PN-ABM-347
C5-001

79341

AID/CDR
SCIENTIFIC REPORT 1/7/87 - 30/6/88

FERTILIZATION AND SALINE WATER IRRIGATION

Blaustein Institute for Desert Research (BIDR)
Ben-Gurion University of the Negev
Sede Boqer Campus 84993, Israel

and

Institute for Biological Sciences
University of the Philippines at Los Banos (UPLB)
College, Laguna, Philippines

FEB 24 1989

TABLE OF CONTENT

Introduction

(1) Wheat

(1a) Nitrogen source, pH, salinity and wheat growth.
I. Mineral Composition. (Leidi, Silberbush and Lips).

(1b) Nitrogen source, pH salinity and wheat growth
II. Photoysnthesis and salinity (Leidi, Silberbush and Lips).

(2) Maize

(2a) Effect of nitrogen source on growth response to salinity stress in maize and wheat (Lewis, Leidi and Lips).

(2b) A continuous two variable design using the line-source concept (Magnusson, Ben Asher and DeMalach).

(2c) Salinity-fertility interactions under field conditions 1987 maise experiments.
(Magnusson, Ben Asher, De Malach and Lips).

(3) Peanut

(3a) Comparison of the effects of salinity on peanut and cotton grown on nitrate or amonium nutrient solutions.
(Leidi, Silberbush and Lips)

(3b) Nitrogen concentration ammonium/nitrate ratio and NaCl interaction in vegetative and reproductive growth of peanuts.
(Silberbush andLips)

(3c) Effects of KNO_3 on peanut (Aracgus hypogaea L.) irrigated with saline water.
(Reano, Pacardo, Mercado and Lips)

(4) Rice

(4a) Morpho-physiological responses of two rice varieties to varying NRaCl levels and nitrogen sources.
(Reano, Pacardo, Mercado and Lips)

(4b) Effects of KNO_3 on rice (Oryza sativa L.) irrigated with saline water.
(Reano, Pacardo, Mercado and Lips)

Introduction

The present report summarizes research corried out within the framework of project C3-001 from July 1987 to July 1988. Different parts of this work were carried out by the following scientists.

Prof. J. Ben Asher
Dr. Avi Golan
Prof. Y. Heimer
Dr. J. DeMalach
Prof. O. A. M. Lewis
Dr. E. O. Leidi
Prof. S. H. Lips
Mr. D. Magnuson
Prof. B. T. Mercado
Dr. R. Nogales
Prof. E. C. Pacardo
Mr. J. Reaño
Dr. M. Silberbush
Dr. M. I. M. Soares

Following our first year of work, the present results show two trends of our developing work: (a) The continuation of our studies on the interaction of Na^+ and Cl^- ions with inorganic nitrogen and K^+ on the growth and productivity of crops; (b) The beginning of studies of physiological mechanisms responsible for the results observed.

The work reported here and in our previous report indicate that increasing the supply of selected inorganic nitrogen compounds and K^+, frequently enhances the salt-tolerance of crops. In addition, a new approach is developing as a result of our observations: the use of salinity to increase productivity of some crops. This new line of research is based on two sets of experimental results: (a) the salinity enhancement of flowering and gynophore production observed in peanut plants and (b) the salinity-stimulated translocation of assimilates from leaves to filling grains in wheat.

Further studies along these lines of research are already underway and their results will be reported in our third and final report in 1989.

Prof. S. H. Lips
Principal Investigator

(1a) Nitrogen source, pH, salinity and wheat growth.
I. Mineral composition. (Leidi, Silberbush and Lips).

Summary

The interactions between N-form (NH_4^+ or NO_3^-), NaCl concentration and pH of the nutrient solution were studied with wheat (Triticum aestivum L. cv. Barkai) grown in hydroponics. Plant growth was reduced by increasing NaCl concentration from 0 to 100 mM. Increasing the pH from 5 to 8 resulted in reduced growth of NH_4^+-grown plants, but not of NO_3^- grown plants, in all the NaCl concentrations. K^+ concentration in the shoot was inversely correlated with Na^+, but directly correlated with shoot dry weight. These correlations were affected, however, by the N-form applied. The sensitivity of NH_4^+-fed plants to NaCl may be due mainly to the reduction of K^+ concentration in the shoot.

Introduction

The increased use of saline water for irrigation has renewed the interest in plant nutrition and nitrogen (N) fertilization under saline conditions (Kafkafi, 1984; Feigin, 1985). The form of N nutrition may exert a considerable influence on the mineral composition of plants (Allen & Smith, 1986; Allen, Thomas and Raven, 1986; Kirkby and Mengel, 1967; Kurvits and Kirkby, 1980; Reisenauer, 1978). Ammonium (NH_4^+) increased the anion uptake whereas nitrate (NO_3^-) increased cation concentration in wheat (Triticum aestivum L.) plants quite markedly (Cox and Reisenauer, 1973). Changes of pH in the nutrient medium, associated with the source of N, also affected the uptake of ions by the roots (Kirkby and Mengel, 1967; Raven and Smith, 1976). The pH in the growth medium determines the solubility and the availability of many nutrients to the plant (Alam, 1981; Marschner, 1986). This complexed effect must be accounted for while studying plant response to salinity, either for the effect on root growth per se (Marschner, 1986) or those effects derived from differential ion uptake.

In this study we examined the combined effects of N-source, pH and salinity on different aspects of plant growth. In a second paper we present the results of these effects on photosynthesis and transpiration.

Materials and Methods

Wheat (T. aestivum L. cv. Barkai) plants were germinated in vermiculite for seven days and then were transferred to aerated nutrient solutions, eight seedlings per 20-litre container. The solutions contained 4

mM N, either as $(NH_4)_2SO_4$ or $Ca(NO_3)_2$. The other components of the nutrient solution were: 3 mM K^+, 1 mM $H_2PO_4^-$, 2 mM Ca^{2+}, 1 mM Mg^{2+} and 1 (NO_3^--solution) or 4 (NH_4^+-solution) mM SO_4^{2-}.

Micronutrients were supplied at the same concentrations as in a Long-Ashton solution (Hewitt, 1966), and iron as 40 mg Fe-EDDHA per litre. The N-source treatments were combined with 5 NaCl concentrations (0, 25, 50, 75 and 100 mM), 3 pH levels for the NH_4^+ (5.0, 6.5 and 8.0) and 4 pH values (5.0, 6.5, 8.0 and 9.0) for the NO_3^- solutions, in 2 replications. The pH was checked daily and corrected by concentrated KOH or H_2SO_4 solutions. The nutrient solutions were changed once a week.

Dry weight (70°C) of the shoots and the roots and root length (Tennant, 1975) were measured in 56 days old plants. Plant samples were washed in H_2SO_4 + H_2O_2, and analyzed for total (reduced) N by the Nessler reagent, and Ca^{2+} by titration with EDTA. Chloride (Cl^-), sodium (Na^+) and potassium (K^+) were measured in hot water extraction, using a chloridometer (Corning Chloride Analyzer 926) and flame photometer, respectively.

Results

Shoot and Root Growth

Shoot dry weight was reduced by increasing the NaCl concentration both in NO_3^- and NH_4^+ grown plants (Fig. 1a). Plant growth was also reduced by high pH, at all the NaCl concentrations, but more in NH_4^+ grown plants. In the lower NaCl concentrations, dry weight production was similar in the two N sources, suggesting that under non-saline conditions the two N forms were equally effective. Root dry weight and root length (Figs. 1b and 1c, respectively) were both depressed by high salinity levels and by NH_4^+. However, the number of root tips per m of root length (Fig. 1d) was relatively higher in the NH_4^+ grown plants. The correlation between shoot and root dry weight are presented in Figure 2. Within each pH, the two growth parameters were correlated over all the NaCl concentrations. The slopes of the different lines are actually the shoot/root ratios, which appeared to be indifferent to the pH in the NO_3^- treatments. In the NH_4^+ treatments, however, these ratios were relatively higher, but decreased with the pH.

The N concentration in the shoot (Fig. 3a) was slightly reduced by the increase in salinity levels in plants grown in NH_4^+ or in NO_3^-. No effects of pH were observed on N uptake. The potassium concentration in the shoot was reduced by increased NaCl concentration in the growth solution in both the N sources (Fig. 3b). Ammonium-grown plants showed lower K^+

concentrations than those grown on NO_3^-, and the highest pH (i.e. pH 8) resulted in a considerable decrease in K^+ uptake.

High NaCl concentrations and high pH values resulted in an increase in Na^+ and Cl^- uptake. Sodium and Cl^- concentrations (Figs. 3c and 3d, respectively) increased in both NH_4^+ and NO_3^- grown plants with the NaCl concentration, with a minimum at pH 6.5. On the other hand, while Ca^{2+} concentration systematically decresed with the pH in NO_3^--grown plants, shoot Ca^{2+} concentration of NH_4^+-grown plants was curvilinearly affected by pH, with a minimum at pH 6.5 (Fig. 3e).

Shoot dry weight of wheat plants grown under the different treatments was highly correlated with K^+ concentration in the shoot (Fig. 4). While the relationship between the two variables were linear for plants grown with NO_3^-, shoot dry weight was curvilinearly correlated with K^+ in plants grown with NH_4^+. Figure 5 reveals that shoot dry weight decreased logarithmically with Na^+ concentration in the shoot. On the other hand, K^+ and Na^+ in the plants were inversely correlated, even the K^+ concentration was always lower in plants grown with NH_4^+ (Fig. 6).

Discussion

In studies with rice (Oryza sativa L.), Alam (1981) showed an optimal dry matter accumulation at pH between 5.5 and 6.5, which agrees with the presented results (Fig. 1). Lovatt (1986) showed that ammonia toxicity was enhanced under salinity by inhibiting de novo arginine synthesis in squash (Cucurbita pepo L.) plants. Since NH_4^+ tends to change into NH_3 in high pH (pK=9.2), which is in return toxic to plants (Bennet and Adams, 1970; Maynard and Barker, 1969), this notion agrees with the reduction in shoot and root growth obtained in NH_4^+ and in relatively high pH (Fig. 1). As reported by Schenk and Wehrman (1979), root length of cucumber (Cucumis sativus L.) plants was severely inhibited by NH_4^+ concentrations as low as 0.05 mM. As for the salinity level, Kurth et al. (1986) reported that moderate salinity levels enhanced root length and weight in cotton (Gossypium hirsutum L.). On the other hand, Devitt, Stolzy and Jarrell (1984) observed a decline in root weight of wheat as a result of increased osmotic potential of the nutrient solution. However, within each osmotic potential, the increase in Na^+ concentration resulted in a decrease in root elongation.

Decreases in growth rates caused by salinity can be a result of a decrease in protein content in the plant (Cooke, Oliver and Davies, 1979). At this respect, conflicting results were reported in different plant species (Alam, 1981; Blamey et al., 1982; Ingestad, 1979; Islam, Edwards and Asher,

1980). In this study, NH_4^+ slightly increased N concentration as related to NO_3^- (Fig. 3a), as was reported also by Cox and Reisenauer (1973).

The correlations between shoot dry weight and K^+ concentration in the plant agree with the mutual stimulation in uptake by plants between K^+ and NO_3^- exhibited by Blevins et al. (1978). Rama Rao (1986) reported a critical K^+ concentration for deficiency between 3.8 and 4.1% (0.97 and 1.05 mmol g^{-1}, respectively) in dry weight of the whole plant at 30 to 45 days old plants. Considering these values, the K^+ concentration in the shoots of both NO_3^- and NH_4^+ grown plants at the higher NaCl concentrations (i.e. 75 and 100 mM) were below the critical value for K^+ deficiency. Ammonium grown plants exhibited K^+ deficiencies even at 25 mM NaCl when grown at pH 8 in the nutrient solution.

These results may be explained by an increase in the permeability of the root membranes and the loss of selectivity as a result of an increase in the Na^+/Ca^{2+} ratio in the external solution (Greenway and Munns 1980). Apparently, Na^+ is not restricted to the root system as a way to cope with the increase in salinity level in the growth medium (Devitt, Stolzy and Jarrell, 1984), but it migrates to the shoot and plays a role in the osmoregulation of the plant (Devitt et al., 1984). However, Na^+ in high concentrations can effectively compete with K^+ for uptake by the root (Silberbush and Ben-Asher, 1987). In the case of salt-sensitive species like maize (Zea mats), however, Na^+ exclusion occurred at the plasms membrane of the xylem parenchyma cells (Schubert and Lauchli, 1986). The control of Na^+ translocation from the root to the shoot is by K^+/Na^+ exchange. The exclusion of Na^+ at the root surface restricts Na^+ uptake by the plant root by pumping Na^+ out of the root cells back to the external medium.

The concentration of Ca^{2+} in the plant decreased with the pH in NO_3^--grown plants while it had a minimal value at pH 6.5 in NH_4^+-grown wheat plants (Fig. 3e). That is, unlike the results of Alam (1981), who observed an increase in Ca^{2+} concentration in shoot of rice with the increase of the solution pH. Calcium concentration was also reduced by NaCl concentration, probably due to the inhibition of Ca^{2+} uptake caused by Na^+ (Cramer, Lauchli and Polito, 1985). The N-source also influenced Ca^{2+} uptake. Ammonium grown plants had lower Ca^{2+} concentration than of those grown with NO_3^-. The need for extra supply of Ca^{2+} under NH_4^+ nutrition in several plant species was already reported (Fenn, Taylor and Horst, 1987; Taylor, Fenn and Horst, 1985).

The higher Cl^- concentration which was observed in the higher pH and NaCl concentrations (Fig. 3d) may be the result of an increased Cl^- uptake

rate, probably operated by a Cl^-/OH^- antiporter (Jennings, 1986) and also by a dilution effect due to the reduction in plant growth (Fig. 1a). Concentrtions of inorganic anions like Cl^- are often higher in leaves of NH_4^+ grown plants (Haynes and Goh, 1978). This stimulation of Cl^- influx is believed to be the result of a larger amount of OH^- ions in the cytoplasm which can be exchanged with other anions (Jennings, 1986).

The results indicate that plant growth was inhibited mainly by Na^+ accumulation in the shoot, via its competition with K^+. When NO_3^- was the only source of N, the competition was only between these two cations (Ca^{2+} was relative unaffected). However, when N was supplied as NH_4^+ then an additional cation, with a similar character as K^+, was introduced into the system and apparently competed with the other two cations. The increase of the pH to 8 in the NH_4^+ solutions caused a sharp increase in Na^+ concentration in the plant, which was associated with the reduction of K^+ concentration. Furthermore, some of the NH_4^+ was changed into NH_3, whch is toxic to plants (Bennet and Adams, 1970; Maynard and Barker, 1969). The interactions among these factors apparently were manifested in the growth of the tested wheat plants (Findenegg, 1987). This effect may be crucial to the plant when Na^+ concentration is relatively high, and K^+concentration in the plant tissues becomes marginal. Under these conditions the presence of NH_4^+ suppresed the concentration of K^+, and consequently increased the plant suseptibility to NaCl.

References

Alam, S.M., 1981. Effects of solution pH on the growth and chemical composition of rice plants. Journal of Plant Nutrition, 4, 247-260.

Allen, S. and Smith, J.A.C., 1986. Ammonium nutrition in Ricinus communis: Its effect on plant growth and the chemical composition of the whole plant, xylem and phloem saps. Journal of Experimental Botany, 37, 1599-1610.

Allen, S., Thomas, G.E. and Raven, J.A., 1986. Relative uptake rates of inorganic nutrients by NO_3^-- and NH_4^+-grown Ricinus communis and by two Plantago species. Journal of Experimental Botany, 37, 419-428.

Blamey, F.P.C., Edwards, D.G., Asher, C.J. and Kim, Moo-Key., 1982. Response of sunflower to low pH. In: Plant Nutrition. Proceedings of the 9th International Colloquium on Plant Nutrition, Vol. 1 (Ed. by A. Scaife), pp. 66-71. Commonwealth Agricultural Bureaux.

Bennet, A.C. and Adams, F., 1970. Concentration of NH_3(aq) required for incipient NH_3 toxicity to seedlings. Soil Science Society of America Proceedings, 34, 259-263.

Blevins, D.G., Hiatt, A.J., Lowe, R.H. and Leggett, J.E., 1978. Infuence of K on the uptake, translocation, and reduction of nitrate by barley seedlings. Agronomy Journal, 70, 393-396.

Cooke, R.J., Oliver, J. and Davies, D.D., 1979. Stress and protein turnover in Lemna minor. Plant Physiology, 64, 1109-1113.

Cox, W.J. and Reisenauer, H.M., 1973. Growth and ion uptake by wheat supplied nitrogen as nitrate, or ammonium, or both. Plant and Soil, 38, 363-380.

Cramer, G.R., Lauchli, A. and Polito, V.S., 1985. Displacement of Ca^{2+} by Na^{+} from plasmalemma of root cells. A primary response to salt stress? Plant Physiology, 79, 207-211.

Devitt, D., Jarrell, W.M., Jury, W.A., Lunt, O.R. and Stolzy, L.H., 1984. Wheat response to sodium uptake under zonal saline-sodic conditions. Soil Science Society of America Jornal, 48, 86-92.

Devitt, D., Stolzy, L.H. and Jarrell, W.M., 1984. Response of sorghum and wheat to different K^{+}/Na^{+} ratios at varying osmotic potentials. Agronomy Journal, 76, 681-688.

Feigin, A., 1985. Fertilization management of crops irrigated with saline water. Plant and Soil, 89, 285-299.

Fenn, L.B., Taylor, R.M. and Horst, G.L., 1987. Phaseolus vulgaris growth in an ammonium-based nutrient solution with variable calcium. Agronomy Jornal, 79, 89-91.

Findenegg, G.R., 1987. A comparative study of ammonium toxicity at different constant pH of the nutrient solution. Plant and Soil, 103, 239-243.

Greenway, H. and Munns, R., 1980. Mechanisms of salt tolerance in nonhalophytes. Annual Review of Plant Physiology, 31, 149-190.

Haynes, R.J. and Goh, K.M., 1978. Ammonium and nitrate nutrition of plants. Biological Review, 53, 465-510.

Hewtt, E.J., 1966. Sand and water culture methods used in the study of plant nutrition,. 2nd Edition, Commonwealth Agricultural Bureaux, Farnham Royal.

Ingestad, T., 1979. A definition of optimum nutrient requirements in birch seedlings. III. Influence of pH and temperature of nutrient solution. Physiologia Plantarum, 46, 31-35.

Islam, A.K.M.S., Edwards, D.G. and Asher, C.J., 1980. pH optima for crop growth. Results of a flowing solution culture experiment with six species. Plant and Soil, 54, 339-357.

Jennings, D.H., 1986. Salt relations of cell, tissues and roots. In: Plant Physiology. A Treatise, Vol. IX (Ed. by F.C. Steward) pp. 225-379. Academic Press Inc.

Kafkafi, U., 1984. Plant nutrition under saline conditions. In: Soil Salinity under Irrigation. Processes and Management. Ecological Studies 51 (Ed. by I. Shainberg and J. Shalhevet), pp. 319-331. Springer-Verlag, Berlin, Heidelberg, New York and Tokyo.

Kirkby, E.A. and Mengel, K., 1967. Ionic balance in different tissues of the tomato plant in relation to nitrate, urea, or ammonium nutrition. Plant Physiology, 42, 6-14.

Kurth, E., Cramer, G.R., Lauchli, A. and Epstein, E., 1986. Effects of NaCl and $CaCl_2$ on cell enlargement and cell production in cotton roots. Plant Physiology, 82, 1102-1106.

Kurvits, A. and Kirkby, E.A., 1980. The uptake of nutrients by sunfower (Helianthus annuus) growing in a continuous flowing culture system, supplied with nitrate or ammonium as nitrogen source. Zeitschrift fur Pflanzenernahrung und Bodenkunde, 143, 140-149.

Lovatt, C.J., 1986. Salinity stress results in ammonia intoxication. Plant Physiology, 80(Supplement), 10.

Marschner, H., 1986. Mineral Nutrition of Higher Plants. Academic Press, London.

Rama Rao, N., 1986. Potassium requirements for growth and its related processes detemined by plant analysis in wheat. Plant and Soil, 96, 125-131.

Raven, J.A. and Smith, F.A., 1976. Nitrogen assimilation and transport in vascular land plants in relation to intracellular pH regulation. New Phytologist, 76, 301-312.

Reisenauer, W.M., 1978 Absorption and utilization of ammonium nitrogen by plants. In: Nitrogen in the Environment, Vol. 2 (Ed. by D.R. Nielsen and J.G. McDonald) pp. 157-170. Academic Press, New York.

Schenk, M. and Wehrmann, J., 1979. The influence of ammonia in nutrient solution on growth and metabolism of cucumber plants. Plant and Soil, 52, 403-414.

Schubert, S. and Lauchli, A., 1986. Na^+ exclusion, H^+ release, and growth of two differnt maize cultivars under NaCl salinity. Journal of Plant Physiology, 126, 145-154.

Silberbush, M. and Ben-Asher, J., 1987. The effect of salinity on parameters of potassium and nitrate uptake of cotton. Communications in Soil Science and Plant Analysis, 18, 65-81.

Taylor, R.M., Fenn, L.B. and Horst, G.L., 1985. The influence of calcium on growth of selected vegetable species in the presence of ammonium nitrogen. Journal of Plant Nutrition, 8, 1013-1023.

Tennant, D., 1975. A test of a modified line intersect method of estimating root length. Journal of Ecology, 63, 995-1001.

Figure Captions

Fig. 1. Shoot (a) and root (b) dry weight, root length (c) and root tips density (d) of wheat plants grown in hydroponics with different concentrations of NaCl, NH_4^+ or NO_3^- nitrogen, and different ph values of the nutrient solution for 56 days. The bars represent LSD (P =0.05) for each NaCl concentration.

Fig. 2. Shoot vs. root dry weight of wheat plants as affected by the N-source (NH_4^+ or NO_3^-) and pH. Note that while for NH_4^+ the slope (i.e. shoot/root ratio) decrease with pH, it stays rather constant in NO_3^--grown plants.

Fig. 3. Mineral composition of shoots of wheat plants grown in different concentrations of NaCl, N-source, and ph of the nutrient solution. The bars represent LSD (P =0.05) for each NaCl concentration.

Fig. 4. The correlation between shoot dry weight and K^+ concentration in the shoot of wheat plants grown with NH_4^+ or NO_3^-, and with different NaCl concentration and pH of the nutrient solution.

Fig. 5. The relationship between Na^+ concentration in the shoot and shoot dry weight of wheat grown with different NaCl concentrations, N-source, and pH of the nutrient solution.

Fig. 6. The correlation between K^+ and Na^+ cconcentrations in shoots of wheat plants grown with NH_4^+ or NO_3^-, and with different NaCl concentrations and pH of the nutrient solution.

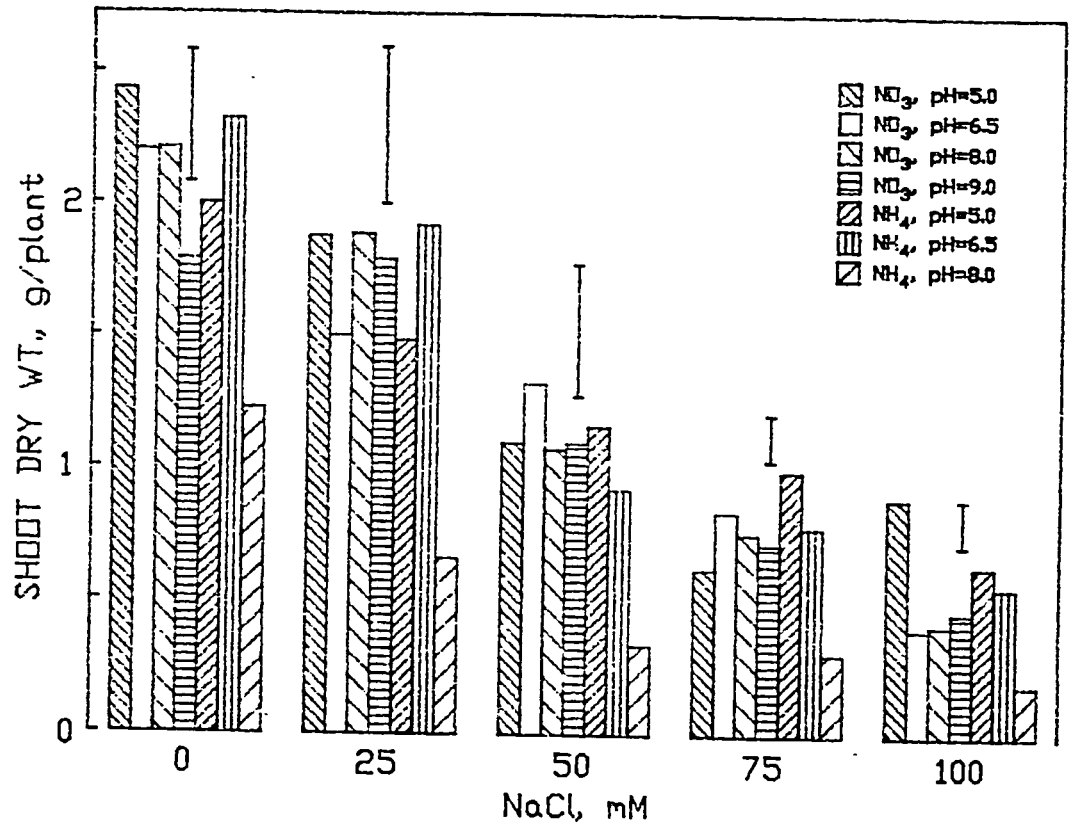

SHOOT DRY WT., g/plant
0
1
2
0
25
50
75
100
NaCl, mM
NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0

Fig. 1a.

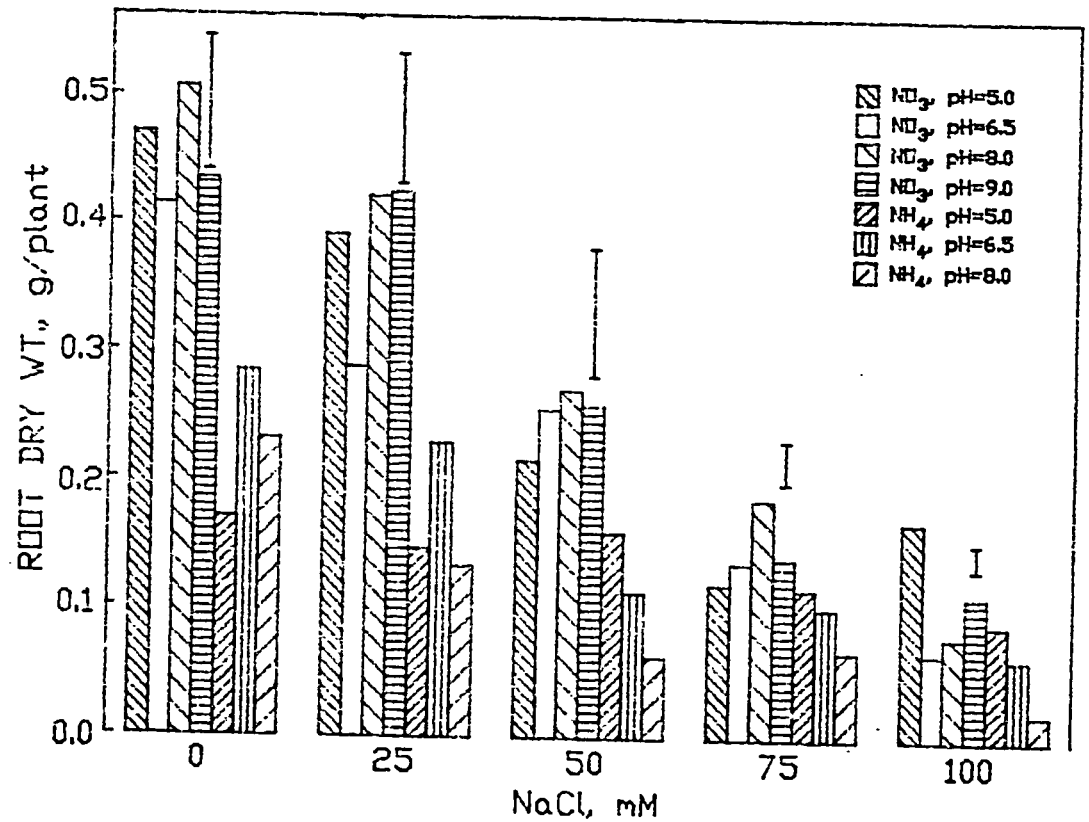

ROOT DRY WT., g/plant
0.0
0.1
0.2
0.3
0.4
0.5
0
25
50
75
100
NaCl, mM
NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0

Fig. 1b.

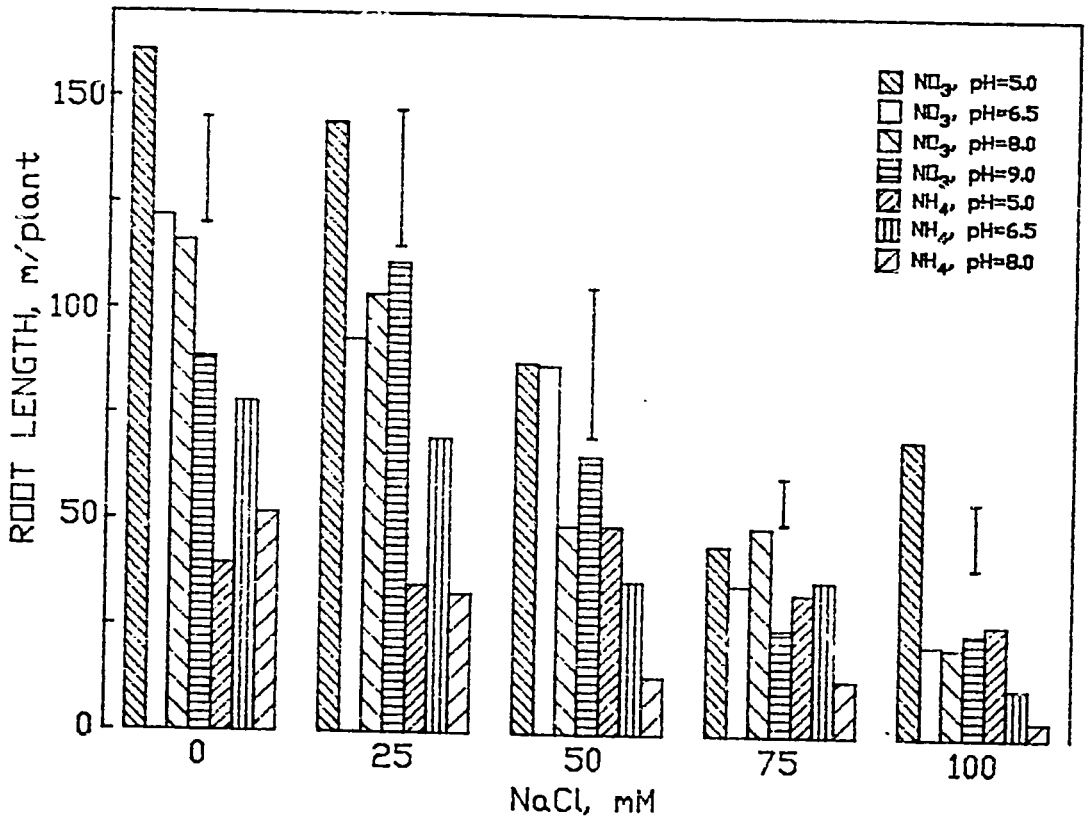

ROOT LENGTH, m/plant
150
100
50
0
0
25
50
75
100
NaCl, mM
NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0

Fig. 1c.

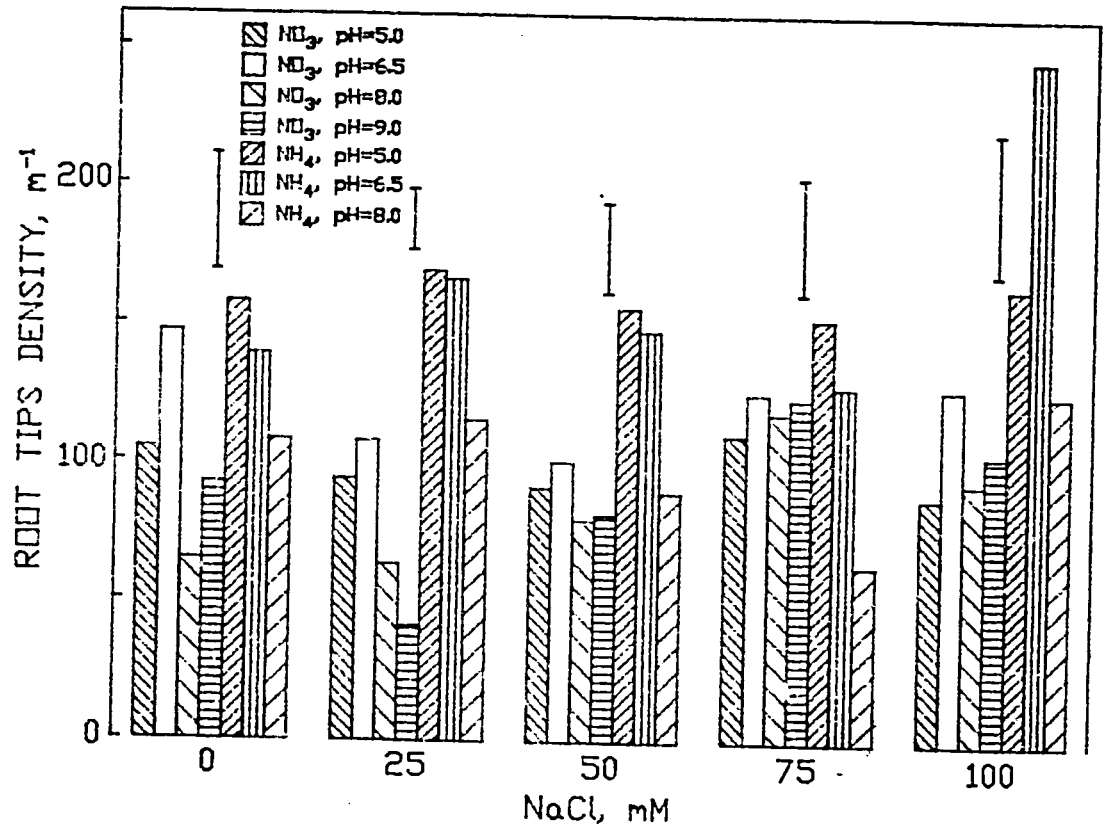

NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0
ROOT TIPS DENSITY, m-1
0
100
200
0
25
50
75
100
NaCl, mM

Fig. 1d.

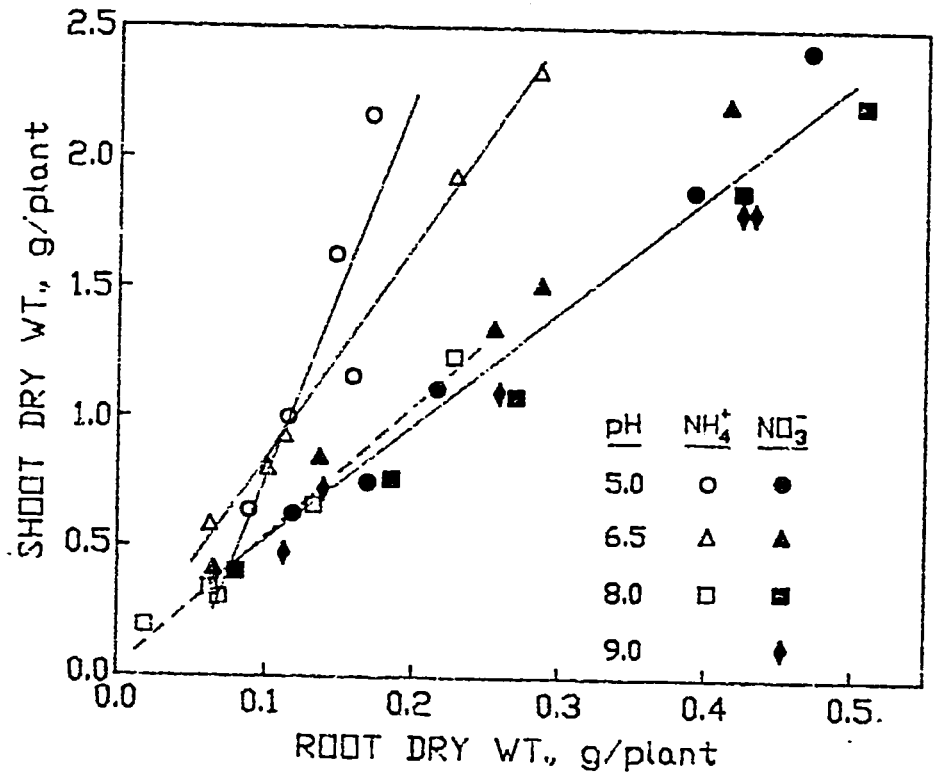
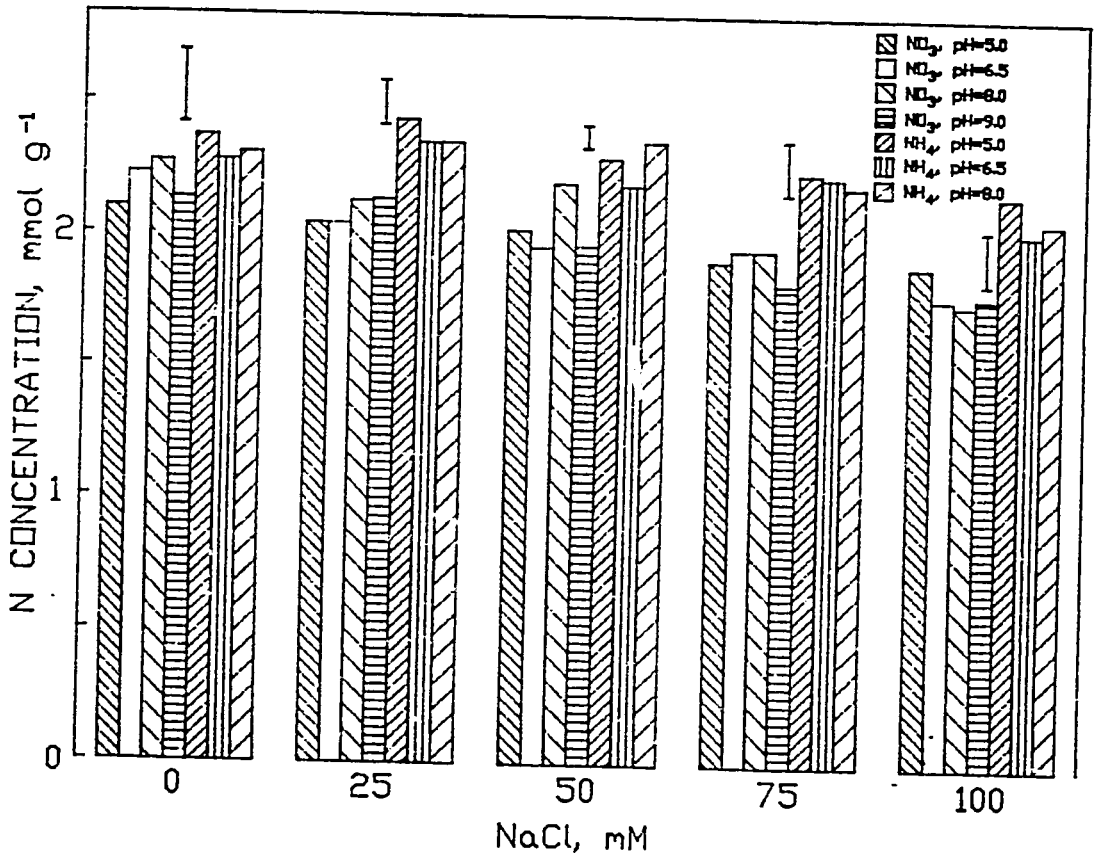

SHOOT DRY WT., g/plant
ROOT DRY WT., g/plant
0.0
0.5
1.0
1.5
2.0
2.5
0.1
0.2
0.3
0.4
0.5
pH
NH_4^+
NO_3^-
5.0
6.5
8.0
9.0

Fig. 2.

