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FERTILIZATION AND SALINE WATER IRRIGATION

Dr. S. Herman Lips and Dr. Jiftah Ben Asher
Center for Desert Agrobiology
J. Blaustein Institute for Desert Research
Ben-Gurion University of the Negev
Sede Boqer 84990
ISRAEL

and

Dr. Enrique P. Pacardo
Institute for Environmental Science and Management
University of the Philippines at Los Baños
College, Laguna
PHILIPPINES

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I - Introduction

The present report summarizes research carried out within the framework of project C5-001 from July 1988 to March 1990. Different parts of this work were carried out by the following scientists:

Prof. Jiftah Ben Asher - Israel
Ms. M. Angeles Botella - Spain
Ms. Cristina Cruz - Portugal
Dr. Martin Giskin - Israel
Dr. Eduardo O. Leidi - Spain
Prof. Owen A. M. Lewis - South Africa
Prof. S. Herman Lips - Israel
Ms. Hanna Jaenicke - Germany
Mr. Dale Magnusson - USA
Mr. Joel de Malach - Israel
Dr. B. T. Mercado - Philippines
Dr. Enrique C. Pacardo - Philippines
Dr. Jose Reaño - Philippines
Ms. Ruth Shaked - Israel
Dr. Moshe Silberbush - Israel
Dr. M. I. M. Soares - Israel

Work presented here describes studies of physiological mechanisms of salt-tolerance under laboratory conditions coordinated with experimental work under field conditions. Cooperation with our Philippino colleagues has yielded interesting and important results both in the lab and in the field. Peanut production in our joint experimental field in the Philippines is three fold higher than the local average although irrigated with saline water from Laguna de Bay. This has been possible by the introduction of trickle irrigation and fertilizer management adequate for saline conditions. If funding to go on during three more years becomes available, introducing better varieties and optimizing irrigation and fertilization management could further increase peanut production to ten fold today's average in the Philippines using while using available brackish water during the dry season .

Field workers in the Philippines mastered the use of trickle irrigation rapidly and effectively in our joint experimental field between Manila and Los Baños. Peanut production irrigated with saline water and enhanced nitrogen fertilization in the Philippines yielded relatively good crops. Encouraging results have been obtained by Philippino coworkers in greenhouse experiments with wheat and rice on the enhancement of salt-resistance by adequate fertilization. These laboratory and field experiments have set the foundation to obtain superior yields of other vegetable crops which the Philippino local and export market could absorb. The use of trickle irrigation with saline water allows production of cash crops during the dry season, when field are idle due to lack of rainfall.

At the same time, study of ways to enhance salt tolerance of crops by simple agrotechniques goes on. We have learned about the effects of salinity on the distribution of assimilates, the determination of sink priority by different forms of nitrogen, salt resistant mechanisms in rice, pH effect on sali-tolerance of plants growing on either ammonium or nitrate, etc.

This is the final report for the three year project supported by AID/CDR (C5-001). We have learned much but it is clear that we are at the beginning of the development of agrotechniques to use saline water irrigation. Work based on our experience is now carried out not only in Israel but in Philippines, Thailand, Kenya, Mexico, Portugal and Spain.

SALINITY AND NITROGEN NUTRITION STUDIES ON PEANUT AND COTTON PLANTS

E. O. LEIDI, M. SILBERBUSH, M. I. M. SOARES and S. H. LIPS

Desert Agrobiology Center, J. Blaustein Institute for Desert Research and Department of Biology, Faculty of Natural Sciences, Ben-Gurion University of the Negev. Sede Boqer 84993, Israel.

ABSTRACT. The effect of the nitrogen form (NH_4^+ or NO_3^-) added to the nutrient solution and salinity levels (NaCl) were studied in peanut and cotton plants grown in hydroponics. Growth inhibition by salinity affected mainly to NH_4^+-fed plants. Salinity and nitrogen form had different effects in the levels of K^+ and Na^+ in the shoots of these two species. Salinity only reduced photosynthesis in severe stressed cotton plants. A high correlation was observed between the level of K^+ and stomatal conductance. Ammonium resulted in a less efficient use of nitrogen under saline conditions for both species.

INTRODUCTION

The need to increase the use of brackish water for agriculture in Israel and other arid areas of the world, as well as the increasing salinization of large agricultural areas, has generated interest on the interrelationship between mineral nutrition of plants and salinity (1,2). The type of nitrogen in the medium can exert a considerable influence on the mineral composition of the plants (3,4,5,6). The N form mainly affects the relative uptake of cations and anions by plants (3,5).

Salinity is known to inhibit uptake of several nutrients such as NO_3^- (7), K^+ and Ca^{2+} (8), causing nutrient imbalances in the plant. Furthermore, the study of the factors limiting plant growth under saline conditions is complex due to the variety of responses of plant species to salinity in terms of ion uptake and adaptative mechanisms to salinity and water stress (9, 10).

In this paper, we report results of studies on growth, photosynthesis and ion uptake of two different plant species which vary in their salt-tolerance (salt-tolerant cotton and salt-sensitive peanut) when grown under different salinity levels and inorganic nitrogen compounds.

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 vermiculite and seedlings of uniform size and appearance were selected and transferred to the nutrient solutions. The different nutrient solutions were placed in 20 l plastic containers with 8 plants in each of them. Two duplicate containers were provided for each treatment. Two nitrogen forms (NO_3^- and NH_4^+) were supplied at different salinity levels in the basic nutrient solutions. The composition of nutrient solutions (in mM) was as following:

	NO_3^-	NH_4^+	SO_4^{2-}	$H_2PO_4^+$	K^+	Ca^{2+}	Mg^{2+}
Nitrate solution	4	-	2.5	1	4	2	1
Ammonium solution	-	4	4.5	1	4	2	1

Micronutrients were supplied at the concentrations prescribed by the Long Ashton nutrient solution (11). Concentrations of NaCl used were 0, 10, 20, 35, 50, 75 and 100 mM for peanut (salt-sensitive), and 0, 50, 100, 150, 200, 250 and 300 mM for cotton (salt-tolerant). NaCl concentrations were increased stepwise at the beginning of the experiments to avoid osmotic shock to the plants. Solutions were changed weekly and water losses were replaced daily. Greenhouse daily temperatures fluctuated between 23.0º and 29.1º with night temperatures between 9.8º and 13.1º. Relative humidity was 25-35% during the day, increasing at night to 70-80%. Midday irradiance was 700-800 $\mu mol \cdot m^{-2} s^{-1}$.

Photosynthesis, transpiration and stomatal conductance were determined in fully expanded leaves of plants grown for 15 days, using a portable infrared gas analyzer (ADC, LCA-2) at a constant photon flux of 700 $\mu mol\ m^{-2}\ s^{-1}$.

Plants were harvested after 22 days and dried at 70º C for 48 h. The dry material was then weighed and total nitrogen determined after digestion with H_2SO_4 and H_2O_2 using the Nessler reagent. Part of the dry material collected was extracted in hot water to determine concentrations of Cl- (Corning chloride-meter), K+ and Na+ (Corning-EEL flame photometer).

RESULTS AND DISCUSSION

Increasing concentrations of NaCl in the nutrient solutions caused reduced dry mass production of peanut and cotton plants (Table 1). Cotton plants died at 300 mM NaCl under the growth conditions prevalent in the greenhouse, while plants grown in 250 mM NaCl had necrotic areas in the leaves and stopped growing after the first week. Root dry weigh in both species was more affected by salinity when NH_4^+ was the form of nitrogen present in the nutrient medium. Ammonium is a metabolically more expensive N source for roots than NO_3^- (12) because it is exclusively assimilated in the roots (12,13,14). The relatively large demand for carbon allocation for NH_4^+ assimilation in roots may result in insufficient carbon available for root growth. Lewis et al. (14) found a considerable greater sensitivity to salinity in wheat and maize plants fed with NH_4^+ rather than NO_3^-. It was suggested that salinity inhibits NH_4^+ detoxification by reducing the levels of arginine synthesis in squash plants (15). Salsac et al. (16) hypothesized that NH_4^+ nutrition could lead to insufficient water uptake because of the reduced intake of mineral ions (mainly K^+) and organic anions that can operate as osmotica. Thus, the larger growth inhibition caused by salinity in NH_4^+ -fed plants may be the result of a combination of several factors ranging from effects on water status and carbon partitioning to inorganic ion (K^+ and Ca^{2+}) induced deficiencies by NH_4^+ and Na^+.

Ammonium-grown cotton plants produced less biomass than plants grown on NO_3^-, whereas peanut plants had similar growth in both nitrogen forms. This may reflect a higher capacity of peanut to assimilate

NH_4^+ in the roots. Growth inhibition in NH_4^+-fed plants was observed in several species such as cucumber, castor bean and bean (17, 18, 19). Other plant species such as soybean (20), rice (21) and tomato (22) grew equally well in NH_4^+- and in NO_3^--containing medium.

Table 1. Shoot and root growth of peanut and cotton plants grown on NH_4^+- or NO_3^--solutions and different salinity levels. Within species, values in columns followed by the same letter are not significantly different (LSD Test, $P < 0.05$).

	NO_3^-		NH_4^+	
NaCl (mM)	Shoot (g dry weight plant^{-1})	Root	Shoot (g dry weight plant^{-1})	Root
PEANUT				
0	1.98a	0.55a	1.96a	0.48a
10	1.95a	0.45ab	1.65bc	0.37abc
20	1.95a	0.52a	1.77b	0.45ab
35	1.63b	0.46ab	1.54c	0.43ab
50	1.53b	0.44ab	1.14d	0.35bc
75	1.31c	0.39b	1.06d	0.39bc
100	1.11d	0.40b	0.81e	0.27c
COTTON				
0	1.41a	0.29ab	0.73a	0.23a
50	1.36a	0.38a	0.56b	0.19a
100	0.84b	0.23bc	0.57b	0.18a
150	0.75c	0.28b	0.47c	0.18a
200	0.50d	0.17cd	0.37d	0.10b
250	0.40e	0.16d	0.34d	0.09b
300	0.36e	0.11d	0.23e	0.06b

Increasing salinity resulted on a decrease of total N content of the shoots (Table 2) irrespective of nitrogen form supplied or plant species. The concentration of nitrogen in plant parts, however, remained fairly unchanged (data not shown). Findenegg et al. (23) found that the increase of Cl^- concentration in the medium did not change the level of total N in sugarbeet leaves.

Sodium chloride in the nutrient medium caused a decrease of K^+ concentration and content in the plants as well as an increase of Na^+ and Cl^- levels (Table 2). However, Na^+ levels in peanut shoots increased markedly only at the highest NaCl concentration (100 mM), while in cotton every increase in salt concentration was accompanied by an increase of Na^+ concentration in the shoot. Na^+ uptake by peanut resembled that of a Na^+-excluder species, whereas cotton showed characteristics of Na^+-includer species (24). It is not clear whether Na^+ exclusion provides higher tolerance to salt-sensitive species (25, 26). In some cases, salt-exclusion may constitute a mechanism to cope with salinity (10, 24, 27). The relative

Table 2. Content of N, K^+, Na^+ and Cl^- in shoots of peanut and cotton plants grown with NH_4^+- or NO_3^--solutions under differente salinity levels. Within species and for each nitrogen source, values in column followed by the same letter are not significantly different (LSD Test, $P < 0.05$).

N source	NaCl (mM)	N	K^+	Na^+	Cl^-
			(mmoles . shoot^{-1})		
PEANUT					
NO_3^-	0	4.70a	2.01a	0.05a	0.37a
	10	4.90ab	1.80b	0.04b	0.51b
	20	5.17b	1.84b	0.04b	0.52b
	35	3.93c	1.52c	0.05a	0.52b
	50	3.83c	1.27d	0.04a	0.54b
	75	3.10d	1.06e	0.04b	0.71c
	100	2.64e	0.93e	0.08c	0.94d
NH_4^+	0	5.01a	1.30a	0.04a	0.37a
	10	4.09b	0.97b	0.02b	0.33a
	20	4.57c	0.95b	0.03ac	0.37a
	35	4.07b	0.82c	0.03c	0.28b
	50	2.91d	0.56d	0.02b	0.25b
	75	2.77de	0.46e	0.04d	0.43c
	100	2.49e	0.35f	0.16e	0.64d
COTTON					
NO_3^-	0	3.66a	1.03a	0.10a	0.56a
	50	3.80b	0.83b	0.51b	1.01b
	100	2.05c	0.40c	0.91c	1.00b
	150	1.96c	0.36c	1.11d	1.29c
	200	1.09d	0.24d	1.27e	1.36c
	250	0.73e	0.24d	2.57f	1.88d
	300	0.68e	0.24d	3.11g	1.67e
NH_4^+	0	1.82a	0.50a	0.10a	0.42a
	50	1.50b	0.23b	0.33b	0.39a
	100	1.67c	0.18c	0.61c	0.57b
	150	1.25d	0.13de	0.86d	0.78c
	200	0.79e	0.11d	0.96e	0.99d
	250	0.65e	0.17ce	3.26f	1.48e
	300	0.45f	0.12d	1.89g	1.03d

increase of Na^+ and Cl^- in cotton plants to increasing salinity in the medium may have in cotton a osmoregulatory function.

Inhibition of NO_3^- uptake by salinity has been reported by Aslam et al. (7) and Silberbush et al. (28). In our work, salinity affected uptake of NH_4^+ or NO_3^- ions to a similar extent according to the values of nitrogen content (Table 2).

Decrease in K^+ uptake in the presence of Na^+ and NH_4^+ was also observed (Table 2). Lower levels of K^+ in NH_4^+-fed plants could be related to the higher sensitivity of these plants by inducing mineral deficiencies. Potassium uptake in cotton plants was apparently more affected by increases in salt level.

Relationships between Na^+ and K^+ in the different treatments are presented in Fig. 1 in which the ratio between the two ions in the plant vs. their ratio in the nutrient solution are plotted. The K^+/Na^+ ratios in the plant are presented in logarithmic scale. Both ratios followed a first-order exponential function, which are represented by the calculated lines. The higher initial K^+/Na^+ ratio in peanuts is the result of relatively higher K^+ and lower Na^+ concentrations, which supports the suggestion of a relatively effective Na^+-exclusion mechanism in peanuts as compared to cotton.

Fig. 1. Effect of K^+/Na^+ ratio in the nutrient solution on the K^+/Na^+ ratio in the shoots of peanut and cotton plants grown in nutrient solutions containing NO_3^- or NH_4^+ and different salinity (NaCl) levels.

Table 3. Photosynthetic activity, transpiration rate, stomatal conductance and chlorophyll concentration of leaves from peanut and cotton plants grown in nutrient solutions containing NO_3^- or NH_4^+ and different salinity (NaCl) levels. Within species and for each N source, values in columns followed by the same letter are not significantly different (LSD Test, P<0.05).

N source	NaCl (mM)	Photosynthesis (mmoles $m^{-2}s^{-1}$)	Photosynthesis (mmoles g $chlo^{-1}s^{-1}$)	Transpiration rate (b) (mmol m^{-2} s^{-1})	Stomatal conductance (mmol m^{-2} s^{-1})	Chloro-phylls (g m^{-2})
PEANUT						
NO_3^-	0	9.8a	18.2ab	13.6ab	1055a	0.53a
	10	8.1bc	17.2a	14.2a	857b	0.47a
	20	10.4a	20.9bc	12.6bc	863b	0.50a
	35	9.4ac	17.6a	13.9a	973ab	0.52a
	50	10.1a	19.2ab	11.1cd	657c	0.50a
	75	7.9b	17.2a	12.0c	508d	0.44a
	100	8.8abc	22.6c	10.5d	412d	0.34b
NH_4^+	0	10.2a	20.0a	11.6ac	870a	0.50a
	10	9.4ab	17.3b	12.2a	709ab	0.53a
	20	10.4a	21.2a	8.8bd	581bc	0.48a
	35	10.6a	18.8ab	9.7bc	604bc	0.54a
	50	10.1a	19.5ab	10.6c	489c	0.51a
	75	9.0ab	18.8ab	8.5d	321d	0.45a
	100	8.6b	24.3c	7.8d	266d	0.34b
COTTON						
NO_3^-	0	7.2ab	24.4ab	13.0a	870a	0.29a
	50	7.6ab	24.9a	10.5b	536b	0.31a
	100	8.4a	25.1a	10.6b	535b	0.33a
	150	8.0ab	24.1ab	10.9b	506b	0.33a
	200	6.9b	21.4b	5.7c	285c	0.32a
NH_4^+	0	8.0a	23.1a	12.6a	718a	0.35a
	50	7.2ab	19.8b	11.6ab	606ab	0.36a
	100	5.9bc	14.7c	11.1b	516b	0.41b
	150	7.0ab	15.3c	7.7c	265c	0.46b
	200	4.8c	13.5c	6.2d	175c	0.36a

Photosynthetic activity of the youngest fully expanded leaves (Table 3) was affected by salinity to a very small extent. Only cotton leaves at the highest salt concentration showed a considerable reduction in

photosynthesis per leaf area unit. This inhibition, however, may have been due to decreased stomatal conductivity to CO_2 and the consequent.reduction of intercellular CO_2 partial pressure.

Calculating the rates of photosynthesis on chlorophyll basis (Table 3), one could observe an increase of activity at the highest NaCl level in peanut and a decrease in cotton. This changes in photosynthesis rates are due to changes in the levels of leaf chlorophyll of peanut but not in cotton (Table 3) in which chlorophyll concentration remained remarkably unaffected by the salinity of the nutrient solutions.

Several publications presented conflicting results about the effects of salinity on photosynthesis. In cotton, increases in stomatal as well as mesophyll resistance have been reported as affecting photosynthesis under salinity (29, 30). The decrease of photosynthesis in bean plants under salinity was attributed to a reduction in the efficiency of ribulose-1,5-biphosphate carboxylase (31). In mangrove, salinity induced K^+ deficiency associated to a loss of functional Photosystem II (32). In other cases, however, salinity did not result in a major decrease of the photosynthetic activity of spinach (33), sugar beet (34).or wheat and maize (13).

In the present experiments, transpiration rates and stomatal conductance decreased only at the highest levels of salinity in both species, cotton and peanut (Table 3). This limited response of transpiration and stomatal conductance to salinity may be related to the osmotic adjustment of the leaves after exposure of plants to osmotic stress. This low response of transpiration to salinity was similarly observed in wheat and maize (13).

Water use efficiency (WUE) is the ratio between net CO_2 assimilation and transpiration (35). Calculation of WUE in these experiments was based on the gas exchange measurements done with the IRGA at a given moment. In the present experiments WUE did not clearly increase with salinity (data not presented) as reported by others (36). The main reason for this difference may rely on the momentary WUE values obtained from IRGA measurements, which do not reflect cumulative values of carbon gain per unit water lost during longer periods of time. The increases in WUE observed in our experiments were only marked in cotton at high salt concentrations and in NH_4^+-fed plants. These were also the treatments where salinity-reduced stomatal conductance affected transpiration more than photosynthesis.

A highly significant correlation (at $P< 0.01$ level) was observed between shoot growth and K^+ concentration for peanut ($r= 0.85$ and $r= 0.92$, NO_3^-- and NH_4^+-plants respectively) and cotton ($r= 0.89$ and $r= 0.86$) plants. Shoot growth and the concentration of Na^+ and Cl^- the shoots were negatively correlated ($P< 0.01$) in peanut (Na^+: $r= -0.78$ and $r= -0.70$; Cl^-: $r= -0.92$ and $r= -0.78$) as well as in cotton (Na^+: $r= -0.96$ and $r= -0.96$; Cl^-: $r= -0.94$ and $r= -0.90$).

Photosynthetic rates were significantly correlated ($P< 0.01$) with leaf Cl^- concentrations in cotton growing in NO_3^- ($r= 0.97$, parabolically) or NH_4^+ ($r= -0.81$), whereas in peanut such a correlation was observed only in NH_4^+ fed plants ($r= -0.83$) . Leaf Cl^- levels were negatively correlated to stomatal conductance in peanut ($r= -0.89$ and $r= -0.77$, NO_3^-- and NH_4^+-plants respectively) and cotton ($r=-0.88$ and $r= -0.95$). The most interesting correlation was found between leaf K^+ level and stomatal conductance, principally in peanut ($r= 0.92$ and $r= 0.99$, for NO_3^-- and NH_4^+-fed plants respectively). This is not surprising in view of the importance of K^+ fluxes on stomatal opening in many species (25). Sodium

was the ion which correlated better with stomatal conductance in cotton, although negatively (r= -0.88 and r= -0.99, for NO_3^-- and NH_4^+-fed plants respectively).

Although NH_4^+ and NO_3^- elicited similar responses in peanut plants in the absence of salt, these nitrogen forms interacted differently with salinity: a larger inhibition of shoot growth was observed in NH_4^+-fed peanut plants than in NO_3^--fed plants. Ammonium-fed plants produced less dry matter than NO_3^--fed cotton plants. Ammonium nutrition represented an additional stress for cotton plants. This compounded stress by salinity and NH_4^+ may be due to a combination of several factors. Nitrate seems to be a better N source than NH_4^+ when growing plants under saline conditions. The main difference between species resulted from the ability of peanut to maintain a high selectivity of K^+ over Na^+ uptake at increasing NaCl levels, a characteristic already observed in some salt-sensitive species (9).

Photosynthesis was affected by salinity only in cotton growing in relatively high salt concentrations. It remains to be tested whether this decrease was due to salinity induced K^+-deficiency. Photosynthesis values by themselves are hardly a suitable parameter to evaluate the salt tolerance of plants. In long-term experiments, salinity reduced biomass production is a result of a decreased leaf area at early stages of plant development. After adjustment to salt stress, photosynthesis seemed to be fairly resistant to salinity. At high salinity levels, the drop of photosynthesis may be due indirectly to reduced K^+ concentration in the leaves which affect stomatal conductance.

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Table 1. Shoot and root growth of peanut and cotton plants grown on NH_4^+ - or NO_3^--solutions and different salinity levels. Within species, values in columns followed by the same letter are not significantly different (LSD Test, $P < 0.05$).

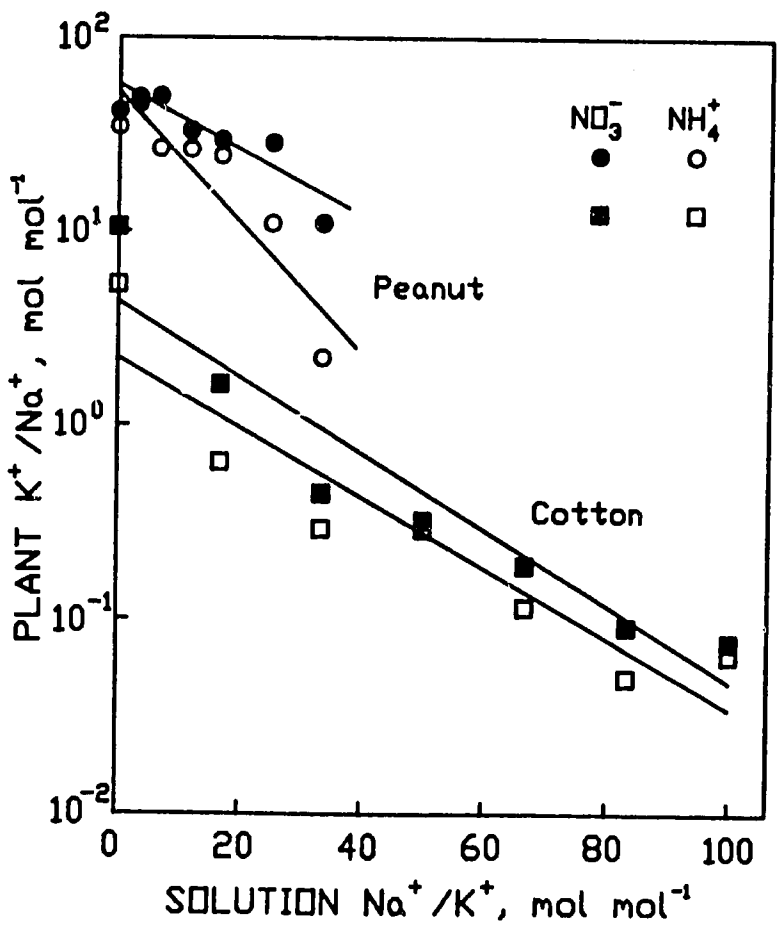
NaCl (mM)		NO_3^- Shoot (g dry weight plant^{-1})	NO_3^- Root (g dry weight plant^{-1})	NH_4^+ Shoot (g dry weight plant^{-1})	NH_4^+ Root (g dry weight plant^{-1})
0	PEANUT	1.98a	0.55a	1.96a	0.48a
10	PEANUT	1.95a	0.45ab	1.65bc	0.37abc
20	PEANUT	1.95a	0.52a	1.77b	0.45ab
35	PEANUT	1.63b	0.46ab	1.54c	0.43ab
50	PEANUT	1.53b	0.44ab	1.14d	0.35bc
75	PEANUT	1.31c	0.39b	1.06d	0.39bc
100	PEANUT	1.11d	0.40b	0.81e	0.27c
0	COTTON	1.41a	0.29ab	0.73a	0.23a
50	COTTON	1.36a	0.38a	0.56b	0.19a
100	COTTON	0.84b	0.23bc	0.57b	0.18a
150	COTTON	0.75c	0.28b	0.47c	0.18a
200	COTTON	0.50d	0.17cd	0.37d	0.10b
250	COTTON	0.40e	0.16d	0.34d	0.09b
300	COTTON	0.36e	0.11d	0.23e	0.06b

Table 2. Content of N, K^+, Na^+ and Cl^- in shoots of peanut and cotton plants grown with NH_4^+- or NO_3^- solutions under differente salinity levels. Within species and for each nitrogen source, values in column followed by the same letter are not significantly different (LSD Test, $P < 0.05$).

