Fig. A5C). Percent increase in fresh to dry weight ratio of high sodium treatments for these leaves averaged 27% of the control. Root fresh to dry weight ratios displayed the opposite trend with respect to sodium in experiment 2, decreasing with increasing external sodium concentration, while in experiment 4 there were no significant differences in root ratios due to sodium level (Table A1).

The ratios of root dry weight to the total leaf dry weights are shown in Figs. A8 and A9. In experiment 3 the high sodium treatments exhibit significantly higher ratios than the control, with no potassium effect or potassium-sodium interaction (Fig. A8). In experiment 4 a number of leaves were lost due to insect damage or abscission. When this occurred, the whole plant was excluded from calculation of the mean. Smaller sample sizes have the effect of decreasing the degree of confidence in the estimates of population mean and variance. This may have contributed to the lack of significant differences in root to leaf dry weight ratios in this experiment (Fig. A7). The general trends, however, seem to be similar in the two experiments.

Tissues ion contents

Leaf age and treatments had a marked effect on Ca, K and Na contents in the leaves. Ca contents increased with leaf age. The ratio of expanded to young leaf contents was about 4 in the low salt and about 2 in the high salt treatments. Ca levels of young leaves were affected little by the sodium-potassium treatments (Fig. A8A). Expanded leaves showed significant decrease in Ca level with increasing Na, but no effect due to external K except for a higher Ca content at 0.1 mM K in experiment 2 (data not shown). Declines in Ca level at high Na in general were not alleviated by high K.

K levels decreased with leaf age. Internal potassium levels of young leaves (Fig. A8B) showed no significant differences between treatments, except for a low internal potassium in experiment 2 at 0.1 mM K, 100 mM Na and in experiment 3 at 10 mM K, 100 mM Na, and a high potassium level in experiment 3 at 10 mM K, 1 mM Na (data not shown). Potassium levels in expanded leaves increased with increasing substrate potassium and decreased with increasing sodium. In addition, potassium-sodium interactions occurred with probabilities greater than 95% in leaves five and six in experiment 3 (data not shown), and in leaves one, two, three and four in experiment 4 (Fig. A8B). In experiment 4 the effect of these interactions was that the percent decrease in internal potassium in the high potassium/high sodium treatment was less than in the low potassium/high sodium. However, in experiment 3 the reverse was true;

increasing external potassium intensified the sodium effect on internal potassium (data not shown).

Sodium levels in all tissues (Fig. A8C, Table A2) increased with increasing sodium concentration but were largely unaffected by potassium and potassium-sodium interaction. Sodium levels in older leaves (Fig. A8C) and in roots (Table A2) were increased to a much greater extent (20 to 100 times) than in young leave (from not significant to a sixfold increase).

Table A2. Effect of K/Na ratio on calcium, potassium and sodium contents in the root (meq/100g dry weight).

Experiment	Ion	Treatment (K and Na in nutrient solution, mM)					
		K Na	K Na	K Na	K Na	K Na	K Na
2		0.1 1	1 1	10 1	0.1 100	1 100	10 100
	Ca	13.04a	12.32ab	11.56ab	11.04ab	11.33ab	10.48b
	K	37.79a	84.92b	196.72c	43.72a	101.21b	171.79c
	Na	0.60ab	0.63a	0.67b	57.21c	59.70c	54.24c
3			1 1	10 1		1 100	10 100
	K		181.52a	212.00b		111.26c	160.75d
	Na		1.16a	0.93a		29.28b	23.20b
4		1 1	10 1	1 75	10 75	1 125	10 125
	Ca	14.91a	11.19b	11.90b	8.39c	10.92b	8.00c
	K	189.70a	203.52a	163.24b	161.07b	126.32c	150.61b
	Na	1.11a	0.73a	25.29b	26.79b	37.33c	37.88c

Root calcium levels (Table A2) were mostly unaffected by treatment in experiment 2, while in experiment 4 increasing potassium appeared to decrease calcium levels in the root. In experiment 4 increasing sodium up to 75 mM decreased internal calcium, but there was no difference between the 75 mM and 125 mM treatments at equal potassium levels. There were no potassium-sodium interactions in the root in any experiment. In the roots internal potassium increased with increasing external potassium and decreased with increasing external sodium in all cases with the exception of experiment 2 in which the root potassium was unaffected by sodium level in the medium. Internal ion levels in the three experiments were in fair agreement. The exception was experiment 3, which had low root calcium levels (data not shown).

Discussion

In experiments 3 and 4 plants were harvested at corresponding plastochron ages, despite the fact that these were sometimes separated by a number of days. This study demonstrates the importance of a developmentally-based index when dealing with data gathered under different environmental regimes. The fact that the rate of progression of the Plastochron Index changed with differing sodium treatment shows that at the same chronological age, the plants were at different developmental ages. Comparing data from plants at different developmental ages can give misleading results. On the same date, plants in experiment 4, treatment 1 mM K, 1 mM Na were as much as two PI units older than plants of treatment 1 mM K, 125 mM Na (Fig. A3). Thus, there were two units difference between the Leaf Plastochron Index (LPI) of leaves of the same serial number in the two treatments, where

$$LPI = PI - x$$

and x is the serial number of the leaf under consideration (Erickson and Michelini, 1957). In experiment 4 the K content of leaf five at 1 mM K, 1 mM Na was 63.88 meq/100 g dry weight; this is significantly higher than the K content of the same leaf at 1 mM K, 125 mM Na, i.e., 32.14 meq/100 g dry weight. But if plants of the two treatments were harvested on the same day, the LPI of leaves of treatment 1 mM K, 125 mM Na would be two units less, as the stressed plants develop less rapidly. Assuming that all the leaves go through similar changes in K level with age, leaf five of the high NaCl treatment would have a K level similar to that of leaf seven at that treatment i.e., at 79.19 meq/100 g dry weight in experiment 4. This is actually higher than the K level of leaf five at the low, 1 mM Na treatment (Fig. A8B). Therefore comparing leaves of the same serial number of plants of different Na treatments on the same date could lead to erroneous conclusions concerning the effect of salt stress on leaf K levels. In addition, plotting a parameter against PI rather than time often reduces the variability (Fig. 2), which again could make it easier to differentiate treatments effects (Michelini, 1958; Silk, 1980). Thus the Plastochron Index is a valuable tool for correlating morphological and physiological events in plants. It is of particular utility in studies of environmental stresses which may affect the rate, but not the sequence of development.

Some of the discrepancies between experiments 3 and 4 were related to root data. Root to leaf dry weight ratios in experiment 3 were more than twice those in experiment 4 (Figs. A6 and A7). Differences in root dry weights between experiments were greater than leaf dry weight differences. Also, trends of increasing root dry weight with increasing Na level which appeared in experiment 3 were absent in experiment 4. PI is a leaf-based developmental index, and it is possible that root growth is not linked closely to the ontogeny of the shoot. Although the shoots in experiments 3 and 4 had identical developmental ages at harvest, it is possible tha root development differed. If this were the case, PI can only be applied to the above-ground part of the plant in this study.

The Na level in the medium had a strong effect in all experiments on dry weight, fresh to dry weight ratio, leaf area, and root to leaf dry weight ratio. All these effects have been well documented for cotton in the literature (Calahan, 1977; Kent and Läuchli, 1985; Lashin and Atanasiu, 1972; Läuchli and Stelter, 1982; Rathert, 1983). Also negatively affected were leaf initiation rate and leaf relative growth rate. The same results were found in cotton under drought stress (Mutsaers, 1983). There were no K effects or K/Na interactions, with a few exceptions in fresh to dry weight ratios. Therefore it can be concluded that there is not potential for ameliorating the adverse effects of salinity on cotton, with respect to the parameters discussed above, by potassium fertilization in the absence of pre-existing potassium deficiencies. It is clear that salinity, subjected at an early age, has a detrimental effect on vegetative growth in cotton. However, it has been reported that cotton becomes more resistant to salt stress during later stages of development, and plants affected by salinity at an early stage may recover sufficiently to match yield of unstressed plants. This was recently found to be the case in cotton irrigated with drainage water of medium salinity (Rains et al., 1987).

From Fig. 1 it can be seen that leaves one and two were out of the exponential growth phase (below 40 mm) by the time the salinity treatment was imposed, although they had reached only half to three quarters of their final lengths. This pattern was true for all plants in experiments 3 and 4. On the basis of the fraction of final length, it can be assumed that at the point at which salinity treatments were imposed leaves one and two had completed cell division and henceforth would increase their size through cell expansion. Statistical analysis showed that there were no in differences in leaf dry weight and area due to salinity treatment in leaves one and two, leaves presumably exposed to salt stress during cell expansion but not during cell division. Dry weight and area differences did occur in leaves three and older, that is, leaves which were exposed to NaCl during their cell division stage and throughout their growth. This suggests that salinity-related declines in cotton leaf growth may be mediated more through cell division than cell expansion. However, in order to make this statement with confidence it would be necessary to undertake further, anatomical studies, such as those made on cotton roots (Kurth et al., 1986). Fresh to dry weight ratios in salt-stressed plants, however, were significantly different in all leaves, including one and two, showing that the water content of cells was affected in these leaves. Ivanitskaya (1962) made similar observations, i.e., in cotton grown in NaCl-amended soil the area of individual cells was less affected than total cell numbers and leaf one was affected to the same extent as other leaves. Strogonov (1964) came to a similar conclusion, that in cotton salinity inhibits cell division and stimulates cell expansion.

The mechanism for growth inhibition under saline conditions is still debated. It may be an osmotic phenomenon, or caused by a specific ion effect. Cutler et al., (1977) found that under water deficit cotton cell size was smaller. In Ivanitskaya's (1962) study Na_2SO_4-treated cotton plants had smaller cell sizes while cell number was less affected, and NaCl-treated cotton plants had cell size larger

than the control, while cell number was decreased. Therefore, it may be that NaCl salinity causes growth reductions in cotton by a specific chloride effect on cell division. Other researchers, however, have shown that water stress in cotton affects cell division, not cell expansion (Berlin et al., 1982). When one looks at the literature on other species the lack of consensus continues. NaCl has been found to affect primarily cell size in kenaf (Curtis and Läuchli, 1987), and in bean it has been reported to decrease cell size without affecting cell number (Meiri, 1967), and to decrease cell number, while having a minor effect on cell size (Wignarajah et al., 1975).

In cotton there is not a simple correlation between biomass and yield (Mantell et al., 1985). All experiments in the present study were terminated close to the end of the vegetative stage, at the onset of the reproductive phase. Cotton becomes less sensitive to salt at flowering, and the reduction in tissue potassium due to salinity is less (Lashin and Atanasiu, 1972). Flowering and bott opening are stimulated by Na (Mantell et al., 1985), although Na also increases boll shedding, and reduces fiber yield and quality, while potassium improves fiber quality (Marcus-Wyner and Rains, 1982). Consequently, no definitive conclusions as to lint yield or quality can be made based upon the results of the present study. It is possible, however, to conclude that salt stress has a detrimental effect on vegetative growth of cotton which cannot be offset by K amendment.

The ion data indicate some interesting conclusions as to how cotton deals with nutritional disorders. Leaf ion levels seem to be more closely correlated with leaf age than with plant age. Ca and Na increased and K decreased in expanded leaves in all treatments. Also young leaves seem to be buffered from some of the nutritional vagaries which affect older leaf tissues. In young leaves Ca, Na and K contents were not influenced by the different treatments, while high external Na treatments increased Na accumulation, decreased Ca accumulation and increased the K depletion of leaves with age (Figs. A8A-C). K treatments had little effect on Ca and Na content in leaves. But, tissue K in older leaves increased with increasing K supply. High Na treatments caused significant declines in Ca levels of older leaves, whereas Ca in young leaves was unaffected by Na treatments (Fig. A8A). This result is in contrast to recent data obtained with barley (Lynch, Thiel and Läuchli, unpublished) and lettuce (Lazof and Läuchli, unpublished) where Ca supply to young leaves appeared very salt-sensitive. The mechanism of this differential response in cotton relative to two other crops species is unknown.

Sodium in the young leaves of high salt plants was maintained at a very low level, comparable to levels in older leaves at only 1 mM external NaCl (Fig. A8C). The level of Na in young growing tissue under high external salt conditions may be highly regulated. Na levels may be low in the young leaves due to dilution by rapid growth, while Na accumulates to high levels in the older leaves where it moves preferentially with the transpiration stream over extended periods of time.

Internal K also was strongly affected by Na treatment in the older leaves, while in younger leaves K levels were largely unaffected by external Na and maintained at high concentration (Fig. A8B). An interesting exception was the low, 0.1 mM K treatment (data not shown). Suboptimal K supply seemed to impair the ability of young leaves to maintain high internal K under high external Na, although it did not affect the ability of the young leaves to exclude Na. Potassium is a highly mobile ion. There is evidence in the literature that retranslocation of potassium is unaffected by high Na (Hajji and Grignon, 1985). K may reach the younger leaves through retranslocation from the older leaves, which suffered from salinity-induced potassium declines. On the other hand, young leaves have a high demand for K in cell growth. In cotton the young leaves seem to have a high selectivity for K, enabling them to maintain high internal K levels important to turgor regulation for growth under salt stress.

The older leaves seem to undergo definite changes in ion levels with changing LPI. This has also been found to be the case for K contents of grape leaves (Freeman and Kliewer, 1984; Malstrom, 1964). Movement and partitioning of nutrient elements in cotton seems to be under a high degree of control. Young leaves have the ability to maintain adequate Ca and K and low Na levels at high external Na concentrations. Cotton is a Na accumulator, but it seems to be able to tolerate high shoot Na levels by setting up a K/Na selectivity in young leaves, in addition to K/Na selectivity in the root (see Läuchli and Stelter, 1982). It must be concluded, however, that supraoptimal K supply cannot ameliorate the negative effects of high external Na on nutrition in cotton. There is probably little nutritional advantage to be gained from K fertilization of cotton under NaCl stress as long as K levels in the soil are adequate for normal growth under non-saline conditions.

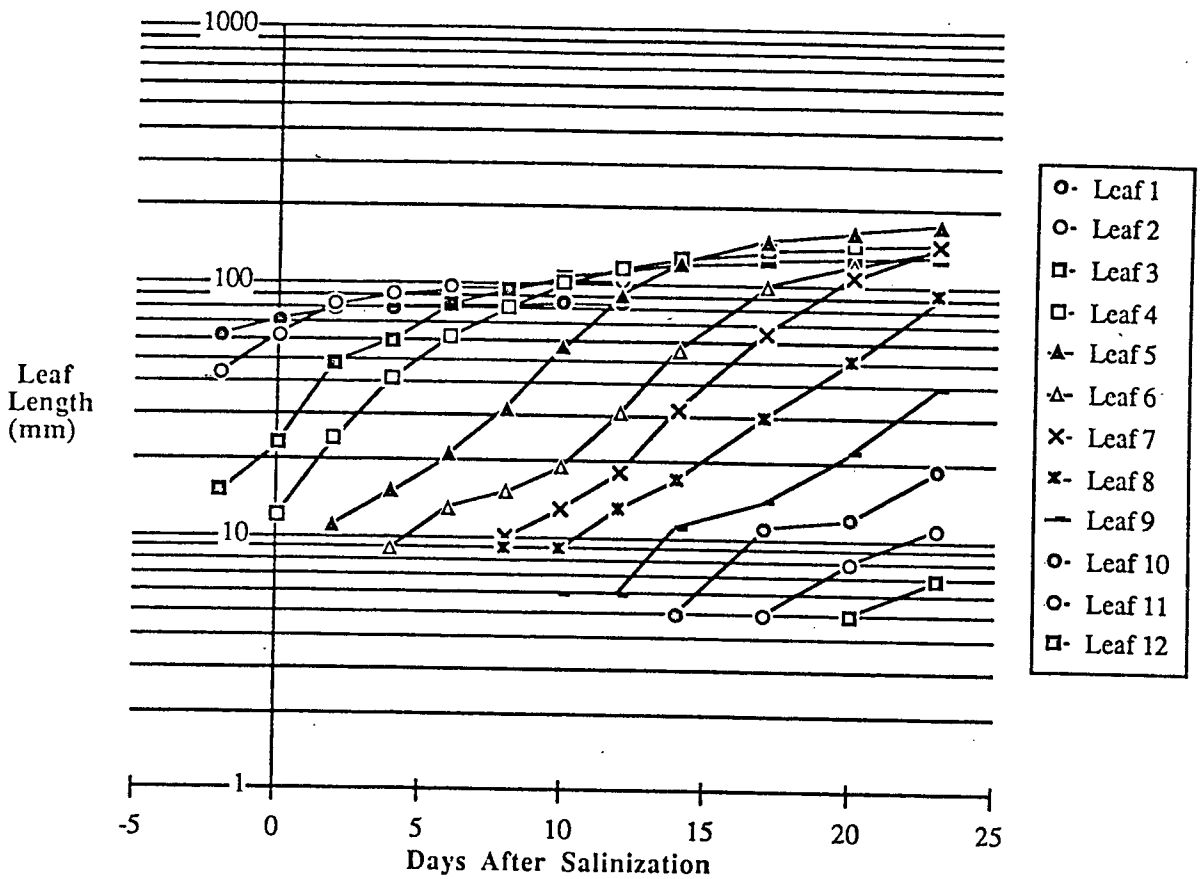


Fig. A1. Logarithmic plot of leaf length of successive leaves as a function of time for a single plant. (Experiment 3).

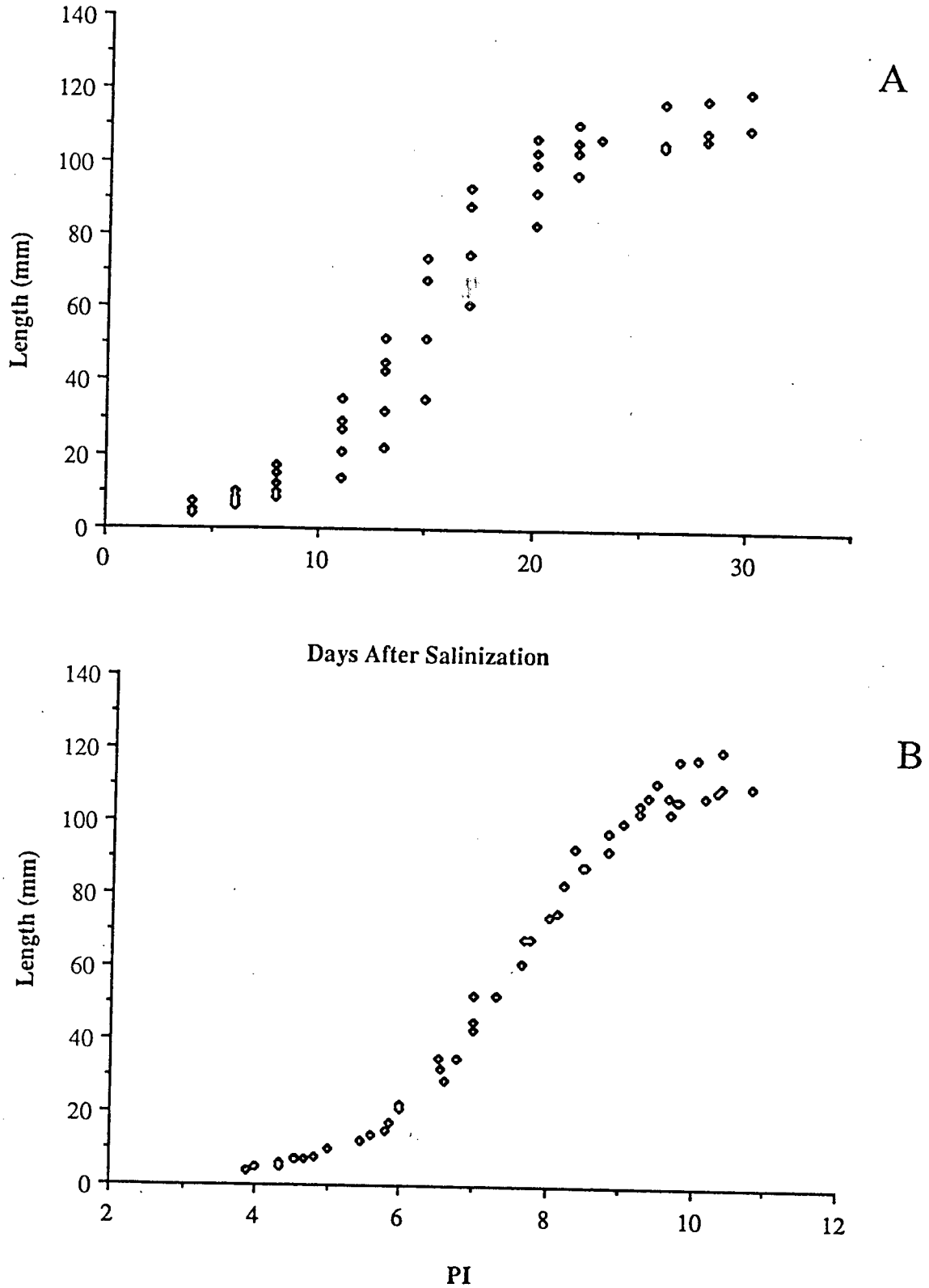


Fig. A2. Leaf length of leaf 5 as a function of days of growth (A) and of Plastochron Index PI (B). (Experiment 4).

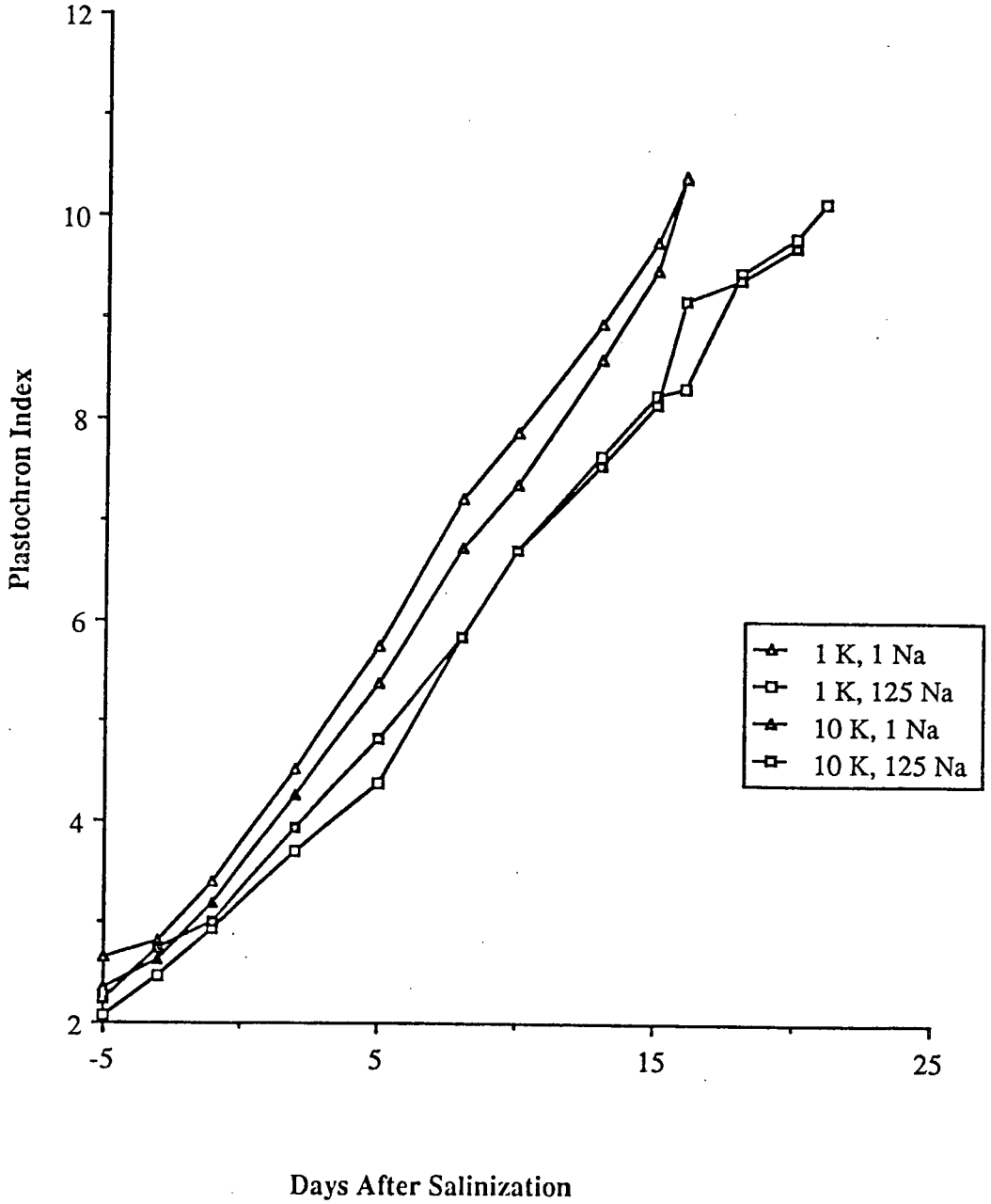


Fig. A3. Effect of K/Na ratio on plastochron index. Means, n = 6. (Experiment 4).

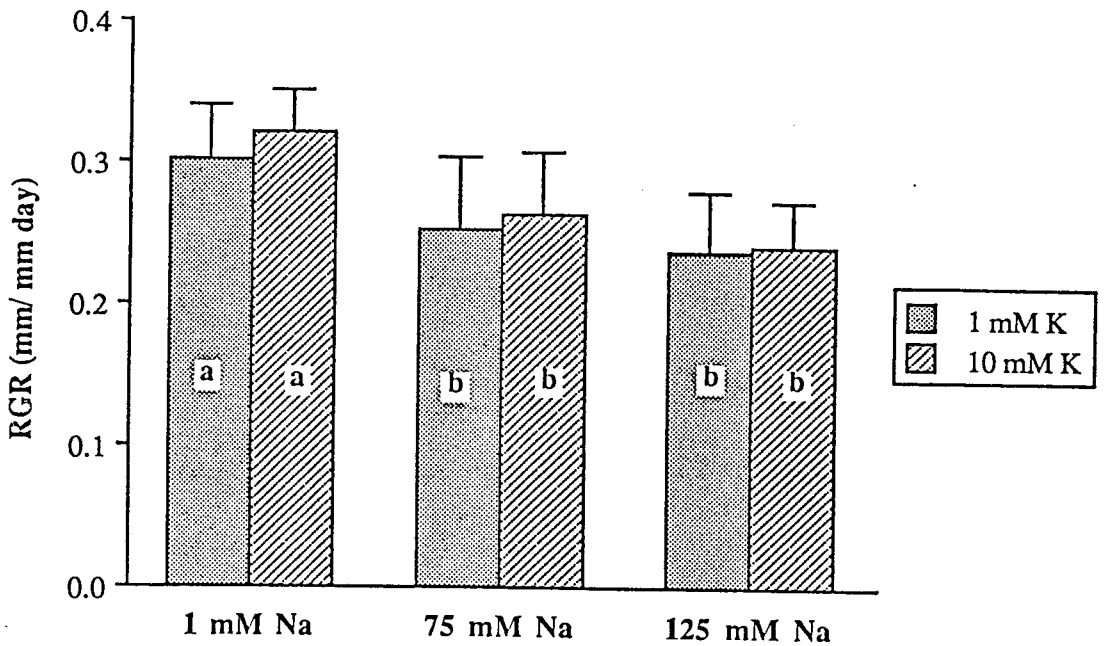


Fig. A4. Effect of K/Na ratio on leaf relative growth rates (RGR). Means ± S.D., n = 18. Columns with the same letter are not significantly different at the 95% level according to Fisher's PLSD. (Experiment 4).

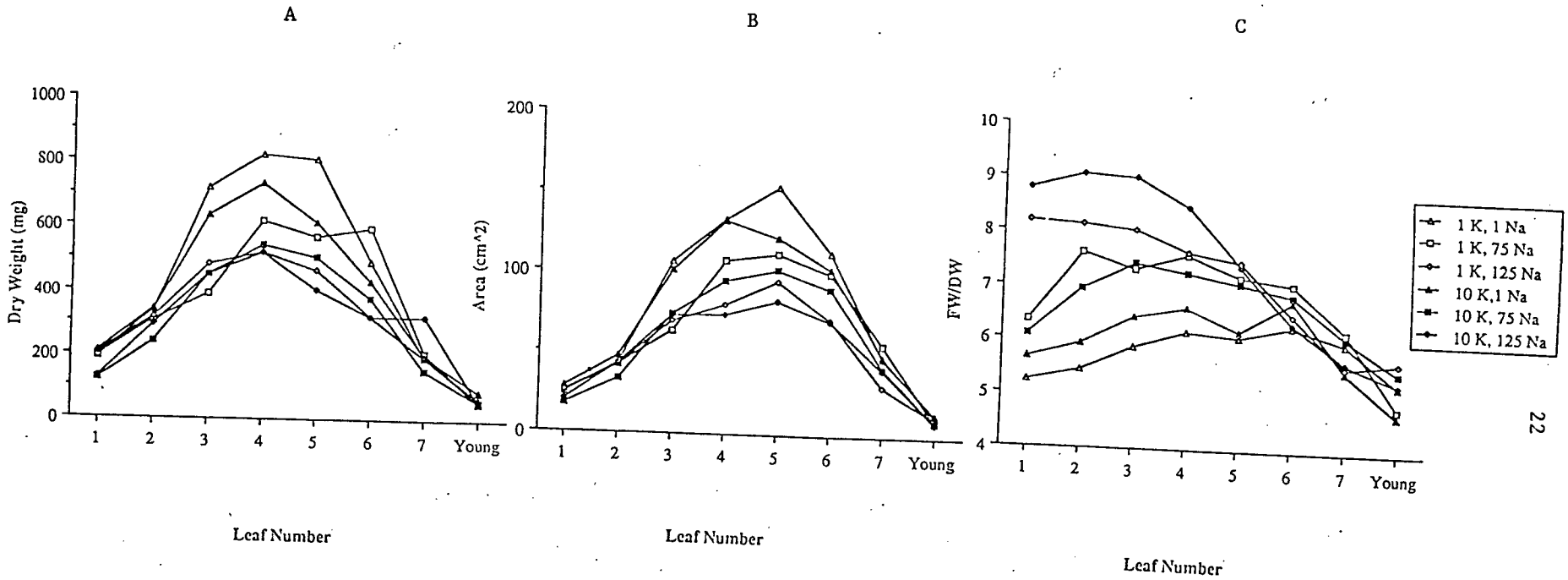


Figure A5. Effect of K/Na ratio on leaf dry weights, (A), areas, (B), and fresh weight: dry weight ratios (FW/DW) (C). Means, n = 6. (Experiment 4).

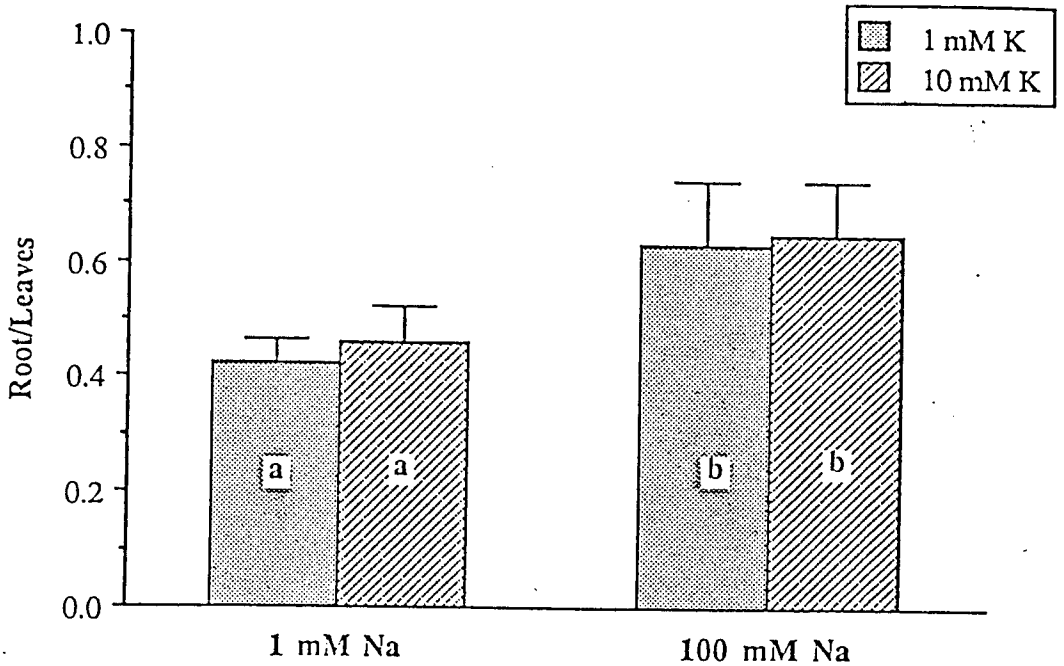


Fig. A6. Effect of K/Na ratio on root:leaf dry weight ratios. Means ± S.D., n = 6. Columns with the same letter are not significantly different at the 95% level according to Fisher's PLSD. (Experiment 3).

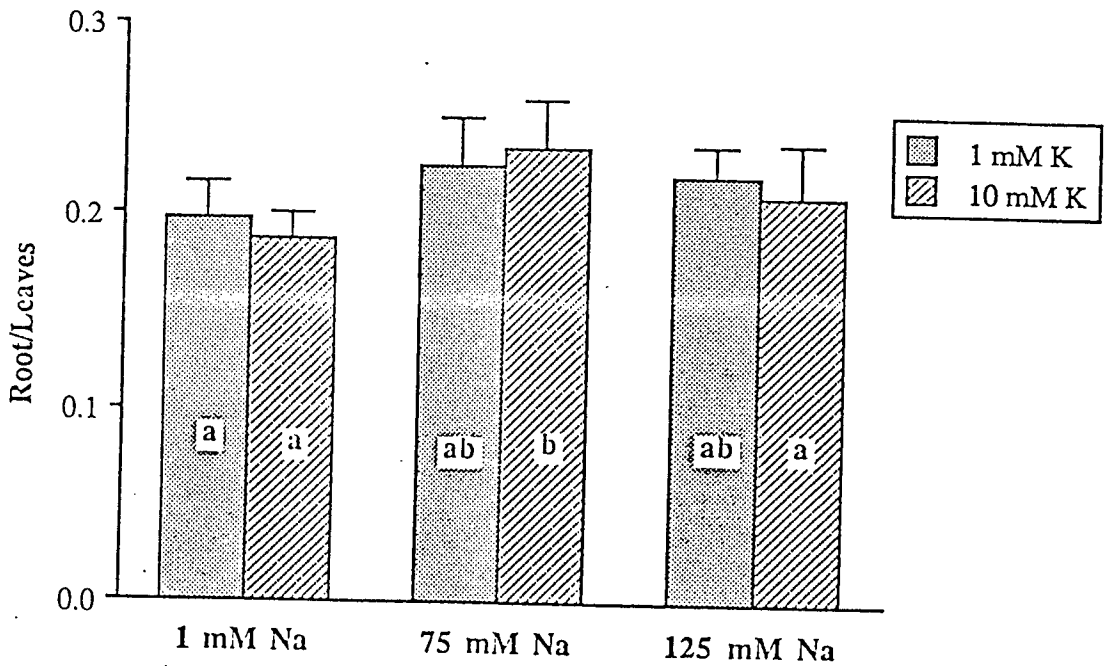
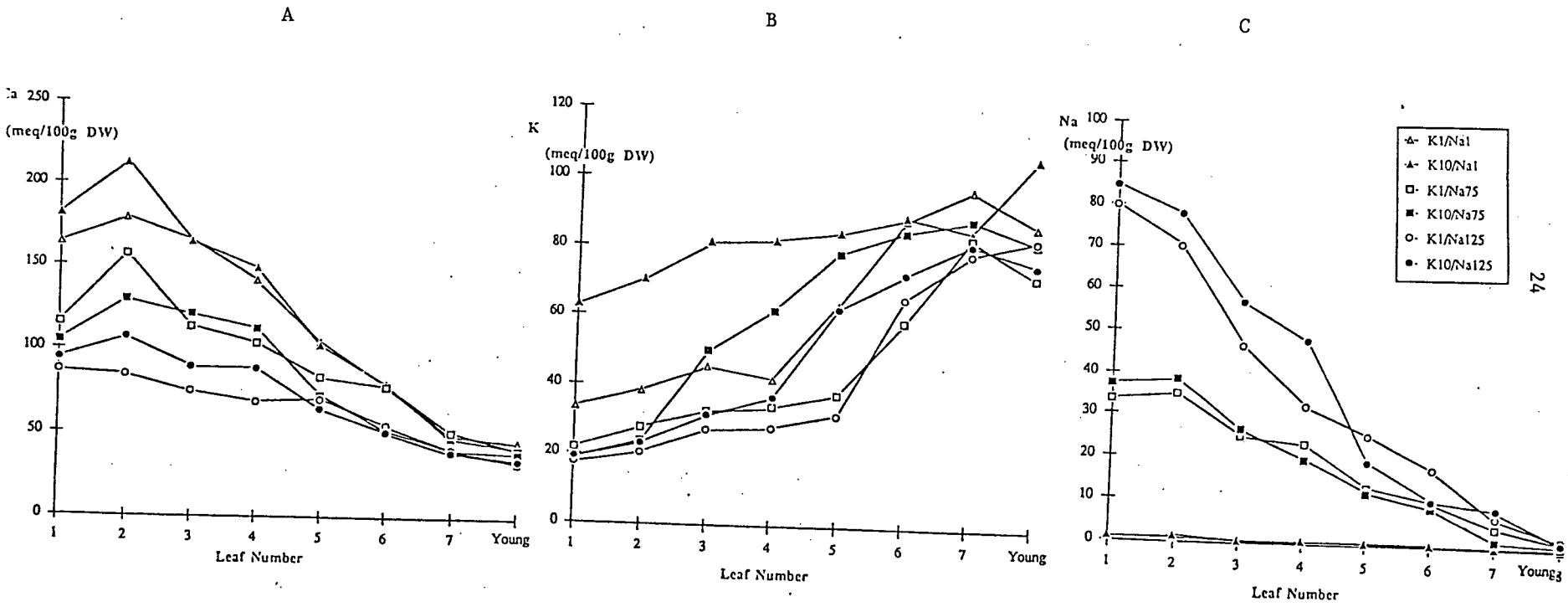


Fig. A7. Effect of K/Na ratio on root:leaf dry weight ratios. Means ± S.D., n = 3. Columns with the same letter are not significantly different at the 95% level according to Fisher's PLSD. (Experiment 4).