Fig. 3a.


N CONCENTRATION, mmol g⁻¹
0
1
2
0
25
50
75
100
NaCl, mM
NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0

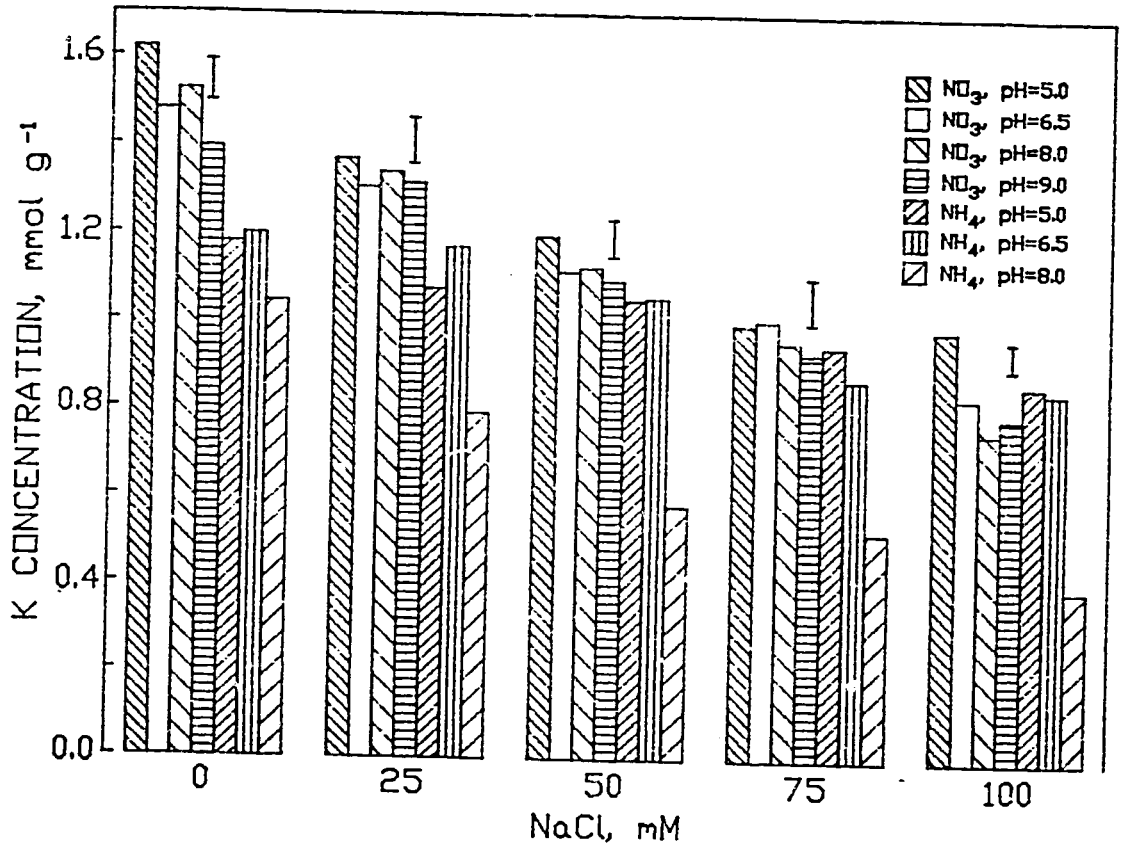

K CONCENTRATION, mmol g-1
1.6
1.2
0.8
0.4
0.0
0
25
50
75
100
NaCl, mM
NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0

Fig. 3b.

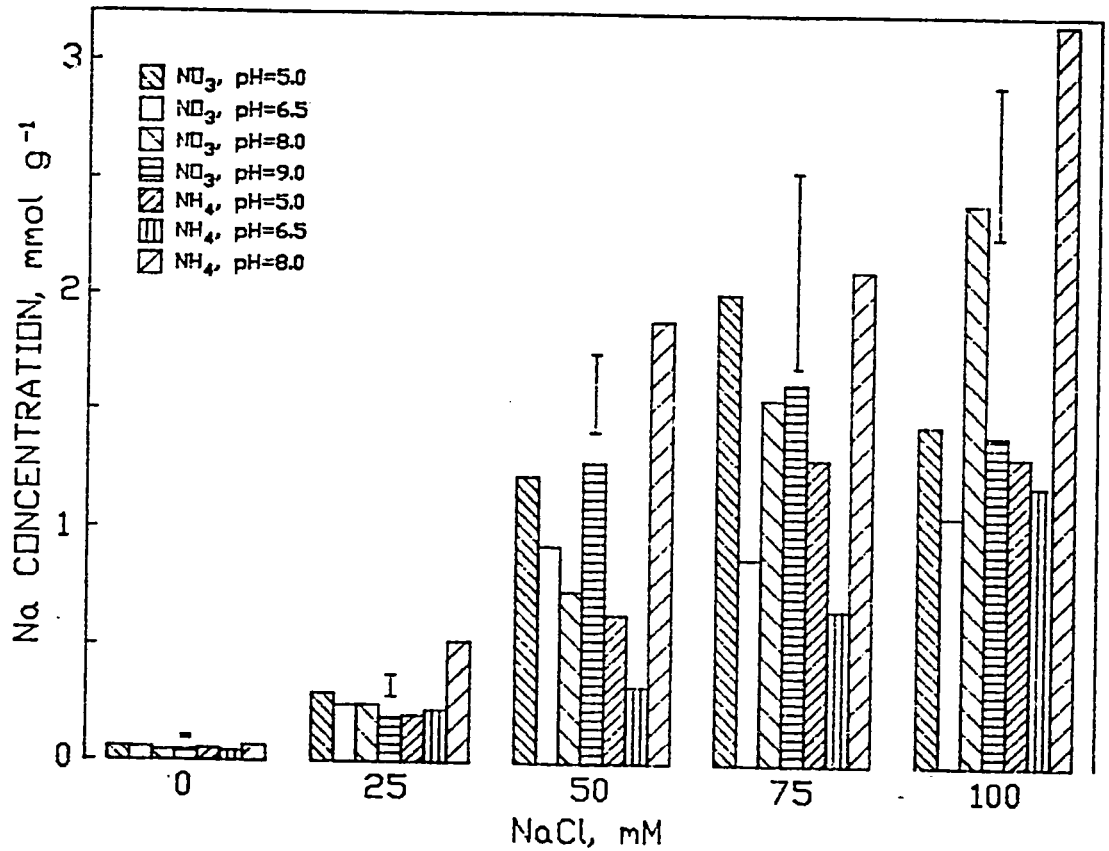

NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0
Na CONCENTRATION, mmol g-1
0
1
2
3
0
25
50
75
100
NaCl, mM

Fig. 3c.

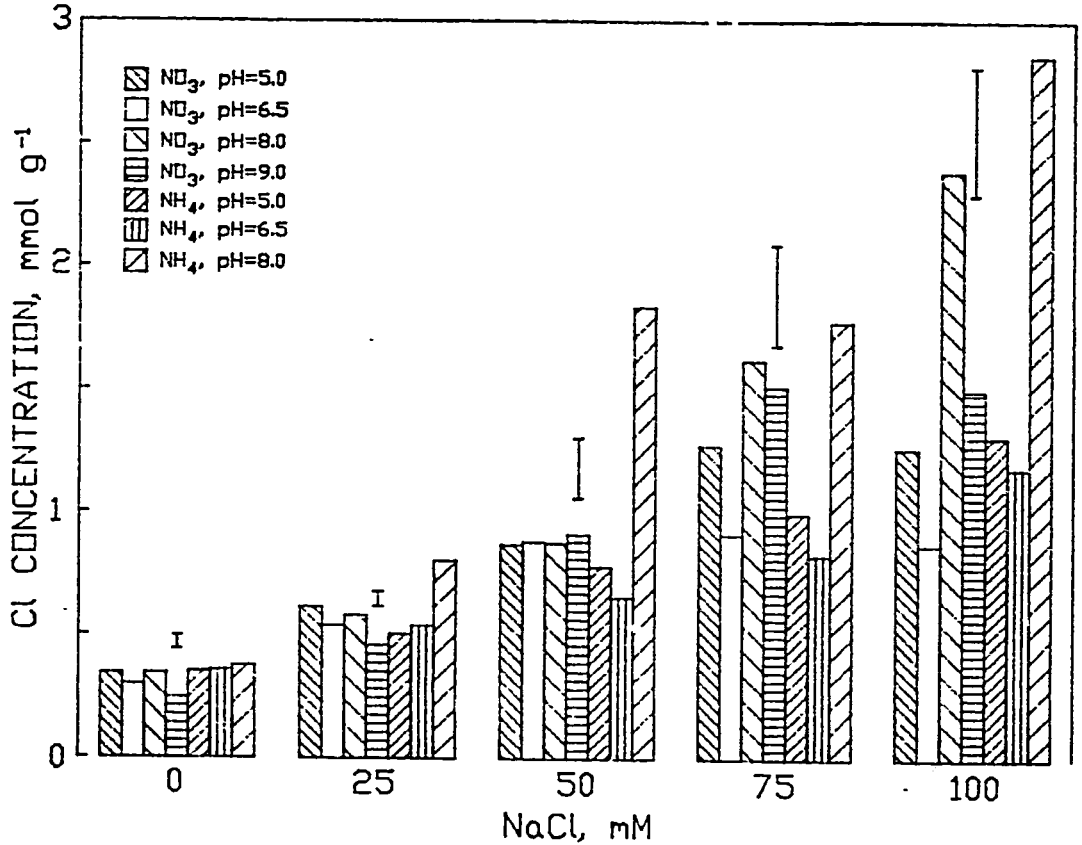

NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0
Cl CONCENTRATION, mmol g-1
0
1
2
3
0
25
50
75
100
NaCl, mM

Fig. 3d.

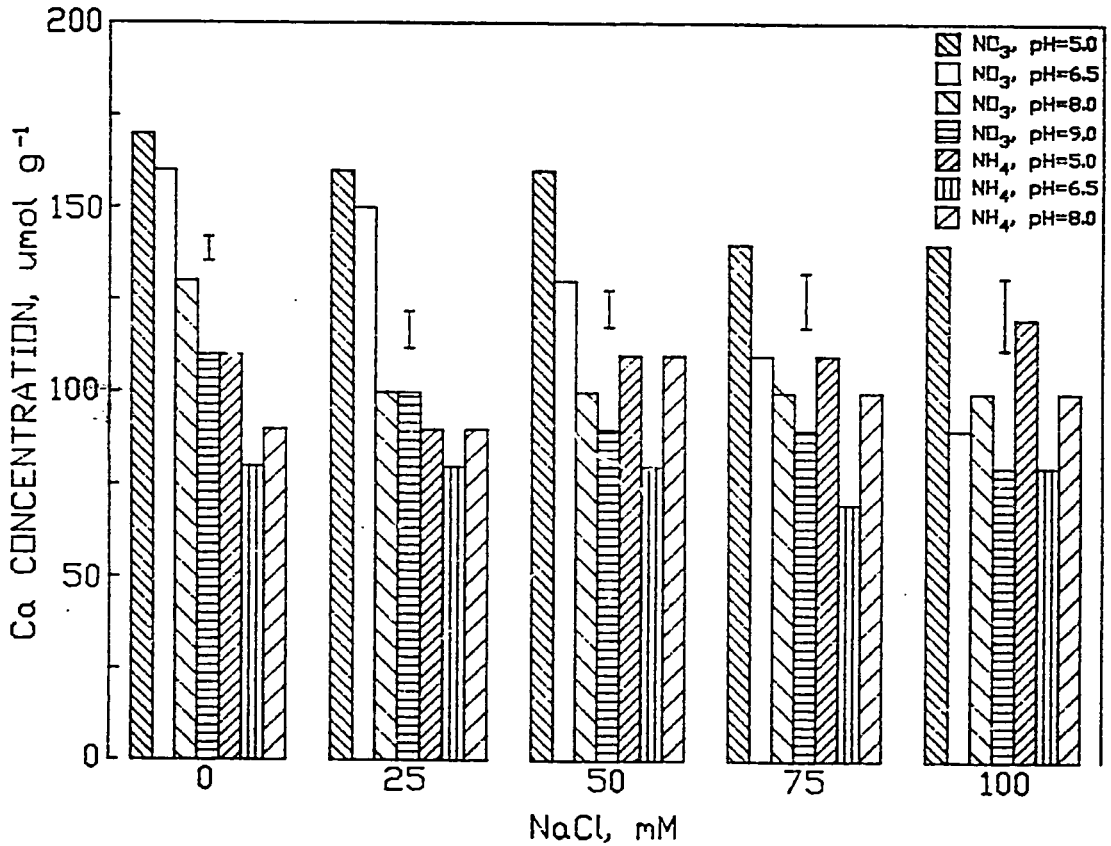

200
150
100
50
0
Ca CONCENTRATION, umol g-1
0
25
50
75
100
NaCl, mM
NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0

Fig. 3e.

Fig. 4.

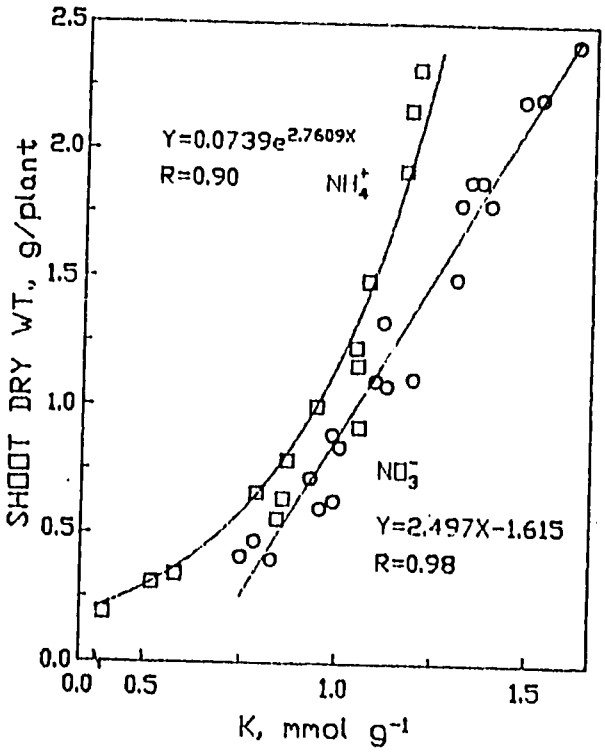

Y=0.0739e^2.7609X
R=0.90
NH4+
NO3-
Y=2.497X-1.615
R=0.98
SHOOT DRY WT., g/plant
K, mmol g-1
0.0
0.5
1.0
1.5
2.0
2.5

Fig. 5.

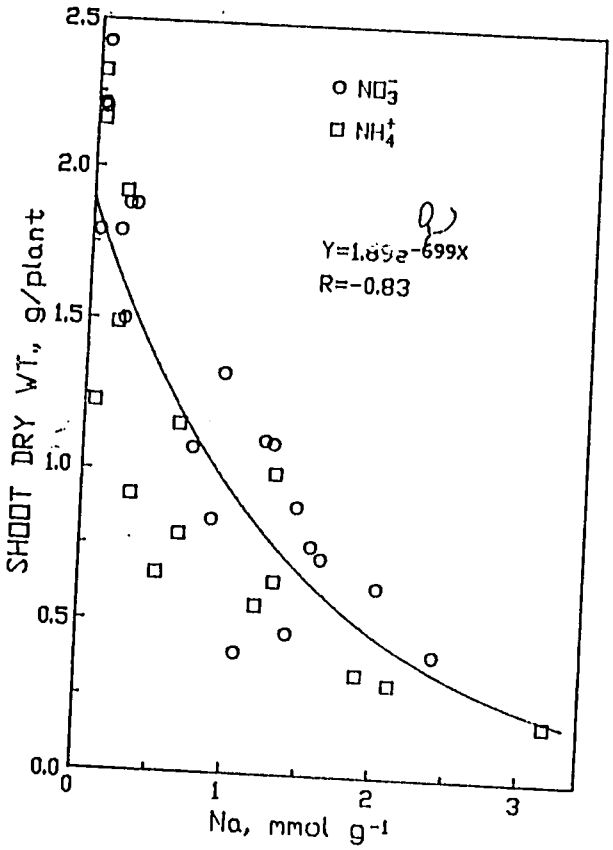
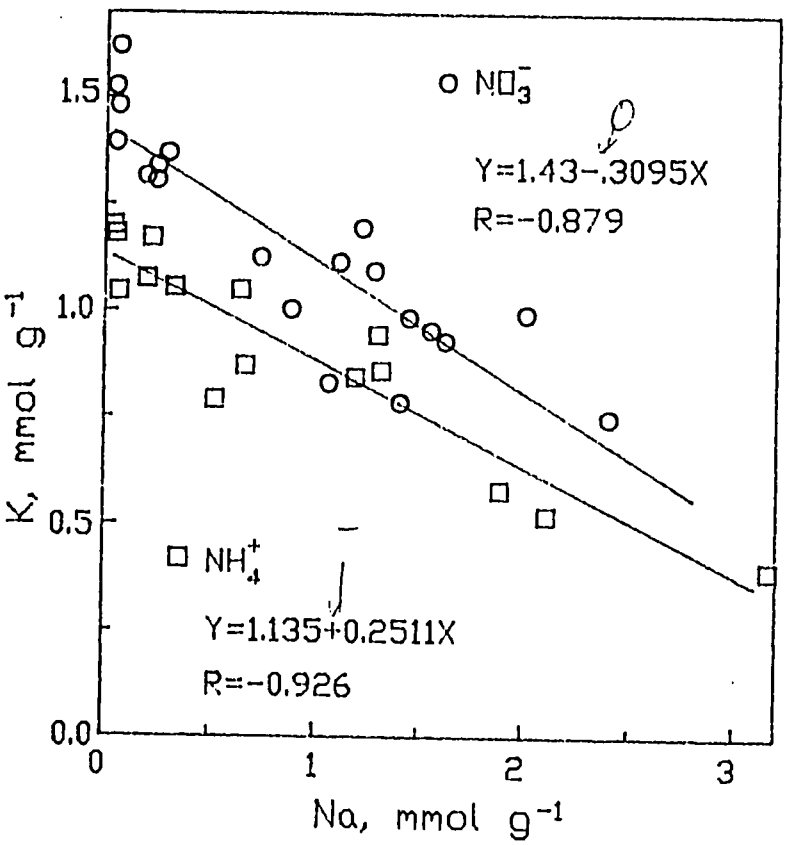

2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
SHOOT DRY WT., g/plant
Na, mmol g-1
o NO3-
□ NH4+
Y=1.892e-699X
R=-0.83

Fig. 6.


1.5
1.0
0.5
0.0
K, mmol g⁻¹
0
1
2
3
Na, mmol g⁻¹
o NO3⁻
Y=1.43-.3095X
R=-0.879
□ NH4⁺
Y=1.135+0.2511X
R=-0.926

(1b) Nitrogen source, pH, salinity and wheat growth.
II. Photosynthesis and transpiration (Leidi, Silberbush and Lips).

Summary

The interactions betwen N-form (NH_4^+ or NO_3^-), NaCl concentration and pH of the nutrient solution were studied in wheat (Triticum aestivum L. cv. Barkai) grown in hydroponics. The effects on mineral contents and on plant growth were reported in Part I. Photosynthetic rate was not affected by salinity, and so was the transpiration rate. Stomatal conductance, however, decreased with NaCl concentration. Chlorophyll content in the leaves was reduced in NH_4^+-grown plants when the pH was raised to 8, but more modeately in NO_3^--grown plants. Consequently, there was a difference between photosynthesis per leaf area or per chlorophyll content. The interaction between K^+ and Na^+ and its possible effect on photosynthesis and transpiration are discussed.

Introduction

The increased use of saline water for irrigation has renewed the interest in plant nutrition and nitrogen (N) fertilization under saline conditions (Kafkafi, 1984; Feigin, 1985). The form of N nutrition may exert a considerable influence on the mineral composition of plants (Allen and Smith, 1986; Allen, Thomas and Raven, 1986; Kirkby and Mengel, 1967; Kurvits and Kirkby, 1980; Reisenauer, 1978). In wheat (Triticum aestivum L.) grown with ammonium (NH_4^+) the level of anion intake increased whereas nitrate (NO_3^-) increased cation concentration in the plant quite markedly (Cox and Reisenauer, 1973). Changes of pH in the nutrient medium, associated with the source of nitrogen (N), also affected the uptake of ions by the roots (Kirkby and Mengel, 1967; Raven and Smith, 1976). The pH in the growth medium determines the solubility and the availability of many nutrients to the plant (Alam, 1981; Marschner, 1986). This complexed effect must be accounted for while studying plant response to salinity, either for the effect on root growth per se (Marschner 1986) or those effects derived from differntial ion uptake.

In Part I (Leidi, Silberbush and Lips) of this series we studied the effects of N source, pH and salinity on wheat plant growth and on mineral composition. In this paper we present a study on the effects of these factors on growth, photosynthetic activity, the water use by the plants.

Materials and Methods

Wheat (T. aestivum L. cv. Barkai) plants were germinated in vermiculite for seven days, and then were transferred to aerated nutrient solutions, eight seedlings per 20-liter container. The nutrient solutions contained 4 mM N, either as NH_4^+ or as NO_3^-, applied as $(NH_4)_2SO_4$ or $Ca(NO_3)_2$, respectively. The other components of the nutrient solution were: 3 mM K^+, 1 mM $H_2PO_4^-$, 2 mM Ca^{2+}, 1 mM Mg^{2+}, and 1 (NO_3^--solution) or 4 (NH_4^+-solution) mM SO_4^{2-}.

Micronutrients were as in a Long-Ashton solution (Hewitt, 1966), and iron as 40 mg Fe-EDDHA per litre. The N-source treatments were combined with 5 concentrations of NaCl (0, 25, 50, 75 and 100 mM), 3 pH levels for the NH_4^+ (5.0, 6.5 and 8.0) and 4 pH values (5.0, 6.5, 8.0 and 9.0) for the NO_3^- solution, in 2 replications. The pH was checked daily, and corrected with concentrated KOH or N_2SO_4 solutions when required. The nutrient solutions were changed once a week. Photosynthesis, transpiration and stomatal conductance were measured in young and fully expanded leaves using a portable InfraRed Gas Analyzer (LCA-2 Analyzer, ADC), at atmospheric CO_2 concentration and in the differential mode, at constant radiation flux (500 umol m^{-2} s^{-1} PAR). Chlorphyll was extracted from leaf discs in 100% methanol, and determined by spectrophotometry according to Arnon (1949).

Dry weight of the shoots and the roots and root length, total (reduced) N, Ca^{2+}, Cl^-, Na^+ and K^+ were measured in 56 days old plants (for more details see Leidi, Silberbush and Lips).

Results

The effects of NaCl concentration, pH and N-form on growth parameters and on mineral composition of wheat plants were reported in Part I (Leidi, Silberbush and Lips). The present paper dealt with the effects of these factors on photosynthesis and transpiration.

Table 1 presents correlation coefficients among measured growth parameters and mineral contents of wheat plants grown under the experimental conditions. Photosynthesis per leaf area unit was inversely-correlated to N concentration, but not with any of the other measured parameters. The inverse-correlation between photosynthesis per mg chlorophyll and chlorophyll concentration is actually a self-correlation. Transpiration rate, on the other hand, was correlated with stomatal

conductance. Chlorophyll concentration was correlated with K^+ and inversely-correlated with Na^+ and Cl^-.

Figure 1 presents photosynthesis rate (a) per leaf area unit, or (b) per g chlorophyll. While there was no effect of NaCl concentration on photosynthesis expressed on leaf area basis (Fig. 1a), there was such an effect when it was expressed per g chlorophyll. Definitely, the difference is due to the effect of N-form, pH and NaCl concentration on chlorophyll content (Fig. 1c).

Transpiration rate and stomatal conductance are presented in Figure 2a and 2b, respectively. Transpiration rate was not affected by NaCl concentration and by the pH in NO_3^--grown plants. It increased, however, with pH in NH_4^+-grown plants, an effect which was reduced by high NaCl concentrations (Fig. 2a). Stomatal conductance, on the other hand, was affected both by NaCl concentration and by pH (Fig. 2b). The major reduction in stomatal conductance due to NaCl occurred in NH_4^+-grown plants in a high pH (i.e. pH 8).

Figure 3 presents the correlation between transpiration and stomatal conductance. Plants grown with NH_4^+ or NO_3^- reacted differently to combinations of NaCl concentration of pH, while NH_4^+-grown plants were more sensitive to changes in stomatal conductance in their transpiration. The linkage is via K^+ concentration in the leaves, as shown in Figure 4 and Table 1. However, these relationships between stomatal conductance and K^+ concentration were very much affected by pH of the nutrient solution, and were different in NH_4^+ or NO_3^--grown wheat plants.

Discussion

The photosynthetic rate per unit area of leaf was not reduced by the different salt treatments (Fig. 1a), while shoot dry weight (Fig. 1a, Part I) and consequently leaf surface area per plant decreased with the increased NaCl concentration. These results indicate that plant growth decreased mainly as a result of the dark respiration, which led to a reduction i net CO_2 assimilation rate (Hoffman and Phene, 1971). Kingsbury, Epstein and Pearcy (1984) also observed a relatively higher photosynthesis in wheat under salinity stress in long-term experiments. The chlorophyll concentration in the leaves (Fig. 1c) was reduced by NaCl concentration mainly at high ph, and more in NH_4^+ grown plants than in NO_3^- grown wheat plants. According to Robinson, Downton and Millhouse (1983), salt stress did not reduce the photosynthetic potential of spinach (Spinacia oleracea) leaves. The rate of photosynthesis per mg chlorophyll, on the other hand, was actually higher in

plants grown with NaCl, but because of a lower chlorophyll concentration in the laves. In a Na^+ exluder soybean (Glycin max), cv. Ransom, net photosynthesis was not reduced in 100 mM NaCl, whereas in an includer cultivar (cv. Bragg) photosynthesis was consistently inhibited in NaCl concentrations above 20 mM (Moftah and Michel 1986). Higher CO_2 fixation rates in salinized plants than in the control were observed in sugarbeet (Beta vulgaris L.) (Huer and Plaut, 1984). In lettuce (Lactuca sativa), however, similar net carbon exchange rates were obtained, while dry weight, leaf area and stomatal conductance were reduced at 10 or 100 mM NaCl, respectively (Carter and Cheeseman, 1987). At this respect, Rawson (1986) has pointed out that gas analysis techniques, which do not account for carbon allocation, might lead to biased conclusions as for salinity tolerance of the photosynthetic system. Measurement of relative leaf expansion rate pecific leaf weight and water use efficiency are directly affected by salinity.

The transpiration rate was only slightly affected by salinity (Fig. 2a), in spite of the decrease in stomatal conductance at the highest NaCl concentration (Fig. 2b). The relationship between transpiration and stomatal conductance (Farquhar and Sharkey, 1982) means that if the water vapor pressure inside the leaf (e_i) is assumed to be the saturation pressure at the leaf temperature, the reduction in water potential in the salt treatments may affect the e_i in such a way that no relation between transpiration and stomatal conductance could be observed. Devitt, Stolzy and Jarrell (1984) found an increase of the diffusive resistance in leaves of wheat as a result of a decrease in the osmotic potential. Based on the decrease in the diffusive resistance at relatively low K^+/Na^+ ratios, they suggested that the plants improved their osmoregulation in the presence of salt.

The indifference of the photosynthetic system to salinity (Fig. 1a) was probably due to the relative tolerance of the key-enzymes to salt but no protein synthesis (Cooke, Oliver and Davies, 1979; Shomer-Ilan et al., 1979), which reduced chlorophyll synthesis (Figs. 1b and 1c). Transpiration rate was little affected by salinity, but not stomatal conductance (Figs. 2a and 2b, respectively). Active openings of stomata requires a flow of K^+ in the epidermis, which is also affected by Ca^{2+} concentration (Humbler and Hsiao, 1969; Paschke, 1979). The correlation between stomatal conductance and K^+ concentration in the shoot (Fig. 4) agrees with these references. In Part I (Leidi, Silberbush and Lips) we presented competition between K^+ and Na^+ concentration in the shoot. It may be concluded that stomatal conductance, even if it is a sensitive measured parameter which was significantly correlated with K^+, Ca^{2+}, transpiration, and shoot and root growth (Table 1), was not a limiting factor to plant growth in this experiment, because the plants were grown in hydroponics and faced no water shortage. Under field

conditions, however, this parameter might play a meaningful role in plant production under saline conditions. The interaction between Na^+ and K^+ was definitely the direct means by which salinity affected plant growth and production. This effect was mainly via protein and chlorophyll synthesis, which in turn reduced photosynthesis by the whole plant.

References

Alam, S.M., 1981. Effects of solution pH on the growth and chemical composition of rice plants. Journal of Plant Nutrition, 4, 247-260.

Allen, S. and Raven, J.A., 1983. NH_4^+ as N source causes increased water uptake by Ricinus. In: Membrane Transport in Plants (Ed. by W.J. Cram, K. Janacek, R. Rybova and K. Sigler), pp. 105-106. J. Wiley and Sons, Chichester.

Allen, S. and Smith, J.A.C., 1986. Ammonium nutrition in Ricinus communis: Its effect on plant growth and the chemical composition of the whole plant, xylem and phloem saps. Journal of Experimental Botany, 37, 1599-1610.

Allen, S., Thomas, G.E. and Raven, J.A., 1986. Relative uptake rates of inorganic nutrients by NO_3^-- and NH_4^+-grown Ricinus communis and by two Plantago species. Journal of Experimental Botany, 37, 419-428.

Arnon, D.I., 1949. Copper enzymes in isolated chloroplasts. Polyphenol-oxydase in Beta vulgaris. Plant Physiology, 24, 1-15.

Carter, D.R. and Cheeseman, J.M., 1987. Non-stomatal effects of salinity on photosynthesis in Lectuca sativa. Plant Physiology, 83 (Supplement), 99.

Cook, R.J., Oliver, J. and Davies, D.D., 1979. Stress and protein turnover in Lemna minor. Plant Physiology, 64, 1109-1113.

Devitt, D., Stolzy, L.H. and Jarrell, W.M., 1984. Response of sorghum and wheat to different K^+/Na^+ ratios at varying osmotic potentials. Agronomy Journal, 76, 681-688.

Farquhar, G.D. and Sharkey, T.D., 1982. Stomatal conductance and photosynthesis. Annual Review of Plant Physiology, 33, 317-345.

Feigin, A., 1985. Fertilization management of crops irrigated with saline water. Plant and Soil, 89, 285-299.

Hauer, B. and Plaut, Z., 1984. Photosynthetic activity of sugarbeet cultivars of different salinity tolerance. In: Advances in Photosynthesis Research (Ed. by C. Sybesma), Vol. IV, pp. 423-425. Martinus Nijhoff/Dr. W. Junk Publishers, The Hague.

Hewitt, E.J., 1966. Sand and water culture methods used in the study of plant nutrition, 2nd edn. Commonwealth Agricultural Bureaux, Farnham Royal.

Hoffman, G.J. and Phene, C.J., 1971. Effects of constant salinity levels on water use efficiency of bean and cotton. Transactions of the American Society of Agricultural Engineering, 14, 1103-1106.

Humbler, G.D. and Hsiao, T.C., 1969. Specific requirement for potassium for light-activated opening of stomata in epidermis strips. Plant Physiology, 44, 230-234.

Kafkafi, U., 1984. Plant nutrition under saline conditions. In: Soil Salinity under Irrigation. Processes and Management. Ecological Studies 51 (Ed. by I. Shainberg & J. Shalhevet), pp. 319-331. Springer-Verlag, Berlin, Heidelberg, New York & Tokyo

Kingsbury, R.W., Epstein, E. and Pearcy, R.W., 1984. Physiological responses to salinity in selected lines of wheat. Plant Physiology, 74, 417-423.

Kirkby, E.a. and Mengel, K., 1967. Ionic balance in different tissues of the tomato plant in relation to nitrate, urea, or ammonium nutrition. Plant Physiology, 42, 6-14.

Kurvits, A. and Kirkby, E.a., 1980. The uptake of nutrients by sunflower (Helianthus annuus) growing in a continuous flowing culture system, supplied with nitrate or ammonium as nitrogen source. Zeitschrift fur Pflanzenernahrung und Bodenkunde, 143, 140-149.

Leidi, E.O., Silberbush, M. and Lips, S.H. Nitrogen source, pH, salinity and wheat growth. I. Mineral composition. (Submitted to New Phytologist).

Marschner, H., 1986. Mineral Nutrition of Higher Plants. Academic Press, London.

Moftah, A.E. and Michel, B.E., 1986. Effect of salinity on growth and photosynthesis of soybean cultivars differing in salt tolerance. Plant Physiology, 80 (Supplement), 123.

Paschke, K., 1979. Movement of stomata. In: Physiology of Movements (Ed. by W. Haupt and M.E. Feinleib), Encyclopedia of Plant Physiology (NS), Vol. 7, pp. 383-441. Springer-Verlag, Berlin.

Raven, J.A. and Smith, F.A., 1976. Nitrogen assimilation and transport in vascular land plants in relation to intracillular pH regulation. New Phytologist, 76, 301-312.

Rawson, H.M., 1986. Gas exchange and growth in wheat and barley grown in salt. Aust. Journal of Plant Physiology, 13, 475-489.

Reisenauer, w.M., 1978. Absorption and utilization of ammonium nitrogen by plants. In: Nitrogen in the Environment, Vol. 2 (Ed. by D.R. Nielsen and J.G. McDonald), pp. 157-170. Academic Press, New York.

Robinson, S.P., Downton, W.J.S. and Millhouse, J.A., 1983. Photosynthesis and ion content of leaves and isolated chloroplasts of salt-stressed spinach. Plant Physiology, 73, 238-242.

Shomer-Ilan, A., Samish, Y.B., Kipnis, T., Elmer, D. and Waisel, Y., 1979. Effects of salinity, N-nutrition and humidity on photosynthesis and protein metabolism of Chloris gayana Kinth. Plant and Soil, 53, 477-486.

Figure Captions

Fig. 1. Photosynthesis rate per (a) leaf area unit or (b) g chlorophyll and (c) chlorophyll content of wheat plants grown in hydroponics with different concentrations of NaCl, NH_4^+ or NO_3^- nitrogen, and different pH values of the nutrient solution. The bars represent LSD ($\underline{P}$ -0.05) for each NaCl concentration.

Fig. 2. The effect of NaCl concentration, N-source and pH of the nutrient solution on (a) transpiration and (b) stomatal conductance of wheat. Th bars represent LSD ($\underline{P}$ =0.050) for each NaCl concentration.

Fig. 3. The correlation between transpiration rate and stomatal conductance of wheat plants grown either in NH_4^+- or NO_3^--nitrogen, different NaCl concentrations and pH of the nutrient solution.

Fig. 4. The effect of pH and N-source on the relationships between stomatal conductance and K^+ concentration in leaves of wheat plants.

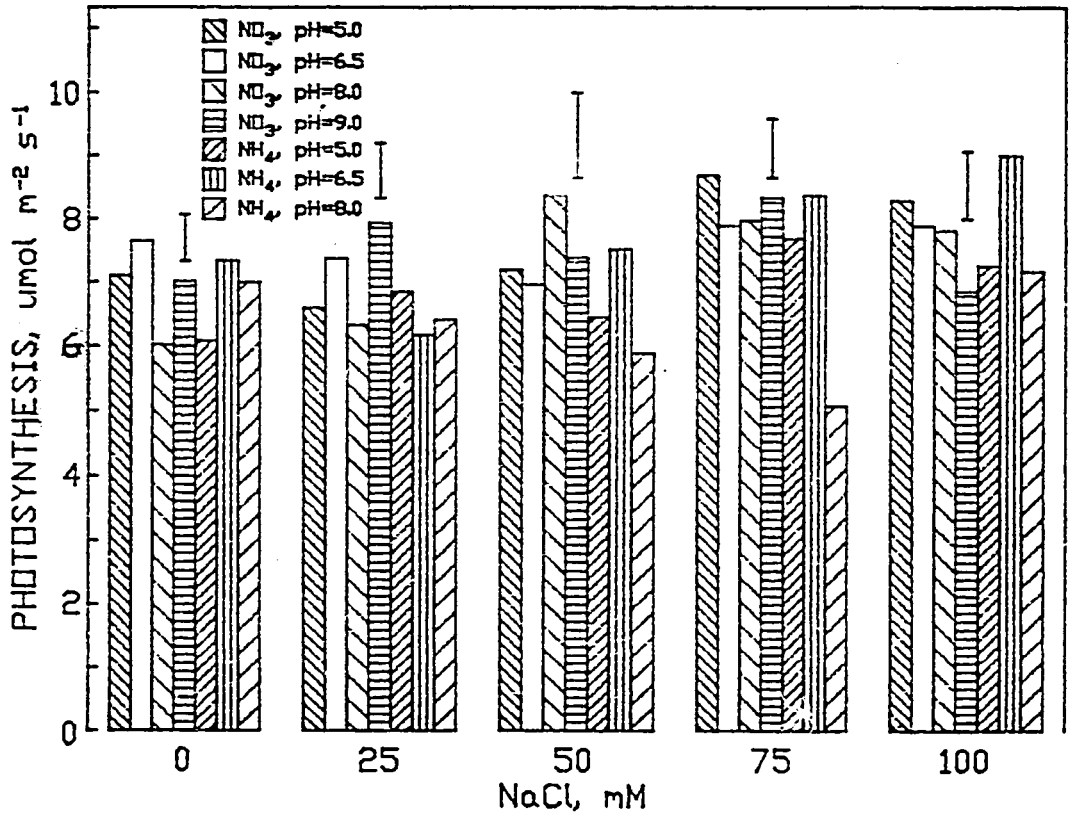

NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0
PHOTOSYNTHESIS, umol m-2 s-1
0
2
4
6
8
10
0
25
50
75
100
NaCl, mM

Fig. 1a.