N source	NaCl (mM)	N	K^+	Na^+	Cl^-
			(mmoles . shoot^{-1})		
			PEANUT		
NO_3^-	0	4.70a	2.01a	0.05a	0.37a
	10	4.90ab	1.80b	0.04b	0.51b
	20	5.17b	1.84b	0.04b	0.52b
	35	3.93c	1.52c	0.05a	0.52b
	50	3.83c	1.27d	0.04a	0.54b
	75	3.10d	1.06e	0.04b	0.71c
	100	2.64e	0.93e	0.08c	0.94d
NH_4^+	0	5.01a	1.30a	0.04a	0.37a
	10	4.09b	0.97b	0.02b	0.33a
	20	4.57c	0.95b	0.03ac	0.37a
	35	4.07b	0.82c	0.03c	0.28b
	50	2.91d	0.56d	0.02b	0.25b
	75	2.77de	0.46e	0.04d	0.43c
	100	2.49e	0.35f	0.16e	0.64d
			COTTON		
NO_3^-	0	3.66a	1.03a	0.10a	0.56a
	50	3.80b	0.83b	0.51b	1.01b
	100	2.05c	0.40c	0.91c	1.00b
	150	1.96c	0.36c	1.11d	1.29c
	200	1.09d	0.24d	1.27e	1.36c
	250	0.73e	0.24d	2.57f	1.88d
	300	0.68e	0.24d	3.11g	1.67e
NH_4^+	0	1.82a	0.50a	0.10a	0.42a
	50	1.50b	0.23b	0.33b	0.39a
	100	1.67c	0.18c	0.61c	0.57b
	150	1.25d	0.13de	0.86d	0.78c
	200	0.79e	0.11d	0.96e	0.99d
	250	0.65e	0.17ce	3.26f	1.48e
	300	0.45f	0.12d	1.89g	1.03d

Table 3. Photosynthetic rate, transpiration rate, stomatal conductance and chlorophyll concentration of leaves of peanut and cotton plants grown in nutrient solutions containing NO_3^- or NH_4^+ and different salinity (NaCl) levels. Within species and for each N source, values in columns followed by the same letter are not significantly different (LSD Test, P<0.05).

N source	NaCl (mM)	Photosynthesis (mmoles $m^{-2}s^{-1}$)	Photosynthesis (mmoles $g^{-1}chl^{-2}$)	Transpiration rate (b). (mmol $m^{-2}s^{-1}$)	Stomatal conductance (mmol $m^{-2}s^{-1}$)	Chloro-phylls (g m^{-2})
				PEANUT		
NO_3^-	0	9.8a	18.2ab	13.6ab	1055a	0.53a
	10	8.1bc	17.2a	14.2a	857b	0.47a
	20	10.4a	20.9bc	12.6bc	863b	0.50a
	35	9.4ac	17.6a	13.9a	973ab	0.52a
	50	10.1a	19.2ab	11.1cd	657c	0.50a
	75	7.9b	17.2a	12.0c	508d	0.44a
	100	8.8abc	22.6c	10.5d	412d	0.34b
NH_4^+	0	10.2a	20.0a	11.6ac	870a	0.50a
	10	9.4ab	17.3b	12.2a	709ab	0.53a
	20	10.4a	21.2a	8.8bd	581bc	0.48a
	35	10.6a	18.8ab	9.7bc	604bc	0.54a
	50	10.1a	19.5ab	10.6c	489c	0.51a
	75	9.0ab	18.8ab	8.5d	321d	0.45a
	100	8.6b	24.3c	7.8d	266d	0.34b
				COTTON		
NO_3^-	0	7.2ab	24.4ab	13.0a	870a	0.29a
	50	7.6ab	24.9a	10.5b	536b	0.31a
	100	8.4a	25.1a	10.6b	535b	0.33a
	150	8.0ab	24.1ab	10.9b	506b	0.33a
	200	6.9b	21.4b	5.7c	285c	0.32a
NH_4^+	0	8.0a	23.1a	12.6a	718a	0.35a
	50	7.2ab	19.8b	11.6ab	606ab	0.36a
	100	5.9bc	14.7c	11.1b	516b	0.41b
	150	7.0ab	15.3c	7.7c	265c	0.46b
	200	4.8c	13.5c	6.2d	175c	0.36a


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}

WHEAT GROWTH AS AFFECTED BY NITROGEN TYPE, pH AND SALINITY.
I. Biomass production and mineral composition.

LEIDI E.O.*, M. SILBERBUSH and S.H.LIPS

Desert Agrobiology Center (J. Blaustein Institute for Desert Research) and Department of Biology (Faculty of Natural Sciences), Ben-Gurion University of the Negev. Sede Boqer 84993, Israel.

*Present address: UEI Fisiología Vegetal, Estación Experimental del Zaidín (CSIC), Avda. Cervantes 2, E-18080 Granada, Spain.

Summary

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

Key words: Triticum aesttivum, ammonium, ion interaction, nitrate, salinity.

Introduction

The demand to use brackish water for irrigation is increasing in Israel and in other arid regions of the world and has renewed the interest on plant nutrition and nitrogen fertilization under saline conditions (see reviews by Kafkafi, 1984 and Feigin, 1985). The form of nitrogen nutrition may exert a considerable influence on the mineral composition of plants (Kirkby and Mengel, 1967; Kurvits and Kirkby 1980; Allen et al., 1985). According to Cox and Reisenauer (1973), ammonium increased anion uptake whereas nitrate increased cation concentration in wheat plants quite markedly. Changes in pH of the nutrient medium and the type of nitrogen supplied affected ion uptake (Kirby and Mengel, 1967; Raven and Smith, 1976).

The pH of the growth media determines the solubility and availability of many nutrients to the plant (Marschner, 1986). The complex interaction between all these parameters must be understood while studying plant responses to salinity due to its effect on root growth *per se* (Marschner, 1986) or the effects derived from differential ion uptake.

In this study we examined the interactions between of the form of nitrogen supplied, the pH of the nutrient medium and its salinity (NaCl concentration) on different aspects of wheat growth.

Materials and Methods

Petit

Wheat (*Triticum aestivum* L. cv. Barkai) plants were germinated in vermiculite for seven days and transferred then to aerated nutrient solutions, eight seedlings to each 20-liter container. Nutrient solutions contained 4 mM nitrogen, either as $(NH_4)_2SO_4$ or as $Ca(NO_3)_2$. Additional components of the nutrient solutions were: 4 mM K^+, 1 mM $H_2PO_4^-$, 2 mM Ca^{2+}, 1 mM Mg^{2+} and 2.5-4.5 mM SO_4^- (NO_3^-- and NH_4^+-solutions respectively). Micronutrients were supplied as prescribed in Long Ashton nutrient medium (Hewitt, 1966) and iron was provided as 4 mg. l^{-1} Fe-EDDHA. Averages of daily maximum and minimum temperatures in the greenhouse during the growing period were 19.3 and 7.5 °C respectively. In sunny days, photosynthetic photon flux density was between 700-800 $\mu mol\ m^{-2}s^{-1}$ at noon.

Five salinity levels were provided as 0, 25, 50, 75 and 100 mM NaCl. Ammonium containing solutions were set to onesolutions were set to one of the following pH levels: 5, 6.5 and 8. The pH of nitrate-containing solutions was 5, 6.5, 8 or 9. All treatments were repeated twice. The pH of the nutrient solutions was determined and adjusted daily with KOH and H_2SO_4. Nutrient solutions were changed weekly.

Dry weight of 56 days old plants was determined by drying at 70° for 48 h. Root length was

determined according to Tennat (1975). Samples of the dry material were ashed in H_2SO_4 + H_2O_2, analyzed for total (reduced) nitrogen with the Nessler reagent. Ca^{2+} was titrated with EDTA. Cl^- was extracted in hot water and measured with a chloridometer (Corning Chloride Analyzer 926). Na^+ and K^+ concentrations in the same water extract were determined with a flame photometer .

Results and Discussion

Shoot and root growth

Shoot dry weight declined with increasing NaCl concentration of nutrient solutions containing either NO_3^- or NH_4^+-nitrogen. (Fig. 1a). Plant growth also decreased with increasing pH, this effect being more pronounced in NH_4^+-fed plants. Similar observations were obtained by Alam (1981) with rice, in which optimal dry matter accumulation took place at pHs between 5.5 and 6.5, which agrees with the results presented here. Findenegg (1987) similarly observed a pH optimum between 5.0 and 6.0 for several species grown on NH_4^+. The significative growth reduction observed in NH_4^+-grown plants at high pH could be related to an specific NH_3 toxicity effect due to the prevalence in the medium of NH_3 at high pH (pK= 9.2) (Bennet and Adams, 1970; Goyal and Huffaker, 1984). More recently, Findenegg et al. (1989) have reported an increase of free NH_4^+ in sugar beet leaves when increasing the pH of the nutrient medium. These authors suggested that ammonium accumulation in leaves could have been responsible for the growth depression registered at high pH.

Root dry weight (Fig. 1b) and root length (Fig. 1c) decreased with increasing NaCl concentrations as well as NH_4^+ nitrogen in the medium. However, the number of root tips per meter of root length (Fig. 1d) was relatively higher in nutrient solutions with NH_4^+ suggesting that NH_4^+ inhibited root elongation. Enhanced root length and root weight was observed in cotton exposed to moderate salinity levels (Kurth et al. 1986). Devitt et al. (1984) reported decreased wheat root weight induced by an increase in osmotic potential of the nutrient solution, while the increase in Na^+ level within each osmotic potential led to a decrease in root elongation. Root growth depression as a consequence of NH_4^+ nutrition has been also observed with other species such as cucumber (Schenk and Wehrmann, 1979), *Plantago* (Blacquière et al., 1987) and maize and wheat (Lewis et al., 1989). The precise effect of NH_4^+ on root elongation, however, remains to be studied. The relatively larger root growth inhibition detected in NH_4^+-fed plants under saline conditions compared to NO_3^--fed plants may be related also to the reported inhibition of NH_4^+ detoxification under salinity due to inhibition of arginine synthesis (Lovatt, 1986).

The ratio of shoot to root dry weight (Fig. 2) was no affected by pH over all the salinity range studied. The shoot/root ratio, expressed by the slopes of the different lines, was

unaffected by pH in NO_3^--containing media. The shoot/root ratio was higher but decreased with pH in NH_4^+-grown plants. The higher shoot/root ratios exhibited by NH_4^+-fed plants was the consequence of the marked inhibition of root growth observed in NH_4^+-containing media (Lewis et al., 1987, 1989). The effect of NH_4^+ on the shoot/root ratio may vary according to the plant species (Blacquière et al., 1987).

N, K, Na, Cl, and Ca concentrations in shoots

Nitrogen concentration in the shoot (Table 1) was slightly reduced by the increase in salinity levels in plants grown in NH_4^+ or in NO_3^-. No effect of pH was observed on N concentration (Table 1). Although neither salinity nor pH of the nutrient medium have a marked effect on N concentration in the shoots, growth was limited by nitrogen uptake and assimilation. In fact, a high correlation between shoot growth and nitrogen concentration was found in NO_3^- - and NH_4^+-fed plants ($r= 0.84$, $P<0.01$, and $r= 0.56$, $P< 0.01$, respectively).

Potassium concentration in the shoots was reduced by increasing NaCl levels in solutions containing either NO_3^- or NH_4^+. Cramer et al. (1985) have shown that Na^+ displaced Ca^{2+} from root membranes and increased efflux of cytosolic K^+. Silberbush and Ben-Asher (1987) have reported competitive inhibition of K^+ uptake by roots under high Na^+ levels. Ammonium-grown plants showed lower K^+ concentrations than NO_3^- -grown plants, and the highest pH (i.e. pH 8) used in these experiments resulted in a considerable decrease of K^+ uptake. Reduced K^+ uptake in NH_4^+-fed plants has been frequently reported (Haynes and Goh, 1978; Gashaw and Mugwira, 1981; Blacquière et al., 1987; van Beusichem et al., 1988). Ammonium inhibition of net K^+ uptake has been shown in other plant species (Bloom and Finazzo, 1986; Vale et al., 1987; Topa and Jackson, 1988). Ammonium nutrition would affect cation uptake as a consequence of the intracellular buffering mechanism which maintains electroneutrality by a net efflux of H^+ and reduced intake of K^+ or Ca^{2+} (van Beusichem et al., 1988). Potassium concentration in shoots of plants fed with either nitrogen form at the highest salt levels (i.e. 75 and 100 mM NaCl) was below the critical level for K^+ deficiency indicated by Rama Rao (1986).

High NaCl concentrations and high pH in the nutrient medium resulted in an increase in Na^+ and Cl^- uptake. We observed the minimum level of Na^+ and Cl^- in shoots generally at pH 6.5. Findenegg et al. (1989) reported higher Cl^- uptake by sugar beet plants with increasing pH. In our experiments, the highest concentration of Cl^- in plants was obtained at the highest pH and NaCl level and may be the result of enhanced Cl^- uptake generated by a Cl^-/OH^- antiporter as suggested by Jennings (1986), superimposed to a concentration effect due to limited plant growth. The increase of the Na^+/Ca^{2+} ratio in the solution by NaCl l may result in increased permeability of the root membranes to Na^+ and Cl^- due to loss in membrane selectivity (Greenway and Munns, 1980).

Calcium concentration in shoots decreased with increasing pH in NO_3^--grown plants.

Calcium level was curvilinearly affected by pH in NH_4^+-grown plants, with a minimum at pH 6.5. Decrease of Ca^{2+} uptake under low pH in the growth medium have been reported for other plant species (Ingestad, 1979; Aslam, 1981).

Shoot growth of wheat plants cultivated in media with different salinity levels and pH treatments was highly correlated with K^+ concentration in the shoots (Fig. 3a). These results could be expected in view of the role of K^+ as the main osmoticum in plants mediating cell expansion (Hsiao and Läuchli, 1986). This relation was linear for plants grown on NO_3^- but curvilinear for NH_4^+-grown plants. Shoot growth was logarithmically related to shoot Na^+ concentration (Fig. 3b). A low substitution of Na^+ for the roles of K^+ in wheat plants would only be expected in the presence of adequate K^+ levels (Flowers and Läuchli, 1983). An inverse correlation between K^+ and Na^+ levels in shoots (Fig. 3c) was also observed. The slope of the curves shows the variation in K^+/Na^+ ratio with increasing salinity level of the nutrient medium. Lower K^+/Na^+ ratio values are evident in NH_4^+-fed plants at tdifferent salinity levels suggesting a limited capacity to maintain adequate K^+/Na^+ ratios in shoots. This ratio has been considered a critical factor related to salt tolerance in several species (Greenway and Munns, 1980).

Wheat growth might be inhibited mainly by Na^+ accumulation in the shoot and its competition with K^+ uptake. The Na^+ vs K^+ competition was mainly restricted to these two cations in NO_3^--fed plants. However, when nitrogen was supplied as NH_4^+, the pattern of cation uptake changed (probably through regulatory mechanisms of the intracellular pH) resulting in depressed K^+ and Na^+ uptake. The highest pH caused a sharp increase in Na^+ concentration in the shoots of NH_4^+-fed plants associated with a decrease in the shoot K^+ level probably as a consequence of loss of selective properties in the root cell membranes. Ammonium nutrition determined additional constraints to plant growth (through root growth inhibition, lower K uptake). Consequently, NO_3^- seems to be a better nitrogen source than NH_4^+ in terms of plant tolerance to environmental stresses such as salinity and extreme pH values in the growing medium.

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Table 1. Effect of nitrogen source (NO_3^- or NH_4^+), salinity and pH of nutrient solutions on nitrogen, potassium, sodium, calcium and chloride concentrations in shoots of wheat plants grown in hydroponics.

Nitrogen source	pH	NaCl (mM)	N	K^+	Na^+	Ca^{2+}	Cl^-
			mmoles· g^{-1} DW				
NO_3^-	5.0	0	2.94	1.62	0.06	0.17	0.35
		25	2.86	1.37	0.29	0.16	0.62
		50	2.83	1.20	1.22	0.16	0.87
		75	2.67	1.00	2.01	0.14	1.27
		100	2.75	0.99	1.49	0.14	1.26
	6.5	0	3.32	1.18	0.54	0.16	0.36
		25	3.42	1.08	0.20	0.15	0.51
		50	3.22	1.05	0.64	0.13	0.78
		75	3.15	0.95	1.30	0.11	1.00
		100	3.04	0.86	1.32	0.09	1.31
	8.0	0	3.13	1.48	0.06	0.13	0.30
		25	2.86	1.31	0.24	0.10	0.54
		50	2.74	1.12	0.93	0.10	0.88
		75	2.73	1.01	0.88	0.10	0.91
		100	2.49	0.83	1.06	0.10	0.87
	9.0	0	3.19	1.20	0.04	0.11	0.36
		25	3.30	1.17	0.22	0.10	0.54
		50	3.08	1.06	0.33	0.09	0.66
		75	3.13	0.87	0.66	0.09	0.83
		100	2.84	0.85	0.19	0.08	1.18
NH_4^+	5.0	0	3.18	1.53	0.05	0.11	0.35
		25	2.98	1.34	0.25	0.09	0.58
		50	3.09	1.13	0.73	0.11	0.88
		75	2.74	0.96	1.55	0.11	1.62
		100	2.46	0.75	2.40	0.12	2.39
	6.5	0	3.23	1.05	0.07	0.08	0.38
		25	3.30	0.79	0.52	0.08	0.81
		50	3.31	0.58	1.89	0.08	1.83
		75	3.08	0.52	2.11	0.07	1.77
		100	2.90	0.40	3.17	0.08	2.86
	8.0	0	2.99	1.40	0.05	0.09	0.25
		25	2.99	1.32	0.19	0.09	0.46
		50	2.75	1.10	1.28	0.11	0.91
		75	2.55	0.93	1.62	0.10	1.51
		100	2.50	0.79	1.41	0.10	1.50
$LSD_{0.05}$			0.26	0.24	0.65	0.42	0.02

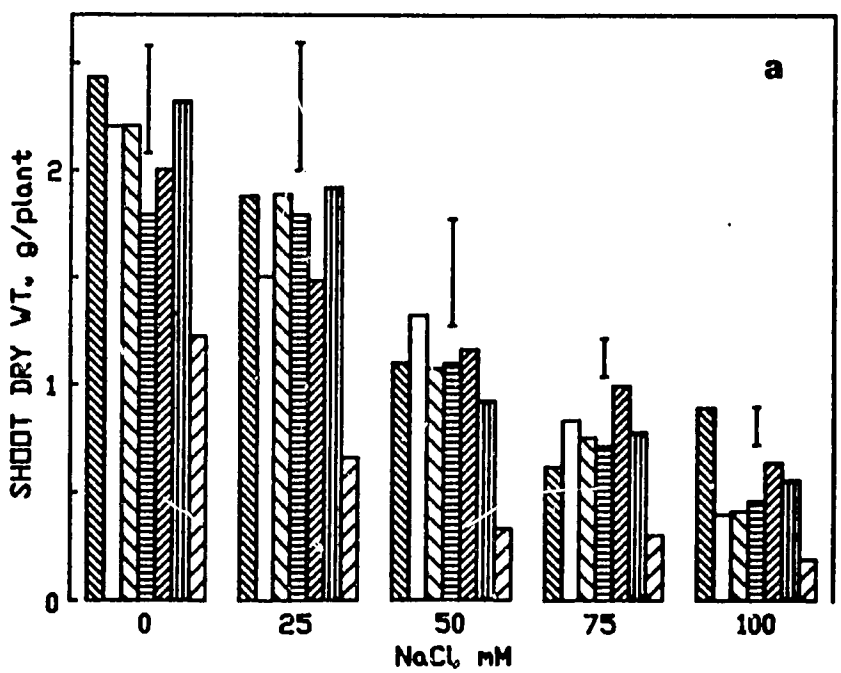
Legends to Figures:

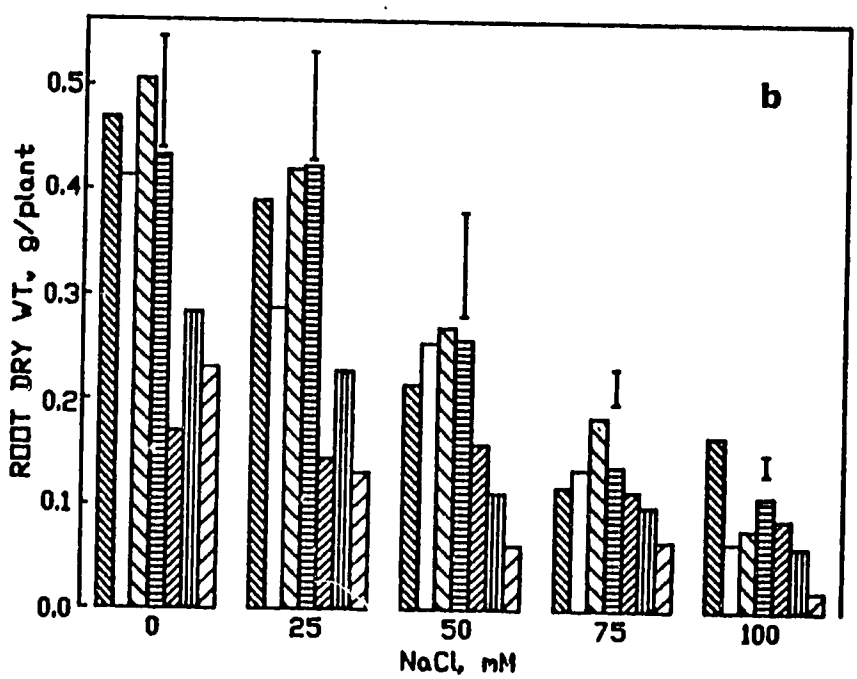
Fig. 1. Effect of nitrogen source (NO_3^- vs. NH_4^+), salinity level and medium pH on wheat plants grown in hydroponics: (a), shoot dry weight; (b), root dry weight; (c), root length; and (d), root tips density. Bars represent LSD ($P \leq 0.05$) within each NaCl level.

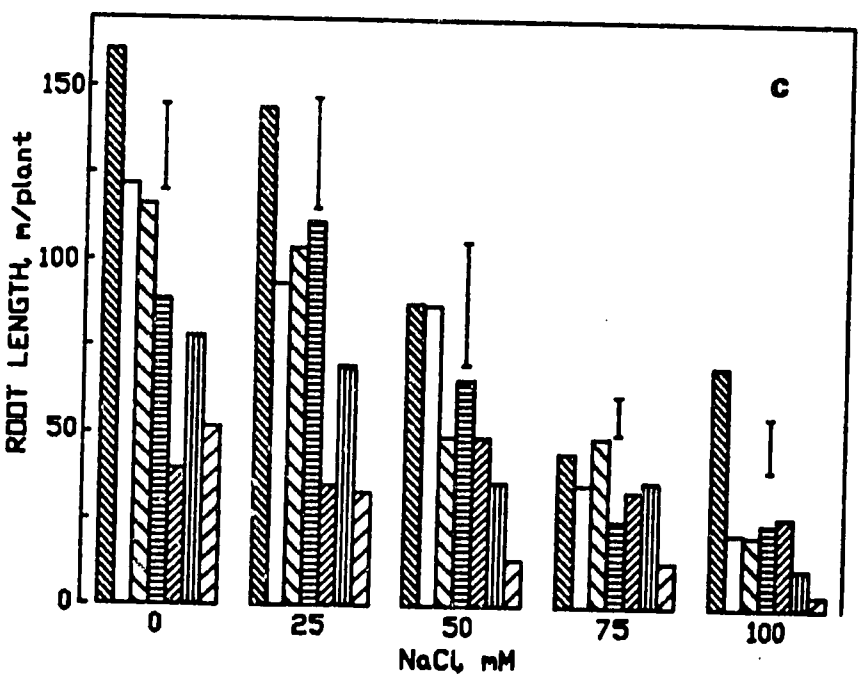
Fig. 2. Effect of nitrogen source (NO_3^- vs. NH_4^+), salinity level and medium pH on the relationship between shoot and root growth of wheat plants grown in hydroponics.

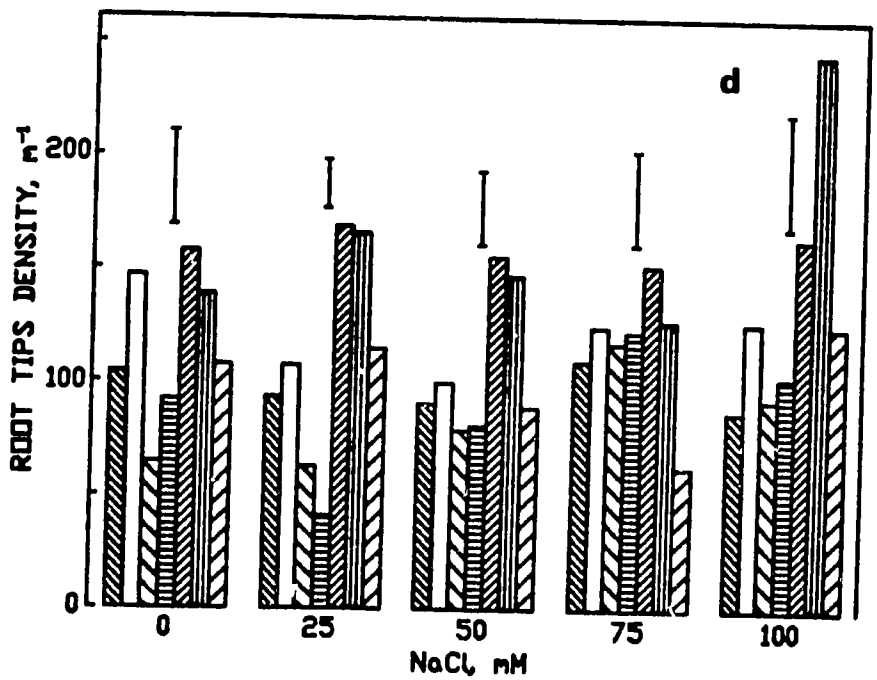
Fig. 3. Effect of nitrogen source (NO_3^- vs. NH_4^+), salinity level and medium pH on wheat plants grown in hydroponics. Relations between (a), shoot growth and shoot K^+ concentration; (b), shoot growth and shoot Na level; (c), levels of K^+ and Na^+ in shoots.