Figure A8. Effect of K/Na ratio on leaf calcium (A), potassium (B) and sodium (C) levels. Means, n = 6. (Experiment 4).



B. Potassium requirement of cotton under different salinities.

A. Meiri and Margot Shuali

Introduction.

For most agricultural soils the soluble K concentration is < 1 mM. Plants with a high-affinity K uptake system can grow well in nutrient solution of very low K concentrations provided the K supply is maintained (Asher and Ozanne, 1967). In soil this supply is maintained by the release of exchangeable or fixed potassium from the solid phase and by mass-flow and diffusion of K from the bulk soil into the rhizosphere. Sodium salinity decreases plant growth and Na competes with K uptake. Both effects decrease the K requirements of the plants. But Na interference to uptake may require a higher soil solution K concentration for optimal growth. The main objectives of these experiments were: to study the potassium requirements of cotton under saline conditions; to find to what extent high sodium reduces K uptake; and to find whether tissue K requirements change under saline conditions. The K range tested was 0-2 mM. The effects were studied from the analysis of the response functions of different plant parameters to K concentration in the medium at given salinities.

Materials and methods.

Two experiments where conducted in a controlled temperature (25+-2Co) glass house in Bet-Dagan, Israel. Exp. 1 compared 8 K levels (0.027-1.018mM) in a non saline solution during the period Dec. 86 - Jan. 87. Exp. 2 compared 7 K levels (0.05-2.05mM) in two salinities, medium (50 mM NaCl) and High (100 mM NaCl), during the period March - Apr. 87. Day length and radiation differed between periods and relative humidity was not controlled.

To obtain a series of low K concentrations the seedlings where transferred into a modified half strength Hoagland solution with no K (K was replaced by NH_4). Then the K concentration was raised to the expected levels with KNO_3, and maintained in each pot with KNO_3 solution supplied continuously with a peristaltic pump. The concentrations and flow rates were estimated to cover a wide range of K supplies, and most treatments were supplied with less than the plants' requirements for maximum growth. Preliminary data of K uptake for plants of different sizes was used to estimate the K input. In each case the number of plants left in the container was considered. We assumed that K uptake is a function of the solution concentration and the plant size. With these assumptions an input of less than the maximum uptake rate should establish a steady state. This steady state as defined by input-uptake implies a constant medium concentration if the medium volume is constant. Volumes were maintained by a constant head water supply. Volumes, K concentration, salinity, and inputs of water and K were monitored daily. These measurements allowed daily balances, and estimates of ET and ion uptake.

Cotton (var. SJ2) was germinated in vermiculite. Fourteen seedlings where transferred into 14.5 liter pots 13 and 9 days after planting (DAP) in the non saline and saline experiments respectively. Each treatment was in a single pot. Plants were harvested progressively to monitor growth, and tissue ion contents and sap

composition were determined on composite samples of 2-4 plants. The small plant number helped in maintaining a stable uptake and concentration in each container. The plants were divided into stems+petioles and leaves of different development stages and fresh weights determined. The leaves were divided into two subsamples. One was frozen and then sap was expressed and monitored for OP, EC and RI. The second leaf subsample and the stems were oven dried. The dry matter was analyzed for Cl, K and Na in weak acid extract. As leaves showed different levels of green color, the leaves of the final harvest were analyzed for chlorophyll.

For non destructive growth analysis the four plants left for final harvest served as replications. Daily leaf lengths of these plants were analyzed according to the plastochron index procedure (Ericson and Michalini,1957). The lnL (natural log of the length measurements of each leaf) were plotted over time. Then a linear regression was calculated for all the points that showed a constant relative elongation rate (RER). For different leaves the number of observations was 3 to 8 (mean 4.55) and the regression coefficient $r^2>0.86$. The age for a given plastochron was taken as the age when this leaf reached the length of 20 mm. The leaf emergence rate (LER) expressed as mean interval in days per plastochron was calculated as linear regression of the age in days over the plastochron of all leaves on a given plant. The final length of individual leaves and the linear rate of increase in total leaf length (Sum of all leaf lengths) were also used as non destructive growth parameters.

The differences between K levels in the different salinity levels prevented the use of analysis of variance to compare treatment effects; The analysis considered the response functions to K, an approach that allows flexibility in the medium concentrations as long as we interpolate the results within a reasonable range.

Results and discussion.

Fig. B1 presents the K input and K concentration in the growth medium of representative treatments. It is evident that the experimental technique maintained constant K concentrations in growth medium when input rates where correctly estimated. With a too large input there was a gradual increase in the K concentration in the medium (Fig B1 initial period). Any stop in the supply resulted in a rapid decrease in the K concentration in the medium (Fig B1, days 33-35). The mean K concentrations of the growth medium prior to each harvest (Table B1) were used as the basis for the comparison of treatments effects. Adequate supply of all elements except K was achieved by replacing the solutions every 2 to 3 days. On replacements the old solution was analyzed and KNO_3 was added to restore the K concentration in each container.

Growth was monitored by daily measurement of leaf length, and by monitoring plant weights on each harvest. Weight data is presented as total weight per pot which is the sum of weights of all harvests and as the mean weight of plant that was left for final harvest (Table B2). For exp. 1 only shoot weight is presented and for exp 2. also the total weight which is the sum of shoot and root weight. The non saline

experiment (Exp 1) was conducted on December-January and the medium and high salinity experiments (Exp 2) on March-April.

Table B1. The mean concentrations of potassium and sodium in the medium of the different treatments (mean over time mM).

Low Salinity	Medium Salinity		High Salinity	
K	K	Na	K	Na
0.027	0.048	51.53	0.063	98.09
0.027	0.072	50.91	0.136	97.97
0.128	0.192	49.03	0.298	102.13
0.291	0.482	48.50	0.623	99.69
0.751	0.693	48.34	0.900	99.06
0.770	1.460	53.16	1.493	103.50
0.976	2.042	51.38	1.901	92.25
1.018				

The less favorable growth conditions for cotton on January than on March resulted in smaller plants. In the non saline experiment the highest K level treatment was 1 mM and in the saline experiments it was ~2 mM.

Table B2. The influence of the medium K levels under three salinity levels on cotton yields, as total yield per pot, which is the sum of weights of all harvests, and weight of the final harvest plants (Dry matter yields g).

Low Salinity		Medium Salinity			High Salinity			
Per Pot	Per Plant	Per Pot		Per Plant		Per Pot		Per Plant	
Shoot	Shoot	Total	Shoot	Total	Shoot	Total	Shoot	Total	Shoot
14.62	2.08	20.99	25.10	2.69	3.22	17.12	21.02	2.26	2.80
25.37	4.51	29.86	35.87	4.58	5.73	27.47	33.98	4.06	5.01
18.36	3.33	33.69	42.57	5.79	7.43	24.03	31.06	3.67	4.89
27.13	3.72	26.82	34.34	4.70	6.16	21.79	26.98	3.09	3.71
32.68	6.57	34.35	41.86	4.53	5.54	18.24	24.66	1.57	2.34
30.84	3.25	27.04	33.88	3.24	4.04	20.36	27.10	2.89	3.81
33.24	5.04	27.68	33.97	2.65	3.30	24.10	29.93	3.49	4.37
35.60	6.52								

The dry weights of plants in the low salt experiment (Exp 1) increased with the increase of K concentrations up to 1.01 mM. An initial strong response below 0.29 mM was followed by a more gradual response. The initial rapid response was similar to the response of many plants as reported by Asher and Ozanne (1967). But the gradual response range exceeded the range of response to solution K for most plants. For the medium and high salt levels (Exp 2) total weights per

pot were larger at the lower salinity. The final plant weights were greater in the lower salinity only in K levels 2-4. In both salinities maximum weight was found with solution K concentration of about 0.1 mM (K level 2 and 1 in the medium and high salt, respectively), with some yield reduction at higher K concentration. The data are very scattered and from composite samples with no replications, and we cannot conclude whether the differences in the response function between the salinity or K levels were significantly different. The non destructive data of leaf lengths were analyzed using different parameters. The total elongation rate of all leaves (sum of all leaves per plant) (Figure B2) agrees with the weight data of final harvest of Exp 2. It shows optimal K concentrations for both salt levels, and larger plants at the lower salinity in K solutions 2-4. Comparison of all three experiments shows that the K requirement for maximum growth decreased with the increase in salinity. The K concentrations that corresponded to maximum growth rates were 1.01, 0.48 and 0.14 mM/l for the low, medium and high salt respectively.

The leaf growth analysis that compared the age in days for different plastochrons and the initial relative elongation rates (RLER) for different leaves did not show clear differences due to K treatments except for a reduced RLER in the two youngest leaves at the lowest K treatments. The differences in final leaf length were also not significant in most cases.

Since low K treatments looked paler, leaves from the final harvest in the experiment 2 were analyzed for chlorophyll content. Figure B3 presents data of young and mature leaves for all K levels and the two salt levels. In all cases the chlorophyll reached maximum levels at about or less than 0.1 mM K in solution. The chlorophyll content was somewhat higher at the lower salinity. Differences between leaf groups within the same salinity were not synchronized with age.

For the non saline experiment the sap analysis for OP and K of fully developed and small leaves (< 30 mm) is presented in figure B4. The young leaves show higher sap Op and higher sap K content. Increasing solution K level produced a lower OP in small leaves, and a higher sap K which was most clear in old leaves. In the saline experiments sap and dry matter analysis data are presented. Leaf sap Op and EC was higher in the high salt treatments (Figure B5). At high solution K, sap OP and EC were somewhat lower in the older leaves (no. 2) and higher in young leaves (4 or 5). The dry matter analysis data is presented for the different leaves in 4 treatments (low and high salinity and k) (Figure B6) and for the young and the mature leaves in all treatments (Figure B7). The data show age and treatment effects. An increase in salinity increased the tissue chloride and sodium content, and decreased the tissue potassium content. Salinity effect on tissue K was small in low K treatments and in old leaves but decreased by 30% the K content in young leaves of high K treatments. Increase in medium K increased K in all tissues. This effect was relatively small in mature leaves and was very large in the young leaves and in stems+petals. In the K deficient treatments the tissue K content which was low in all leaves increased in the young leaves more than in the stems. The medium K had a small and inconsistent effect on the tissue Na or Cl content. Cl and Na increased and K decreased significantly with leaf age. Stems+petioles were similar to young

leaves. There is a preference for Na accumulation in old leaves and K accumulation in young leaves.

Considering the low levels of K in the solutions it was not expected to have a significant competition effect on the uptake of Na or change in the uptake of Cl. On the other hand the tested solutions K concentration range should cover deficient as well as sufficient K levels. And the tissue K analysis indeed show very large differences in response to all mentioned factors. In all cases the high solution K resulted in a high tissue K.

The K/Na ratio changed during development of each leaf. Potassium accumulated preferentially in young leaves. Therefore, in a growing leaf K/Na was initially larger and it decreased to <1 in older leaves. For each leaf the tissue composition reflects the balance between influx and efflux. The influx may reflect both xylem and phloem transport. The efflux is only phloem transport. We don't know about any selectivity mechanism that will preferentially change the composition of the xylem reaching different leaves. Also this change in composition should all be controlled by phloem transport.

A comparison of the growth data (Table B2, Figure B2) with tissue K and Na data (Figures B4,B6,B7) show that a wide range of tissue K or Na and K/Na ratio does not change growth. Reduced growth in saline treatments was found only at solution K < 0.1 mM, while tissue K increased up to 0.4 mM solution K. Growth data (Table B2, Figure B2) indicate that Na may replace K function under K deficiency, since the solution K sufficient for maximum growth decreased with the increase in salinity.

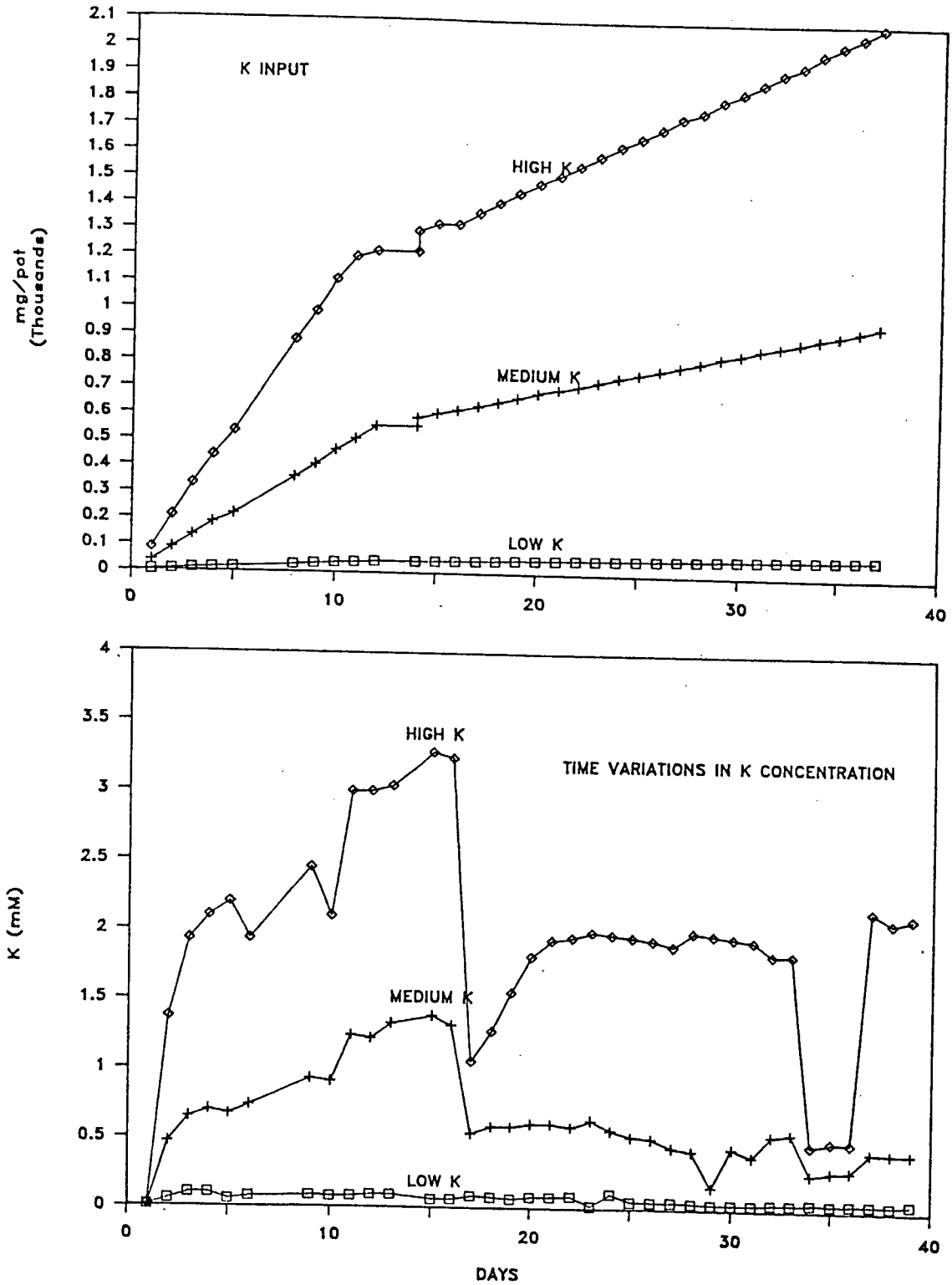


Figure B1. K input and time variations in the solution K concentrations in 3 representative treatments in the medium salinity experiment.

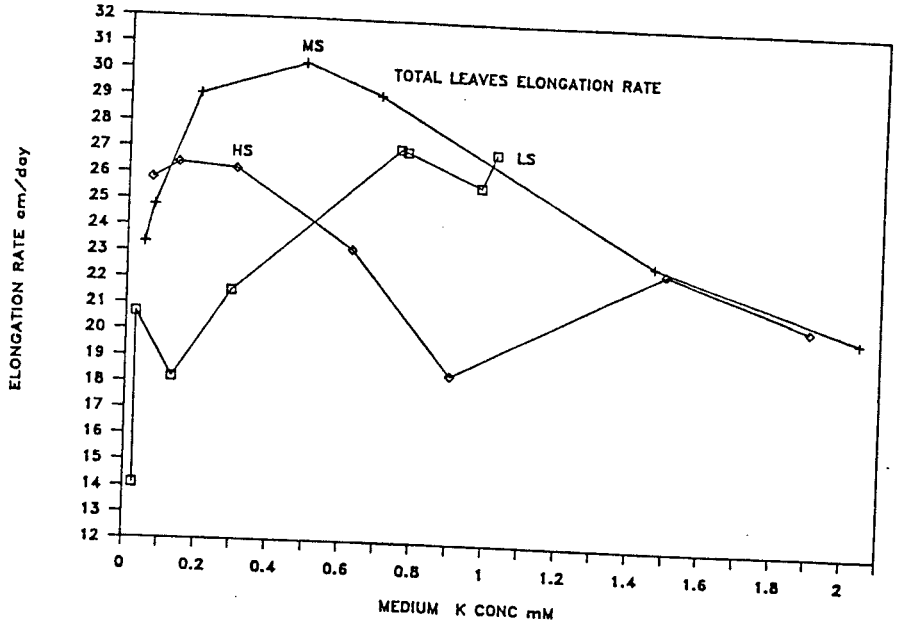


Figure B2. The influence of the nutrient solution salinity and K levels on the elongation rate of plant leaves (Sum of all leaves lengths).

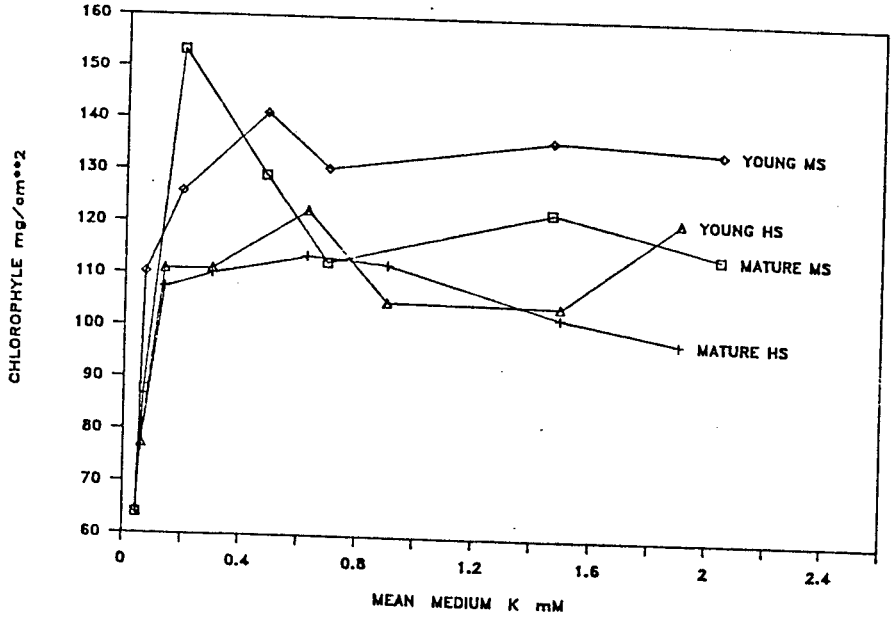


Figure B3. The influence of the nutrient solution salinity and K levels on the chlorophyll content of cotton leaves of different age.

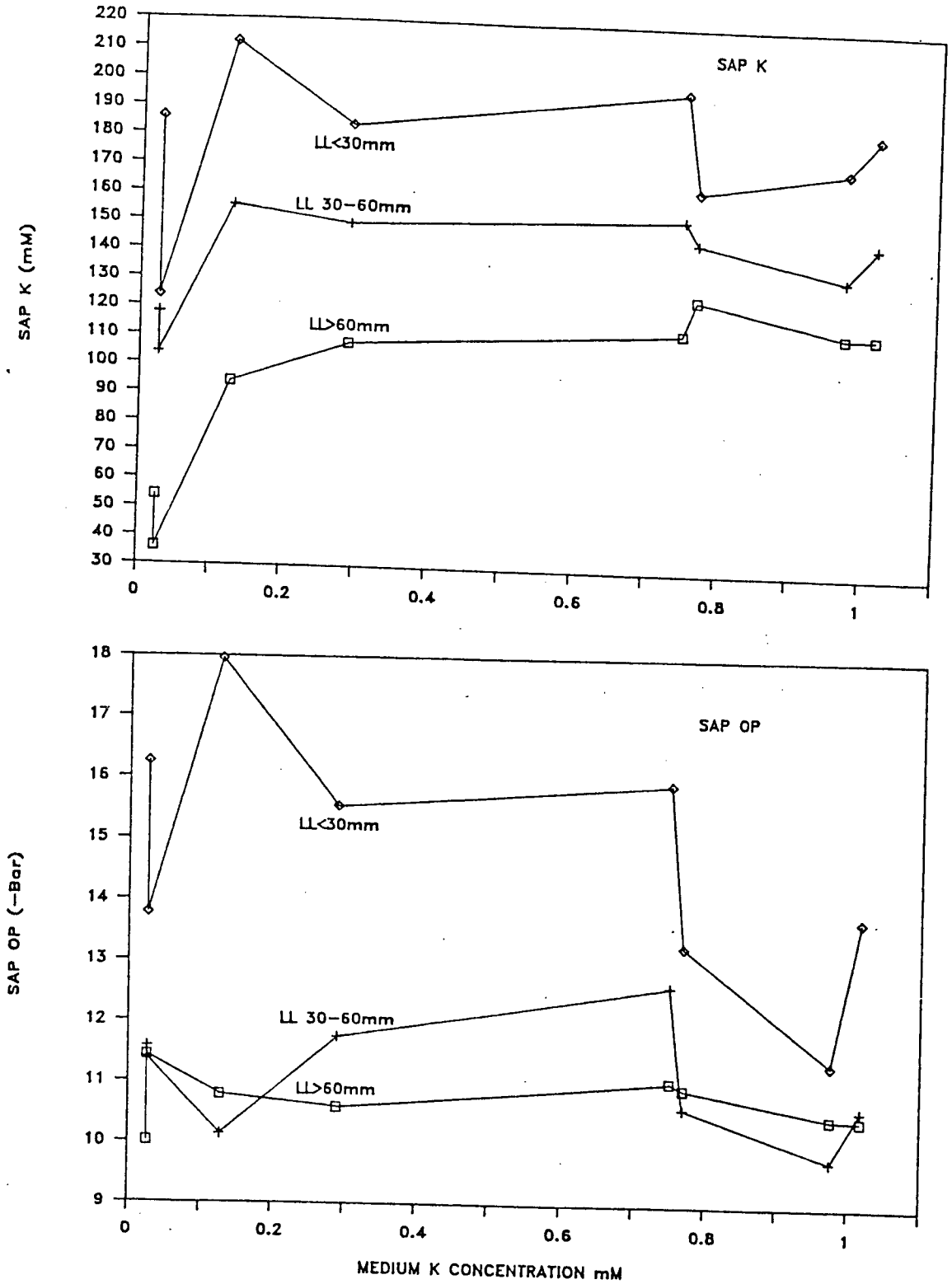


Figure B4. The influence of leaf growth stage and the K content in a non-saline nutrient solution on the leaves sap OP and K content.

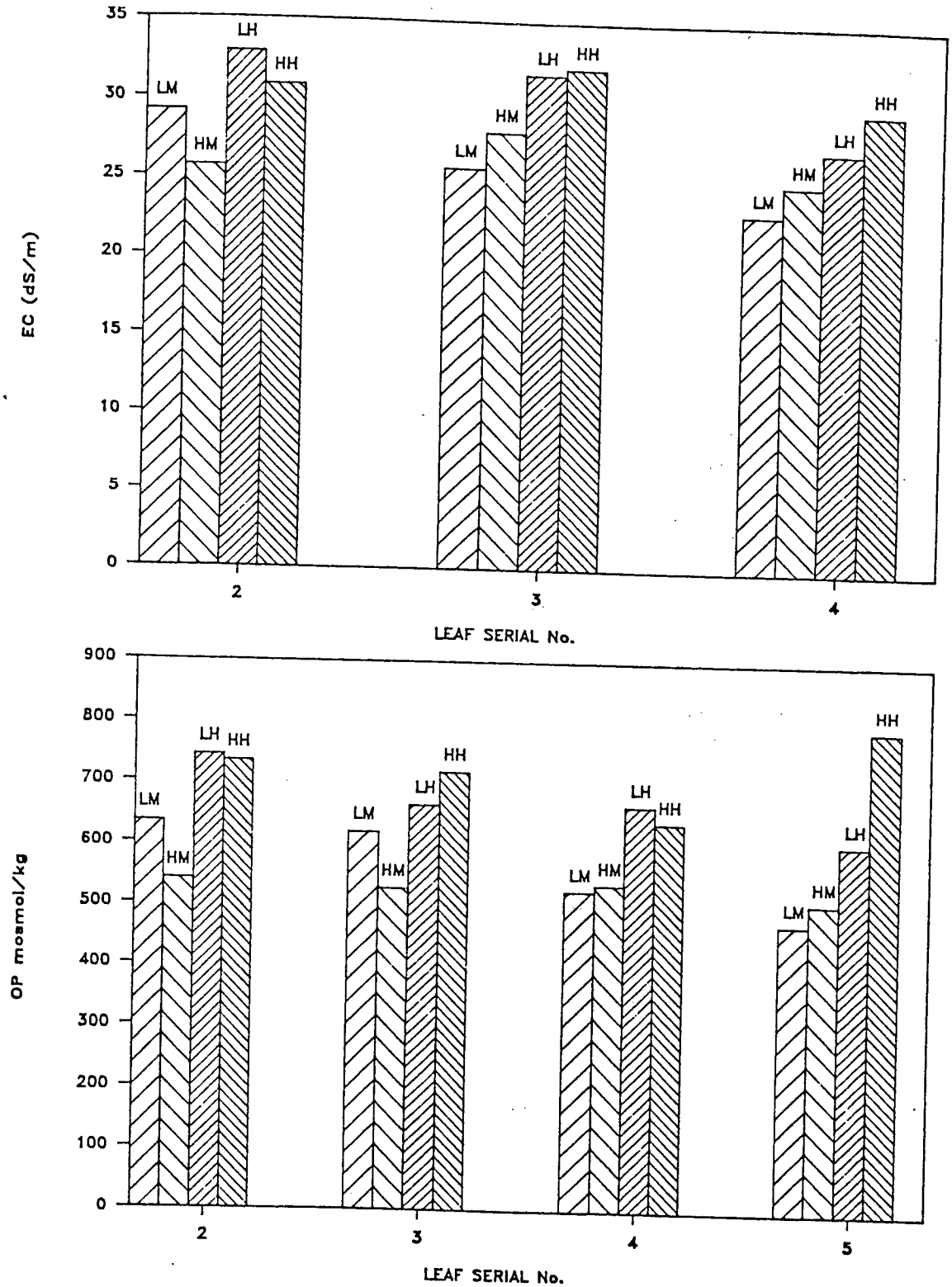


Figure B5. The influence of the solution salinity and K levels on the EC and OP of the sap of leaves of different age (Leaf age = leaf serial number. First label on each column for K and second for salinity. L,M,H = Low, Medium and High).

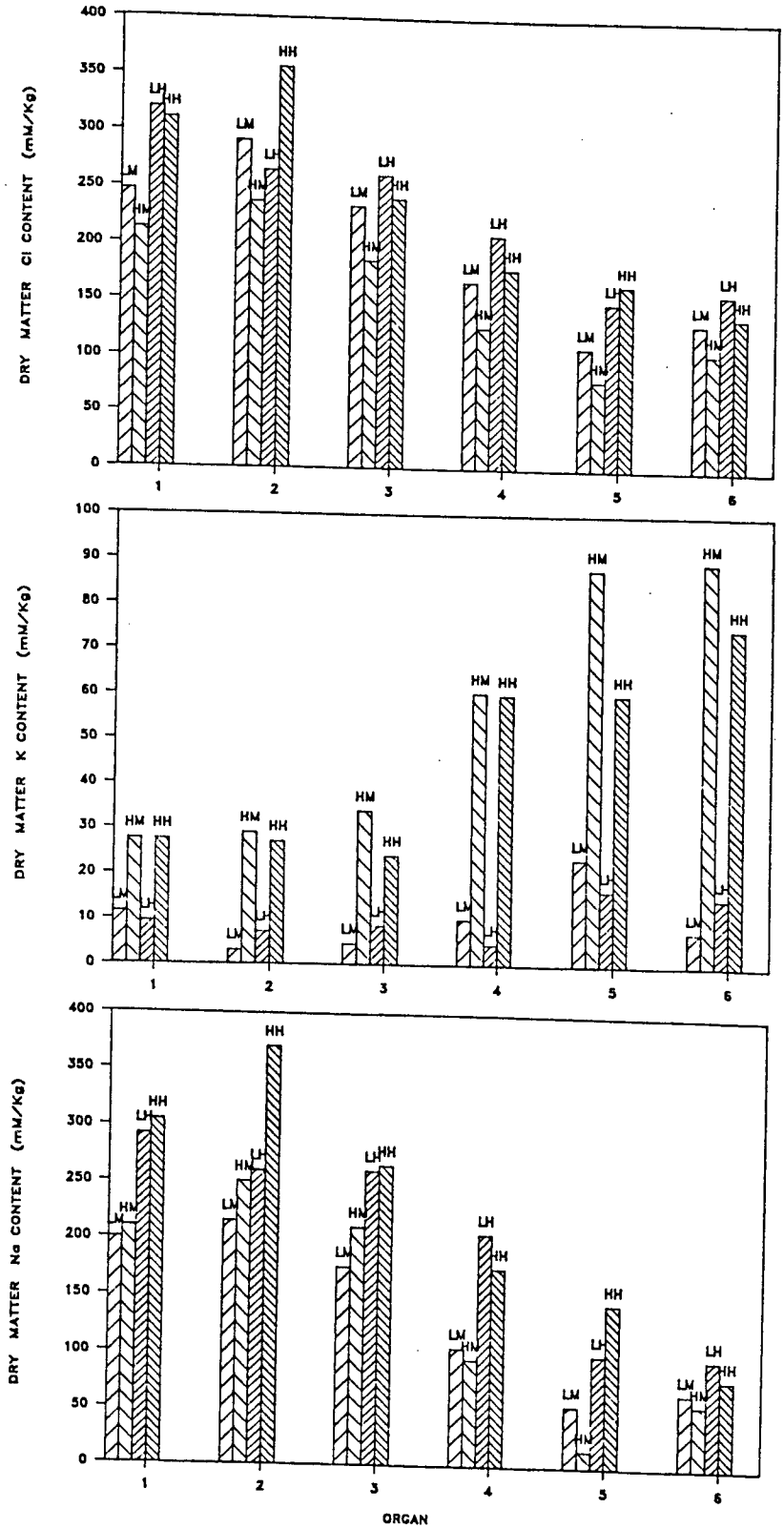


Figure B6. The influence of the solution salinity and K levels on the Cl, K and Na content in different organs. (1-5 = serial leaf number, 6 = stems+petals. First label on each column for K and second for salinity. L,M,H = Low, Medium and High).

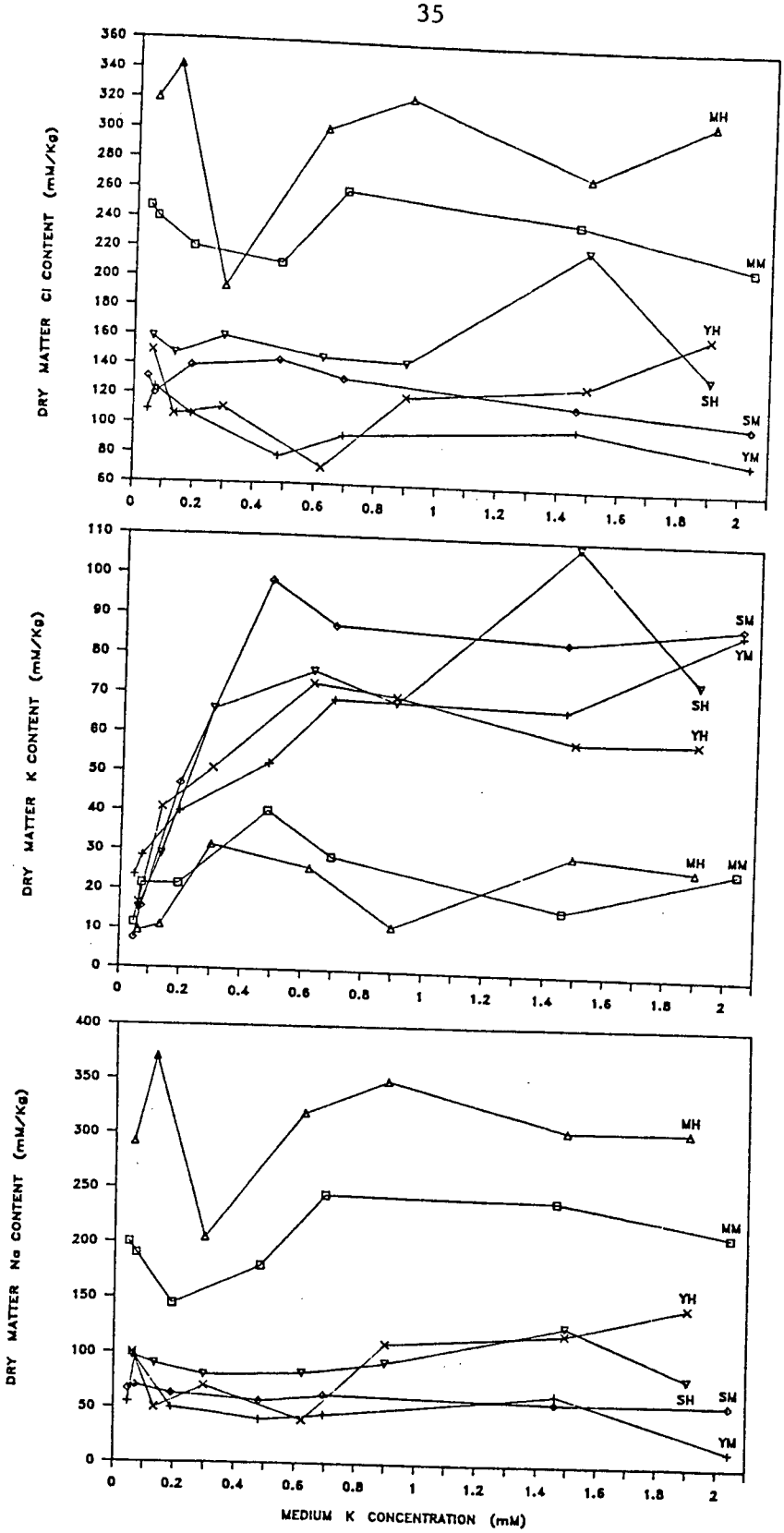


Figure B7. The influence of the solution salinity and K levels on the Cl, K and Na content in young leaves, mature leaves and stems+petals. (Labels are Y, M , ST = young, mature and stems+petals; L and H Low and High salinity).