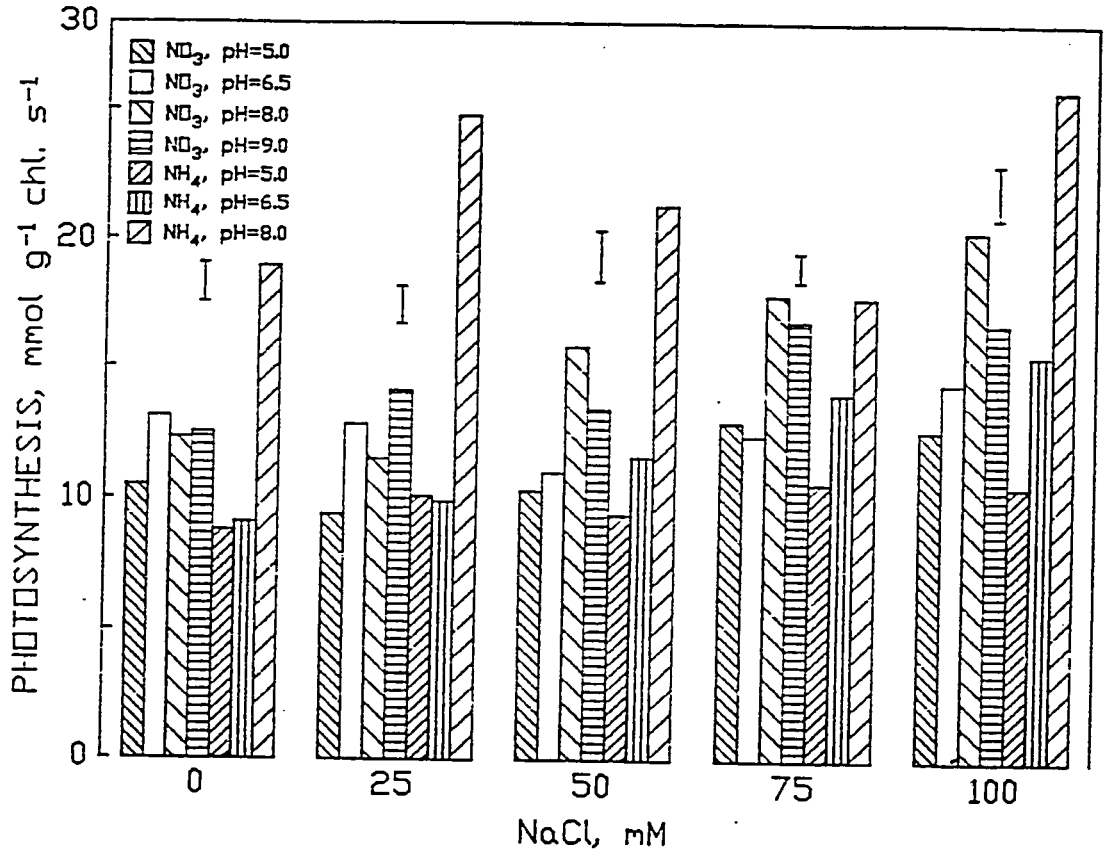

30
20
10
0
PHOTOSYNTHESIS, mmol g-1 chl. s-1
NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0
0
25
50
75
100
NaCl, mM

Fig. 1b.

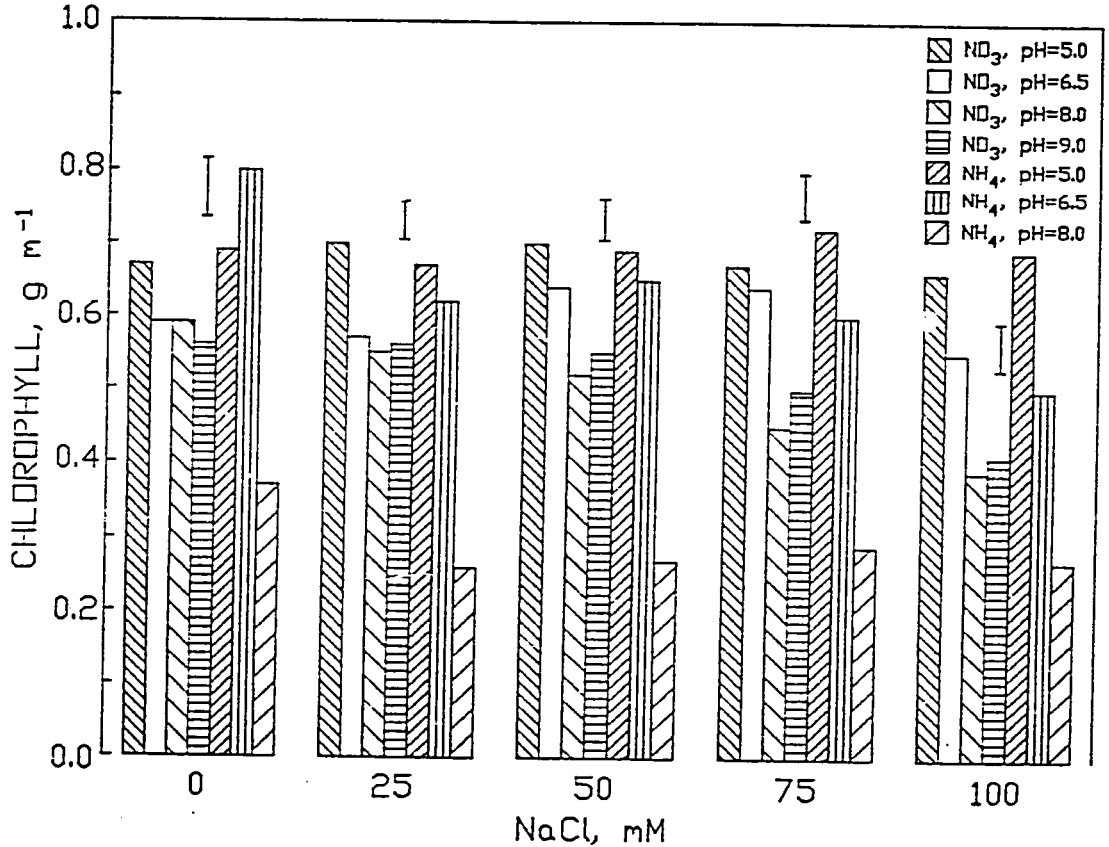

1.0
0.8
0.6
0.4
0.2
0.0
CHLOROPHYLL, g m-1
0
25
50
75
100
NaCl, mM
NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0

Fig. 1c.

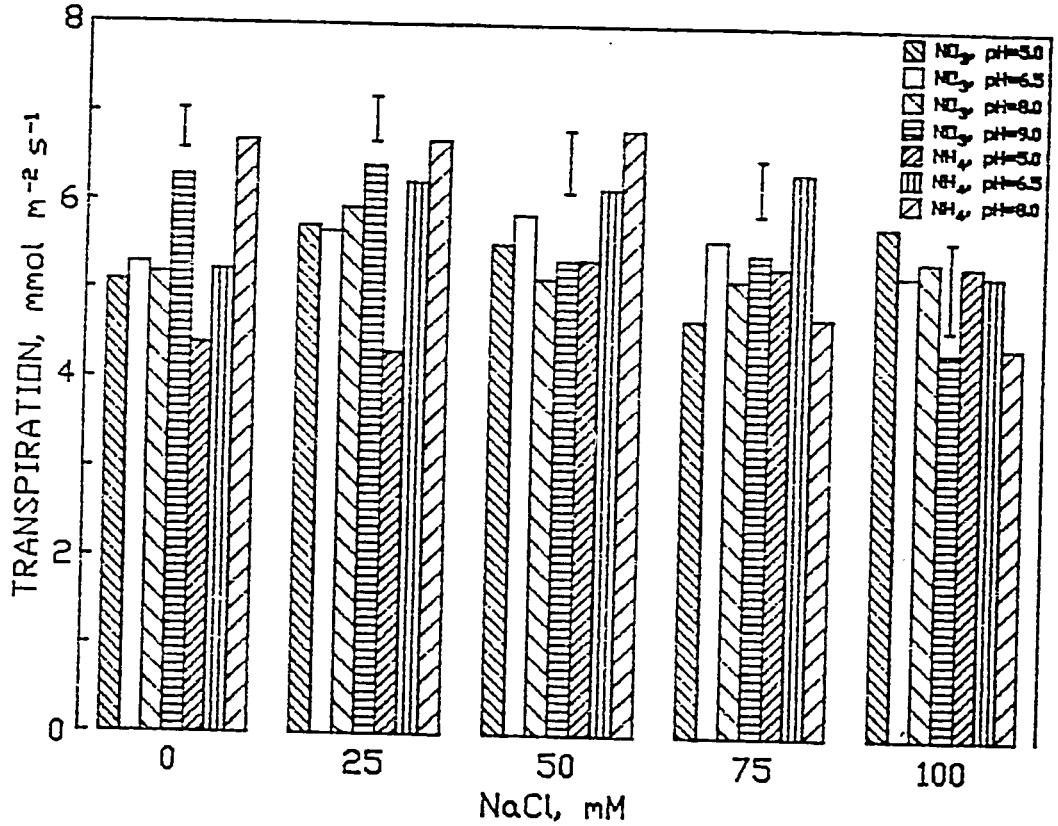

TRANSPIRATION, mmol m-2 s-1
0
2
4
6
8
0
25
50
75
100
NaCl, mM
NO3, pH=5.0
NO3, pH=6.5
NO3, pH=8.0
NO3, pH=9.0
NH4, pH=5.0
NH4, pH=6.5
NH4, pH=8.0

Fig. 2a.

Fig. 2b.

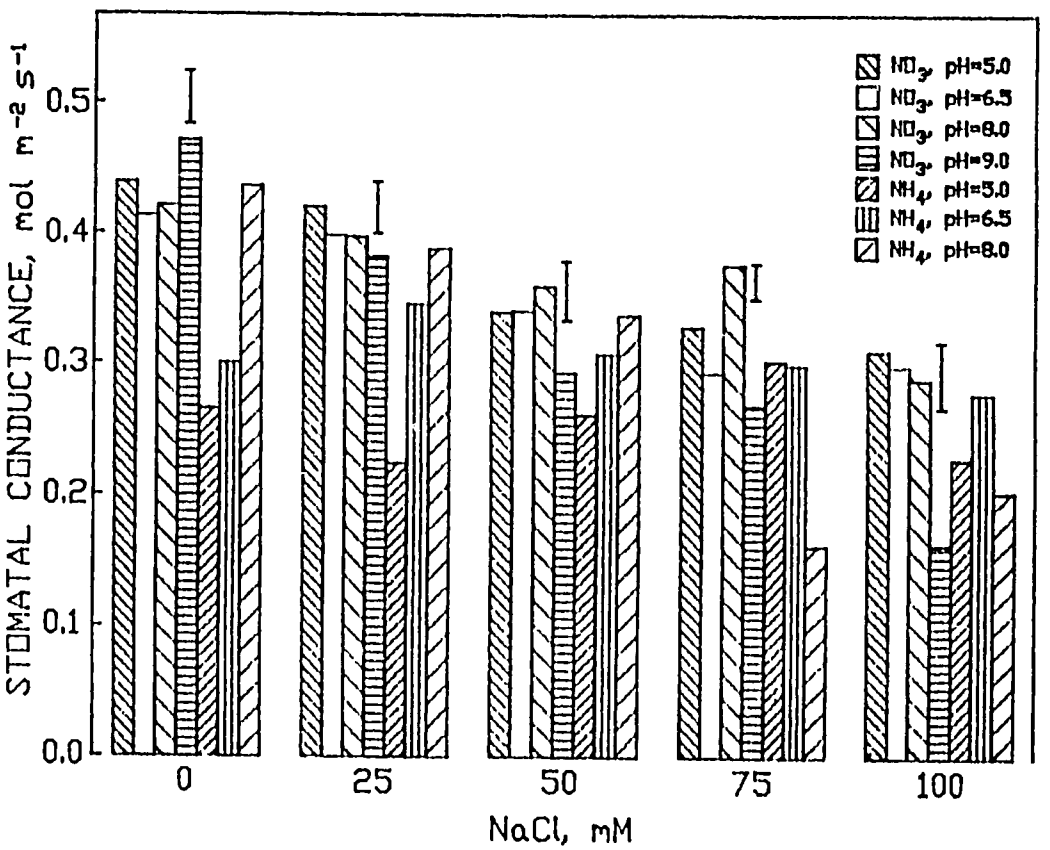
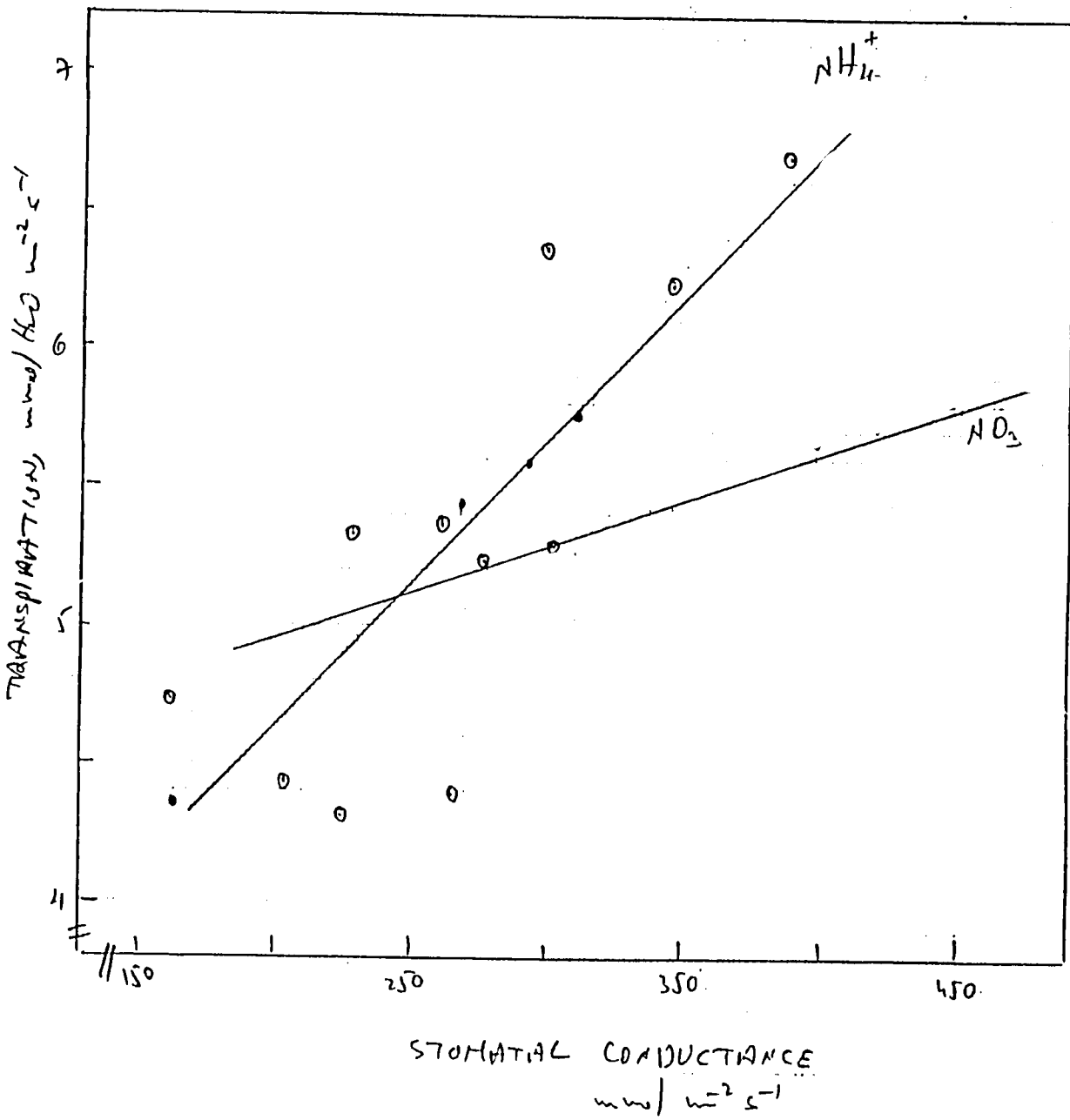

STOMATAL CONDUCTANCE, mol m^{-2} s^{-1}
0.0
0.1
0.2
0.3
0.4
0.5
0
25
50
75
100
NaCl, mM
NO_3, pH=5.0
NO_3, pH=6.5
NO_3, pH=8.0
NO_3, pH=9.0
NH_4, pH=5.0
NH_4, pH=6.5
NH_4, pH=8.0

Fig. 3.


NH_4^+
NO_3
TRANSPIRATION, mmol H_2O m^{-2} s^{-1}
7
6
5
4
150
250
350
450
STOMATAL CONDUCTANCE
mmol m^{-2} s^{-1}

NH_4^+: pH=6.5; r=0.67; y=100.49x+292.30
pH=8.0; r=0.84; y=404.75x+335.64

NO_3^-: pH=5-8; r=0.91; y=180.88x+149.89
pH=9.0; r=0.96; y=458.96x-187.99

SCK

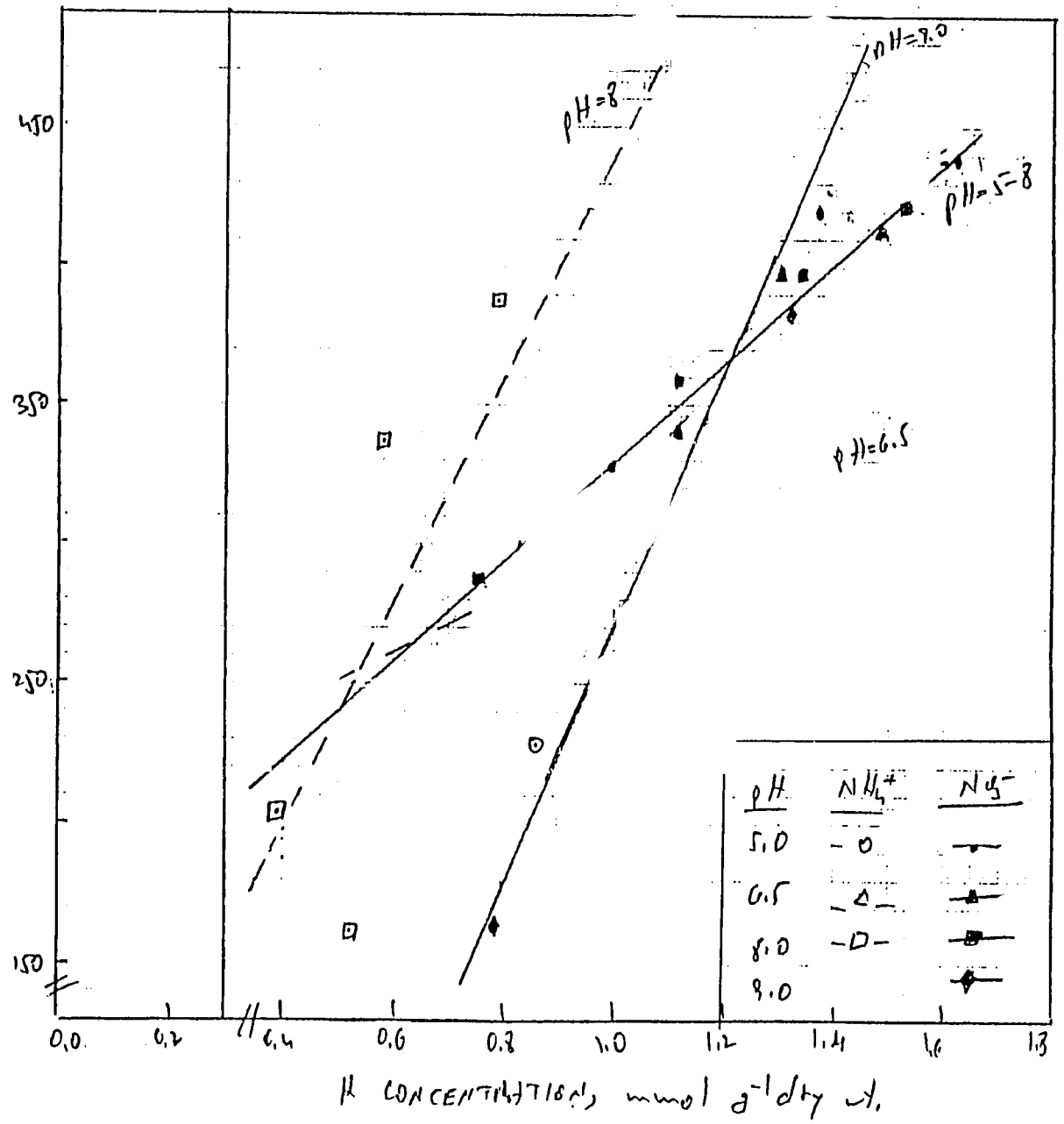


Table 1. Correlation coeficients of growth parameters of wheat plants grown in hydroponics with NO_3^- or NH_4^+, 0 or 50 mM NaCl, and different pH of the nutrient solution.

	SDW	RDW	RL	PhS	TR	SC	CHL	PCHL	N	K	Ca	Na
RDW	0.85a	-										
RL	0.83a	0.93a	-									
PS	ns	ns	ns	-								
TR	ns	ns	ns	ns	-							
SC	0.58a	0.76a	0.73a	ns	0.57a	-						
CHL	0.56a	ns	0.45b	ns	ns	ns	-					
PCHL	-0.63a	-0.41b	-0.50b	ns	ns	ns	-0.49b*	-				
N	0.42b	ns	ns	-0.51a	ns	ns	ns	ns	-			
K	0.90a	0.91a	0.90a	ns	ns	0.71a	0.62a	-0.67a	ns	-		
Ca	0.36c	0.47b	0.65a	ns	ns	ns	ns	ns	ns	0.50b	-	
Na	-0.82a	-0.69a	-0.63a	ns	ns	-0.58a	-0.49b	0.58a	-0.50b	-0.80a	ns	-
Cl	-0.80a	-0.68a	-0.64a	ns	ns	-0.58a	-0.59a	0.67a	-0.44b	-0.83a	ns	0.96a

SDW - Shoot Dry Weight
RDW - Root Dry Weight
RL - Root Length
PhS - Photosynthesis per Leaf Area
PCHL - Photosynthesis per g Chlorophyll
CHL - Chlorophyll
TR - Transpiration
SC - Stomatal Conductance

a,b,c,ns - significance of 0.001, 0.01, 0.05, not significant, respectively.

* - CHL and PCHL are actually self-correlated.

(2a) Effect of nitrogen source on growth response to salinity stress in maize and wheat (Lewis, Leidi and Lips).

The effect of ammonium and nitrate nutrition on salinity stressed maize and wheat grown hydroponically was assessed from growth rate and gas exchange experimentation. In both maize and wheat the ammonium grown plants showed a much greater sensitivity to salinity toxicity than did nitrate grown plants, the fresh and dry mass of the former being considerably lower than that of the latter when exposed to 60 - 80 mM salinity. Possible reasons for this effect are discussed. Shoot:root ratios indicated that shoot growth was retarded to a far greater extent than root growth in salinity stressed plants of both wheat and maize fed the two nitrogen sources.

Gas exchange studies showed no significant inhibition of photosynthetic rate in salinity stressed plants of either species fed nitrate or ammonium, except in severly wilted plants fed ammonium at the highest (80 mM) salinity concentration. The same was largely true for stomatal conductance, transpiration rate and transpiration ratio (water use efficiency).

In nitrate fed wheat, raising the calcium concentration from 2 mM to 12 mM in the presence of 60 mM salinity produced an 11% increase in growth. This effect is ascribed to improved nitrate uptake due to calcium protection of the nitrate transporter and was not evident in ammonium grown wheat.

Two major effects have been identified as the probable causes of salinity toxicity in various plants: the ionic toxicity effect and the osmotic effect. The ionic effects include interference with nitrogen uptake, dislocation of nitrogen assimilation and protein assembly, inteference with the transport of essential ions within the plant and a lowering of net photosynthetic rates in the affected plants. The osmotic effects are associated with lack of cell wall extension and cellular expansion leading to cessation of growth. A range of opinions exist as to which of these factors is chiefly operative in the manifestation of salinity toxicity in various plant species. Rawson (1986), for example, reports a salinity-induced decrease in photosynthetic rate in wheat and barley, while water use efficiency is only marginally affected. Downton (1977) also reports a decrease of photosynthetic rate in salinity-stressed grapevines with an accumulation of intermediates of the glycolytic pathway. Terry and Waldron (1986), however, observed no effect on the rate of photosynthesis in sugarbeet of salinity levels of up to 250 mM in the feeding medium, the toxicity effects being brought about by salinity-induced changes in leaf water status which could be almost completely offset by increases in relative humidity. Huffaker and Rains (1986) report an increased activity of the nitrate transporter by the addition of calcium to salinity-stressed barley,

increasing the rate of nitrate assimilation and seedling growth in these plants. Helel and Mengel (1979) report an improvement of growth and nitrogen utilization in young, salinized barley plants by the addition of potassium to the saline nutrient medium. Termaat and Munns (1986) have shown that both osmotic and ionic effects are operative in salinity toxicity induction in barley, wheat and clover, the ionic effects being ascribed to a possibile reduction in the rate of transport to the shoot of an essential nutrient.

In the work to be described here further factors which could be involved in the response of plants to salinity stress have been investigated: the effect of the form in which nitrogen is fed to the plant (ammonium or nitrate) and the photosynthetic pathway (C3 or C4) which the plant possesses. These effects were quantified by the measurement of growth rate, moisture content, root:shoot ratio, photosynthetic rate, transpiration rate, stomatal conductance and transpiration ratio (water use efficiency) in the expeimental plants.

MATERIALS AND METHODS

Triticum aestivum L. var. Barkay and Zea mays L. var. Hassen were grown to 31 d and 21 d, respectively in hydroponic culture, after which the plants were harvested.

Growth Conditions. The maize plants were raised in the open during July and August under conditions suitable for plants possessing the C4 pathway. Midday irradiance was c. 2500 uE m^{-2} s^{-1}, midday temperatures fluctuated between 28 and 35°C and night temperatures did not fall below 20°C. Daytime relative humidity varied between 20 and 35%. The wheat plants were raised in a fibreglass-roofed greenhouse during September and October under conditions more suitable for plants possessing the C3 photosynthetic pathway. Midday temperatures in the greenhouse fluctuated between 25 and 30°C with night temperatures between 7 and 14°C. Daytime relative humidities were between 25 and 35%, but night-time humidities rose on occasions to 85%. Midday irradiance on the usually cloudless days was measured at betwen 700 and 750 uE m^{-2} s^{-1}.

Experimental Detail. In the maize experiments, eight plants were grown in each of sixteen 20 l plastic containers with holes drilled in the lids to accommodate them. The plans were grown to 21 days on well aerated Long Ashton growth media modified to contain nitrate-only or ammonium-only as the 4 mM nitrogen source (Hewitt, 1966), the pH of the solutions being

maintained at between 7.0 and 7.9. Two containers of eight plants each served as the non-saline control for the nitrate fed plants and a further two for the ammonium fed plants. The other containers were divided into 20 mM NaCl, 50 mM NaCl and 80 mM NaCl treatments (2 containers each) for ammonium fed plants and nitrate fed plants. The plants were harested in pairs after 21 days, divided into root and shoot, and the fresh and dry weight of each pair detemined. In the wheat experiments non-saline controls were as for the maize expeiments but only one salinity level, 60 mM NaCl, was used. This is the approximate concentration of salinity in the Negev aquifer, where the major solute is NaCl. Previous experimentation had shown this salinity level to be satisfactory for the production of stress symptoms in wheat without killing the plants. The remaining containers were divided into 2 mM, 6 mM and 12 mM Ca treatments (2 containers each) for salinity stressed nitrate fed and ammonium fed plants. The plants were harvested after 31 days and treated as in the maize experiments. In all the above experiments NaCl was added to the nutrient solutions only after the plants were 7 days old and then only in 20 mM per day increments.

Gas exchange analysis

Net photosynthetic rate (Pn) and transpirational water loss (Tr) were determined by the use of a Parkinson's leaf chamber linked to an ADC infra-red gas analyzer (Analytical Development Corporation, Hoddesdon, England). Determinations were made on five separate plants belonging to each treatment and the results for each treatment averaged. For maize plants, gas exchange determinations were made an hour before midday at an irradiance of 2500 uE m^{-2} s^{-1}, a temperature of 35°C and an ambient relative humidity of 30%. For wheat plants, these determinations were made at an irradiance of 700 uE m^{-2} s^{-1}, a temperature of 28°C and an ambient relative humidity of 35%. Stomatal conductivity (Gs) was calculated from these figures using Parkinson's formulae (ADC LCA instruction manual, 1986), and transpiration ratio (TR) was calculated by dividing Tr by Pn. Gas exchange determinations were made on clear days one or two days before the date of harvest.

RESULTS

The respective growth response of nitrate and ammonium fed maize plants to salinity stress can be observed in the data recorded in Table 1. From these data it is obvious that nitrate fed plants are far more salt-tolerant than their ammonium fed counterparts under the expeimental conditions. Whereas nitrate fed plants showed no reduction in dry mass and only a slight reduction in fresh mass up to the 50 mM salinity level, the effect of salinity on the fresh and dry mass of ammonium fed plants even at a concentration of 20 mM was very marked and became increasingly so with

increasing salinity. While all the nitrate fed plants were still growing vigoously at the 80 mM salinity level, many of the ammonium fed plants were showing signs of severe wilt and some were actually dying. The contrast of the salinity response of the plants fed the two nitrogen sources is amplified by the fact that under non-saline conditions the ammonium-fed plants were perceptably larger than the nitrate fed plants, a feature already noted by Murphy (1985).

An inspection of the shoot:root ratios recorded in Table 1 shows that in plants fed both nitrogen sources the salinity effect on growth was more noticeable in the shoots than in the roots. A remarkable feature of the non-salinity stressed plants in this expeiment was that the fresh weight shoot:root ratios in the ammonium fed plants is smaller than those of the nitrate fed plants. Thus the retarding effect of ammonium nutrition on root growth observed in C3 plants such as barley and wheat (Lewis & Chadwick, 1984; Lewis, Fulton & Von Zelewski, 1986) was not apparent in this C4 plant. There was also a slight decrease in the moisture content of both ammonium and nitrate fed plants with increasing salinity.

Net photosynthetic rate showed no significant response to salinity stress except in the case of the severly wilted ammonium fed maize plants exposed to 80 mM (Table 2). In this case it is doubtful whether reduced photosynthesis was due to the ionic effect of the salinity of the nutrient solution, as water stress had apparently already caused plant collapse and a considerable reduction in stomatal conductance. Stomatal conductance showed a slight decline with increasing salinity, in spite of which transpiration rate showed some increase (Table 2). The exceptions to this were the 80 mM salinity stressed ammonium fed plants which showed severe retardation of stomatal conductance and transpiration rate. Transpiration ratio showed an increase with salinity concentration (i.e., a decrease in water use efficiency) in both ammonium and nitrate fed plants, especially in the case of the 80 mM salinity stressed ammonium fed plants.

In the expeimentation with wheat plants only one salinity level was used (60 mM NaCl). The calcium level was varied between 2 mM (approximately the normal level found in Long Ashton nutrient solutions) and 12 mM in order to observe whether the beneficial effect of Ca on the growth of salinity stressed nitrate grown barley plants (Huffaker & Rains, 1986) could also be

TABLE 1 Response of plant size, shoot:root ratio and moisture content of nitrate and ammonium fed maize plants to different salinity concentrations. Maize plants were harvested in pairs and the average combined mass of each pair ± standard deviation from the mean is shown.

NaCl conc. (mM)	Total plant mass Fresh mass (g)	Total plant mass Dry mass (g)	Shoot mass Fresh mass (g)	Shoot mass Dry mass (g)	Root mass Fresh mass (g)	Root mass Dry mass (g)	Shoot/root ratio Fresh	Shoot/root ratio Dry	Moisture content: total plant %	Moisture content: shoot %	Moisture content: root %
NITRATE FED PLANTS (4mM N)											
0	58.55±4.38	4.01± 0.28	36.68±2.86	2.98±0.15	21.88±1.66	1.04±0.13	1.67	2.87	93.2	91.9	95.2
30	56.55±5.94	4.19± 0.37	34.16±4.20	2.97±0.36	22.39±2.30	1.22±0.12	1.53	2.43	92.6	91.3	94.6
50	51.38±5.73	3.94± 0.38	28.47±5.15	2.74±0.49	22.92±3.25	1. 2±0.11	1.24	2.28	92.3	90.4	94.8
80	39.66±3.60	3.31± 0.30	21.71±0.32	2.26±0.84	17.95±1.21	1.08±0.03	1.21	2.09	91.7	89.6	94.1
AMMONIUM FED PLANTS (4mM N)											
0	73.35±8.33	4.74± 0.49	43.08±2.64	3.53±0.26	30. 2±3.37	1.21±0.18	1.43	2.92	93.5	91.8	96.1
30	50.04±5.30	3.26± 0.27	27.67±1.79	2. 3±0.19	22.37±1.95	.96±0.18	1.24	2.41	93.5	91.7	95.7
50	41.89±1.31	3.08± 0.10	22. 6±3.13	2.23±0.22	19. 3±2.25	.85±0.08	1.17	2.26	92.6	90.1	95.6
80	25.66±3.60	2.18± 0.51	14.06±2.48	1.51±0.27	11.65±1.28	.67±0.11	1.21	2.25	91.5	89.3	94.2

TABLE II Response of net photosynthetic rate, transpiration rate, stomatal conductance and transpiration ratio (water utilization efficiency) of maize plants to different salinity concentrations. Measurements were made at an irradiance of 2500µE $m^{-2}s^{-1}$, a temperature of 35°C and an ambient relative humidity of 30%. (No readings of plants growing in 30mM saline solutions were made).

NaCl conc. (mM)	Net Photosynthetic rate (µmol $m^{-2}s^{-1}$)	Transpiration rate (µmol $m^{-2}s^{-1}$)	Stomatal Conductance (µmol $m^{-2}s^{-1}$)	Transpiration ratio (molH_2O/mlCO_2)
NITRATE FED PLANTS				
0	25.95± 1.90	8.04±0.52	376± 32	309
50	27.51± 3.21	9.17±0.19	337± 39	333
80	24.64± 1.81	9.44±0.43	302± 39	383
AMMONIUM FED PLANTS				
0	28.11± 3.75	9.42±0.49	420± 83	335
50	28.39± 0.83	10.02±0.46	373± 45	353
80	15.62±10.45	7.24±2.58	190±119	464

found in salinity stressed nitrate and ammonium grown wheat. These results are reported in Tables 3 and 4. It was not possible to investigate this calcium effect in salinity stressed maize plants because of the early end of the growing season.

The fresh and dry mass data recorded in Table 3 show that under non-saline conditions, nitrate grown wheat plants were larger than ammonium grown plants, a feature contrasting with the results reported above for maize plants. Like maize, however, the ammonium grown wheat plants showed a greater sensitivity to salt stress than did the nitrate grown plants (42% vs 33% fresh mass growth retardation). The shoot:root ratios in both ammonium and nitrate fed plants dropped perceptably in response to salinity, indicating that shoot growth was more severely affected by salinity than root growth.

In ammonium fed plants the level of calcium in the feeding media produced no significant effect on the growth rate of the salinity stressed plants (Table 3). In nitrate fed plants provided with higher concentrations of calcium in their feeding media showed decreased sensitivity to salinity, the fresh mass of saline stressed plants growing in 12 mM Ca being 11% greater than those growing in 2mM Ca. These data serve to support Huffaker & Rains's (1986) evidence that calcium serves as a protectant for the nitrate transporter in the presence of salinity, leading to greater productivity in salinity stressed plants.

The gas exchange data shown in Table 4 do not indicate any perceptable effect of salinity or calcium concentration on the rate of net photosynthesis in ammonium or nitrate fed wheat plants. There does not appear to be any statistically significant effect of calcium or salinity level on stomatal conductance, transpiration rate or transpiration ratio in wheat plants under the experimental conditions.

DISCUSSION

The most significant findings of the experimentation reported above are that in both hydroponically grown maize and wheat, ammonium fed plants show a considerably greater sensitivity to salinity than do nitrate fed plants, an effect that is likely to be enhanced under field conditions. The cause of

TABLE III Response of plant size, shoot:root ratio and moisture content of wheat plants to different concentrations and combinations of Ca and NaCl. Wheat plants were harvested in pairs and the averaged combined mass of each pair ± standard deviation from the mean is shown.

Ca conc. (mM)	NaCl conc. (mM)	Total plant mass Fresh mass (g)	Total plant mass Dry mass (g)	Shoot mass Fresh mass (g)	Shoot mass Dry mass (g)	Root mass Fresh mass (g)	Root mass Dry mass (g)	Shoot/root ratio Fresh mass	Shoot/root ratio Dry mass	Moisture content: total plant %	Moisture content: shoot %	Moisture content: root %
						NITRATE FED PLANTS (4mM N)						
2	0	6.73±0.60	0.64±0.06	4.13±0.39	0.47±0.04	2.60±0.26	0.16±0.03	1.59	2.94	90.5	88.6	93.8
2	60	4.45±0.60	0.46±0.06	2.34±0.32	0.33±0.05	2.10±0.28	0.13±0.01	1.12	2.59	89.7	85.9	93.8
6	60	4.75±0.31	0.51±0.03	2.47±0.19	0.37±0.03	2.27±0.14	0.14±0.01	1.09	2.63	89.3	85.1	93.8
12	60	5.05±0.61	0.56±0.06	2.57±0.33	0.4 ±0.05	2.47±0.30	0.17±0.02	1.04	2.37	88.9	84.4	93.1
						AMMONIUM FED PLANTS (4mM N)						
2	0	5.78±0.84	0.57±0.09	3.57±0.55	0.45±0.08	2.21±0.31	0.13±0.02	1.62	3.75	90.1	87.4	94.3
2	60	3.37±0.37	0.40±0.04	1.94±0.23	0.31±0.03	1.42±0.14	0.09±0.01	1.36	3.44	88.1	84.0	93.7
6	60	3.79±0.68	0.46±0.08	2.18±0.41	0.35±0.06	1.61±0.27	0.12±0.02	1.35	2.92	87.9	83.9	92.5
12	60	3.29±0.58	0.42±0.07	1.94±0.32	0.33±0.05	1.34±0.26	0.09±0.02	1.46	3.65	87.2	82.9	93.3

TABLE IV Response of net photosynthetic rate, transpiration rate, stomatal conductance and transpiration ratio (water utilization efficiency) of wheat plants to different concentrations and combinations of Ca and NaCl. Measurements were made at an irradiance of 700 uE m^{-2} s^{-1}, a temperature of 26 - 28°C and an ambient relative humidity of 35%.