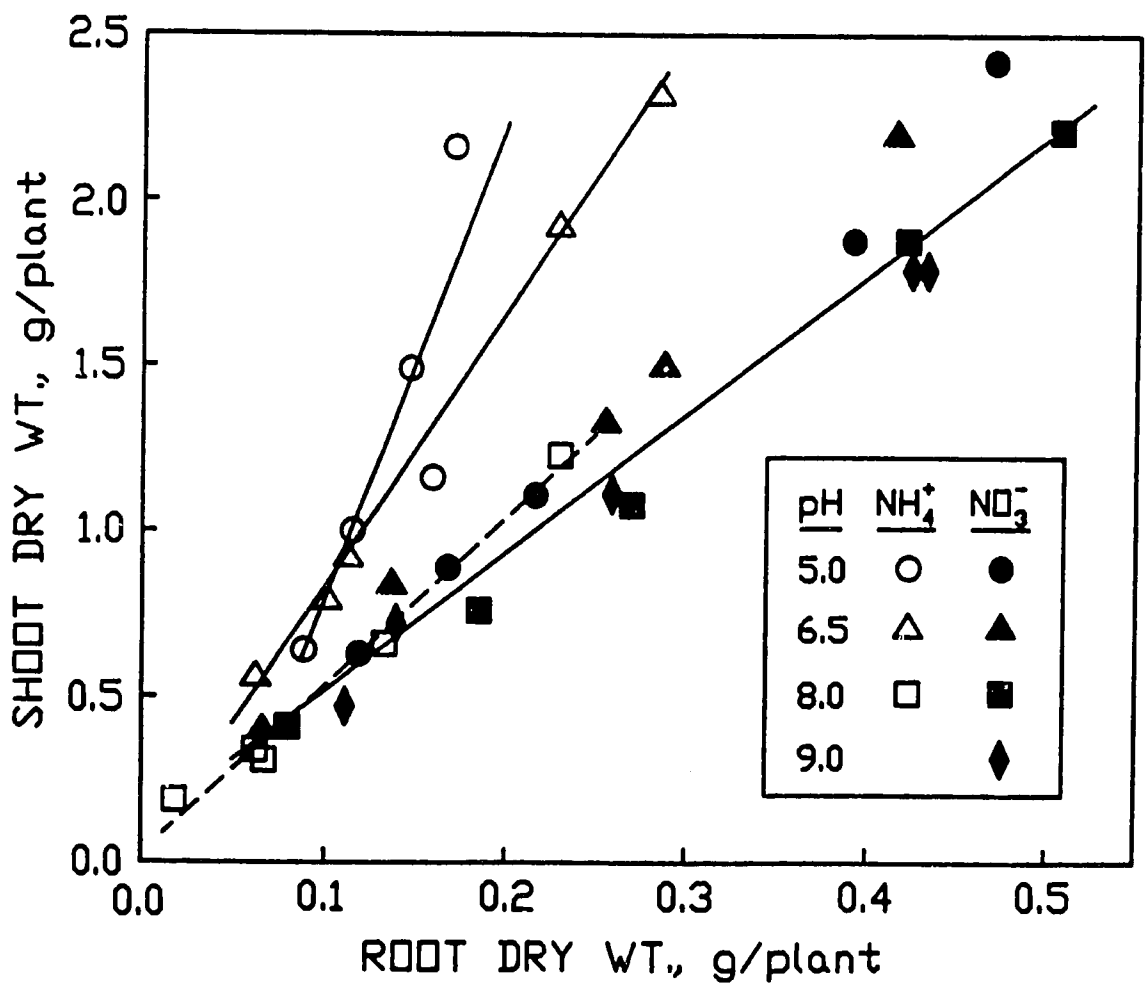
NO_3, pH=5.0
NO_3, pH=6.5
NO_3, pH=8.0
NO_3, pH=9.0
NH_4, pH=5.0
NH_4, pH=6.5
NH_4, pH=8.0

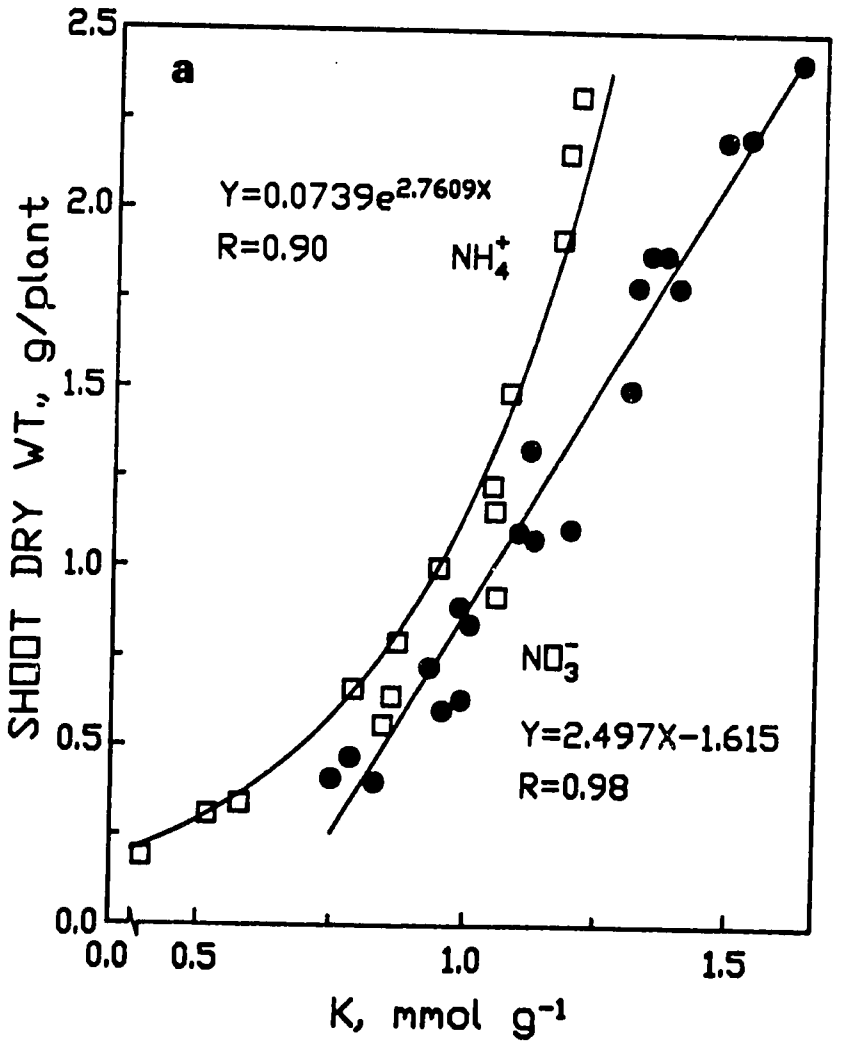

a
SHOOT DRY WT. g/plant
0
1
2
0
25
50
75
100
NaCl, mM

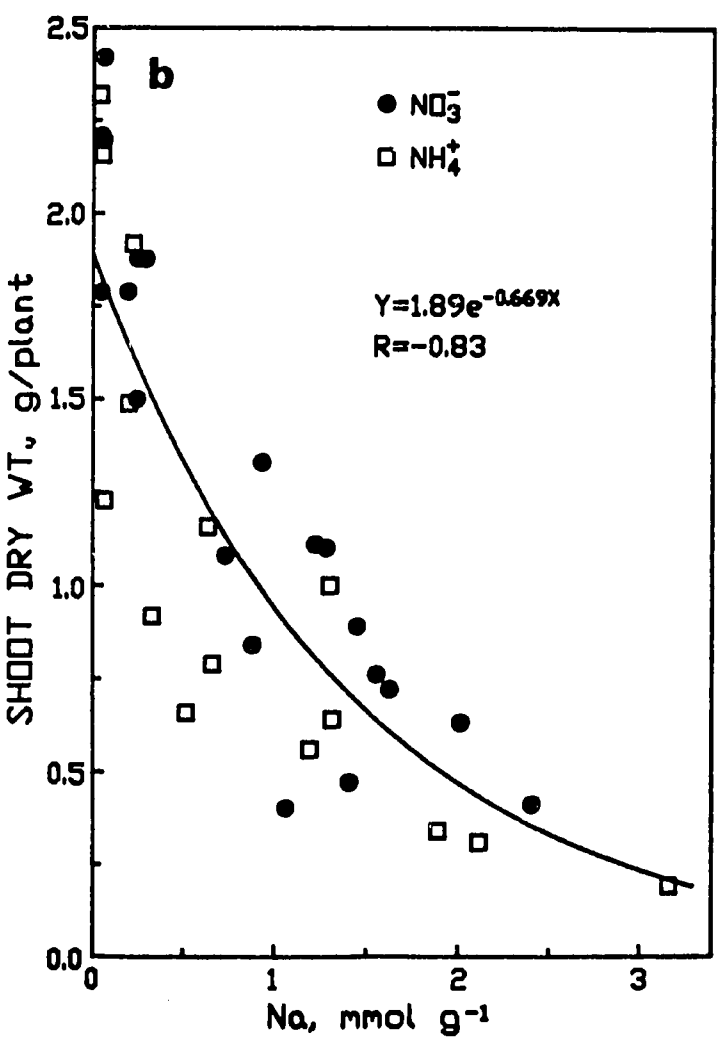

b
ROOT DRY WT, g/plant
0.0
0.1
0.2
0.3
0.4
0.5
0
25
50
75
100
NaCl, mM

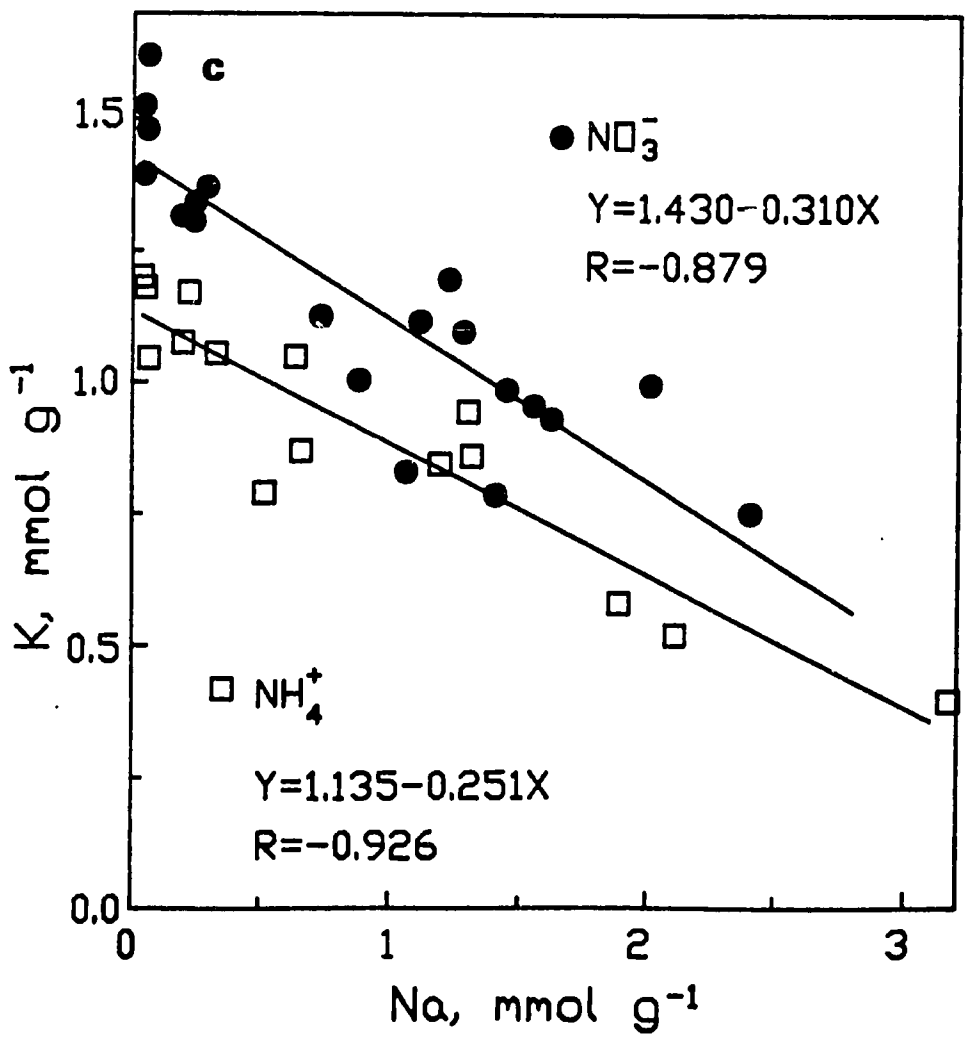

c
ROOT LENGTH, m/plant
150
100
50
0
0
25
50
75
100
NaCl, mM


d
ROOT TIPS DENSITY, m⁻¹
200
100
0
0
25
50
75
100
NaCl, mM


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


a
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


b
NO_3^-
NH_4^+
$Y=1.89e^{-0.669X}$
R=-0.83
SHOOT DRY WT, g/plant
Na, mmol g^{-1}
0.0
0.5
1.0
1.5
2.0
2.5
0
1
2
3


c
1.5
1.0
0.5
0.0
0
1
2
3
K, mmol g⁻¹
Na, mmol g⁻¹
NO3⁻
Y=1.430−0.310X
R=−0.879
NH4⁺
Y=1.135−0.251X
R=−0.926

WHEAT GROWTH AS AFFECTED BY NITROGEN TYPE, pH AND SALINITY. II. PHOTOSYNTHESIS AND TRANSPIRATION.

LEIDI E.O.*, M. SILBERBUSH AND S.H.LIPS

Desert Agrobiology Center, J. Blaustein Institute for Desert Research and Department of Biology, Faculty of Natural Sciences, Ben-Gurion University of the Negev, Sede Boqer 84993, Israel.

*Present address, IJEI Fisiología Vegetal, Estación Experimental del Zaidín (CSIC), Avda. Cervantes 2, E-18080 Granada, Spain.

Summary

The interactions between the form of nitrogen (ammonium or nitrate) supplied, NaCl concentration and pH of the nutrient media were studied on wheat (*Triticum aestivum* L. cv. Barkal) plants growing in hydroponics. The effects of these parameters on mineral content and plant growth were reported in our previous paper (Leidi et. al., 1990b).

Neither photosynthetic or transpiration rates were affected by salinity in the range of NaCl concentrations used. Stomatal conductance, however, decreased with increasing NaCl concentrations in the medium. Chlorophyll content of the leaves of ammonium-fed plants decreases with increasing pH. This response is more moderate in nitrate-grown plants. Consequently, a difference is observed between photosynthesis rates expressed on the basis of leaf area or of chlorophyll content. The relative content of K^+ and Na^+ and its possible effect on photosynthesis,transpiration, stomatal conductance, and the relationships with shoot growth are discussed.

Key words: Triticum aestivum, ammonium, nitrate, salinity, NaCl, pH, photosynthesis, stomatal conductance, transpiration.

Introduction

The increased use of saline water for irrigation has renewed the interest on mineral nutrition and especially nitrogen nutrition under saline conditions (Kafkafi 1984; Feigin 1985). The form of nitrogen supplied to plants may exert a considerable influence on their mineral composition (Kirby and Mengel 1967; Kurvits and Kirkby, 1980; Allen et al., 1985). The level of anion intake was stimulated by ammonium in wheat, whereas nitrate increased cation concentration in these plants (Cox and Reisenauer 1973). Changes in pH of the nutrient medium, in the presence of different forms of nitrogen, also affected the uptake of ion by the roots (Kirby and Mengel 1967; Raven and Smith 1976). The pH of the growth medium determines the solubility and availability to the plant of numerous nutrients (Marschner 1986).

In our previous paper (Leidi et al. 1990b) we report our studies on the effect of nitrogen form supplied, pH and salinity on growth of wheat plants and on their mineral content. In this paper we report on the effect of these factors on photosynthetic activity,water use efficiency and their relations with plant growth in wheat.

Materials and methods

Petit

Wheat (*Triticum aestivum* L. cv. Barkal) plants were germinated in vermiculite for seven days and transferred then to aerated nutrient solutions, eight seedlings to each 20-liter container. Nutrient solutions contained 4 mM nitrogen, either as $(NH_4)_2SO_4$ or as $Ca(NO_3)_2$. Additional components of the nutrient solutions were: 4 mM K^+, 1 mM $H_2PO_4^-$, 2 mM Ca^{2+}, 1 mM Mg^{2+} and 2.5-4.5 mM SO_4^- (NO_3^-- and NH_4^+-solutions respectively). Micronutrients were supplied as prescribed in Long Ashton nutrient medium (Hewitt, 1966) and iron was provided as 4 mg. l^{-1} Fe-EDDHA. Averages of daily maximum and minimum temperatures in the greenhouse during the growing period were 19.3 and 7.5 °C respectively. In sunny days, photosynthetic photon flux density was between 700-800 µmol $m^{-2}s^{-1}$ at noon.

Five salinity levels were provided as 0, 25, 50, 75 and 100 mM NaCl. Ammonium containing solutions were set to one of the following pH levels: 5, 6.5 and 8. The pH of nitrate-containing solutions was 5, 6.5, 8 or 9. All treatments were repeated twice. The pH of the nutrient solutions was determined and adjusted daily with KOH and H_2SO_4. Nutrient solutions were changed weekly.

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 a constant radiation flux (500 μmol m^{-2} s^{-1} PAR). Chlorophyll was extracted from leaf discs in 80% acetone and assayed spectrophotometrically according to Arnon (1949).

Results and Discussion

The effects of NaCl concentration, pH of nutrient solutions and nitrogen form supplied to the plants on their growth parameters and mineral composition have been reported in our previous paper (Leidi et al. 1990b).

Photosynthesis expressed on a unit area basis was not affected by salt concentrations up to 100 mM NaCl (Fig. 1a) even when shoot dry mass (see Leidi et al., 1990b) and leaf area of the plants decreased with increasing NaCl concentration. These results contradict other reports in which reduction of photosynthesis was observed in plants grown in the presence of NaCl and attributed to increases in stomatal resistance (Gale et al., 1967; Downton, 1977; Longstreth and Nobel, 1979; Walker et al., 1981) or the reduction in capacity of the photosynthetic machinery (Seemann and Critchley, 1985; Seemann and Sharkey, 1986). However, in the long-term, leaf adaptation to mild salinity stress may be based on the adjustment of some metabolic processes, such as photosynthesis, to stress. According to Gupta and Berkowitz (1988) chloroplastic osmotic adjustment may facilitate adaptation of the photosynthetic mechanism to water stress. There are additional reports showing no significant response of photosynthetic rate to salinity (Kaiser et al., 1983; Plaut and Heuer, 1985; Terry and Waldron, 1986; Lewis et al., 1989; Leidi et al., 1990a). After adjustment to salinity stress, an increase in photosynthetic activity was observed in wheat by Kingsbury et al. (1984). We agree with Kriedemann (1986) who has pointed out, the extension rather than the activity of the pnotosynthetic area is the determinant of plant productivity. As a result, although the rate of photosynthesis on the unit area basis of wheat is not affected by concentrations of NaCl up to 100 mM, the rate of photosynthesis of the entire plant is lower in the presence of salt because of a limited expa.ision of the leaves.

Some authors have reviewed on the possible causes of leaf growth reduction by salinity (Munns and Teermat,1986; Kriedemann, 1986). Teermat et al. (1985) concluded that changes in leaf extension would be determined by changes in cell wall properties. On the other hand, Neumann et al. (1988) recently indicated that salinity affects growth rate by decrease in turgor. One may also speculate that leaf expansion under saline conditions is limited by the intake of nitrogen by the plants, which is reduced in the presence of NaCl (Leidi et al., 1990b). A steady supply of nutrients (N, P, K, Mg) is important for maintaining leaf expansion (Dale 1982). Enhancing the supply of nitrogen to peanut plants inhibited by NaCl, caused a complete recovery of plant

growth (Silberbush and Lips, 1988) since the uptake of nitrogen to the plant was renewed and allowed full expansion of leaves as well as production of new ones. However, one should not exclude the possibility that the factors limiting leaf expansion under saline conditions differ with plant species.

Chlorophyll concentration in the leaves (Fig. 1c) decreased with NaCl as the pH of the medium increased. This phenomenon was more pronounced in ammonium than in nitrate-fed plants. According to Mengel and Kirkby (1987) high levels of NH_4^+, K^+ and Ca^{2+} restricts Mg^{2+} uptake and Mg^{2+} deficiency results in lower chlorophyll content. The rate of photosynthesis on a chlorophyll basis was actually higher in plants grown in the presence of NaCl (Fig. 1b). Similar effects were observed in spinach by Robinson et al. (1983). One should assume that a considerable amount of leaf chlorophyll under non-saline conditions is not actively involved in light-harvesting reactions (Thornber, 1975). Consequently, the decrease of this non-active chlorophyll by salinity does not affect photosynthetic rate, resulting instead in an apparent increase of photosynthetic efficiency when expressed on the basis of leaf chlorophyll content.

Transpiration rate was unaffected by 0-100 mM NaCl, within the range of pH between 5 and 9, when nitrogen was applied as nitrate (Fig. 2a). In ammonium-fed plants, transpiration rate increased with the pH of the medium and decreased with NaCl concentration. Stomatal conductance in ammonium-fed plants, on the other hand, was decreased with increasing NaCl concentration in the medium. This decrease in stomatal conductance was further enhanced by high pH (e.g. pH 8.0) (Fig. 2b).

The lack of correlation between shoot K^+ concentration and stomatal function observed in this experiment was similarly reported for initial stages of K^+ depletion (Hsiao and Läuchli, 1986). Sodium and Cl^- concentration in the shoots was negatively correlated to stomatal conductance in ammonium-fed plants ($r= -0.52$ and $r= -0.49$, $P< 0.05$, respectively), suggesting a higher sensitivity because of lower shoot K concentration of ammonium-fed plants and the smaller effectiveness of Na^+ as a replacement of K^+ in stomatal opening (Hsiao and Läuchli, 1986).Seemann and Critchley (1985) also reported a negative relation between Cl^- and stomatal conductance in bean plants. Devitt et al. (1984) showed an increase in 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.

Water use efficiency (WUE) (the ratio of net CO_2 assimilation to transpiration as recorded with a portable infrared gas analyzer) reached a maximum at 75-100 mM NaCl disregarding medium pH

and type of N used (dat not presented). Other reports have shown similar effects of salinity on WUE (Rawson 1986; McCree and Richardson 1987; Lewis et al. 1989).

Photosynthesis was not correlated to stomatal conductance suggesting that the intercellular CO_2 concentration (C_i) was not the limiting factor of photosynthesis under the conditions of these experiments. According to Hsiao and Läuchli (1986), deficiency of K^+ as well of other mineral nutrients can reduce transpiration affecting stomatal movement. This was the case only in ammonium-fed plants at the highest pH level where a reduction of transpiration was recorded when increasing salinity level (Fig. 2b) and could be correlated with an important reduction in K^+ level (Leidi et al., 1990b).

Photosynthesis tolerance to salinity may be due to the adjustment of the photosynthetic machinery to salinity (Kaiser et al., 1983; Plaut et al., 1989) at early growth stages. Transpiration rate in our experiments was little affected by salinity, but not so stomatal conductance. The relative amount of Na^+ and K^+ was definitely the parameter which seems most related to plant growth and production under saline conditions. However, the relation of their concentrations and growth seems the final balance in the plant reaction to stress. The negative correlation between Na^+ and shoot growth does not necessarily imply a negative effect of Na^+ on plant metabolism at the time of sampling. In fact, no negative correlation of Na^+ and Cl^- concentration on photosynthesis and transpiration was observed. Both ions could contribute to the osmotic adjustment without causing any extensive and direct harm to metabolism. Photosynthesis adjusted to the full range of salinity caused by concentrations of NaCl up to 100 mM and no inhibition of photosynthetic rate per unit area could be observed. Salinity definitely inhibited leaf expansion and subsequently total leaf area per plant and biomass production. The growth reduction by salinity occuring at the initial stages of plant growth (through short-term effects inhibiting photosynthesis, changes in carbon allocation and mechanisms leading to a reduction in leaf expansion) restrict the future photosynthetic capacity of the salt-stressed plant and thus its final biomass production.