C. The effect of Na/K salinity on growth and the solute composition of leaves of cotton, peanut and melon seedlings.

D. Lauter, A.Meiri, A. Feigin and M. Hinnen.

Introduction.

Salt stress increases the concentration of inorganic solutes in plants and often increases the concentration of organic solutes such as sugars and organic acids (Cochian and Lucas, 1982). In some instances the effect of salt stress, or high osmotic pressure in the rooting medium, (OP_o), on the solute composition of the plant has been associated with a decrease in growth (Bolanus and Longstreth, 1984). However, iso-osmotic media of different composition can cause changes in the concentration of inorganic ions in a tissue without affecting growth (Bernstein, 1963). With such evidence some have concluded that salt stress is usually unrelated to inorganic ion content in a tissue, and that plants can tolerate a wide range of different solute composition (Bernstein, 1963. Hsiao et al, 1984). Others have claimed that ion excess may still be the principal cause of salt stress, but the type of ion that accumulates in a tissue is of less consequence than the total amount of ions in a tissue and their distribution among organelles (Gifford and Evans, 1981. Mott and Steward, 1972).

Low growth rate and high solute availability will increase OP_i and turgor in the absence of a turgor regulatory mechanism (Cram, 1976. Stevenson and Cleland, 1982). Also, not all higher plants can osmotically adjust, and many can only partially maintain turgor in response to salt stress and water deficit (Turner and Jones, 1980). The capacity of some higher plants to maintain a particular OP_i and cell turgor by the use of different solutes at the same OP_o, defined to be iso-osmotic regulation (Wyn Jones and Gorham, 1983), has been cited as evidence for a mechanism of osmotic and turgor homeostasis(Cram, 1976. Mott and Steward, 1972. Patrick, 1984). Different iso-osmotic media can have a negligible effect on growth (Bernstein, 1963. Rathert, 1982), so that the effect of iso-osmotic media on the composition of a tissue can be determined in the absence of interactions between growth rate and solute transport.

This study compared the growth and leaf sap osmolytes of three crops, differing in salt tolerance and Na uptake, in iso-osmotic media with different $[K]_o$:$[Na]_o$ ratios. An increase in $[K]_o$ fraction was assumed to increase the solute availability. The salt tolerance is in the order cotton > melon > peanut. Cotton and melon transport and peanut does not transport Na to the shoot.

Materials and Methods.

Peanut (Arachis hypogea L. cv. Shulamit), cotton (Gossypium hirsutum cv. Acala SJ2) and melon (Cucumis melo L. cv. Galia) were grown in greenhouses at Bet Dagan, Israel. The crops were treated with saline iso-osmotic nutrient solutions that contain different concentrations of $[K]_o$ and $[N]_o$ as chlorides, in addition, there were non-saline controls. Basal nutrients in the peanut and cotton experiments consisted of 2 mM $Ca(NO_3)_2$, 0.25 mM K_2HPO_4, 0.25 mM

KH_2PO_4, 1 mM $MgSO_4$, 1 mM $CaCl_2$, 1 mM KCl, 0.2 mM FeEDDHA, 12.5 M H_3BO_3, 2.5 M $MnCl_2$, 1 M $ZnSO_4$, 0.25 M $CuSO_4$, and 0.05 M Na_2MoO_4. Each experimental unit consisted of four plants in a bucket containing 15 liters. Solutions were watered daily to bring them to volume which resulted in relatively constant OPo. Experiments were terminated when controls had transpired a total of about 7 liters per experimental unit. Supplement 1 mM $Ca(NO_3)_2$, 0.25 mM H_2KPO_4 and 0.1 mM FeEddha were added to the controls and low salt level treatments after controls had transpired 5 liters.

In all treatments the basal Na concentration was 0.1 mM and the basal K concentration was 1.7 mM. For peanut at the lower salt level (Cl=30 mM, OPo=54 mosmol kg^{-1}) the $[K]_o$:$[Na]_o$ ratio in mM:mM was 0:30, 10:20, 20:10 or 30:0. At the high salt level (Cl=60 mM, OP_o=108 mosmol kg^{-1}) the $[K]_o$:$[Na]_o$ ratio in mM:mM was 0:60, 10:50, 20:40, 30:30,or 60:0. For cotton at the low salt level (Cl=75 mM, OP_o=135 mosmol kg^{-1}) the $[K]_o$:$[Na]_o$ ratio, in mM:mM was 0:75, 25:50, 50:25 or 75:0. At the high salt level (Cl=150 mM, OP_o=270 mosmol kg^{-1}) the $[K]_o$:$[Na]_o$ ratio, in mM:mM, was 0:150, 25:125, 50:100, 75:75, 100:50, 125:25 or 150:0. The treatment descriptions do not include basal concentrations. There were three replications of each treatment in the peanut experiment and four replications of each treatment in the cotton experiment.

The peanut experiment was carried out in July. Seeds were germinated on germination paper soaked with 1 mM $CaCl_2$. After 7 days seedlings were transferred to solution cultures inside a greenhouse. The treatments were applied at 11 days after planting. Plants were grown for the following 30 days, during which time the daily low and high temperatures averaged 26 and 38°C, respectively. Daily measurements of leaf length were started 10 days before harvest to differentiate between expanding and expanded leaves.

The cotton experiment was carried out in June. Seeds germinated in coarse sand which was prerinsed with saline solution (75 mM NaCl and 2 mM CaCl2) in order to prevent shock upon transfer to their treatments. After 5 days seedlings were transferred to their treatments. Plants were grown for 33 days after planting in an air-conditioned greenhouse. Temperature was maintained between 25 and 28°C. Daily measurements of leaf length started 22 days before harvest to differentiate between expanding and expanded leaves.

Melons were grown in a glasshouse in aeroponic system and were exposed, beside the non saline control, to two salt levels each with three different $[K]_o$:$[Na]_o$ ratios. The composition of the solutions and the experimental details are presented in the melon report (report E). The plants used in this part of the study were planted on January and harvested 43 days after planting. The $[K]_o$:$[Na]_o$ ratios in mM:mM were 5:5 in the non saline control (EC=1.5 dS/m); 5:40, 22.5:22.5, and 40:5 in the low salinity (EC=4.5 dS/m); and 5:80, 42.5:42.5 and 80:5 in the high salinity (EC= 9.0 dS/m).

Growth was measured by determining shoot dry weight at the end of the growing period of cotton and peanut, and by taking daily measurements of leaf length of cotton and melon. The relative rate of leaf elongation and leaf emergence rate of cotton and melon followed the plastochron model (Erickson and Michelini, 1957). Plastochron was

defined as a leaf at a length of 20mm (L_{ref}) and a plastochron index (PI) was the amount of plastochrons at a given time calculated according to eq. 1,

$$1)\ PI = n + (\ln(L_n)-\ln(L_{ref}))/(\ln(L_n)-\ln(L_n+1))$$

where ln is the natural logarithm, n is the serial number of a leaf longer than L_{ref} and L is leaf length in mm. The relative leaf elongation rates (R) was calculated from the linear regression of ln L over time for the exponential growth period of each leaf according to eq. 2,

$$2)\ \ln(L_t) = \ln(L_0)+Rt$$

where L_t and L_0 are the leaf lengths at time t and time 0. Leaf emergence rate (LER) was calculated according to eq. 3,

$$3)\ PI_t = PI_0+LER*t$$

Similar analysis for cotton growth was used by Papp and Läuchli (report A).

Between 21 and 30 days after planting (DAP), the pressure volume curve of expanding leaves of cotton (usually the second or third youngest visible leaf) was determined. The negative of the reciprocal of leaf water potential, determined by a pressure chamber, was plotted against the fraction of water lost and the sap osmotic potential was obtained from the extrapolation of the curve phase with zero turgor to the saturated volume. Our method generally followed the procedure of Bolanos and Longstreat (1984) for salt- stressed alligator weed. Maximum water content was assumed after plants were placed in a dark room for 12 h. Dehydration was accomplished by letting leaves dry in an open plastic bag at room temperature and thus only a small amount of water was expressed by the pressure chamber. The treatments that were measured had $[K]_o$:$[Na]_o$ ratios of 0:0, 0:75, 75:0, 0:150, 75:75 and 150:0 mM:mM. In each treatment, measurements were taken of three leaves, and each leaf was cut of different experimental unit.

Shoot weight and leaf samples of cotton and peanut were taken 34 and 30 DAP, respectively, and leaves of melon were sampled at 43 DAP. The night before harvest the peanut and cotton plants were placed in darkness at a temperature of 26°C. The following morning, samples were collected of the two oldest expending leaves and the youngest expended leaf. Leaves were taken only from the main branch of cotton and from two to three of the larger brunches of peanut. Melon leaves were sampled at predown and divided into three groups <60mm, 60-100mm and >100mm in length. The length groups correspond to fast growing, slow growing and fully expanded leaves. Leaves were frozen and the sap was expressed with a metal press. The osmotic pressure of the sap (OP_i) was determined by freezing point depression with a micro-osmometer (Precision Instruments). Other measurements of the aqueous contents in leaf sap included: K, Na, Cl, EC and index of refraction (IR), which were measured by flame photometer, chloridometer, electric conductivity meter and a refractivity meter, respectively.

The contribution of K, Na and Cl to the EC in sap could be estimated from eq. 4,

4) EC(dS m-1) = (K*0.064 + Na*0.041 + Cl*0.065)*(M m-3/dS m2)

where the factor for each ion is its equivalent conductance at 25o C.

The influence of the $[K]_o$:$[Na]_o$ ratio on sap osmotic pressure, the contribution of inorganic ions to sap osmotic pressure, and the difference between sap osmotic pressure and the osmotic effect of inorganic ions was interpreted at each salt level by determining if the dependent variables were affected by $[K]_o$ according to a linear model. (The slope of a dependent variable vs. $[Na]_o$ is always the reverse of the $[K]_o$ effect). The concentration of K, Na,and Cl in leaf sap was expressed in mosmol kg-1 which is equal to the concentration in mM times an osmotic coefficient of 0.9 mosmol kg-1 mM-1.

Results.

Growth .

Increase in salinity reduced the growth of all three crops. For cotton and peanut a wide range of $[K]_o$:$[Na]_o$ ratios in the rooting media within each salt level did not affect shoots wights or leaves length (Table C1). Only at the high salt level and at the highest ratios was there evidence of a growth inhibition which was associated with the appearance of necrotic leaf margins. While, melon, show a larger damage by iso-saline media high in [K]o (see melon - report E tables E2, E3). Melon plants that were grown to maturity stopped growth earlier and did not yield fruit at the high [K]o high salinity.

Necrotic leaf margins showed up on the older leaves due to the ionic composition of a medium in both cotton and peanut. In cotton, necrosis appeared at a $[K]_o$:$[Na]_o$ ratio of 125:25 which did not affected more than Na salinity the emergence and expansion of leaves or shoot dry weight (Tables C1, C2). In peanut necrosis appeared at a $[K]_o$:$[Na]_o$ ratio of 60:0 which also decreased shoots weight (Table C1).

Table C1. The effect of the medium salinity $[Cl]_o$ and the $[K]_o$:$[Na]_o$ ratio on cotton and peanut shoot dry weight, leaf length and weight of leaves with necrotic edges. (Data are means and standard error (SE). 'Shoot weight' is the total weight including necrotic leaves. 'Leaf length' is the length of expanded leaves on the main branch, not including the seed leaves).

$[Cl]_o$	$[K]_o$ (mM)	$[Na]_o$	Weight (g dry weight/plant) Shoot	Necrotic Leaves	Leaf Length mm
			Peanut		
0	0	0	8.63 (0.80)	- - -	59 (3)
30	0	30	8.08 (0.40)	- - -	58 (1)
30	10	20	7.68 (0.18)	- - -	56 (2)
30	20	10	7.84 (0.36)	- - -	59 (2)
30	30	0	7.79 (0.45)	- - -	56 (4)
60	0	60	6.69 (0.42)	- - -	51 (1)
60	10	50	6.35 (0.17)	- - -	54 (2)
60	20	40	5.99 (0.52)	- - -	51 (1)
60	30	30	7.18 (0.61)	- - -	53 (2)
60	60	0	4.66 (0.19)	1.29 (0.22)	51 (4)
			Cotton		
0	0	0	7.85 (0.36)	- - -	133 (3)
75	0	75	6.04 (0.24)	- - -	122 (4)
75	25	50	6.37 (0.13)	- - -	120 (3)
75	50	25	6.47 (0.27)	- - -	113 (2)
75	75	0	5.46 (0.23)	- - -	119 (3)
150	0	150	2.67 (0.15)	- - -	102 (3)
150	25	125	2.92 (0.08)	- - -	96 (3)
150	50	100	3.25 (0.10)	- - -	94 (3)
150	75	75	2.56 (0.18)	- - -	95 (3)
150	100	50	3.30 (0.25)	- - -	97 (2)
150	125	25	2.96 (0.19)	0.24 (0.10)	97 (4)
150	150	0	2.11 (0.08)	0.68 (0.03)	92 (2)

Among indicators of cotton growth, based on leaf length, the relative rate of leaf elongation (R) was least sensitive to the medium salinity or composition (Table C2). Leaf emergence rates (LER) (Table C2) and the length of expended leaves (Table C1) were inhibited by high salinity but were unaffected by the composition of iso-osmotic media up to 125 mM $[K]_o$ (Table C2). Only the [K]o:[Na]o ratio of 150:0 caused a decrease in LER (Table C2) and in the length of expanded leaves (Table C1). The leaf growth parameters of melon show a higher sensitivity than cotton leaves. R of melons leaves decreased with the increase in salinity with no clear composition effect, and LER decreased also with the increase in $[K]_o$ fraction (Table C2).

Table C2. The influence of the medium salinity $[Cl]_o$ and $[K]_o$:$[Na]_o$ ratio on cotton and melon leaves development according to the plastochron model. (Relative leaf elongation rates (R) and leaves emergence rates (LER) were calculated according to eq. 2 and 3 respectively, Lref was 20 mm).

$[Cl]_o$	$[K]_o$	$[Na]_o$	LER	R
	mM		PI*day-1	day-1
		Cotton		
0	0	0	0.4265	0.3487
75	0	75	0.4145	0.3446
75	25	50	0.4289	0.3687
75	50	25	0.4294	0.3567
75	75	0	0.4213	0.3576
150	0	150	0.3347	0.3489
150	25	125	0.3312	0.3521
150	50	100	0.3525	0.3329
150	75	75	0.3207	0.3335
150	100	50	0.3687	0.3617
150	125	25	0.3209	0.3620
150	150	0	0.3094	0.3523
		Melon		
10	5	5	0.3392	0.2046
50	5	45	0.2725	0.1874
50	25	25	0.2849	0.1930
50	45	5	0.2525	0.1824
90	5	85	0.2445	0.1658
90	45	45	0.2441	0.1595
90	85	5	0.2273	0.1644

Sap composition.

The proportion of $[K]_o$ and $[Na]_o$ in iso-osmotic media did not have large effect on sap osmotic pressure (OP_i) in comparison to the effect of salt level (OP_o) and leaf growth stage in all three crops (Table C3). In all cases the slope of sap OP vs $[K]_o$ at each salt level was generally near zero. Only at the highest OP_o an increase in $[K]_o$:$[Na]_o$ ratio caused an increase in the sap OP of expanded leaves (Table C3). In contrast, the intercepts of sap OP vs. $[K]_o$ at each salt level indicated that OPi was sensitive to changes in OP_o and leaf growth stage. Salt stress increased sap OP, and the sap OP of expanding leaves was lower than of expanded leaves at the low OP_o and controls in cotton and peanut and in all salt levels in melon (Table C3). Low OP of expanding leaves has been attributed to the dilution of solutes due to high rates of expansive growth (Cosgrove, 1986).

Table C3. The effect of the salinity level $[Cl]_o$ and $[K]_o$:$[Na]_o$ ratio on the pre-dawn osmolites content in peanut, cotton and melon leaves at different development stages. (Linear regression, according to: Variable=a$[K]_o$+b, were preformed at each salt level and leaves group. The slope vs. $[Na]_o$ is the negative of a. Statistical analysis tested the probability of a slope not grater than zero as determined by the t-test; ns=non significant, *, ** and *** stands for significant at 0.05, 0.01 and 0.001 levels, respectively).

$[Cl]_o$	Dependent Variable	Leaf growth stage: Expanding a	Expanding b	Expanded a	Expanded b
			Peanut		
0	$[OP]_i$	297		340	
	$[K]_i$	92		83	
	$[Cl]_i$	36		60	
30	$[OP]_i$	356	0.81ns	384	1.32ns
	$[K]_i$	108	0.87	114	1.92
	$[Cl]_i$	41	0.25	39	0.32
60	$[OP]_i$	429	0.34ns	432	1.17*
	$[K]_i$	118	0.66**	114	1.41***
	$[Cl]_i$	56	0.64***	112	0.59***
			Cotton		
0	$[OP]_i$	400		451	
	$[K]_i$	127		67	
	$[Na]_i$	4		4	
	$[Cl]_i$	97		171	
75	$[OP]_i$	520	-0.005ns	542	0.001ns
	$[K]_i$	151	0.66	70	2.09
	$[Na]_i$	24	-0.26	97	-1.22
	$[Cl]_i$	127	-0.44	209	-0.39
150	$[OP]_i$	582	-0.100ns	583	0.524***
	$[K]_i$	152	0.52**	80	1.53***
	$[Na]_i$	38	-0.22***	129	-0.91***
	$[Cl]_i$	118	0.13ns	217	-0.03ns
			Melon		
		Leaves >60mm a	Leaves >60mm b	Leaves 60-100mm a	Leaves 60-100mm b
10	$[OP]_i$	248		236	
	$[K]_i$	93		87	
	$[Na]_i$	4		3	
	$[Cl]_i$	18		18	
50	$[Op]_i$	264	0.21	252	0.54
	$[K]_i$	90	0.70	89	0.97
	$[Na]_i$	16	-0.32	14	-0.31
	$[Cl]_i$	26	0.017	30	0.077
90	$[OP]_i$	300	0.12ns	304	0.31ns
	$[K]_i$	92	0.67**	91	0.94**
	$[Na]_i$	29	-0.33***	29	-0.34**
	$[Cl]_i$	43	0.045ns	43	0.40*

$[Cl]_o$	Dependent Variable	Leaves >100mm a	Leaves >100mm b
10	$[OP]_i$	274	
	$[K]_i$	95	
	$[Na]_i$	5	
	$[Cl]_i$	15	
50	$[Op]_i$	300	0.67
	$[K]_i$	70	1.85
	$[Na]_i$	27	-0.66
	$[Cl]_i$	39	0.094
90	$[OP]_i$	339	0.96**
	$[K]_i$	80	0.77***
	$[Na]_i$	66	-0.84**
	$[Cl]_i$	73	0.76**

Consistent with the measurements of sap OP, the relationship between leaf water potential and relative water content in expanding leaves of cotton was affected by OP_o but did not change due to the composition of iso-osmotic media (Figure C1). The pressure volume curves indicate also that the proportion of $[K]_o$ did not affect cell turgor in the expanding leaves of cotton. The OP_i at full turgor is represented by the intercepts in Fig. C1 and is equal to 437, 498 and 571 mosmol kg^{-1} for the control, low OP_o and high OP_o, respectively. These values approximated the intercepts of sap OP vs. $[K]_o$ at each salt level (Table C3).

Higher proportion of $[K]_o$ caused a linear increase in $[K]_i$ in all three crops, and a linear decrease in $[Na]_i$ in cotton and melon. Peanut is a Na excluder and had only trace Na levels in the leaves. For cotton and melon the sum of $[K]_i+[Na]_i$ increased with the increase in $[K]_o$ despite the decrease in $[Na]_i$. $[Cl]_i$ increase with the increase in $[K]_o$ in peanut and melon but not always in cotton. The sum of $[K]_i+[Na]_i+[Cl]_i$ increased with the increase in the medium K fraction in all three crops (Table C3, Figures C2-C4).

Table C4. The influence of iso-osmotic composition on the sap OP and the change in contribution of the medium salinity ions to sap OP, according to: $Y = a[K]_o+b$. (data of high salt treatments. The intercept is in mosmol/kg and the slope in mosmol/kg/mosmol/kg).

Dependent Variable	Leaves growth stage: Expanding a	Expanding b	Expanded a	Expanded b
		Peanut		
$[K+Cl]_i$	177	1.30***	216	1.41***
$[OP]_i$	429	0.341ns	432	1.17*
$[OP]_i-[K+Cl]_i$	250	-0.96**	215	-0.82ns
		Cotton		
$[K+Na+Cl]_i$	293	0.43***	432	0.60***
$[OP]_i$	568	-0.09ns	583	0.42**
$[OP]_i-[K+Na+Cl]_i$	275	-0.53**	151	-0.17ns
		Melon		

	Leaves<60mm a	Leaves<60mm b	Leaves 60-100mm a	Leaves 60-100mm b	Leaves>100mm a	Leaves>100mm b
$[K+Na+Cl]_i$	164	0.38ns	163	1.00**	211	1.70**
$[OP]_i$	300	0.12ns	304	0.31ns	339	0.96**
$[OP]_i-[K+Na+cl]_i$	136	0.26ns	141	-0.69*	127	-0.74**

A solute balance was made for the high salt treatments that showed maximum medium concentration and composition effect on the sap (Table C4, Figures C2-C4). In all these cases the sum $[K+Na+Cl]i$ increased significantly with the increase in $[K]_o$. This increase was larger for older leaves and in the order melon>peanut>cotton. In melon the increase in $[K]_i$ was larger than the decrease in $[Na]_i$ and also $[Cl]_i$

increased. In peanut $[K]_i$ and $[Cl]_i$ increased, it is a Na excluder and had only trace $[Na]_i$ levels. In cotton $[K]_i$ increased, $[Na]_i$ decreased to a lesser extend and there was no change in $[Cl]_i$ (Table C3, Figures C2-C4). In expanded leaves of cotton and peanut the increase in $[OP]_i$ was proportional to the increase in $[K+Na+Cl]_i$, but $[OP]_i$ was not affected by the $[K]_o$:$[Na]_o$ ratio in expanding leaves (Table C4, Figures C2,C3). Thus in expanding leaves the difference between [OP]i and $[K+Na+Cl]_i$ significantly decreased at higher concentrations of $[K]_o$ (Table C4) which indicates that an increase in the K fraction caused a decrease in the total concentration of solutes other than K, Na and Cl. In melon small leaves the sum of $[K+Na+Cl]_i$ and the $[OP]_i$, as well as the differences between these parameters, were similar for all combinations. In leaves >60 mm the increase in ions content was faster than the increase in $[OP]_i$ and the differences between these parameters decreased with the increase in $[K]_o$.

Contribution of the salt ions to the electrical conductivity (EC) of the sap can indicate possible other solute changes. The contribution of the K, Na and Cl to the sap EC, for leaves that show significant change in OPi-$[K+Na+Cl]_i$, was calculated according to eq.4 and these values were linearly correlated with the measured sap EC (Table C5). The order of the contribution of the conductivity of K^+, Na^+ and Cl^- to the sap conductivity was peanut > cotton > melon. Thus in the expending leaves of peanut, the decrease in $[OP]_i$-$[K+Cl]_i$ due to a higher proportion of $[K]_o$ probably presents the largest and expanded melon leaves the smallest decrease in the concentration of organic osmolytes with low conductance. Sugars are among such osmolites and they show this order of response (Table C5).

Table C5. The influence of the import of inorganic solute to expanding leaves on the EC of the leaf sap and the effect of $[K]_o$:$[Na]_o$ ratio on the % sugar in leaf sap. (Data for high salt treatments. 'r' is the correlation coefficient, 'n' is the number of comparisons and 'p' is the probability according to a t-test that the slope is zero or of the opposite direction).

Crop	Leaves	Correlation of Sap EC vs EC of $[K+Na+Cl]_i$ Slope (dS/dS)	r	n	Linear regression of % Sugar vs. $[K]_o$ Intercept (% and SE)	Slope %/mM	P
Peanut	Expanding	0.82	0.98	5	4.6 (2)	-.01	0.02
Cotton	"	0.65	0.98	7	6.1 (0.4)	-0.006	0.08
Melon	Expanded	0.57	0.96	3	3.0 (0.3)	-0.001	n.s.

In all cases the increase in calculated EC was larger than the increase in measured EC. This should indicate a decrease in other conducting solutes. Data on other ions is available for melon (report E) which showed the largest difference. In melons the increase in $[K]_o$ resulted in a significant decrease in shoot $[Ca]_i$ and $[Mg]_i$.

Discussion.

The experiments on peanut, cotton and melon showed that a high proportion of $[K]_o$ eventually inhibited growth, possibly by causing ion excess, as indicated by an increase in $[K+Na+Cl]_i$ and an increase in OP_i of expanded or, in the case of melon, nearly expanded leaves. In agreement with the suggestion that high $[K]_o$ caused ion excess, the slope of $[K]_o$ vs. $[K]_i$ did not substantially differ among the three crops, but the total amount of inorganic solutes imported to the leaves of the more $[K]_o$ tolerant crop, cotton, was less responsive to changes in proportion of $[K]_o$. Cotton leaves maintained more constant $[K=Na+Cl]_i$ because $[Na]_i$ substitute for $[K]_i$ with the $[K]_o$:$[Na]_o$ ratio changes to a larger extend than in melon, and $[Cl]_i$ increased with the increase in $[K]_o$ fraction in the order peanut > melon > cotton. Ion excess due to high $[K]_o$ was also indicated for sorghum (Weimberg et al, 1984).

However, results were in basic agreement with the view that inhibition of growth by salt stress (high OP_o) is not usually due to ion excess. Increasing the proportion of $[K]_o$ caused large increase in $[K+Na+Cl]_i$ before affecting growth. The emergence and growth rates of leaves of non-halophytes has been shown to be sensitive to OP_o (Cosgrove, 1986). In these experiments emergence rates were more sensitive to salinity stress than growth rates.

Yet, the ionic composition of the media and the inorganic ion composition of leaves did not significantly affect emergence and expansion rates of cotton leaves, and had only small effect on leaves growth parameters during the first 43 days after planting of melons. The progressive decrease in the growth rate of melon (Report E) caused by ion excess did not show up immediately following the application of salt stress.

If ion excess was avoided long term exposure to different iso-osmotic media caused changes in composition of organic and inorganic osmolytes in leaves without affecting growth. The capacity of a tissue to maintain a particular OPi when subjected to iso-osmotic treatments of different composition was apparent in expanding leaves, but not evident in expanded leaves. Under iso-osmotic conditions, turgor homeostasis in expanding leaves of cotton was also apparent (Fig. C1) and was likely in expanding leaves of peanut and melon.

Changes in the composition of osmolytes under iso-osmotic conditions were not a consequence of stress since iso-osmotic media negligibly affected the length of expended leaves and shoot dry weight of cotton or peanut except at the highest $[K]_o$:$[Na]_o$ ratios (Table C1). The stress caused by the highest $[K]_o$:$[Na]_o$ ratios did not result in any abrupt changes in the sap osmotic pressure or $[K+Na+Cl]_i$ (Figs. C2-C4). It also did not change the initial rates of leaves elongation (R) or leaves emergens rate (LER) of cotton, and have only small effect on R and LER of melon (Table C2). Homeostasis of OP_i and cell turgor in expanding leaves under conditions which did not affect growth but caused different import rates of total inorganic solutes, suggest an osmoregulatory mechanism that could buffer against changes in OP_i and cell turgor by controlling the total concentration of intracellular organic osmolites.

Our study did not show a capacity to maintain constant OP_i by limiting the total amount of inorganic ions imported to a tissue. Recent descriptions of the kinetics of ion uptake by roots have shown a non-saturable, linear component in response to external concentrations

beyond several mM (Borstlap, 1981. Cochian and Lucas, 1982), unless a solute was excluded, e.g. Na from peanut leaves (Table C3).

In newly expanded leaves, of cotton and peanut iso-osmotic treatments of different solute availability did not significantly affect the total concentration of organic osmolytes, and consequently changed sap osmotic pressure (Figs. C2,C3), while in melon it did affect the organic osmolites in expanded and not in rapidly expanding leaves. Other examples in the literature are consistent with the different response of expanding and expanded leaves of cotton, peanut and melon. The oldest trifoliate of bean had a higher sap OP when treated with the more available NaCl, in comparison to an iso-osmotic medium of Na_2SO_4 (Meiri and Poljakoff-Maiber, 1971). Sap Op in the rapidly expanding seedlings of sunflower were not affected by the composition of iso-osmotic media, which consisted of polyethylene glycol or NaCl (Wyn Jones and Gorham, 1983). These results indicate that the high concentration of sugars and organic osmolytes that have been observed in the mature leaves of plants which were K deficient (Pitman and Cram, 1973) and had water deficit (Cutler et al, 1977) may be partially due to the reduction in sink strength.

The control of the total concentration of organic solutes in expanding leaves of cotton and peanut suggests that an osmoregulatory mechanism influenced the transport of photosynthate to the expanding mesophyll cells via the phloem.

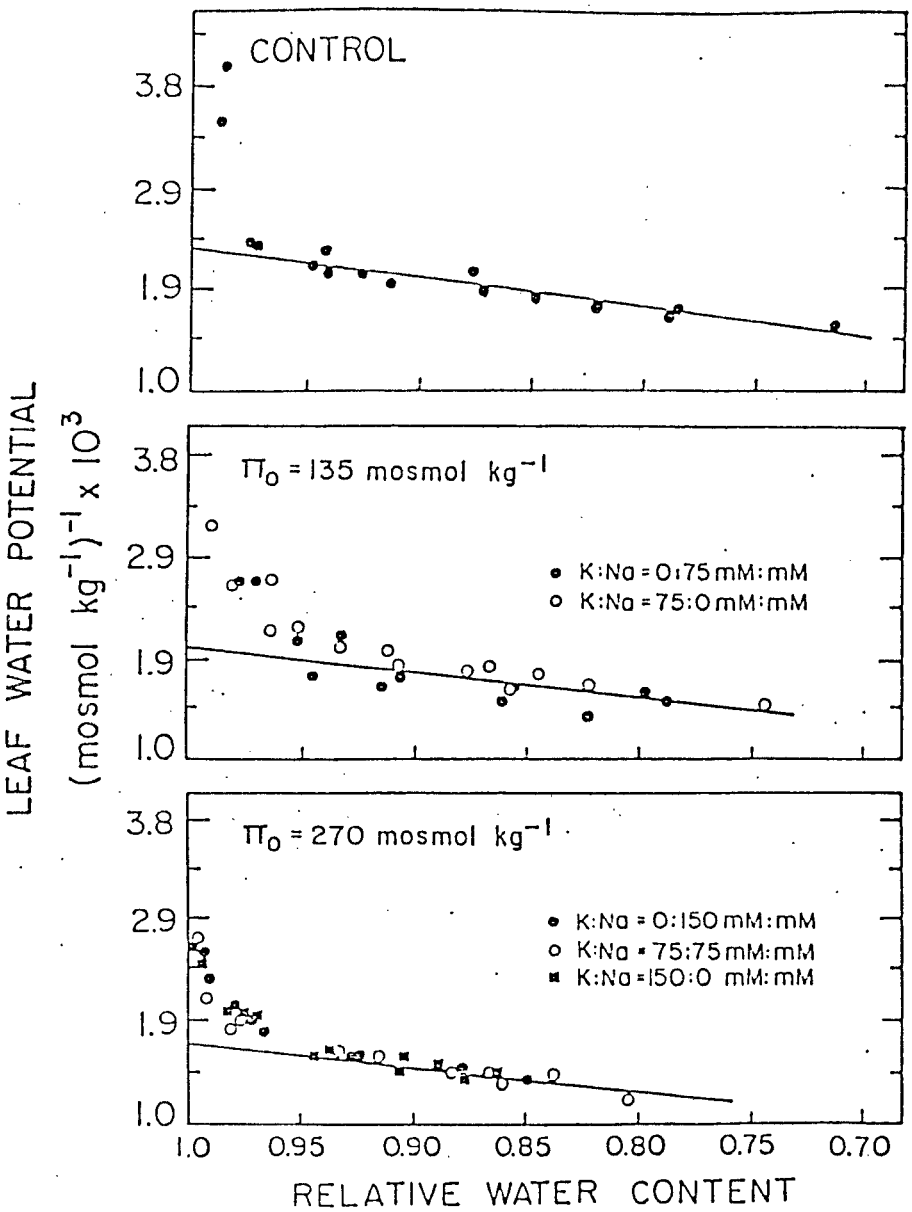


Figure C1. The effect of salt level OP_o and the $[K]_o$:$[Na]_o$ ratio on the relationship between leaf water content and the reciprocal of leaf water potential in expanding leaves of cotton. (Relative water content is the amount of water in leaf divided by the amount of water in the same leaf when it was fully hydrated. The estimate of OP_i at different water contents is represented by the solid line at each salinity level. The OP_i at full turgor is represented by the intercept and is equal to 437, 498 and 571 mosmol/kg for the control, low OP_o and high OP_o, respectively. All measurements are included in the figure).