Ca conc. (mM)	NaCl conc. (mM)	Net photosynthetic rate (umol $m^{-2}s^{-1}$)	Transpiration rate (umol $m^{-2}s^{-1}$)	Stomatal conductance (umol $m^{-2}s^{-1}$)	Transpiration ratio molH_2O/mol CO_2
			NITRATE FED PLANTS		
2	0	8.51±0.50	5.81±0.46	280±29.3	683
2	60	8.32±1.73	5.46±1.11	217±64.4	656
6	60	9.29±0.92	6.97±0.49	285±16.1	750
12	60	8.71±1.10	7.25±0.61	298±35.6	832
			AMMONIUM FED PLANTS		
2	0	8.75±1.26	7.49±0.81	330±48.8	856
2	60	7.91±1.24	6.32±1.53	226±73.1	799
6	60	8.28±0.72	6.38±0.56	268±27.7	770
12	60	7.59±0.53	6.04±0.64	237±39.2	796

this effect is not immediately apparent but could possibly be ascribed to one of the following factors:

a) In wheat and maize, nitrate assimilation takes place primarily in the shoot and ammonium assimilation in the root. As the root is in immediate contact with the saline containing nutrient medium it is possible that nitrogen assimilation in ammonium fed plants is dislocated by ionic effects which would not interfere with leaf-based nitrogen assimilation.

b) In nitrate fed plants a malate-nitrate shuttle is operative between shoot and root (Ben-Zioni, Vaadia & Lips, 1971). The absence of ths shuttle in ammonium fed plants cold bring about ion translocatory problems which are acerbated by the uptake of NaCl.

c) The assimilation of the bulk of nutrient nitrogen in the roots of ammonium fed plants necessitates the diversion of large quantities of carbon to the root to provide the carbon skeletons of the products of the GS-GOGAT pathway. It is possible that this carbon metabolism is inhibited by the presence of high concentrations of sodium and chloride ions in the root.

The results of this expeimentation also indicate that in maize and wheat inhibition of photosynthesis is not one of the manifestations of salinity toxicity except as a secondary effect in already heavily damaged plants. Suppression of nitrate uptake or assimilation which can be partly releived by the presence of high concentrations of calcium does appear to be a contributory factor to salinity toxicity in wheat. Our own conclusions are that osmotic factors resulting in curtailment of cell growth and eventual leaf wilt were the prime cause of salinity toxicity in the experimental plants, but further research on the water status of salinity stressed wheat and maize plants under the above conditions is necessary to confirm this.

(2b) A continuous two variable design using the line-source concept. (Magnusson, Ben-Asher and DeMalach)

Abstract

Multivariable experiments involving different water salinities are usually conducted using drip irrigation. Preparing the irrigation system to apply these different treatments requires a considerable investment of labor and materials. This study was conducted to examine an alternative irrigation system that was relatively simple and inexpensive, yet produced gradients of two variables. A variation of the line-source irrigation system was tested using water salinity and N levels as variables. The middle line of a triple line-source irrigated with saline water (7.0 dS m^{-1}) while the two parallel outside lines irrigated with nonsaline water (1.0 dS m^{-1}). A second triple line-source using only nonsaline water was superimposed perpendicularly on the first set. Ammonium nitrate was injected into the middle line. This layout produced linear gradients for both variables (r^2=0.99) perpendicular to their source and provided every possible combination of saline water concentrations (7.0 to 1.0 dS m^{-1}) and N levels (8.1 to 0.0 mmol L^{-1}). It proved to be a simple yet highly informative system.

Introduction

Continuous variable experiments have been used and modified since Fox (1973) first introduced the concept. The design has been a useful research tool for observing crop response surfaces (Bauder et al., 1975). Hanks et al. (1976) further popularized it by developing the line-source sprinkler system. Lauer (1983) extended this concept by constructing a triple line-source system, which supplied uniform water application while producing a N gradient by injecting N into the middle line. The line-source has been basically limited to a single variable. In this study it was successfully used with two variables while maintaining a uniform water application.

Materials and Methods

Two triple line-source systems were used to study the interactive effects of different irrigation water salinities and ammonium nitrate concentrations on corn (Zea mays L.) growth and development (Fig. 1). The first set of three parallel lines (saline set) provided the salinity gradient (7.0 to 1.0 dS m^{-1}). Each line supplied equal water amounts. The middle line was irrigated with water from a local well (7.0 dS m^{-1}) while the two outside lines were irrigated with nonsaline water (1.0 dS m^{-1}).

The second set of three lines supplied only nonsaline water. Ammonium nitrate was injected into the middle line creating a sprinkler-supplied N gradient ranging from 8.1 to 0.0 mmol L^{-1} (640 to 0 kg N ha^{-1}, based on 564 mm of total water applied). This set of irrigation lines was superimposed perpendicularly to the saline set, thus creating four replications of the various combinations arranged radially around the intersection of the N and saline water source lines. As in the saline set, each of the three lines supplied equal amounts of water.

Each line was 42 m long and 12 m from its parallel neighbor. Naan[1] 323/92 sprinklers (Naan Mechanical Works, Israel) with 3.5 mm range by 2.5 mm spreader nozzles were spaced 6 m apart along each line. They had a wetting radius of 12 m and were mounted on risers, initially 0.8 m high, which were raised twice during the year to accommodate increasing plant height. Pressure regulators were used with each sprinkler to maintain a uniform pressure of 0.3 MPa. The plots were irrigated twice a week. The saline set irrigated first, immediately followed by the N set. For most irrigations only a small amount of water necessary for N distribution was applied through the N set. This pattern allowed the salts to be rinsed from the leaves and yet maintained a high salinity gradient.

Samples of water applied to the plot were collected during each irrigation using 10 cm diameter funnels attached to collection bottles. Figure 1 shows the location of these bottles in the experimental plot. In addition to irrigation amounts, electrical conductivities (ECi), and N concentrations were measured in each sample.

Results and Discussion

The average total amount of water applied between July 29 and September 3 was 202 mm. The Christiansen uniformity coefficient for this period was 0.95.

---

1. Trade names are given only for the benefit of the reader and do not imply endorsement or preferential treatment by the authors or Ben-Gurion University of the Negev.

ECi decreased linearly away from the saline line (Fig. 2). Nitrogen level slightly affected the ECi parallel to the saline line (Fig. 3). Every unit increase in N concentration (Mmol L^{-1}) resulted in a 0.08 dS m^{-1} increase in ECi. This should be taken into consideration when irrigating with saline water.

By adjusting the amount of water irrigated through the N set we were able to vary the salinity gradient. Normally, for each irrigation, about 90% of the water was applied through the saline set and 10% through the N set. However, during one irrigaiton, the amount of water applied through the saline set was reduced to 50%. As a result, a reduction of the salinity gradient was achieved yet linearity was maintained. The highest ECi of the samples taken from this irrigation was 4.3 dS m^{-1} compared to the normal high of 7.0 dS m^{-1} (Fig. 3), thus demonstrating that the system could be used to manipulate the salinity gradient.

The nitrogen set produced similar results. Figure 4 shows that N concentration of the irrigation water at various distances away from the N source line. Parallel to the source line, N was constant. The N gradient was controlled by adjusting the amount of N injected into the middle line.

The system was easy to install, virtually trouble free, and required little maintenance. The lack of randomization, which creates an increasing bias moving toward the center of the plot, and small sampling area are limitations which must be considered for each experiment.

References

Bauder, J.W., R.J. Hanks, and D.W. James. 1975. Crop production function determinations as influenced by irrigation and nitrogen fertilization using a continuous variable design. Soil Sci. Soc. Am. Proc. 39: 1187-1192.

Fox, R.L. 1973. Agronomic investigations using continuous function experimental designs-nitrogen fertilization of sweet corn. Agron. J. 65: 454-456.

Banks, R.J., J. Keller, V.P. Rasmussen, and G.D. Wilson. 1976. Line source sprinkler for continuous variable irrigaiton-crop production studies. Soil Sci. Soc. Am. J. 40: 426-429.

Lauer, D.A. 1983. Line-source sprinkler system for experimentation with sprinkler-applied nitrogen fertilizers. Soil Sci. Soc. Am. J. 47: 124-128.

List of Figures

Fig. 1: Experimental plot layout of the irrigation system designed to produce salinity and N gradients.

Fig. 2: Changes in irrigaiton water elecrical conductivity (ECi) as a function of distance from the saline line. Taken at 1.5 m from the N line.

Fig. 3: Changes in irrigation water electrical conductivity (ECi) as a function of distance from the N line. Taken at 1.5 m from the saline line.

Fig. 4: Changes in N concentration in the irrigation water as a function of distance from the N line. Taken at 1.5 m from the saline line. (Note; 8.1 mmol L^{-1} is equivalent to 640 kg ha^{-1}, based on 564 mm of total water applied.)

Figure 1. Experimental plot layout of the irrigation system designed to produce salinity and N gradients.

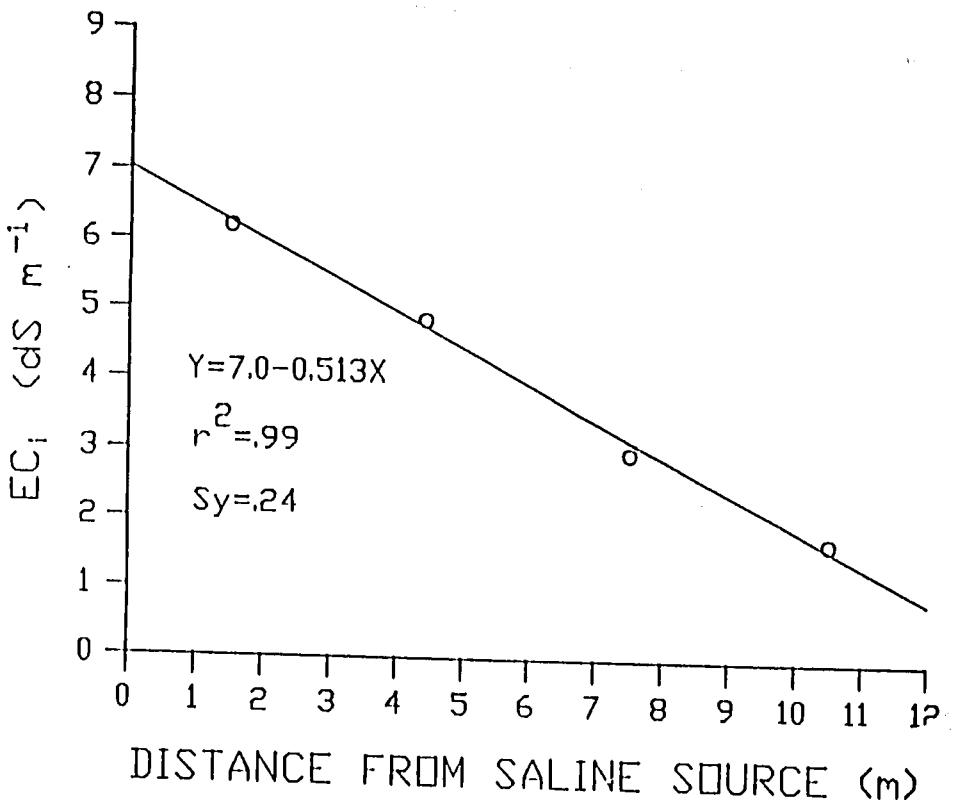


Figure 2. Changes in irrigation water electrical conductivity (ECi) as a function of distance from the saline line. Taken at 1.5 m from the N line.

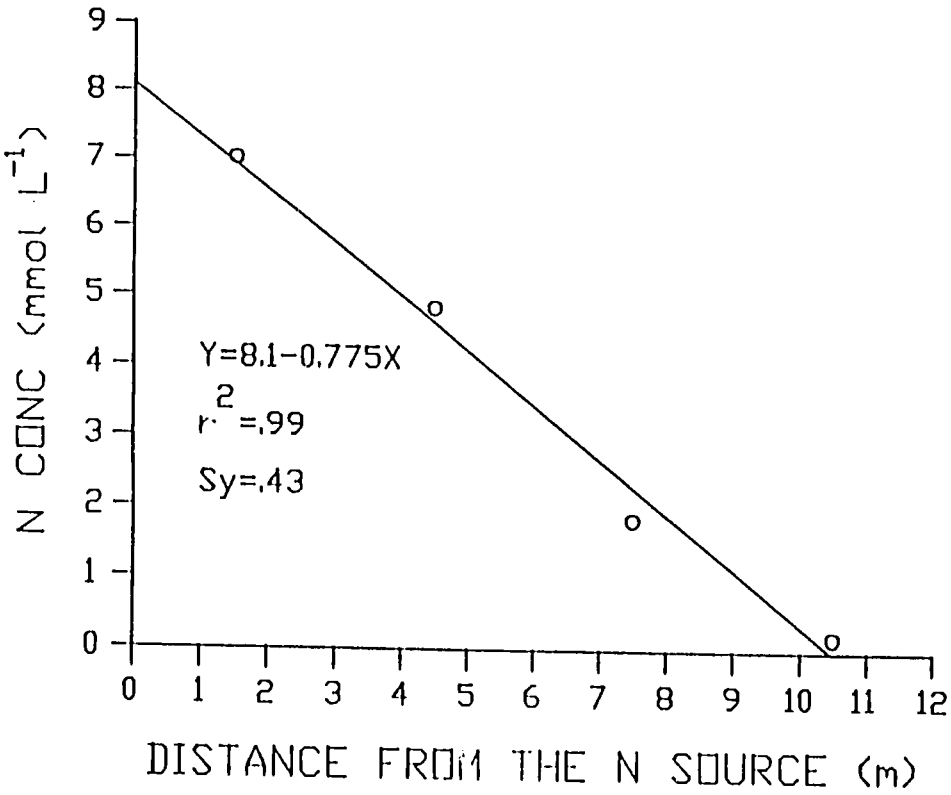


Fig 3. Changes in irrigation water electrical conductivity (ECi) as a function of distance from the N line. Taken at 1.5 m from the saline line.

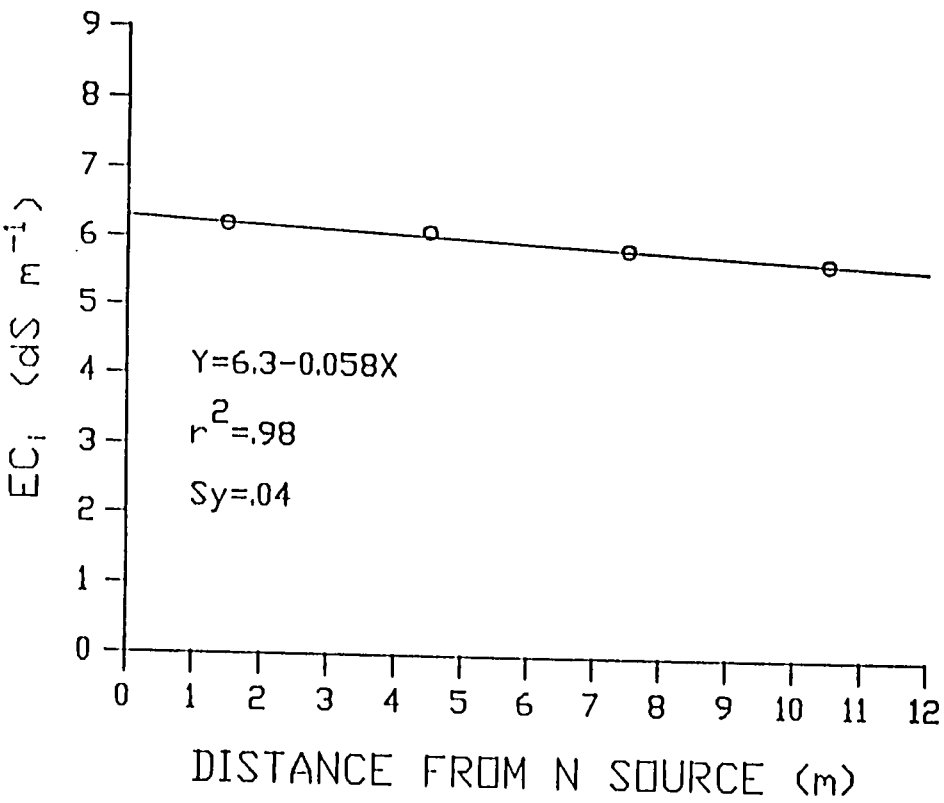
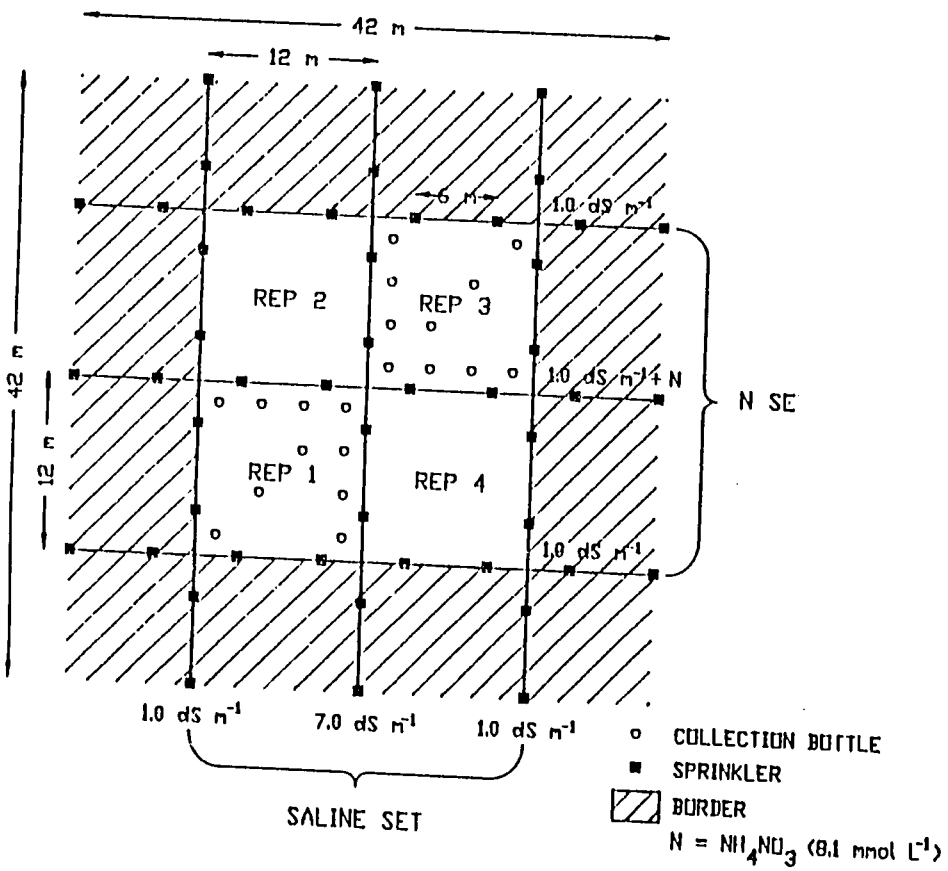


Figure 4. Changes in N concentration in the irrigation water as a function of distance from the N line. Taken at 1.5 m from the saline line. (Note: 8.1 mmol L^{-1} is equivalent to 640 kg ha^{-1} based on 564 mm of total water applied).



(2c) Salinity fertility inteaction under field conditions.
1987 maise experiment.
(Magnusson, Ben-Asher, DeMalach, and Lips)

Introduction

Salinity is one of the greatest limitations to crop production in many arid regions of the world today. Fresh water for irrigation is often limited in these areas while saline water is often present. Thus making the option of utilizing the saline water for growing crops an attractive solution. Crops vary in their ability to grow in saline water and each seems to have a "threshold" value where yields begin to suffer as a result of increasing the water salinity. If the threshold could be shifted slightly it would open the door for crops previously restricted from certain areas because of salinity. This was one of the objectives of our experiment conducted with corn (Zea Mays L.) We examined the influence fertilizer (N) has on crops grown under various salt water concentrations.

The second objective was to test a new experimental irrigaiton design. The design was constructed to provide a large spectrum of information from a small area regarding the interaction of two variables.

Materials and Methods

Irrigation System and Operation

Two triple line source systems were installed at the Ramat Negev Experimental Station to study the interactive effects of saline irrigation water concencentrations (7.0 to 1.0 dS m^{-1}) and ammonium nitrate amounts (8.1 o 0.0 mM) on corn (Zea mays L.) growth and development (Figure 1). The first set of three parallel lines (saline set) provided the salinity gradient. Each line supplied equal water amounts. The middle line was irrigated with water from a local well (7.0 dS m^{-1}) while the two outside lines were irrigated with fresh water (1.0 dS m^{-1}) from the National Water Carrier (NWC).

The second set (N set) used only fresh water and ammonium nitrate was injected into the middle line creating the N gradient. This set was superimposed perpendicularly to the saline set, thus creating four repetitions of the various combinations. As in the saline set, each of the three lines supplied equal water amounts.

Each line was 42 m long and 12 m from its parallel neighbor. Naan[3] 323/92 sprinklers with 3.5 mm range by 2.5 m spreader nozzles were spaced 6 m apart along each line. They had a wetted radius of 12 m and were mounted on risers 0.8 m high which were raised twice during the year.

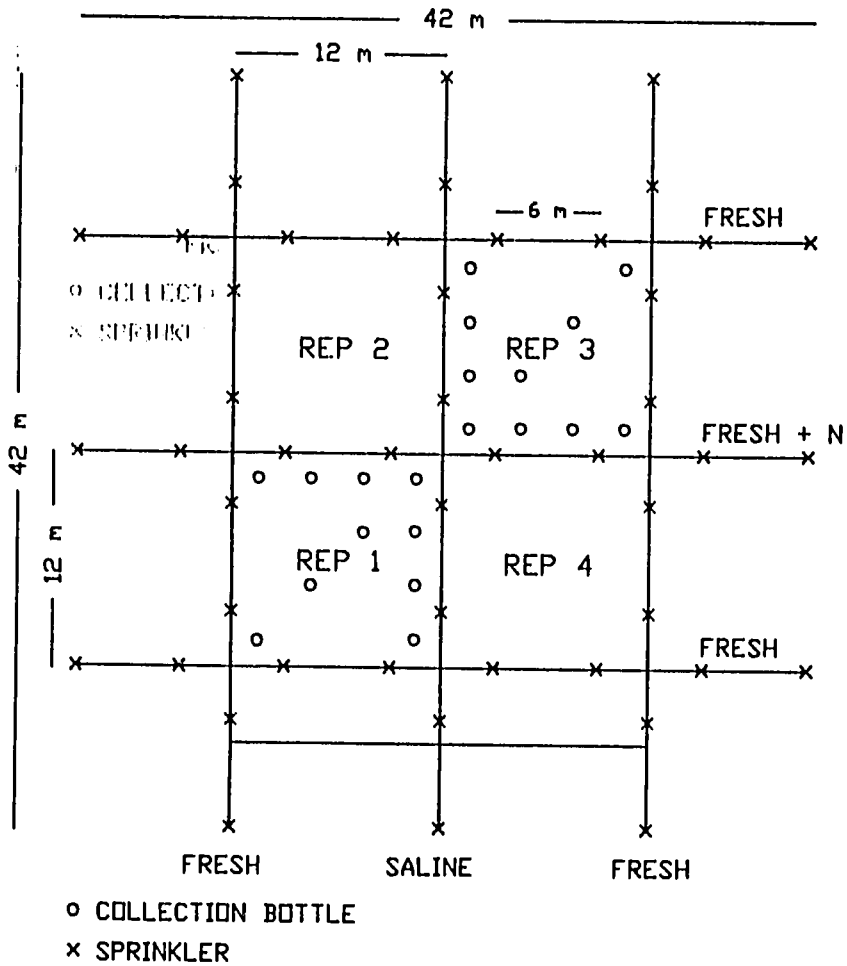


Figure 1: Expeimental plot layout of the irrigation system designed to produce saline and N gradients. FRESH = fresh water (1.0 dS m^{-1}); SALINE = saline water (7.0 dS m^{-1}); FRESH + N = fresh water + NH_4NO_3 (8.1 mM).

Pressure regulators were used with every sprinkler to maintain a uniform pressure of 0.3 MPa. Irrigations were scheduled twice a week according to class A pan evaporation and a crop coefficient. The saline set was always irrigated first, immediately followed by the N set. For most irrigations only a small amount of water necessary for N distribution was applied through the N set. This pattern allowed the salts to be rinsed from the leaves and yet maintained a high saline gradient.

This design provided a uniform water application within the sampling area, yet at the same time gave a 2-way continuous gradient of N and salinity. In order to help us better understand the water distribution in the plot, a computer model that simulated actual irrigation amounts was developed. Figure 2 is a model output of a typical irrigation for one of the four reps.

Plot Information and Data Collection

On July 8 Hazera 712 seed corn was hand planted in rows 1 m apart and 42 m long. Seedling rate was 75,000 seed ha^{-1} at 2 cm depth. The soil was loess and the plot had been idle the previous 3-4 years. Prior to planting the plot was irrigated to ensure germination and to bring the upper layers to field capacity. On July 26, two weeks after emergence, we began irrigating with saline water through the middle line of the saline set and N was injected into the middle line of the N set. All amounts of fresh and saline water as well as NH_4NO_3 amounts are reported in Table 1.

Aluminum access tubes for neutron probe readings were installed and readings were taken at 30, 60 and 90 cm once a week just prior to irrigaiton. Soil samples were taken three times during the season in order to monitor the electrical conductivity of the soil (Ec_1). Various plant measurements were also taken during the year.

Samples of water applied to the plot were collected during each irrigation using 10 cm polypropylene funnels mounted on stakes and attached to collection bottles by a 1 m long hose. Irrigation water elecrical conductivities (EC_1), amounts, and ion concentrations were measured from these samples.

Plants were harvested in one meter sections in evey row. This gave a harvest area of one square meter for each treatment sample. We did not harvest the meter closest to the irrigation lines in order to reduce the effect any leaking water on yield. Thus a total of 10 rows with 10 one meter sections were harvested from each of three repetitions. The ears were

removed from the stalk and both were weighed separately. Subsamples from various treatments were oven dried to determine dry weight.

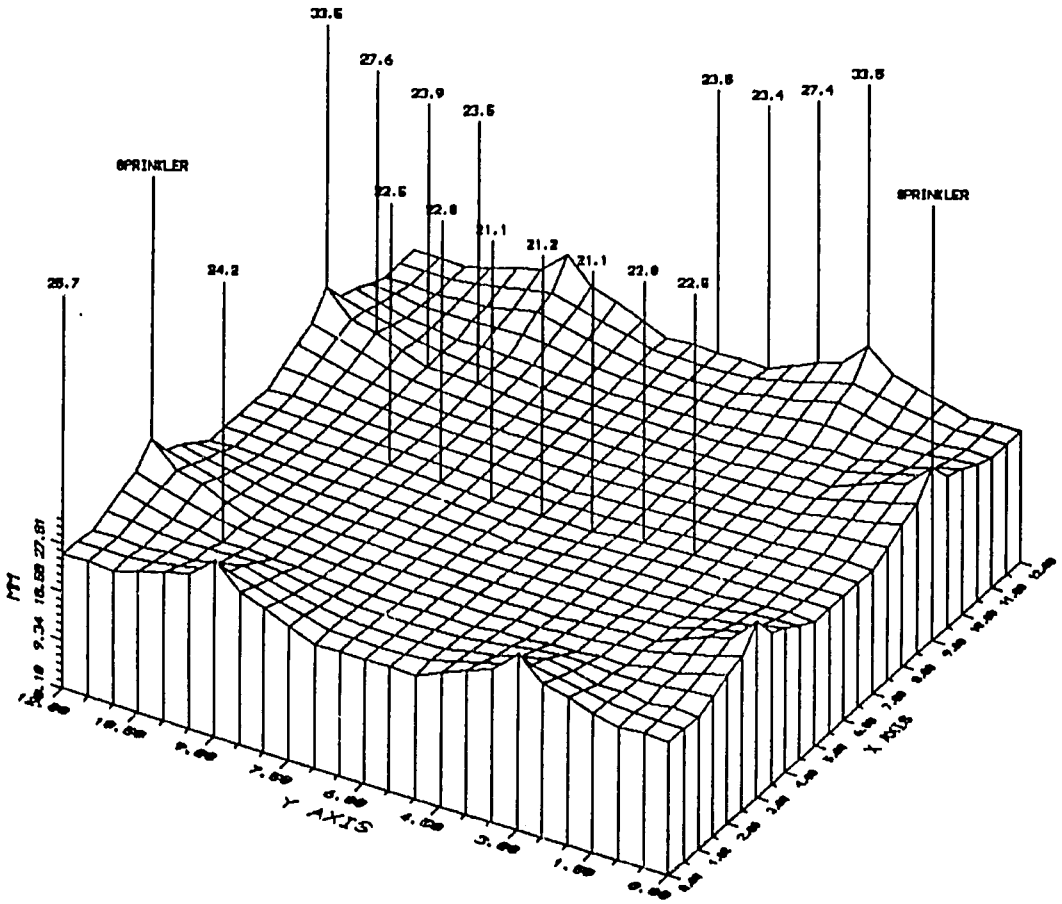


Figure 2: Computer simulated water uniformity for typical irrigation for one rep.
Overview of Irrigation Uniformity from Program Sprink (1 Rep). This figure appears to have two separate titles. One on the figure itself and one listed in list at end of paper. Which is correct?

DAY of YEAR	H2O SALT	H2O FRSH	H2O SALT 1 LN	H2O FRSH 5 LNS	H2O S SET 3 LNS	H2O N SET 3 LNS	H2O AVE.	H2O ACCUM.	N ACCUM.
	----m3----		----------%----------				----mm----		kg/ha
189	27.0	127	17.5	82.5	51.3	48.7	71.5	71.5	0.0
190	2.5	12.5	16.7	83.3	50.0	50.0	7.0	78.5	0.0
193	0.0	48	0.0	100.0	50.0	50.0	18.0	96.5	0.0
197	0.0	48	0.0	100.0	50.0	50.0	22.7	119.2	8.8
200	0.0	48	0.0	100.0	50.0	50.0	21.9	141.1	17.6
203	0.0	48	0.0	100.0	50.0	50.0	24.0	165.1	26.4
207	0.0	48	0.0	100.0	50.0	50.0	21.0	186.1	61.4
210	8.0	40	16.7	83.3	50.0	50.0	22.0	208.1	96.4
214	4.0	20	16.7	83.3	50.0	50.0	11.5	219.6	113.4
218	9.0	39	18.8	81.3	56.3	43.8	21.4	241.0	148.4
221	7.0	35	16.7	83.3	50.0	50.0	20.4	261.4	183.4
225	12.0	41	22.6	77.4	67.9	32.1	22.7	284.1	218.4
228	14.0	34	29.2	70.8	87.5	12.5	23.4	307.5	253.4
232	18.0	189	8.7	91.3	26.1	73.9	90.0	397.5	288.4
235	0.0	6	0.0	100.0	0.0	100.0	3.0	400.5	323.4
239	14.0	34	29.2	70.8	87.5	12.5	23.8	424.3	358.4
242	15.0	40	27.3	72.7	81.8	18.2	27.9	452.2	393.4
246	16.0	43	27.1	72.9	81.4	18.6	28.1	480.3	428.4
249	14.0	34	29.2	70.8	87.5	12.5	23.8	504.1	463.4
253	13.0	35	27.1	72.9	85.4	14.6	21.6	525.7	498.4
256	16.0	35	31.4	68.6	86.3	13.7	23.0	548.7	533.4
260	14.0	42	25.0	75.0	75.0	25.0	25.2	573.9	568.4
263	15.0	42	26.3	73.7	75.4	24.6	25.7	599.5	603.4
267	15.0	34	30.6	69.4	87.8	12.2	22.1	621.6	638.4
270	16.0	34	32.0	68.0	88.0	12.0	22.5	644.1	673.4
274	12.0	34	26.1	73.9	87.0	13.0	20.7	664.8	708.4
277	0.0	412	0.0	100.0	6.8	93.2	185.4	850.2	743.4

Table 1: Record of each irrigation for H_2O, N and salt.

Results and Discussion

Water Quantity and Quality

Following the onset of irrigation with saline water (day 210) the N set contributed approximately 50% of the water amount during the first 4 irrigations. We believed that this was too much and would cause leaching of the salts because the N set was always irrigated last. Soil samples taken on day 223 confirmed our suspicions. Thus, beginning on day 225 we sought to decrease the water applied through the N set without reducing the actual N amounts. We were able to reduce the amount from 50% to approximately 13% with a few exceptions when the system malfunctioned. On day 232 the N set failed to stop and applied 4 times the regular amount of irrigation to the plot. This was estimated to be about 90 mm. This most surely leached any salts and N down to the lower profiles. Irrigations and treatments were begun again one week later (day 239). Soil samples taken on day 253 revealed that salts were beginning to build up once again but by this stage the crop was in less salt sensitive stages. We were unable to detect the soil salinity at the end of the season, as the system once again malfunctioned applying approximately 185 mm to the plot during the last irrigation of the season. This irrigation probably had little effect on yield but it effectively erased any soil salinity.

Overall Performance of the Irrigation System

The total average water amount measured from nine irrigations between July 29 and September 3 was 202 mm. The data and figures shown are for this period. The Christiansen uniformity coefficient for this period was .95.

The EC_1 decreased linearly moving perpendicularly away from the saline line (Figure 3). It remained constant, parallel to the line and was slightly affected by N (Figure 4). Every mM increase in N resulted in a .078 dS m^{-1} increase in EC_1. This should be taken into consideration when irrigating with saline water.

The nitrogen set produced similar results. Figures 5 and 6 show the N concentration of the irrigation water at various locations in the plot. The N gradient was controlled by adjusting the amount of N injected into the middle line.

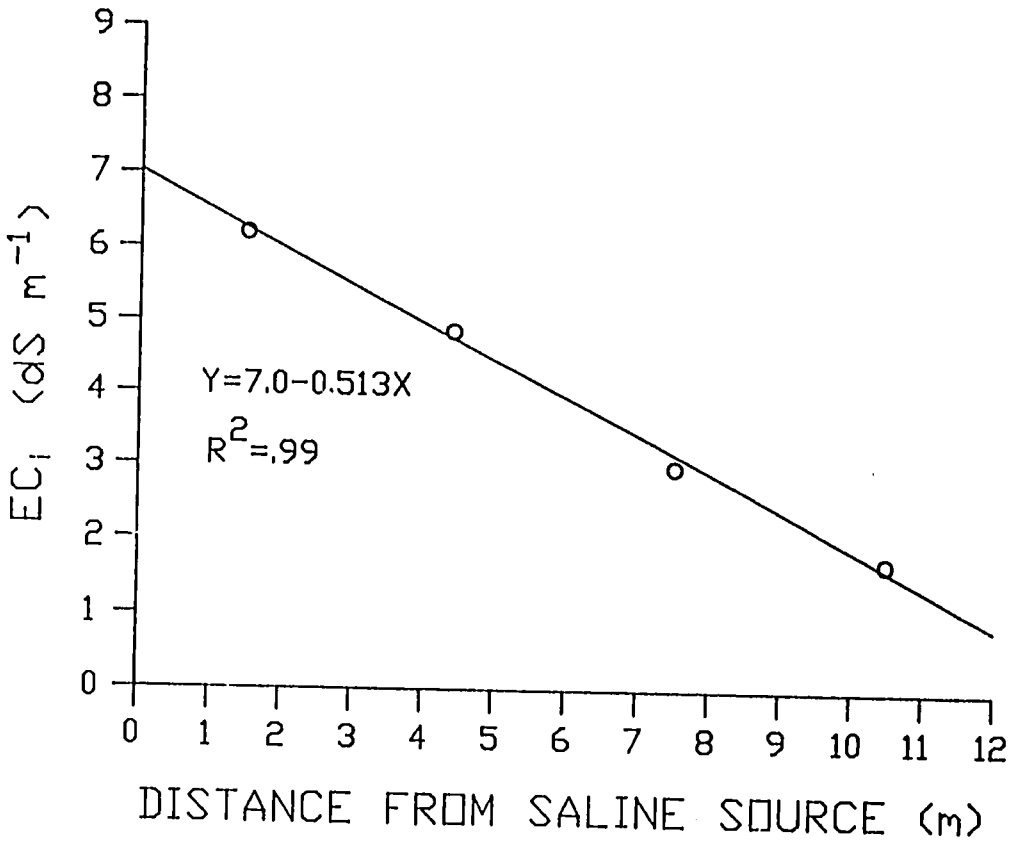


Figure 3: Changes in EC_1 as a function of distance from the saline line. Taken at 1.5 m from the N line. Leave entire page or reduce figure size

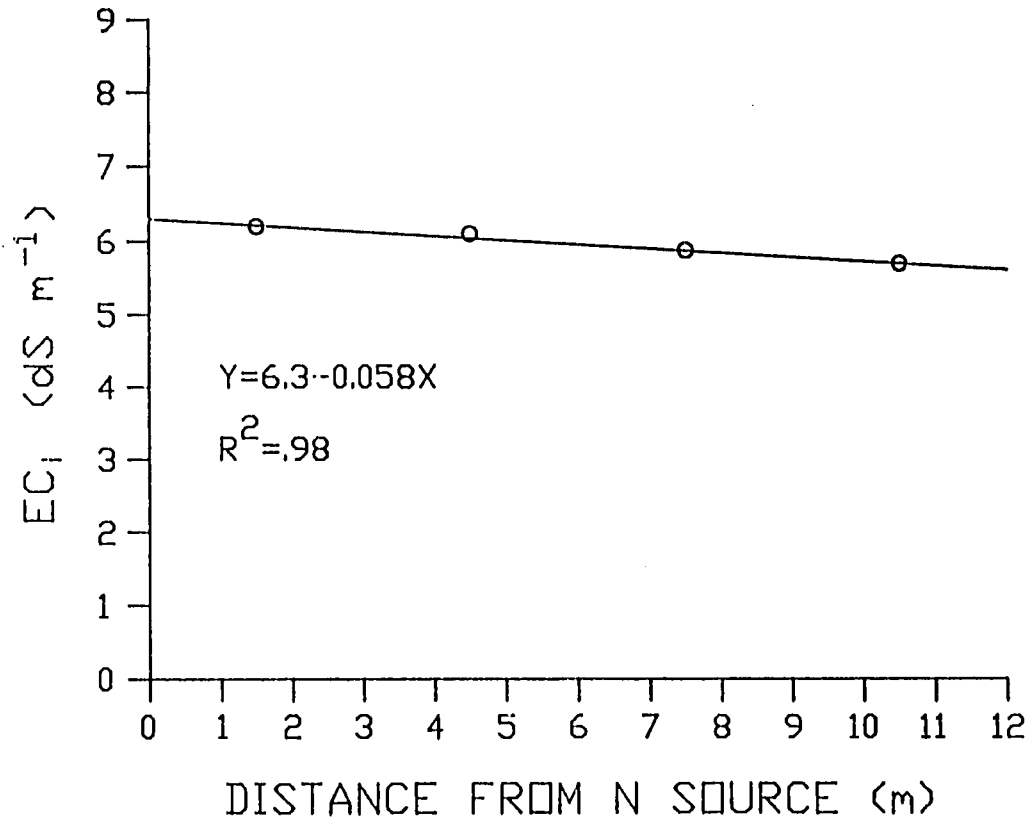


Figure 4: Changes in EC_1 as a function of distance from the N line. Taken at 1.5 m from the saline line.