Acknowledgements

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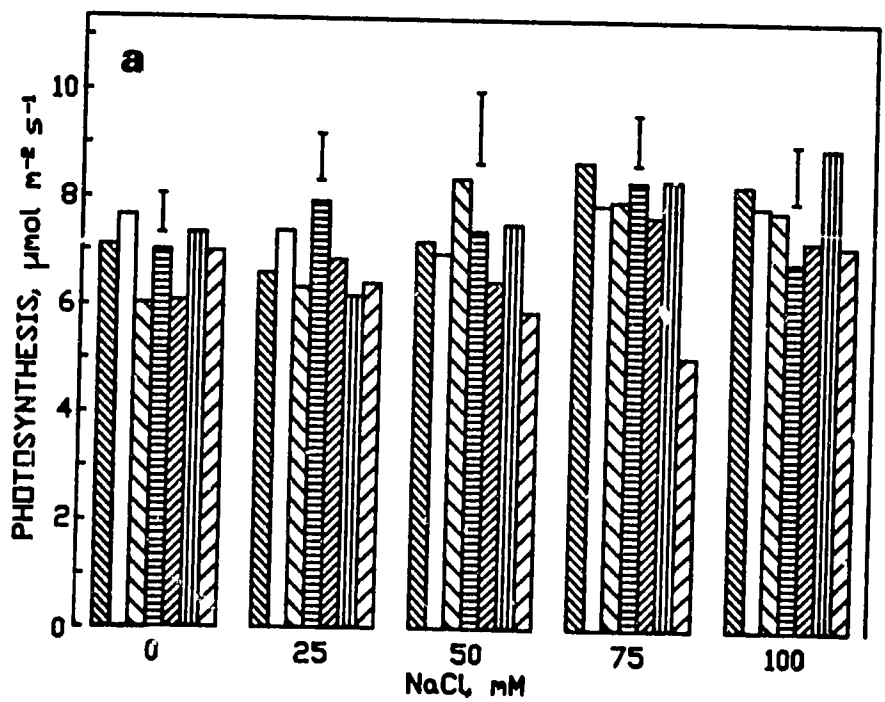
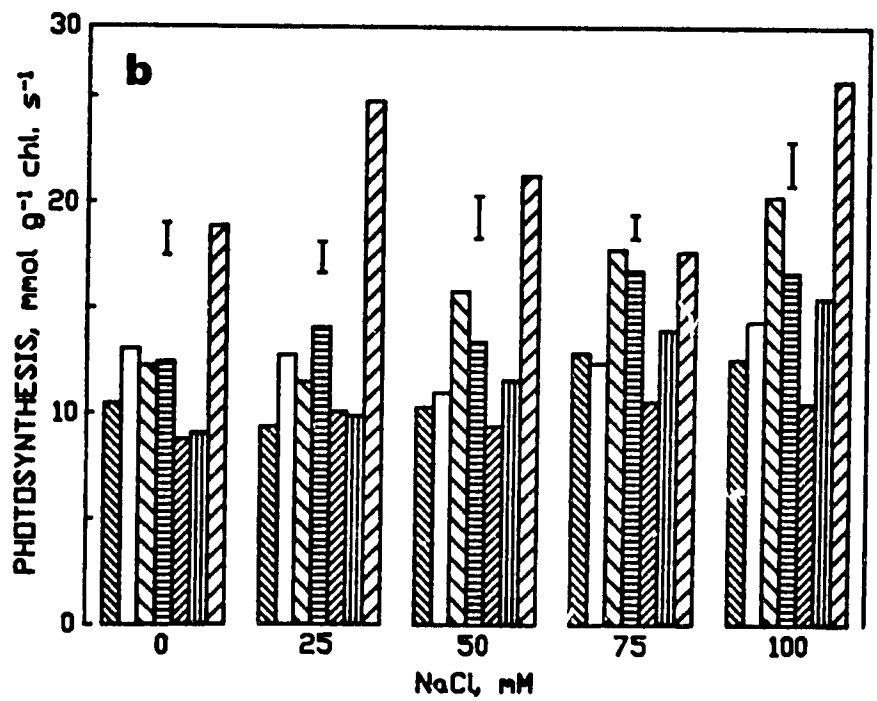
Legends of Figures:

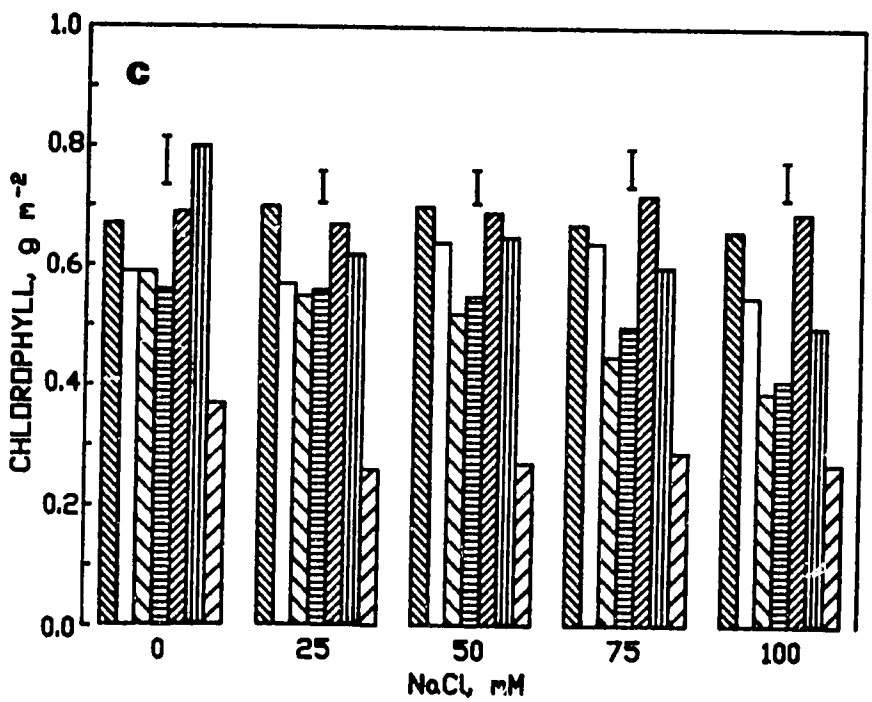
Fig. 1. Effect of nitrogen source (NO_3^- vs. NH_4^+), salinity level and medium pH on wheat plants grown in hydroponics: (a), photosynthesis per unit leaf area; (b), photosynthesis per mg of chlorophyll; and (c) chlrophyll concentration. Bars respresent LSD ($P \leq 0.05$) within each NaCl level.

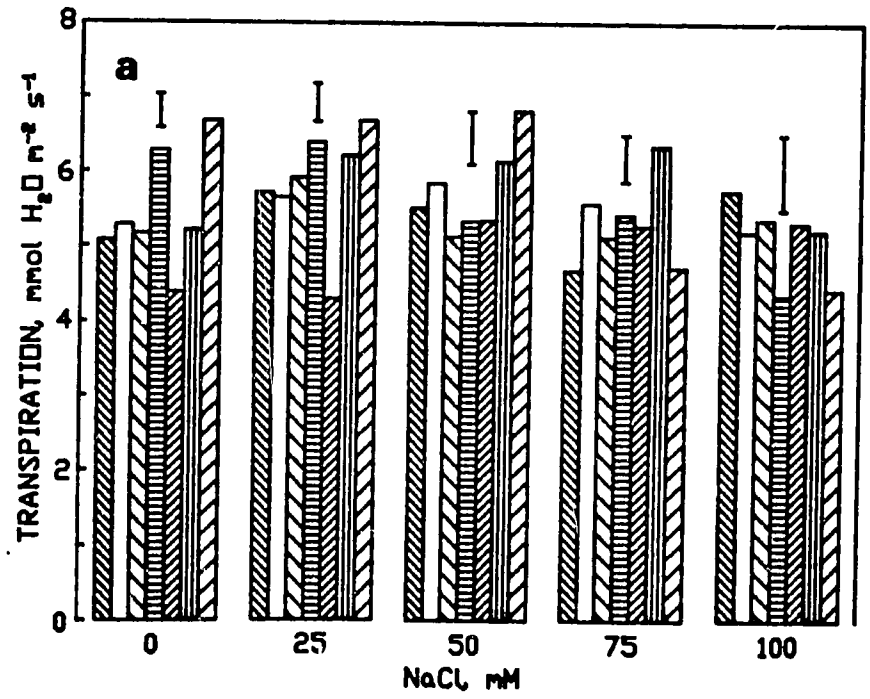
Fig. 2. Effect of nitrogen source (NO_3^- vs. NH_4^+), salinity level and medium pH on wheat plants grown in hydroponics: (a), transpiration rate; and (b), stomatal conductance. Bars respresent LSD ($P \leq 0.05$) within each NaCl level.

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


a
PHOTOSYNTHESIS, µmol m⁻² s⁻¹
0
2
4
6
8
10
0
25
50
75
100
NaCl, mM


b
PHOTOSYNTHESIS, mmol g-1 chl. s-1
30
20
10
0
0
25
50
75
100
NaCl, mM


c
CHLOROPHYLL, g m⁻²
1.0
0.8
0.6
0.4
0.2
0.0
0
25
50
75
100
NaCl, mM


a
TRANSPIRATION, mmol H_2O m^{-2} s^{-1}
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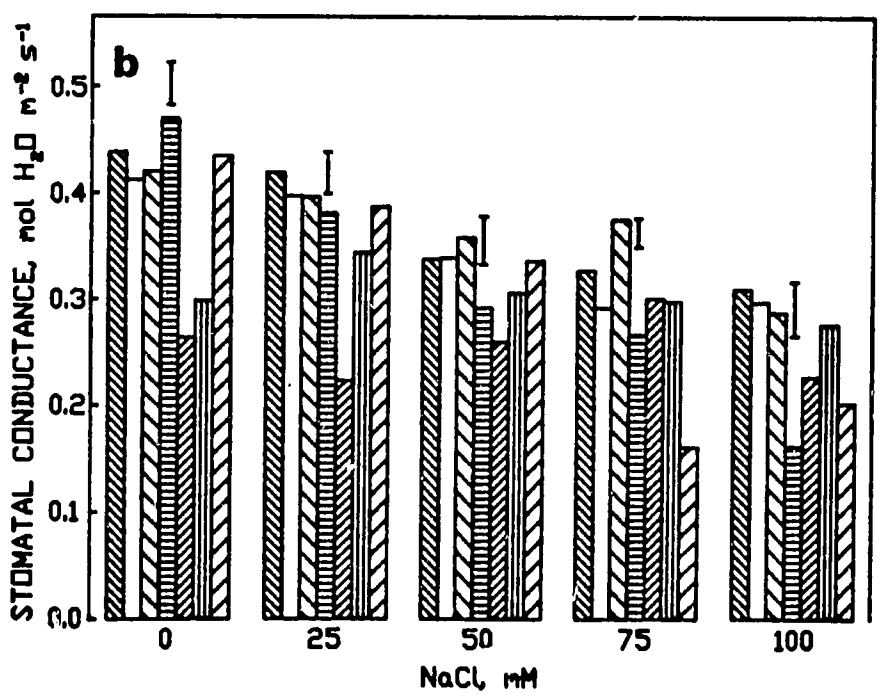
2
4
6
8
0
25
50
75
100
NaCl, mM


b
STOMATAL CONDUCTANCE, mol H2O m-2 s-1
0.0
0.1
0.2
0.3
0.4
0.5
0
25
50
75
100
NaCl, mM

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Effect of NaCl salinity on photosynthesis, ^{14}C-translocation, and yield in wheat plants irrigated with ammonium or nitrate solutions

E. O. Leidi* and S. H. Lips

Plant Adaptation Research Unit, J. Blaustein Institute for Desert Research and Department of Biology, Ben-Gurion University of the Negev, Sede Boqer 84993, Israel

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Summary. The effect of salinity (50 mM NaCl) on wheat photosynthesis, transpiration, growth and grain yield of plants growing in sand irrigated with nutrient solutions containing different nitrogen sources (NO_3^- or NH_4^+) is described. At this salinity level, little yield decrease was observed although vegetative growth was affected to a larger extent. Salinity induced enhanced translocation of assimilates from the flag leaf to developing grains. No significant differences were observed between salt-stressed plants irrigated with either ammonium or nitrate. The nitrogen source mainly affected kernel growth rate and final weight.

The increased use of brackish water (3–8 dSi m^{-1}) for irrigation has resulted in a growing interest in the possible ways to increase yields under such limiting conditions. Some authors (Kafkafi 1984; Feigin 1985) have reviewed the effects of salinity on cation and anion uptake considering the antagonism phenomena in ion uptake mechanisms as the basis for reduction of depressive effects of salinity through enhanced fertilization. Others (Kingsbury et al. 1984; Rawson 1986; Schubert and Läuchli 1986; Robertson and Wainwright 1987) have studied the differential responses of genotypes to salinity, developing an alternative approach to overcome the decrease in yield caused by this type of stress.

In the present report, we studied the effect of two nitrogen forms (NH_4^+ and NO_3^-) and NaCl (0 and 50 mM) on biomass and grain production, dry matter partitioning, photosynthetic activity and photosynthate translocation in wheat plants growing in dune sand.

* Present address: UEI Fisiologia Vegetal, Estación Experimental del Zaidin (CSIC), Aptdo. 419, E-18080 Granada, Spain

Materials and methods

Plant material and growth conditions

Wheat (*Triticum aestivum* L. cv. Barkai) plants were germinated and grown in black polyethylene bags of sand irrigated with nutrient solutions in a greenhouse until maturity. Ten seeds per sand bag were sown of which 6 uniform plants were selected at the second leaf stage. Plants were maintained as a single tiller by cutting off secondary tillers throughout the entire life cycle, immediately upon their emergence. The polyethylene bags contained sand (10 kg) placed over a coarse gravel layer (3 kg) and 8–10 drainage openings (6 mm diameter) at the bottom. Maximum and minimum temperature averages during the growth period (November to April) were 18.5 and 7.0 °C respectively. Nutrient solutions contained 4 mM nitrogen either as $(NH_4)_2SO_4$ or as $Ca(NO_3)_2$. Additional components of the solution were: 3 mM K^+, 1 mM $H_2PO_4^-$, 2 mM Ca^{2+}, 1 mM Mg^{2+}, and 1 mM or 4 mM SO_4^{2-} (NO_3^- or NH_4^--based solutions respectively). Micronutrients were supplied at the concentration prescribed in the Long Ashton nutrient solution (Hewitt 1966) and iron as 40 mg Fe-EDDHA l^{-1}. These nutrient solutions (each containing nitrogen either as ammonium or nitrate) were combined with two salinity levels: 0 and 50 mM NaCl. Plants were irrigated with tap water until the second leaf stage at which time supply of the nutrient solutions was started. Pots were irrigated every 3 days with fresh nutrient solutions in excess of field capacity to flush the sand of any residual "old" solution to avoid salt and nutrient accumulation. Nitrification was not avoided and nitrate was detected by analysis of sand samples of ammonium treatments.

Determination of photosynthetic activity and transpiration rate. The photosynthetic activity and transpiration rate of the flag leaf were determined at different time intervals (83, 88, 96, 103, 109, 116, 122, 125, 130 and 137 days after emergence) using a portable infrared gas analyzer (LCA-2, ADC) connected to a Parkinson's leaf chamber at a constant light irradiation of 500 μE m^{-2} s^{-1} at atmospheric CO_2 concentrations.

^{14}C pulse and sampling

A plexiglass chamber 2 × 10 cm was attached to the middle part of the flag leaves. This chamber was connected to an air circulation closed system into which 4 μCi of $^{14}CO_2$ were introduced for a period of 15 min. Air through this system was recirculated with a peristaltic pump. Photon flux at the chamber level was 400–450 μE m^{-2} s^{-1}. After the 15 min of $^{14}CO_2$-feeding the unassimilated isotope remaining in the closed system was

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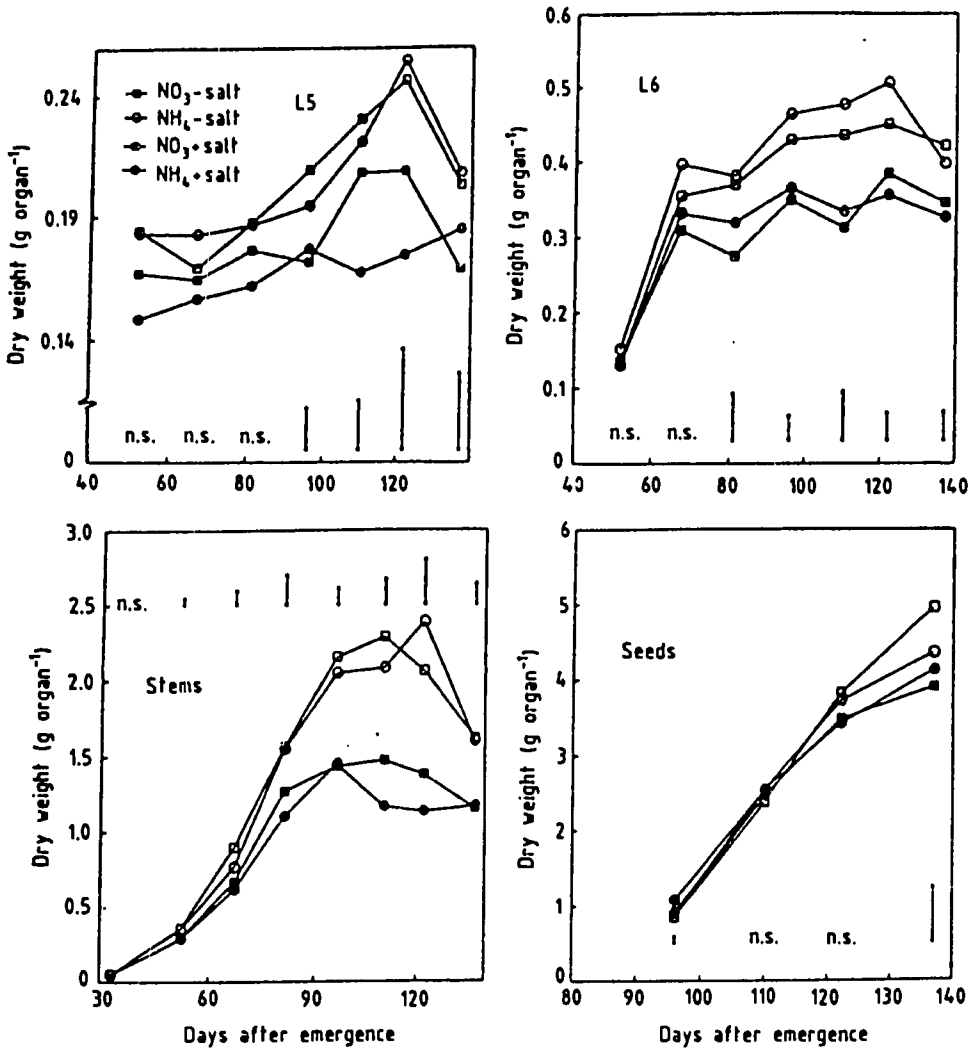

Fig. 1. Dry matter accumulation in different plant parts (5th leaf (L5), flag leaf (L6), stem and seeds) of wheat plants grown on nitrate (NO_3) or ammonium (NH_4) with (+) or without (−) 50 mM NaCl (in g · organ^{-1}). Each data point represents the mean of 6 replicates. Bars indicate LSD values at 5% level

trapped in concentrated KOH. Leaf disks were immediately sampled and placed in scintillation vials containing 1 ml of 0.6 N solution of a surface-active organic base (NCS Tissue Solubilizer) in toluene. The remaining plant parts were weighed and frozen at −20 °C for further analysis. After 24 h digestion, the solution in the vials was bleached with 1 ml of a saturated solution of benzoyl peroxide in toluene. After addition of standard scintillation solution, radioactivity was assayed in a liquid scintillation counter (1217 Rackbeta, LKB Wallac).

Distribution of ^{14}C-assimilates was analysed in the following plant parts: 5th and 6th (flag) leaves, stems, glumes and kernels. Samples were treated as described above. Frozen samples of the $^{14}CO_2$-exposed area of the flag leaf were taken to analyse distribution of radioactivity in fractions soluble and insoluble in ethanol as described by West et al. (1986). Two different experiments (each with 2 replicates in time) were carried out to chase ^{14}C-partitioning at different growth stages: (1) a short-term chase following ^{14}C-distribution at 0, 24 and 48 h labelling at 3 and 4 days after full anthesis, and (2) a long-term chase pulsing 8 and 14 days after full anthesis analyzing the plants 10 and 20 days afterwards.

Sequential harvests

At 8 different dates during the growth cycle, 6 plants per treatment were harvested each time and oven-dried (70 °C, 48 h) to determine dry weight. Dry samples of the different organs were ground in a mill and digested with $H_2SO_4+H_2O_2$ for further determination of nitrogen (using Nessler's reagent) and K^+ and Na^+ by flame photometry (Corning-EEL). A completely randomnized design with 6 replications was used.

Results and discussion

Growth, grain yield and yield components

The main differences between treatments observed in dry mass accumulation by leaves and stems (Fig. 1) were due to the NaCl concentration. At full anthesis (81 days after emergence), plants grown in a saline medium had lower dry weight (16–25% in the flag leaf and 20–30% in the stems) than those grown without NaCl. Considering the nitrogen soure, ammonium-fed plants had higher leaf dry mass than plants receiving nitrate.

The final yield (as weight of kernels per spike) (Table 1) was reduced by 5–20% depending on the

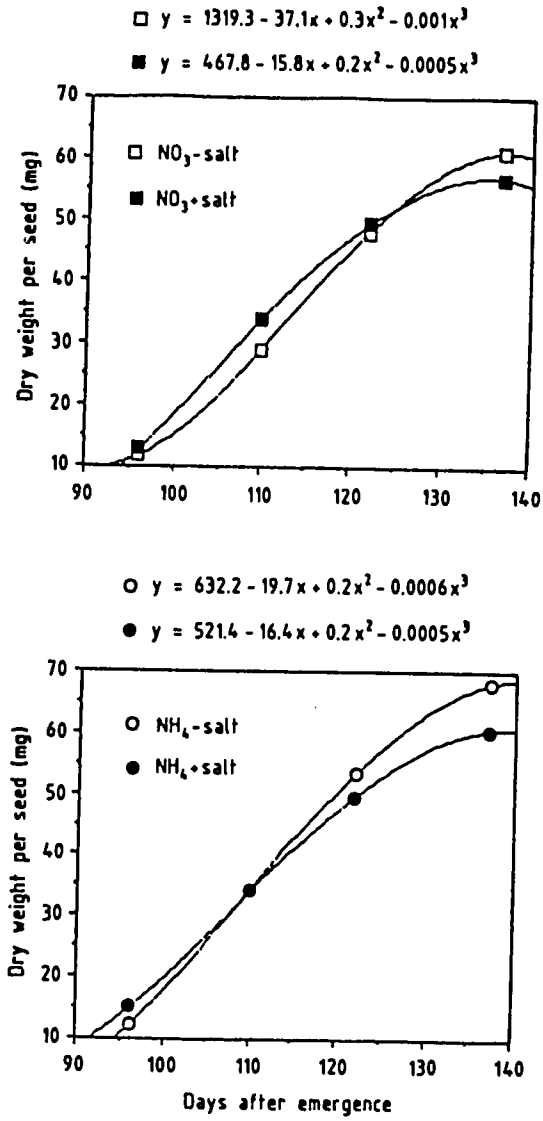

Fig. 2. Growth rate (dry matter basis) of individual seeds from plants grown on nitrate (NO_3) or ammonium (NH_4) with (+) or without (−) 50 mM NaCl (in mg · seed^{-1}). Each data point represents the mean of six replicates

Table 1. Dry weight of spikes and kernels and number of kernels per spike in wheat plants grown with nitrate or ammonium with or without 50 mM NaCl. Values in column followed by the same letter are not significantly different (LSD Test, 5% level)

Treatment	Spikes (g)	Kernels (g)	Number of kernels	Weight per kernel (mg)
NO_3 (−) salt	5.88a	4.95a	82.0a	61.0a
NO_3 (+) salt	5.03b	3.90b	69.0b	56.7b
NH_4 (−) salt	5.82a	4.35ab	64.2b	67.9c
NH_4 (+) salt	5.17b	4.12b	68.3b	60.4a

nitrogen source. Growth rate of kernels (Fig. 2) was also affected by salinity and nitrogen form. Those from plants receiving nitrate had the lowest growth rate. The number of spikes per unit area is usually considered the most important component of yield (Leyshon et al. 1980). However, in our experiment where single-tiller plants were used, the components affecting yield were grain weight and number. Higher vegetative growth observed in ammonium-fed plants in sand resembled the results obtained by M. Silberbush and S. H. Lips (personal communication) when using different ratios of ammonium to nitrate. However, in our single-tiller plants, ammonium nutrition failed to produce a higher yield than nitrate-fed plants. The reason for this discrepancy may reside on the higher tillering capacity of ammonium-fed plants which did not express itself in our experiments.

Salinity reduced total dry weight of spikes and total grain yield but there was little effect on kernel weight (Table 1). Similarly, Mass and Poss (1989), studying sensitivity of growth stages of wheat to salt, indicated that grain yield reduction caused by salt stress resulted more from fewer seeds per plant than from smaller kernels. Salinity depressed vegetative growth more than grain yield these results agreeing with those of Francois et al. (1986).

No effect of the nitrogen source on the final yield of plants in saline conditions was observed. Under non-saline conditions nitrate-fed plants gave a higher grain yield than ammonium-fed plants. The higher yield of nitrate-fed plants was due to a higher number of kernels per spike whereas ammonium-fed plants compensated for the lower number of grains by producing a larger kernel size. Leyshon et al. (1980) did not observe any influence of nitrogen form on average seed size in wheat but reported a substantial increase (46–75%) in the number of spikes in ammonium-grown plants which determined the overall increase in grain yield. Spratt and Gasser (1970), however, did not find differences in the number of spikes per unit area between both nitrogen forms. Other authors (Bakr Ahmed et al. 1984) obtained higher yields in ammonium-fed plants without indicating the main yield component affected.