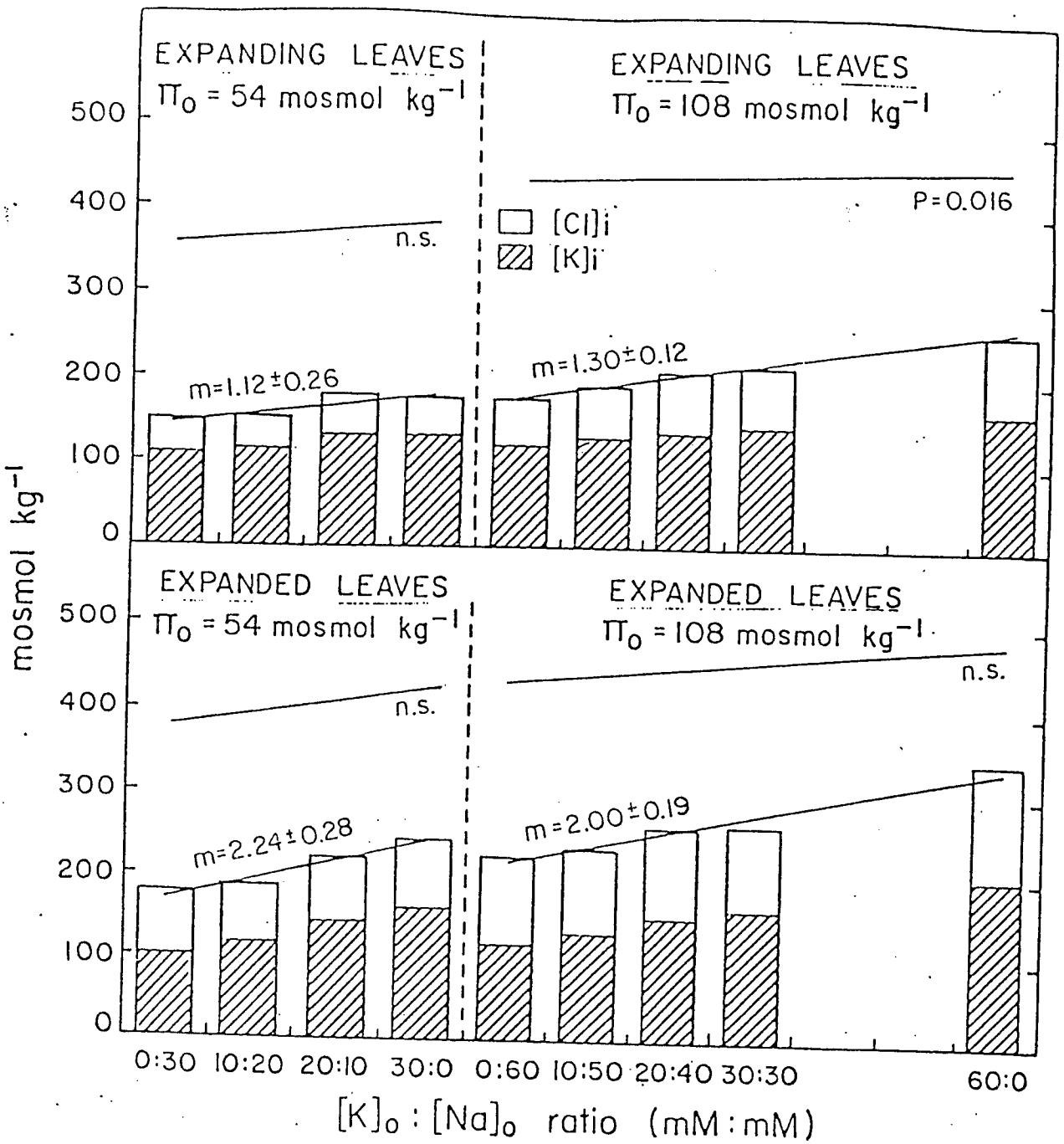


Figure C2. The effect of salt level OP_o and the $[K]_o$:$[Na]_o$ ratio on sap osmotic pressure and the sum of $[K]_i$ and $[Cl]_i$ in expanding and the youngest expanded leaves of peanut. (The top line is the slope of OP_i vs $[K]_o$, and the bottom line is the slope of $[K+Cl]_i$ vs $[K]_o$. 'p', the probability that there is no difference between the two slopes according to a t-test. n.s., non-significant differences. 'm' the slope of $[K+Cl]_i$ vs $[K]_o$ and its s.e. in units of mosmol kg^{-1} mM^{-1}. $[Na]_i$ was < 2 mosmol kg^{-1} in leaf sap).

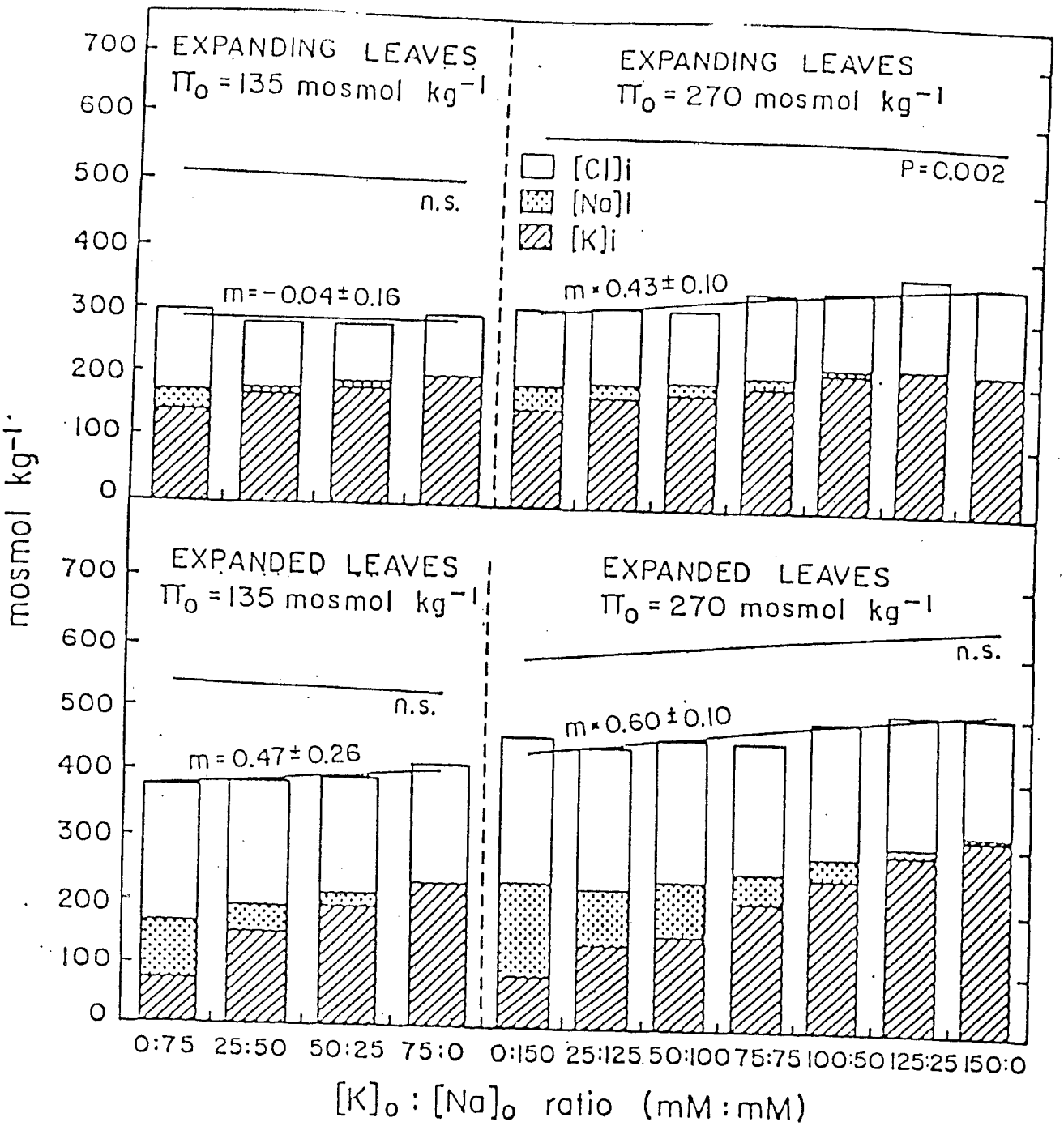


Figure C3. The effect of salt level OP_o and the $[K]_o$:$[Na]_o$ ratio on sap osmotic pressure and the sum of $[K]_i$, $[Na]_i$ and $[Cl]_i$ in expanding and the youngest expanded leaves of cotton. (The top line is the slope of OP_i vs $[K]_o$, and the bottom line is the slope of $[K+Cl]_i$ vs $[K]_o$. 'p', the probability that there is no difference between the two slopes according to a t-test. n.s., non-significant differences. 'm' the slope of $[K+Cl]_i$ vs $[K]_o$ and its s.e. in units of mosmol kg^{-1} mM^{-1}. (Na]i was < 2 mosmol kg^{-1} in leaf sap).

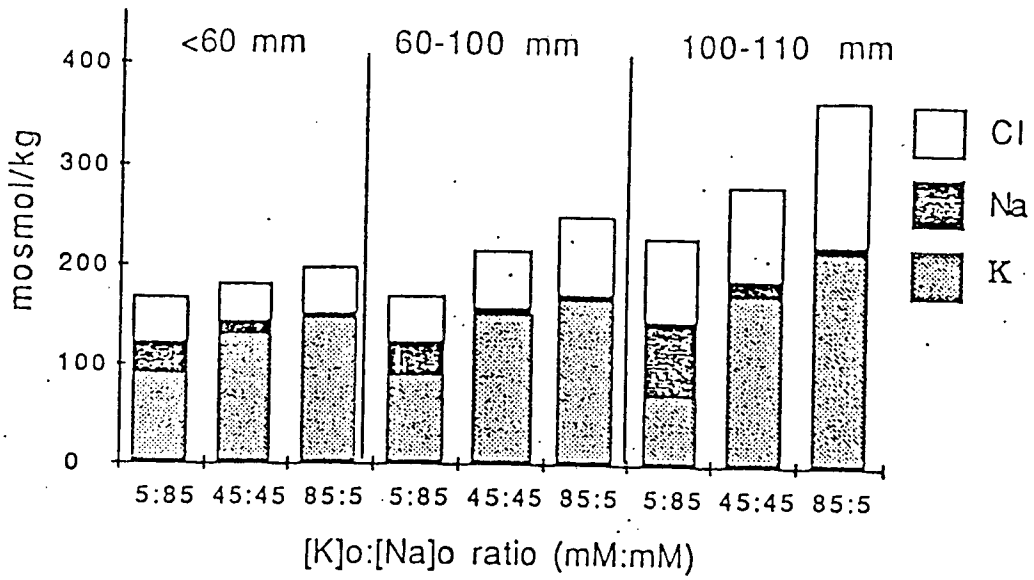


Figure C4. The effect of $[K]_o$:$[Na]_o$ ratios in high salt media on $[K]_i$, $[Na]_i$, $[Cl]_i$ and the sum $[K+Na+Cl]_i$ in melon leaves of different lengths (growth stages).

D. Potato (Var Desiree) response to salinities of different K/Na ratios.

A. Meiri, A. Feigin, D. Levi and Sala Feigenbaum.

Introduction.

The purpose of the present study was to obtain information on the response of potato plants to the addition of K fertilizers into sodium chloride salinated nutrient solution. Potassium concentrations up to 20 mM in solutions of total salinities of 2 - 7.5 dS/m resulted in different K/Na ratios at three salinity levels. The effects on yields, evapotranspiration and tissue ion contents were determined.

Materials and Methods.

Eight treatments representing three salt levels and different K/Na ratios were tested (table D1). To maintain relatively stable nutrient solution composition we used an aero-hydroponic system (Feigin et al., 1984) with 130 l solution storage containers. The storage containers were covered by means of a plastic board on which two polystyrene boxes were mounted. Each box contained six plants. Each container with 12 plants was an experimental unit, plot. The plants were held by their crowns and the roots remained hanging in the air. Only later the roots reached the bottom of the boxes. A small electric pump installed on the pot cover between the boxes continuously circulated the solutions from the main container into a closed plastic hose system having two nozzles against each root system. After washing the roots the solution flowed back into the main container.

Potato stems, separated from the mother tuber growing in a volcanic rock (lapilli-tuff), were transplanted into holes made in the top of each box on Feb. 2 while having a total length of 35-40 cm and a normally - developed root system. The lower part of each transplant (~18 cm), without leaves, was placed inside the box. The rest of the transplanted shoot, 7-10 cm in length, having 4-6 leaves, were left above the covering of the boxes. All the transplants grew well and shortly after planting (4 days) many roots were observed. Final treatment salinity levels were reached gradually over the first 12 days after transplanting. After obtaining a full ionic strength the solutions were replaced every week. The first solution replacement took place on Feb. 20. The water volumes in these containers were restored two or three times a week and the rates of transpiration were calculated. Since the total quantity of water used in this experiment was about 20 m^3, the solutions were prepared from tap water. The Cl, SO_4, HCO_3, Na, Ca, Mg and trace levels of NO_3 in the tap water were counted. H_2SO_4 was used for pH adjustment. The concentration and composition of fresh and used solutions where determined on the day of replacement.

On Feb 21 and 26 and March 3 and 12 two plants, per container, and on March 27, 50 days after transplanting, the last four plants were harvested for yield and chemical analysis. The shoot development was normal. On the other hand, probably due to the effect of light penetrating into the polystyrene boxes, the tubers did not grow

normally. New sprouts appeared on the young tubers and many of the stolons developed into shoots. Consequently the experiment was terminated before reaching the tuber yields. The plant materials, shoots and roots at the first 4 harvests and shoots, roots and tubers at the final harvest were oven dried and analyzed for dry matter content and the concentrations of Kjeldahl-N, NO_3-N, Cl, P, K, Na, Ca and Mg.

Results and discussion.

The use of large nutrient solution volumes (130 L) reduced but did not eliminate time variations in the solution composition. These variations in K and Na content for the 1 mM K treatment in the three salinity levels are presented in figure D1. In all cases K concentration decreased between replacements of the solutions. This reduction, which was the result of uptake by plants, was larger in the lower salt treatments with the large plants. It was also larger in the last intervals when plants were larger. On the last sampling, final K concentration in the control was almost zero. The Na concentration in the solutions increased during the different intervals in the low and medium salinities and decreased in the high salinity. These changes in concentrations are the result of the ion to water uptake ratio in each case and the restoring of the volume with tap water. For the high salt treatment water uptake was reduced and Na uptake increased to result in a decrease in Na concentration even in the potato which is a Na excluder. Later the mean concentrations of the medium solutions (Table D1) rather the intended levels were used to present the results. EC was stable in all treatments and was slightly higher at higher K/Na ratios. Cl concentration decreased slightly in the low and high salinities. Na decreased at high salt and low K and increased in all other treatments. K decreased in all cases, more in the lower salinities.

Table D1. The salinity and K content of the nutrient solutions. (means and std for the differential experimental period).

	Observed								Planned		
Tr	EC dS/m		Cl		Na mM		K		Cl	Na mM	K
	mean	std	mean	std	mean	std	mean	std			
1	2.07	0.06	8.5	1.6	11.2	2.3	0.66	0.39	10	9	1
2	2.16	0.12	8.8	1.4	5.4	0.5	4.50	0.67	10	5	5
3	4.56	0.10	30.2	2.0	29.8	2.1	0.78	0.26	30	29	1
4	4.65	0.09	30.3	0.9	26.5	2.5	4.74	0.36	30	25	5
5	4.92	0.07	30.6	1.0	12.8	3.0	19.30	1.62	30	10	20
6	7.44	0.21	59.2	1.6	56.9	3.7	0.95	0.11	60	59	1
7	7.63	0.12	59.4	2.4	54.0	4.0	4.88	0.28	60	55	5
8	7.71	0.24	58.6	2.0	40.8	2.6	19.34	2.00	60	40	20

Total yield per container, which combines data of all harvests, and final plant weights decreased with the increase in salinity, and in each salinity level increased with the increase in K level (Table D2). The increase in plant weight in each treatment over time was described as a linear function (Table D3), the slopes of which decreased with the increase in salinity and increased in each salinity level with the

increase in K. The differences between treatments were most significant at the final harvest (Table D2) and larger in shoots than in roots. One can conclude that the potato responded positively to K fertilization over the entire tested ranges of salinity and K. This positive yield response to K indicates larger K requirements of potatoes than for many other plants (Asher and Ozanne, 1967). But, the increase in yield with high K under high salinity cannot indicate a beneficial effect of K alleviating salinity damage. The yield increase in response to K was maximal in the low salinity and decreased with the increase in salinity (Figure D2). And the relative yield decrease due to salinity (Table D2) was larger at 5mM K as compared with 1mM K for all three salt levels and at 20mM K it was larger than in 1 or 5 mM K for the two higher salt levels. An alleviation of the salinity damage should show up at least by a smaller relative decrease in yield under high K level.

Table D2 Salinity and K influence on potato fresh yields.

Tr	Final Plants weight g/plant			Total yield per pot g/pot			Relative total yield	
	Shoots	Roots	Total	Shoots	Roots	Total	3 salt levels	2 salt levels
1	393a	71ab	463a	2616b	234d	2850b	1.00	
2	421a	75a	496a	2988a	297c	3284a	1.00	
3	245b	48c	292b	1896c	184e	2080c	.73	1.00
4	302b	60b	362b	2147c	194de	2341c	.71	1.00
5	408a	80a	487a	2536b	313bc	2849b		1.00
6	106d	27d	132c	936d	340b	1303d	.46	.63
7	113cd	29d	141c	969d	394a	1362d	.41	.58
8	173c	44c	217b	1257d	196de	1452d		.51

Table D3. Linear regression parameters for the increase of fresh weight over time. FW = a + b*T (units: FW=g/pot; b=g/(pot*day); T=days).

Tr	a	b	r2
1	-244	13.1	.985
2	-247	14.1	.964
3	-129	8.5	.804
4	-182	10.4	.931
5	-265	13.5	.993
6	-32	3.5	.729
7	-38	3.6	.845
8	-87	5.7	.982

The accumulative evapotranspiration (ET) (Table D4) decreased with the increase in salinity with small differences according to the K/Na ratios in each salt level. Therefore all the treatments for a given salinity were combined in figure D3. The figure shows that the ET decreased with the increase in the medium salinity since the beginning of the differential treatments.

Table D4. Potassium and salinity levels influence on the accumulative ET of potato plants.

Tr	ET (liters/pot)
1	113ab
2	118a
3	95ab
4	91b
5	99ab
6	58c
7	65c
6	65c

The water production function (a plot of yield over ET), was similar for all treatments. Table D5 presents the parameters of the linear regression of fresh yields and show that shoot growth was more sensitive to the stresses of salinity or K deficiency. The evaporation calculated from the total yield regression was 12.3 L/pot.

Table D5. The parameters of the fresh weight water production functions. FW=a+b*ET (units: FW=g/pot; b=g/litter; ET=litter/pot).

	a	b	r2
Shoots FW	-410	26.5	0.753
Roots FW	42	3.3	0.648
Total FW	-367	29.7	0.748

The ion contents in plant shoots and tubers in the final harvest are presented in table D6. K and Na data is presented also in figures D4 and D5.

Table D6. Salinity and K level influence on the ions content in plant tissues (% dry weight).

Harvest	Ion	Plant part	Treatment 1	2	3	4	5	6	7	8
5	K	Shoot	5.7cde	7.5ab	6.4bcd	6.6bc	8.0a	5.0e	5.3de	7.1ab
5		Root	0.8d	2.1ab	1.6c	2.0bc	2.6a	1.8c	2.1bc	2.7a
5	Na	Shoot	0.31cde	0.14e	0.47bc	0.39bcd	0.23de	1.06a	0.99a	0.56b
5		Root	0.81a	0.29c	0.61b	0.54b	0.33c	0.91a	0.81a	0.53b
5	Ca	Shoot	5.2bc	5.0cd	5.2bc	5.1bcd	4.4d	6.1a	5.8ab	4.8cd
5	Mg	Shoot	1.3	1.2	1.4	1.9	1.3	1.7	1.6	1.4
3	Cl	Shoot	3.9d	5.0d	11.2b	10.7bc	9.3bc	13.7a	14.2a	13.6a
5		Root	3.2d	4.0cd	5.4bcd	6.2bc	7.6ab	8.2ab	6.3bc	9.7a
3	NO_3*	Shoot	0.91ab	0.98a	0.79bc	0.77bc	0.76bcd	0.59e	0.63de	0.71cde
5	N**	Shoot	4.8a	4.8a	4.6ab	4.9a	4.4abc	4.2bc	4.1c	4.2bc
5		Root	4.1	3.9	3.9	3.5	3.7	3.3	3.6	3.8
5	P	Shoot	0.68	0.70	0.63	0.68	0.69	0.69	0.70	0.65
5		Root	0.53	0.93	0.85	1.22	0.93	0.73	0.60	0.79

* N in NO_3
** Total N

K content increased in shoots and roots with the increase in medium K in all salt levels. Shoot K was about 3 times higher than root K, and decreased with the increase in salinity, except for tr 1 (low salt low K) where K depletion from the medium (Table D1, Figure D1) was probably the cause for the low tissue K. Root K was similar for a given medium K at all salt levels, also except for tr. 1. Na content was much lower than K content in the shoot and only slightly lower in the roots. The Na content of shoot and root tissues increased with the increase in the medium salinity and decreased with the increase in the medium K. In the low and medium salt treatments root Na was higher than shoot Na, while in the high salt treatments the shoot Na was higher. Root data represent mainly root cell contents, and are influenced by treatment effect on short distance uptake. The low salt low K treatment showed a higher Na content in the root than the low K medium salinity treatment. Strong inhibition of Na uptake in the low K range is indicated by a significant reduction in Na uptake with slight increase in medium K. Such inhibition is expected in the system 1 range. A linear relation was found between K/Na ratios in the plant and in the growth medium. The K/Na ratio was higher in the shoots than in the roots in any medium (Figure D5). For root this relation had a large intercept and small slope, implying a large affinity for K that decreases with the increase in K concentration. High salinity did not change this ratio. For shoots the intercepts were larger and decreased with the increase in salinity. Shoot data represent also a second control step in the long distance transport. In Na excluding plants, the high selectivity toward K uptake from the low salt low K treatments of this second step decreased with increased salinity and K in the growth medium.

Solution data and the plant fresh weights were used to estimate K uptake rates (mM/g*day) (Figure D6). The data show that K uptake increased with the increase in medium K, and for the 1 and 5 mM K treatments uptake decreased with the increase in salinity.

Calcium tissue content showed a small increase with the increase in the medium salinity and a large decrease with the increase in the medium K. Magnesium decreased with the increase in K, but not significantly.

Chloride tissue content increased with the increase in the medium salinity with no large effect of K/Na ratio in the medium.

Nitrate tissue content decreased with the increase in the medium salinity with no large effect to the K level. The decrease is probably the result of a competition with the chloride.

Total tissue N as determined by Kjeldahl decreased with the increase in the medium salinity. Phosphate did not differ significantly.

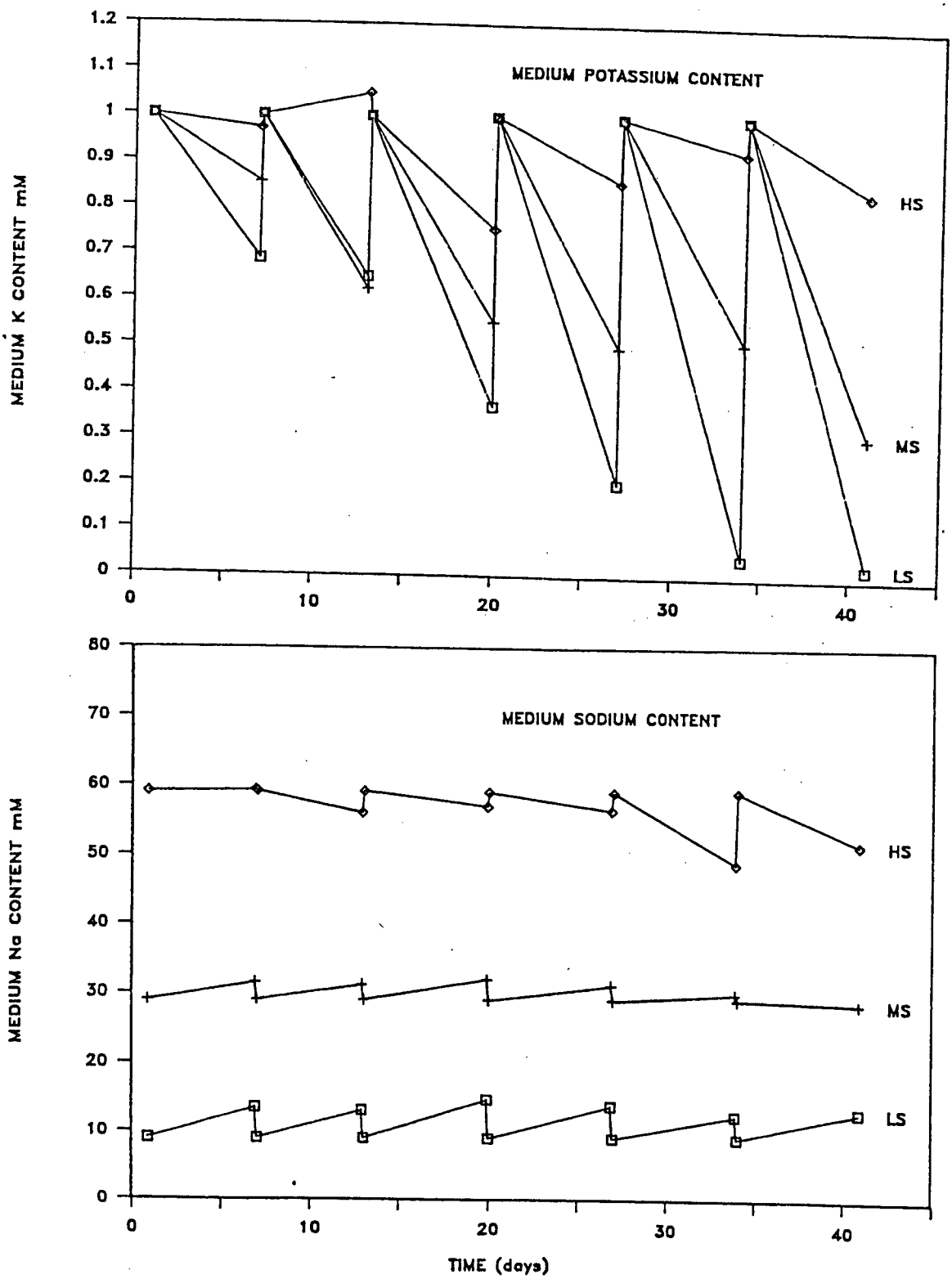


Figure D1. Time variations in the K and Na concentrations in the nutrient solutions of the low K treatments.

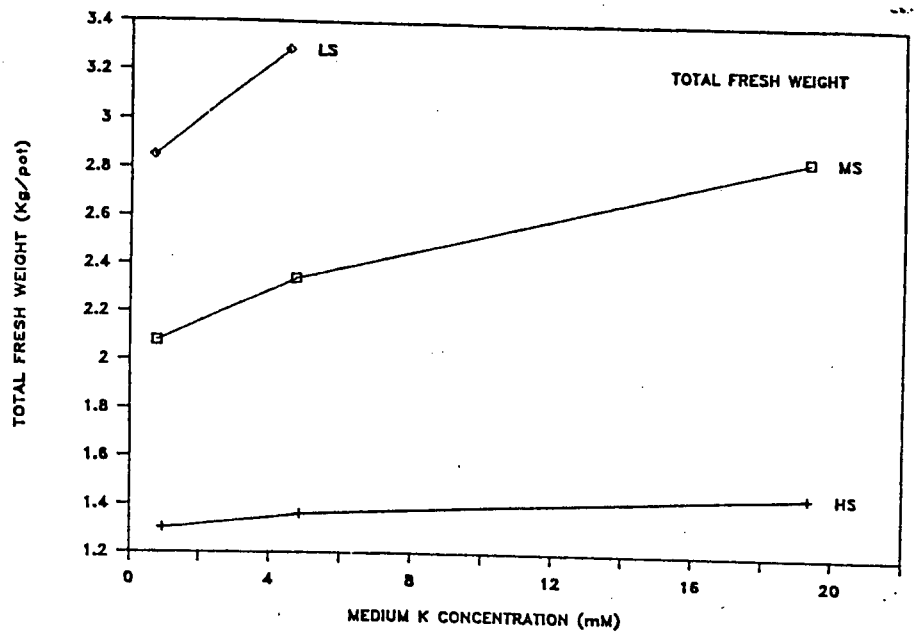


Figure D2. The influence of the medium salinity and k content on the total fresh yields per container (sum of all harvests).

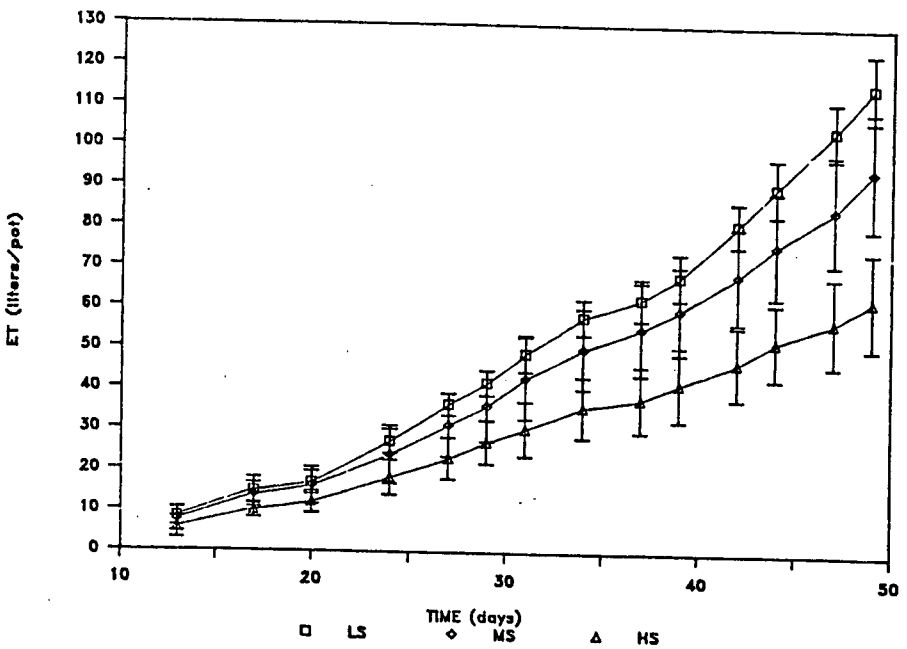


Figure D3. Salinity influence on the cumulative ET (means+std for all K levels).

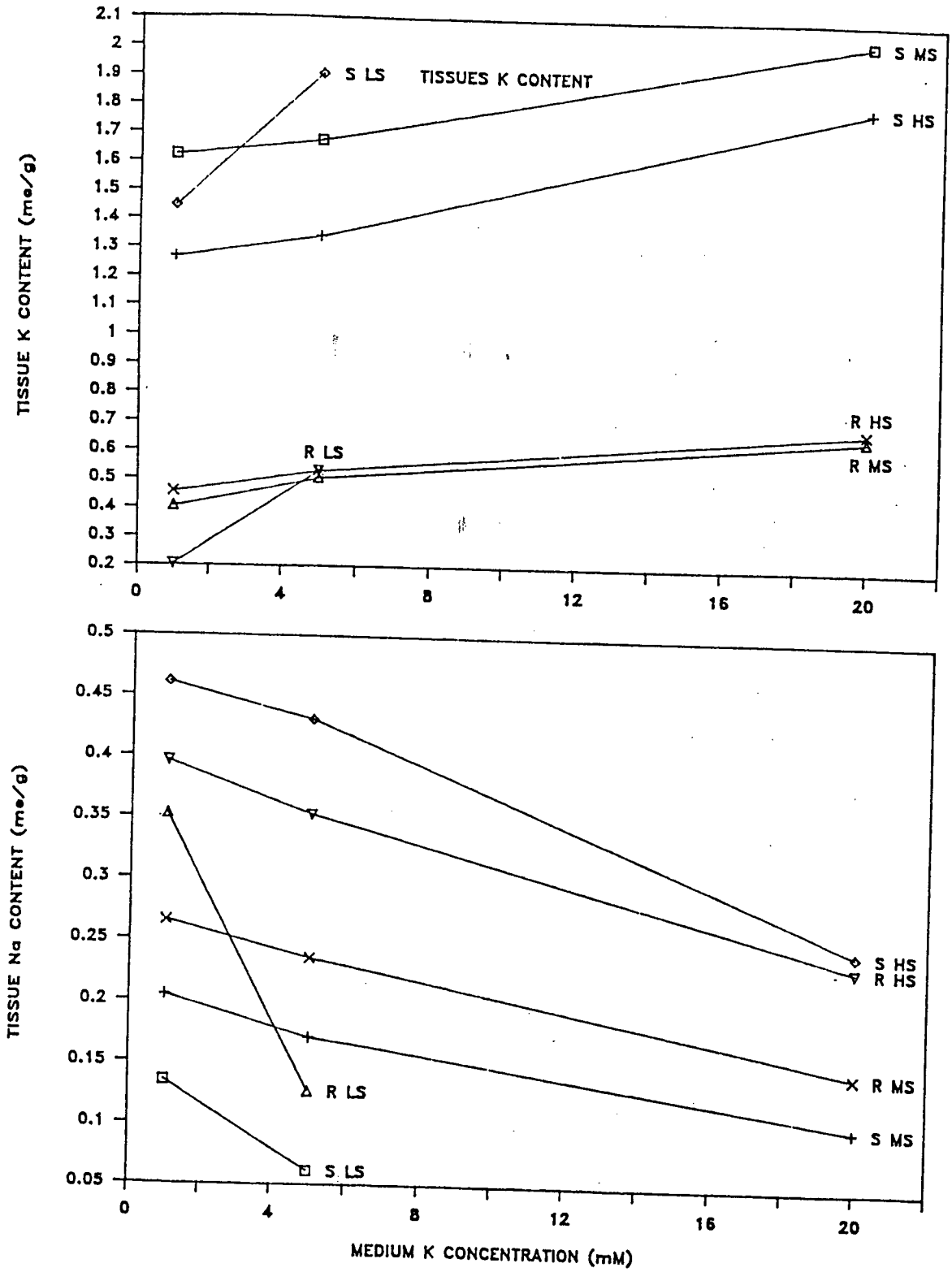


Figure D4. The influence of the medium salinity and k content on the potassium and sodium content in roots and shoots.

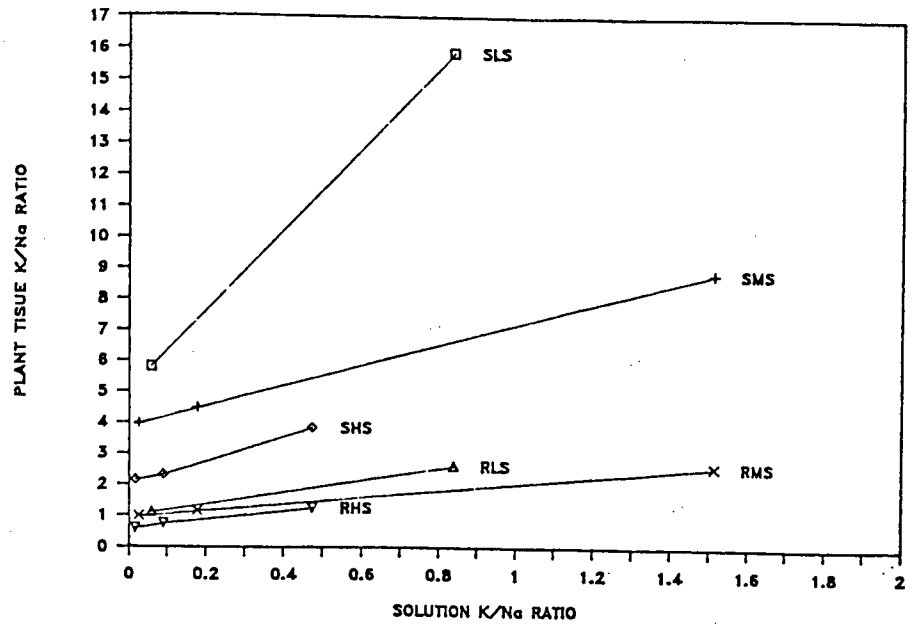


Figure D5. Tissue as related to medium K/Na ratios.