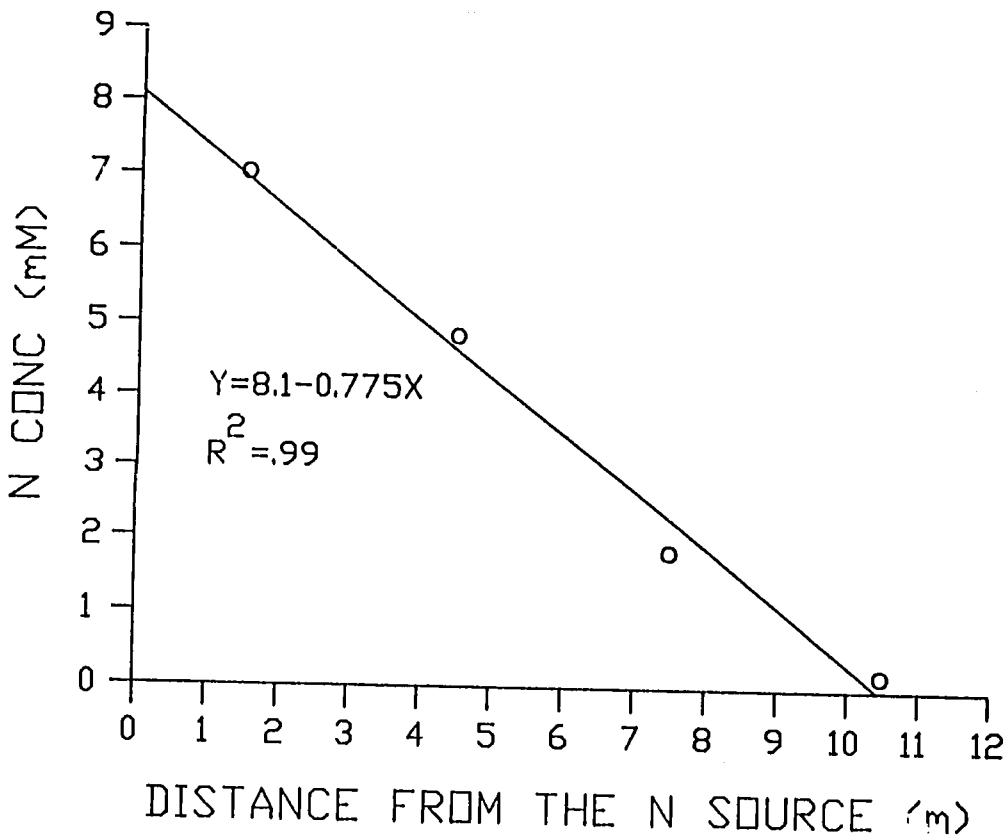


Figure 5: Changes in N concentration in the irrigation water as a function of distance from the N line. Taken at 1.5 m from the saline line.

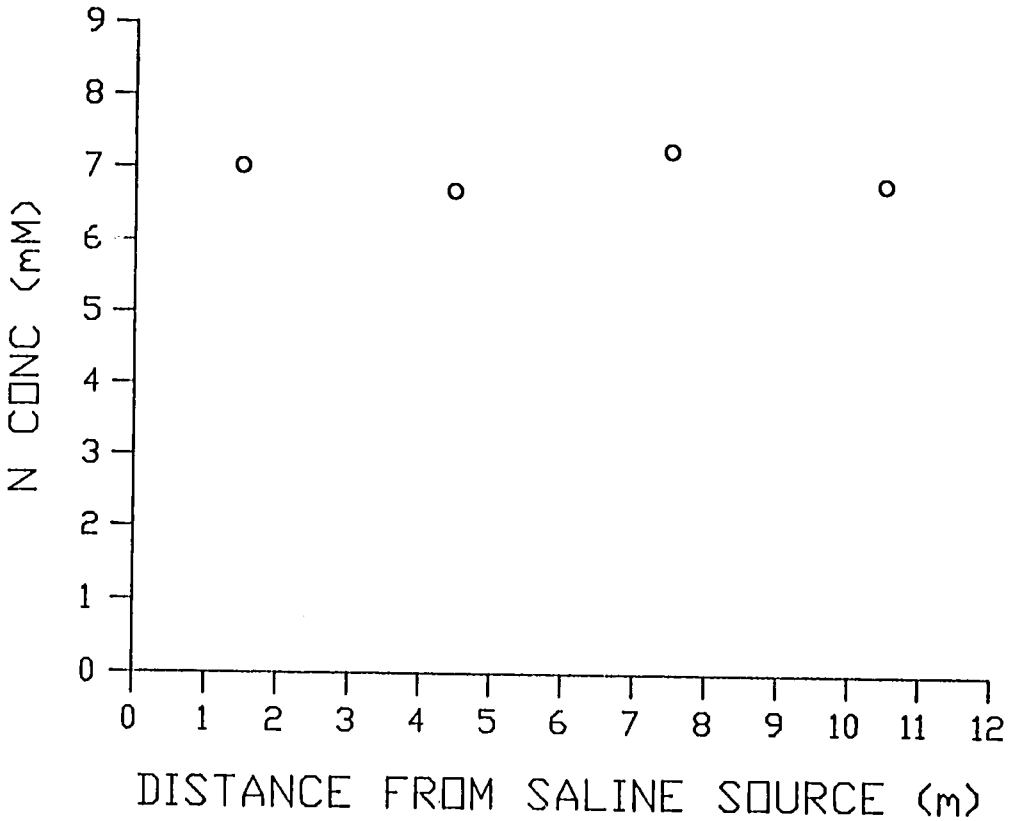


Figure 6: Changes in N concentration in the irrigation water as a function of distance from the saline line. Taken at 1.5 m from the N line

Crop Growth

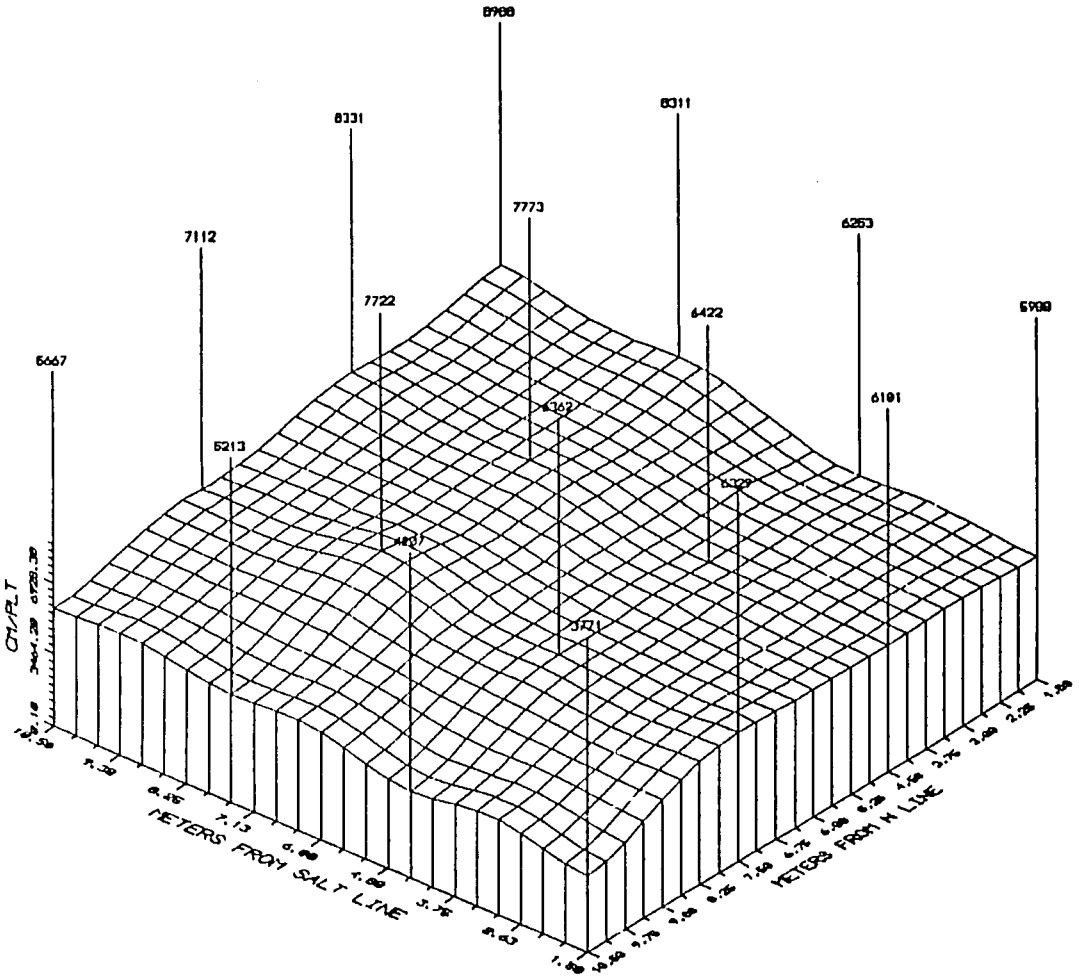
On July 12 50% emergence was recorded. Final plant counts taken July 29 averaged 74,900 plants ha^{-1}. About 10 days after emergence it was observed that the corn's growth was stunted and uneven. Soil samples revealed that K was low (4 ppm) and on July 28 we applied 200 kg ha^{-1} of K. Even after the adition of K the growth rate continued to be slow and uneven. This hindered our plant growth measurements. However, by the time of tasel emergence treatment differences were visible becoming evident. Leaf area measurements taken from one rep on August 30 (day 242) are shown in Figure 7.

Crop Yield

Both stover and ear yields were affected more by N than by salt in this experiment. The lowest yields for all parameters measured was at the low N high saline treatment in each rep. Figures 8 and 9 show a 3-D overview of the average of 3 reps for stover and ear yields. The actual values for 16 selected location are also displayed in the figures. Figure 10 shows an overview of the entire 4 replications for the stover yield. The fourth quadrant is actually an average of the 3 harvested reps and is displayed to give the overall picture of the experimental area. The trends are fairly clear to see. There are cerrtain peaks and depressions which are a bit more difficult to make statements about. I feel that even though certain rsults are consistent in the 3 measured reps (Figure 10), many of the results were blurred by the early erratic growth rates. Stover yields were quite good while ear yields were low. There are two reasons besides the one already mentioned for this. First, the variety was a silage corn which is grown for its stover production rather than it's grain yield. Secondly, we harvested the corn during the early stages of R5 (dent stage). Thus the kernels were still accumulating dry weight during this time.

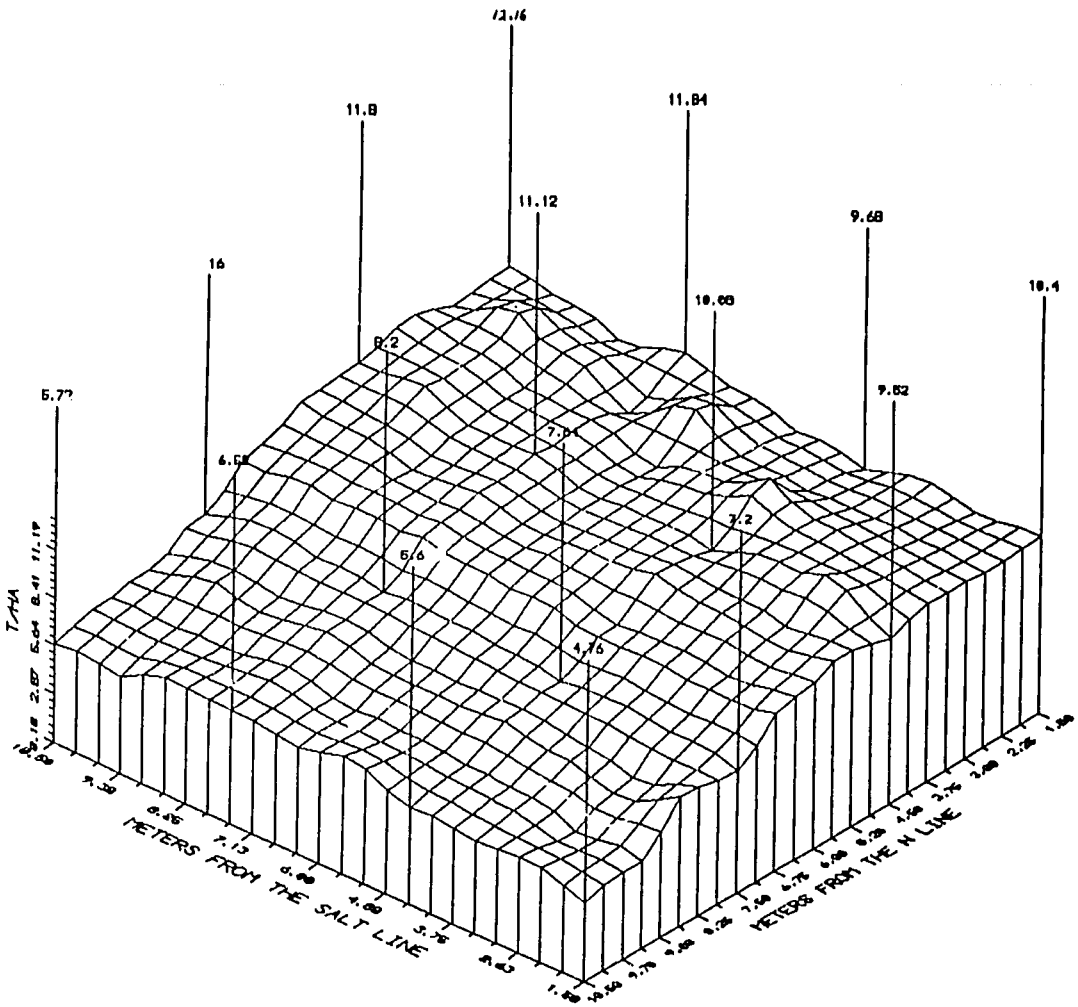
Statistical Analysis

Due to the lack of randomization, the normal ANOVA could not be used to evaluate significance. We, therefore, sought to use geostatistical methods which analyze spatial variability. As the application of this approach is rather new to agriculture, there is still some uncertainity in interpreting the results. At the time of this report the analysis of semi-variograms for stover, ear, and biomass are progressing but regrettably are not yet ready for presentation.



MAIZE LEAF AREA TAKEN 8/30/87 FROM REP 3

Figure 7: Maize Leaf Area taken 8/30/87 from Rep 3.



MAIZE 87 STOVER DRY YIELD (AVE. OF 3 REPS)

Figure 8: Maize 87 Stover Dry Yield (Ave. of 3 Reps).

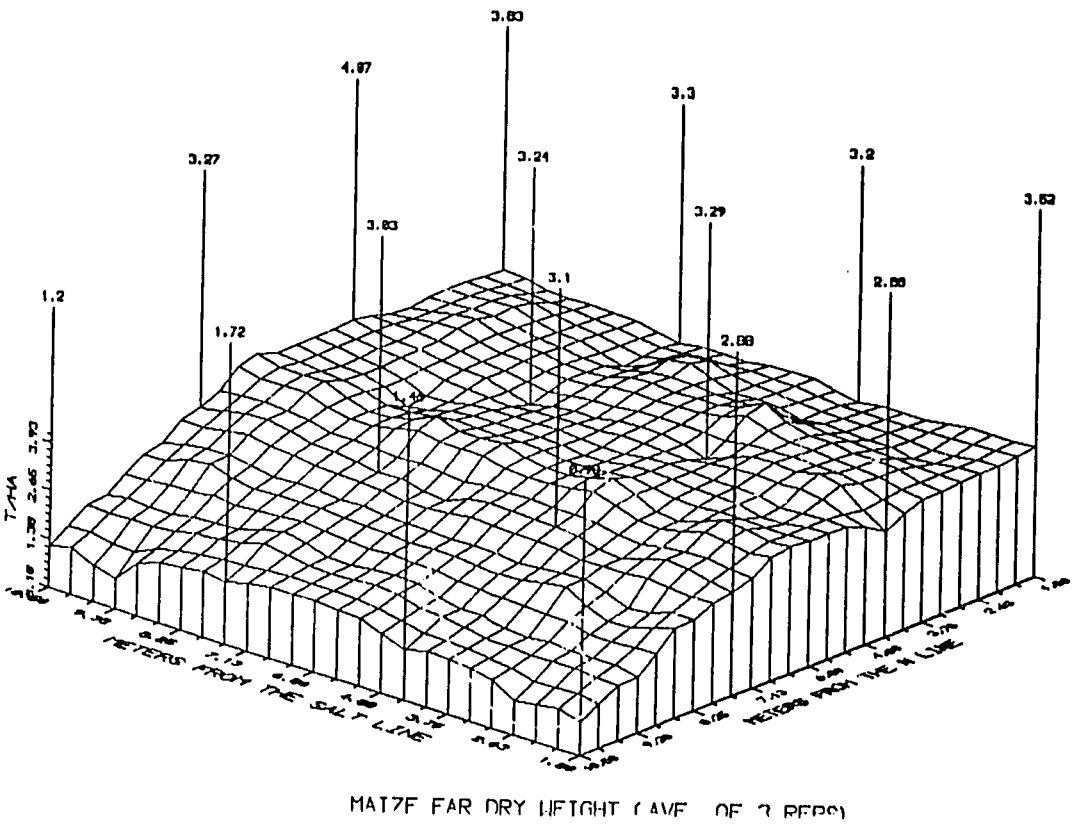


Figure 9: Maize Ear Dry Weight (Ave. of 3 Reps).

MZ87 DRY STOVER YIELD OVERVIEW OF PLOT

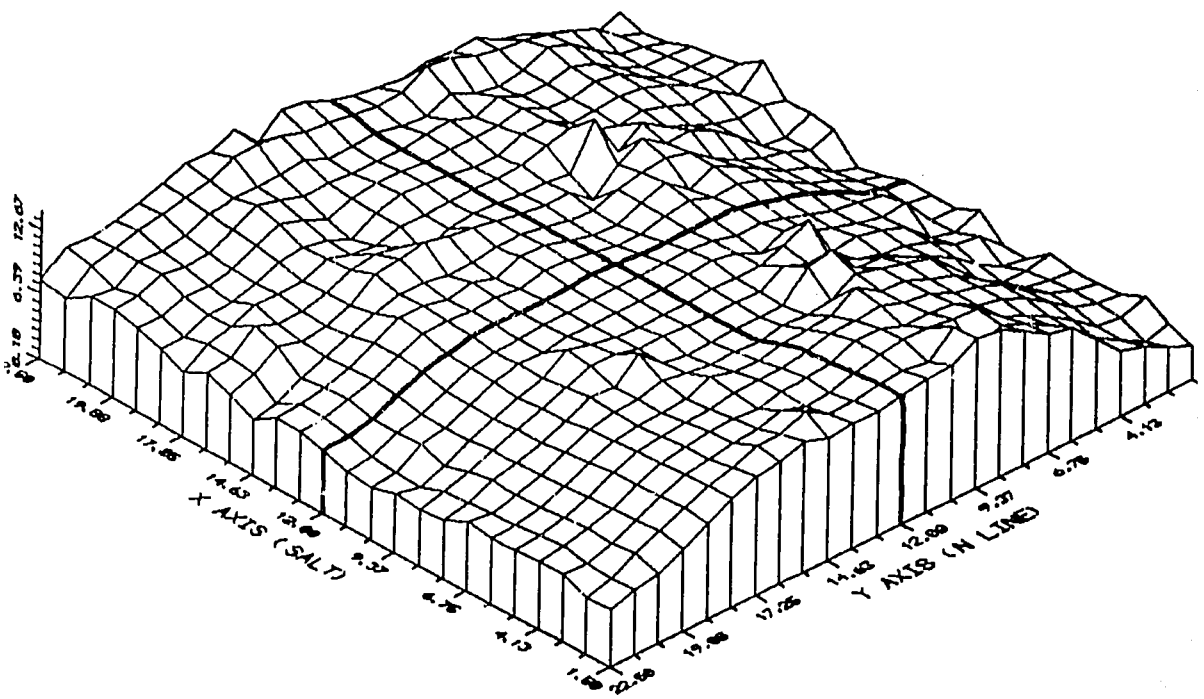


Figure 10: MZ87 Dry Stover Yield Overview of Plot.

Conclusions and Recommendations

System Design

We were very pleased with the overall performance and results of the irrigation design. The system was easy to install and required little maintenance. The two times the system malfunctioned was not a weakness of the design only the operation of it. The design produced large amounts of information and we were limited only by our own ability in collecting it. There were very few adjustments needed and the ones that were necessary were made early in the season. Considering the information produced and the relative ease in constructing and operating this system, it is a very attractive alternative to traditional designs. We believe it will be a very promising tool for observing response surfaces using more than one variable.

Salinity and Nitrogen Interaction

It is difficult to make any concrete statements based on this years experiment. The trends are evident. But the question, "if N counteracts the harmful effects of salinity", is less clear. The saline treatment did not begin until 19 days after germination. It is suspected that there may have been some downward movement of salts during the next two weeks, and there certainly was on day 232 when the system failed to stop. Thus the full effect of the saline treatment was probably not felt. It is known that corn is more sensitive in the early stages than at later stages of growth. This coupled with the early sporadic growth patterns make specific conclusions difficult to make. It is, therefore, recommended that the next experiment be conducted with the same experimental design on a more uniform soil, and begin the treatments immediately after germination. This will hasten the soil salinity buildup and give us a better indication of the early effects of N and salinity interactions.

List of Figures and Tables

Figure 1: Experimental plot layout of the irrigation system designed to produce saline and N gradients. FRESH = fresh water (1.0 dS m^{-1}); SALINE = saline water (7.0 dS m^{-1}); FRESH + N = fresh water + NH_4NO_3 (8.1 mM).

Figure 2: Computer simulated water uniformity for typical irrigation for one rep.

Figure 3: Changes in EC_1 as a function of distance from the saline line. Taken at 1.5 m from the N line.

Figure 4: Changes in EC_1 as a function of distance from the N line. Taken at 1.5 m from the saline line.

Figure 5: Changes in N concentration in the irrigation water as a function of distance from the N line. Taken at 1.5 m from the saline line.

Figure 6: Changes in N concentration in the irrigation water as a function of distance from the saline line. Taken at 1.5 m from the N line.

Figure 7: Maize leaf are of one rep taken 8.30/88.

Figure 8: Maize stover dry yield (Average of 3 reps).

Figure 9: Maize ear dry weight (Average of 3 reps).

Figure 10: Maize stover dry yield (Overview of 4 reps).

Table 1: Reconrd fo each irrigation for fresh and salt wate and N applied.

(3) Peanut

(3a) Comparison of the effects of salinity on peanut and cotton grown on nitrate or ammonium nutrient solutions. (Leidi, Silberbush and Lips)

Introduction

The increase in the use of brackish water for agriculture has determined a renewed interest on plant nutrition and fertilizer applicaiton under saline conditions (Kafkafi 1984; Feigin 1985). The source of nitrogen in the medium can exert a considerable influence on the mineral composition of the plants (Kurvits and Kirkby 1980; Kirkby and Mengel 1967; Reisenauer 1978; Allen and Smith 1986). On the other hand, salinity can inhibit uptake of several nutrients like nitrate (NO_3^-)-N (Aslam et al., 1984), K^+ and Ca^{2+} (Cramer et al., 1986) while increase levels of others, like Cl^- and Na^+ (Greenway and Munns 1980) induce nutrient imbalances.

Furthermore, the study of the major limiting factors to plant growth under saline conditions is complexed due to the differential response of plant species to salinity in terms of ion uptake and mechanisms which enable plants to recover stresses caused by ion excess and water deficit (Greenway and Munns 1980; Gorham et al. 1985). In this paper we report on growth, photosynthesis and ion uptake of two different plant species which vary in ther salt-tolerance which were studied under different salinity levels and nitrogen sources.

Materials and Methods

Peanut (Arachis hipogaea L. cv. Shulamit) and cotton (Gossypium hirsutum L. cv. SJ-1-171) plants were grown in aerated nutrient solutions under greenhouse conditions. The seeds were germinated in moist vermiculite and uniform seedlings were transferred to the nutrient solutions. Two nitrogen sources (ammonium and nitrate) were applied and different salinity levels for peanuts and cotton plants considering their different salt tolerance. The composition of the basic nutrient solutions were the following (in mM):

	NO_3^-	SO_4^{-2}	$N_2PO_4^-$	K^+	Ca^{2+}	Mg^{2+}	NH_4^+
Nitrate solution	4	1.5	1	3	2	1	--
Ammonium solution	--	3.5	1	3	2	1	4

Micronutrients were supplied at the same concentrations as the Long-Ashton nutrient solution (Hewitt 1966). Salinity levels were 0, 10, 20, 35, 50, 75 and 100 mM NaCl for peanut, and 0, 50, 100, 150, 200, 250 and 300 mM NaCl for cotton. The NaCl concentrations were increased in steps to avoid a shock to the plants salt concentration. The solutions were changed weekly and water losses were replenished daily.

Photosynthesis and transpiration were determined in recently expanded leaves of plants grown under experimental conditions for 15 days, using a portable infrared gas analyzer (LCA-2, ADC) at constant light irradiation (700 umol/m^2/s).

The plants were then harvested and dried at70°C for 48 h and weighed. Nitrogen was determined after digestion with H_2SO_4 + H_2O_2 using the Nessler's reagent, and Cl^-, Na^+ and K^+ were analyzed in hot water extracts using a chloride-meter and a flame-photometer, respecitively.

Results and Discussion

Increasing NaCl concentrations reduced shoot dry weight in peanut and cotton plants (Table 1). Cotton plants died at 300 mM NaCl, whereas plants grown in 250 mM NaCl had necrotic leaves, and growth was ceased within a week. Root dry weight was more sensitive to salinity when ammonium was the N source, in both the species. Apparently, salinity reduces ammonia detoxification declining de novo synthesis of arginine in squash (Cucurbita pepo) plants (Lovatt 1986). This phenomenon could explain the higher growth inhibition caused by salinity when plants were grown in ammonium, although a combined effect by decreased K^+ and Ca^{2+} uptake should not be discarded. Ammonium-grown cotton plants showed a lower dry matter accumulation than those grown on nitrate, whereas peanut plants had similar growth in both the N sources. It may indicate on a differential capacity of both species to assimilate ammonium in the roots. Growth reduction in ammonium-fed plants were observed in several species (cucumber, castor beans, bean) (Schenk and Wehrmann, 1979; Allen et al., 1985; Chaillou et al., 1986) while in others (wheat, soybean, rice, tomato) (Cox and Reisenauer, 1973; Rufty et al., 1983; Alam, 1984; Peet et al., 1985) ammonium- vs. nitrate-fed plants presented similar growth.

Considering the relative growth depression caused by salt comparing similar levels, there was no marked indication of higher tolerance in cotton than in peanut as previously reported (Maas, 1986). Only in 50 mM NaCl, nitrate-grown cotton plants had 96 percent shoot dry weight of the control while peanut had 77 percent. However, at 100 mM NaCl, the percentages

were 59 (cotton) and 56 (peanut) indicating small differences in tolerance. This could be explained by the fact that cotton is most salt-sensitive in the seedling stage (Bernstein and Hayward, 1958; Abul-Naas and Omran, 1974), when the levels of NaCl were increased.

Photosynthesis and transpiration

Photosynthetic activity in the youngest fully expanded leves (Tables 2 and 3) was not clearly affected by salinity levels. Only cotton leaves at the highest salt concentration showed a considerable reduction in photosynthesis per leaf area unit. However, considering the photosynthetic activity per unit of chlorophyll (Table 5a and 5b), there was an increase of activity at the highest NaCl level in peanut and a decrease in cotton. Transpiration rate and stomatal conductance decreased to some extent with the increase in salt level. In fact, a high linear correlation coefficient occurred between transpiration and stomatal conductance of each of the N sources, in both the species (Table 4). These results could suggest that the effect of salinity on photosynthesis was different in the two study species.

Several reports have presented conflicting results about the effects of salinity on photosynthesis (Berry and Downton, 1982). In cotton, increases in stomatal as well as mesophyll resistance have been reported as affecting photosynthesis under salinity (Gale et al., 1967; Longstreth and Nobel, 1979). In Phaseolus vulgaris, lower photosynthetic capacity in salt-treated plants by a reduction in the efficiency of ribulose-1,5-bisphosphate (RUBP) carboxylase (Seemann and Sharkey, 1986). However, in spinach (Spinacia oleracea) salt stress did not result in any major decrease in the photosynthetic potential of the leaf (Kaiser et al., 1983; Robinson, et al., 1983).

Water Use Efficiency

Water use efficiency (WUE) (Table 6) as the ratio between net CO_2 assimilation and transpiration (Hsiao and Lauchli, 1984) did not clearly increase with salinity as it was reported by others (McCree and Richardson, 1987), although there was an increase of WUE in cotton with NaCl concentration and ammonium-growing peanut plants.

Concentration and Content of N, Cl^-, Na^+ and K^+ in the Shoots

Increase of the salinity level resulted in a decrease in N content (Table 7) irrespectively of the nitrogen source or plant species. Salt also decreased K^+ concentration and content in the plant, and increased Cl^- level. However,

Na^+ levels in peanut increased markedly only at the highest NaCl concentration in solution, while in cotton each increase in the salt level was accompanied by an increase of Na^+ concentration in the shoot. Peanut pattern of Na^+ uptake resembled that of Na^+-excluder species, whereas cotton showed characteristics of Na^+-includer species. It is not clear whether Na^+ exclusion provides a higher tolerance in salt-sensitive species (Lessani and Marschner, 1978; Schubert and Lauchli, 1986). In some cases, however, salt-exclusion may be a mechanism of coping with saline conditions (Lauchli, 1984; Gorham et al., 1985). In cotton, the relative increase of Na^+ and Cl^- to the external increase in salinity level could be used for adjustment of the turgor maintainance, although under such conditions an effective ion compartmentation would be necessary to avoid toxic effects of ion excess. However, Rathert (1982) demonstrated that genotypical salt tolerance was negatively correlated with Na^+ and Cl^- accumulation in the leaves.

Inhibition of NO_3^- uptake by salinity was previously reported (Aslam, et al., 1984) and was registered in the present experiment (Table 8), but salinity apparently affected N uptake similarly in the ammonium-fed plants as well from the values of N cntent.

The decrease in K^+ uptake by Na^+ and NH_4^+ was also observed. Lower levels of K^+ in ammonium-fed plants could contribute to the higher salt sensitivity in these plants by inducing deficiencies. K^+ uptake in cotton plants was apparently more affected by increases in salt level, as could be seen from Figs.

The relationships between Na^+ and K^+ in the different treatments are presented in Fig. 1 as the ratio between the two ions in the plant vs. the ratio in the solution. Note that K^+/Na^+ ratio in the plant is in a logarithmic scale. The two ratios obeyed a first-order experimental function, which are represented by the calculated lines. The relatively higher initial K^+/Na^+ ratio in peanuts is the result of relatively higher K^+ and lower Na^+ concentrations, which indicates about the Na^+-exlusion nature of peanuts compared to cotton. Furthermore, while cotton plants exhibited a similar slope of the functions of two N^+ sources (which indicate a similar decay factor), peanuts fed with ammonium had a stripper slope than those fed with nitrate. This indicates that peanuts treated with ammonium are more sensitive to Na^+/K^+ ratio (and alkalinity) than those treated with nitrate.

This difference between ammonium and nitrate-fed peanuts is probably due to the mutual uptake enhancement of Na^+ and K^+. The fact that cotton did not exhibit such a difference may indicate the ability of Na^+ to replace K^+ in the tolerant species cotton, but not in the salt sensitive

species peanuts (Greenway and Munns, 1984), which may serve as an index for salinity tolerance.

Relationships between photosynthesis, transpiration, and stomatal conductance with leaf ion concentrations.

The photosynthetic rate was correlated with leaf Cl concentration in cotton growing in nitrate (r = 0.97, parabolically) or ammonium (r = -0.81), whereas in peanut there was such a correlation only in NH_4-fed plants (r = -0.83). Despite the fact that there was no correlation between photosynthesis and stomatal conductance in both the species, leaf chloride levels were negatively correlated to stomatal conductance in peanut and cotton. However, the most interesting relation was observed between the leaf potassium level and the stomatal conductance, principally for peanut (for NO_3-fed plants, r = 0.92) and NH_4^+-fed plants, r = 0.99), whereas in cotton Na was the cation which was higher correlated with stomatal conductance (this time negatively) of leaves from NO_3^- (r = -0.88) or NH_4^+-growing plants (r = -0.99).

Conclusions

In spite of giving similar growth responses when ammonium was used as N source in peanut, it failed to do so when the salinity level was increased. In cotton, ammonium produced lower dry matter yield than nitrate, indicating that it was not the adequate N source under the applied conditions. Consequently, salt stress was an overlapping stress that plants had to overcome. Reasons for hgher detrimental efects of salinity in ammonium-fed plants could be the reduced ammonia detoxification capacity under salinity (Lovatt, 1986) plus concurrent factors, like reduced K uptake, and probably Ca (Fenn et al., 1987) by the combined effect of NH_4^+ and Na^+ probably due to cation competition.

Photosynthesis was clearly affected by salinity only in cotton grown under high salt levels. If this decrease was due to salinity-induced K^+ deficiency, as Ball et al. (1987) have shown for Avicennia marina remains to be tested. This fact also support the low correlation of photosynthesis with yield, and the complexity of the growth inhibition phenomenon caused by salinity. In agreement with Rawson (1986), our results showed that photosynthesis values alone are hardly a suitable variable in evaluating the responses of plants to salinity. PS processes are salt-tolerant. The effect is indirect, via mineral nutrition (K^+) and protein metabolism (chlorophyll).

References

Abul-Naas, A.A. and M.S. Omran, 1974. Salt tolerance of seventeen cotton cultivars during germination and early seedling development. Z. Ack. Pflanzenbau. 140: 229-236.

Alam, S.M., 1984. Effect of nutrient solution pH and N-sources (NH_4^+/NO_3^-) on the growth and elemental conten tof rice plants. Agronomie 4: 361-365.

Allen, S., J.A. Raven and G.E. Thomas, 1985. Ontogenetic changes in the chemical composition of Ricinus communis grown with NO_3^- or NH_4^+ as N source. J. Exp. Bot. 36: 413-425.

Allen, S. and J.A.C. Smith, 1986. Ammonium nutrition in Ricinus communis: Its effect on plant growth and the chemical composition of the whole plant, xylem and phloem saps. J. Exp. bot. 37: 1599-1610.

Aslam, N., R.C. Huffaker and D.W. Rains, 1984. Early effects of salinity on nitrate assimilation in barley seedlings. Plant Physiol. 75: 321-325.

Ball, M.C., W.S. Chow and J.M. Anderson, 1987. Salinity-induced potassium deficiency causes loss of functional photosystem TT in leaves of the grey mangrove, Avicennia marina, through depletion of the atrazine-binding polypeptide. Aust. J. Plant Physiol. 14: 351-361.

Bernstein, L. and H.E. Hayward, 1958. Physiology of slat tolerance. Ann. Rev. Plant Physiol. 9: 25-46.

Berry, J.A. and W.J.S. Downton, 1982. Environmental regulation of photosynthesis. In: Photosynthesis: Development, Carbon Metabolism and Plant Productivity, Vol. 2 (Govindjee, Ed.) pp. 263-343. Academic Press Inc., New York.

Chaillou, S., J.F. Morot-Gaudry, L. Salsac, C. Lesaint and E. Jolivet, 1986. Compared effects of NO_3^- and NH_4^+ on growth and metabolism of French bean. Physiol. Veg. 24: 679-687.

Cox, W.J. and H.M. Beisenauer, 1973. Growth and ion uptake by wheat supplied nitrogen as nitrate, ammonium, or both. Plant Soil 38, 363-380.

Cramer, G.R., A. Lauchli and V.S. Polito, 1985. Displacement of Ca^{2+} by Na^{+} from the plasmalemma of root cells. A primary response to salt stress? Plant Physiol. 79, 207-211.

Feigin, A., 1985. Fertilization management of crops irrigated with saline water. Plant Soil 89, 285-299.

Gale, J., H.C. Kohl and R.m. Hagan, 1967. Changes in the water balance and photosynthesis of onion, bean and cotton plants under saline conditions. Physiol. Plant. 20: 408-420.

Gorham, J., R.G. Wyn Jones and E. McDonnell, 1985. Some mechanisms of salt tolerance in crop plants. Plant Soil 89: 15-40.

Greenway, H. and R. Munns, 1980. Mechanisms of salt tolerance in nonhalophytes. Ann. Rev. Plant Physiol. 31, 149-190.

Hsiao, T.C. and A. Lauchli, 1984. Role of potassium in plant-water relations. In: Advances in Plant Nutrition, Vol. 2 (P.B. Tinker, A. Lauchli, Eds.) pp. 281-312. Praeger Scientific, Greenwood Press, Inc., Westpert, Connecticut.

Kafkafi, U., 1984. Plant nutrition under saline conditions. In: Soil Salinity under Irrigation. Processes and Management (I. Shainberg, J. Shalhevet, Eds.) pp. 319-331. Springer-Verlag, Berlin, Heidelberg, New York, Tokyo.

Kaiser, W.M., H. Weber and M. Sauer, 1983. Photosynthetic capacity, osmotic response and solute content of leaves and chloroplasts from Spinacia oleracea under salt stress. Z. Pflanzenphysiol. 113: 15-27.

Kirkby, E.A. and K. Mengel, 1967. Ionic balance in different tissues of the tomato plant in relation to nitrate, urea, or ammonium nutrition. Plant Physiol. 42, 6-14.

Lauchli, A., 1984. Salt exclusion: an adaptation of legumes for crops and pastures under saline conditions. In: Salinity Tolerance in Plants. Strategies for Crop Improvement (R.C. Staples, G.H. Toennissen, Eds.) pp. 171-187. John Wiley and Sons, New York.

Longstreth, D.J. and P.S. Nobel, 1979. Salinity effects on leaf anatomy, consequences for photosynthesis. Plant Physiol. 63: 700-703.

Lovatt, C.J., 1986. Salinity stress results in ammonia intoxication. Plant Physiol. (Supplement) 80: 10.

Maas, E.V., 1986. Salt tolerance of plants. Appl. Agric. Res. 1: 12-26.

Mc Cree, K.J. and S.G. Richardson, 1987. Salt increases the water use efficiency in water stressed plants. Crop Sci. 27: 543-547.

Peet, M., C.D. Raper, L.C. Tolley and W.P. Robarge, 1985. Tomato responses to ammonium and nitrate nutrition under controlled root-zone pH. J. Plant Nutr. 8: 787-798.

Reisenauer, H.M., 1978. Absorption and utilization of ammonium nitrogen by plants. In: Nitrogen in the Environment, Vol. 2 (D.R. Nielsen, J.G., Mac Donald, Eds.), pp. 157-170. Academic Press Inc.

Robinson, S.P., W.J.S. Downton and J.A. Millhouse, 1983. Photosynthesis and ion content of leaves and isolated chloroplasts of salt-stressed spinach. Plant Physiol. 73, 238-242.

Rufty, T.W., C.D. Raper and W.A. Jackson, 1983. Growth and nitrogen assimilation of soybeans in response to ammonium and nitrate nutrition. Bot. Gaz. 144: 466-470.

Schenk, M. and J. Wehrman, 1979. The influence of ammonia in nutrient solution on growth and metabolism of cucumber plants. Plant Soil 52, 403-414.