Photosynthesis, transpiration, and stomatal conductance

Salinity reduced photosynthetic activity of the flag leaf only in nitrate-fed plants (Fig. 3). Leaves from ammonium-fed plants had lower photosynthetic rates than those from nitrate-fed plants, although this reduced activity per unit area was compensated by a higher total leaf area (data not shown). Salinity had an inconsistent effect on the transpiration rate although it frequently reduced stomatal conductance.

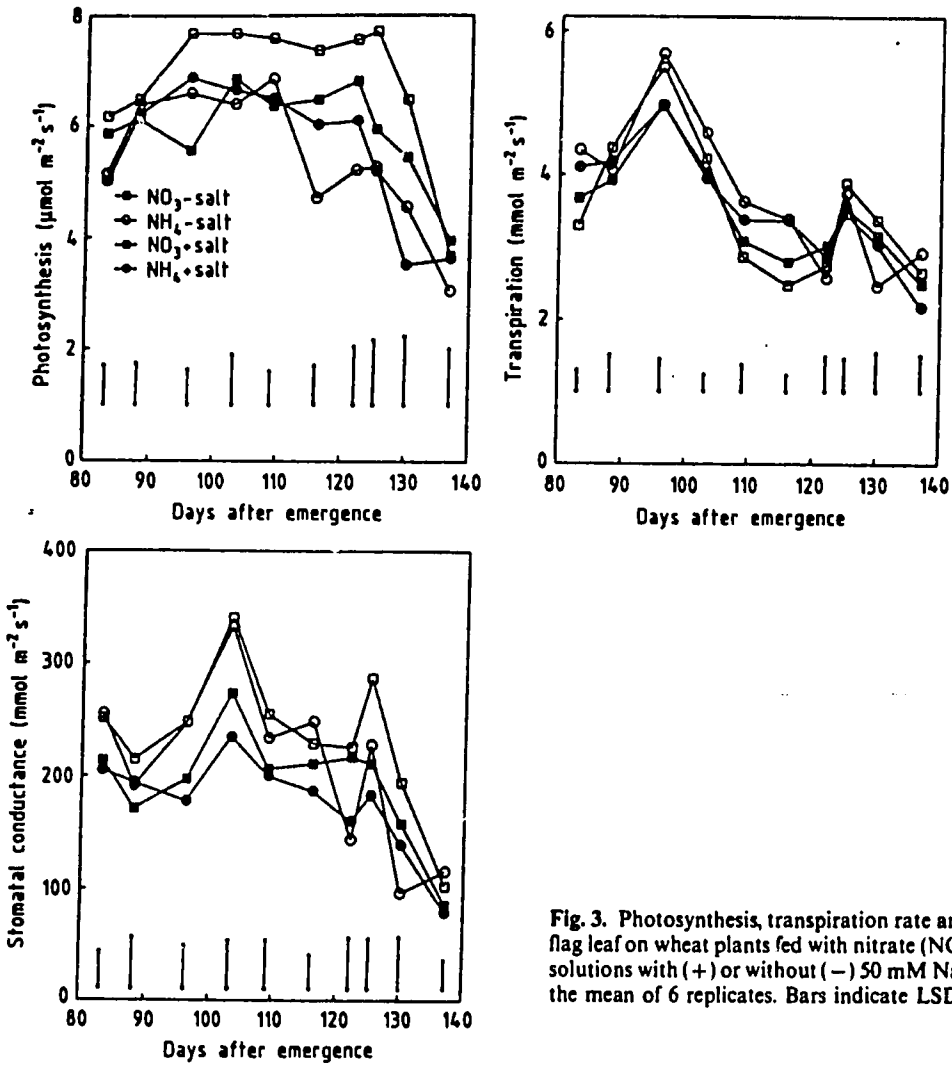

Fig. 3. Photosynthesis, transpiration rate and stomatal conductance in the flag leaf on wheat plants fed with nitrate (NO_3) or ammonium (NH_4) based solutions with (+) or without (−) 50 mM NaCl. Each data point represents the mean of 6 replicates. Bars indicate LSD values at 5% level

^{14}C-labelling studies

^{14}C-translocation from the flag leaf to the kernels were studied through various pulse-chase experiments (Table 2). There was a significant salinity-induced increase in the relative proportion of ^{14}C-assimilates translocated to the kernels after both short- and long-term chase periods. This observation agrees with the slopes of the curves of dry matter accumulation in the grain (Fig. 2) for the different treatments. Ammonium-fed plants showed higher rate of ^{14}C-translocation that may be attributed partly to the fact that these plants were a little more advanced in ontogeny, starting flowering 2-3 days prior to nitrate-fed plants. A similar suggestion was advanced to explain differential translocation rates in soybeans (Pearen and Hume 1981).

Fritz et al. (1987) reported that salt stress reduced the translocation of ^{11}C-labelled assimilates to the roots. Bhivare and Chavan (1987) observed in French

Table 2. ^{14}C-translocation into kernels of wheat plants growing with nitrate or ammonium with or without 50 mM NaCl. Values represent relative content of the label in the kernel in relation to the label in the rest of plant parts sampled: leaves (from 3rd to 6th), stem, and chaff (includes all non-grain parts of the ear). A single plant per treatment was labeled in each experiment

Treatment	Experiment 1		Experiment 2	
	24 h	48 h	24 h	48 h
Short-term chase				
NO_3 (−) salt	23.9	55.9	44.1	72.4
NO_3 (+) salt	55.9	76.5	65.4	75.7
NH_4 (−) salt	47.3	74.5	59.9	63.8
NH_4 (+) salt	74.8	82.9	59.4	64.5
	10 days	20 days	10 days	20 days
Long-term chase				
NO_3 (−) salt	63.2	60.2	80.5	93.1
NO_3 (+) salt	79.5	90.0	96.0	97.7
NH_4 (−) salt	72.2	72.8	89.5	93.5
NH_4 (+) salt	91.1	94.3	94.0	98.3

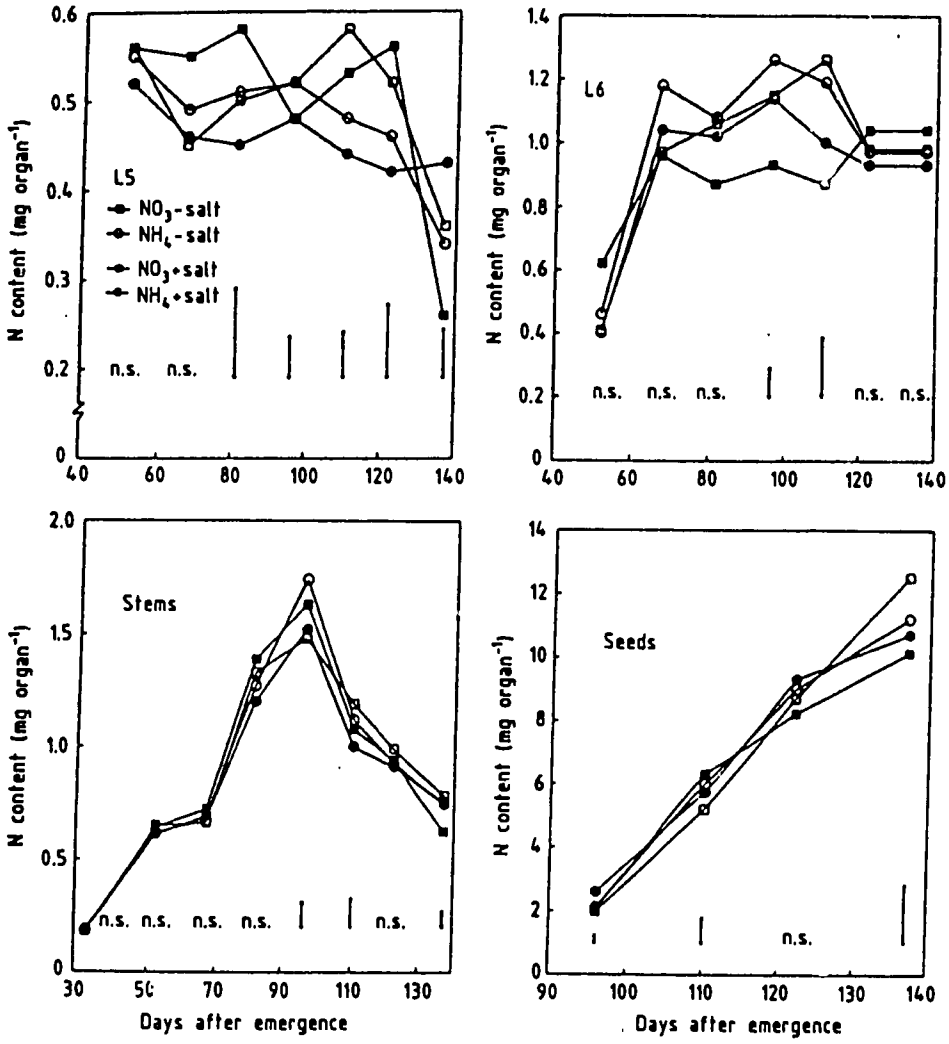

Fig. 4. Nitrogen content in different plant parts (5th leaf (L5), flag leaf (L6), stem and seeds) of wheat plants grown on nitrate (NO_3) or ammonium (NH_4) with (+) or without (−) 50 mM NaCl (in mg N · organ^{-1}). Bars indicate LSD values at 5% level

bean that the transport of radioactivity in short-term chases (1 h) from source to sink was adversely affected by salinity.

Analysing the relative distribution of radioactivity between ethanol-soluble and insoluble fractions (Table 3), it appears that the proportion of label in soluble compounds was higher in treatments with NaCl. This situation may reflect an adaptative osmoregulatory mechanism as described by Greenway and Munns (1980) although alternative explanations for the phenomenon are possible. The production of transfer carbohydrates, such as sucrose, precedes the export of assimilates (Dale 1985) and is one of several potential mechanisms for controlling carbohydrate export (Geiger and Giaquinta 1982). Thus, higher levels of transfer carbohydrates in salt-stressed plants generated for osmoregulation could explain, from another viewpoint, the higher translocation rates of photosynthates to grains observed in these plants.

Nitrogen concentration and translocation efficiency

Concentration of nitrogen in the leaves and stems decreased as a function of time during the growth cycle whereas the N content presented a parabolic pattern following N accumulation in the grain (Fig. 4). Nitrogen content in the grain presents a typical cumulative pattern. Nitrogen concentration in the salt-treated plants was slightly higher although these differences were not evident in the mature grains.

Nitrogen translocation efficiency and N harvest index were calculated according to Cox et al. (1986). No statistically significant differences were observed in the efficiency of translocation or the harvest index. This implies that our treatments (N source and salinity) did not affect yield by affecting translocation rates of nitrogen reserves. The capacity of the flag leaf to assimilate inorganic nitrogen has not been studied in this work, but has been reported by Soares and Lewis

(1986). The fact that the flag leaf, contrary to leaf 5, does not exhibit aging characteristics (Fig. 4) on day 137 is in agreement with reports by Soares and Lewis (1986). These investigators observed, using ^{15}N-isotopes, active assimilation of nitrate and ammonium by the flag leaf during grain filling and the immediate translocation of ^{15}N-organic nitrogen to the grains. The flag leaf, therefore, may be an important provider of carbon and nitrogen assimilates to the grain at a time when the rest of leaves are in an advanced aging stage.

Potassium and sodium concentration

Leaf K^+ concentrations (Table 4) were within the sufficiency ranges presented by Rama Rao (1986). The small differences in K^+ concentration observed between nitrate- or ammonium-fed plants may be an indication of the low interference of the later ion in K^+ uptake when grown in sand. Potassium continued its accumulation in several organs (flag leaf, stem, non-grain parts of the ear) when requirements for growth were fulfilled, while its concentration in the kernels was limited. This agrees with the reports of Martin and Platz (1982) and Haeder (1982). Salinity seemed to slow down this K^+ build up in the vegetative parts of the plant (flag leaf and stem) and increase it in the reproductive parts (chaff and kernels).

Sodium concentration was slightly higher in plant parts from salinized nitrate-fed plants (Table 4). With the exception of kernels, the remaining plant parts presented an increase in Na^+ level with time.

Increased K^+ concentration in the chaff of spikes from salt-treated plants and their higher levels of Na^+ (Table 4) may have contributed to the increase of the sink-source osmotic gradient in addition to the solute gradient induced by synthesis of reserve polysaccharides in the grain. Both processes may determine acceleration of assimilate translocation to the kernels as was also suggested by Martin and Platz (1982).

Table 3. Percentage of radioactivity in ethanol-soluble (EtOH-sol.) and insoluble (EtOH-insol.) fractions after labelling (short-term chase) in flag leaves of wheat plants growing with nitrate or ammonium with or without 50 mM NaCl

Treatment	Fraction	Experiment 1		Experiment 2	
		24 h	48 h	24 h	48 h
NO_3 (−) salt	EtOH-sol.	38.7	36.4	42.1	34.3
	EtOH-insol.	61.3	63.6	57.9	65.7
NO_3 (+) salt	EtOH-sol.	47.5	39.4	44.8	37.6
	EtOH-insol.	52.5	60.6	55.2	62.4
NH_4 (−) salt	EtOH-sol.	36.3	33.4	40.8	35.8
	EtOH-insol.	63.7	66.6	59.2	64.2
NH_4 (+) salt	EtOH-sol.	38.3	35.1	44.2	38.1
	EtOH-insol.	61.7	64.9	55.8	61.9

Conclusions

Salinity depressed vegetative growth more than grain yield. No differences in final yield due to type of nitrogen supplied were observed in salt-stressed plants. Under outdoor conditions, with water stress effects added to salt stress because of higher evaporative demand, more extensive yield reductions may be ob-

Table 4. Concentration of potassium and sodium in different plant parts at different growth stages (mmol · g DW^{-1}). Values in column for each growth stage followed by the same letter are not significantly different (LSD test, 5% level)

Stage	Flag leaf		Stem		Chaff		Kernel	
	K	Na	K	Na	K	Na	K	Na
Flowering								
NO_3 (−) salt	0.62a	0.02a	0.67a	0.02a	0.35a	0.02a	–	–
NO_3 (+) salt	0.57b	0.14b	0.62b	0.21b	0.25b	0.07b	–	–
NH_4 (−) salt	0.67c	0.02a	0.62b	0.02a	0.32a	0.02a	–	–
NH_4 (+) salt	0.65c	0.13b	0.68a	0.15b	0.37a	0.05a	–	–
Mid-filling								
NO_3 (−) salt	0.49a	0.02a	0.62a	0.03a	0.25a	0.02a	0.19a	0.02a
NO_3 (+) salt	0.62b	0.16b	0.67a	0.33b	0.34b	0.14b	0.18a	0.06b
NH_4 (−) salt	0.62b	0.02a	0.72b	0.02a	0.25a	0.03a	0.18a	0.03a
NH_4 (+) salt	0.57c	0.14b	0.83c	0.36b	0.35b	0.07c	0.20a	0.08b
Maturity								
NO_3 (−) salt	0.92a	0.04a	1.23a	0.05a	0.40a	0.02a	0.12a	0.02a
NO_3 (+) salt	0.82b	0.40b	1.08b	0.83b	0.57b	0.27b	0.17b	0.07b
NH_4 (−) salt	1.08c	0.04a	1.33c	0.04a	0.32a	0.03a	0.14a	0.02a
NH_4 (+) salt	0.93a	0.58b	1.07b	0.40c	0.43c	0.16c	0.15b	0.06b

served and differential performance under each nitrogen form may occur.

In the present experiments, differences in total grain yield due to nutritional N forms were due to individual grain weight and number of seeds per spike.

Salinity induced an accelerated translocation of assimilates from the flag leaf to the developing grains. This effect was more pronounced in nitrate- than in ammonium-fed plants. The enhanced availability of labeled ethanol-soluble compounds (monosaccharides) could partially explain the accelerated translocation of recently fixed assimilates from the flag leaf to the kernels. An alternative, or additional, explanation could be the build-up of K^+ and Na^+ in the non-grain parts of the ear observed under salinity.

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MORPHO-PHYSIOLOGICAL RESPONSES OF TWO RICE VARIETIES TO VARYING NaCl LEVELS AND TWO NITROGEN SOURCES

J. F. Reano[1], E. P. Pacardo[1], B. T. Mercado[1] and S. H. Lips[2]

ABSTRACT

The morpho-physiological responses of salt-sensitive IR-28 and salt-tolerant Nona Bokra rice varieties grown hydroponically in five NaCl levels (0, 25, 50, 75, 100 mM) and two N-sources (4 mM each of ammonium and nitrate) were investigated under greenhouse condition. Significant interactions among variety, N-source and NaCl levels were generally observed on the different growth parameters, photosynthesis, transpiration, stomatal conductance and protein contents of shoot and root tissues. Increasing NaCl concentration resulted to a marked reduction in shoot and root growth of both rice varieties when fed with ammonium. However, growth of both nitrate-fed rice varieties were not severely affected despite increasing NaCl levels. Photosynthesis, transpiration and stomatal conductance did not differ significantly in both varieties at low NaCl levels (0 - 50 mM) regardless of N-source applied. Slight increases in photosynthesis and transpiration were noted at mild salinity level (25 mM NaCl) especially for nitrate-grown Nona Bokra variety. Protein contents in shoot and root tissues generally increased in both varieties under salt-stressed conditions.

Key words - Ammonium, nitrate, salinity tolerance, *Oryza sativa* L., growth, photosynthesis, transpiration, stomatal conductance, protein contents.

INTRODUCTION

Rice (*Oryza sativa* L.) has been generally classified as a salt-sensitive crop species (Maas and Hoffman, 1977). Several studies indicated that majority of the rice varieties suffered serious salt injuries at an electrical conductivity of 8 to 10 mmhos/cm at 25 °C (IRRI, 1975 and Mercado et al. 1974). However, it has been reported lately that salinity tolerance of rice varies considerably among varieties. Fageria (1985) categorized these varieties as tolerant, moderately susceptible and susceptible ones based on dry matter growth accumulation and yield reduction.

Recently, there has been a growing interest to breed salt-tolerant rice variety adaptable under saline conditions. The International Rice Research Institute has been actively involved in screening and selection of salt-tolerant rices for several years. Despite the accumulation of good data, however, few studies were so far conducted on the morpho-physiological behavior of different varieties in relation to salinity and nitrogen nutrition.

The present study reports some of the morphological and physiological responses of salt-tolerant and salt-sensitive rice varieties to varying NaCl levels and nitrogen sources.

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[1] Botany Department, Institute of Biological Sciences, University of the Phillipines at Los Baños, College, Laguna 4030, Phillipines

[2] The Jacob Blaustein Institute for Desert Research, Ben-Gurion University of the Negev, Sede Boqer Campus, Sede Boqer 84993, Israel

MATERIALS AND METHODS

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 pH of the solution was maintained at a range of 5.0-6.0 using concentrated KOH or H_2SO^4 to adjust the pH. Culture solutions were changed regularly every week.The different treatments were 5 NaCl levels (0, 25, 50,75, 100 mM), 2 N-sources (4mM each NH_4^+ and NO_3^-) and 2 rice varieties (salt-sensitive IR-28 and salt-tolerant Nona Bokra). The experimental design used was 5 x 2 x 2 factorial in Randomized Complete Block (RCB). Different growth data such as leaf area, shoot length, shoot dry weight, root length, root dry weight and shoot: root ratio were collected at final harvest i.e. 6 weeks after treatment (WAT) application. Photosynthetic and transpiration rates as well as stomatal conductance of the longest, youngest and fully expanded leaves were measured using Parkinson's leaf chamber attached to ADC infrared gas analyzer (Analytical Development Corporation, Hoddesdon, England) at atmospheric CO_2 concentrations in the differential mode and constant radiation (PAR, 500 umol/m2/sec.). Root and shoot tissue samples were taken at 6 WAT for protein content analysis. Protein assay was done following the Lowry method.

RESULTS

Morphological Responses

Highly significant interactions among varieties, nitrogen sources and NaCl levels were observed in all morphological parameters gathered such as leaf area, length and dry weights of shoots and roots (Table).

Shoot Length. A remarkable decrease in shoot length was noted in salt-sensitive IR-28 variety when grown in ammonium under NaCl-stressed condition. Shoot length of salt-tolerant Nona Bokra variety started to decline only at 75 mM and 100 mM NaCl levels. On the other hand, shoot length did not vary significantly when both varieties were fed with nitrate even under NaCl-stressed condition (Figure).

Root Length. Roots of both varieties were generally longer in nitrate-fed as compared to ammonium-fed plants (Figure). Nitrate-grown Nona Bokra tended to elongate its roots faster under NaCl-stressed condition in relation to control plants. The reverse holds true for nitrate-grown IR-28 variety. Nitrate-grown IR-28 had shorter roots than control plants when grown in NaCl-stressed condition. Root length of both varieties decreased with increasing levels of NaCl when fed with ammonium - nitrogen (Figure).

Shoot Dry Weight. Dry matter accumulation in the shoot of both varieties was greatly reduced at increasing NaCl concentrations when supplied with ammonium - nitrogen. On the other hand, nitrate - nitrogen stimulated dry matter accumulation in shoots of both varieties when grown at lower concentration of NaCl (25 mM). Beyond this concentration, shoot dry weight was much lower than in the nitrate-grown control plants (Figure).

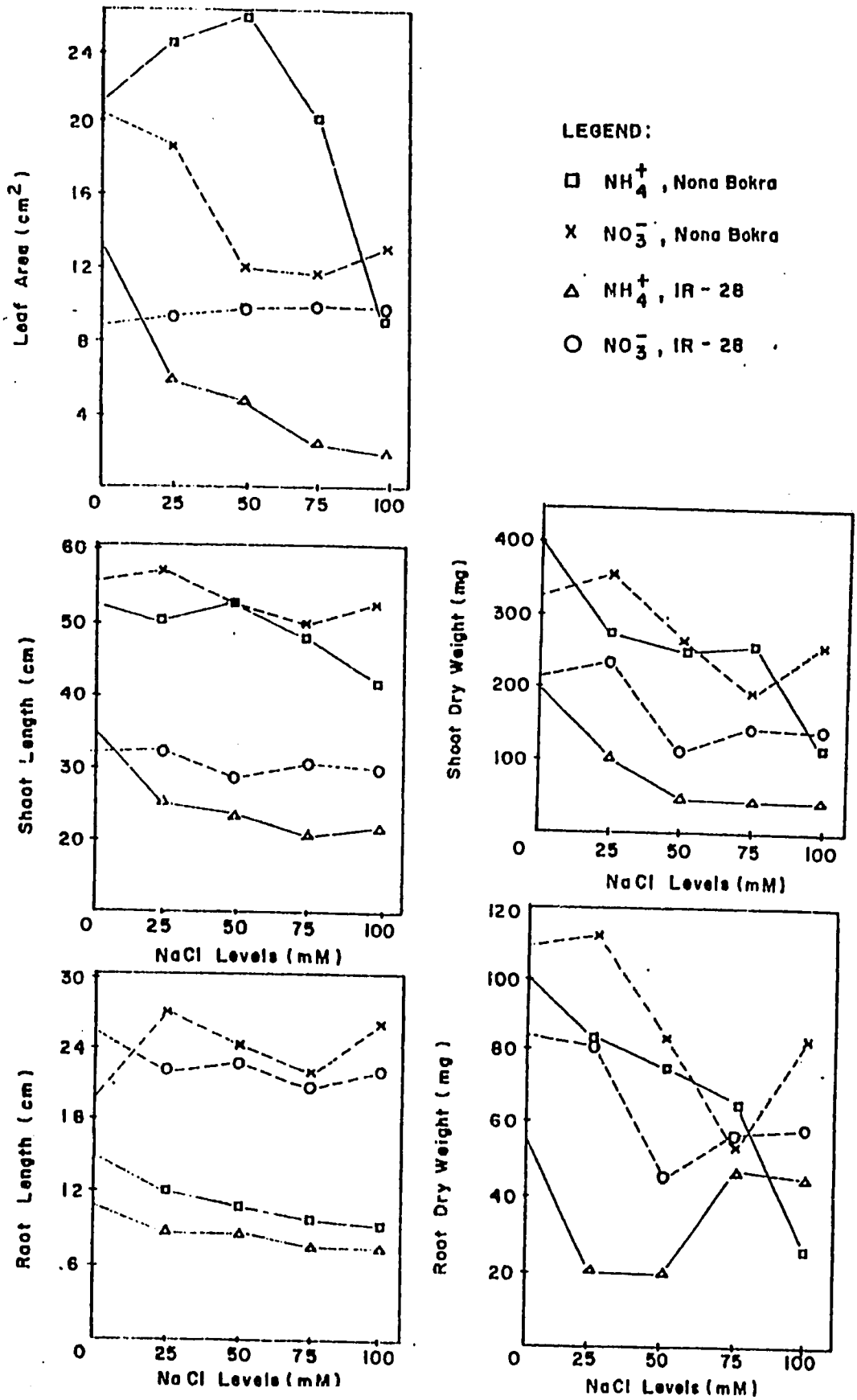

Figure 1. Morphological responses of two rice varieties to varying NaCl levels and two nitrogen sources.