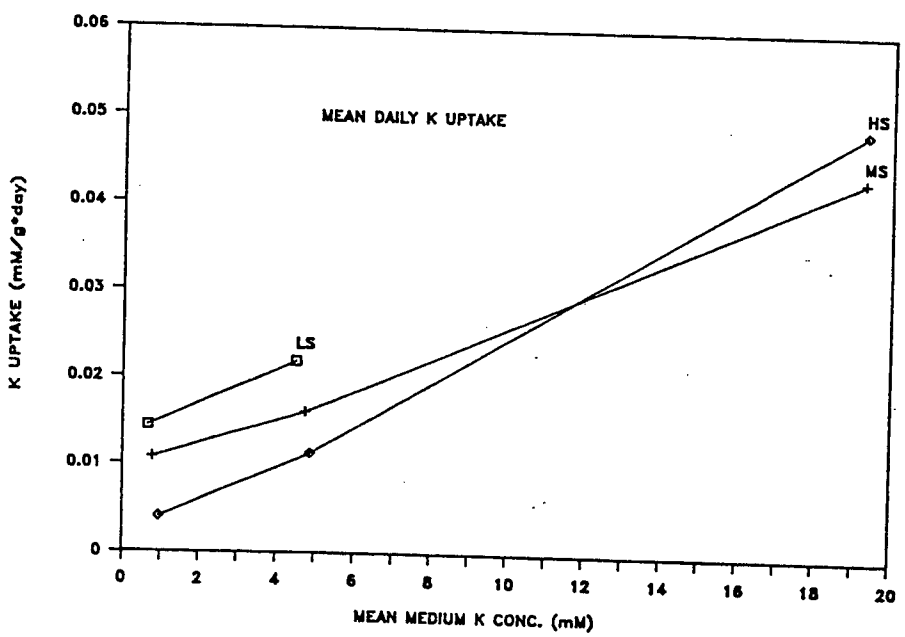


Figure D6. The influence of the medium salinity and k content on the K uptake rates (mM/gFW*day).

E. Melons (Var Galia) response to salinities of different K/Na ratios.

A. Feigin, A. Meiri, Irit rilska and D. Lauter.

The purpose of this study was to obtain information on the response of melons to salinity with different K/Na ratios. K/Na ratios of 0.06 to 16 at salinity range of 1.5 - 9.0 dS/m were tested. The effects on yield weight and quality, dry matter production and tissue ions contents were determined.

Materials and Methods.

A green house experiment was conducted in Bet - Dagan, Israel. Seven treatments, the combination of three salt levels and different K/Na ratios were tested, in a three randomized blocks design. The composition of the solution is given in table E1. An aero-hydroponic system (Feigin at al., 1984) with 130 l solution storage containers was used to maintain relatively stable nutrient solutions compositions. Description of the system is given in the potato experiment report (Report D). The solutions were replaced weekly and their volume was restored once or twice a week. The large water volumes in this experiment required the use of tap water and to consider its ions content on the preparing of the solutions.

Table E1. The chemical composition of the nutrient solutions in the melons experiment (taking into account the tap water composition).

Tr	EC dS/m	K+	Na+	Ca++	Mg++ mM/L	H+	Cl-	NO_3-	SO_4--	HCO_3-	H_2PO_4-
1	1.5	5	5	12	6	1.5	6	8	3	4	1
2	4.5	40	5	12	6	1.5	41	8	3	4	1
3	4.5	22.5	22.5	12	6	1.5	41	8	3	4	1
4	4.5	5	40	12	6	1.5	41	8	3	4	1
5	9.0	80	5	12	6	1.5	81	8	3	4	1
6	9.0	42.5	42.5	12	6	1.5	81	8	3	4	1
7	9.0	5	80	12	6	1.5	81	8	3	4	1

Thirty-day-old seedlings where transplanted into the growing boxes on Jan. 13 1986. There were 4 plants per box and 8 per container (= experimental unit = plot). Solutions were salinized gradually over the first week. Single plant samples per box were taken on 29, 36,43 and 141 days after transplanting (DAP). Fruit was collected between 97-141 DAP. The plants shoots, roots and fruits weights and their ion contents where determined according to standard methods. Fruits where divided into inner and outer parts for determination of the total soluble solids (TSS).

Results and Discussion.

Observations show significantly larger damage in the high K salinity. Plants were smaller and had large necrotic areas.

Fruit yield data are presented in table E2 and figure E1. A significant yield reduction was found with the increase in salinity, and within the high salt levels with the increase in K level. In treatment 5 (80 mM K) there was almost no yield and the existing fruits where damaged to the extent that TSS analysis was impossible. Total soluble solids values were higher inside the fruits. Treatments high in K in both saline treatment had lower TSS, although treatments effects, within location, were not statistically significant.

Table E2. Effect of K/Na ratio and total salinity level on fresh yield and TSS of the fruit sap from the inner and outer pericarps.

Tr	Salinity	Medium (mM)		Fresh yield	TSS in fruit sap (%)	
		K	Na	Kg/plant	inside	outside
1	Low	5	5	3.69a	8.8	6.5
2	Medium	40	5	2.69bc	9.2	7.1
3	"	22.5	22.5	3.39ab	10.3	7.6
4	"	5	40	2.74bc	10.2	7.5
5	High	80	5	0.05e	-*	-*
6	"	42.5	42.5	1.17d	8.6	6.4
7	"	5	80	1.94cd	10.8	7.9

The increase in K proportion in each salinity level had a deleterious effect on shoot growth throughout the experimental period (Tables E3). This effect showed up more strongly on the final harvest (Table E3, Figure E1), when yield at medium salinity with 40 mM K was similar to yield at high salinity with 80 mM Na. The effect was stronger on shoot than on root growth and the shoot/root weight ratio decreased from > 7 in the control to 2.2 - 4.7 in the saline treatments.

Table E3. Effect of K/Na ratio and total salinity level on mean daily ET (litter/plant*day); dry matter yields of shoots in all harvests and roots and fruit final data (g DM per plant).

Tr	Shoot harvest			Final harvest			ET	
	1st	2nd	3rd	Shoot	Root	Fruit	Total	L/plday
1	3.7	8.4a	16.5a	147.8a	20.4cde	202.4ab	370.6	1.007
2	2.4	5.2bc	8.4cde	69.0de	30.2abc	170.6ab	269.8	0.632
3	3.2	7.2ab	13.1abc	127.3ab	29.8abc	247.0ab	404.1	0.835
4	3.3	7.2ab	11.6abcde	114.9ab	30.9ab	185.6ab	331.4	0.787
5	2.0	4.0bc	7.4de	16.3eigh	4.3f	0.1d	21.2	0.242
6	2.6	5.3abc	6.8e	52.8de	11.5ef	75.8c	140.1	0.407
7	2.5	3.8c	8.8bcde	83.8cd	17.7de	156.0b	257.5	0.473

Salinity and K/Na ratio effect on tissue cation contents is presented for shoots in table 4, and for roots and fruits in table 5. Potassium content was much higher in shoot and fruit than in roots.

Sodium showed only small differences between organs. Calcium in shoots was much higher than in fruits. Magnesium was highest in shoots and lowest in roots. Potassium and Na contents were lower and Ca content was higher in the final harvest. Between organs K and Na shoots>fruit>root and Ca shoot>>>fruit.

Table E4. Effect of K/Na ratio and total salinity level on the shoots cations content at the beginning (B) and the end of the growing season (% Dry weight).

Ion	K		Na		Ca		Mg		Cl	
Tr	B	E	B	E	B	E	B	E	B	E
1	5.5de	3.4c	0.60g	0.52fg	4.1ab	9.3ab	0.74abc	0.87ab	1.31e	1.87d
2	10.1b	9.3b	0.60g	0.18g	1.9cd	4.3cd	0.60bc	0.43cd	3.55cd	3.50b
3	8.1c	6.8c	1.00ef	0.68ef	3.1bc	6.3bc	0.79a	0.70bc	3.46d	2.84c
4	4.5ef	2.3de	1.78bcd	1.81bc	4.0ab	9.1ab	0.87a	0.94a	2.65de	2.97c
5	13.7a	12.8a	0.53g	0.51fg	1.4d	1.1d	0.53c	0.21e	6.12a	8.38a
6	10.2b	8.7b	1.52d	0.97ef	2.1cd	2.5d	0.67abc	0.34de	5.60ab	7.69a
7	3.8f	1.5e	3.40a	2.87a	3.4bc	9.5ab	0.85a	0.89ab	4.18bcd	4.43b

Table E5. Effect of K/Na ratio and total salinity level on final roots and peak season fruit cations content (% dry weight).

	Root				Fruit				
Tr	K	Na	Mg	Cl	K	Na	Ca	Mg	Cl
1	0.75cd	0.23d	0.24ab	0.25c	6.4bc	0.46c	0.64a	0.57ab	0.78e
2	1.07c	0.12d	0.19ab	0.41c	8.9a	0.36c	0.20cd	0.52abc	1.23cd
3	-	-	0.36a	-	6.8b	0.67b	0.33b	0.45bc	1.10d
4	0.74cd	0.74abc	0.20ab	0.45c	5.5bc	1.82a	0.35b	0.50bc	1.32c
5	3.03a	0.20d	0.18ab	1.80a	9.4a	0.20c	0.08d	0.30c	2.37a
6	1.85b	0.76ab	0.27ab	1.11b	9.1a	0.81b	0.12cd	0.41bc	2.21ab
7	0.44d	0.92a	0.24ab	0.43c	4.4c	1.99a	0.29c	0.38bc	1.52b

Salinity and K/Na ratio influenced the ions content in the different organs to different extend. Figure E_2 shows effects of salinity, K level and K/Na ratio on shoot and fruit ion contents, observed at medium K concentration. Each line represents a different salinity. The line slope gives the effect of K within a given salinity. The vertical difference between lines gives the Na effect for a given K and the horizontal difference the K effect for a given Na.

Addition of NaCl to a given K salinity had no effect on the shoot Ca or Mg content. It decreased the shoot K content slightly and the shoot Na content considerably. There was a similar decrease in shoot K content and a similar increase in shoot Na content for a given increase in medium Na irrespective of the absolute tissue or medium K or Na content. This indicates no competition between Na and the divalent cations, and a stoichiometric competition between Na and K over the entire tested range. For a given salinity the increase in K proportion

resulted in an increase in shoot K and a decrease in shoot Na, Ca and Mg. This confirms the Na and K competition, but indicates a competition between K and the divalent cations in shoot uptake.

The fruit data for Na show similar curves to the shoot data. K content in the fruits did not decrease to the low levels found in the shoot, and show saturation at about 40 mM medium K. Medium K/Na ratio had only slight effect on the content of Ca and no effect on the content of Mg in the fruits.

The data indicate similar competition between K and Na in uptake by shoots or fruits and very different competition between the mono and divalent cations between shoots and fruits. The shoots Ca and Mg were not influenced by Na and were reduced strongly by K. However, accumulation in the fruit of Ca and Mg was inhibited strongly by both Na and K. There was somewhat stronger effect of K on Ca accumulation in the fruit. But the Mg accumulation was inhibited by K and Na to the same extent.

The differences in competition of monovalent with divalent cations, between shoot and fruit, should be related to the different supply systems of these organs. The import of ions into mature shoot tissues is mostly in the xylem, and the export of ions is in the phloem. Competition between K and Na can be in both phases of loading or unloading the tissue (although there are more evidences for K than for Na phloem transport). The relatively small differences in concentrations of Na and K between fruit and shoot support the hypothesis of phloem transport on these cations. Since a larger xylem flow volume per unit dry weight is expected into the transpiring shoot than into the non transpiring fruit, the import into fruits is mainly in the phloem. There is also solute outflow from the fruit. Although we don't have information on Ca transport in the phloem or on K or Na influence on this transport, the different competitions on shoot and fruit ions content call for such a possibility.

The significant changes in shoot cation composition that follow the changes in the medium composition could be responsible for the specific K toxicity. Sodium salinity improved fruit quality as measured by TSS to a larger extend than K salinity. the two types of salinities caused a similar decrease in fruits divalent cations contents. These changes may influence fruit quality. The effect of the cation composition on fruit quality requires a more detailed investigation.

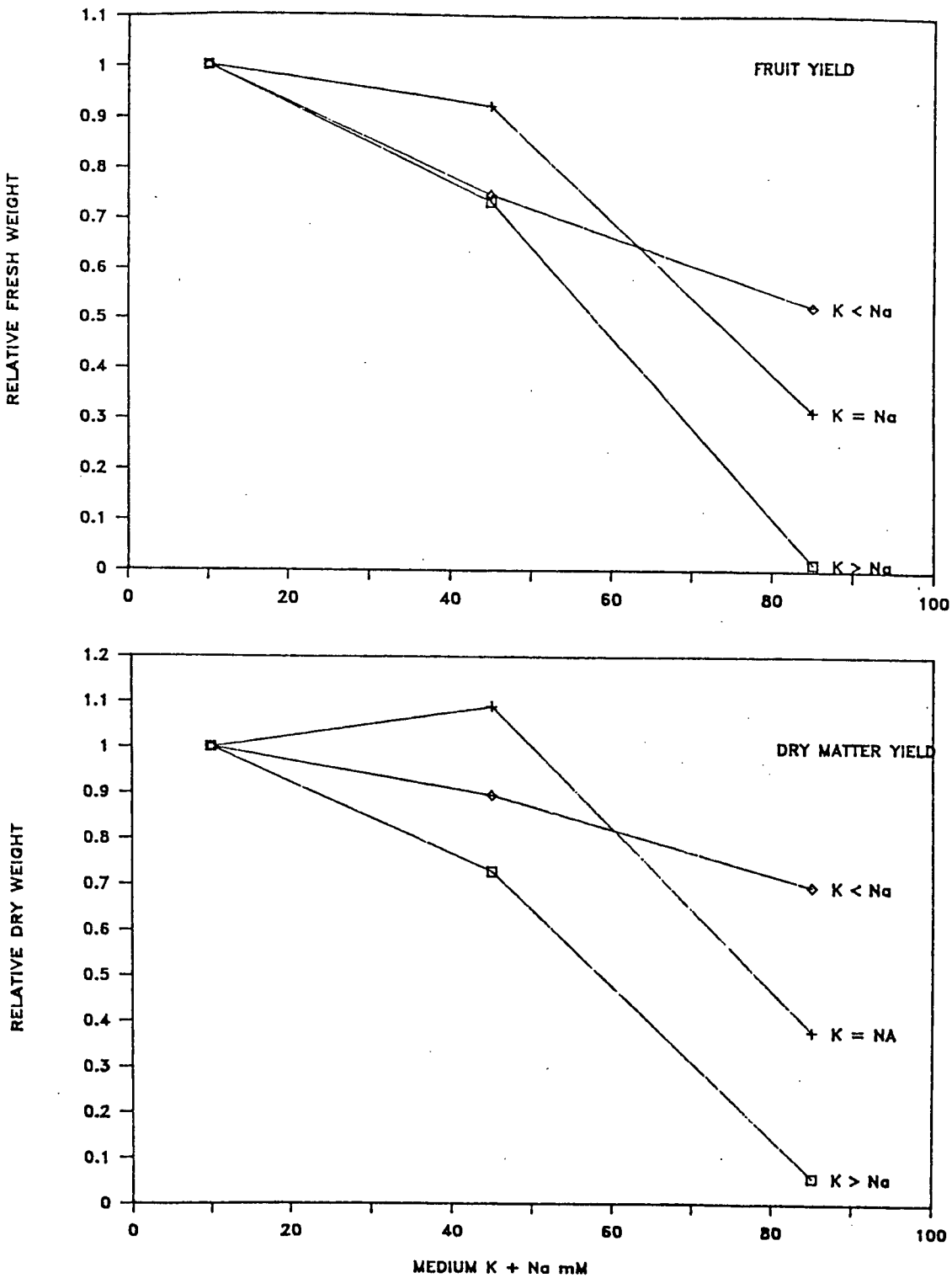


Figure E1. The influence of the [K]o:[Na]o ratio on the salt tolerance of melon (var. Galia) (Data of relative fresh weights of fruits and total dry weight).

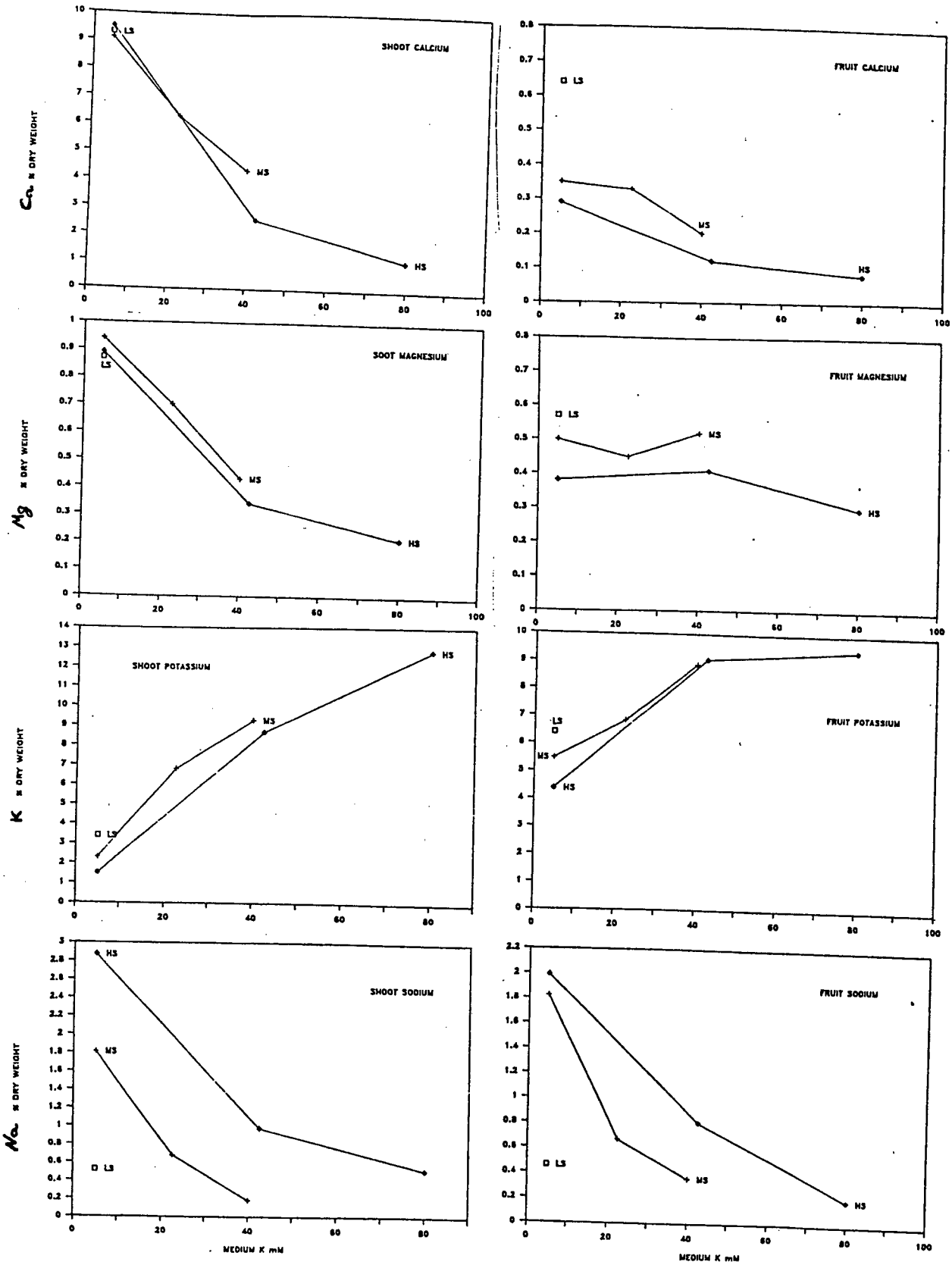


Figure E2. The influence of media salt levels [K+Na]o and its [K]i and [Na]i content on shoot and fruit cations content. (Labels LS, MS, HS - Low, Medium and High salinities).

F. Potassium, calcium, magnesium, sodium and salinity in soil solutions and rhizospheres.

C.A. Tyson and D.N. Munns

Summary

We investigated the effects of salinity and related factors on the availability of K in the soil solution and rhizosphere of low-K soils with high fixing capacity.

Exchange and solution K were highest in the surface 0 to 25 cm and were 2 to 5 times lower at 50 to 75 cm. Other cations - Ca, Mg, and Na - varied less with depth. At all depths sampled, addition of NaCl increased the concentrations of K, Ca and Mg as well as Na in the displaced soil solution. Salt also lowered the soil pH by about 0.5, and the solution silica by about 50%.

Salt increased the uptake of Na, Ca and Mg by barley seedlings (i days). It caused slight but significant increases in K uptake at intermediate salinity, and decreases at high salinity.

Barley roots lowered the Na concentration in low-salt soils. They raised the Na concentration in salinized soils and the concentrations of Ca and Mg in all the soils. They markedly lowered the K concentrations in rhizosphere soil solution. Salinity enhanced the accumulation of soluble and exchangeable Na, Ca and Mg near the root surface. Most significantly, K levels at the root surface were less severely depressed with increasing salinity. This observation helps explain why salt did not reduce K uptake from the soil.

Introduction

The soil solution has become recognized as a useful indicator of the nutritional status of a given soil. Levels of nutrients in the soil solution are in quasi-equilibrium with exchangeable, sorbed, and solid phase nutrients, and indicate the rhizosphere intensity levels which actively absorbing roots will encounter. Similarly, measurement of toxins such as sodium in soil solution taken at actual field moisture levels should be a more direct measure of root exposure. The objectives were as follows:

A. To determine the influence of increasing levels of soil salinity and varying soil moisture content on the cation composition of the soil solution.

B. To determine how increasing salinity influences the chemical composition of the soil solution within a soil profile.

C. To determine the temporal shifts in soil solution levels of cations following K fertilization under treatments of increasing salinization.

D. To determine the shifts that occur in the cation composition of soil solution of rhizosphere soil compared to that of uncropped bulk soil under treatments of K fertilization and salinization.

E. To determine effects of salinity on gradients of exchangeable cations in the rhizosphere.

Materials and Methods

Soils: Three soils from Kings County, California were selected on the basis of their differences in texture, clay mineralogy, K levels, and $CaCO_3$ content (Table F1.). All three soils are typic xerorthents. Soils were sampled at three depths: 0-25, 25-50, and 50-75 cm. At each depth, soils were thoroughly mixed, dried at 60 c, and sieved through a 2 mm screen.

Table F1. Chemical properties of soils in rhizosphere studies.

Soil Series	Depth (cm)	pH (1:1 paste)	CEC (cmole c/kg)	Exch K 1N NH_4OAc (mg/kg)	HCl Extr K (mg/kg)	Total K %	Organic Carbon %	$CaCO_3$ %
Kimberlina fsl	0-25	7.3	10	60	630	1.34	0.69	--
	25-50	7.7	11	36	515	1.33	0.41	--
	50-75	8.0	10	34	500	1.32	0.17	--
Nord fsl	0-25	7.8	15	157	625	1.47	1.17	--
	25-50	8.1	14	42	525	1.42	0.55	--
	50-75	7.7	14	42	475	1.49	0.32	--
Jakeside cl	0-25	7.8	24	118	420	1.3	1.1	4.0
	25-50	7.9	23	72	320	1.29	0.33	4.0
	50-75	7.8	23	72	300	1.39	0.11	3.6

Salinization Treatments: Soil was salinized by the addition of NaCl. A slurry of a known mass of soil with a solution containing the desired level of NaCl was created, shaken on a horizontal shaker for one hour, dried at 60°c, and sieved through a 2 mm screen.

A. Soil solution composition as influenced by moisture content and NaCl level.

Samples from the surface 25 cm of Nord fine sandy loam and Kimberlina fine sandy loam were salinized to levels of 0, 10, and 30 cmole c Na/kg soil. Triplicate 10.0 g samples of treated soil were placed in 50 mL Nalgene polypropylene centrifuge tubes. Distilled water was then added at levels corresponding to 15, 25, 50, and 100% soil moisture on a mass basis. Centrifuge tubes were capped and incubated for 72 hours at 25°c. Soil solution was immiscibly displaced following the procedure described by Mubarak et al (1977). Ten mL CCl_4 was introduced into the centrifuge tubes. The tubes were recapped and

shaken ten minutes on a horizontal shaker. Samples were centrifuged for 90 minutes at 39,000 g using a Sorvall RC-2B Refrigerated Superspeed Centrifuge equipped with an SA-600 rotor. Supernatant soil solution was pipetted from the centrifuge tubes and filtered through 5um Millipore filters. Calcium and magnesium in the soil solution were determined by atomic absorption, while potassium and sodium were determined by flame emission on a Perkin Elmer 560 spectrophotometer.

B. Soil solution composition as influenced by depth in the soil profile and NaCl level.

Samples of Nord fsl, Kimberlina fsl, and Lakeside cl were salinized at levels of 0, 4, and 10 cmolec Na/kg soil as previously described. Triplicate 10.0 g samples from the interval 0-25, 25-50, and 50-75 cm deep in the pedon were placed in centrifuge tubes. Samples of Nord fsl and Kimberlina fsl were watered to 25% moisture, while the Lakeside cl was watered to 30% moisture on a mass basis. Soil solution was displaced and extracted as before. Ca, Mg, K, and Na were measured in the soil solution. The pH of the soil solution was measured with a glass electrode (Orion), and soluble silica measured by the colorimetric blue silicomolybdous acid procedure of Weaver et al (1968).

C. Soil solution composition as influenced by K fertilization, salinization, depth in the soil profile, and time.

Triplicate 10.0 g samples of Nord fsl from the intervals 0-25, 25-50, and 50-75 cm in the pedon were salinized at levels corresponding to 0, 4, and 10 cmolec Na/kg soil. Samples were placed in 50 mL Nalgene centrifuge tubes. Soils were fertilized at levels of either 0 or 100 mg K/kg soil, added as KCl in the irrigating solution as soils were watered to 25% moisture. Samples were capped and incubated at 25 c for either 1, 5, 10, or 30 days, with soil solution again being obtained after these times by immiscible displacement with CCl_4. K, Na, Ca, and Mg levels in soil solution were determined over time.

D. Rhizosphere shifts in solution cation composition compared to uncropped bulk soil.

Soil solution from rhizosphere soil was obtained by growing barley (Hordeum vulgare L., cv. CM 72) seedlings under very high density in inclined acrylic boxes containing soils salinized at either 0, 4, or 10 cmolec Na/kg soil. Barley roots grew along the faces of the boxes, effectively covering the surface. After eight days of growth, plants were harvested , with soil adhering to the roots being gently removed and collected as rhizosphere soil. Soil solution was immiscibly displaced with CCl_4 and analyzed for K, Na, Ca and Mg. Soil Solution was compared with that of uncropped soil with the same soil moisture content. Barley roots and shoots were harvested and also analyzed for Na, K, Ca, and Mg in order to determine how increasing salinity affects the net uptake of these cations.

E. Exchangeable cation gradients in the rhizosphere.

Growth boxes were designed, whereby roots of very densely seeded barley completely covered the exposed end-plane of a cylinder

containing the test soil (Fig. F1A.). The exposed plane was covered with a very fine mesh 80 micrometer polypropylene screen, which permitted the proliferation of root hairs but not roots into the soil. This plane was then taken to simulate the rhizosphere of a root, with depletion and accumulation of cations occurring laterally away from the root plane. After eight days of growth, cylinders were detached and placed in a soil microtome (Fig. F1B). Soil thin sections were cut using disposable microtome blades. Sections were immediately extracted with neutral 1N ammonium acetate and analyzed for K, Na, Ca, and Mg. Results of sequential thin sections give exchangeable-cation composition profiles within the rhizosphere. Nord fsl, Kimberlina fsl, and Lakeside cl at depths of 0-25, 25-50, and 50-75 cm were again used. Salinization levels were 0, 4, or 10 cmolec Na/kg soil. K fertilization occurred at rates of 0 and 100 mg K/kg soil added as KCl.

Results and Conclusions

To date, none of the research has been finalized. The data and information presented here is a summary of work in progress. Immiscible displacement with CCl_4 proved to be an efficient extractant of soil solutions in a wide range of soil moisture contents in the soil tested. Recovery of soil solution in Nord fsl ranged from 66% at 15% soil moisture to 95% recovery at 100% soil moisture on a mass basis (figure F2).

Part A.

Tables F2 and F3 represent the soil solution data for the surface 25 cm of the Nord fsl and Kimberlina fsl. The same data are presented on the basis of a concentration of charge (cmole c/kg soil) in Tables F2 and of mass concentration (mg/L) in Tables F3. Values of the total charge of cations in solution were obtained from the analysis of an aliquot of the soil solution. Values were extrapolated to the total volume of solution known to be in the soil, even though displacement of the soil solution was not quantitative. This assumption that the sampling of the soil solution is representative of all the solution in the soil is lent credence by a comparison of the amount of charge added in the form of NaCl versus that recovered in the extrapolated values, a summation of charge of K, Na, Ca, and Mg (e.g. in the Nord fsl of Table 1, 100 mmole c NaCl/kg soil was added, and 109 mmole c cations/kg was calculated as being in the soil solution).

Addition of NaCl greatly increases the concentrations of all cations in the soil solution, as cations are displaced from exchange sites. With increasing dilution, the total amount of monovalent charge (K+Na) increases, while divalent charge (Ca+Mg) tends to decrease. This is a demonstration of the valence dilution effect, where with progressive dilution, divalent cations are preferentially adsorbed, while more of the monovalent cations are in free solution. A cation such as K should therefore have a greater mobility in more dilute solutions. This mobility will influence its diffusivity to absorbing root surfaces, and should also tend to enhance K leaching.

Part B.

Solution K levels declined markedly with depth in the pedon (Table F4), as did the exchangeable and nonexchangeable K (Table F1). Further investigations will be made on the plant availability of K at these different depths with increasing salinity. Though K is generally the cation taken up in the greatest amounts by plants, its levels in the soil solution are extremely low compared to Na, Ca, and Mg.

With increasing salinization, the pH of the soil solutions decreased (fig. F3). The greatest pH reduction generally occurred with the first input of NaCl. There was a corresponding decrease in solution silica (fig F3.), which may be related to increased K concentrations and stability of K-silicate minerals during progressive salinization.

Part C.

Soil solution K declined with time following K fertilization (Fig. 4). The soils are rich in micaceous minerals in the clay and silt sizes, and there appears to be considerable fixation of fertilizer K, particularly in the first ten days. Increasing Na elevated K levels throughout the experiment. On a relative basis, however, salinization does not appear to influence K fixation. Over the 30 day period, solution K was reduced 41%, 39%, and 38% for the 0, 4, and 10 cmole c Na/kg soil treatments, respectively. For Na, Ca, and Mg the changes are much more subtle, but levels of these cations appear to increase slightly over time (data not shown).

Part D.

Increasing salinization greatly increased solution levels of K, Na, Ca, and Mg in both rhizosphere and bulk soil (Fig. F5). The relatively large amounts of Na, Ca, and Mg resulted in a slight accumulation of these cations in the rhizosphere of barley. Under low Na conditions there was appreciable depletion of Na in the soil solution, as barley absorbs significant amounts of Na. The greatest rhizosphere effect as measured in the soil solution came with K, where depletion was very dramatic (fig. F5A.). Plant tissue dry weight was not significantly different amongst the three salinity treatments during the eight day period of growth. Data for net uptake of cations by barley in the surface 25 cm of Nord fine sandy loam are summarized in table F5. On a charge basis, net uptake of Na by the barley seedlings was the greatest, even with no NaCl addition to the soil. Salt addition of 4 cmole c Na/kg soil resulted in significantly increased plant uptake of Na, K, Ca, and Mg compared to the unsalinized soil. At the highest salinity treatment of 10 cmole c Na/kg soil, net K uptake was depressed.

Table F2. Effects of salinity and water content on solution cations (charge/soil mass)

Salinity Level (mmole c Na/kg soil)	Soil Moisture % (w/w)	SOLUTION CATIONS K	Na	Ca	Mg	Total Cations in solution	Charge Ratio (monovalent/divelent)
		mmole c/kg soil at a given soil moisture % (w/w)					
				Nord fsl			
0	15	0.06	2.1	4	0.70	6.9	0.46
	25	0.09	2.9	3.6	0.74	7.3	0.69
	50	0.11	3.5	3.5	0.68	7.8	0.86
	100	0.13	4.6	3.5	0.61	8.8	1.21
100	15	0.32	69	36	9.2	115	1.55
	25	0.34	73	30	7.5	111	1.92
	50	0.4	76	31	6.0	113	2.05
	100	0.42	82	32	5.0	119	2.21
300	15	0.59	224	58	12.9	295	3.16
	25	0.54	230	55	11.8	297	3.47
	50	0.65	246	46	11.0	302	4.51
	100	0.77	252	41	8.6	302	5.10
				Kimberlina fsl			
0	15	0.02	0.31	0.78	0.09	1.2	0.38
	25	0.02	0.43	1	0.17	1.6	0.38
	50	0.04	0.59	1.48	0.29	2.4	0.36
	100	0.07	0.65	1.85	0.31	2.9	0.33
100	15	0.09	60	33	5.7	99	1.55
	25	0.09	62	31	5.4	98	1.71
	50	0.14	70	26	4.9	101	2.27
	100	0.15	70	25	4.9	100	2.35
300	15	0.18	225	58	8.9	292	3.37
	25	0.17	232	55	8.9	296	3.63
	50	0.19	239	50	8.3	297	4.10

Table F3. Effects of salinity and water content on cation concentration in soil solutions.

Salinity Level (mmole c Na/kg soil)	Soil Moisture % (w/w)	Solution Cations K	Na	Ca	Mg
		(mg/L soil solution)			
		Nord fsl			
0	15	16.5	320	530	57
	25	14.1	270	290	36
	50	8.1	160	140	17
	100	5.1	105	70	7
100	15	84	10630	4750	740
	25	53	6700	2440	360
	50	31	3500	1250	150
	100	17	1880	640	60
300	15	153	34500	7750	1050
	25	84	21200	4380	570
	50	52	11300	1750	280
	100	30	5800	820	100
		Kimberlina fsl			
0	15	4.7	48	104	11
	25	3.2	40	81	9
	50	3.1	27	59	7
	100	2.7	15	37	4
100	15	23	9250	4380	460
	25	14	5730	2500	260
	50	10	3190	1050	120
	100	6	1610	500	60
300	15	47	34500	7670	720
	25	27	21000	4380	430
	50	15	11000	2010	200
	100	9	5500	890	90

Table F4. Effects of Salinity and Depth on Solution Cations.

Salinity Level	Depth	K	Na	Ca	Mg	total cations in solution
mmole c Na/Kg soil	cm	mmole c/kg soil at 25% soil moisture (w/w)				
			Nord fsl.			
0	0-25	0.089	3	3.5	0.7	7.4
	25-50	0.025	4.9	2.2	1.5	8.6
	50-75	0.024	6.4	2.6	2.4	11.5
40	0-25	0.208	24.5	15.2	4.5	44.4
	25-50	0.055	26.3	15.8	5.6	47.7
	50-75	0.04	29.1	16.5	8.6	54.3
100	0-25	0.321	67.9	29.9	7.2	96.4
	25-50	0.081	67.7	27.7	9.7	105.2
	50-75	0.065	67.9	26.9	13.4	108.3
			Kimberlina fsl.			
0	0-25	0.022	0.5	1.1	0.3	1.9
	25-50	0.01	0.5	0.8	0.2	1.5
	50-75	0.008	0.6	0.8	0.2	1.6
40	0-25	0.053	17	15.6	3.7	36.4
	25-50	0.037	17	15.6	3.3	35.9
	50-75	0.034	16.8	15.6	5	37.4
100	0-25	0.082	62.9	27.8	6.5	97.3
	25-50	0.057	62.1	28.3	5.8	96.3
	50-75	0.045	62.5	27.4	6.6	96.5
			Lakeside cl.			
0	0-25	0.031	1.2	3.1	0.53	4.9
	25-50	0.01	0.9	1.4	0.3	2.6
	50-75	0.01	0.9	1	0.3	2.2
40	0-25	0.063	13.4	23.8	3.3	40.6
	25-50	0.035	13.3	20.2	3.8	37.3
	50-75	0.046	11.4	21.3	5.4	38.1
100	0-25	0.077	48.8	38.6	5.9	93.4
	25-50	0.042	48.7	35.6	6.7	91.0
	50-75	0.044	44.1	35.6	9.6	89.3

Table F5. Net uptake of cations by barley in the surface 25 cm of Nord fine sandy loam.