Schubert, S. and a. Lauchli, 1986. Na^+ exclusion, N^+ release, and growth of two different maize cultivars under NaCl salinity. J. Plant Physiol. 126, 145-154.

Seemann, J.R. and T.D. Sharkey, 1986. Salinity and nitrogen effects on photosynthesis, ribulose-1,5-bisphosphate carboxylase and metabolite pool sizes in Phaseolus vulgaris L. Plant Physiol. 82: 555-560.

Table 1. Shoot and root dry weights of peanut and cotton plants grown in NO_3^- or NH_4^+ solutions and different NaCl concentrations.

PEANUT	NO_3^-		NH_4^+		Shoot/root ratio.	
NaCl concn. (mM)	Shoot (g/plant)	Root	Shoot (g/plant)	Root	NO_3^-	NH_4^+
0	1.98	0.55	1.96	0.48	3.6	4.1
10	1.95	0.45	1.65	0.37	4.3	4.5
20	1.95	0.52	1.77	0.45	3.7	3.9
35	1.63	0.46	1.54	0.43	3.5	3.6
50	1.53	0.44	1.14	0.35	3.5	3.3
75	1.31	0.39	1.06	0.39	3.4	2.7
100	1.11	0.40	0.81	0.27	2.8	3.0
LSD 0.05 Shoot		0.12				
Root						
COTTON						
0	1.41	0.29	0.73	0.23	4.9	3.2
50	1.36	0.38	0.56	0.19	3.6	2.9
100	0.84	0.23	0.57	0.18	3.6	3.2
150	0.75	0.28	0.47	0.18	2.7	2.6
200	0.50	0.17	0.37	0.10	2.9	3.7
250	0.40	0.16	0.34	0.09	2.5	3.8
300	0.36	0.11	0.23	0.06	3.3	3.8
LSD 0.05 Shoot		0.06				
Root						

Table 2. Photosynthesis, transpiration rate and stomatal conductance in leaves of peanut plants growing in nutrient solutions with nitrate or ammonium with different salinity levels.

Nitrogen source	NaCl conc. (mM)	Photosynthetic activity. (umol/m2/s)	Transpiration rate. (mmol/m2/s)	Stomatal conductance (mmol/m2/s)
NO3	0	9.78	13.65	1055
	10	8.07	14.18	857
	20	10.45	12.61	863
	35	9.43	13.89	973
	50	10.12	11.08	657
	75	7.96	12.04	508
	100	8.77	10.52	412
NH4	0	10.23	11.63	870
	10	9.37	12.17	709
	20	10.41	8.77	581
	35	10.57	9.60	604
	50	10.14	10.60	489
	75	9.03	8.52	321
	100	8.59	7.85	266
LSD 0.05		1.32	1.03	139

Table 3. Photosynthesis, transpiration rate and stomatal conductance in leaves of cotton plants grow[illegible]n nutrient solutions with nitrate or ammonium with different salinity levels.

Nitrogen source	NaCl conc. (mM)	Photosynthetic activity. (umol/m2/s)	Transpiration rate. (mmol/m2/s)	Stomatal conductance (mmol/m2/s)
NO3	0	7.23	13.00	870
	50	7.65	10.55	536
	100	8.38	10.65	535
	150	8.03	10.90	506
	200	6.87	5.70	285
NH4	0	7.99	12.58	718
	50	7.18	11.65	606
	100	5.92	11.08	516
	150	7.00	7.68	265
	200	4.83	6.24	175
LSD 0.05		1.40	1.10	163

Table 4. Linear correlation coefficients of the relation between photosynthesis (PS), transpiration (T) and stomatal conductance (SC).

	N source	Relation	Linear correlation coefficient.	Statistical significance.
Peanut	NO3	PS vs SC	0.43	* (P 0.05)
		T vs SC	0.85	*** (P 0.001)
	NH4	PS vs SC	0.65	***
		T vs SC	0.83	***
Cotton	NO3	PS vs SC	0.09	n.s.
		T vs SC	0.91	***
	NH4	PS vs SC	0.74	***
		T vs SC	0.99	***

Table 5a. Photosynthesis per unit of chlorophyll in leaves of peanut and cotton plants growing in nutrient solutions with nitrate or ammonium with different salinity levels (in umol/g chlorophyll/s).

PEANUT N source	NaCl concn.	Photosynthetic activity
NO3	0	18.2
	10	17.2
	20	20.9
	35	17.6
	50	19.2
	75	17.2
	100	22.6
NH4	0	20.0
	10	17.3
	20	21.2
	35	18.8
	50	19.5
	75	18.8
	100	24.3
LSD 0.05		2.7

COTTON N source	NaCl concn.	Photosynthetic activity
NO3	0	24.4
	50	24.9
	100	25.1
	150	24.1
	200	21.4
NH4	0	23.1
	50	19.8
	100	14.7
	150	15.3
	200	13.5
LSD 0.05		3.2

Table 5b. Chlorophyll concentration in leaves of peanut and cotton plants growing in nutrient solutions with nitrate or ammonium with different salinity levels (in g/m2).

PEANUT		Chlorophyll concentration	COTTON		Chlorophyll concentration
N source	NaCl concn.		N source	NaCl concn.	
NO3	0	0.53	NO3	0	0.29
	10	0.47		50	0.31
	20	0.50		100	0.33
	35	0.52		150	0.33
	50	0.50		200	0.32
	75	0.44	NH4	0	0.35
	100	0.34		50	0.36
NH4	0	0.50		100	0.41
	10	0.53		150	0.46
	20	0.48		200	0.26
	35	0.54	LSD 0.05		0.05
	50	0.51			
	75	0.45			
	100	0.34			
LSD 0.05		0.10			

Table 6. Water use efficiency of peanut and cotton plants growing in nutrient solutions with nitrate or ammonium with different salinity levels.

PEANUT	WUE x 10-5		COTTON	WUE x 10-5	
NaCl conc. (mM)	Nitrate	Ammonium	NaCl conc. (mM)	Nitrate	Ammonium
0	71.6	88.0	0	55.6	63.5
10	56.9	77.0	50	72.5	61.6
20	82.9	118.7	100	78.7	53.4
35	67.9	109.1	150	73.7	91.1
50	91.3	95.7	200	120.5	77.4
75	66.1	106.0			
100	83.4	109.4			

Table 7. Concentration of nitrogen, chloride, sodium and potassium in shoots of peanut and cotton plants growing in nutrient solutions with nitrate or ammonium under different salinity levels.

PEANUT Nitrogen source	NaCl concn.(mM)	N	Cl	Na	K
			(mmol/g DW)		
NO3	0	2.37	0.19	0.024	1.011
	10	2.51	0.26	0.020	0.923
	20	2.66	0.27	0.019	0.946
	35	2.40	0.32	0.028	0.933
	50	2.51	0.35	0.028	0.835
	75	2.36	0.54	0.028	0.807
	100	2.37	0.85	0.076	0.839
NH4	0	2.56	0.19	0.019	0.665
	10	2.48	0.20	0.012	0.592
	20	2.58	0.21	0.020	0.537
	35	2.64	0.18	0.020	0.532
	50	2.56	0.22	0.020	0.494
	75	2.62	0.41	0.040	0.440
	100	3.09	0.80	0.193	0.431
COTTON					
NO3	0	2.59	0.40	0.069	0.731
	50	2.79	0.74	0.372	0.607
	100	2.44	1.19	1.081	0.482
	150	2.63	1.73	1.439	0.482
	200	2.16	2.69	2.523	0.479
	250	1.80	4.65	6.359	0.585
	300	1.89	4.60	8.585	0.662
NH4	0	2.50	0.58	0.123	0.683
	50	2.67	0.70	0.638	0.412
	100	2.91	0.99	1.056	0.308
	150	2.68	1.68	1.843	0.286
	200	2.17	2.71	2.545	0.293
	250	1.91	4.36	9.590	0.488
	300	1.96	4.48	8.209	0.541

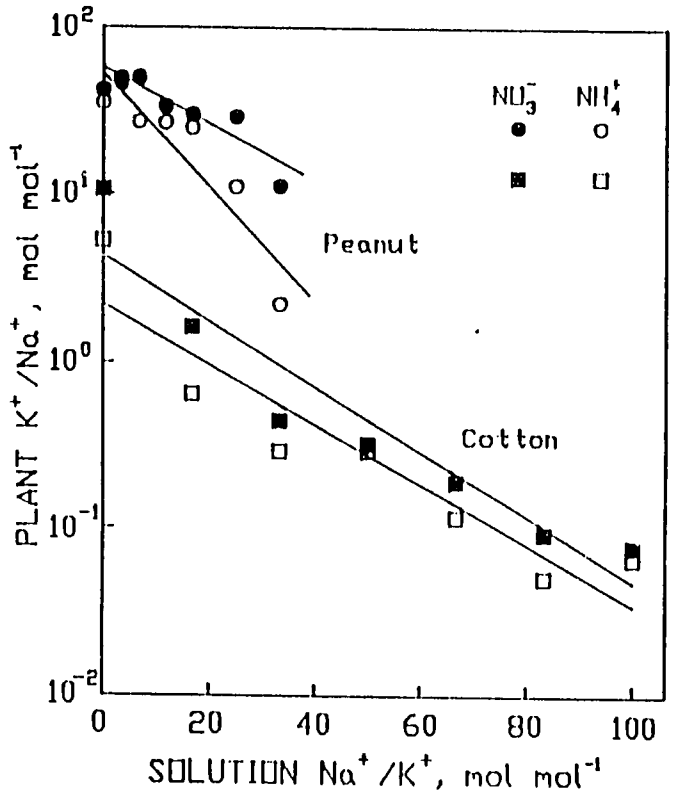
Table 8. Content of nitrogen, chloride, sodium and potassium in shoots of peanut and cotton plants growing in nutrient solutions with nitrate or ammonium under different salinity levels.

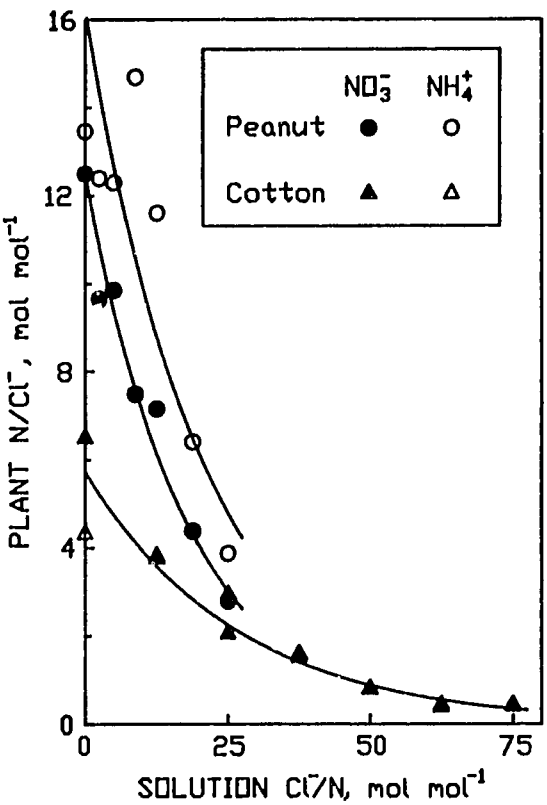
PEANUT

Nitrogen source	NaCl concn.(mM)	N	Cl	Na	
			(mmol/shoot)		
NO3	0	4.70	0.37	0.048	2.01
	10	4.90	0.51	0.039	1.80
	20	5.17	0.52	0.037	1.84
	35	3.93	0.52	0.046	1.52
	50	3.83	0.54	0.043	1.27
	75	3.10	0.71	0.037	1.06
	100	2.64	0.94	0.085	0.93
NH4	0	5.01	0.37	0.037	1.30
	10	4.09	0.33	0.020	0.97
	20	4.57	0.37	0.035	0.95
	35	4.07	0.28	0.031	0.82
	50	2.91	0.25	0.023	0.56
	75	2.77	0.43	0.042	0.46
	100	2.49	0.64	0.156	0.35
LSD 0.05		0.32	0.04	0.004	0.10

COTTON

NO3	0	3.66	0.56	0.097	1.03
	50	3.80	1.01	0.507	0.83
	100	2.05	1.00	0.909	0.40
	150	1.36	1.29	1.114	0.36
	200	1.09	1.36	1.274	0.24
	250	0.73	1.88	2.567	0.24
	300	0.68	1.67	3.112	0.24
NH4	0	1.82	0.42	0.093	0.50
	50	1.50	0.39	0.328	0.23
	100	1.67	0.57	0.606	0.18
	150	1.25	0.78	0.860	0.13
	200	0.79	0.99	0.931	0.11
	250	0.65	1.48	3.261	0.17
	300	0.45	1.03	1.889	0.12
LSD 0.05		0.14	0.07	0.062	0.04


10^2
10^1
10^0
10^{-1}
10^{-2}
PLANT K^+/Na^+, mol mol^{-1}
NO_3^-
NH_4^+
Peanut
Cotton
0
20
40
60
80
100
SOLUTION Na^+/K^+, mol mol^{-1}


16
12
8
4
0
0
25
50
75
PLANT N/Cl⁻, mol mol⁻¹
SOLUTION Cl⁻/N, mol mol⁻¹
NO₃⁻ NH₄⁺
Peanut
Cotton

(3b) Nitrogen concentration, ammonium/nitrate ratio and NaCl interaction in vegetative and reproductive growth of peanuts. (Silberbush and Lips)

Peanuts (Arachis hypogaea L.) grown with NO_3^- and saline water in hydroponics responded positively to addition of nitrogen (N) in their vegetative growth, but not in desert dune sand. In order to clarify these conflicting results, peanuts plants were grown in a greenhouse pot experiment with fine calcareous sand. The nutrient solution contained 0 or 50 mM NaCl and 2 or 6 mM N in the form of Ca $(NO_3)_2$, NH_4NO_3 or $(NH_4)_2SO_4$. Three replicates were harvested after 48 days (beginning of reproductive stage), and three after 109 days (pod filling). In addition, gynophores were treated with 0, 50, 100, 150 and 200 mM NaCl outside the growth pot to check their sensitivity to salt. Shoot dry weight became greater with increasing NH_4^+/NO_3^- ratio. Increasing the N concentration from 2 to 6 mM did not change shoot dry weight of the NH_4NO_3 or NH_4^+-fed plants, but caused a reduction in shoot dry weight of NO_3^--fed plants. Shoot dry weight was not affected by increasing the NaCl concentration to 50 mM. Salt caused an increase in the number of gynophores per plant and a reduction of the mean pod weight. A NaCl concentration of 100 mm and above reduced cynophore vitality. It is concluded that the salt sensitivity of peanut plants resides mainly in the sensitivity of the reproductive organs.

Introduction

Peanut plants (Arachis hypogaea L.) are classified as moderately sensitive to salinity (Maas and Hoffman, 1977). Conflicting results were obtained in previous studies of peanut plants in response to nitrate-nitrogen (NO_3^--N) and salinity when grown hydroponically (Silberbush et al., 1988) or in dune sand in the field (Silberbush et al., 1985). Peanut plants assimilate atmospheric N through symbiosis with Rhizobium spp. When supplemented with NO_3^-, the contribution of Rizobium-fixed N to the plant's nutrition is reduced (Hopmans et al., 1984; Becana et al., 1985, Peoples et al., 1986; Buttery and Dirks, 1987). This is important to plants being irrigated with brackish water, because most Rhizobium strains are sensitive to salinity (Singleton and Bohlool, 1983; Botsford, 1983, 1984).

Plants grown in nutrient solutions under controlled conditions usually prefer NO_3^- to NH_4^+ (Scherer and Mackown, 1987). However, N uptake from mixtures of the two is often better than from NO_3^- alone (Below and Gentry, 1987; Bock, 1987; Scherer and MacKown, 1987). No reference of this kind is available on legumes. Little is known about the effect of N form or NH_4^+/NO_3^- ratio on plant reaction to salt, although there is evidence that

some plant species may grow better under saline conditions when fed with both NO_3^- and NH_4^+ (Lips et al., 1987).

The economical importance of peanut plants, the problems involved in cultivation on sandy dunes and the conflicting results obtained in the field (Silberbush et al., 1985) led to the present study of peanut plants grown in a greenhouse with saline water and different inorganic N forms.

Materials and Methods

Experimental Procedure

Peanut plants (Arachis hypogaea L. cv. Shulamit) were grown in a greenhouse in black polyethylene pots with 10 kg fine desert dune sand (Calcareous, Typic Torripsamment) on top of 3 kg gravel, one plant per pot. The seeds were sown at the end of June, irrigated with tap-wate for 10 days and then subjected to the different nutritional treatments. The experimental layout was a factorial design of 2 water salinities (0 and 50 mM NaCl), 2 N concentrations (2 and 6 mM) and 3 NH_4^+/NO_3^- ratios (0/1, 1/1 and 1/0), in 6 replicates in randomized blocks. The following nutrients were applied to all the treatments. 0.25 mM $Ca(H_2PO_4)_2$, 1.5 mM K_2SO_4, 1 mM $MgSO_4$, 75 uM Fe-EDDHA and micronutrients according to Hoagland and Arnon (1950). NH_4^+ and NO_3^- were applied as $(NH_4)_2SO_4$ and $Ca(NO_3)_2$, respectively. The pots were irrigated in excess of their capacity every 2 days, and the leachates were analyzed for their EC_{25} to ensure efficient displacement of the old solution and to avoid accumulation of salts.

Vegetative Growth

Three blocks were randomly selected and harvested on 10 August 1986. The plants were cut at the soil surface, and leaves and stems were separately dried at 60° for 48 h, weighed, ground and samples were digested in $H_2SO_4 \cdot H_2O_2$. Total (reduced) N was determined by the Nessler reagent, phosphate-P by the ammonium molybdate-ascorbic acid method (Murphy and Riley 1962, and Ca^{2+} and Mg^{2+} were assayed by titration with EDTA. The following ions were determined in water extracts: NO_3^--N by the Szechrome-NAS reagent (R & D Authority, Ben-Gurion University of the Negev, Beer Sheva, Israel) after the solutions were cleared with $Al_2(SO_4)_3$; Cl^- by titration with $AgNO_3$ using a specific electrode and K^+ and Na^+ by flame photometry.

Reproductive Growth

The drip/trickling irrigation method resulted in the accumulation of salts at the margins and the upper wetted soil in very high concentrations, much higher than the original irrigation water (Silberbush and Ben-Asher,

unpublished results). These findings led to the study of salt effect on the reproductive organs of peanut plants. The remaining 3 blocks were grown with the original treatments until seed filling. In addition, plants grown in the absence of NaCl but with NH_4^+ or NH_4NO_3 (which were statistically similar in their vegetative growth) were randomly selected to study the effect of NaCl on gynophore growth and development. Black polyethylene bags with 10 kg fine sand were placed besides the pot with the plant, so that a portion of the gynophores was diverted to the side bags. Saline solutions which contained 0, 50, 100, 150 or 200 mM NaCl were applied in excess to 4 side bag replicates every 2 days. After 2 additional months (i.e. on 10 October) the gynophores in these additional pots were cut from the plant, counted, and classified as "live" or "dead". The total number of gynophores from each plant and the number of pods formed in the side bags were also counted. The shoots and the pods were dried at 60°C and weighed for dry matter.

Shoot dry weight at two growth stages are presented in Tab. 1 together with reproductive characteistics of peanut plants grown in sand with different concentrations of NaCl and N, and different NH_4^+/NO_3^- ratios. The increase in N concentration when applied as NO_3^- resulted in a decrease in yield parameters. This was not the case, however, when NH_4NO_3 or NH_4^+ were used at 2 and 6 mM N, resulting in similar yields. Increasing the NH_4^+ proportion increased dry matter yield of peanut plants of both vegetative or reproductive parts. NaCl at 50 mM did not significantly change shoot dry weight, but it doubled the number of gynophores per plant. The number of pods collected from the pot was similar with or without NaCl, but their mean weight was rduced by salt.

Concentrations of the different mineral nutrients in leaves and stems of 48 day old peanut plants were correlated within each treatment, and only the concentraitons in the leaves are presented (Fig. 1). Concentrations of NO_3^--N, Ca^{2+} and Mg^{2+} did not change among the different treatments and are not presented. Total N, K^+ and P concentrations became greater with the relative increase in NH_4^+ in the nutrient medium. The change in P concentration was the greatest.

The correlations between the various measured factors are presented in Table 2 (the insignificant factors have been omitted). All three major nutrients in the plants (i.e. N, P, K^+), but not NO_3^--N, were positively correlated to each other and to shoot dry weight. Na^+ and Cl contents were not associated with a reduction in shoot dry weight, but were associated with the number of gynophores per plant, as was the concentration of NaCl

(Table 1). The latter concentrations of ions did not change the number of pods, but reduced pod mean weight.

The results in Table 3 are normalized means of vital gynophores in each pot in order to provide a common ground for comparison between pots with uneven number of gynophores. The small number of treatments allowed the use of LSD as an estimate of the significant difference. The test was done on the transformed values of the percent vital gynophores P (expressed as a fraction): θ^{o}=arcsin P (Rholf and Sokal, 1981). Gynophores were sensitive to NaCl concentration in their surrounding medium (Table 3). Although 50 mM NaCl did not affect the vitality of the gynophores, higher concentrations increased their mortality.

Discussion

The peanut seeds used in this experiment were not inoculated with Rhizobium and the soil was collected from an unstablized, uncultivated sand dune. The only N source for the plants was that of the applied nutrient solution. Even so, the increase in N concentration from 2 to 6 mM was not associated with a similar increase in shoot dry matter production (Table 1). A nitrogen concentration of 2 mM was therefore sufficient. The increase in N percentage in the shoot when N, applied either as NH_4^+ or as NH_4NO_3, was increased to 6 mM (Fig. 1) was therefore due to luxury consumption. Application of NO_3^--N resulted in the lowest plant production. It reduced plant growth and nutrient uptake when its concentration was increased from 2 to 6 mm. NO_3^--N was also associated with a reduction in P percentage in the plant. An interaction between P and NO_3^- uptake is a common phenomenon (Miller 1974), but in our case it presumably was not the major cause of the poor P uptake by the plants. The increse of the NO_3^--N concentration in the nutrient solution from 2 to 6 mM did not significantly change P- percentage in the leaves or the stems (Fig. 1). The explanation may be, therefore, the change in pH at the root surfaces caused by different cation-anion balances: The soil contained crystalline $CaCO_3$, which should induce a pH 8.3 in the balanced soil solution. Absorption of N exclusively in the NO_3^- form should have caused an increase in the pH at the root surface (Barber 1984) because fo the low buffer capacity of this soil (Schaller, 1987). The relatively high pH would, in turn, cause P uptake by the plant to decrease to very low levels (Barber, 1984, Dunlop and Bowling, 1978). Changing the N form from NO_3^- to NH_4NO_3 or NH_4^+ doubled the percentage of P in the leaves and also shoot dry weight, while N and K^+ percentages increased. These results indicate that P was the limiting growth factor in NO_3^--N fed peanut plants, probably because of the relatively high pH at the root-soil interface.

Increasing the concentration of NO_3^- in the nutrient solution from 2 to 6 mM resulted in about 50% reduction of Na^+ in leaves of peanut plants grown with 50 mM NaCl (Fig. 1). A similar but more moderate reduction occurred for the Cl^- concentration in the leaves. This difference between the two ions indicates that the main effect of NO_3^- was on Na^+ concentration in the leaves, while Cl^- followed because of the cation-anion balance. These findings cannot be explained as simple ionic relationships, but are probably the result of indirect physiological processes induced by NO_3^- supply to the plants.

The increase in the NaCl concentration did not cause a reduction in shoot dry weight in any of the N concentrations or forms, although it was associated with the increase in Na^+ and Cl^- percentages in the shoot (Fig. 1). Na^+ and Cl^-, in turn, were associated only with reproductive development (Table 2). Vegetative growth of peanut plants seems to be rather tolerant to 50 mM Nacl, while the reproductive organs, i.e. the gynophores and the pods, are relatively sensitive. Their development was affected not only by the direct contact with the external saline medium, as the total number of gynophores was doubled due to the 50 mM NaCl in the nutrient solution. This indicates that the accumulation of Na^+ and Cl^- in the shoot caused some changes within the plant, even if they were not manifested by a reduction in shoot dry matter production. The increase in the number of hynophores was expressed later by an increase in the number of pods per plant (Tab. 1). The major effect of NaCl on peanut plants was on their pod yield. Even with a similar number of pods per plant, their mean weight became smaller due to the treatment with 50 mM NaCl. A further increase in the NaCl concentration in the soil solution increased the mortality of gynophores. The most widely used method of irrigation with saline water is the use of drip/trickling, which applies water from a point source and leaches the soluble salts continuously away. Use of this method avoids the accumulation of soluble salts near the emitter. Plants grown close to the emitter line, place their roots in an appropriate location so that the plants are not exposed to the salts with accumulated at the margins of the wetted soil (Silberbush and Ben-Asher, unpublished results). The gynophores which originated from the branches and elongated down into the soil below, could not avoid contact with the saline soil surface, which might contain very hgh concentration of salts. Sensitivity of peanut plants to salt under field conditions is, therefore, mainly due to salt hazard to their reproductive organs. These findings explain the conflicting results obtained in the field, where pod yield was severely reduced by water with EC_{25} of 4.5 dS m^{-1} while the hay yield was relatively unaffected (Silberbush et al. 1985).

References

Barber, S.A., 1984. Soil Nutrient Bioavailability. J. Wiley & Sons, New York, N.Y., p. 138-139. ISBN 0-471-09032-8.

Becana, M., Aparicio-Tejo, P.M. and Sanchez-Diaz, M., 1985. Nitrate and nitrite reduction by alfalfa root nodules: accumulation of nitrite in Rhizobium meliloti bacteroids and senescence of nodules. Physiol. Plant 64, 353-358.

Below, F.E. and Gentry, C.E., 1987. Effect of mixed N nutrition on nutrient accumulation, partitioning, and productivity of corn. J. Fertilizer Issues 4, 79-85.

Beyer, W.H. (ed.), 1968. CRC Handbook of Tables for Probability and Statistics. 2nd Ed., pp. 368-378. CRC Press Inc., Boca Raton, FL. ISBN 0-8493-0692-2.

Bock, B.R., 1987. Increases in maximum yield of spring wheat by maintaining relatively high ammonium/nitrate ratios in soil. J. Fertilizer Issues 4, 68-72.

Botsford, J.L., 1983. Effect of saline and alkaline conditions on growth of peanut (Arachis hypogaea) rhizobia. Micribios. Lett. 24, 75-80.

Botsford, J.L., 1984. Osmoregulation in Rhizobium meliloti: inhibition of growth by salts. Arch. Microbiol. 137, 124-127.

Buttery, B.R. and Dirks, V.A., 1987. The effects of soybean cultivar, rhizobium strain and nitrate on plant growth, nodule mass and acetylene reduction rate. Plant Soil 98, 285-293.

Dunlop, J. and Bowling, D.J.F., 1978. Uptake of phosphate by white clover. II. The effect of pH on the electrogenic phosphate pump. J. Exp. Bot. 29:1147-1153.

Hall, D.A., 1983. The influence of nitrogen concentration and salinity of recirculating solutions on the early-season vigour and productivity of glasshouse tomatoes. J. Hort. Sci. 58, 411-415.

Hoagland, D.R. and Arnon, D.I., 1950. The Water-Culture Method for Growing Plants Without Soil. Univ. California, Berkeley, Circ. 347, 32 pp.

Hopmans. P., Douglas, L.A. and Chalk, P.M., 1984. Effects of soil salinity and mineral nitrogen on the acetylene reduction activity of Trifolium subterraneum L. - Aust. J. Agric. Res. 35, 9-15.

Lips, S.H., Soares, M.I.M., Kaiser, J.J. and Lewis, O.A.M., 1987. K^+ modulation of nitrogen uptake and assimilation in plants. In: Inorganic Nitrogen Metabolism (W.R. Ullrich, P.J. Aparicio, P.J. Syrett and F. Castillo, eds.), pp. 233-239 Springer-Verlag, Berlin ISBN 3-540-17532-6.

Maas, E.V. and Hoffman, G.J., 1977. Crop salt tolerance - current assessment. J. Irrig. Drain. Div. ASCE (IR-2) 103, 115-134.

Miller, M.W., 1974. Effect of nitrogen on phosphorus absorption by plants. In: The Plant Root and its Environment (E.W. Carson, ed.). pp. 643-668. University Press, Univ. Virginia, Charlotteville, VA ISBM 0-8139-0411-0.

Murphy, J. and Riley, J.P., 1962. A modified single solution methd for the determination of P in natural waters. Anal. Chim. Acta 27, 31-36.

Peoples, M.B., Pate, J.S., Atkins, C.A. and Bergersen, F.J., 1986. Nitrogen nutrition and xylem sap composition of peanut (Arachis hypogaea L. cv Virginia Bunch). Plant Physiol. 82, 946-951.

Rholf, F.J. and Sokal, R.R., 1981. Statistical Tables. 2nd Edition. Pp. 53-56, W.H. Freeman and Co., New York, ISBN 0-7167-1257-1.

Schaller, G., 1987. pH changes in the rhizosphere in relation to the pH-buffereing of soils. Plant Soil 97, 439-444.

Scherer, H.W. and MacKown, C.T., 1987. Dry matter accumulation, N uptake, and chemical composition of tobacco grown with different N sources at two levels of K. J. Plant Nutr. 10, 1-14.

Silberbush, M., Ben-Asher, J., Kafkafi, U. and Lips, S.H., 1985. Fertigation of peanuts grown in sandy dunes and irrigated by trickling with slaine water. In: Drip/Trickle Irrigation in Action. Proc. 3rd Intl. Drip/Trickle Irrig. Congr. ASAE, 2, 652-658. Fresno, Ca. ISBN 0-444-42641-8.

Silberbush, M., Golan-Goldhirsh, A., Heimer, Y., Ben-Asher, J. and Lips, S.H., 1988. Response of peanuts (Arachis hypogaea L.) grown in saline nutrient solution to potassium nitrate. J. Plant Physiol. 132, 229-233.

Singleton, P.W. and Bohlool, B.B., 1983. Effect of salinity on the functional components of the soybean-Rhizobium japonicum symbiosis. Crop Sci. 23, 815-818.

Figure Caption

Fig. 1: Concentration of N, P, K, Na^+ and Cl^- in leaves of peanuts grown in sand with different concentrations of NaCl and N, and different NH_4^+/NO_3^- ratios in the nutrient solution. Bars with different letters represent means which differ significantly ($P<0.05$) according to Duncan's New Multiple Range Test (Beyer, 1968).

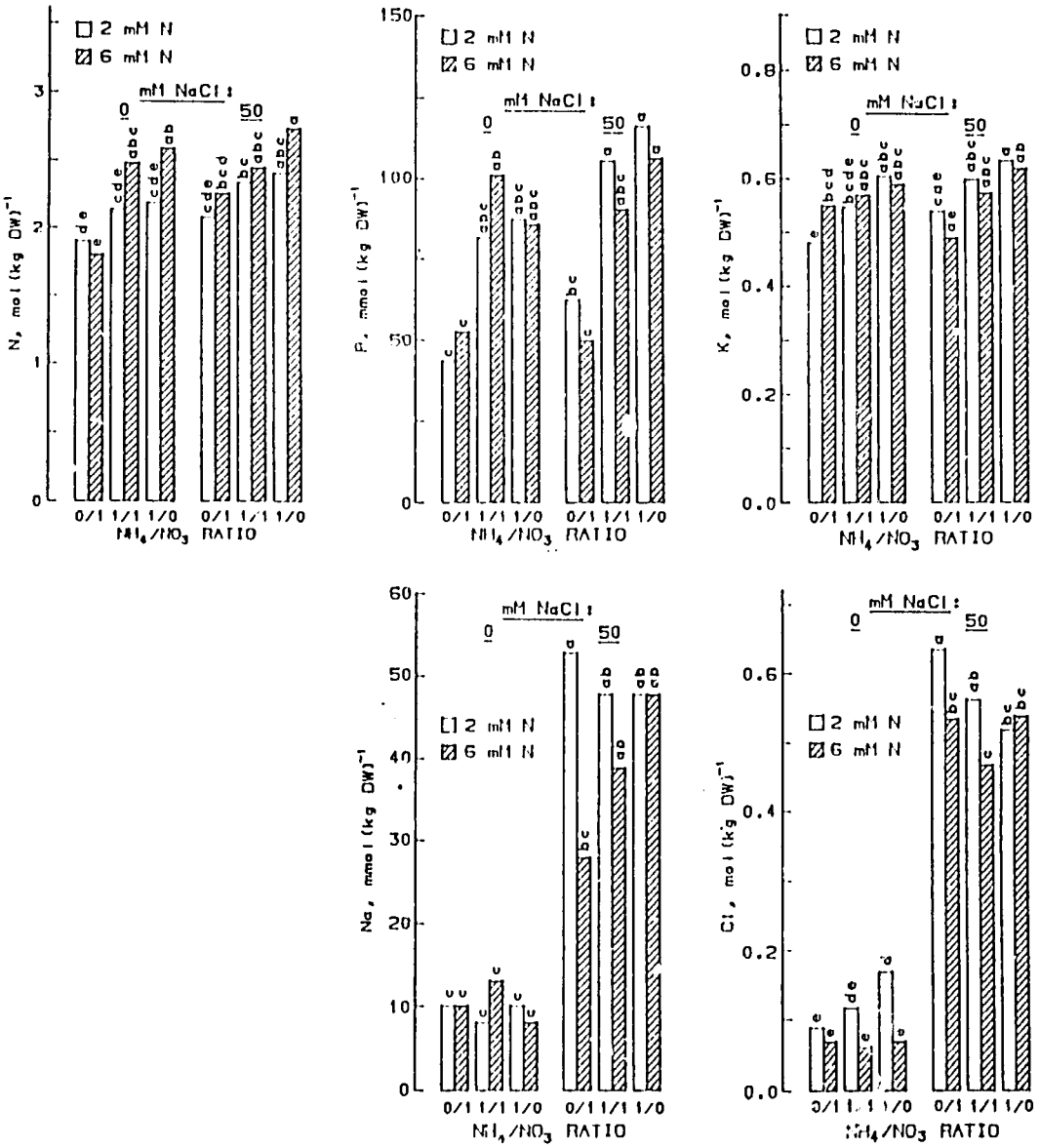


Fig. 1. Concentrations of N, P, K^+, Na^+ and Cl^- in leaves of peanuts grown in sand with different concentrations of NaCl and N, and different NH_4^+/NO_3^- ratios in the nutrient solution. Bars with different letters represent means which differ significantly ($P<0.05$) according to Duncan's New Multiple Range Test (Beyer 1968).

Tab. 1. Vegetative and reproductive growth of peanut plants grown with different concentrations of NaCl and N , and different NH_4^+/NO_3^- ratios. Pod DW includes only the pods which were grown within the pot. Within each column, means with different letters are significantly different ($P<0.05$) according to Duncan's New Multiple Range Test (Beyer 1968).

N	N-form	Shoot DW, g (plant)$^{-1}$		Gynophores	Pods	Pod DW,
mM		48 days	109 days	plant^{-1}	plant^{-1}	g (plant)$^{-1}$
				0 NaCl		
2	NO_3^-	5.3^{a-d}	37^{ab}	64^{d-f}	28^{b-d}	22^{cd}
	NH_4NO_3	8.5^{a}	37^{ab}	69^{de}	32^{a-c}	32^{bc}
	NH_4^+	8.3^{a}	53^{ab}	74^{c-e}	41^{ab}	43^{ab}
6	NO_3^-	3.7^{d}	19^{b}	27^{f}	12^{d}	9^{d}
	NH_4NO_3	7.7^{ab}	40^{ab}	58^{ef}	37^{a-c}	32^{bc}
	NH_4^+	7.3^{a-c}	67^{a}	116^{ab}	50^{a}	49^{a}
				50 mM NaCl		
2	NO_3^-	4.0^{cd}	47^{ab}	99^{b-d}	41^{ab}	19^{cd}
	NH_4NO_3	7.9^{a}	63^{a}	118^{ab}	30^{bc}	16^{cd}
	NH_4^+	6.8^{a-d}	56^{ab}	125^{ab}	49^{a}	26^{cd}
6	NO_3^-	4.4^{b-d}	39^{ab}	70^{de}	19^{cd}	12^{d}
	NH_4NO_3	5.8^{a-d}	52^{ab}	110^{a-c}	35^{a-c}	19^{cd}
	NH_4^+	5.1^{a-d}	57^{ab}	142^{a}	35^{a-c}	20^{cd}

b. 2 Correlation coefficients among different yield parameters and neral composition of peanuts grown with different con centrations of .Cl N, and different NH_4^+/NO_3^- ratios. N, NO_3^-, P, K^+, Na^+, Cl^- - rcentages of nitrogen, nitrate-N, phosphate, potassium, sodium and loride in the leaves, res pectively; SDW1 - shoot DW, 48 days; SDW2 - oot DW, 109 days; Gyn - no. of gynophores per plant; Pods - no. of ds per pot; PDY - Pod DW yield; MPW - pod mean weight. *, **, *** - gnificance level of 0.0 01, 0.01, 0.05, res pectively.

	N	NO_3^-	P	K^+	Na^+	Cl^-	SDW1	SDW2	Gyn	Pods	PDY
$^-$ 3	-										
	0.76**	-									
	0.63*	-	0.91***								
+	-	-	-	-							
-	-	-	-	-	0.95***						
W1	-	-	0.61*	-	-	-					
W2	0.74**	-	0.67**	0.62*	-	-	-				
n	0.76**	-	0.66**	0.59*	0.71**	0.64*	-	0.89***			
ds	0.57*	-	0.61*	0.56*	-	-	-	0.75**	-		
Y	-	-	-	-	-	-	0.71**	-	-	0.73**	
W	-	-	-	-	-0.85***	-0.88***	-	-	-0.66**	-	-

Tab. 3 Percentage of pods produced by peanut gynophores treated with different NaCl concentrations. Means follwed by the same letter do not differ significantly at $P<0.05$ according to LSD.

NaCl mM	Vital gynophores %
0	100[a]
50	97[a]
100	62[b]
150	26[c]
200	0[d]

(3c) Effects of KNO_3 on peanut (Arachis hypogaea L.) irrigated with saline water.
(Reano, Pacardo, Mercado and Lips)

Introduction

The detrimental effects of salinity on the physiological and biochemical processes of peanuts have already been reported. Charan and Karadge (1980a) observed that chlorophyll content was mainly affected by NaCl. Na_2SO_4 treatment resulted in a lower photosynthetic rate of decrease in CO_2 fixation. This could be attributed possibly to the depression of chloroplast metabolism in peanuts grown under salt-stress which eventually limit growth of the plants (Sanjeeva, Reddy and Das, 1978). Furthermore, NaCl salinity altered stomatal characteristics and behavior of peanuts. It changed the percent distribution of stomatal types, frequency and index (Devi and Rao, 1980).

Irrigation of peanuts with saline water containing NaCl or Na_2SO_4 resulted in a decrease in pod yield but increased total lipid content of seeds. Silberbush et al. (1985), however, showed that salinity hazards in peanuts can be reduced by adequate KNO_3 fertilization. They claimed that the major effects of salinity on peanut was due to Na-K interaction.