Root Dry Weight. Dry accumulation patterns in the root behave similarly with that of the shoot for both varieties supplied with either nitrate or ammonium under NaCl-stressed condition (Figure).

Leaf Area. There was an increase in the leaf area of ammonium-grown Nona Bokra at 0-50 mM NaCl. At a much higher NaCl levels (75 and 100 mM NaCl), leaf area declined abruptly (Figure). IR-28 variety supplied with ammonium decreased markedly with increasing concentrations of NaCl. Leaf area of nitrate-fed Nona Bokra started to decline only at 50-100 mM NaCl. However, leaf area of nitrate-fed IR-28 did not change significantly with increasing levels of NaCl.

PHYSIOLOGICAL RESPONSES

Photosynthesis. Ammonium-grown IR-28 variety exhibited a slight increase in photosynthetic rates at low NaCl level (25 mM). Both varieties however, started to decrease their photosynthetic rates at NaCl levels higher than 50 mM. In case of nitrate grown Nona Bokra, photosynthetic rate declined abruptly only at concentration higher than 75 mM. Nitrate-grown IR-28 exhibited much lower photosynthetic rates at 50 mM (Figure).

Transpiration. There was a slight increase in transpiration in all the treatments except in ammonium grown Nona Bokra (Figure). This increase was generally observed at 0-50 mM NaCl. The transpiration rate of ammonium grown Nona Bokra decreased slightly at 25-50 mM NaCl, reaching its peak at 75 mM then, abruptly dropped to zero at 100 mM NaCl. The nitrate grown Nona Bokra, on the other hand, gradually increased its transpiration rate at 0-50 mM, started to decline at 50-75 mM and then levelled off between 75-100 mM. The IR-28 variety grown in either nitrate or ammonium increased its transpiration rate up to 50 mM only, after which transpiration abruptly dropped to zero.

Stomatal Conductance. A remarkable increase in stomatal conductance was observed in ammonium grown IR-28 from 0-50 mM NaCl. At higher NaCl levels, stomatal conductance abruptly dropped to zero. On the other hand, nitrate grown Nona Bokra had slight increase in stomatal conductance at 0-25 mM NaCl, then gradually declined at 25-75 mM and finally levelled off between 75-100 mM NaCl (Figure). For ammonium-grown Nona Bokra, stomatal conductance decreased gradually from 0-50 mM then increased between 50-75 mM. Beyond this level, it dropped abruptly to zero due to complete wilting.

Protein Content. Significant interaction effects of nitrogen source, variety and NaCl levels were observed in shoot and root protein content. The highest protein content was assayed in ammonium grown Nona Bokra. As shown in Figure , there was a proportional increase in protein content of ammonium grown Nona Bokra shoots with increasing levels of NaCl. Opposite observation was observed for ammonium-grown IR-28 variety.

The shoot protein content of nitrate-fed Nona Bokra increased only at 25 mM NaCl. Nitrate grown IR-28 however, increased its shoot protein content with increasing NaCl levels. The root protein content of ammonium-grown Nona Bokra did not differ significantly in all the treatments. The salt-sensitive IR-28 variety however, increased its protein content at 25 mM NaCl. A marked increase in protein content was observed in nitrate-grown Nona Bokra. In the nitrate-grown variety, the increase in protein content was noted only at 50 mM NaCl.

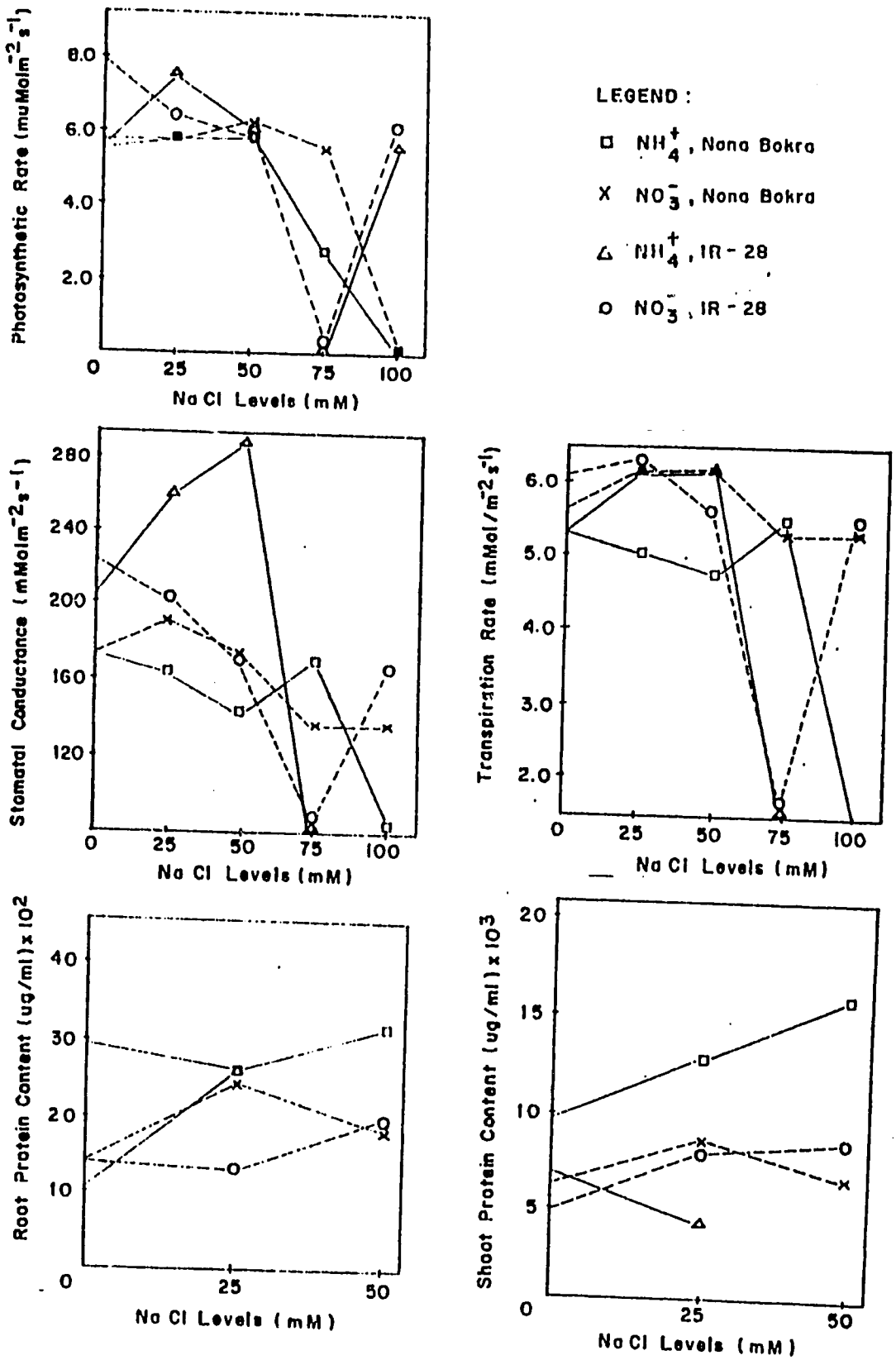

Figure 2. Physiological responses of two rice varieties to varying NaCl levels and two nitrogen sources.

DISCUSSION

The data presented here clearly indicate possible beneficial effects of nitrate nitrogen under salt-stressed condition. This observation is generally true for salt-tolerant Nona Bokra and salt-sensitive IR-28 rice varieties. Several researchers reported antagonistic relationship between nitrate and chloride ions especially under saline conditions. Addition of high concentration of nitrate can partially alleviate the detrimental effect of salinity on plant growth by reducing chloride uptake (Kafkafi et al, 1982).

One of the most significant effects of ammonium observed in this experiment was the cessation of root elongation especially in salt-sensitive IR-28 variety grown in increasing NaCl levels. It appears that ammonium becomes more toxic when plants were exposed to salinity stress. The toxic effects of ammonium have already been documented in some plants, such as, cucumber (Schenk and Wekrman, 1979), radish (Goyal et al, 1982) and tomato (Magallals and Wilcox, 1983).

The data reveal that moderate salinity (25 mM NaCl) enhanced root and shoot growth in both rice varieties. This is in agreement with the observation of Kurth et al. (1986) in cotton. They explained this observation on the basis of an increase in cell wall extensibility due to displacement of calcium from wall polysaccharides by sodium ions during mild salt-stressed condition. Consequently, this favors growth processes to occur.

The results confirm the observation of Sharma (1986) that the concentration at which salinity brings about severe reduction in photosynthesis varies greatly in the different plant species and varieties. The Nona Bokra rice variety had higher salinity tolerance level than IR-28 when applied with nitrate nitrogen. However, there was a slight increase in photosynthetic rate of ammonium grown IR-28 at 25 mM NaCl. According to Gale and Poljakoff-Mayber (1970), low concentration of salts do not always reduce but may even enhance photosynthesis especially among halophytes. This was also noted in non-halophytes but relatively salt-tolerant plants like sugar beets (Hauer and Plaut, 1984). Perhaps the results suggest that salinity tolerance can be increased possibly by manipulating nitrogen nutrition (Silberbush and Lips, 1988).

The general trend in the transpiration rates of nitrate and ammonium grown Nona Bokra are very similar to that of stomatal conductance (Fig.). It appears quite clearly that stomatal conductance is more closely associated with transpiration rather than photosynthesis. The relationship between stomatal conductance and transpiration has already been reported earlier (Farquhar and Sharkey, 1982). This relationship indicates that if the water vapor inside the leaf is assumed to be the saturation pressure at the leaf temperature, the reduction in water potential due to salt treatments may affect the water vapor gradient between leaf and atmosphere. On the other hand, conflicting results were reported in case of photosynthesis. In cotton, for example, increase in stomatal and mesophyll resistances have been reported to affect photosynthesis under salt-stressed environment (Longstreth and Nobel, 1979).

Salinity generally increased shoot and root protein contents of both rice varieties. Singh et al. (1985) identified 26 kilodalton polypeptide being synthesized and accumulated by unadapted cultured tobacco cells during adaptation to NaCl. The same group of workers (Singh et al., 1987) tentatively called this stress protein as osmotin which occurs in two forms: an aqueous soluble form (osmotin I) and a detergent soluble form (osmotin II) in approximate ratio of 2:3. The existence of such stress proteins might also hold true in rice especially in salt-tolerant Nona Bokra variety during its adaptation to salt-stressed conditions. Further studies on this aspect is therefore being recommended.

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METABOLIC EFFECTS OF SALINITY AND NITROGEN-SOURCE APPLICATION SCHEMES ON WHEAT (*Triticum aestivum* L.)

J. F. Reaño[1], E. P. Pacardo[1], B. T. Mercado[1] and S. H. Lips[2]

ABSTRACT

The metabolic effects of nitrogen source application schemes on wheat (*Triticum aestivum* L. cv. Barkai) grown in NaCl-stressed conditions were studied inside a greenhouse. The different treatments such as five ammonium/nitrate application schemes and two NaCl levels (0 and 60 mM) were laid out in 2 x 5 factorial experiment in randomized complete block design with four replications. Significant interaction effects between nitrogen source application schemes and NaCl salinity were observed in shoot and root fresh weights, photosynthesis, transpiration, stomatal conductance, leaf protein content and grain yield parameters.

The data generally indicate favorable effects of combined ammonium and nitrate application on the over-all metabolic processes that would give higher grain yield in wheat even under salt-stressed condition. The results also suggest that ammonium and nitrate are better sources of nitrogen at vegetative and reproductive stages, respectively. These observations hold true for both saline and non-saline conditions. Bigger and heavier grains were produced by wheat grown in NaCl-stressed condition especially in the presence of nitrate.

Key words: *Triticum aestivum* L., salinity, ammonium, nitrate, growth, photosynthesis, transpiration, stomatal conductance, water use efficiency, protein content, grain yield

INTRODUCTION

Nitrate and ammonium are the two major sources of nitrogen that can be taken up and utilized by plants. The potential capacity of plants to metabolize these ions varies considerably according to plant species (Cox and Reisenauer, 1973; Krajina et al., 1973; Allen and Smith, 1986), and probably among varieties within each species. The different processes leading to the assimilation of inorganic nitrogen to its organic form are quite sensitive to environmental stresses like salinity.

It has been reported recently that salinity tolerance can be possibly increased by adequate nitrogen fertilization (Silberbush, 1986). Lips and Silberbush (1987) observed that salinity did not affect grain yield of wheat grown in saline medium supplied with nitrate. However, Leidi et al. (1987), emphasized that nitrogen fertilization as a method to enhance tolerance of plants to salts was more effective in plants grown in hydroponics than in soil cultures.

The basic explanation for the apparent ameliorative effects of adequate nitrogen nutrition has not been fully elucidated so far. Aslam et al. (1984) stated that the assimilation of nitrate, the predominant form of nitrogen available in an aerobic

[1] Botany Department, Institute of Biological Sciences, University of the Phillipines at Los Baños, College, Laguna 4030, Phillipines

[2] The Jacob Blaustein Institute for Desert Research, Ben-Gurion University of the Negev, Sede Boqer Campus, Sede Boqer 84993, Israel

environment, is critical if plants are to adapt, grow and reproduce in saline conditions. The present study reports the effects of nitrogen-source application schemes on the growth, yield and some metabolic processes in salt-stressed wheat.

MATERIALS AND METHODS

Wheat plants (*Triticum aestivum* L. var. Barkai) were grown inside the greenhouse during the winter period of 1987-88 in black polyethylene bags containing 10 kg. fine desert dune sand (Calcareous, Typic Torripsamment) on top of 3 kg. gravel. The newly sown seeds were irrigated with ordinary tap water for two weeks prior to treatment application.

The different treatments such as five nitrogen source-application schemes and two NaCl levels (0 and 60 mM) were laid out in 2 x 5 factorial in randomized complete block design with four replications. The different nitrogen source-application schemes were: 4 mos. NH_4^+ ; 4 mos. NO_3^- ; 1 mo. NH_4^+ + 3 mos. NO_3^- ; 2 mos. NH_4^+ + 2 mos. NO_3^- and 3 mos. NH_4^+ + 1 mo. NO_3^-. Ammonium and nitrate were applied at constant concentration of 6 mM at total duration of 4 months using $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ as nitrogen sources respectively. The concentrations of other macro and micro- nutrients were based mainly on modified Long-Ashton solution (Hewitt,1966). The pH of the culture solution was adjusted to a range of 5.5 to 6.0 using either concentrated KOH or H_2SO_4.

The culture solution mixtures were irrigated at field capacity every treatment application. The frequency of application was two to three times or more per week depending on the irrigation requirements of the plants. NaCl salinization was done gradually during the first week of treatment application. Full strength (60 mM NaCl) solution was applied from the second week onwards to the succeeding treatments.

The different growth parameters were gathered at vegetative stage, i.e., two months after the first treatment application. The growth data gathered were root length, root radius, root fresh weight, root dry weight, shoot length, shoot fresh weight, shoot dry weight, leaf area and number of tillers. Root length was measured by the line-intersect method (Tennant, 1975). Mean root radius was calculated from the root fresh weight and the length, assuming the roots to be smooth cylinders and the fresh weight to equal the volume (i.e. root density = 1 g cm^{-3}).

Photosynthesis, transpiration and stomatal conductance were measured by the use of Parkinson's leaf chamber attached to an ADC infrared gas analyzer(Analytical Development Corporation, Hoddesdon, England). Measurements were done an hour before midday at an irradiance of 700 uE m^{-2} s^{-1}, at a temperature of 28 C. and ambient relative humidity of 35%. Water use efficiency (WUE) or transpiration ratio was calculated by dividing transpiration (Tr) by net photosynthesis (Pn). The protein content of the longest and youngest fully expanded leaf was determined following the Lowry method. All parameters such as photosynthesis, transpiration, stomatal conductance, water use efficiency and protein content were gathered monthly for four months.

Half of the experimental plants were allowed to grow until maturity. Data on grain yield, number of seeds and seed weight were collected at the final harvest. All data were analyzed statistically using the analysis of variance (ANOVA) procedure for F-test described by Gomez and Gomez (1976). The treatment means were compared by using the Duncan's Multiple Range Test (DMRT).

RESULTS

Vegetative Growth Parameters

Shoot and Root Fresh Weights. Significant interaction between sodium chloride (NaCl) and nitrogen (N)-source application schemes was observed only on shoot and root fresh weights. However, NaCl salinization had remarkable effects on all growth parameters except on root radius and shoot/root ratio. On the other hand, the different N-source application schemes affected all the parameters except shoot length, leaf area and root radius (Fig). Shoot and root fresh weights of wheat grown in NaCl-stressed condition were much lower than the control plants. The highest shoot fresh weight at unstressed condition (0 mM NaCl) was obtained in plants applied with a combination of ammonium and nitrate.

Shoot and Root Dry Weights. Regardless of N-source application schemes, plants grown in NaCl-stressed condition had lower shoot and root dry weight compared to the control. Application of ammonium and nitrate during the first and second months of growth generally enhanced higher shoot dry matter accumulation. On the other hand, increased dry weight was noted in plants fed with nitrate alone (Table).

Shoot and Root Length. As shown in Table , elongation of shoot and root was markedly inhibited when plants were grown in NaCl-stressed condition. No significant differences were observed in shoot length of plants treated with different N-source application schemes.

Leaf Area and Number of Tillers. There was a marked reduction in leaf area and number of tillers in NaCl-stressed plants compared to the control ones. However, leaf area did not vary in all the N-source application schemes. On the other hand, fewer number of tillers were noted in nitrate fed plants irrespective of the NaCl salinization treatment. Ammonium apparently enhanced the production of more tillers at vegetative stage of wheat growth.

Root radius and Shoot / Root Ratio. Root radius of wheat was not affected by the different N-source application schemes and/or NaCl salinization. Likewise, NaCl salinization did not alter the shoot/root ratio of wheat plants. However, different N-source application schemes had significant effects on shoot/root ratio. Higher ratio was obtained in plants supplied with ammonium.

Physiological and Biochemical Parameters

Photosynthesis. Slight increase in photosynthetic rate was observed in NaCl-stressed plants applied with nitrate alone at two months after treatment (MAT) application (Fig). At 3 MAT, rates of photosynthesis were relatively very low. However, the general trend was similar with the photosynthetic rates taken at 2 MAT. NaCl-stressed plants had higher photosynthetic rates than the unstressed ones fed with either nitrate or ammonium. All the rest of the treatments were comparable in both conditions. Likewise, no significant variation in photosynthetic rate was observed among the treatments at 1 MAT.

Transpiration. Salinized plants at 1 MAT had higher transpiration rates than the control (Fig). The transpiration rates at 1 MAT did not differ consistently among the different N-source application schemes in both growing conditions except for the unstressed nitrate-fed plants.

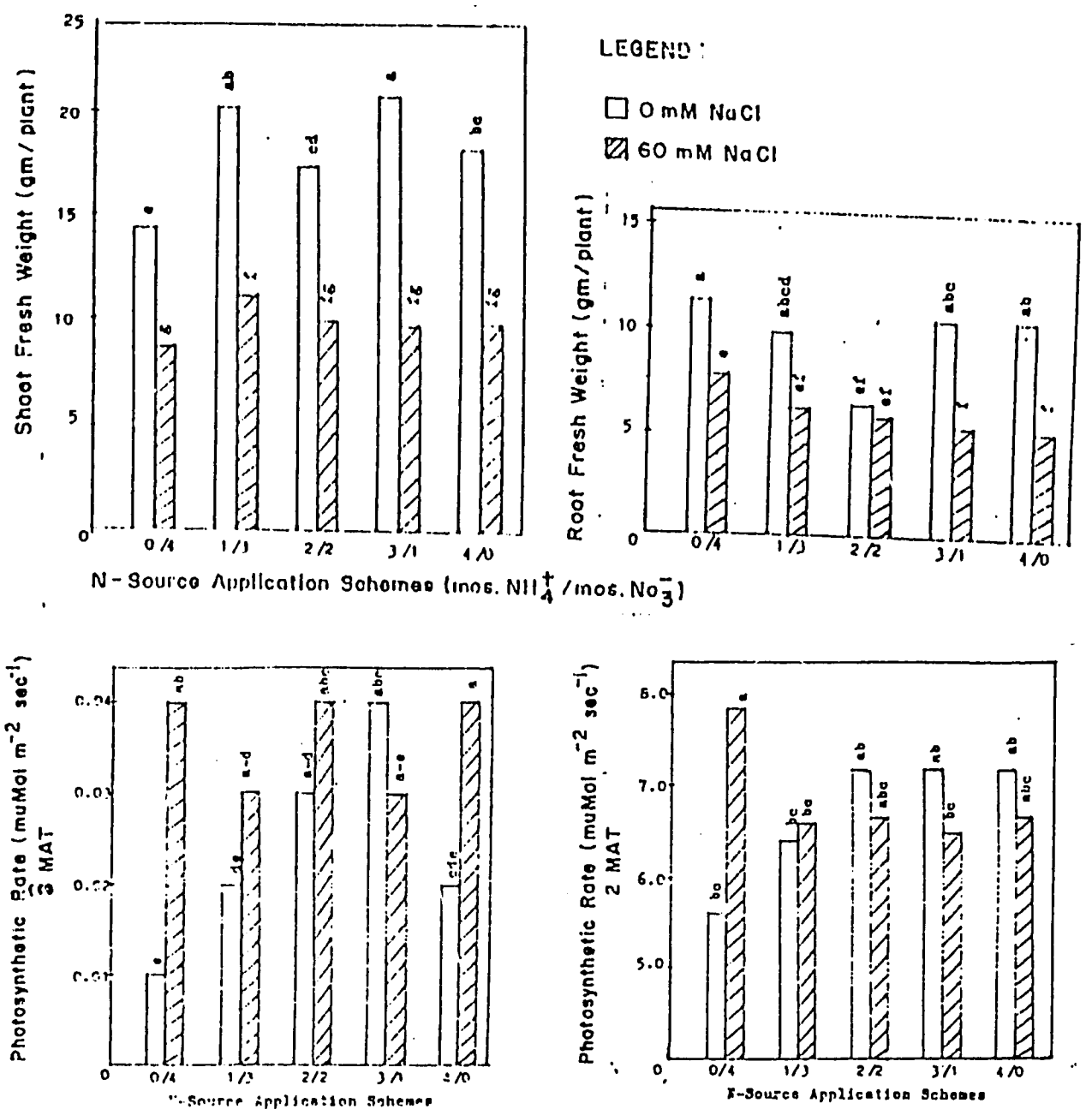

Figure 1. Effect of salinity and nitrogen-source application schemes on growth and photosynthesis of NaCl-stressed wheat.

Stomatal Conductance. As shown in Table , increasing the concentration of NaCl at 60 mM resulted to an increase in stomatal conductance, irrespective of N-source application schemes. The interaction between NaCl and N-source application schemes was significant only at 2 MAT. There was a marked reduction in stomatal conductance of NaCl-stressed plants fed with nitrate for 4 months. The rest of the treatments had comparable stomatal conductance (Fig).

Water Use Efficiency (WUE). At 1 MAT, water use efficiency generally decreased when wheat plants were grown in NaCl-stressed condition, except those unstressed nitrate-fed plants. Similar trend was observed on WUE of plants at 2 MAT. The WUE did not vary significantly among treatments at 3 MAT.

Leaf Protein Content. Highly significant interaction effects between NaCl levels and N-source application schemes were noted on the leaf protein content of wheat plants at 1, 2 and 3 MAT (Table). The leaf protein content generally increased remarkably in plants grown in NaCl-stressed condition. This observation holds true for all sampling periods except on leaves of nitrate-fed plants analyzed at 1 MAT (Fig). On the other hand, the highest leaf protein content was determined in nitrate fed plants grown in unstressed condition.

At 2 MAT, the leaf protein content was lowest in either NaCl-stressed or unstressed condition. NaCl-stressed plants receiving ammonium at 1, 2, 3 and 4 months duration had similar leaf protein content which was higher than the control ones. Under unstressed condition, the leaf protein content at 3 MAT increased with prolonged ammonium addition. However, highest leaf protein content was observed in NaCl-stressed condition fed with a combination of ammonium and nitrate, i.e., 2 months ammonium + 2 months nitrate).

Reproductive Growth Parameters

Grain Yield per Plant. Grain yield markedly decreased in NaCl-stressed plants subjected to different N-source application schemes except those that were fed with ammonium for 4 months (Fig). In this case, grain yield in salt-stressed and unstressed conditions were comparable. The highest yield was obtained when plants were supplied with ammonium for first 3 months and then shifting to nitrate for the last one month, i.e., at grain-filling stage. Yield tended to increase when plants were fed with nitrate at later stages of growth especially under NaCl-stressed condition.

Number of Seeds per Plant. The general trend for the number of seeds was similar to the grain yield per plant (Fig). The only difference was the higher number of seeds observed in unstressed ammonium-fed plants compared to NaCl-stressed ones. Furthermore, the number of seeds in all ammonium treated plants were comparable in all the treatments. Nitrate-fed plants had the lowest number of seeds in both conditions. The increase in the number of seeds in plants applied with ammonium alone for 4 months may be due to more number of tillers produced.

Average Seed Weight. The average seed weight of each seed dramatically increased in all nitrogen treatments when plants were exposed to NaCl salinity (Fig). The highest average seed weight was obtained in nitrate-fed plants grown in NaCl-stressed condition. Unstressed plants applied with ammonium alone produced smaller and lighter seeds compared to nitrate grown ones under the same conditions.