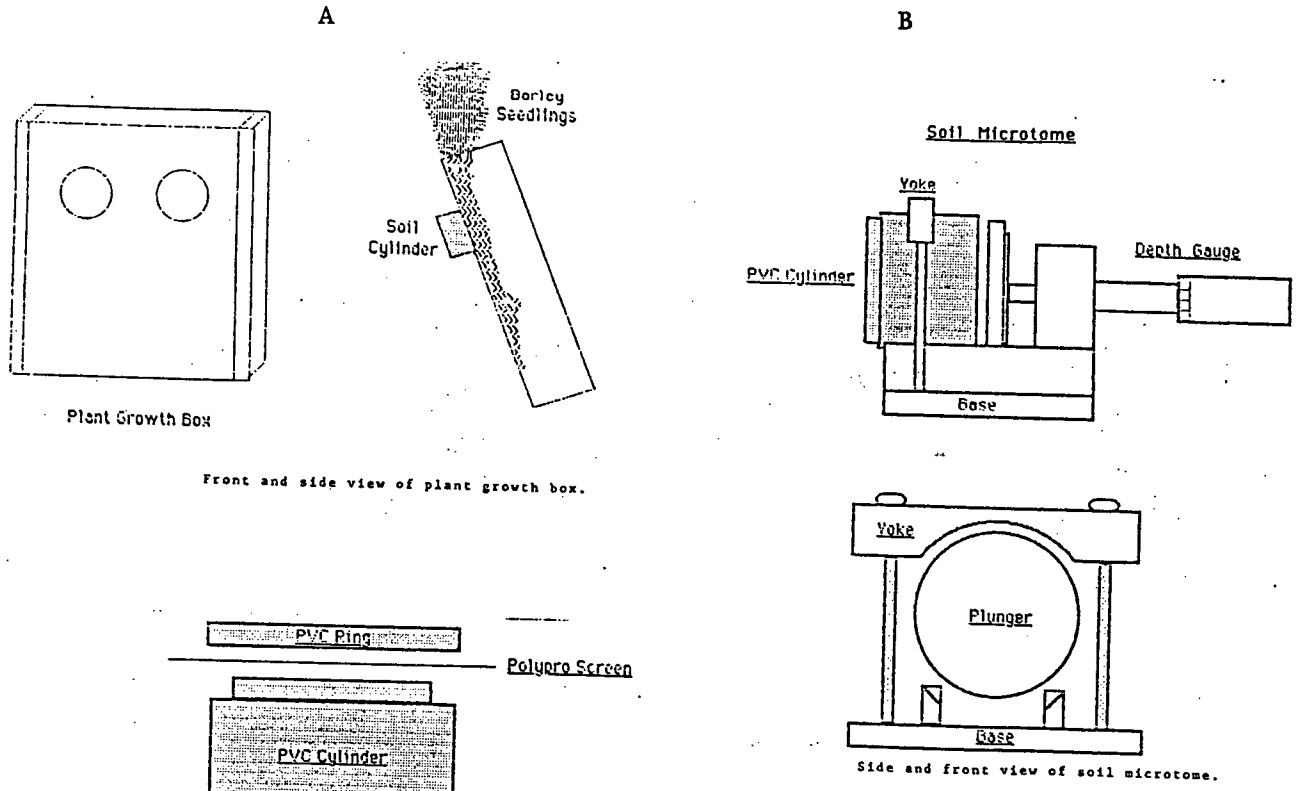
Salinity Treatment (meq NaCl/100g soil)	Atlantables			
	K	Na	Ca	Mg
	meq/box			
0	0.07 b	1.23 a	0.33 a	0.15 a
4	0.94 c	3.00 b	0.39 b	0.17 b
10	0.61 a	3.35 c	0.41 b	0.19 b

Values are average of three replicates.
Values within a column followed by the same letter do not differ significantly at the 5% level by Duncan's multiple range test.

Part E.

Data presented here is for the surface 25 cm of the Nord fsl. Potassium in the unsalinized treatment had a steep depletion profile extending approximately 3 mm from the root surface (fig. F6A.). Depletion of K in the medium Na treatment was nearly as extensive, but more diffuse. At the high Na treatment, K depletion is much narrower. This may suggest a depressed uptake of K at higher levels of salinity, which is also supported in the data of Part 1D. Rhizosphere sodium patterns largely reflect the treatment additions of Na (fig. F6B.). Under low Na levels there is a significant drawdown of Na near the root surface. In the medium and high Na treatments, there is accumulation of Na near the root surface, reflecting mass flow in excess of uptake. Calcium and magnesium profiles in the rhizosphere are quite similar, showing accumulation near the root surface that increases with increasing salinity (Fig. F6C,D).

Figure F1. Equipment for measuring cation gradients in the rhizosphere (Section E). A. Growth boxes and soil cylinder, B. Microtome for sectioning soil after contact with roots.



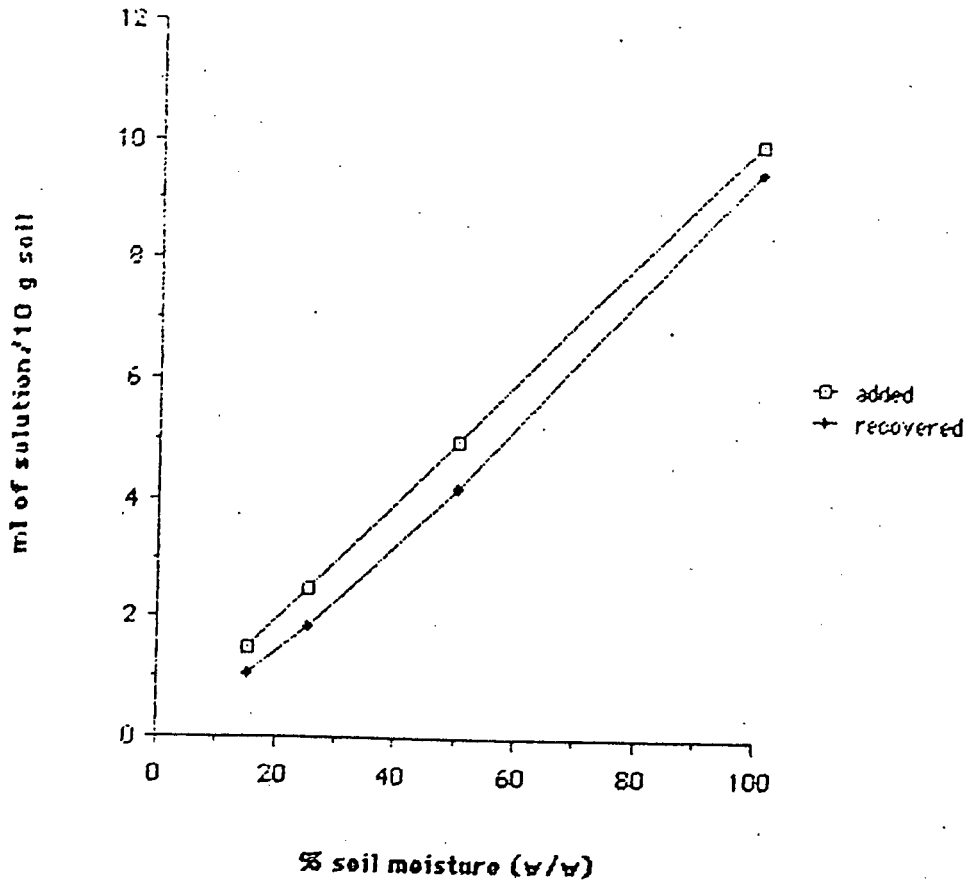


Figure F2. Recovery of soil solution by carbon tetrachloride displacement at different soil water contents.

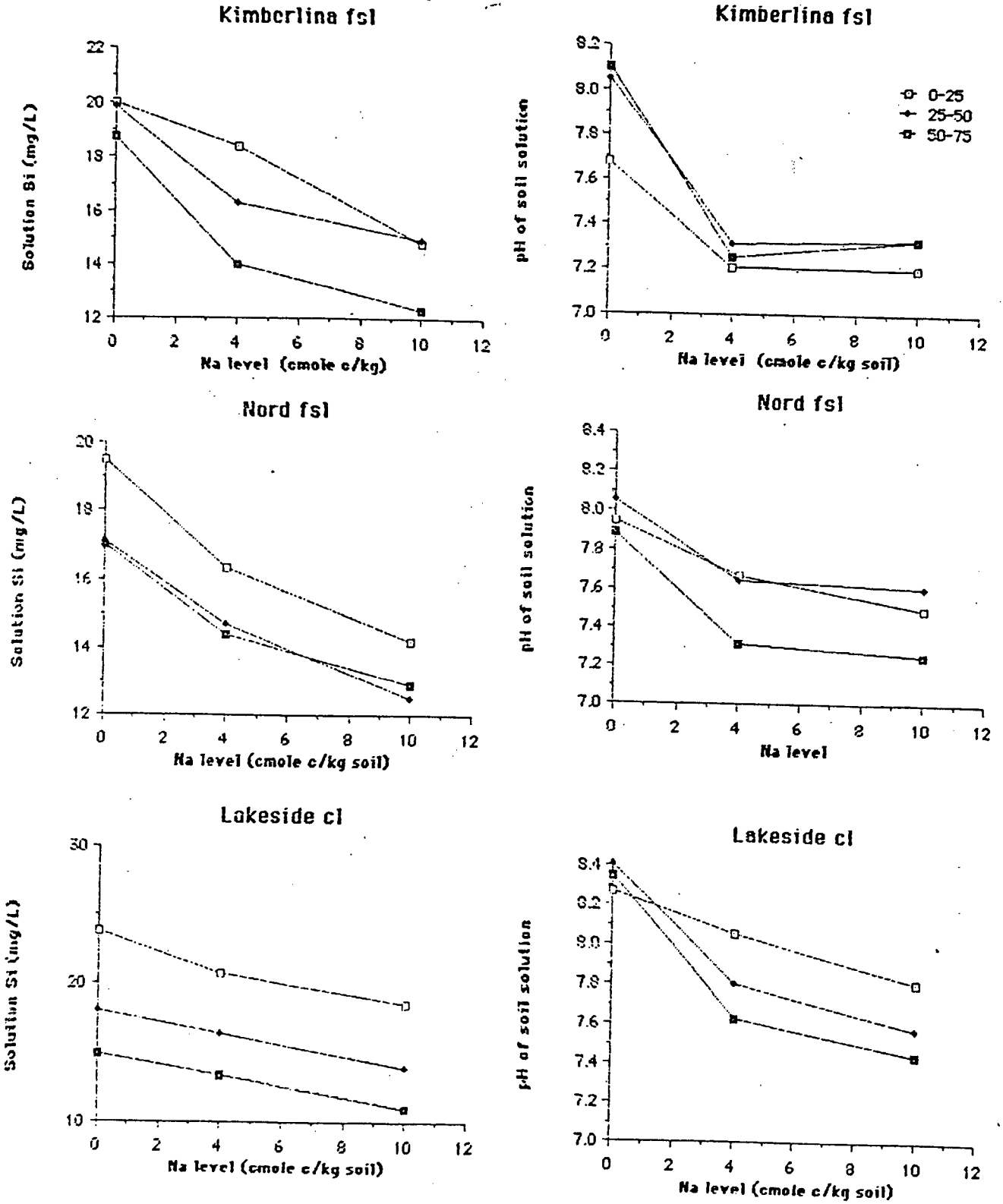


Figure F3. Effects of salt treatment on soil pH and solution silica for samples taken at 3 depths in 3 soils (section B).

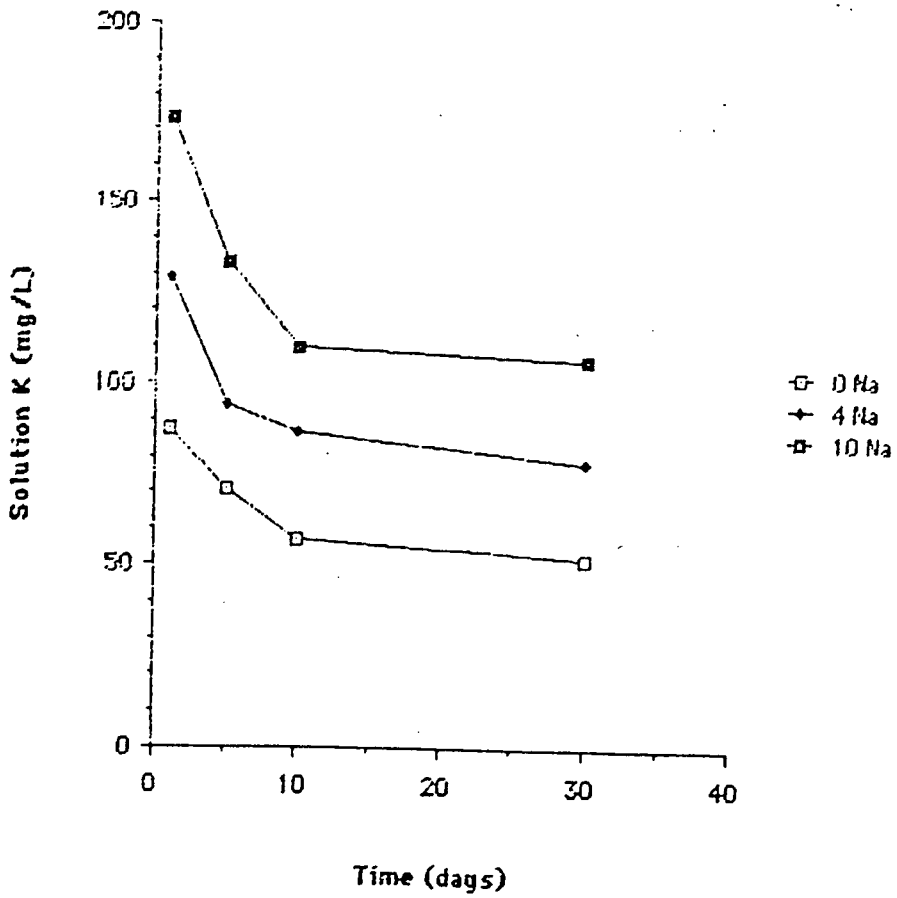
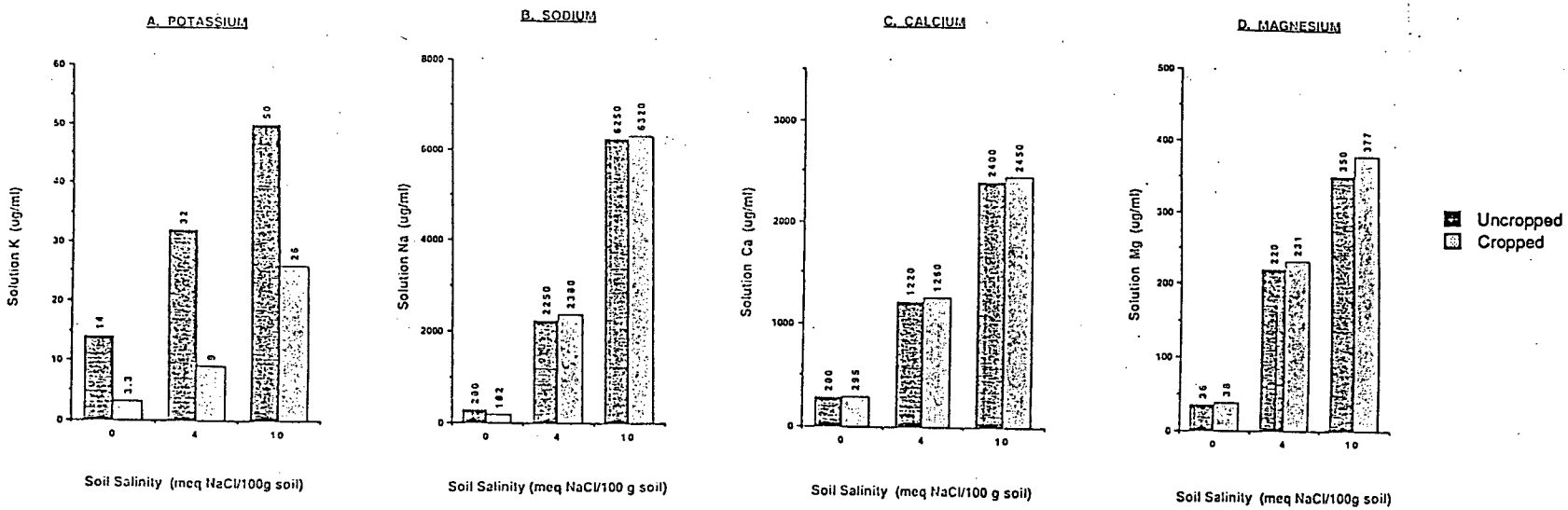


Figure F4. Soil solution following K fertilization (section C).

Figure F5. Effects of salinity on solution cations in bulk and rhizosphere soils (section D). Comparisons of uncropped soil with rhizosphere soil removed from roots of densely planted barley seedlings.



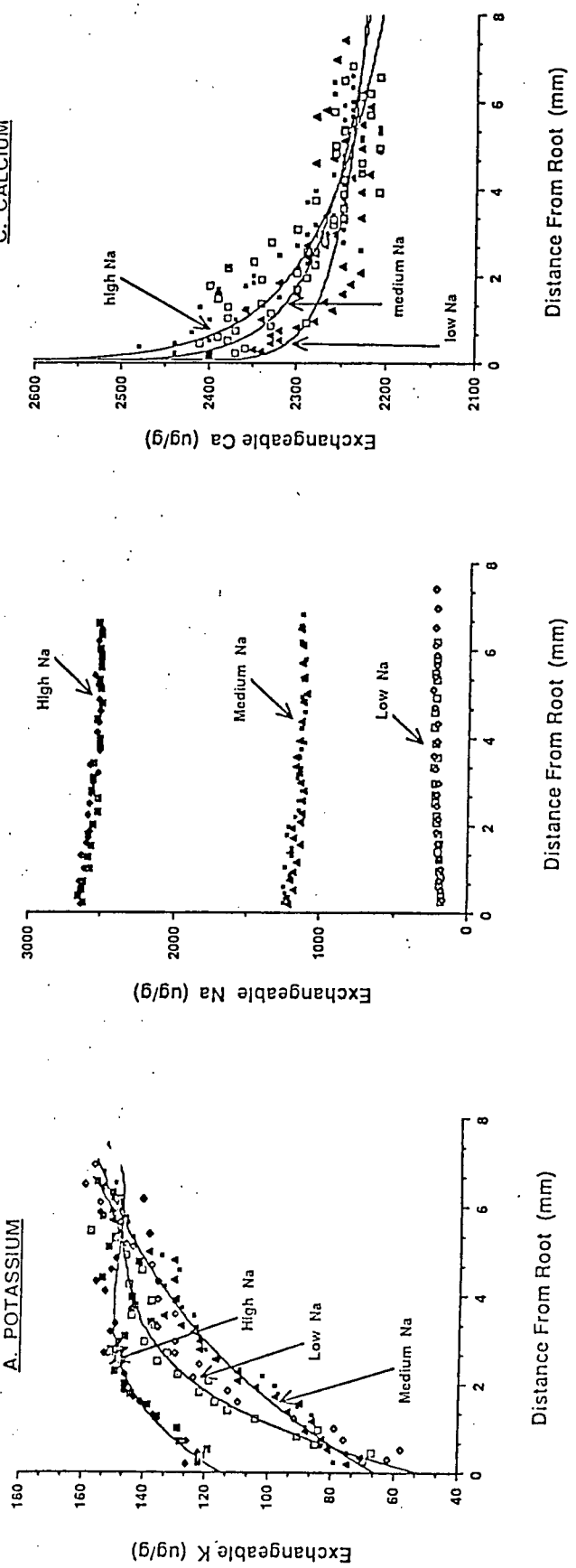


Figure F6. Gradients of exchangeable + soluble K, Na and Ca with distance from roots, at three levels of salinization (section E). Magnesium behaved like Ca.

G. Potassium Distribution in a Sandy Soil Exposed to Leaching With Saline Water.

Sala Feigenbaum

Summary

The distribution and movement of potassium was studied in a sandy soil exposed to leaching with saline and sodic waters. The data reported and discussed were from laboratory and field experiments.

Downward movement of applied potassium was related to the level of total salt and the amount at the leaching solution

From the calculated potassium balance sheet some of the added potassium was not found in the ammonium acetate extract. the unaccounted potassium increased with increasing salinity in the irrigation water. It seems, that this potassium was fixed by the soil clay minerals. The data of both, columns and field experiments suggest that the exposure of a soil to leaching with saline and sodic solution effects the process of K fixation.

Introduction

Potassium fertilizer applied to a soil is adsorbed to exchangeable and non exchangeable sites and does not move beyond the zone of application (Munson and Nelson 1963). Losses of potassium reported by Bertsch and Thomas (1985) from irrigated soils are relatively low, in the range of 1.5 to 57 kg ha per year. Movement of applied potassium into deeper soil layers is expected in a coarse-textured sandy soil, with very low CEC. Farina and Graven (1973) reported losses of potassium by leaching up to 100 kg K ha^{-1} year below the rooting depth in a sandy soil. When some crops are irrigated with water, containing high levels of Na, Mg, and Ca salts, potassium adsorption, desorption and dissolution processes will be affected and there may cause some movement into deeper soil layers (Pratt and Laag 1967; Meiri et al. 1984; Ganje and Page 1970). Leaching excess salts is an essential management practice in irrigation with saline water. In a leaching program to remove soluble and exchangeable Na from exchange sites, calcium salts are usually used (USDA Handbook 60). During this process not only sodium but also potassium might be displaced and could be lost from the root zone.

Some experiments conducted in semi-arid regions have shown no response to potassium fertilizers. The potassium-supplying power of soils from arid and semi-arid regions is usually so great, that large quantities of K removed by cropping hardly affected the available K fraction (Cook and Hutcheson [1960]).

Soils in semi-arid regions are slightly weathered and high in potassium-bearing minerals (micas) with a high rate of K release (Schroeder [1974]). In loessial soils K supplying power is so large that crop responses to potassium additions are not expected even after many years of intensive cropping (Feigenbaum and Kafkafi [1972]). In sandy soils with low CEC and low clay content that have been

intensively cropped and irrigated with saline waters potassium is expected to decrease. The depletion of potassium from the root zone can be either by exchange or downward leaching by the percolating salts, or by uptake by high K requirement crops like potatoes (300-500 kg K/ha/year).

The objective of this study was to measure the distribution and losses of native and applied potassium fertilizer in a sandy soil exposed to leaching with saline waters.

Materials and Methods

A sandy soil Quartzipsamment from non K-fertilized plots of a field experiment irrigated with saline water was used to study the downward movement and leaching of potassium in soil columns. Approximately 650 g of soil was packed into the column (50 mm diameter and 200 mm long) using a long-stemmed powder funnel. Special care was taken to produce a homogeneous soil packing throughout the column, to minimize particle size separation. Filled soil columns were uniformly packed by dropping each column 10 times from a height of two centimeters. The soil columns were saturated with distilled water to displace as much air as possible from the soil pores. Following saturation, a constant height of water was maintained at the surface. Two treatments of K adding with time were carried out, one to non leached soil, the other to preleached soil column with saline solution. Potassium at 3.14 me K per soil column, was added to the surface as a concentrated solution of KCl, equivalent to fertilizer application in the field at the rate of 600 kg K per hectare, the above treatments were selected so that K movement through a finite depth in the column could be observed.

The leaching solution used in the experiment contained a salt mixture of NaCl and CaCl, at two total concentrations of 5 and 50 me/L with SAR of 1.6 and 5.2 respectively. The flow rate was kept constant at 10 ml/h in all the treatments during the leaching periods. The amounts of solution leached through the column were 280, 560, 840 and 1620 ml, equivalent to 140, 280, 420, and 820 mm surface irrigation. Leachate was collected in 20 ml fractions and its K and Na content determined at the end of the leaching periods the soil columns were dismantled, and the soil was horizontally sliced into 20 mm increments. Potassium was extracted by ammonium acetate and determined by the standard method. Potassium values were expressed in me/100 g air dried soil and represent the amount of soluble plus exchangeable K in the soil water system.

Results and Discussion

Potassium concentration in the effluent, leached with the two salt solutions (5 and 50 me/L) for treatments receiving no K are presented in Figure G1.

In both salt solutions the concentration of potassium in the effluent was high, about 1.7 me K/l and decreased with increasing leaching volume until a constant level of K release was obtained. In

the treatment containing low salt in the leaching solution, a sharp peak of displaced K could be seen after the first two pore volumes (280 ml) and followed by a sharp drop. A constant K-level (0.6 me K/l) was observed after 400 ml solution had passed through the soil column. In the treatment containing high salt concentration, two rates of K release - slow and fast - were observed with increasing leaching volume. The first, up to 1000 ml and the second up to 1700 ml, respectively. The final rate of K release was found to be 0.4 md/L, and was comparatively lower than the constant K release value found for low salt leaching solution.

The K accumulated in the effluent from columns with applied potassium, after previous leaching are presented in Figure G2. The total amount of potassium removed from the soil columns was 0.8 and 2.18 me K/col. in the low and high salt percolating solutions, respectively. After leaching the soil columns with about 840 ml of low and high salt solutions, 15% and 50% of the applied K was found in the effluent, respectively (Figure G2).

The 840 ml percolating solution assumed to simulate a field irrigated continuously with 420 mm water. It could be assumed that a previously leached sandy soil, with a low cation exchange capacity (5.2 me/100 g) (Table G1), can still hold 50% of the applied potassium even after leaching with a saline water. In field practice where such continuous irrigation rate is seldom applied and there are drying periods between irrigations, a lower leaching efficiency of applied potassium would be expected.

Table G1. Characteristics of the soil

Depth	Coarse sand	Fine sand	Silt	Clay	pH	CaCo	EC	CEC	Exch. K	Exch. Na
	---------- % ----------					%	dS m^{-1}	---	me $100\ g^{-1}$	---
0 - 20	25.7	66.2	3.6	4.5	7.82	3.6	0.92	5.0	0.57	0.20
20 - 40	26.0	66.8	3.2	4.0	7.76	3.5	0.85	5.2	0.62	0.22
40 - 60	21.1	65.0	6.9	7.0		5.9	0.87	4.9	0.70	
60 - 90	15.0	68.0	9.0	8.0		7.2	1.04	5.6	0.83	
90 - 120	15.5	67.0	8.2	9.3		3.2	1.07	5.8	0.67	

The distribution of K in the soil column, where potassium was applied on the surface before leaching of the columns with the two salt solutions, are presented in Figure G3. After leaching the soil columns with 280 ml solution (equivalent to 140 mm irrigation), the exchangeable K moved only to a depth of about 8 cm for the low percolating salt solutions. In the soil column leached with the higher salinity level (50 me/l) potassium was leached from the surface, increased with depth and then fell to the level of the original exch. K (about 0.6 me/100 g soil). Leaching the columns with 560 ml solution showed the same pattern for the movement of K in the column for the low salt leaching solution, as was found in the 280 ml. Most of K in the profile of soil column, leached with high salt concentration, was found in the bottom. The data suggest movement of applied K to a deeper

layer with increasing salt concentrations and amount of the percolating solution. These observations could be explained by the competition between Na and Ca in the leaching solution and the K applied to the soil, or by displacement of the exchangeable K by the added Na and Ca cations.

The effect of salt concentration and the amount of the percolating solution on K balance are summarized in Table G2. The amount of K in the effluent increased with increasing concentration and amount of the solution percolating through the soil columns (A). Potassium application to the leached and unleached soil affect K exchangeable level in the soil, leached by high salt concentration (B).

Table 2. The effect of salt (NACl + $CaCl_2$) concentration and the amount of the percolating solution on K-balance.

Treatments				Potassium		
Surface added K	Leaching solutions			Potassium		
	Conc.	Amount**	SAR	In the leachate (A)	In column as exchangeable + soluble (B)	Fixed calculated (C)
me/col.	me/l	ml/column		me/col	me/col	
			Applied K to a leached soil column			
3.14*	5	280	1.6	0.30	6.05	-0.6
3.14	5	560	1.6	0.60	6.10	-0.1
3.14	5	1680	1.6	0.80	5.70	-0.6
3.14	50	280	5.2	0.50	4.65	-0.90
3.14	50	560	5.2	1.30	3.85	-1.20
3.14	50	1680	5.2	2.20	2.25	-1.20
			Applied K to unleached soil column			
3.14	5	280	1.6	0.35	6.05	-0.40
3.14	5	560	1.6	0.50	5.93	-0.35
3.14	50	280	5.2	0.30	5.75	-0.80
3.14	50	560	5.2	0.80	4.20	-1.10
3.14	50	1680	5.2	2.18	3.65	-1.00

* 3.14 me is equal to 600 kg K/ha.
** 140 ml - 1 pore volume. The initial amount of exch. K was 3.70 me/col.

Taking into consideration the initial 3.70 and applied 3.14 me K/col. some potassium was unaccounted for after a balance was calculated (C). This suggests that during the continuous leaching with salt mixture some of the added K becomes non-extractable by ammonium acetate. When the column was leached with good quality water (5 me/l mixed salt solution) only a small fraction of K was not accounted for. Increasing concentration of the salt in the percolating solution (50

me/l), resulted in much K being unaccounted for. The volume of the leaching solution had a small effect on this fraction, assuming that fixation of added K could occur in the presence much Na (Volk 1938).

Results of K analysis from a field experiment carried out (by Meiri et al. (1984) on the same soil (as for the columns) and irrigated with three levels of saline water are presented in Table G3. The salinity levels in the water were 1.3, 3.3 and 4.0 dSm/cm. Two months after potassium was applied it was found that exchangeable K decreased slightly with increasing salinity compared within the layers for the two K treatment. The data for soluble K in that field experiment were not consistent, but were taken into consideration for calculating K balance. The distribution of Cl with depth can serve as an indicator of the effective depth of leaching in the field. It is clear that until the data when total irrigation amounted to 280 mm, no leaching beyond that depth could be observed.

Table G3 Exchangeable and soluble K and Cl, as affected by potassium fertilization and irrigation with saline water[4].

	17.2.83					10.4.83		
K_{fert}[1]	0	300	0	0	0	300	300	300
EC[2]	1.3	1.3	1.3	3.3	4.0	1.3	3.3	4.0
Irr[3]	100	100	180	180	180	180	180	180
Depth cm	Exchangeable K me/100 g soil							
0 - 20	0.57	0.87	0.46	0.40	0.41	0.64	0.53	0.49
20 - 40	0.62	0.71	0.55	0.40	0.47	0.63	0.56	0.54
40 - 60	0.70	0.74	0.66	0.52	0.67	0.60	0.57	0.54
	Soluble K me/100 g soil							
0 - 20	0.016	0.037	0.016	0.020	0.024	0.036	0.052	0.034
20 - 40	0.019	0.024	0.021	0.019	0.027	0.030	0.059	0.030
40 - 60	0.019	0.025	0.027	0.020	0.037	0.031	0.029	0.023
	Soluble Cl me/l							
0 - 20			12.5	28.4	20.0	13.5	28.5	25.0
20 - 40			5.1	22.3	13.5	8.6	21.3	10.2
40 - 60			2.3	3.0	5.5	3.5	6.5	3.6

[1] K_{fert} = Potassium fertilization $Kgha^{-1}$
[2] EC = Electrical conductance of water dS/m
[3] Irr = Irrigation depth mm
[4] These data were taken from a report by Meiri et al., 1984.

A potassium balance in soil was calculated from the differences between total initial K (soil extractable + applied) and total final K (soil extractable + plant removed K) (Table G4).

Table G4 Potassium balance sheet of soil (0-40 cm) irrigated with saline water*

Salinity treatment dSm/m	Initial extr. K	Applied potassium kg/ha	Final extr. K	Potassium removed by plant	Unaccounted K %
1.3	1470	300	1640	49	4.5
3.3	1470	300	1490	49	13.0
4.0	1470	300	1390	52	18.0

* Calculated from the differences between total initial K (soil extractable + applied) and total final K (soil extractable + plant removed K).

Since beyond Cl did not move beyond 40 cm, it is hardly expected that applied K will be found in the field below that depth. The unaccounted potassium increased with increasing salinity in the irrigation water. The deficit of K was 4.5, 13.0 and 18% of the applied fertilizer for the three saline waters, respectively. This deficit of K in the root zone was not entirely explained by leaching from that depth (40 cm). If leaching is not the answer, it is suggested that there is K fixation. In the field where soils are subjected to wetting and drying cycles, as well as increase of Na^+ in the soil, losses of potassium by fixation are much more serious than losses by leaching.

The data from both columns and field experiments carried out on the sandy soil suggests that exposure of a soil to leaching with saline and sodic solution affects the process of K fixation.

It is expected, therefore, that in a soil containing clay with high fixing capacity (like vermiculite) the relative K fixation could be more pronounced when brackish water is used for irrigation.

More detailed studies in this direction are needed to clarify the effect of Na^+ salt addition on K^+ fixation.

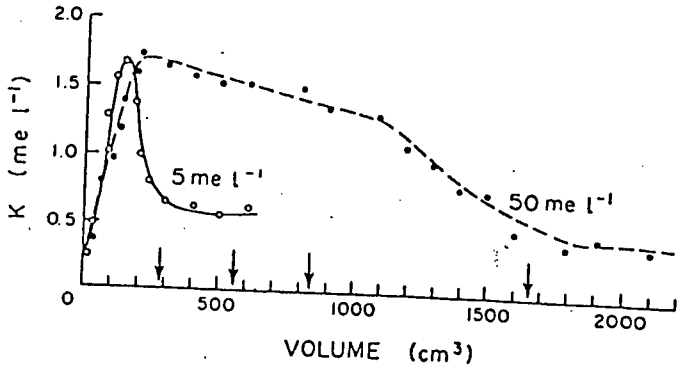


Figure G1. Potassium concentration in the percolating solution for non treated soil.

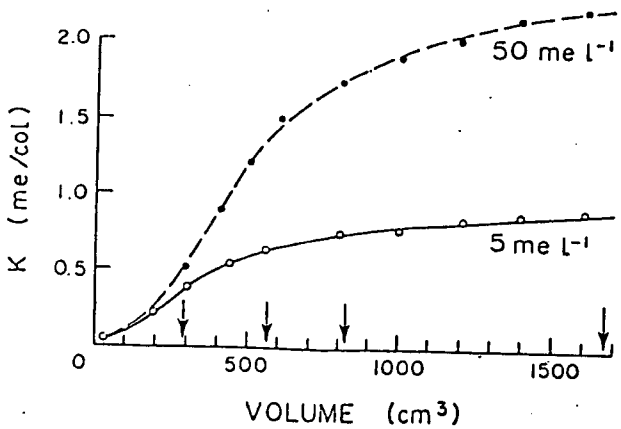


Figure G2. Cumulative amount of leached K as a function of the volume and concentration of the effluent.

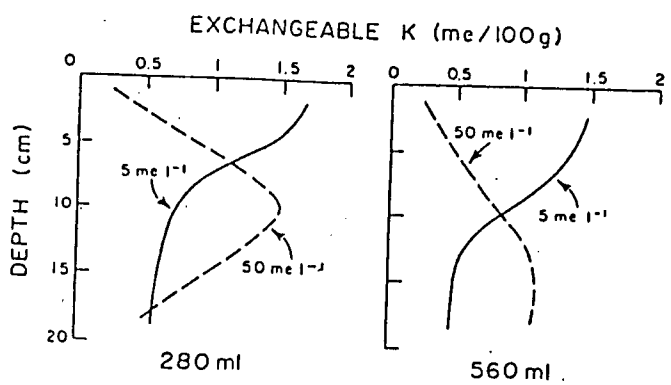


Figure G3. Downward movement of surface applied potassium in a soil column as related to quality and amount of percolating solution. The lines represent actual results taken every two cm.

H. The Effect of Potassium Fertilization on Cotton Response and Potassium Distribution Under Irrigation With Saline Water.