In this study, we report the beneficial effects of KNO_3 fertilization on growth and mineral composition of peanuts irrigated with saline water.

Materials and Methods

The effect of KNO_3 on the growth and mineral composition of peanut (Arachis hypogaea L. cv. UPL Pn 2) irrigated with saline water was studied at the IBS Greenhouse, University of the Philippines at Los Banos (UPLB) College, Laguna, PHilippines from January to April 1987.

The pot experiment was laid out in a 3 x 3 factorial in completely randomized design (CRD) with two replications. There were two subsamples per replication. The different variables include 3 salinity levels of irrigation water (0.6, 5.6 and 10.6 mmhos/cm at 25°C) and 3 concentrations of KNO_3 (0, 60, 600 ppm).

Different dilutions of pure sea water (EC 32 mmhos/cm at 25°C) and oridinary tap water (EC 0.6 mmhos/cm at 25°C) were prepared prior to treatment applicaiton. The desired electrical conductivity (EC) readings of

the previously mixed saline water and KNO_3 were predetermined using a portable conductivity bridge.

Salinization treatments started at about 6 weeks after seed sowing in pots containing 1.5 kg dried Maahas clay loam soil. The different treatments/solutions were applied as irrigation water in equal volume (i.e., 500 ml/pot). Application of solution mixtures (saline water and KNO_3) was done regularly every other day for a period of 5 weeks. The different cultural management practices like fertilization, seeding, pot management, etc. were adequately provided during the entire period of the experiment.

The different growth parameters gathered were shoot length, root length, fresh and dry weights of roots and shoots and number of leaves/flowers. The mineral nutrient elements as N, K, Ca, Mg, Na and Cl were analyzed from tissue samples following the standard procedures of Yoshida et al., 1976. The visual deficiency or toxicity symptoms were also noted during the growth period.

The data were analyzed statistically. Regression and correlation analyses were also done to detect the relationships of the different parameters gathered.

Results and Discussion

Visual Observations. The early toxicity sympotom in peanuts include apparent temporary wilting which usually starts on younger leaves. This was manifested by "cupping" of leaves. The leaves of peanut were water-soaked in appearance which eventually dried up especially at very high salt-levels (10.6 mmhos/cm) without KNO_3. There was an extensive elongation of few and finer roots. This observation was not noted for plants supplied with higher KNO_3 levels (600 ppm). Higher salinity levels reduced branching and leaf production. The surviving leaves, especially the new ones were exhibiting interveinal chlorosis which resembles that of Fe deficiency. In severe cases the plant ultimately dried up.

Growth. The effects of KNO_3 on the different growth parameters of peanuts irrigated with varying levels of saline water are summarized in Table 1. The interaction effects of KNO_3 and salinity levels (Table 2) were statistically significant in all growth parameters except dry weights of roots and shoots (Table 4). These two parameters, however, were affected by salinity levels alone.

In general, shoot length, shoot fresh weight, root fresh weight and number of flowers decresed almost linearly with increasing salinity levels without KNO_3. Addition of KNO_3 apparently ameliorated the toxic effects of salts on growth. There seems to be an increase in root and shoot fresh weights, shoot length and number of flowers, especially at 5.6 mmhos/cm and 600 ppm KNO_3. At higher salinity levels (10.6 mmhos/cm), the beneficial effects of KNO_3 are not very distinct. The root length, however, increased quite remarkably.

The results generally confirmed previously reported observations on the significant roles of K in plant adapation to environmental stresses like salinity. According to the literature, the biophysical and biochemical function of K in different stages of plant growth and development play a vital role in plant adaptation to stresses. It directly participates in the mechanism of stomatal movements, photosynthesis and osmoregulatory adaptation of plants to stresses like salinity (Beringer and Trolldenier, 1979; Beringer, 1980).

Table 3 shows that the effects of KNO_3 alone was statistically significant only on shoot dry weight of peanuts. Regardless of the salinity levels increasing the concentration of KNO_3 favorably enhanced dry matter accumulation in the shoot. Again, this observation can be explained partially by considering the multifarious roles of K on the different metabolic processes in plants (Evans and Sorger, 1966; Dijkshoorn et al., 1968). Likewise, addition of nitrate would also favor nitrogen metabolism in plants grown in a saline environment.

Nitrogen. The interaction between salinity and KNO_3 was not statistically significant. The same observation holds true for the effect of KNO_3 or salinity *per se* (Table 1). Based on this observation, it seems very likely that peanut plants are not very responsive to added KNO_3 since it can fix atmospheric nitrogen through symbiotic relationship with *Rhizobium* bacteria (Martin et al. 1976).

Chloride. The amount of chloride in shoots generally increased with increasing salinity levels (Table 5), regardless of KNO_3 concentrations. However, it is evident that addition of KNO_3 seemingly depressed chloride uptake to a considerable extent. Addition of 600 ppm KNO_3 appears to be sufficient enough to suppress chloride uptake even at higher salinity levels, i.e., 10.6 mmhos/cm. The injurious effects of excessive Cl^- accumulation on growth have been reported in several crops like avocado (Bingham et al., 1968), grapevines (Bernstein et al., 1965) and in fruit trees of many other woody plants (Bernstein, 1975).

Potassium. A highly significant interaction between salinity and KNO_3 levels was noted on the potassium content of peanuts (Table 1). The general trend indicates that the K content of shoots decreased markedly with increasing salinity levels. The data also suggest a limited K uptake in the presence of excess salts. According to Kuiper (1984) NaCl salinity could inhibit absorption and translocation of K including Ca. The antagonistic relationship of Na and K absorption has also been reported in several crops like rice (Panaullah, 1980; Elms et al., 1977).

Sodium. The sodium content of shoots and roots of peanuts increased markedly especially in the presence of excessive salts. The trend is similar regardless of KNO_3 concentrations. However, there was a slight decrease in Na uptake when 60 ppm KNO_3 was added in the growth medium. This observation also indicates the possible beneficial effects of K^+ in suppressing Na uptake as reported earlier (Panaullah, 1980; Elms et al., 1977). Siiberbush et al. (1985) also claimed that the major effect of salinity on peanut was due to Na-K interactions. In addition, Silberbush et al. (1985) proved that the adverse effects of salinity on peanuts can be reduced by adequate KNO_3 fertilization.

Calcium. The uptake of calcium increased significantly with increasing salinity especially in those salinity treatments without KNO_3 (Table 5). Addition of KNO_3, however, did not cause much variation in Ca content of peanut shoots. In roots, higher salinity (10.6 mmhos/cm) without KNO_3 caused a reduction in Ca concentration in roots. Furthemore, Ca in roots increased with addition of KNO_3 even at higher salinity levels. The data apparently indicate the beneficial effects of Ca in plants grown in saline environment as previously reported by other researchers (Lahaye and Epstein, 1969; Gildensoph and Davis, 1983; Kent and Lanchli, 1985; Marchar, 1986).

Magnesium. the general trend for Mg uptake in shoots of peanut behaves similarly with that of Ca. The concentration of Mg in tissues increased with increasing levels of slainity without KNO_3. According to Murthy and Rao (1965) increasing salinity of the growth medium could result in a stimulation in Mg uptake.

Na/K Rato. The Na/K ratios in shoot and roots of peanuts are presented in Table 9. Addition of KNO_3 in the medium generally resulted in a marked reduction in the Na/K ratio in both organs seen at higher salinity levels (10.6 mmhos/cm). The data suggests that 60 ppm KNO_3 is apparenlty sufficient enough to alter the ratio. It has been previously, hypothisized that higher Na/K ratio in saline environment can impair the selectivity of root

membrane and may lead to passive accumulation of Na in the root and shoot (Kramer et al., 1977).

Correlation Analysis. Table II shows the relationships of salinity levels or KNO_3 with the different growth parameters gathered as detemined by correlation analysis. Salinity was found to be negatively correlated with shoot length, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight and of total N in shoot. Root length of peanuts, on the other hand, was found to be positively correlated with salinity. This observation is also true for Cl, Na, N and Mg uptake. Furthermore, KNO_3 was found to be positively correlated only with shoot dry weight.

Table 1. Summarized results of statistical data analysis on the effect of varying levels of water slainity and KNO_3 on the growth and mineral composition of peanut (Var. UPL Pn_2).

PARAMETER	SALINITY	KNO_3	SALINITY	KNO_3
1. Shoot length (cm)	**	**	**	
2. Root length (cm)	**	*	**	
3. Shoot fresh weight (gm)	**	**	*	
4. Root fresh weight (gm)	**	ns	**	
5. Shoot dry weight (gm)	**	*	ns	
6. Root dry weight (gm)	**	ns	ns	
7. Number of flowers	**	*	**	
8. % Total N in shoot	ns	ns	ns	
9. % Cl^- in shoot	**	**	**	
10. % K in shoot	**	**	**	
11. % K in root	**	**	**	
12. % Na in shoot	**	**	**	
13. % Na in root	**	ns	**	
14. % Ca in shoot	**	**	**	
15. % Ca in root	ns	**	**	
16. % Mg in shoot	**	**	**	
17. % Mg in root	ns	**	ns	

* Significant ** Highly significant ns - Not significant

Table 2. Interaction effects of varying levels of water salinity and KNO_3 on the different growth parameters of peanut (Var. UPL Pn2).

TREATMENT COMBINATIONS		GROWTH PARAMETERS				
Salinity (mmhos/cm)	KNO_3 (ppm)	Shoot Length (cm)	Root Length(cm)	No. of Flowers	Shoot Fresh wt(gm)	Root Fresh wt (gm)
0.6	0	24.50a	18.40c	17.50a	19.85ab	5.50a
0.6	60	21.65abcd	14.95d	12.00abcd	13.95c	2.54cd
0.6	600	23.00ab	17.70c	15.00ab	21.55a	3.70abc
5.6	0	18.70defg	15.50cd	4.50g	7.50d	1.45d
5.6	60	21.50abcdef	15.65cd	14.00abc	13.80c	3.85ab
5.6	600	23.00ab	20.85bc	9.50cdef	15.20abc	2.30cd
10.6	0	10.50h	34.05a	1.50h	2.55e	0.60e
10.6	60	17.15fg	26.25b	11.50bcde	7.20d	1.45d
10.6	600	20.00cbdef	20.60c	8.50cdef	8.45d	2.20cd
GRAND MEAN		20.00	20.44	10.44	12.23	2.59
C.V. (%)		6.65	10.74	22.20	40.45	25.84

Table 3. Interaction effects of varying levels of water salinity and KNO_3 on mineral composition of peanut (Var. UPL Pn2).

TREATMENT COMBINATIONS		MINERAL COMPOSITION[1/] (%)							
Salinity (mmhos/cm)	KNO_3 (ppm)	% Cl in Shoot	% K in Shoot	% K in Root	% Na in Shoot	% Na in Root	%Ca in Shoot	%Ca in Root	% Mg in Shoot
0.6	0	0.68d	0.01e	0.03a	0.01e	0.02g	0.16bc	0.52cdef	0.09bce
0.6	60	0.63d	0.90b	0.15b	0.05e	0.06defg	0.16bc	0.58bcd	0.07bce
0.6	600	0.95d	1.04a	0.10c	0.90d	0.09bcd	0.16bc	0.55bcde	0.07bce
5.6	0	6.45b	0.01e	0.06ef	1.25c	0.12b	0.25b	0.6[illegible]abc	0.09bce
5.6	60	1.88d	0.47c	0.09cd	0.61d	0.11bc	0.18bc	0.67abc	0.12bc
5.6	600	3.57c	0.11d	0.07de	1.52c	0.07cdef	0.12c	0.46def	0.15b
10.6	0	8.77a	0.01e	0.04fg	3.65a	0.17a	0.90a	0.32g	0.17a
10.6	60	5.89b	0.01e	0.04fg	1.53c	0.08bcde	0.18bc	0.71a	0.12bc
10.6	600	6.03b	0.02e	0.03g	2.85b	0.08bcde	0.24bc	0.64abc	0.12bc
GRAND MEAN		3.87	0.29	0.07	1.37	0.09	0.26	0.56	0.13
C.V. (%)		13.86	6.66	14.29	9.14	20.40	19.25	8.61	8.14

[1/] Means followed by same letters are not significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance.

Table 4. Effect of different water salinity levels on shoot and root dry weights of peanuts (Var. UPL Pn 2).

Salinity levels (mmhos/cm)	Shoot Dry wt (gm)	Root Dry[1] wt (gm)
0.6	3.61 a	0.73 a
5.6	2.91 ab	0.46 b
10.6	2.21 b	0.33 b

1 Means followed by same letters are net significantly diferent according to duncan's Multiple Range Test (DMRT) at 5% level of significance.

Table 5. Effect of different levels of KNO_3 on shoot dry weight and root Mg content of peanut (Var. UPL Pn 2).

KNO_3 levels (ppm)	Shoot dry wt. (gm)	Mg content (%) in Root
0	2.25 a	0.26 b
60	2.94 ab	0.42 a
600	3.53 b	0.36 ab

1 Means followed by same letters are not significantly different accoring to duncan's Multiple Range Test (DMRT) at 5% level of significance.

(4) Rice

(4a) Morpho-physiological responses of two rice varieties to varying NaCl levels and nitrogen sources.
(Reano, Pacardo, Mercado and Lips)

Introduction

Nitrate and ammonium are the two major forms of nitrogen that can be assimilated by plants. The potential capacity of plants to metaboiize these ions varies according to plant species (Cox and Reisenauer, 1973; Krajina, et al., 1973; Allan and Smith 1986) and probably among varieties within each species.

The major processes leading to the assimilations of inorganic nitrogen to its organic form are quite sensitive to environmental stresses like salinity, as has been previously reported in literature. Helal and Mengel (1979) reported that NaCl salinizations impaired growth and incorporation of labelled N into the protein fraction paralleled by accumulation of labelled inorganic N in young barley plants.

Based on recent studies on rice, the use of diffeent forms of nitrogen might probably alleviate the toxic effects of salinity. In a recent study of Ramani and Kannan (1986), the presence of $(NH_4)_2SO_4$ reduced the uptake of ^{22}Na-labelled NaCl in 3 rice cultivars differing in their salinity tolerance. It was also noted that the presence of 100 ppm KCl, KNO_3 or NH_4NO_3 reduced Na absorption from 0.1 mM NaCl significantly in all cultivars. Furthermore, chloride transport from 0.1 mM NaCl was reduced by $(NH_4)_2SO_4$ in all the cultivars.

In this study we are reporting some of the morpho-physiological responses of salt-tolerant and salt-sensitive rice varieties to varying NaCl levels and nitrogen sources.

Materials and Methods

This experiment was conducted in the greenhouse of the Plant Adaptation Research Unit, The Jacob Blaustein Institute for Desert Research, Ben-Gurion University of the Negev, Sede Boqer Campus, Israel from September to December 1987.

Seeds of salt-tolerant (Nona-Bokra) and salt-sensitive (IR-28) rice varieties were sown in vermiculite. The two-week old seedlings were

transferred and grown hydroponically in modified Long-Ashton solution containing 4 mM each of ammonium and nitrate. Ammonium chloride (NH_4Cl) and sodium nitrate $NaNO_3$ were the sources of NH_4 and NO_3^-, respectively. The concentrations of other macro- and micro-nutrients added in the medium were based on Long-Ashton solution (Hewitt, 1966).

The diferent treatments were 5 NaCl levels (0, 25, 50, 75, 100 mM); two N-sources (4 mM each NH_4^+ and NO_3^-) and two rice varieties (salt sensitive IR-28 and salt-tolerant Nona-Bokra). The experimental design used was 5 x 2 x 2 factorial in RCB with two replications. There were two sub-samples per replication.

The pH of the solution was maintained at a range of 5.0-6.0 using either concentrated KO_4 or H_2SO_4 to adjust the pH. Culture solutions were changed regularly every week.

The data gathered were the growth parameters such as leaf area, and length and dry weight of shoot and root.

Photosynthetic and transpiration rates of the longest, youngest, and fully expanded leaves were measured using the infrared gas analyzer (LCA-2 Analyzer, ADC), at atmospheric CO_2 concentrations in the differential mode, and at constant radiation (PAR, 500 umol/m^2/S).

The root and shoot tissue samples for nutrient analysis were dried in an oven at 65-70°C. Nitrogen determination was done after digestion and mineralization using concentrated H_2SO_4 and 30% H_2O_2. The digested extracts were analyzed for total N (mostly reduced forms) using Nessler's reagent. Sodium and potassium were also analyzed from the digested extracts by flame emission photometry. Chloride was determined after extraction of tissue samples in hot water using a chloride meter analyzer (Corning Chloride Analyzer 926).

RESULTS AND DISCUSSION

Growth. The general trend indicates that growth in terms of leaf area, shoot and root dry weights and length decreased with increasing levels of NaCl salinities. However, it is interesting to note the apparent beneficial effects of nitrate compared with ammonia as N-source for those plants grown in salt-stressed conditions. Regardless of the variety, the nitrate grown plants seem to tolerate even the highest levels of salinity, i.e., 100 mM NaCl (Figures Ia-E and Plates I and II). In fact, remarkable increases in shoot dry weight, shoot length, root length and leaf area were noted at 100

mM NaCl supplied with 4 mM NO_3^-. This observation was clearly manifested by the salt-tolerant variety Nona Bokra.

The significant differences in salinity tolerance of different rice varieties have already been reported by some researchers (Akbar et al., 1972; Flowers and Yeo, 1981). Fageria (1985) classified these different varieties of rice as tolerant, moderately susceptible, or insusceptible ones, based on dry matter yield and yield reduction. Yeo and Flowers (1985), however, emphasized that there is no single parameter that could fully describe the potential agronomic performance of a salt-tolerant and salt-sensitive variety mainly because of the complicated physiological responses of rice to saline conditions.

The shoot to root ratios are also presented in Figure 1-F. The highest ratio was observed in 25 mM NaCl supplied with NH_4^+. NH_4-N apparently favors shoot growth better than the root, especially the salt-tolerant variety. There was an abrupt decrease in shoot/root ratio of IR-28 at higher NaCl levels, i.e., 50-100 mM NaCl. This clearly indicates its more sensitive response to higher NaCl salinity (Plate 1-A).

The growth responses of plants to different sources of nitrogen vary according to species and varieties (Ikeda and Osawa, 1980 and1981). The growth of most plant species was stunted when ammonium alone was applied as nitrogen source. Some plants, however, grew better when supplied with nitrate-nitrogen alone. Lewis and Chadwick (1983) studied the assimilation of nitrogen in barley. The largest fresh weights and highest $_{15}N$ incorporation rates of 20-day old plants were obtained when nitrate and ammonium were supplied. The nitrate-fed plants had the lowest incorporation rate while the ammonium-fed plants had the lowest fresh weight. These results suggest that a combination of both ammonium and nitrate could be better for plants, especially when grown under salt-stressed conditions.

Photosynthetic and Transpiration Rates. The rates of photosynthesis and transpiration of two rice varieties were determined 3 weeks after treatment application using the infrared gas analyzer (LCA-2 Analyzer, ADC). The data are presented in Figure 2. Regardless of nitrogen source and variety, slight increases in photosynthesis and transpiration were observed at a lower salinity level (25 mM NaCl). The general trends for almost all treatments were similar. There seems to be not much variation in photosythetic and transpiration rates at each salinity treatment. The increase in photosynthetic rate in the presence of low concentration of salts have already been reported in literature. For example, Kingsburg et al.

(1984) observed higher relative photosynthesis in wheat grown in salinity stress condition.

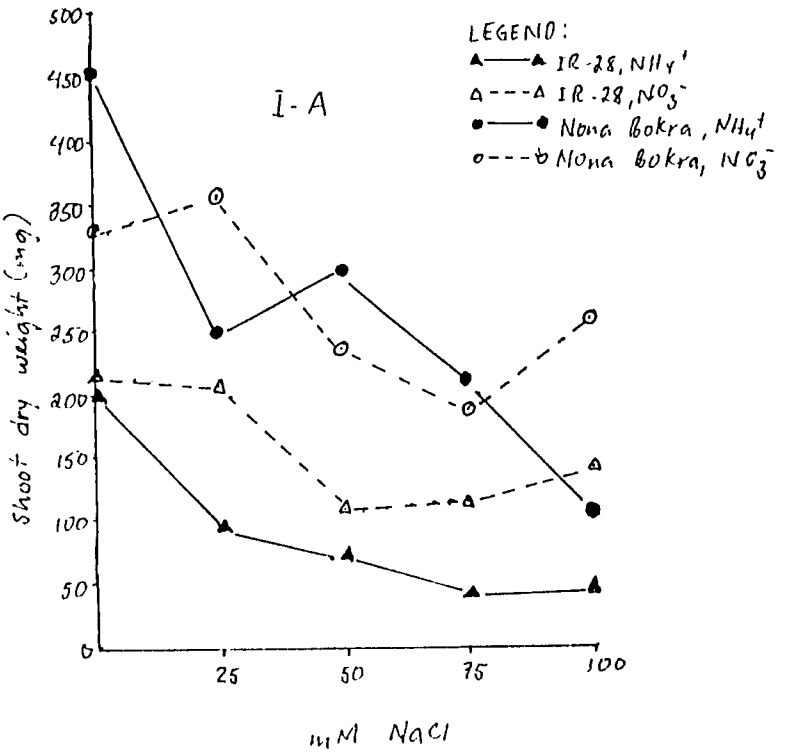
Mineral Nutrient Composition. The chloride, sodium, nitrogen and potassium content of shoots and roots are presented in Figures 3 and 4. In general, the salt-sensitive variety (IR-28) absorbed more chloride and sodium at higher salinity levels. The decline in NH_4^+ grown IR-28 at 100 mM NaCl was due to inhibition in nutrient absorption as a result of complete wilting and death of plants. This was clearly shown in photosynthesis and transpiration data. At a higher level of salinity (i.e. 75-100 mM), NH_4^+-grown plants (IR-28) were no longer showing signs of photosynthesis and transpiration due to total wilting of plants. The NH_4^+-grown Nona Bokra continued to accumulate more Cl^- and Na^+ even at higher salinity levels. This salt-tolerant variety, however, was still surviving despite rapid accumulation of toxic ions. This probably is an indication of its salinity tolerance.

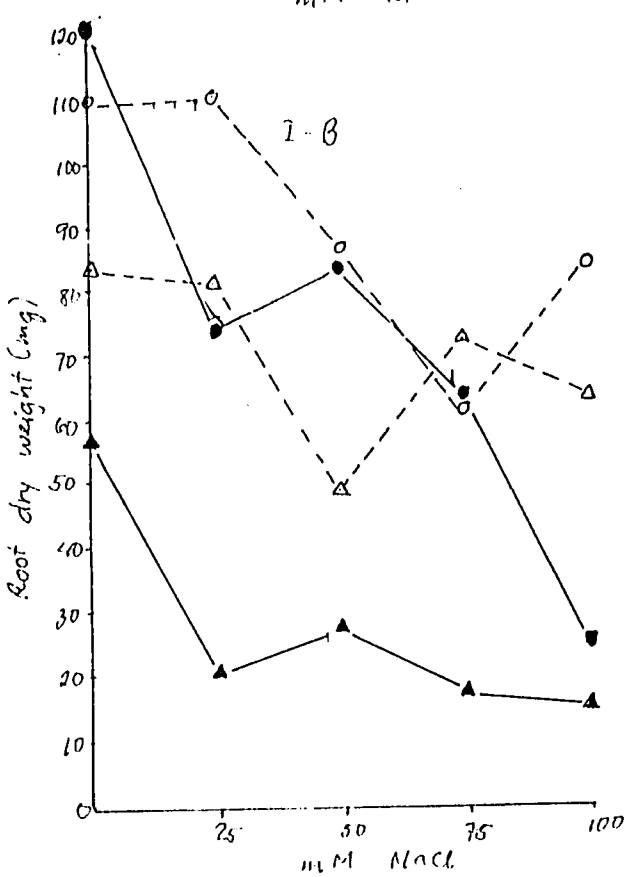
The interesting observation here was the marked decline in Cl^- in Na^+ shoot content of both varieties at higher salinity levels. The reverse holds true for the roots of both varieties. This observation apparently suggest possible re-translocation of toxic ions such as Na^+ and Cl^- in the roots, especially for the salt tolerant variety.

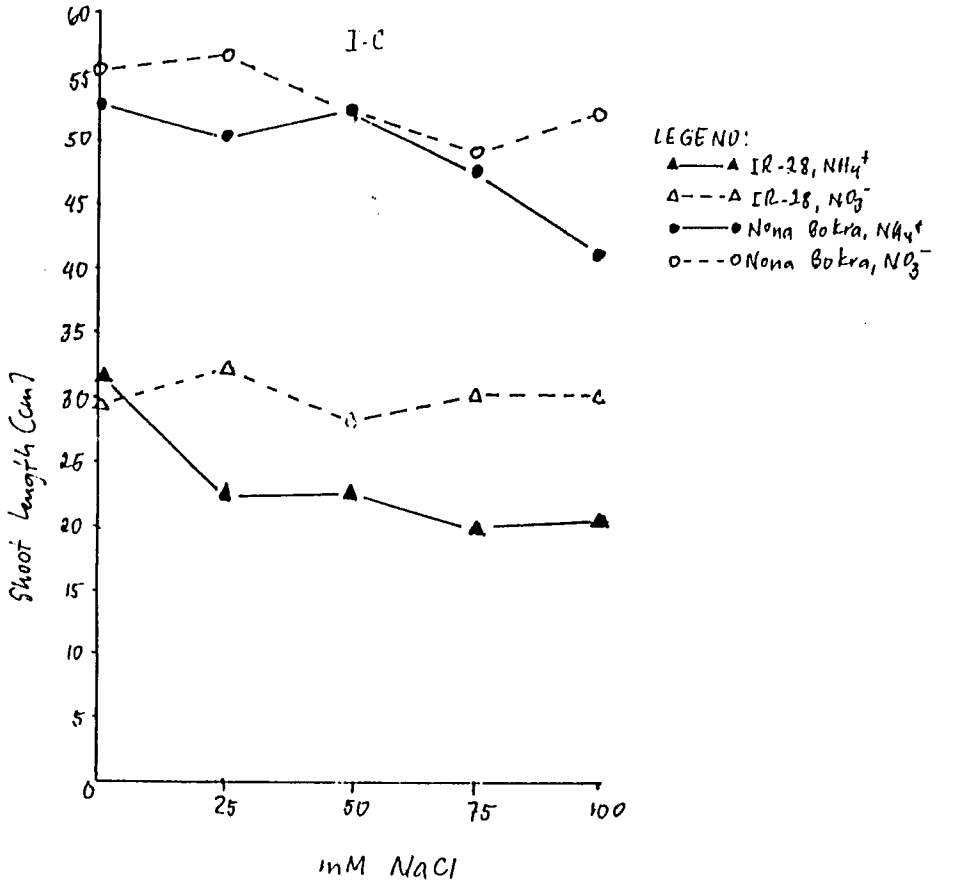
The nitrogen and potassium content of roots and shoots are presented in Figure 4. There seems to be not much variation in nitrogen content except for NH^+_4-grown IR-28. The nitrogen content of IR-28 shoots increases abruptly at 25 mM NaCl. This declines almost linearly with increasing salinity levels.

The potassium content of both varieties generally decreases with increasing salinity levels except for nitrate-grown Nona Bokra. The salt-tolerant variety grown in nitrate continued to accumulate K^+ despite the increasing levels of salinity. This could be one of the possible reasons why it is more tolerant than IR-28. In fact, some researchers pointed out earlier, the possibility of using Na/K ratio as an indicator of salt-tolerance in rice (Hedge and Joshi, 1974; Giriraj et al., 1976; Panaullah, 1980). The nitrate grown salt-tolerant variety had the lowest Na/K ratio. This clearly suggests the importance of K^+ and NO_3^- in the enhancement of salt tolerance in rice.

Figure: I. Dry weights of shoot (A) and root (B) of salt-sensitive (IR-28) and salt-tolerant (Nona Bokra) rice varieties grown hydrophonically in different NaCl levels and two N-sources.







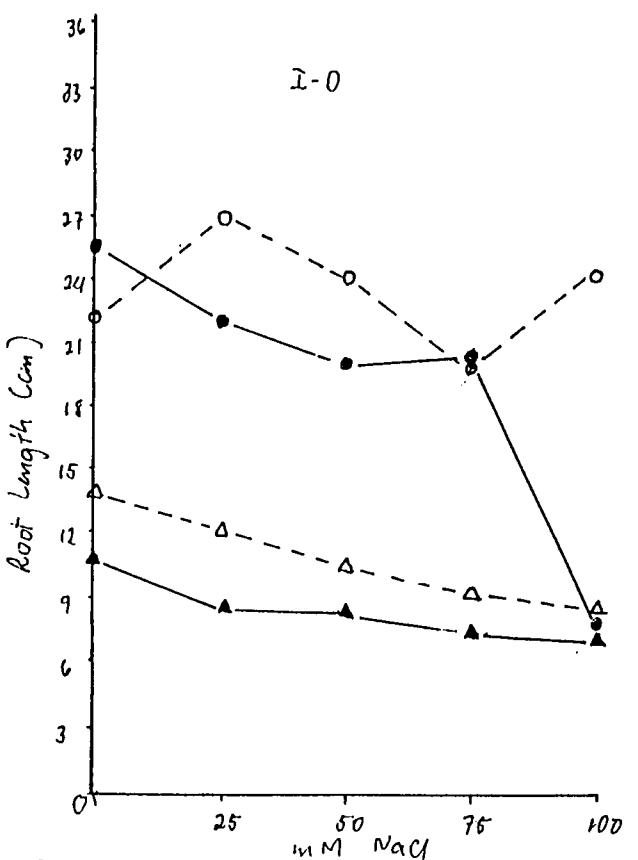
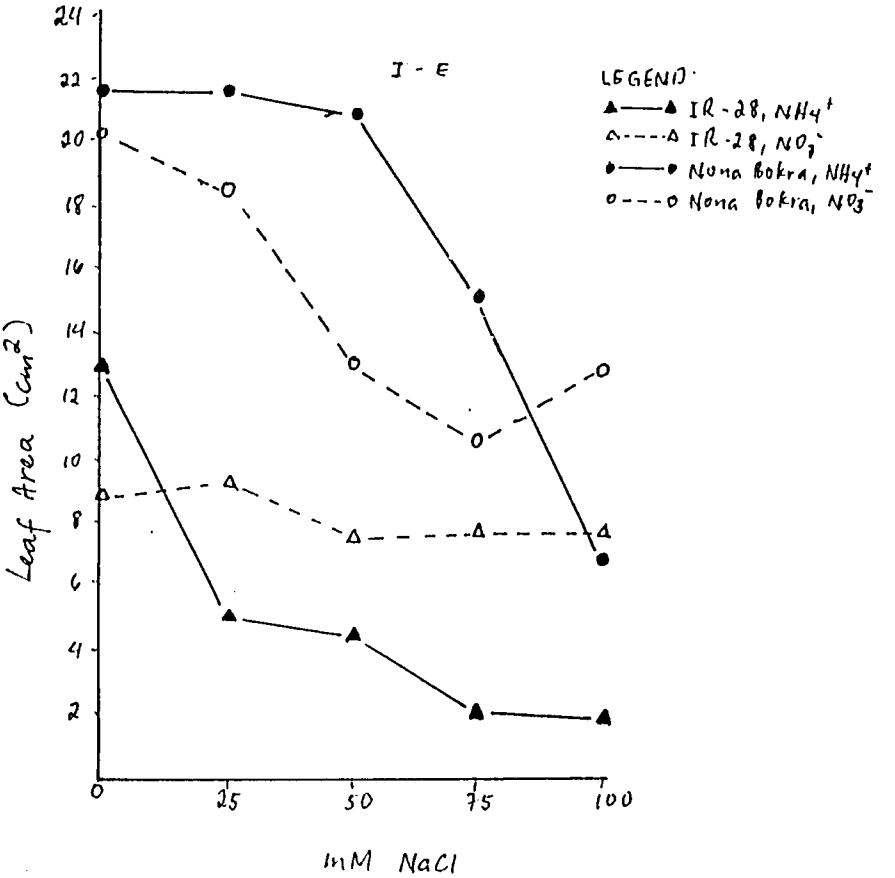
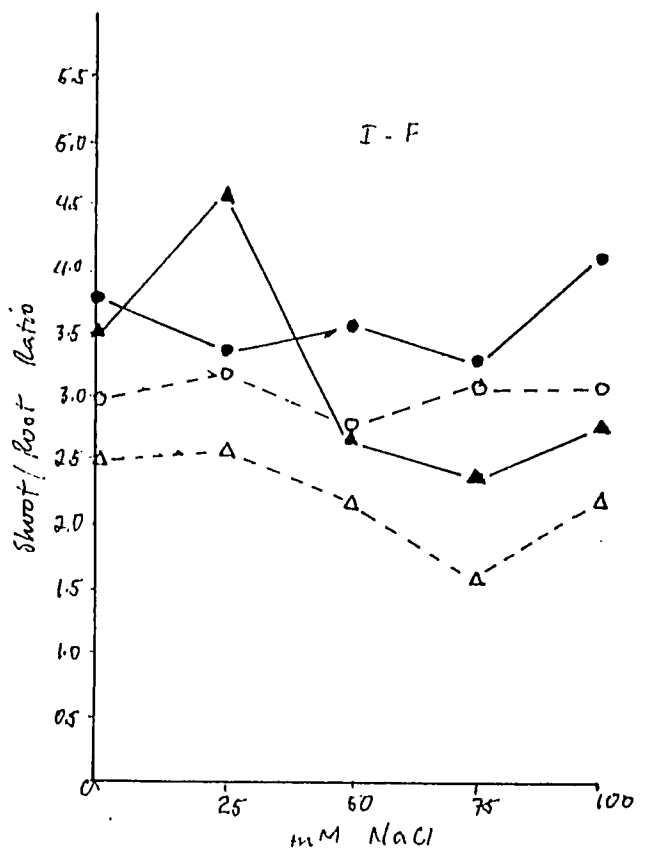
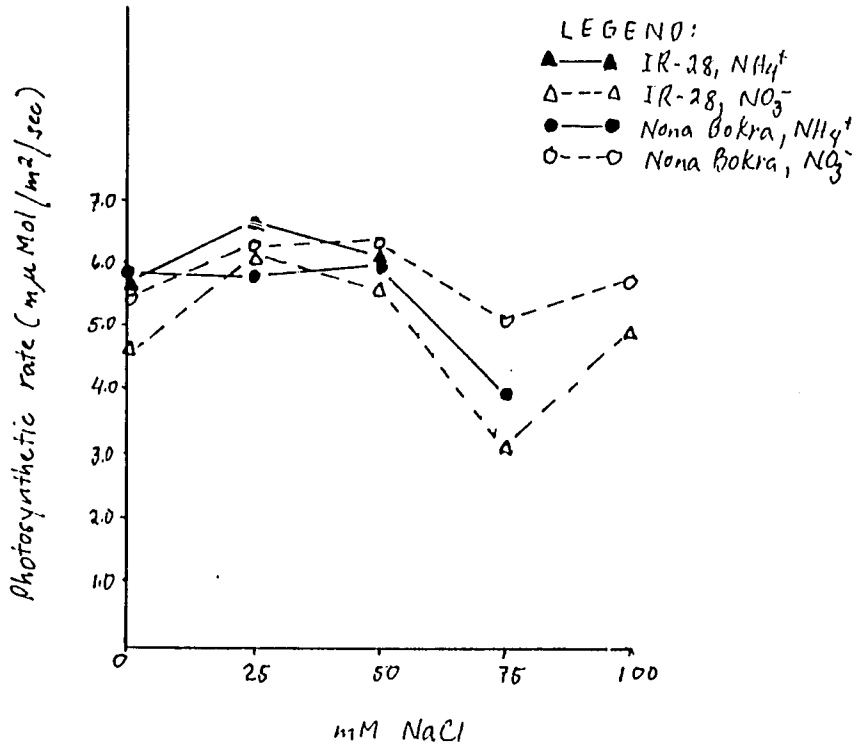


Figure I. Shoot (C) and root (O) length of salt-sensitive (IR-28) and salt-tolerant (Nona Bokra) rice varieties grown hydroponically in varying NaCl levels and two N sources.


I - E
LEGEND:
IR-28, NH4+
IR-28, NO3-
Nona Bokra, NH4+
Nona Bokra, NO3-
Leaf Area (cm2)
24
22
20
18
16
14
12
10
8
6
4
2
0
25
50
75
100
mM NaCl


I - F
Shoot/Root Ratio
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
25
50
75
100
mM NaCl

II-A



II-B

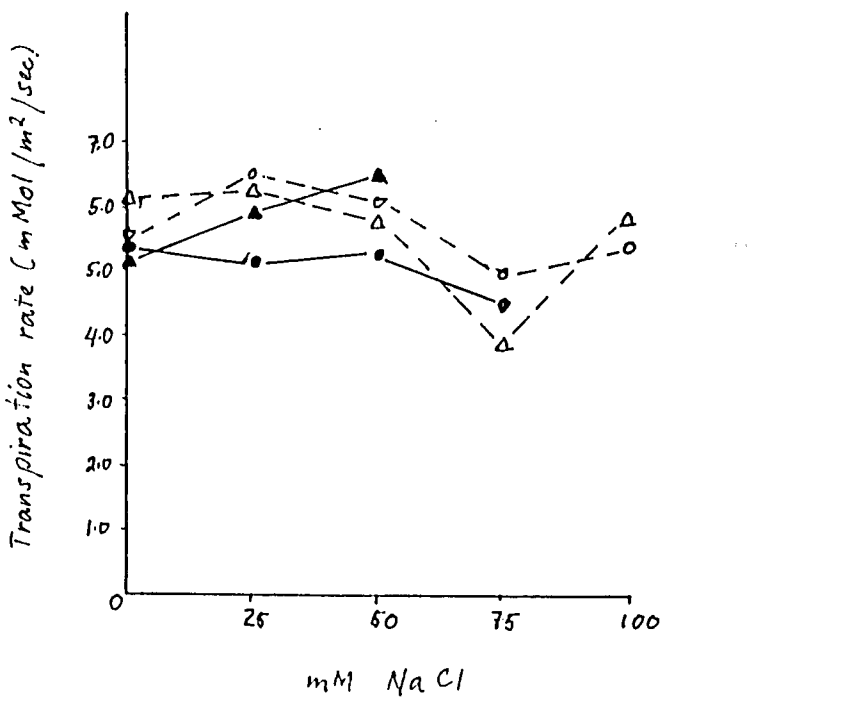


Figure II. Photosynthetic (A) and transpiration (B) rates of salt-sensitive (IR-28) and salt tolerant (Nona Bokra) rice varieties grown hydrophonically in different salinity levels and two nitrogen sources.