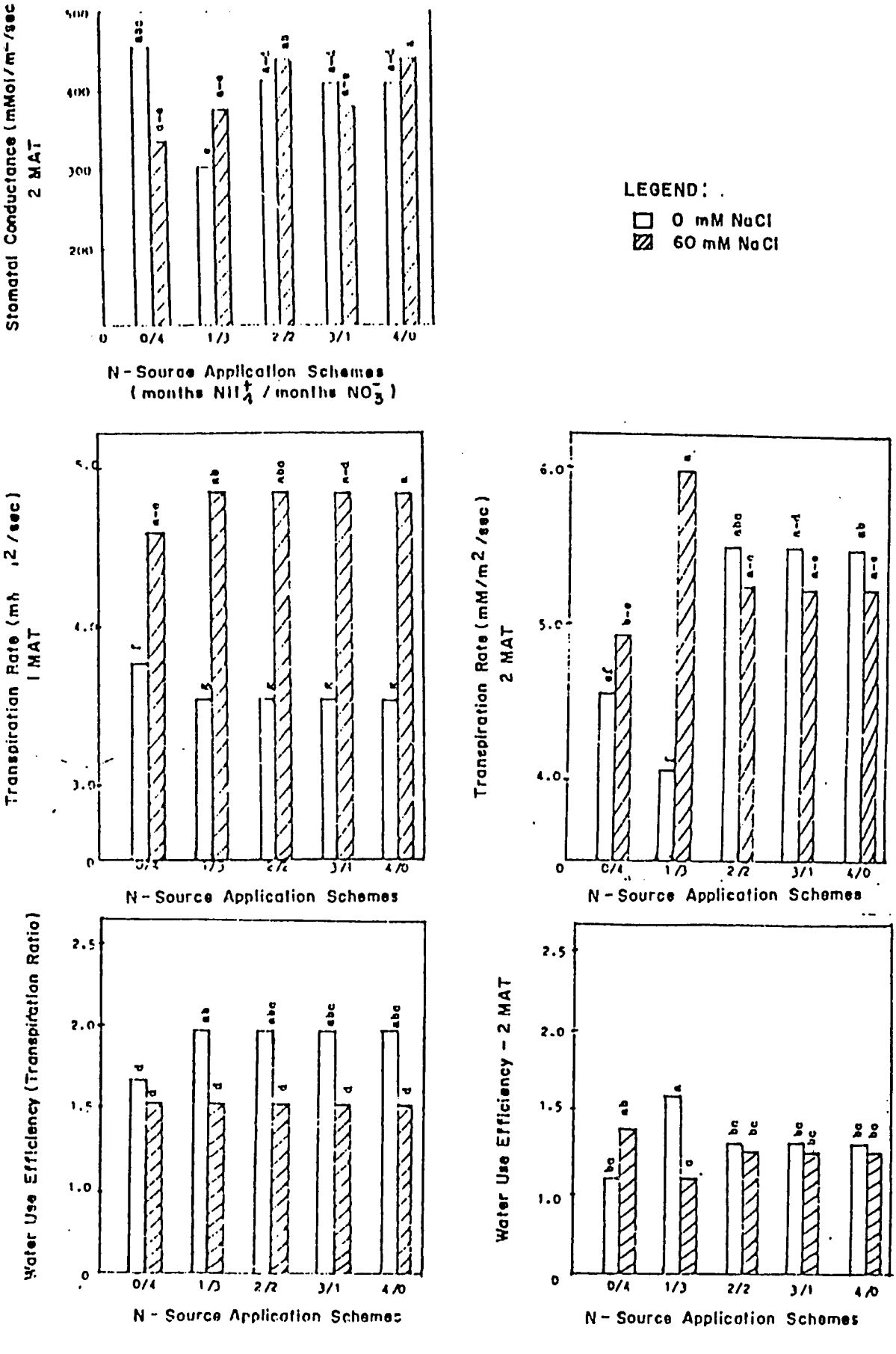

Figure 2. Effect of salinity and nitrogen-source application schemes on stomatal conductance, transpiration and water-use efficiency of NaCl-stressed wheat.

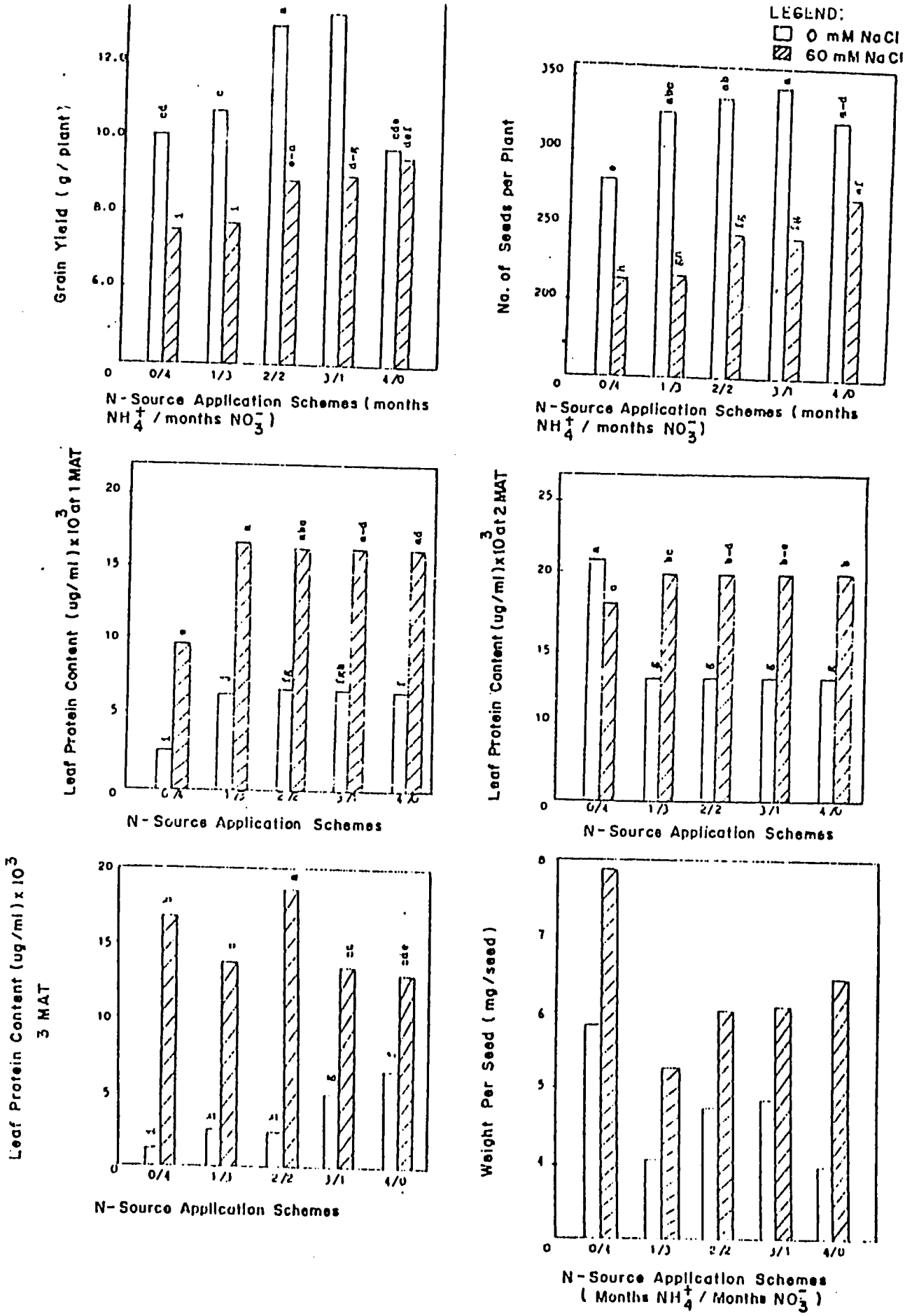

Figure 3. Effect of salinity and nitrogen-source application schemes on leaf protein content, grain yield, number of seeds and weight per seed of NaCl-stressed wheat.

DISCUSSION

The data generally reveal the growth-inhibiting effects of NaCl salinity in wheat plants especially at early vegetative stage of growth, irrespective of N-source application schemes. This observation supports earlier report on wheat by Asana and Kale (1965). According to their study on four varieties of wheat, salinity depressed root more than shoot growth and reduced tillering, leaf size and shoot height.

The results also demonstrate the importance of adequate nitrogen fertilization schemes in order to sustain growth of NaCl-stressed plants. Sharma and Lal (1975) observed that increased application of nitrogen tended to mitigate the adverse effect of increased salinity on wheat crop grown in sandy and clay loam soil.

With regards to N-source application schemes, it seems very likely that a combination of ammonium and nitrate would be more favorable for optimum growth and development of wheat plant. Cox and Reisenauer (1973) and Reisenauer (1978) reported 50% increases in both growth and yield of wheat as a result of controlled ammonium addition to nitrate (i.e., using different ratios of ammonium and nitrate feeding mixtures). According to Hayes and Goh (1978), a possible explanation for these different growth responses lies on the difference in the proportion of carbon allocated to nitrogen compounds and the carbohydrates participating in energy storage and structural activities.

One of the most significant observations in our study is the enhancement of root and shoot elongation as a result of nitrate application throughout the growth period of wheat. Furthermore, less number of tillers was observed in nitrate-grown plants compared to ammonium-grown especially under NaCl-stressed condition. These results are in agreement with the findings of Lewis et al. (1984) in wheat. The possible ameliorative effects of nitrate in salt-stressed plants may be related to this morphological adaptive response.

The data on the physiological parameters such as photosynthesis, transpiration, stomatal conductance and water use efficiency further confirm the favorable growth response in the presence of both ammonium and nitrate in NaCl-stressed and non-stressed conditions. Lewis et al. (1986) showed that a combination of ammonium and nitrate would favor higher photosynthetic rate more than ammonium or nitrate applied singly. Stomatal conductance and transpiration followed similar trend. This means that increase in stomatal conductance will lead to increase transpiration rate.

Furthermore, the results indicate that salinity can stimulate some metabolic processes like photosynthesis and transpiration rates especially if adequate irrigation and proper nitrogen nutrition are maintained. This observation has already been reported earlier. The possible role of sodium on stomatal opening was studied by Devitt et al. (1984). They studied the stomatal responses of sorghum and wheat to different K^+/Na^+ ratios of varying osmotic potentials. Higher transpiration rates at 1230 were consistently on wheat plants grown in higher Na concentrations at each osmotic level. Interpolated Na concentration in the plant tissues suggested that higher Na ion accumulation in the upper leaves coincided with stomatal response. This indicates that Na was also regulating the stomatal mechanism at high Na concentration, independent of the osmotic potential level.

A combination of ammonium and nitrate induced higher protein synthesis especially in salt-stressed plants. As reported earlier by Cox and Reisenauer (1978), the presence of nitrate would promote uptake of potassium ions. The increase in K uptake will probably

induce synthesis of specific proteins (Lubin, 1963; Blevins,1985 and Heimer et al. 1986), which may or may not play important role in plant adaptation to salinity stress.

Higher grain yield was also obtained in plants supplied with a combination of both ammonium and nitrate in both NaCl-stressed and unstressed conditions. This correlates well with previous observations on wheat (Cox and Reisenauer, 1973; and Reisenauer, 1978). In our experiment, it seems that ammonium is a better N-source at vegetative stage, while nitrate becomes more important especially during the grain-filling stage of reproductive growth.

It is interesting to note the apparent beneficial effects of salinity to nitrate application towards the reproductive stage (i.e., grain-filling stage) in order to increase yield even under NaCl-stressed condition. This supports the observation of Torres and Bingham (1973). They found out in their sand-culture experiments that nitrate levels at early spike emergence were closely correlated with grain yields in four wheat varieties irrespective of NaCl levels.

The data on average seed weight suggest that NaCl salinity induced the reproduction of bigger and heavier grains, regardless of N-source application schemes. Lips and Silberbush (1978) reported that salinity enhanced the development (i.e. increase in size) of individual wheat grain in the presence of nitrate. This observation agrees with the findings of Devitt, et al., (1984). They observed that wheat plants accumulating the highest concentration of sodium were the ones with the highest dry matter production and evapo-transpiration rates. According to these researchers, sodium is effectively used in osmoregulation, thus, leading to an improved water and nutrient status of the plant.

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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 (Hodge 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, Laguna, 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.

Salinization treatments started at about 6 weeks after seed sowing in pots containing 1.5 kg dried soil (Haahas 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 (Haas 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 . The effects of varying levels of water salinity and KNO_3 on the growth of rice (var. IR-28) are shown in Figure 1 . These two parameters, however, were affected by salinity levels alone.

Growth in terms of shoot length, root fresh weight and dry weight of roots and shoots decreased with increasing levels of salinity (Fig. 1). Addition of KNO_3 to the medium apparently enhanced the toleance of rice to higher salinity levels. The inhibitory effects of salinity on growth were most pronounced at highest salinity levels (10.6 mmhos/cm) in the absence of KNO_3

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 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 (Figure 1).

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 Trolldemier, 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 1).

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).

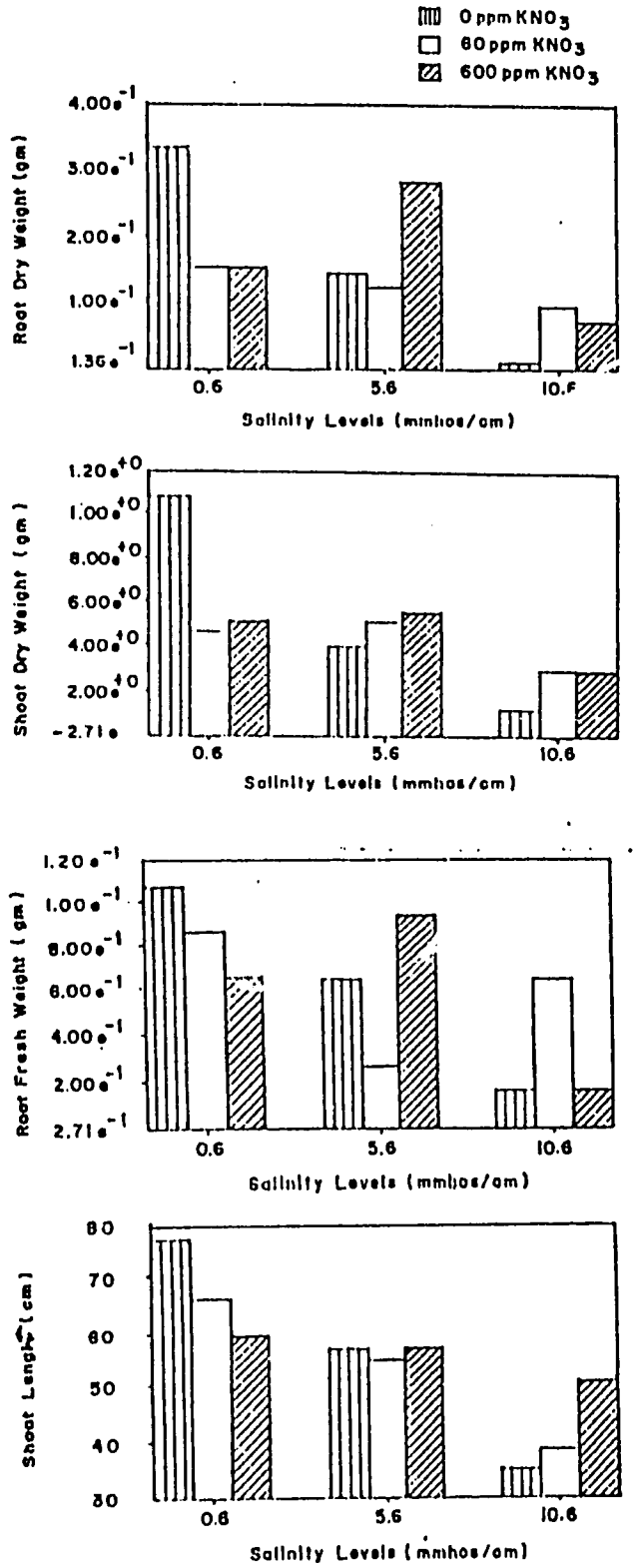

Figure 1. Effect of potassium nitrate on the growth response of salt-sensitive rice variety IR-28 irrigated with different levels of saline water.

Total Nitrogen. The total nitrogen content of rice shoots did not vary much in any of the treatments except for the highest salinity levels (Figure 2). 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 ced 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 (Figure 2). 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 (Figure 2). 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 (Figure 2). 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).

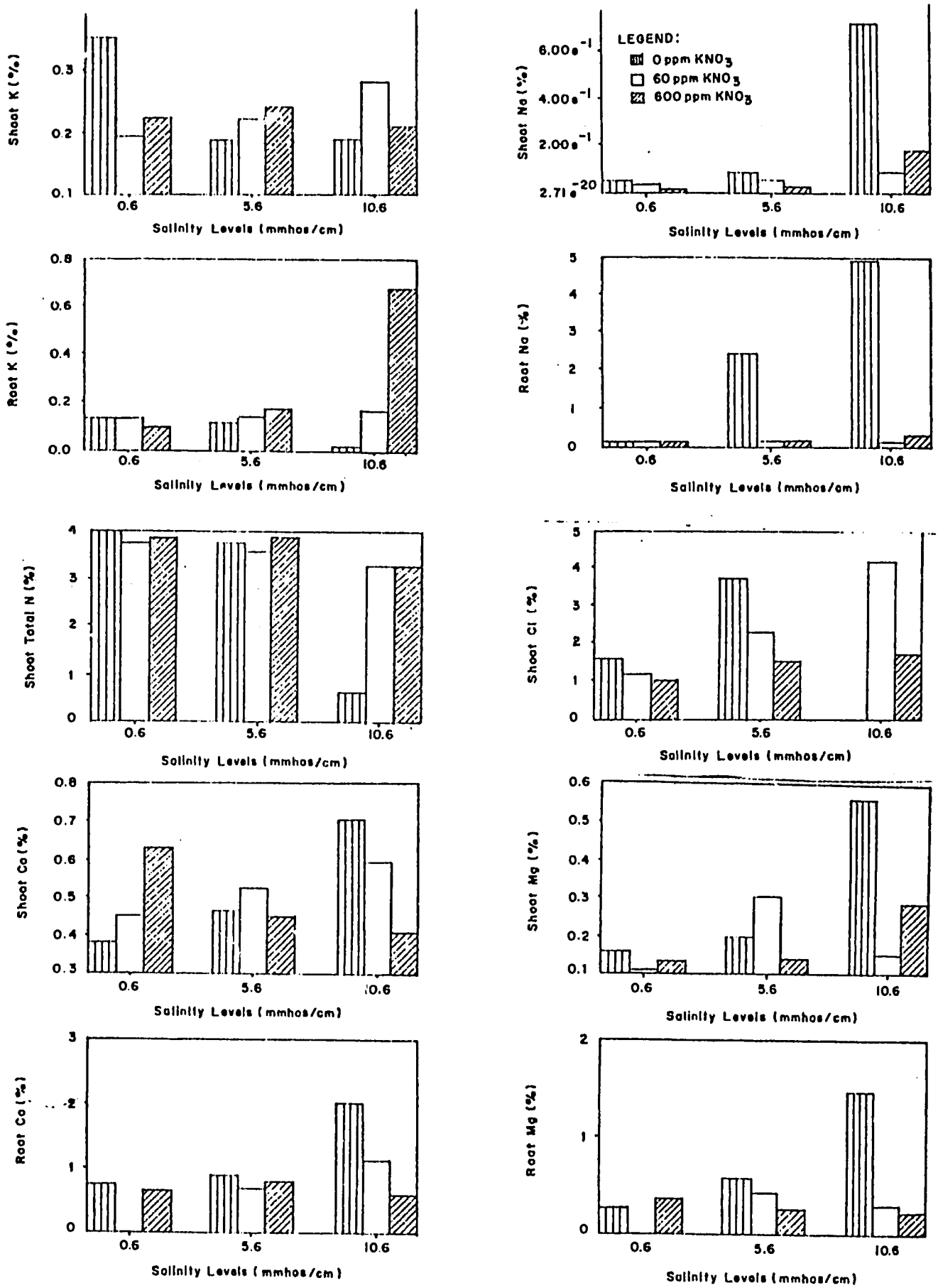

Figure 2. Effect of potassium nitrate on the mineral nutrient uptake of salt-sensitive rice variety IR-28 irrigated with different levels of saline water.

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 disturbed. 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 (Fig.2). 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 magnesium 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 (Fig 2). Murthy and Rao (1965) reported stimulation of Mg uptake with increasing levels of salinity.

Na/K and Na/Ca Ratios As shown in Tables 1 and 2, 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 4). 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 Na/K ratio of rice (var. IR-20) 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	0.20	0.05
0.6	60	no data	0.08
0.6	600	nil	0.05
5.6	0	27.59	0.39
5.6	60	0.29	0.16
5.6	600	0.31	0.08
10.6	0	no data	3.70
10.6	60	0.63	0.28
10.6	600	0.28	0.83

Table 2 Na/Ca ratio of rice (var. IR-20) 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	1.08	0.16
5.6	60	0.13	0.07
5.6	600	0.04	0.04
10.6	0	5.61	1.02
10.6	60	0.09	0.18
10.6	600	0.61	0.29

Table 8: 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)	.690*	.277ns
5. Root fresh weight (gm)	.522*	.142ns
6. Shoot dry weight (gm)	.773*	.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*	.150ns
13. % Na in root	.054ns	.385ns
14. % Ca in shoot	.021ns	.021ns
15. % Ca in root	.354ns	.356ns
16. % Mg in shoot	.530*	.275ns
17. % Mg in root	.140ns	.431*

* Significant

ns - not significant

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 intervelnal 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 shown in Fig 1. The interaction effects of KNO_3 and salinity levels were statistically significant in all growth parameters except dry weights of roots and shoots. These two parameters, however, were affected by salinity levels alone.

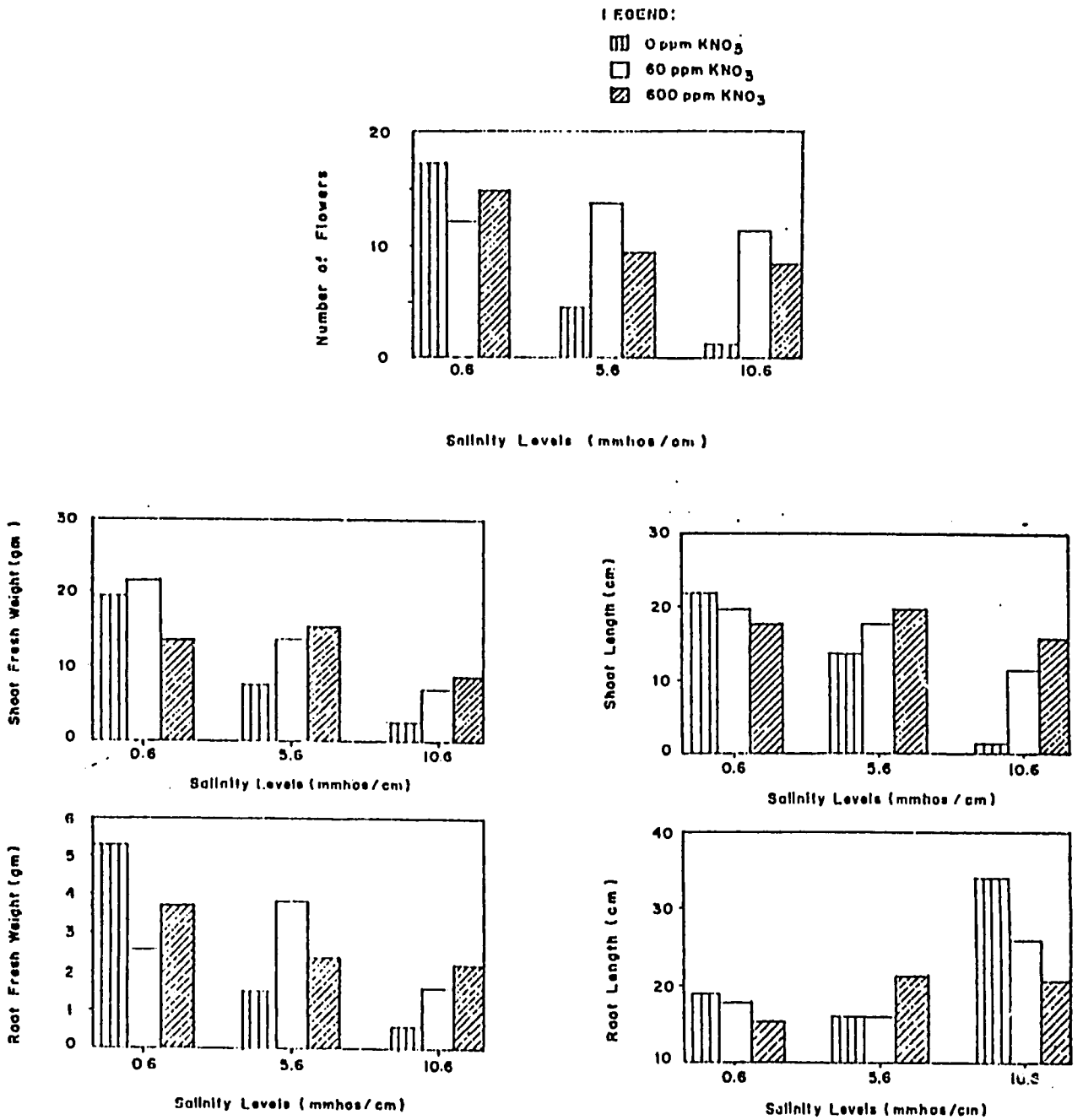

Figure 1. Effect of potassium nitrate on the growth response of peanut (*Arachis hypogaea* L.) irrigated with different levels of saline water.