Sala Feigenbaum and A. Meiri

The purpose of the present study was to obtain information on K behavior in a soil and cotton response to K fertilization under irrigation with saline-sodic water. KCl was applied to the surface layer according to the common agricultural practice. Irrigation was managed to obtain in the different treatments similar leaching volumes, although not similar irrigation volumes or leaching fractions. Cotton was selected as a salt tolerant crop which allowed the use of relatively saline water (up to 7.5 dS/m). The sandy soil was selected for its low cation exchange capacity and low water retention, to obtain maximum leaching effect. A comparison of fallow and planted pots brought up the influence of the K uptake and change in the water balance on the K reactions with the soil and leaching.

Materials and Methods.

A screen house pot experiment with a sandy soil was conducted in Bet-Dagan to study the potassium behavior in soil under irrigation with saline water and its effect on cotton growth. The soil was taken from the upper layer of a non salinized plot in a long term field experiment, the objective of which was to study the irrigation with brackish water in the Besor regional experimental farm in the south coastal area of Israel.

Basic chemical and physical properties of the soil (Quartzipsamment), as determined by standard methods where; Mechanical analysis: Coarse sand 45.6%, fine sand 42.8%, silt 5.4% and clay 6.2%; PH 7.6; Kexch (exchangeable potassium) 0.59 me/100g; CEC (cations exchange capacity) 4.54 me/100g.

The experiment included 12 treatments in four replications in a factorial design. The factors were Planted (treatments 1-6) as compared with Fallow (treatments 7-12) pots, by two levels of Potassium fertilization, by three levels of Salinity in the irrigation water. Calcium and sodium chlorides were added to dilute NH_4NO_3 solution to obtain total salt concentrations of 20 and 50 me/l with SAR of 10. K1 potassium level was equivalent to a dressing of 600Kg/h on surface area basis. The treatments and irrigation solution composition are listed in table H1.

The pots contained 3 Kg of air dry soil pre mixed with 1g/kg of superphosphate and packed to a bulk density of $1.6 g*cm^{-3}$. The volumetric water fraction at pot capacity was 0.145. The pots had holes in the bottoms and drained into collecting pots. Irrigations where given initially every second day and as evapotranspiration (ET) increased daily. The water amounts where calculated to restore the moisture deficit to pot capacity and to obtain similar gravity drained leaching volumes in all treatments.

Table H1. The experimental treatments, the K fertilization level and the irrigation water composition.

With Plants Treat #	Treat.	Without Plants Treat #	Treat.	K Fert. me/pot	Irrigation solution composition ions content me/l Cl	Ca	Na	N*	SAR
1	K1S1	7	K1S1	32.2	0.0	0.0	0.0	3.5	0.0
2	K1S2	8	K1S2	32.2	20.0	4.7	15.3	3.5	10.0
3	K1S3	9	K1S3	32.2	50.0	19.1	30.9	3.5	10.0
4	K0S1	10	K0S1	0.0	0.0	0.0	0.0	3.5	0.0
5	K0S2	11	K0S2	0.0	20.0	4.7	15.3	3.5	10.0
6	K0S3	12	K0S3	0.0	50.0	19.1	30.9	3.5	10.0

* NH_4NO_3

Irrigation and drainage volumes were determined throughout the experimental period. The drainage water were analyzed for the content of Cl, K, Na, Ca, Mg. At the end of the experiment plants where harvested and divided into vegetative and reproductive components. The fresh and oven dry weights (600C) of each organ were determined. Then they where analyzed for their contents of Cl, K, Na, Ca and Mg. After harvest the soil in each pot was divided into four horizontal layers and analyzed for content of soluble Cl, K, Na, Ca and Mg and exchangeable K and Na.

Results.

Plant growth was inhibited by salinity but was not influenced by the potassium fertilization (Table H2). In each salinity level the yields were very similar for the two potassium levels. Salinity inhibited shoot more than root development. Therefore, the shoot/root ratio decreased with the increase in salinity. Among shoot parts the weight proportions of leaves, stems and balls remained constant. The small root system in all treatments is the result of the small pot size and the frequent irrigations. Salinity increased plant succulence as shown by fresh/dry weight ratio.

Table H2. The influence of irrigation water salinity and potassium fertilization on weight of the different plant organs, shoot/root and fresh/dry weight ratio and the relative weight fractions of the shoot organs.

Tr	K	S	weight (g/pot) Dry leaves	Stems	Roots	Bolls	Total	Fresh Total	Ratio FW/DW[1]	S/R[2]	L/PL[3]	ST/PL[4]	B/PL[5]
1	1	1	10.59	11.48	3.20	20.75	46.02	172.4	3.75	13.4	.23	.25	.45
2	1	2	6.83	5.56	2.72	15.24	30.35	145.4	4.79	10.2	.23	.18	.50
3	1	3	4.62	4.53	2.35	9.39	20.89	92.8	4.44	7.9	.22	.22	.45
4	0	1	12.42	12.28	3.48	18.16	46.34	160.2	3.46	12.3	.27	.27	.39
5	0	2	7.55	7.24	3.26	15.66	33.71	141.4	4.20	9.3	.22	.22	.47
6	0	3	5.63	5.24	2.33	9.65	22.85	100.8	4.41	8.8	.25	.23	.42

1) FW/DW = Fresh Weight/Dry Weight ratio
2) S/R = Shoot/Root Weights ratio
3) L/PL = Leaves/Plant " "
4) ST/PL = Stems/ " " "
5) B/PL = Balls/ " " "

Potassium and sodium contents in the different plant parts and the total K uptake per pot are presented in table H3. In the non fertilized treatments the potassium tissue content increased with salinity. These differences were larger in the vegetative organs than in the boll parts. In the potassium fertilized treatments the potassium contents in the tissues decreased with increase in salinity. There were large differences in the plants potassium content due to fertilization between the non salinized treatments and only marginal differences between high salt treatments.

Sodium content was very low in the seeds and lint. In other tissues it increased over the entire range of increase in salinity in the potassium fertilized plants and to the medium salinity level in the non fertilized plants. Potassium fertilization decreased the tissue sodium content in the control and medium salinity but not in the high salinity. The sum of potassium and sodium was similar for all treatments except for tr. 4 (non saline and non fertilized) where it was much lower.

Table H3. Potassium uptake per pot and potassium and sodium content in different parts of cotton plants exposed to different levels of water salinities and soil potassium.

Tr	K	S	Roots	Leaves	Stems	Burrs	Seeds	Lint	K uptake
			K content (me/g dry weight)						me/pot
1	1	0	.507	.827	.462	.533	.330	.381	24.8
2	1	1	.330	.617	.462	.459	.335	.381	14.1
3	1	2	.264	.345	.370	.403	.401	.406	7.7
4	0	0	.147	.216	.170	.355	.277	.284	11.2
5	0	1	.218	.256	.259	.454	.330	.355	10.7
6	0	2	.246	.358	.337	.381	.414	.381	8.2
			Na content (me/g dry weight)						
1	1	0	.074	.035	.017	.000*	.009	.009	
2	1	1	.261	.243	.139	.017	.009	.013	
3	1	2	.261	.487	.226	.052	.017	.017	
4	0	0	.117	.061	.039	.000*	.009	.009	
5	0	1	.374	.426	.239	.065	.009	.009	
6	0	2	.335	.335	.217	.061	.009	.017	
			Potassium+Sodium content (me/g dry weight)						
1	1	0	.581	.862	.479	.533	.339	.389	
2	1	1	.591	.860	.601	.477	.344	.394	
3	1	2	.525	.832	.597	.456	.418	.423	
4	0	0	.265	.277	.209	.355	.285	.293	
5	0	1	.592	.682	.498	.519	.339	.364	
6	0	2	.581	.693	.555	.441	.422	.398	
			Potassium/Sodium ratio						
1	1	0	6.87	23.78	26.55	High	37.93	43.77	
2	1	1	1.26	2.53	3.32	26.41	38.52	29.18	
3	1	2	1.01	.71	1.64	7.73	23.05	23.34	
4	0	0	1.25	3.54	4.34	High	31.81	32.68	
5	0	1	.58	.60	1.08	6.96	37.93	40.85	
6	0	2	.74	1.07	1.55	6.25	47.56	21.89	

* Trace levels

The changes in relative uptake of the two ions is most clear in the K/Na ratio. In the non fertilized treatments the first salinity increment increased K less than Na availability but the second salinity increment increased K more than Na availability. In the fertilized treatments the increase in salinity increased sodium availability and decreased potassium availability.

Potassium uptake by the plants reflects the treatments effects on plants size and tissues potassium content (Table H3). The outcome is a decrease in uptake with the increase in salinity. A higher uptake as a result of fertilization was found in the control and medium salinity but not at high salinity.

The water balance for the different treatments is presented in table H4. In the fallow pots where irrigation compensated for evaporation (E) and drainage (D) the differences between treatments were small in all the balance components, with a small decrease in E with the increase in salinity. In planted pots the large decrease in evapotranspiration (ET) with the increase in salinity led also to a large decrease in irrigation (I). A linear plot of dry matter yield (DMY) over irrigation (I) volume gave linear response DMY=-7.68+0.00306*I (r2=0.99)). The zero yield intercept of this line 2511 ml. was much lower than the mean E in the fallow pots, which indicates a lower E in the planted pots. The leaching fraction (LF) in fallow pots was higher than in planted ones, and did not show clear treatments effect. The LF in the planted pots increased with salinity with no significant effect of the K fertilization.

Table H4. Water balance in cotton planted and fallow pots.

Tr	K	S		I1	D2	E3	ET4	LF5
					(ml/pot)			
1	1	0	Planted	17150	1037		16113	.060
2	1	1	"	12445	1063		11382	.085
3	1	2	"	9046	1320		7726	.146
4	0	0	"	18065	1100		16965	.061
5	0	1	"	13142	1021		12121	.078
6	0	1	"	10614	1640		8974	.155
7	1	0	Fallow	7099	1375	5724		.194
8	1	1	"	6509	1320	5189		.203
9	1	2	"	6319	1459	4860		.231
10	0	0	"	7044	1652	5392		.235
11	0	1	"	6562	1482	5080		.226
12	0	1	"	6474	1404	5070		.217

1) I = Irrigation (ml/pot)
2) D = Drainage (ml/pot)
3) E = Evaporation (ml/pot)
4) ET= Evapotranspiration (ml/pot)
5) LF= Leaching Fraction (Drainage volume/Irrigation volume)

The break-through curves of K, Na, Ca, and Cl of the drainage water over accumulative drainage volumes for all treatments are presented in figures H1-H4. We added 32.2 me/pot potassium as a single surface dressing to half of the treatments. Sodium, calcium and chloride were added in constant concentrations in the irrigation water. Extra 32.2 me/pot of chloride were added with the potassium to the surface.

The Na, Ca and Cl concentrations in the drainage water where higher at higher salinity treatments and in the planted as compared with fallow pots. The plant effect is mainly the result of an increase in water consumption and reduced LF.

Observing the individual ions break-through curves show for Cl (Figure H1) a rapid initial increase followed by a rapid decrease to an almost constant level in the planted pots. In the fallow pots the initial increase was more gradual and the decrease continued throughout the experiment. The Cl concentration responds most rapidly to changes in the LF. The Ca break-through curve (Figure H2) showed a very different shape from the Na one (Figure H3). The Ca curves show a max at the initial increments that decrease to a constant concentration while the Na concentration increased throughout the experiment. These differences are the result of sodification and calcium depletion of the exchange complex in a soil irrigated with water of SAR 10. Ca dissolution should contribute continuously to the drainage water.

The K concentrations in the drainage water (Figure H4) were influenced by the fertilization, by the salinity of the water and by the plants. Contrary to previous ions K uptake by plants played a significant roll in its overall balance. The fallow non-saline concentrations (mean 1.43 me/l) are high for cropped soils and were more than four times the concentrations of the planted non-saline (mean 0.31 me/l). For small plants in the high salt treatments these differences were insignificant. In all cases an increase in salinity resulted in higher K concentrations in the drainage water. In the fertilized non-saline treatment the K concentrations where about 6 me/l and in the saline treatments they reached levels of 25 me/l over a transient period. Salinity increased the drainage K concentration also in the non fertilized pots.

For all parameters the planted pots showed a more rapid increase in drainage concentration than the fallow ones. This was the result of the differences in the pre irrigation soil moisture content. The lower moisture content in the planted pots resulted in more of the piston displacement type of break-through curve, while the higher moisture content in the fallow pots resulted in a stronger mixing.

A plot of the accumulative K losses in the drainage water for fallow pots (Figure H5) shows a large increase in leaching with the increase in salinity. This effect was most noticed in the fertilized pots. These differences in K leaching indicate fixation-exchange-soluble reactions that were left- wise directed under non saline conditions and right-wise under saline. In planted pots uptake by the plants also shifted the reactions to the right. But the uptake by the plants reduced the concentration of the K in the soil solution and the K drainage. The magnitude of the uptake component

decreased with the increase in salinity. Therefore, differences in K leaching between fallow and planted pots were large in the non-saline treatments and small in the high salinities. The competition between Na and K which may also reduce uptake had a smaller effect on total K uptake. Some increase in the K leaching in the saline treatments is the result of the higher drainage volumes.

After harvest the soil was divided horizontally into four layers and analyzed for soluble ions and exchangeable K and Na (Figures H6,H7).

The ions added in the water (Cl, Na and Ca) showed similar profiles of soluble ions and similar concentration orders Cl>Na>Ca. Their concentrations were higher at higher salinities and in planted as compared with fallow pots. In fallow pots the evaporation losses resulted in the accumulation of all these ions in the surface layer. In the medium salinity planted pots the concentrations of these soluble ions increased with depth. The high salinity planted pots showed maximum values for Cl and Ca in the surface layer and uniform profile for sodium.

The K profile was influenced by fertilization and uptake by plants with only a small salinity effect. Fallow fertilized pots had higher soluble K levels than non fertilized ones at all depths. Differences between fallow and planted non fertilized pots showed up over the entire profiles. In fertilized pots the differences were large at the surface layers and decreased with depth to no differences in the bottom layer. The plants could deplete the soil to a minimum of 0.2 me/l. Depth of depletion decreased with increase in the water salinity. The change in depth may indicate a reduced root activity caused by salinity. The soluble K concentration in the bottom layers of all fertilized pots was similar (2.2 - 3.4 me/l), which agrees with the similar final drainage K concentration. The planted pots' K profiles indicate that an increase of the LF or extent of the experimental period should also deplete the lower layer and decrease drainage concentration. In fallow pots a stable drainage K concentrations are expected over a long period.

In all cases pots with plants had a lower exchangeable K than fallow pots with similar treatments. In the non fertilized pots these differences were smaller than in the fertilized ones. These differences resulted from the large depletion of the exchange complex by the plants. All the non fertilized planted treatments had the same Kexch (about 0.2me/100g) over all depths. In the fertilized planted pots Kexch increased with depth with only small differences between salinities. The Kexch in the upper soil layers were only slightly higher than in the non fertilized pots. These data together with the soluble K data show that the upper soil layers were depleted from the fertilizer K. In all the fallow pots Kexch was lower at a higher salinity and there was a gradual increase in Kexch with depth. These profiles indicate a slow soil K depletion which is accelerated by salinity.

Naexch increased with increase in water salinity and was not affected by the K fertilization. This was expected as K quantities were small relative to the inputs of Ca and Na in the irrigation water.

Plants changed the Naexch profile. In the fallow pots Naexch content was constant and in the planted pots it increased with depth. This increase with depth reflects the concentrating of the soil solution and increase in its SAR caused by ET.

The plot of EPP (Exchangeable potassium percentage) against PAR (Potassium adsorption ratio = K/{(Ca+Mg)/2}-0.5) combined all the treatments into one linear regression (EPP=4.68+11.07*PAR; r2=0.935) (Figure H8). This relation indicate that the ratio of K to Ca explains over 93% of the exchange reaction, also under saline conditions, and the high Na had no or only a small effect on the K exchange in this system.

Discussion.

The experiment was designed to study the influence of irrigation water salinity and K fertilization on the K status of a sandy soil, K leaching and cotton response. The salinity levels were chosen to cause a significant yield reduction and the soil was selected for low CEC, and low water holding capacity.

Salinity caused a significant yield reduction. K fertilization did not change the yields at any salt level, meaning that the soil supplied the plants K requirements for maximum growth under these experimental conditions. Considering the tissue K content in treatment 4 to be sufficient, as it had maximum growth, all other treatments had luxurious uptake. A high level of K did not reduce the salt damage to growth. In non fertilized soil increase in salinity increased the tissue K content. This was caused by increasing the concentration of soluble K in the soil solution over a range that provide for high selectivity of K uptake. K fertilization increased considerably the K content of non salinized plants, increased it less for the medium salinized plants and did not change the K content of the high salt plants. Thus, a clear interaction was noticed between effects of irrigation water salinities and K fertilization on the tissue K content. Salinity increased the tissue Na content. K decreased the tissue Na content in the low and medium salinities but not in the high salinity. The treatments influenced considerably the ion contents of the roots, leaves and stems, and less to almost no changes in the composition of the boll parts. In all cases the Na content of the seeds and lint was very low. For the vegetative organs, except for the low salt non-fertilized treatment, all other treatments maintained a constant sum of Na+K in the plant.

The rejection of the hypothesis that high K fertilization can reduce salinity damage was discussed above. Under non-saline conditions fertilizing the soil is aimed at restoring the soil K content and increasing K availability to the plants. Excess irrigation that causes drainage leaches out K from the root zone. A long term negative K balance for the irrigated soil, when K uptake and leaching is larger than fertilizer input, should deplete the soil to K deficient levels. Saline irrigation may accelerate the depletion rate. The higher cation concentrations change the exchange equilibrium and increase the K concentration in the soil solution. It was shown that the change in the K exchange equilibrium was influenced by the change in Ca concentration

in the soil solution while the large increase in Na concentration did not influence the equilibrium. A linear isotherm of EPP/PAR described over 93 percent of the exchange equilibrium. Saline irrigation also requires leaching of the excess salts which may increase the K losses in the drainage water. K uptake is another balance component that is influenced by salinity. K uptake rate is extremely high relative to its content in soluble form in the soil solution. This uptake releases exchangeable and fixed K as was shown above. It will also reduce the K leaching. When salinity reduces the plants size or Na competition decreases the rate of K uptake per unit tissue the plant uptake component decreases.

The increase in salinity resulted in a transient increase in K concentrations in the drainage water but not in its final concentrations in the drainage water or the soil solution. The final K concentration in the drainage water of all the fertilized treatments was about 6 me/l. It was <0.5 and 1.5 me/l in the non-fertilized planted and fallow pots respectively. Observing the final soil data indicate that the identical values in the fertilized pots were a transient meeting of different break-through curves. At the end of the experiment the planted pots had much lower available K (exchangeable and soluble) than the fallow ones. Only the bottom layer of all pots had similar soluble K concentrations. This means that in the planted pots available K reserves for uptake and leaching were much smaller.

The plant, soil and drainage data allowed a complete K balance (Table H6). In all cases the uptake had a significant influence on the balance. Uptake of K was higher when plants where larger at lower salinities. It was also higher for the fertilized plants at the two lower salinities but not at the highest one. Salinity decreased K uptake by plants to a larger extent in the fertilized than in the non fertilized treatments. Leachate-K in the drainage water was larger in the fertilized treatments and at higher salinities. It was also larger from fallow than from planted pots. The differences between fallow and planted pots where large in the non saline treatments and small in the high salt treatments.

Table H6. Potassium balance in fallow and cotton planted pots irrigated with water of different salinity levels and receiving different KCl surface dressing (me/pot).

Tr	K	S		Fert. dressing	Plants uptake	Drainage leachate	Sub1 balance	Soil content initial	Soil content final	Balance[2]
1	1	0	Planted	32.2	24.8	4.2	3.2	15.0	11.6	-6.6
2	1	1	"	32.2	14.1	13.2	4.9	15.0	11.3	-8.6
3	1	2	"	32.2	7.7	19.8	4.7	15.0	12.2	-7.5
4	0	0	"	0.0	11.2	0.3	-11.5	15.0	6.2	2.7
5	0	1	"	0.0	10.7	1.2	-11.7	15.0	5.6	2.3
6	0	2	"	0.0	8.2	2.5	-10.7	15.0	6.2	1.9
7	1	0	Fallow	32.2		9.6	22.6	15.0	30.8	-6.8
8	1	1	"	32.2		13.8	18.4	15.0	27.5	-5.9
9	1	2	"	32.2		20.8	11.4	15.0	20.6	-5.8
10	0	0	"	0.0		2.4	-2.4	15.0	13.9	1.3
11	0	1	"	0.0		3.1	-3.1	15.0	12.1	0.2
12	0	2	"	0.0		4.1	-4.1	15.0	10.9	0.0

1 Sub balance=column5-column6-column7

2 Balance=column10-column9-subbalance

The sub balances that considered only the inputs (fertilizers) and outputs (uptake+leachate) were positive in fertilized and negative in non-fertilized pots. For the non-fertilized pots they were more negative in planted pots. For fertilized pots they were more positive in the fallow pots, and in these pots in the lower salinities. The table summarizes the large increase in leaching with the increase in salinity and the large influence that plant uptake had on the balance. In this sandy soil the added K in the fertilizer increased the soluble K concentration to extremely high levels (26 me/l in the drainage water). However, since the water content of the soil was low, this soluble K was only a small fraction of the added fertilizer. Most of the K was adsorbed and fixed. In all the fertilized pots there was a similar K fixation, or overall negative balance of 5.8-8.6 me/pot. Thus, at least 20% of the K fertilizers were fixed. Release of Kfix in the non fertilized pots, shown by positive balance, was only in the range of 0.0-2.7 me/pot. In the soil major changes took also place in the exchange complex. Fertilization of fallow soils increased the Kexch and uptake by plants or leaching depleted it.

Summary.

The influence of high K fertilization on cotton response and the K balance of planted and fallow soils, when irrigated with saline water was studied in pot experiments.

In non fertilized soils salinity increased K availability and decreased it in fertilized soils. The changes in availability showed up in the K to Na ratios in the plant tissues but did not influence the growth response to salinity.

K fertilization contributed to all K forms. The K balance indicates fixation of about 20%. The unsalinized fallow soils showed doubling of the Kexch. Salinization released exchangeable K and increased the soluble K concentrations. Ninety three percent of this effect was explained by the increase in the soluble Ca concentrations. The very high Na concentrations in the soil solution did not influence this exchange equilibrium.

Salinity increased K leaching. For fallow soils, where leaching is the only output component, this results in a faster K depletion. For planted soils, where uptake is an important output component, the over all output was similar for all salt levels or slightly larger in the unsalinized control. Salinity decreased plant size and K uptake. Thus, for planted soils salinity did not change the K balance.

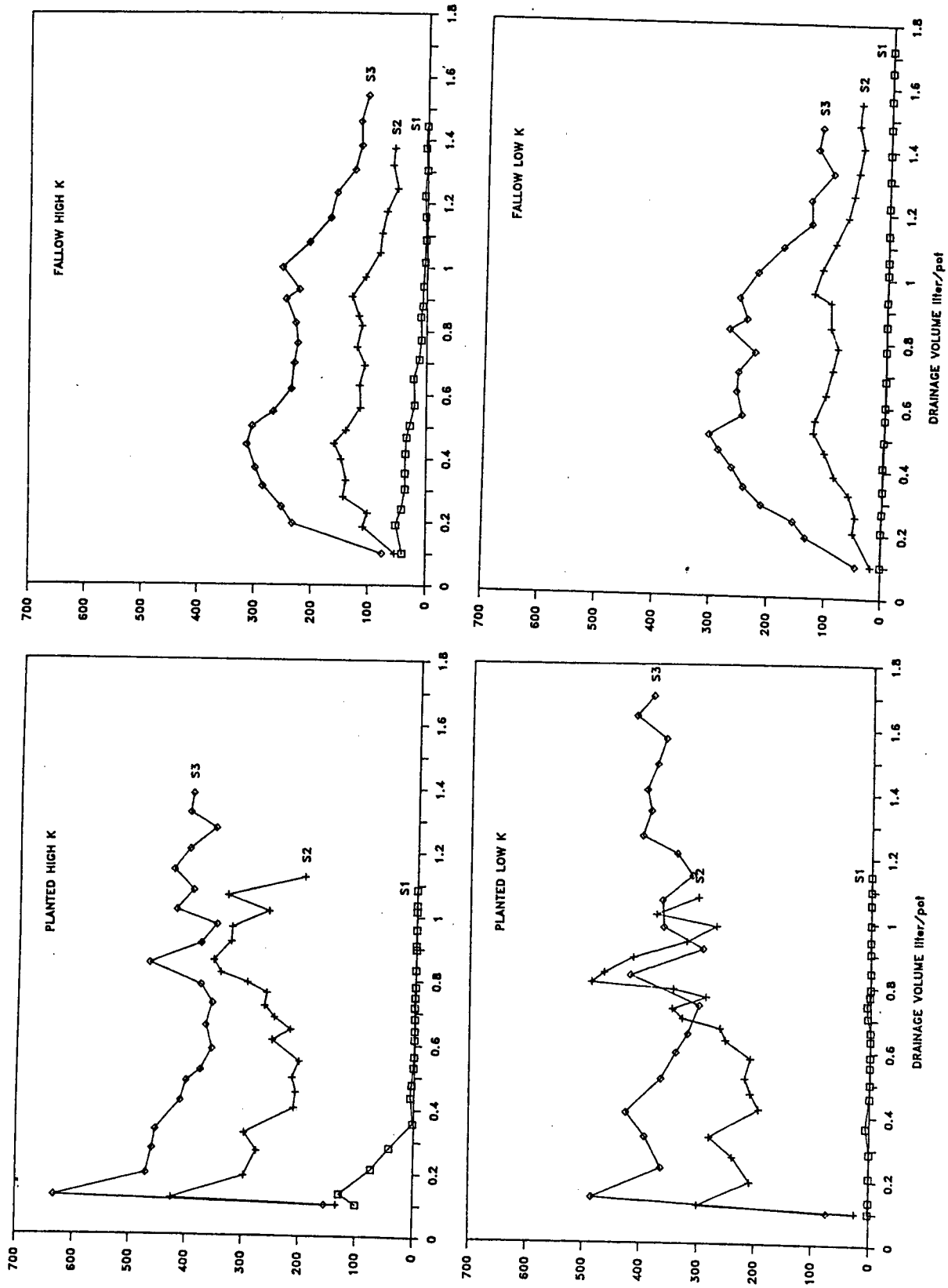


Figure H1. The influence of plants, water salinity and K fertilization on the Cl concentration in the drainage water. (Labels S1, S2, S3 = low, medium and high salinity).

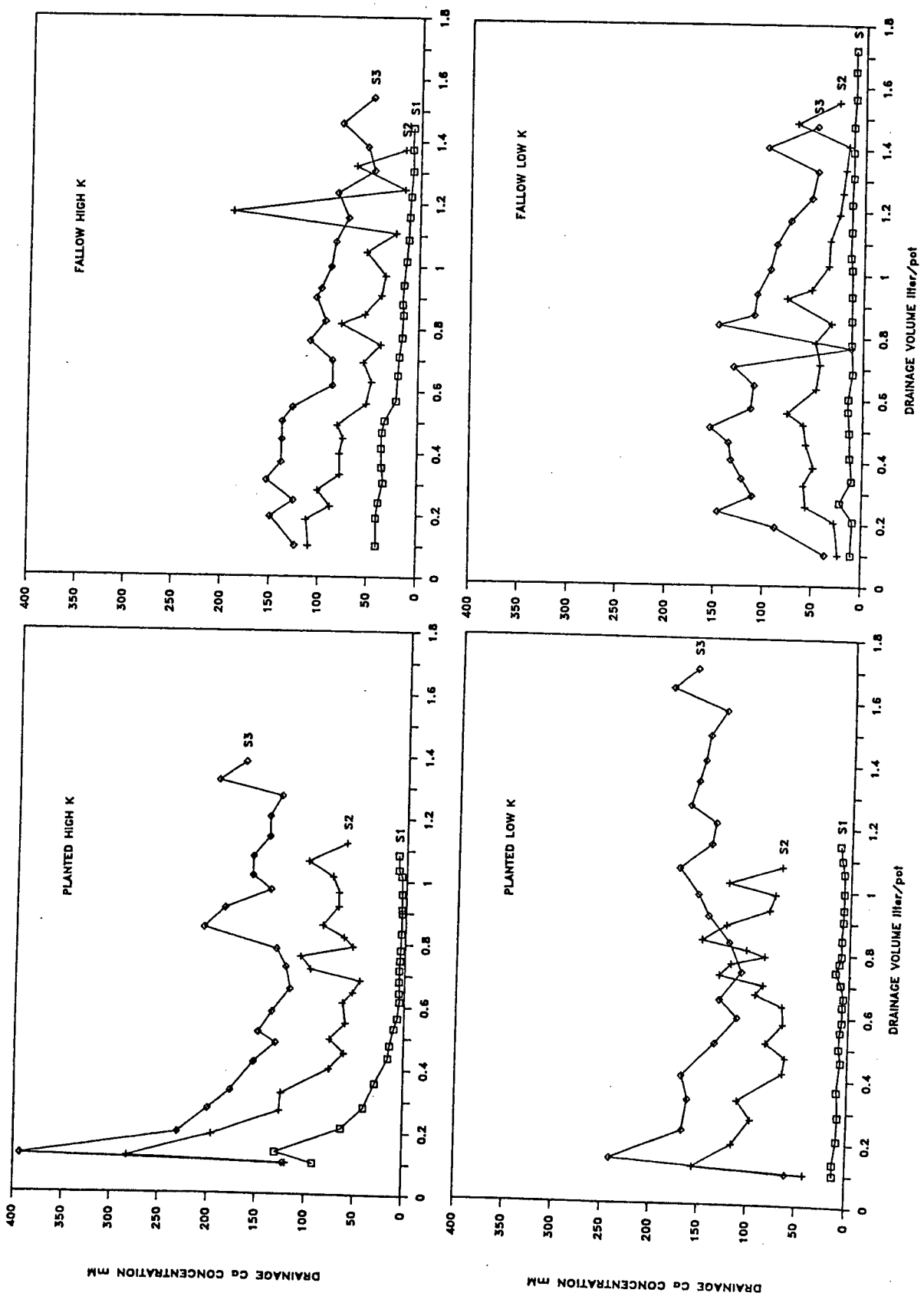


Figure 12. The influence of plants, water salinity and K fertilization on the Ca concentration in the drainage water. (Labels S1, S2, S3 = low, medium and high salinity).

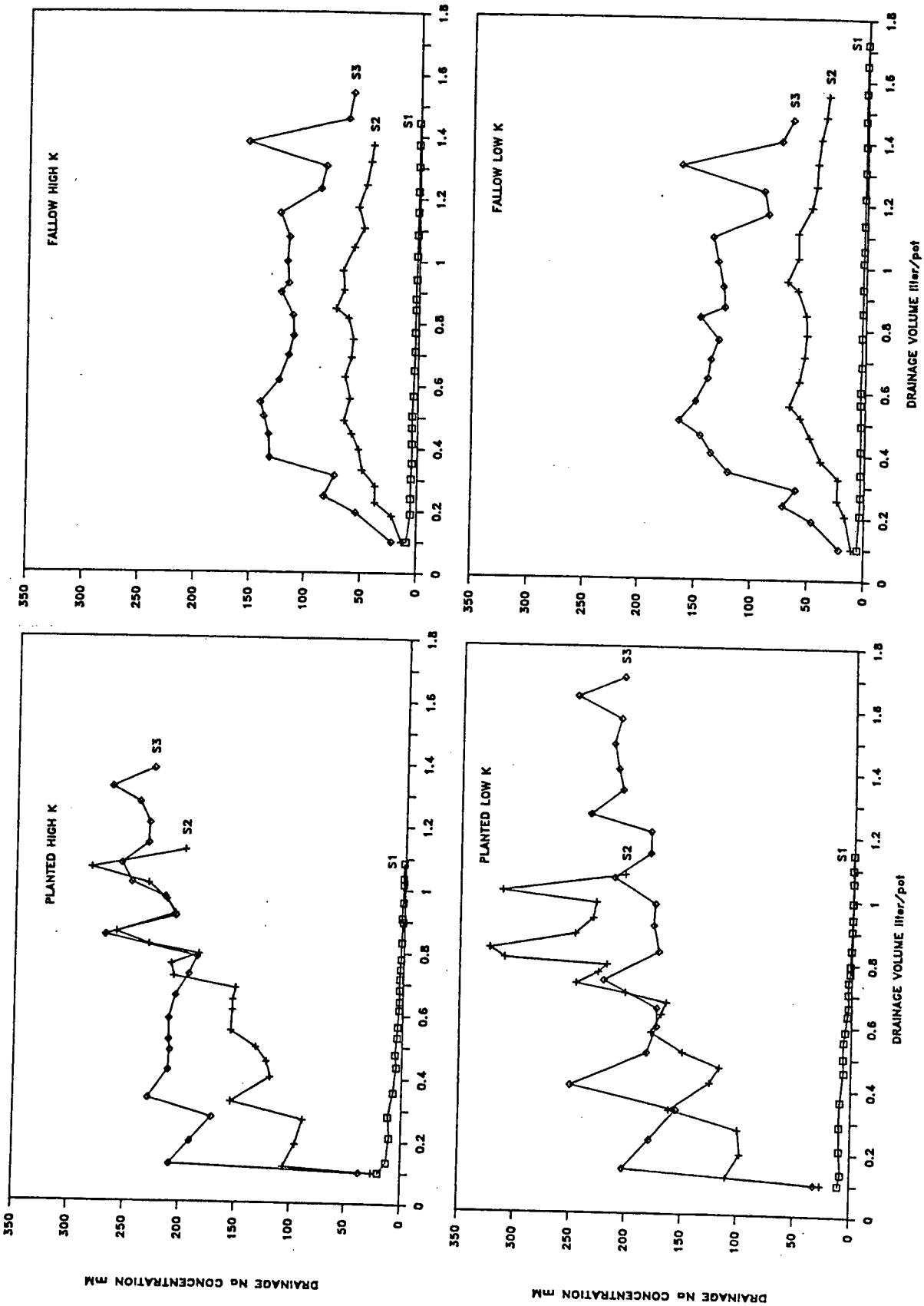


Figure H3. The influence of plants, water salinity and K fertilization on the Na concentration in the drainage water. (Labels S1, S2, S3 = low, medium and high salinity).