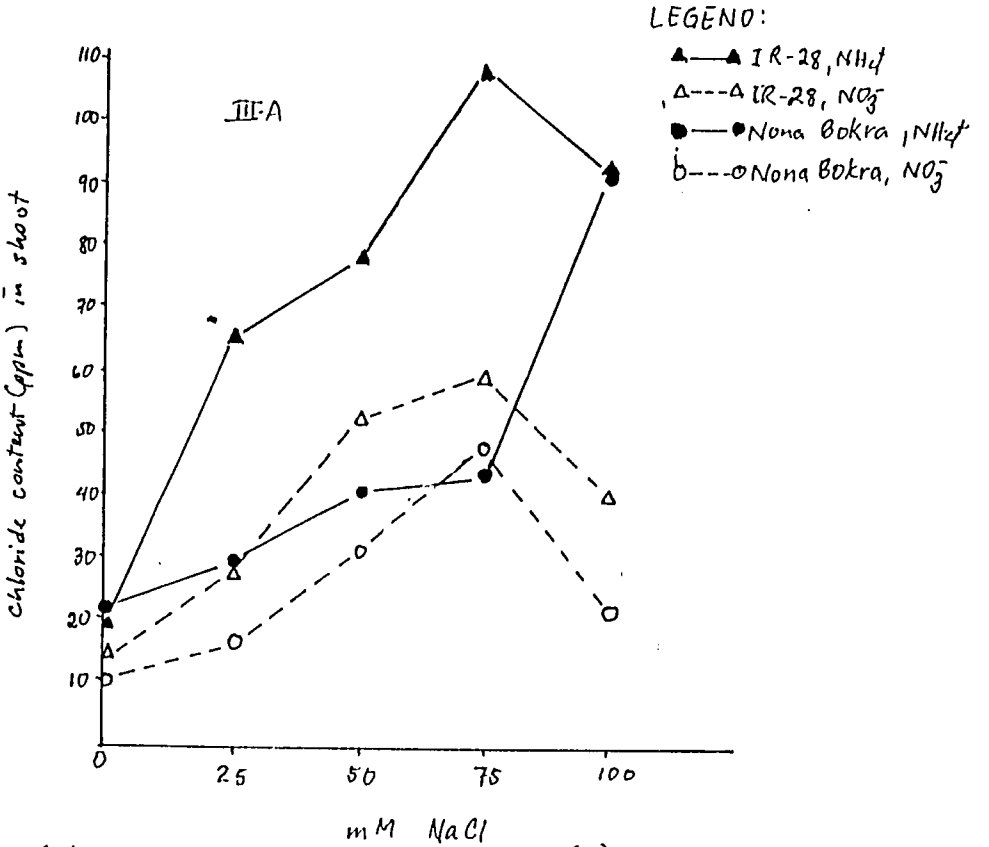


Figure III - Chloride content in shoot (A) and root (B) of salt-tolerant (Nona Bokra) and salt-sensitive (IR-28) rice varieties grown hydrophonically in varying NaCl levels and two N-sources.

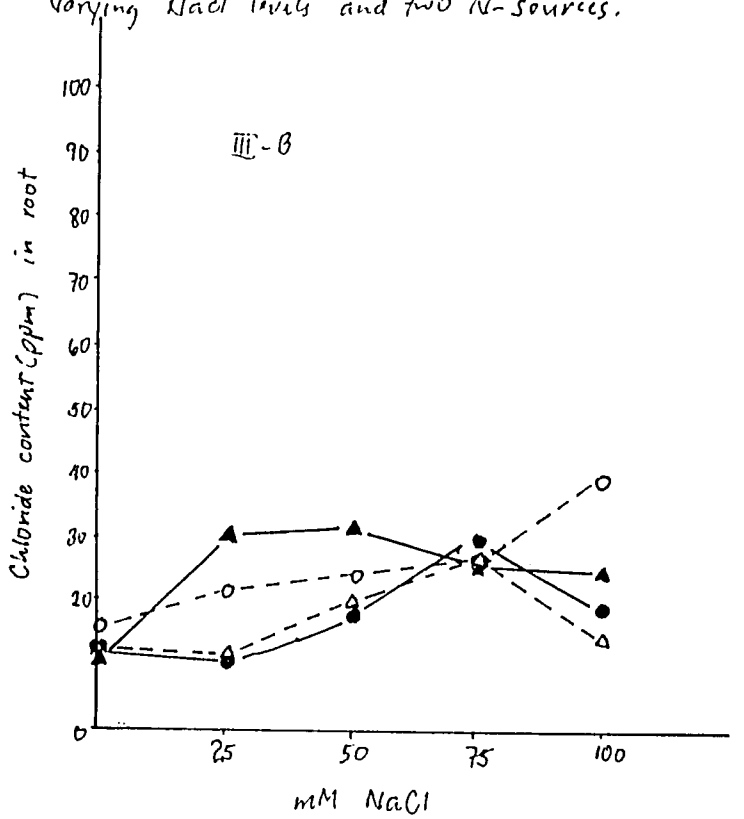
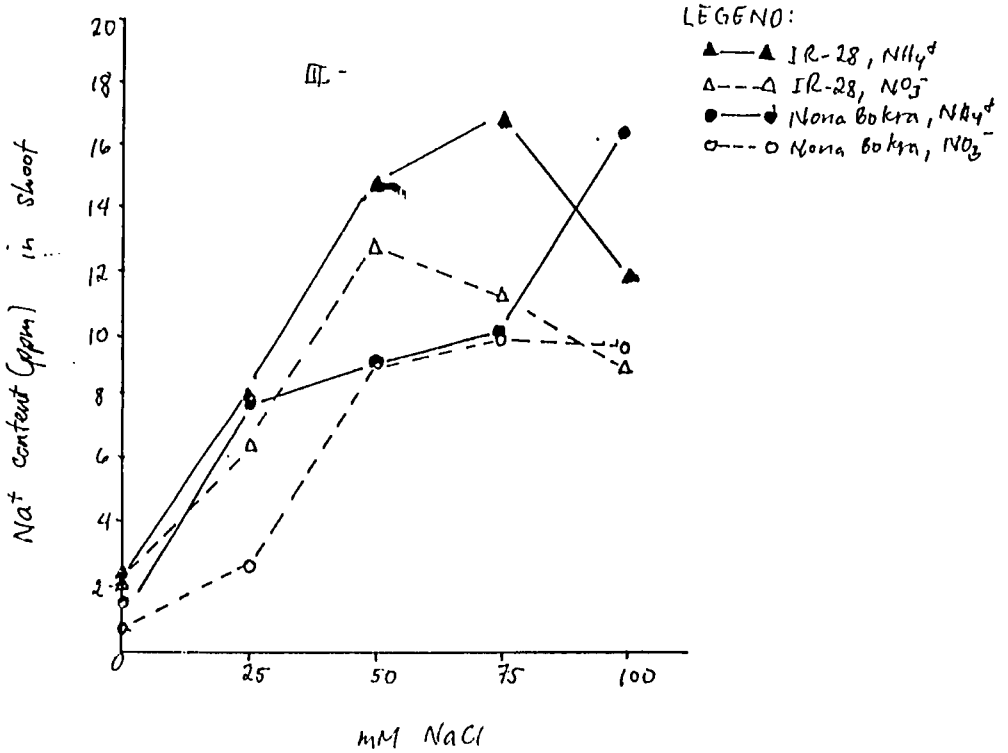
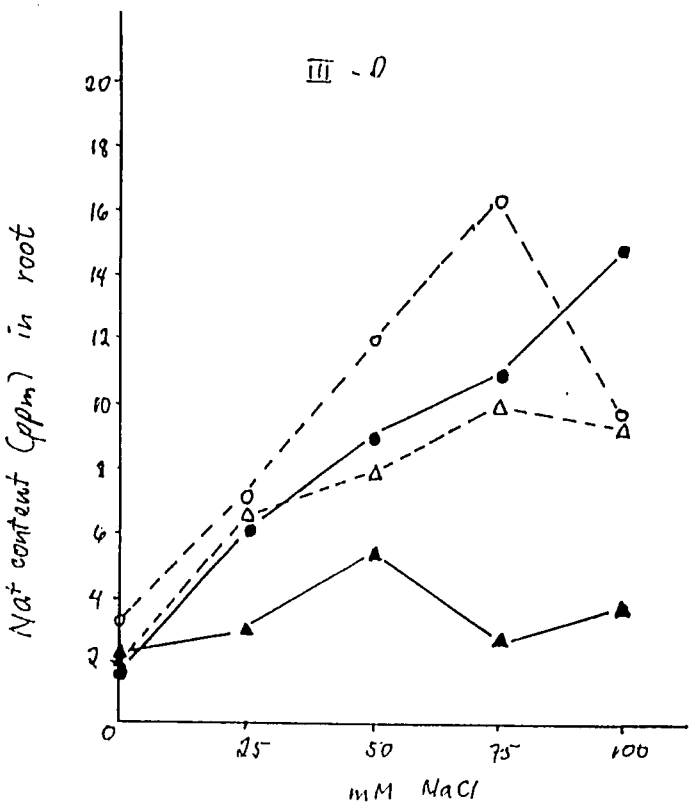
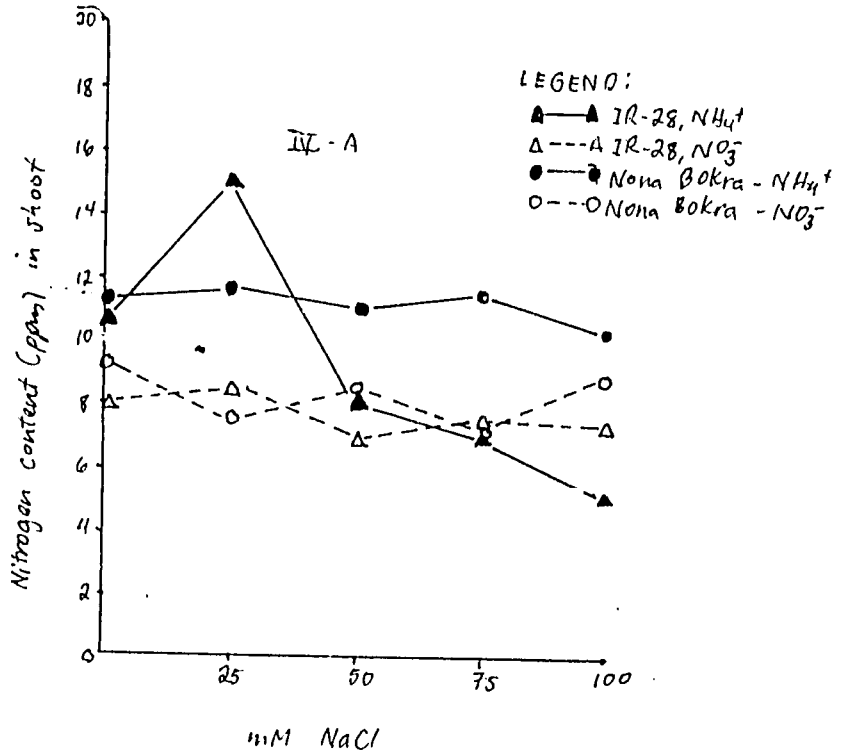


Figure III. Na^+ content in shoot (C) and root (D) of salt-sensitive (IR-28) and salt-tolerant (Nona Bokra) rice varieties grown hydrophonically in varying NaCl levels and two N-sources.







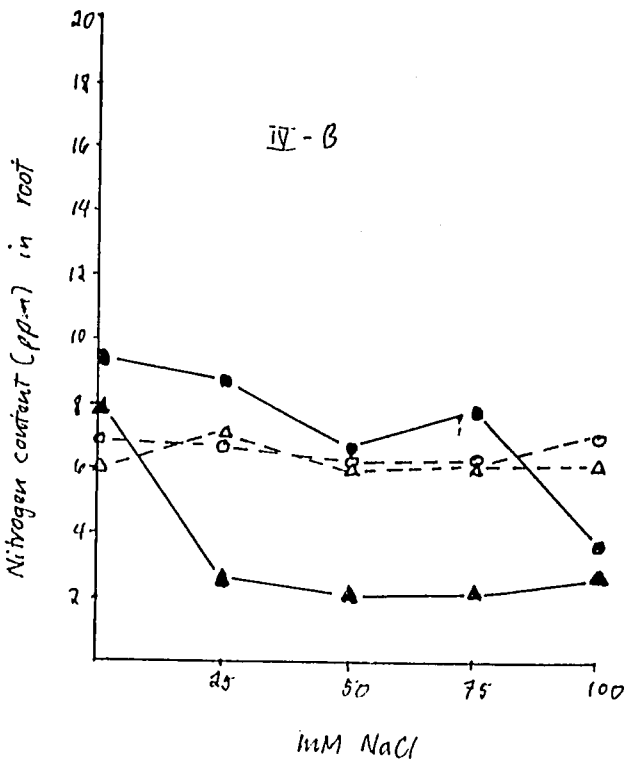


Figure IV. - Nitrogen content of shoot (A) and root (B) of salt-sensitive (IR-28) and salt-tolerant (Nona-Bokra) rice varieties grown hydrophonically in varying NaCl levels and two N-sources.

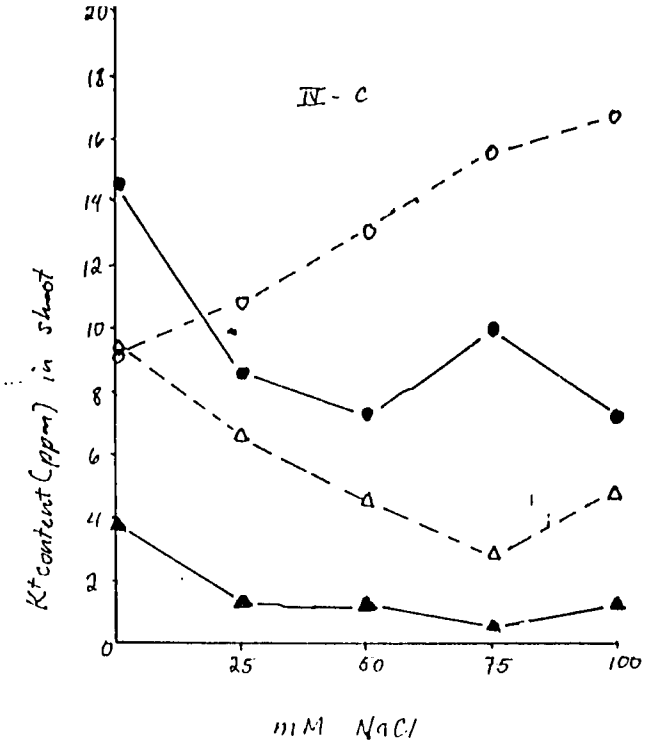
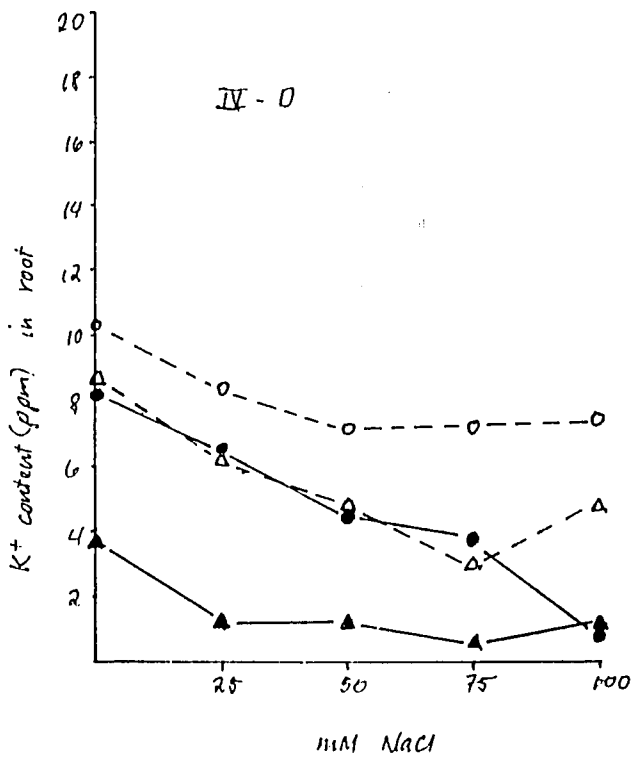


Figure IV. K^+ content of shoot (C) and root (O) of salt-sensitive (IR-28) and salt-sensitive (Nona Bokra) rice varieties grown hydroponically in varying NaCl levels and two N-sources.



A

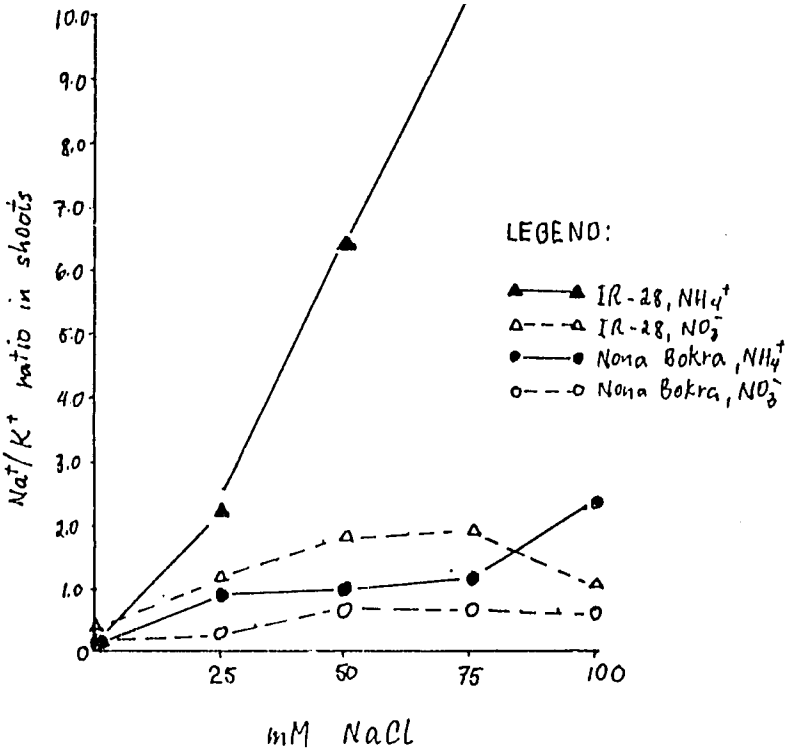
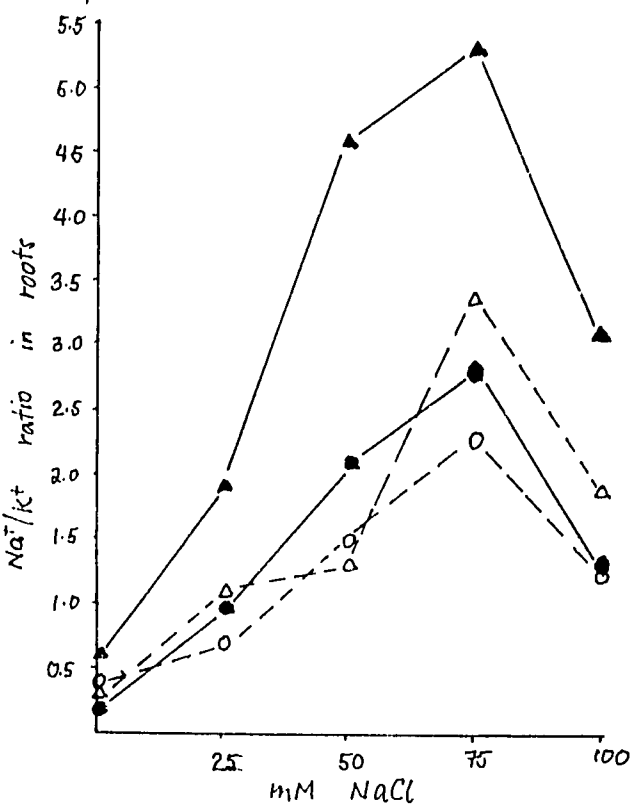


Figure V. Na^+/K^+ ratios of shoot (A) and root (B) of salt-sensitive (IR-28) and salt-tolerant (Nona Bokra) rice varieties grown hydrophonically in varying levels of NaCl and two N-sources.

B



(4b) Effects of KNO_3 on rice (Oryza sativa L.) irrigated with saline water. (Reano, Pacardo, Mercado and Lips)

INTRODUCTION

The favorable ameliorative effects of adequate potassium fertilization in increasing tolerance of plants to environmental stresses like drought and salinity have already been previously documented (Berlinger and Trolldenier, 1979; Silberbush et al., 1985). In rice (Oryza sativa L.), salt tolerance has been reported to be closely associated with the maintenance of high K/Na ratio (Hedge and Joshi, 1974; Giriraj et al., 1976; Panaullah, 1980).

The potassium content of rice straw generally decreased with increasing salinity indicating antagonistic relationships between Na and K transport (IRRI, 1967; Panaullah, 1980). Na transport in salt sensitive variety (IR-28) was higher than the line IR 2153-26-3-5-2 by four-fold at 0.1 mM K. However, Na uptake was depressed by increasing K to 1.0 mM (Elms et al., 1977).

Previous reports show that K fertilization is critical for plants growing in a saline environment. One possible proposition from this observation is that K absorption is limiting under salt stressed condition, and increasing its concentration in the medium would probably improve salt tolerance. This study reports the effects of KNO_3 fertilization on growth and nutrient uptake of rice irrigated with saline water.

MATERIALS AND METHODS

A pot experiment was conducted at the IBS greenhouse, University of the Philippines at Los Banos (UPLB), College, Loguna, Philippines, from January to April 1987.

The different treatments were laid out in a 3 x 3 factorial in a completely randomized design (CRD). The variables were 3 salinity levels of the irrigation water (0.60, 5.6, 10.6 mmhos/cm at 25°C) and 3 concentrations of KNO_3 (0, 60, 600 ppm).

The desired electrical conductivity readings were predetermined using a portable conductivity bridge. Different dilution of pure sea water (EC 32 mmhos/cm at 25°C) was prepared prior to the treatment application.

Growth in terms of shoot length, root fresh weight and dry weight of roots and shoots decreased with increasing levels of salinity (Table 2). Addition of KNO_3 to the medium apparently enhanced the toleance of rice to higher salinity levels (Table 2). The inhibitory effects of salinity on growth were most pronounced at highest salinity levels (10.6 mmhos/cm) in the absence of KNO_3 (Table 2).

The growth response apparently indicate that 60 ppm KNO_3 was already sufficient to counteract the toxic effects of higher salt levels of water applied, i.e., 10.6 mmhos/cm. On the other hand, growth of rice plants at a moderately low salinity level, i.e., 5.6 mmhos/cm was (almost) comparable with the control ones. Addition of KNO_3 up to 600 ppm improved growth in terms of shoot length, root fresh weight, dry weight of shoots and roots (Figures 1a-1d).

The above observations support previous reports on the importance of K nutrition to plants grown under saline conditions. Plants with adequate supply of K respond to salt-induced water stress with a quick reduction in transpiration rate. On the other hand, in K deficient plants stomata are often sluggish and do not close fully, causing high transpirational water loss (Nelson, 1978; Berlinger and Troldemier, 1979).

In rice, salt sodium tolerant varieties/lines are generally observed as efficient absorbers of K from saline/sodic soils (IRRI, 1978; Panaullah, 1980). Thus, high ratio of K/Na in leaves is generally considered to be a better indicator of salt-tolerance in rice (Rana, 1977; Panaullah, 1980; Gill and Dutt, 1981). Na^+/K^+ ratios in this experiments decreased with increasing KNO_3 (Table 4).

Table 6 shows the significant effects of salinity alone on root length and shoot fresh weight of rice. A remarkable decrease in root length and shoot fresh weight of rice was noted with increasing levels of salinity. These observations indicate the deleterious effects of salinity on growth and development of plants which can be generally categorized as water stress, salt stress and ion imbalance stress (Greenway and Munns, 1980; Fageria, 1985).

Salinization treatments started at about 6 weeks after seed sowing in pots containing 1.5 kg dried soil (Maahas clay loam). The different treatments or solutions were applied as irrigation water in equal volume, i.e., 500 ml per pot. This was done regularly every other day for a period of five weeks. The different cultural management practices, e.g., fertilization, weeding, etc. were adequately provided during the entire duration of the experiments.

The different growth parameters gathered were shoot length, root length, fresh and dry weight of roots and shoots, and number of leaves and flowers. Plant tissue analyses of mineral nutrient elements such as N, K, Ca, Mg, Na and Cl were done following the procedures of Yoshida et al., 1976. The visual deficiency or toxicity symptoms were also noted during the growth period.

The data were analyzed statistically using anova, regression and correlation analyses.

RESULTS AND DISCUSSION

Visual observations. The early effect of salinity on rice includes leaf rolling which starts at the tip of the leaves. White leaf tips and white blotches were also observed in surviving leaves. Drying up usually starts with the older leaves. The overall growth of a rice plant is stunted. Fewer tillers and roots were produced especially at higher salinity level in the absence of KNO_3.

Previous reports show that growth responses of rice plants vary depending on its stage of growth (Maas and Hoffman, 1977; Castro and Sabado, 1977; Panaullah and Ponnamperuma, 1980). Rice is reported to be more tolerant during the germination stage; sensitive again during pollination and fertilization and tolerant at maturity (Pearson and Ayers, 1960; Pearson et al., 1966; IRRI, 1967). Considerable variation in salt tolerance of different rice varieties have already been noted (Flowers and Yeo, 1981).

Growth. The interaction effects of salinity levels and KNO_3 were statistically significant on almost all growth parameters measured except root length and shoot fresh weight (Table 1). The effects of varying levels of water salinity and KNO_3 on the growth of rice (var. IR-28) are summarized in Table 2. These two parameters, however, were affected by salinity levels alone.

Total Nitrogen. The total nitrogen content of rice shoots did not vary much in any of the treatments except for the highest salinity levels (Table 3). There was a marked decline in the total nitrogen content of the shoot at 10.6 mmhos/cm salinity levels. Addition of KNO_3 apparently maintains the total nitrogen content similar to control plants. This observation supports the findings of Helal and Mengel (1979) that addition of K enhanced N-uptake (total ^{15}N-content) and incorporation into protein, reduced the accumulation of inorganic N and improved the growth of salinized plants.

Chloride in shoot. Regardless of KNO_3 concentration, the amount of chloride detected in shoot tissues of rice increased with increasing levels of salinity (Table 3). Addition of KNO_3 (600 ppm) depressed Cl^- accumulation in shoots. Plants growing in higher salinity levels without KNO_3 accumulated more Cl^- compared with plants supplied with KNO_3.

The results further strengthened the observations on the growth response of rice. Cl^- ion has been identified as one of the toxic ions that caused adverse metabolic effects. It has been associated with the inactivation of several metabolic enzymes. Sharma et al., 1984 reported that the poor performance of salt sensitive variety of wheat (HD 4502) was traced to the excessive accumulation of Cl^- ions in the shoot tissues.

Potassium content. A highly significant interaction between salinity and KNO_3 levels was noted on the K content of rice (Table 3). There was a decrease in the K content of shoots and roots in the presence of salts. However, addition of KNO_3 seems to favor more K accumulated in shoots and roots.

Panaullah (1980) reported that K content of rice generally decreased with increasing salinity levels suggesting an antagonism between Na and K. This also indicates that K is essential in plants growing in a saline environment. In fact, several workers claimed that salt-/sodium-tolerant plants are generally efficient absorbers of K from saline/sodic soils (Greenway, 1962; Rana et al., 1976; Rana, 1977; IRRI, 1978; Panaullah, 1980).

Sodium content. Accumulation of Na in shoots and roots increased almost linearly in salinized medium without KNO_3. This is clearly more evident in roots (Table 3). However, the presence of KNO_3 appears to depress Na uptake. This indicates the antagonistic relationships between Na^+ and K^+ ions (Panaullah, 1980; Rana, 1977; IRRI, 1978).

Greenway and Munns, (1980) observed that plant resistance to salinity depends on its ability to restrict or prevent the entry of Na to the shoot. This restriction is essential so that the important metabolic processes, e.g., photosynthesis, ATP synthesis are not immigite. Rice has been considered as one of the plant species with a "salt exclusion" mechanism when grown under saline conditions (Yeo and Flowers, 1984).

Calcium content. No definite trend can be established on the uptake of Ca at varying levels of salinity and KNO_3 (Table 3). However, it seems that Ca uptake increases with increasing salinity, especially in the absence of KNO_3. This could also indicate its possible importance in the role of plants growing in saline environments. The beneficial effects of Ca on plants subjected to salt-stressed conditions has been reported earlier (Lahaye and Epstein, 1969; Gildensoph and Davis, 1983; Kent and Lauchli, 1985; Marchars, 1986)

Magnesium content. Generally, the trend for magnessium uptake is quite similar to that of calcium. The concentration of Mg in shoots and roots increased with increasing levels of salinity especially in these treatments without K (Table 3). Murthy and Rao (1965) reported stimulation of Mg uptake with increasing levels of salinity.

Na/K and Na/Ca Ratios As shown in Tables 4 and 5, the Na/K and Na/Ca ratios seemingly increased with increasing levels of salinity. This was clearly observed in those treatments without KNO_3.

It has been clearly established that both Ca and K are required in the growth medium to maintain the selectivity and integrity of cell membranes (Wyn Jones and Lunt, 1967). Calcium is needed for selective transport of ions like K across membranes (Wyn Jones and Lunt, 1967). Rains (1972) emphasized that it is even more important in a saline environment. It has, therefore, been hypothesized that high Na/Ca and Na/K ratios in saline environment may impair the selectivity of root membranes and lead to passive accumulation of Na in the root and shoot (Kramer et al., 1977).

Correlation Analysis. The relationships between salinity levels or KNO_3 with different parameters gathered were also established by correlation analysis. Salinity was negatively correlated with shoot length, shoot fresh weight, root fresh weight, shoot dry weight and percent total N in shoot (Table 6). Only percent Cl^- in rice shoot was found to be negatively correlated with KNO_3. The rest of the parameters i.e., growth and mineral nutrients were found to be positively correlated with KNO_3.

Table 1. Summarized results of statistical data analysis on the effect of varying levels of water salinity and KNO_3 on the growth and mineral composition of rice (Var. IR-28).

PARAMETER	SALINITY	KNO_3	SALINITY × KNO_3
1. Shoot length (cm)	**	ns	*
2. Root length (cm)	**	ns	ns
3. Shoot fresh weight (gm)	**	ns	ns
4. Root fresh weight (gm)	**	ns	*
5. Shoot dry weight (gm)	**	ns	**
6. Root dry weight (gm)	**	ns	**
7. Number of flowers	-	-	-
8. % Total N in shoot	**	**	**
9. % Cl^- in shoot	**	**	**
10. % N in shoot	ns	ns	**
11. % K in root	**	**	**
12. % Na in shoot	**	**	**
13. % Na in root	**	**	**
14. % Ca in shoot	**	**	**
15. % Ca in root	**	**	*
16. % Mg in shoot	**	**	**
17. % Mg in root	*	**	**

* Significant ** highly significant ns - not significant

Table 2. Interaction effects of varying levels of water salinity and KNO_3 on shoot length (SL), root fresh weight (RFW), and dry weights of roots (RDW) and shoots (SDW) of rice (Var. IR-28).

TREATMENT COMBINATIONS		GROWTH PARAMETERS 1/			
Salinity Levels (mmhos/cm)	KNO_3 (ppm)	Shoot Length (cm.)	Root Fresh wt (gm)	Shoot Dry wt (gm)	Root Dry wt (gm)
0.6	0	77.75a	1.07a	1.08a	0.33a
0.6	60	66.30b	0.85abc	0.48bcdc	0.15c
0.6	600	59.75bc	0.65abcd	0.51bcd	0.15c
5.6	0	57.50bcd	0.65abcd	0.41bcdef	0.14cd
5.6	60	55.20bcde	0.75d	0.55bc	0.12cde
5.6	600	57.30 bcde	0.95abc	0.57b	0.28b
10.6	0	35.50g	0.15e	0.11g	0.01g
10.6	60	51.25cdef	0.65abcd	0.30fg	0.09def
10.6	600	38.70 g	0.15 e	0.30 fg	0.07 def
GRAND MEAN		55.47	0.60	0.48	0.15
C.V.(%)		8.25	34.15	20.94	20.71

Table 3.
Interaction effects of varying levels of water salinity and KNO_3 on mineral composition of rice (Var. IR-28).

TREATMENT COMBINATIONS		MINERAL COMPOSITION (%) 1/									
nity Levels hos/cm)	KNO_3 (ppm)	Total N in shoot	Cl in shoot	K in shoot	K in root	Na in shoot	Na in root	Ca in shoot	Ca in root	Mg in shoot	Mg in root
0.6	0	3.94a	1.46cdef	0.35a	0.11b	0.02c	0.03c	0.38f	0.72b	0.16cd	0.26b
0.6	60	3.76abc	1.06def	0.19cde	No data	0.02c	no data	0.45de	no data	0.10f	no data
0.6	600	3.90 ab	0.97def	0.22bcd	0.09b	0.01c	nil	0.63b	0.62b	0.13def	0.35b
5.6	0	3.70abcd	3.68ab	0.19cde	0.12b	0.08bc	2.40b	0.46cd	0.84b	0.19f	0.55b
5.6	60	3.64abcde	2.23c	0.22bcd	0.16b	0.04c	0.05b	0.52c	0.71b	0.30b	0.43b
5.6	600	3.90ab	1.49cde	0.24bc	0.13b	0.02c	0.03c	0.45de	0.77b	0.13def	0.22b
0.6	0	0.58f	No data	0.19cde	nil	0.72a	4.95a	0.71a	2.01a	0.28b	1.51a
0.6	60	3.71bcde	4.17a	0.28ab	0.16b	0.08bc	0.09c	0.41def	1.10b	0.15de	0.29b
0.6	600	3.31bcde	1.69cd	0.21cde	0.68a	0.17b	0.18c	0.60b	0.58b	0.56a	0.21b
AND MEAN		3.34	1.86	0.23	0.16	0.13	0.86	0.51	0.82	0.22	0.42
V. (%)		7.35	16.28	11.75	38.37	33.67	84.68	4.74	30.8	8.29	43.38

1/ Means followed by same letters are not significantly different according in Duncan's Multiple Range Test(D at 5% level of significance.

Table 4. Na/K ratio of rice (var. IR-28) applied with varying levels of saline water and KNO_3.

TREATMENT COMBINATIONS		Na/K RATIO	
Salinity levels (mmhos/cm)	KNO_3 conc. (ppm)	Root	Shoot
0.6	0	.28	0.05
0.6	60	data	0.08
0.6	600		0.05
5.6	0	0.59	0.39
5.6	60	0.29	0.16
5.6	600	0.31	0.08
10.6	0	no data	3.78
10.6	60	0.63	0.28
10.6	600	0.28	0.83

Table 5. Na/Ca ratio of rice (var. IR-28) applied with varying levels of saline water and KNO_3.

TREATMENT COMBINATIONS		Na/Ca RATIO	
Salinity levels (mmhos/cm)	KNO_3 conc. (ppm)	Root	Shoot
0.6	0	0.04	0.03
0.6	60	no data	0.03
0.6	600	nil	0.02
5.6	0	3.08	0.16
5.6	60	0.13	0.07
5.6	600	0.04	0.04
10.6	0	5.63	1.02
10.6	60	0.09	0.18
10.6	600	0.63	0.29

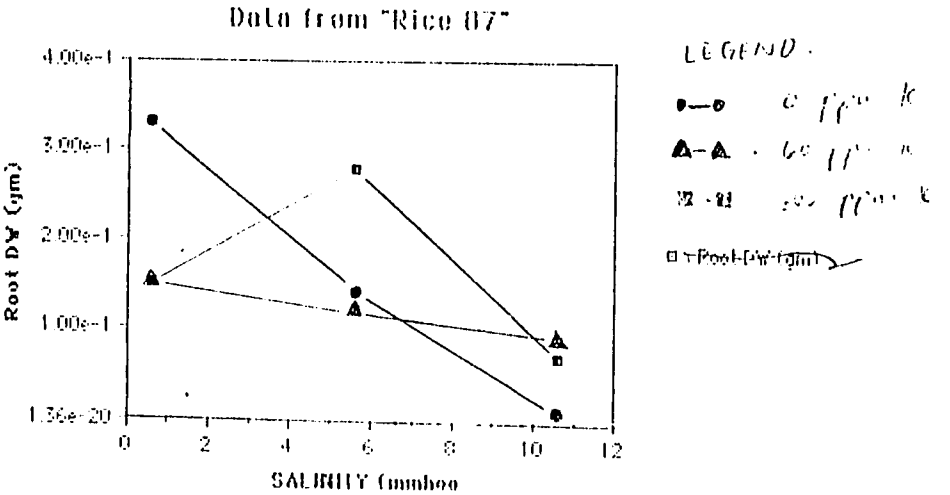
Table 6. Correlation analyses of the relationships of salinity levels and KNO_3 with the different growth parameters and nutritional composition of rice (IR-28).

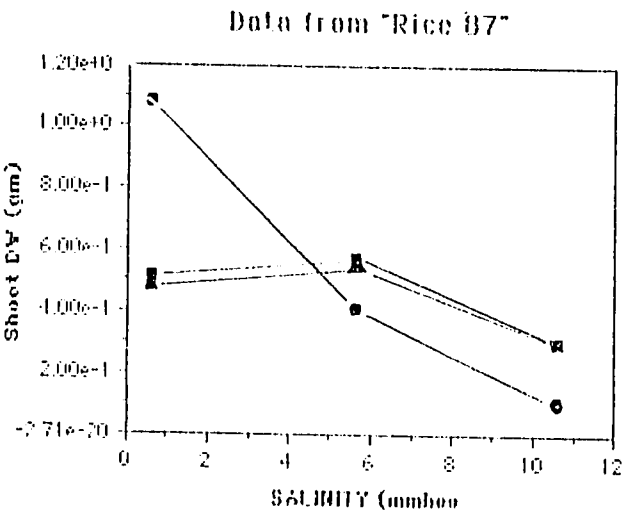
PARAMETERS	SALINITY	KNO_3
1. Shoot length (cm)	.807*	.416ns
2. Root length (cm)	.698*	.134ns
3. Number of flowers	-	-
4. Shoot fresh weight (gm)	.698*	.277ns
5. Root fresh weight (gm)	.522*	.142ns
6. Shoot dry weight (gm)	.721*	.279ns
7. Root dry weight (gm)	.645*	.049*
8. % Total N in shoot	.738*	.051ns
9. % Cl in shoot	.564*	.626*
10. % K in shoot	.288ns	.377ns
11. % K in root	.605*	.412ns
12. % Na in shoot	.771*	.158ns
13. % Na in root	.054ns	.385ns
14. % Ca in shoot	.021ns	.021ns
15. % Ca in root	.254ns	.356ns
16. % Mg in shoot	.530*	.275ns
17. % Mg in root	.140ns	.433ns

* Significant

ns - not significant

Figure 1a.


Data from "Rice 87"
4.00e-1
3.00e-1
2.00e-1
1.00e-1
1.36e-20
Root DW (gm)
0
2
4
6
8
10
12
SALINITY (mmhoo
LEGEND


Data from "Rice 87"
1.20e+0
1.00e+0
8.00e-1
6.00e-1
4.00e-1
2.00e-1
-7.71e-20
Shoot DW (gm)
0
2
4
6
8
10
12
SALINITY (mmhoo