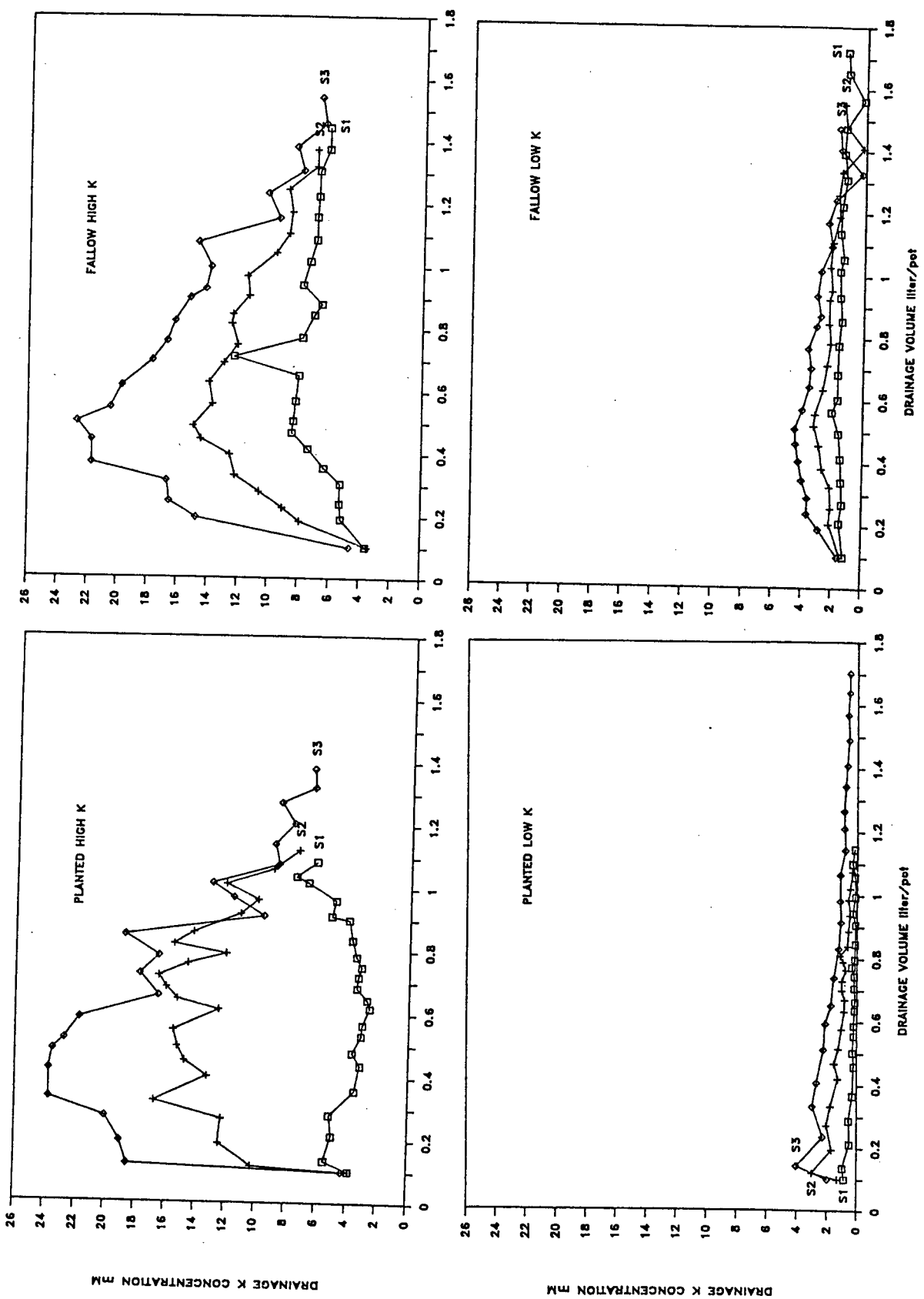


Figure H4. The influence of plants, water salinity and K fertilization on the K concentration in the drainage water. (Labels S1, S2, S3 = low, medium and high salinity).

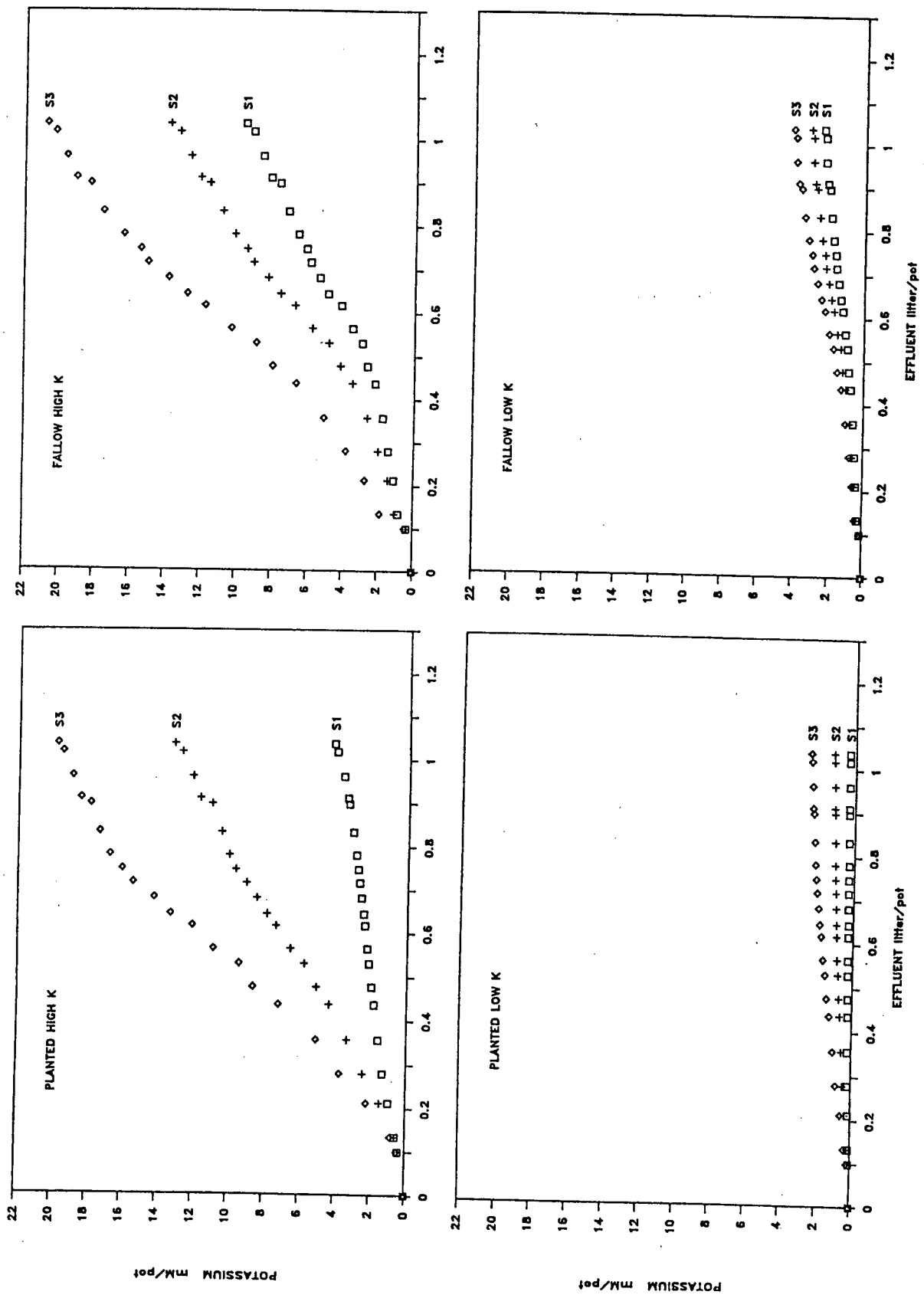


Figure H5. The influence of plants, water salinity and K fertilization on the accumulative K leachate in the draiange water. (Labels S1, S2, S3 = low, medium and high salinity).

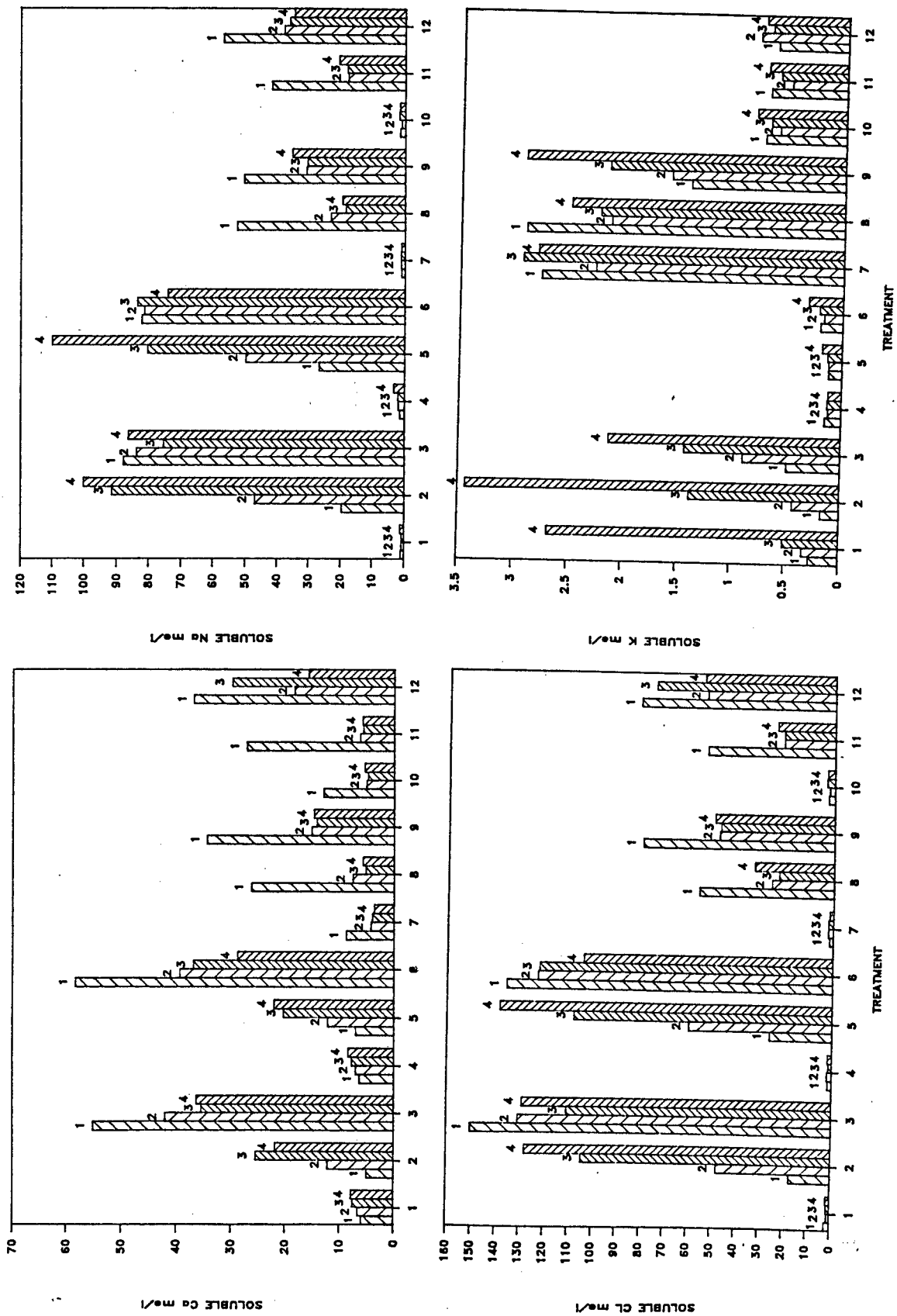


Figure H6. The influence of plants, water salinity and K fertilization on the post harvest profiles of soluble Cl, Ca, Na and K in the pots soil. (Labels 1-4 indicate layers depth).

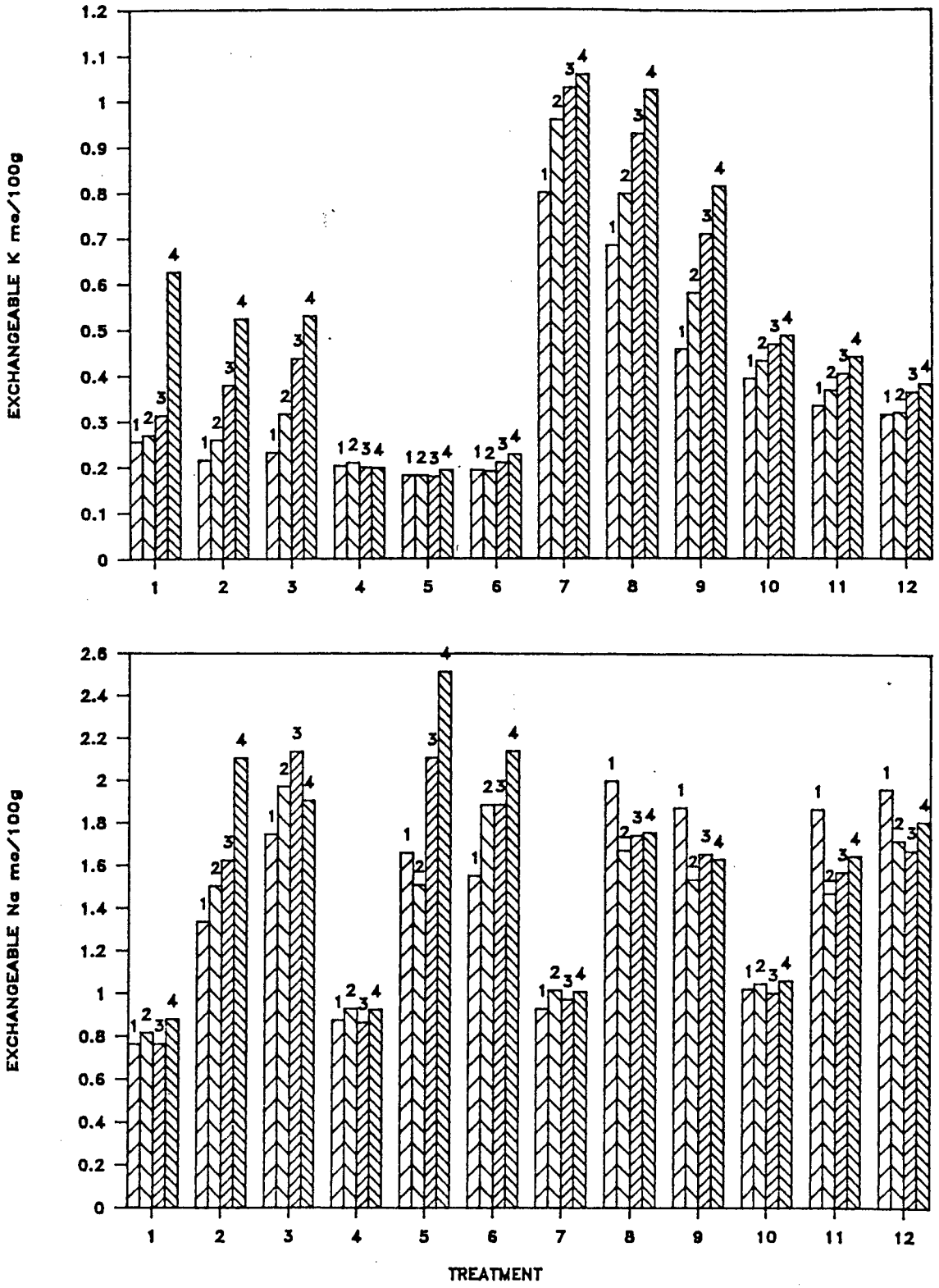


Figure H7. The influence of plants, water salinity and K fertilization on the post harvest profiles of exchangeable Na and K in the pots soil. (Labels 1-4 indicate layers depth).

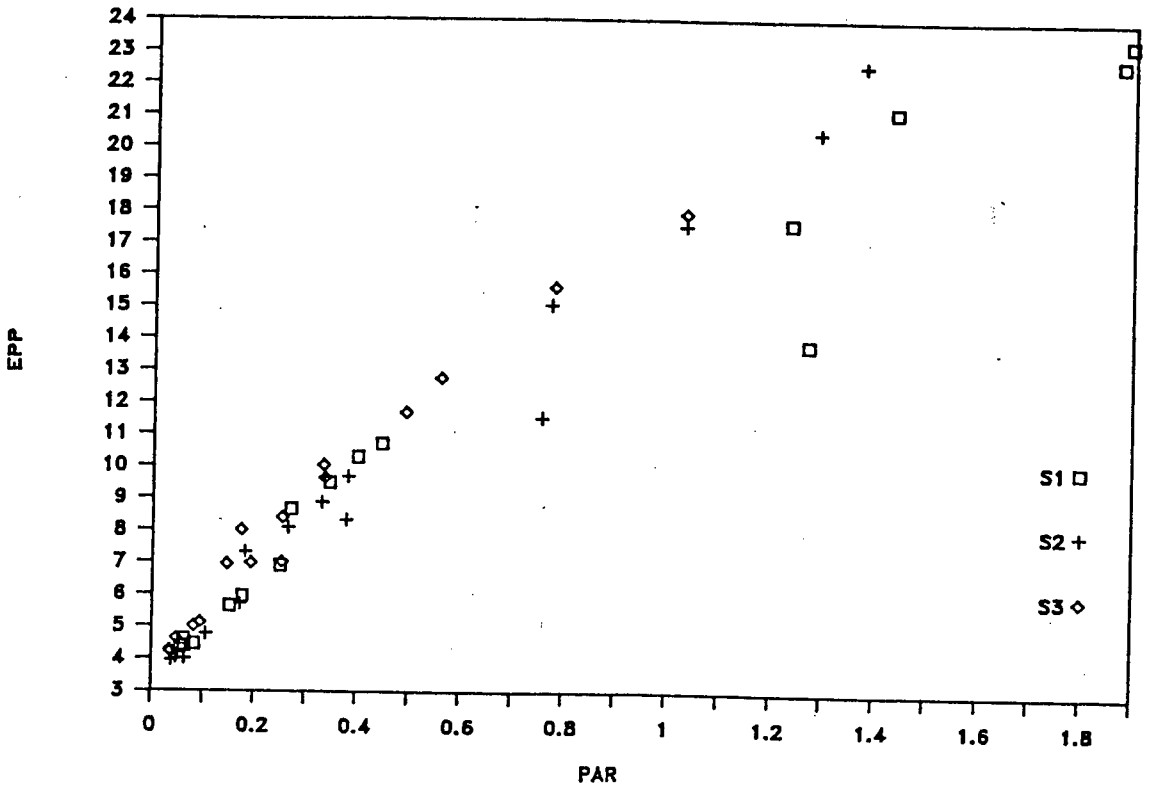


Figure H8. Exchangeable potassium percentage (EPP) relation to potassium adsorption ratio (PAR).

General discussion.

A plant adjustment under saline conditions involves control of its solute content (osmotic adjustment) and of its solute composition. The basic hypothesis behind the idea that K fertilization can modify the crop response to salinity was that impaired tissue K ($[K]_i$) to Na($[Na]_i$) balance can cause an additional damage to the osmotic effect. This impaired balance showed up as a lower $[K]_i$, or higher $[Na]_i$ and reduced $[K]_i$:$[Na]_i$ ratio. If a change in the growth medium K ($[K]_o$) can fully or partly restore the favorable balance it may reduce salinity damage. To answer these questions plant and soil aspects as well as their interactions should be considered. The practical questions for K fertilization of fields under saline conditions are: Can we reduce salinity damage by increasing plant $[K]_i$ and decreasing plant $[Na]_i$? Can we overcome K deficiency under saline conditions by increasing $[K]_o$ level in the growth medium? How does salinity influence K reactions in soil and its mobility and leaching in planted and fallow soils?

To answer the question whether $[K]_o$ can modify $[K]_i$ and $[Na]_i$ and improve growth under sodium salinity we conducted six studies with plants that differ in salt tolerance and in and K uptake. The salt tolerance of the crops was in a decreasing order barley = cotton >melon > peanut > potato (Maas and Hoffman, 1976). Potato and peanut exclude Na, and melon,cotton and barley transfer it to the shoot. The salinity levels in each study were adjusted to the salt tolerance of the tested crop. In experiments that compared the effect of $[K]_o$ < 10mM on cotton the K was added to the saline treatments to obtain a Na K two factor experiments. Following the initial observations that cotton did not show a growth response to $[K]_o$ in the range 1-10mM, a set of studies with potato, cotton, melon and peanut with higher $[K]_o$ levels and the same basic design were conducted. A non saline control was compared with a set of treatments that consist of two iso-osmotic solutions ($[K+Na]_o$=constant) with different ratios of $[K]_o/[Na]_o$. In the potato study the highest $[K]_o$ level was 20mM. For the other crops a substitution of $[K]_o$ for [Na]o covered the range from Na salinity to K salinity. The basic $[K]_o$ level of the control was added to all other treatments.

Potato showed a positive response to K which decreased with the increasing salinity (in absolute or relative values). Thus, potato has a high K requirement at all salinities. But, $[K]_o$ level up to 20 mM did not alleviate the salinity damage. With all other crops the K salinities were more damaging than the Na salinities and a partial replacement of the $[Na]_o$ with $[K]_o$, which can be considered a high K treatment in Na salinity, did not reduce damage. Thus, for these crops the basic $[K]_o$ level was sufficient for maximum growth at all salt level, and growth under Na salinity was controlled by the salinity level (mostly an osmotic effect). Specific ion toxicity was found under K salinity.

All plants showed some capacity to control their solute content. This control involved total solute content (OP_i), and we monitored changes in $[K]_i$, $[Na]_i$, $[Ca]_i$, [Mg]i, $[Cl]_i$, $[NO3]_i$ and organic solutes. Different levels of osmotic adjustments and changes in solute composition were found between crops and between organs on the same plant. Among the above parameters the best control was on total solute

content (OP_i). Among organs, the most stable values were the solute content (OP_i) and the composition of rapidly growing leaves in all cases, and the ion content of cotton bolls.

In all experiments an increase in the $[K]_o$ achieved the goal of increasing $[K]_i$ and decreasing $[Na]_i$ in all organs of Na accumulators and increasing $[K]_i$ in Na excluders. These changes were not identical in all plant organs and not the only ones that were found. Higher $[K]_o$ increased K uptake in Na excluders, increased K uptake more than it decreased Na uptake in Na accumulators, and increased Cl uptake in many cases. Thus, increase in the $[K]_o$ proportion increased solute availability and total tissue content of inorganic ions. The influence of the increase in salinity and $[K]_o$ fraction on (OP_i) and ions in leaves of different ages were monitored for cotton, peanut and melon leaves. Salinity increased $[Cl]_i$ and the sum $[K+Na+Cl]_i$ in all three plants, and to larger extend in older leaves. Increase in $[K]_o$ fraction increased the sum $[K+Na+Cl]_i$ in all plants and $[Cl]_i$ more in peanut and melon than in cotton. The osmoregulating system of the plant partly accounts for the higher tissue ion content by decreasing the organic osmolite content.

Potato data showed that $[K]_i$ in roots was correlated with $[K]_o$, with no effect of the $[Na]_o$ level, and with an effective K uptake at low $[K]_o$. The influence of the increase in salinity and $[K]_o$ on the divalent cations was monitored for melon shoot and fruit, for potato shoot and for cotton (Ca only) individual leaves and roots. $[Na]_o$ did not influence the $[Ca]_i$ and $[Mg]_i$ in melon shoot, did not influence $[Mg]_i$, slightly increased $[Ca]_i$ in potato shoot and decreased $[Ca]_i$ in mature, but not in young, cotton leaves, while increase in $[K]_o$ decreased shoot Ca and Mg in melon and potato. The control on this cation ratio had to be in the entrance to the root or in the transport to the xylem. And in these steps Na was much less competitive to the divalent cations in melon that transfers Na and potato that excludes Na from the shoot, and was competitive with Ca in cotton. However in melon $[Na]_o$ decreased fruit $[Ca]_i$ almost to the same extent and fruit [Mg]i to the same extend as $[K]_o$. This change in Na to bivalent cations competition between melon shoot and fruit indicates another controlled step. This step may be influenced by the $[Na]_i$ level in the melon shoot. The $[K]_i$, $[Na]_i$ and $[Mg]_i$ per dry weight were similar in shoot and fruit (Figure E2). Assuming large differences in xylem transport to transpiring leaves or less-transpiring fruit the similarity in ions content implies phloem transport of these cations to the fruit. We are not aware of any mechanism that can considerably increase the xylem concentration in the stem. Some phloem transport of Na and Mg was reported previously.The much lower $[Ca]_i$ in fruit than in shoot could be explained by differences in xylem flow. But, we are not aware of the mechanism that can modify the xylem composition to show competition between Na and Ca in transport to the fruit and not to the shoot. Such a change could be explained by a competition in the phloem transport. Since Ca is considered as immobile in the phloem it was of interest to find this effect in the melon plant.

The change in K/Na ratio from older to young leaves in the Na accumulators melon and cotton was associated with an increase in Na and decrease in K in old leaves. In the experiment with low K levels the cotton plants accumulated Na in old leaves and transported small

quantities of K from older to younger leaves in deficient K treatments and large quantities in the higher $[K]_o$ treatments. Phloem transport of the K from old to young leaves caused these changes. The question whether this transport terminates when the leaves became autonomous with respect to photosynthates is open. If phloem transport of K decreases during late growth stages the leaves should be more sensitive to K deficiency due to low $[K]_o$ or to competition with Na when their $[K]_i$ depends on the composition of the xylem and K accumulated at earlier stages.

With cotton there was no advantage to the increase in $[K]_o$ in the low range under saline conditions. On the contrary, the data indicate that the minimum $[K]_o$ requirement was lower at higher salinity. These observations indicate a lower K requirement for salinity depressed plants, or that Na can replace some of the K functions in cotton. Such data for Na excluders is required. In deficient K treatments a minimum K level was maintained in old leaves and the $[K]_i$ levels of young leaves were only slightly higher. Cotton maintained a rapid growth rates with rather low $[K]_i$. Thus in these experiments the high $[K]_i$ at higher $[K]_o$ may be considered luxurious.

Soil studies were aimed at understanding the influence of salinity on soil K under cropping conditions. The influence of salinity and K fertilization on the composition of the soil solution and exchange complex with emphasis on K reactions was studied in test tubes. The influence of the soil moisture content, soil type and depth in pedon were additional experimental variables. The influence of salinity on K reactions and transport during leaching was studied in soil columns and fallow pots.

Plant influence on K reactions in the soil was studied in different scales. Microscale - studied the solute profiles within the rhizosphere. Semi-micro scale compared the average rhizosphere with the bulk soil solutions. Macroscale compared the vertical distribution of solutes within the root-zone and the composition of the drainage water.

Increasing salinity increased the concentration of all cations in the soil solution, as the result of the large input of Na (report F) or Na+Ca (reports G,H) and the exchange with the soil natural cations. calcium dissolution could also contribute to these changes. A correlation of the pots soil data (Figure H8) show that the linear relation EPP/PAR (exchangeable potassium percentage/potassium absorption ratio) describes for a sandy soil 93% of the K exchange under a wide range of Na+Ca chloride salinities. Thus, the increase in soluble Ca was responsible for the release of K to the solution and a correction for the large Na concentrations in the soil solution did not improve this correlation.

An increase in soil moisture increases the preferential adsorption of the divalent cations, and, therefore, the amount of the monovalent cations (K+Na) in the solution (report F). Thus, larger K quantities can move to the root surface or with the leaching solution at higher soil moisture contents.

Dry zone soils have young non-stable fractions that release K on desolution. Therefore these soils can supply plants K requirements over

extended periods. Tyson and Munns (report F) showed that addition of NaCl decreased the soil solution pH and silica concentrations, suggesting stabilization of K-silicate minerals by salinity. They also showed K fixation from the soil solution over a period of 4 - 10 days, which was not influenced by salinity when expressed in relative terms, but increased when expressed in absolute terms. Feigenbaum (report G) showed increase in fixation of fertilizer K with the increase in salinity of leaching water of soil columns and in the field. Feigenbaum and Meiri (report H) showed fixation of fertilizer K in fallow and planted soils, under all salinities.

Potassium fixation and attraction to exchange sites limits its movement down the pedon. Field data show maximum K levels at top layers (reports F,H). K profiles in columns or fallow and planted pots show that K fertilizer applied to the surface moves slowly down the profile and salinity accelerates this movement.

The use of water of different salinities to leach fallow soils will integrate all the above mentioned factors with relation to K. The soluble K is only a small fraction of the soil K. Therefore the soil depletion from readily available K depends on desorption of exchangeable K and release of fixed K. Application of K fertilizers increases all three K forms. Salinity accelerated K depletion as it increased the soluble K by decreasing the exchangeable K. The decrease in minerals desolution (report F) or increase K fixation (reports F,G)could influence only slightly the overall balance. The increased soluble K shows up in the soil solution (Figures F4,F5), and in the accelerated depletion in higher drainage K concentrations over larger leaching volumes (Figures G2,H5) and downward wave of decreased exchangeable K (Figures G3,H7). Salinity also accelerated the downward movement of surface K fertilizers within the profile and to the drainage water.

Comparing fallow with planted soils will modify the picture. Most important is the K uptake, but plant influence on other soil environment factors can also interact with the K reactions and the K balance. Under a given irrigation regime planted soil will be at a lower soil moisture content between irrigations and in many cases also during the irrigation. This will result in a lower proportion of K, out of total cations, in the soil solution and drainage of the planted soil. Reduced ET and higher soil moisture which are common under saline irrigation will increase the soil K mobility.

The effect of salinity on the K levels in the rhizosphere and at the root surface was studied with barley, a plant that accumulates sodium. The comparison of the bulk with the rhizosphere soil data and the rhizosphere profiles show transport of all the cations to the root. Ion transport within the rhizosphere combines mass flow and diffusion. For cations whose uptake is faster than the water uptake concentration and diffusion gradients will be towards the root additive to the mass flow. When uptake is slower than water uptake concentration and diffusion gradients will be from the root and against the mass flow. Uptake of K in all salinities and Na in the low salinity was more rapid than water uptake and resulted in a concentration and diffusion gradients from the bulk soil to the root surface. For Na in saline treatments and Ca and Mg in all treatments ion uptake was slower than

water uptake and resulted in concentration and diffusion gradients from the root surface to the bulk soil. High salinity showed a higher K at the root surface and a smaller K gradient extended over a shorter distance within the rhizosphere. This was the result of a decreased K uptake and decreased water uptake, which reduces mass flow uptake but increases the soil moisture content and facilitate diffusion towards the root. Combining the lower K demand with the higher diffusion transport the soil could supply more easy the K demand by the crop under saline conditions.

The over all K balance in planted soil was studied in pots with cotton. The data show that soil K depletion was larger in planted than in fallow soils under all salinities and for fertilized and non-fertilized treatments. Within the planted treatments the increased K leaching with the increase in salinity was balanced by the decrease in K uptake. The conclusion of this experiment was that there is no need for modification of the K fertilization for maintaining soil K levels under saline irrigation. In this experiment the salinity significantly depressed yield and K uptake of cotton which have a relatively low K requirement. These conclusions were the outcome of a single cropping in pots. Under perennial agriculture part of the plant's K returns to the soil during the decomposition of the plant residues. If the return is a small fraction of the uptake (e.g. alfalfa) the extrapolation from a single crop to perennial conditions may be legitimate. For return of a large fraction of the uptake (e.g. cotton) a reduced K uptake under saline conditions will accelerate the soil K depletion, and will require some increase in K fertilizers. This should be a slow and long term effect. Also there is a need perhaps for small adjustment of K fertilization for any leaching of fallow field.

Conclusions.

The over all K balance of a fallow soil was very different from that of a planted soil. Irrigation and leaching of fallow soils followed the expectation to increased K depletion from the profile by the leaching water. However, in planted soil the uptake by the crop was a major balance component. Since salinity decrease the uptake it modifies the over all balance picture. And the depletion of the soil did not increased with the increase in salinity.

Changing $[K]_o$ proportion or increase in $[K]_o$ under saline conditions could change considerably the plants $[K]_i/[Na]_i$ ratio by both increase $[K]_i$ and decrease $[Na]_i$ but not alleviate the salinity damage. Since we have tested a wide variety of crops over a wide range of salinities and tissue Na and K content we can conclude that within the normal saline agriculture practice a change in the tissue K and Na content does not modify significantly the crop response to salinity. And, the primary effect in all our studies was the total salinity, or osmotic, effect.

Plant adjustment under saline conditions involves control of its solute content (osmotic adjustment) and of its solute composition. The control of inorganic osmolites involves uptake and transport processes. The increase in $[K]_o$ increases solute availability since K is a easily

absorbed cation. The uptake sequence is uptake by the root followed by transport to the xylem, two steps that show high affinity for K at low concentrations. At high concentrations K and Na competition was clear. Na salinity decreased Ca in older cotton leaves, K but not Na salinity decreased the shoot Ca and Mg in melon and potato, while both K and Na decreased the fruit Ca and Mg. The xylem transport terminates in the leaves and fruits and any solutes transported out from the leaves should be via phloem transport. Transport into leaves and into fruits can be also phloem transport. Phloem transport is controlled, e.g. back flow of Na to the roots in Na excluders, or transport of K from old to young leaves. We suggest that the change in Na to Ca and Mg competition between shoot and fruit may indicate significant phloem transport of these ions into melon fruits.

A specific ion toxicity was found under K but not Na salinity for a wide range of plants. This toxicity was associated with the larger solute availability with the increase in $[K]_o$ fraction. Availability that modified the plants solute composition to a larger extend and required a larger adjustment of other solutes. Another possible explanation is that control of solute compartmentation in the plant is impaired. The damage may be related to cytoplasm ions content. Plants are adjusted for control of cytoplasm Na levels by Na efflux and sequestration of Na in the vacuoles. They are less adjusted to control high levels of K and therefore under K salinity cytoplasmatic reactions may be more affected.

Salinity increases the concentration of $[K]_o$ in the soil solution and facilitate K transport to the root within the rhizosphere. This makes the soil K more available for plants.

Salinity did not significantly change the K balance in our soil studies. There was no need to increase the soil K to overcome K deficiency. The increase in soil K modified the tissue $[K]_i:[Na]_i$ ratio but did not alleviate the salinity damage. These evidences indicate that there is no need for a major change in K fertilization under saline irrigation at least in the short term.

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Description of cooperation.

Complementary work was conducted in both countries. The work on plant aspects in the US and Israel studied the influence of K levels on cotton response to salinity. The use of the developmental index as the reference for comparing effects was tested in the US and latter adopted in Israel. Concluding that increase the growth medium K does not alleviate salinity damage to cotton, the responses of potato, melon and peanut were studied in Israel. The work on soil aspects in the US concentrated in test tube reactions, the comparison of the bulk soil with the rhizosphere, and the solutes profiles in the rhizosphere of barley. The work in Israel concentrated in the influence of K fertilizers and water salinity on K reactions during leaching of fallow and cotton planted soils.

Dr. Läuchli visited Israel on the middle of the second year to discuss the progress and plan the changes in the original work. Drs. Feigenbaum and Meiri visited the US for final analysis of the work and the preparation of this report.

Evaluation of the research achievements with respect to the original research proposal.

The possibility to alleviate salinity damage by increasing K concentration in the culture solution was tested with cotton, peanut, potato and melon and rejected (Objective 4).

The need for a higher minimum K concentration in the culture solution, to overcome K deficiency under saline conditions, was tested with cotton and rejected (Objective 4).

The influence of different ratios of K/Na under saline conditions on the solute composition of different plant organs and leaves of different development stages was studied with various crops. The existence of control mechanisms on the cellular level and in the transport systems were suggested (Objective 1).

A study of the influence of salinity and K fertilizers on the ion content and K availability in the rhizosphere was conducted with barley. Salinity increased K availability. It replaced exchangeable K and increased the concentration of the soluble K. It increased soil moisture content thus increased the amount of K in solution and facilitate transport to the root. The ion profiles combine mass flow and diffusion. (Objectives 2,5).

Studies with fallow soils showed accelerated K leaching with the increase in water salinity. In planted soils K uptake is a major K depletion component. The increase in salinity decreased uptake and increased leaching. But it did not change the overall K depletion (Objective 4).

Correlations for sandy soil show that PAR describes 93% of the K exchange also under saline conditions (Objective 5)

Our data indicate that only small modification in K fertilization may be required under saline conditions. Therefore the peanut field test (objective 6) was not conducted.

List of publications.

D.J. Lauter, A. Meiri and Shuali Margot . Iso-osmotic regulation of cotton and peanut at saline concentrations of K and Na. Plant Physiol. (in press). Lectures and Posters in Symposia.

Sala Feigenbaum 1986. Potassium distribution in a sandy soil exposed to leaching with saline water. in "Nutrient Balances and the Need for Potassium". 13th Congress of the Inter. Potash Inst. Reims-France.

C.A. Tyson and D.N. Munns 1977. Plant uptake of nutrients from within the rhizosphere of saline soils. 1987 Ann. Meeting ASA, CSSA, SSSA.

D. Lauter, A. Meiri, A. Feigin and M. Hinnen (1988) the effect of saline, iso-osmotic media on plant growth and solute composition of leaves. In Anglo-Israeli Symposium "Quality Production in Protected Cultivation" Bet-Dagan, Israel.

Scientific dissertations

C.A. Tyson. ( ) Plant uptake of nutrients from within the rhizosphere of saline soils (Ph.D. thesis in progress U.C.Davis).

Jeanette C. Papp (1987) The effect of K/Na ratio on growth and ion accumulation of Gossypium hirsutum under NaCl stress (M. Sc. accepted by U.C.Davis).