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 1 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. 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 (Fig 2), 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).

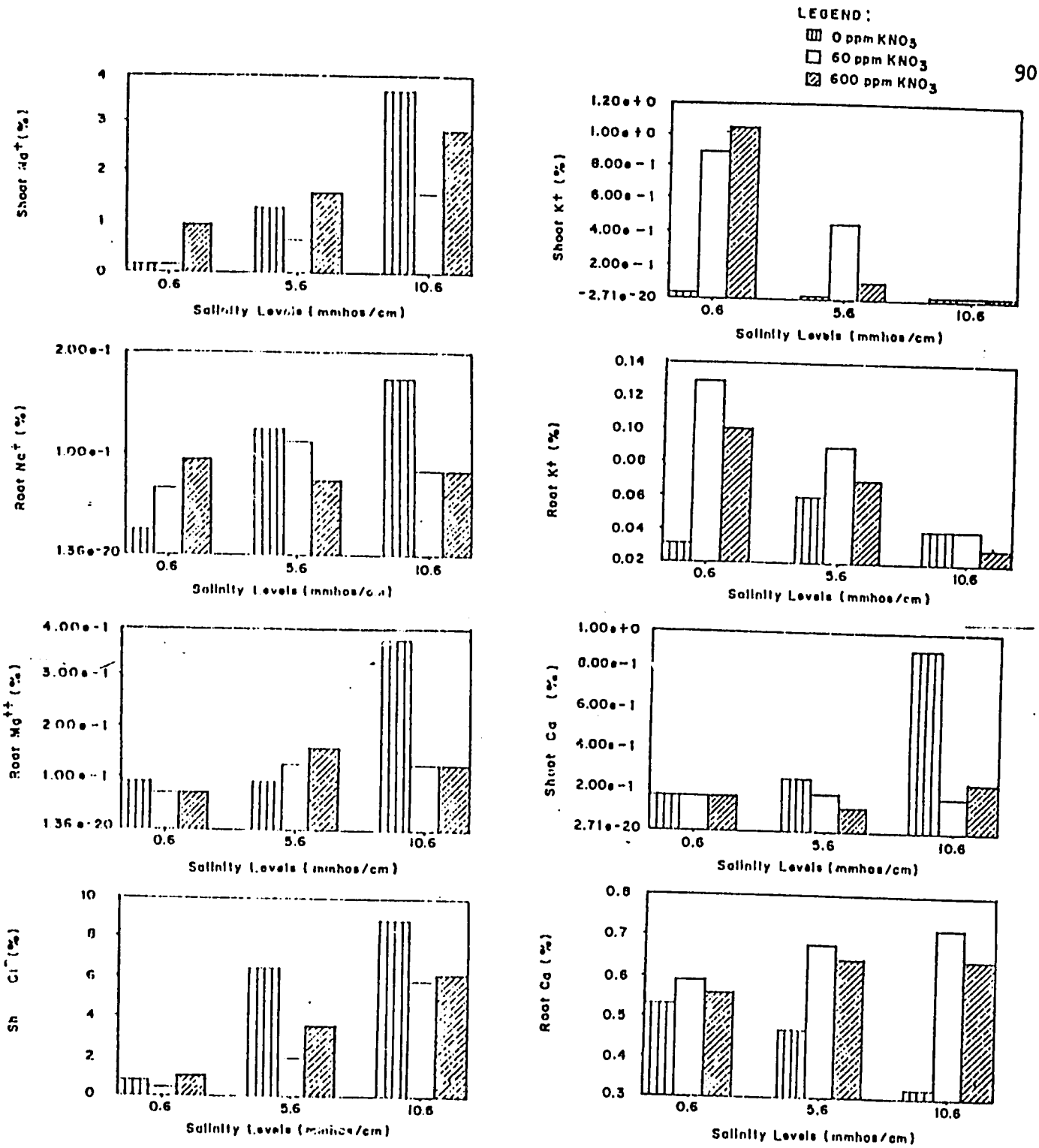

Figure 2. Effect of potassium nitrate on the mineral nutrient uptake of peanut (*Arachis hypogaea* L.) irrigated with different levels of saline water.

Potassium. A highly significant interaction between salinity and KNO_3 levels was noted on the potassium content of peanuts (Fig 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 (Fig 1). 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). Silberbush 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 (Fig 2.). 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 (Fig 2). 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 3. 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 apparently sufficient enough to alter the ratio. It has been previously, hypothesized that higher Na/K ratio in saline environment can impair the selectivity of root

Table 1 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 not significantly diferent according to duncan's Multiple Range Test (DMRT) at 5% level of significance.

Table 2. 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.

Table 4 Correlation analyses of the relationships of salinity levels and potassium nitrate with the different growth parameters and mineral nutrient composition of rice var. IR-28 and peanut cv. UPI-Pn 2. IRS UPLB, Philippines. 1987.

PARAMETERS	SALINITY	KNO_3
	Peanut	Peanut
1. Shoot length (cm)	- .715*	.364 ns
2. Root length (cm)	+ .683*	.120 ns
3. Number of flowers	- .601*	.108 ns
4. Shoot fresh weight (gm)	- .831*	.339 ns
5. Root fresh weight (gm)	- .676*	.074 ns
6. Shoot dry weight (gm)	- .630*	.507*
7. Root dry weight (gm)	- .744*	.049 ns
8. % Total N in shoot	- .437*	.026 ns
9. % Cl in shoot	+ .875*	.119 ns
10. % K in shoot	- .663*	.226 ns
11. % K in root	.155 ns	.400 ns
12. % Na in shoot	+ .813*	.107 ns
13. % Na in root	.540*	.163 ns
14. % Ca in shoot	+ .494*	.307 ns
15. % Ca in root	.028 ns	.050 ns
16. % Mg in shoot	+ .507*	.178 ns
17. % Mg in root	.55 ns	.165 ns

* - Significant
ns - not significant

Table 35. Na/K ratio of rice var. IR-28 and peanut cv UPL Pn 2 applied with varying levels of saline water and KNO_3. IRRI-UPLB, Philippines, 1987.

TREATMENT COMBINATIONS		NA/K RATIO	
Salinity Levels (mmhos/cm)	KNO_3 (ppm)	Peanut Root	Peanut Shoot
0.6	0	0.65	0.55
	60	0.47	0.05
	600	0.87	0.86
5.6	0	2.12	101.55
	60	1.22	1.32
	600	0.97	11.07
10.6	0	4.49	315.22
	60	1.95	117.13
	600	1.41	157.11

Table 36 Na/Ca ratio of rice var. IR-28 and peanut cv. UPL Pn2 applied with varying levels of saline water and KNO_3. IRRI-UPLB, Philippines, 1987.

TREATMENT COMBINATIONS		Na/Ca RATIO	
Salinity levels (mmhos/cm)	KNO_3 (ppm)	Peanut Root	Peanut Shoot
0.6	0	0.03	0.04
	60	0.11	8.29
	600	0.16	5.75
5.6	0	0.19	5.65
	60	0.16	3.37
	600	0.16	13.24
10.6	0	0.53	4.06
	60	0.12	9.43
	600	0.12	12.45

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

Correlation Analysis. Table 4 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.

NITROGEN ASSIMILATION OF PLANTS UNDER STRESS AND HIGH CO_2 CONCENTRATIONS

Lips S. H., E. O. Leidi and M. Silberbush

Most crop plants reduce their biomass production when growing in relative mild salinity (5 - 13 dSi m^{-1}) . This was assumed to be due either to the limited ability of these plants to adjust osmotically to their saline environment or to the energetic cost of the osmotic adaptation process (Yeo, 1983). During the last years an increasingly large number of publications point out that this may not be the case (e.g.: Termaat *et al*, 1985) since plants readily adjust osmotically to these salinity levels. The inhibition of biomass production by salinity is probably due to a number of falling metabolic processes each of which develops at different levels of salinity according to their particular sensitivity to salt. Once we define the physiological characteristics of a given crop, salinity may be applied to enhance quality and quantity of fruit and seed production in the range of 0 - 10 dSi m^{-1}. This idea will be presented in relation to two central primary assimilation processes: uptake of nitrogen and photosynthesis.

Nitrogen uptake and assimilation under saline conditions.

Plants keep a fairly constant concentration of total organic nitrogen under most environmental conditions (Leidi et al, 1989; Silberbush et al, 1988). The amount of nitrogen taken up by the plant determines the amount of biomass they will produce at standards predetermined genetically. Since Cl^- reduces nitrogen uptake, one may assume that salt-induced inhibition of nitrogen uptake limits growth. Nitrogen supplementation to some crops (e.g.: peanut, sunflower, cotton, maize, wheat) prevents or limits salt-inhibition of growth. The sensitivity of different species to salt is reflected in the Cl^- sensitivity of their nitrate uptake mechanisms (Leidi et al , 1989). We compared (Fig. 1) the ratio of total N/Cl^- in the plants as affected by the ratio of NO_3^-/Cl^- in the nutrient medium with salt-sensitive peanut and with salt-tolerant cotton plants. Increasing medium salinity affects more rapidly the uptake of nitrogen by the sensitive than by the tolerant species. It should be possible, consequently, to improve nitrogen uptake by slightly increasing the NO_3^-/Cl^- ratio around the plant roots. When peanut plants are grown in cultures with 0 -100 mM NaCl, plant growth is rapidly inhibited (Fig. 2).

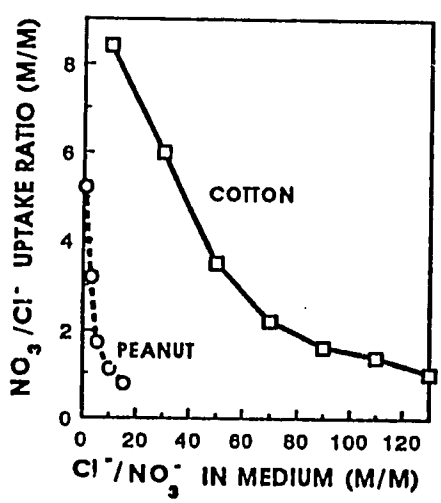

Figure 1: Nitrate uptake as affected by Cl^-

Center of Desert Agrobiology, J. Blaustein Institute for Desert Research and Dept. of Biology. Ben Gurion University of the Negev. Sede Boqer, Israel.

However, if plants growing in 60 mM NaCl, whose growth is inhibited by 40 - 60%, receive in their nutrient medium (sand) increasing concentrations of KNO3 (Fig. 3), the growth of these plants is renewed and reaches rates higher than that of the controls. It was observed that the overall content of chloride by the plants remained fairly constant while the amount of nitrate increases proportionally to growth (Fig. 4).

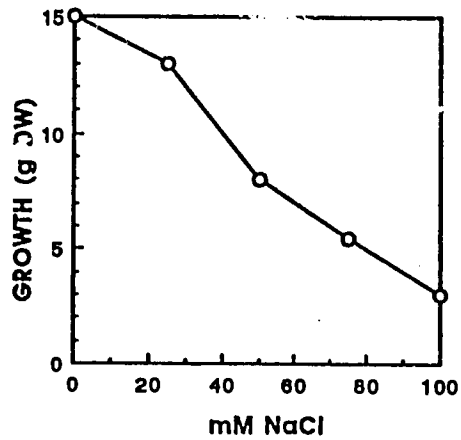

Figure 2: Growth of peanut plants as affected by 60 mM NaCl. No fixed nitrogen added, good nodulation.

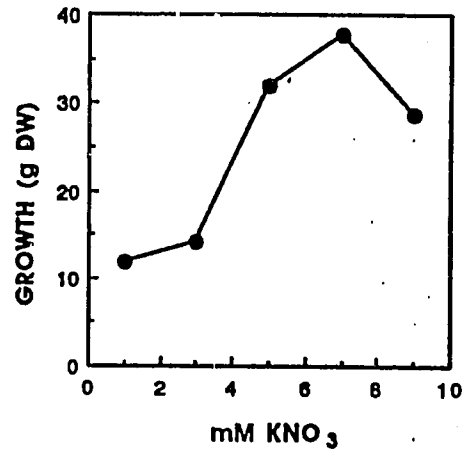

Figure 3: Growth of peanut plants grown in NaCl as affected by KNO_3 concentration

We concluded that the salt-sensitivity of the rhizobium strain in peanut root nodules is very pronounced at even relatively low concentrations of NaCl. The addition of nitrate or ammonium bypass the salt-sensitivity of the root nodules, reestablishes adequate nitrogen supply to plants and the result is uninhibited growth.

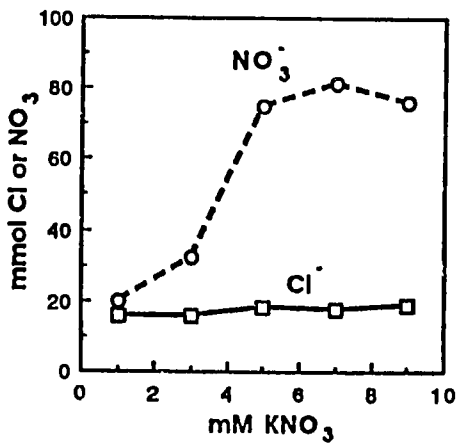

Figure 4: Chloride and nitrogen content of peanut plants grown in 60 mM NaCl as affected by KNO3 concentration in medium.

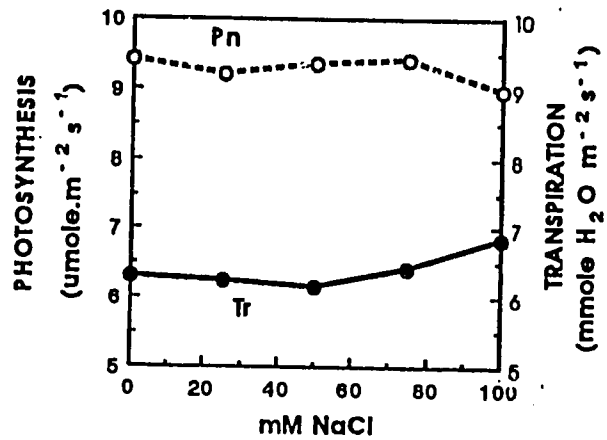

Figure 5: Photosynthesis and transpiration rates of wheat as affected by NaCl concentrations.

Photosynthesis and transpiration

Contrary to nitrate-uptake mechanisms, photosynthesis and transpiration are stable when plants are irrigated with up to 80 mM NaCl (Fig. 4). This is the case for both salt-sensitive and tolerant species. The decreased growth of salt-sensitive plants is not due, at the salinity range indicated, to salt-induced damage to the photosynthetic apparatus. This is the case even when a considerable decrease in extracted chlorophyll is observed.

Study case 1: Peanut production

Since the growth capacity of peanut plants was sensitive to salinity but could be restored by increasing the supply of nitrogen (Fig. 2), we assumed that peanut production could also take place under field conditions when irrigated with saline water supplemented with nitrogen fertilizer (Silberbush et al, 1988). Flowering was greatly stimulated by salinity (Silberbush *et al*, 1988), even in plants with good vegetative growth which did not show any stress symptoms. Salinity damage signs (chlorotic and necrotic leaf areas) appeared in the crop soon after flowering at the time of gynophore development. The end result of our efforts in the field at this stage was that we were obtaining large plants with enhanced flowering but lower yields of seeds. Gynophore development was very sensitive to soil salinity and most of them did not develop pods and seeds when in contact with more than 100 mM NaCl. What was the reason for the salt-sensitivity of peanut during the reproductive stage ? We are presently studying two alternatives: (a) the capacity of the root to discriminate between Cl^- and NO_3^- decreases during gynophore development and (b) gynophores may take up ions from the soil in a way which introduces large amounts of Cl^- into the plant.

As a result of these observations, best results can be achieved today by using saline water (6-10 dSl m^{-1}) during vegetative growth until flowering and continuing irrigation with good quality water (up to1 dSl m^{-1}) during gynophore development. The use of saline water irrigation during the vegetative stage enhances overall production of peanut seeds 70-90 % above yields obtained with peanut plants grown with good quality water during its entire life cycle.

Study case 2: wheat production

The use of saline water irrigation during wheat production differs from that used with peanut. Nitrogen (especially ammonium-nitrogen) stimulates tiller development while chloride inhibits it (Leidi *et al*, 1989). Growth inhibition of wheat by salinity is due to the decrease on the number of tiller produced and on the dry mass of single tillers. As a result, less and smaller grains are produced (Silberbush and Lips, 1989b). Adding nitrogen to the irrigation saline water releases some of the salt-induced inhibition of shoot growth but the effect is less dramatic than in peanuts during the vegetative stage.

With wheat we learned that the type of nitrogen supplied, however, seems to affect the extent of

mobilization of assimilates to filling grains (Botella et al, 1989). Nitrate, but not ammonium-nitrogen, stimulates assimilate translocation from leaves to ears in plants irrigated with saline water (Figure 5). Supply of nitrate, under saline conditions, causes production of larger grains (Silberbush and Lips, 1989b). Translocation of recently photosynthesized 14C-assimilates to the grains is stimulated by salt (Leidi and Lips, 1989). While nitrate-fed plants translocate assimilates to the grains, ammonium-fed plant allocated most of its carbon assimilates to developing young tillers (Fig. 6)(Botella et al., 1989).

From here one may conclude that wheat irrigated with good quality water and ammonium-nitrogen during vegetative growth, followed by saline water (50-60 mM NaCl) and nitrate, may produce a better yield of grain than wheat grown on good quality water throughout its entire growth cycle. In this case the combined effects of nitrate-nitrogen and salinity during the grain filling stage, may result in an increased production of grain biomass.

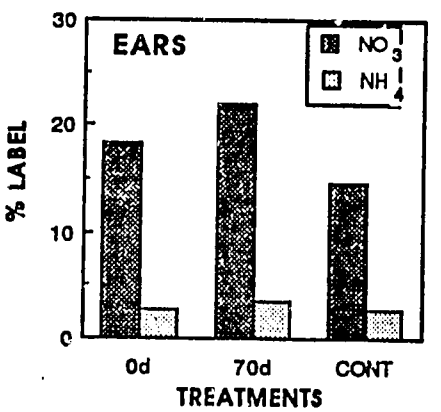

Figure 6: ^{14}C-allocation to ears as affected by the affected type of nitrogen fed to wheat plants. plants.

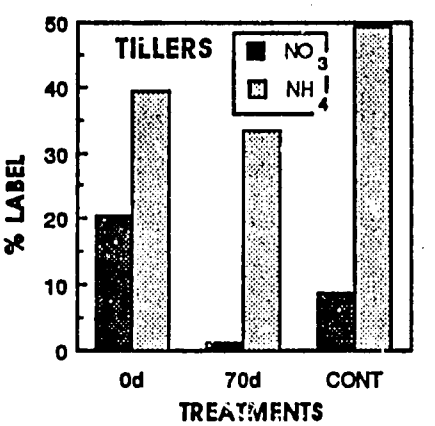

Figure 7: ^{14}C-allocation to young tillers as by the type of nitrogen fed to wheat

Recent work by Berliner et al. (1986) indicates that placement of nitrate in deep layers of soil (about 0.80-1 m deep) promotes wheat root proliferation in this layers. Deep roots allow the plant to use larger amounts of soil moisture in areas where its supply is limited to seasonal rains.

Atmospheric CO_2 concentration and the effects of NaCl on biomass production

Salt-tolerant and salt-sensitive sunflower plants growing in atmospheric CO_2 concentrations (340 ppm) respond to relatively low concentrations of NaCl (10-25 mM) by reducing their growth to some extent. However, when these plants are placed in 1200 ppm CO_2, the same low concentrations of

NaCl will stimulate growth to a large extent (Figs. 3 and 9). Since total nitrogen concentration in the leaves remains constant under all treatments, then the salt-sensitivity of the nitrate uptake mechanism could be also a function of carbohydrate supply to the roots. The concept of stress is, therefore, very much a relative function of environmental conditions.

We are presently studying various aspects of the possible mechanisms involved on this NaCl-stimulation of growth, such as Na^+ and Cl^- distribution and compartmentation, K^+ requirements of the plants under high CO_2, etc.

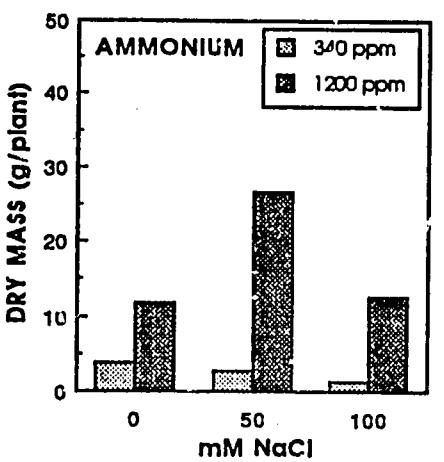

Figure 8: Dry mass production of sunflower plants grown in ammonium nitrogen as affected by CO2 and NaCl concentrations.

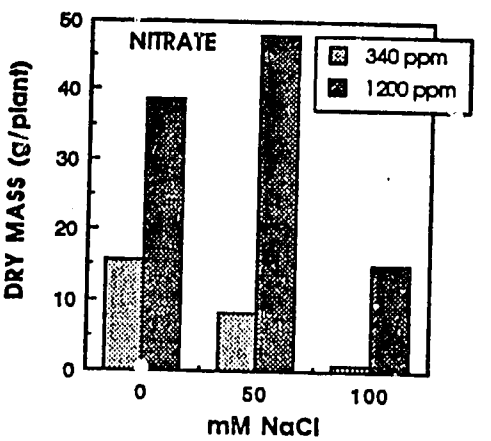

Figure 9: Dry mass production of sunflower plants grown in nitrate nitrogen as affected by CO2 and NaCl.

Determination of sink priorities by salinity in nitrate- and ammonium-fed plants

Wheat plants well supplied with nitrogen develop new tillers even when grain of older tillers is at the filling stage. Nitrate-fed plants produce most or all of its tillers during a limited period of time, mostly during the vegetative stage. During the second period of growth, carbohydrate and nitrogenous reserves of the leaves are transported exclusively to the filling grains. In this way, a large percentage of tillers produces mature ears. Ammonium-fed wheat produces tillers during the entire life cycle of the plant. A smaller percentage of the total number of tillers produced will bear ears and not all of the latter will mature before the onset of plant senescence (Botella *et al*, 1989). Salinity stops development of young tillers and enhances translocation of assimilates to the seeds, both processes are also typical of nitrate-fed wheat plants. The combination of salinity and nitrate produce more efficient plants in the sense that assimilates will be invested totally on grain production and none on the generation of late tillers whose ears will not mature.

These observations confirm our work (Silberbush and Lips, 1989b) in which we reported the production of larger seeds by wheat plants irrigated with saline water and nitrate as compared with

plants receiving saline water and ammonium.

Crop production and salinity

Brackish or saline water with electroconductivities up to 13 dS m^{-1} constitute frequently the main or only water resource for agriculture in extensive arid and desert areas of the world. Even in more humid regions, high water tables, inadequate use of irrigation or excessive pumping from well in costal areas, may cause salinization of the medium in which crops are produced. At this lower range of salinity, nitrogen and potassium fertilization are especially important. Nitrogen can counteract, at this range of electroconductivity, much of the growth inhibition induced by salt when it is provided in adequate amounts, forms (ammonium or nitrate) and timed to specific development stages of the plants.

At higher salt concentrations, the mounting number of metabolic processes affected by salinity cannot be corrected or alleviated by enhanced nitrogen fertilization (Fig. 10).

Plants respond to salinity in different ways since different developmental processes are affected. At this stage of our awareness of the interaction between NaCl and different metabolic processes of the plants we may have to devise different strategies for each crop. Salinity not only inhibits physiological plant processes (nitrogen uptake, chlorophyll synthesis, tiller induction, N_2-fixation) but it stimulates others (flowering, nitrogen uptake under high CO_2, assimilate translocation to fruits and seeds). By alleviating some of the more salt-sensitive processes while stimulating others, we should be able to use saline water (4-10 dSI m^{-1}) to produce better yields.

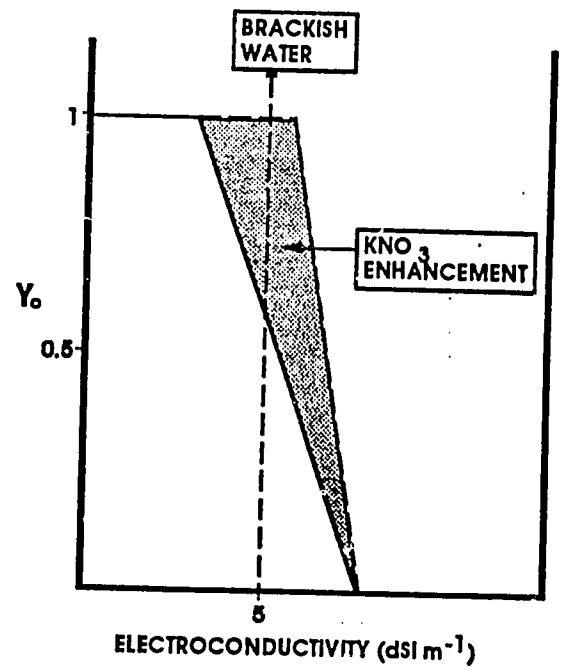

Figure 10: Response of a salt-sensitivity plant to increasing salinity and additional KNO_3.

One can express this assumption in terms of the well known salt-sensitivity Maas and Hoffman (1977) plot (Fig. 10). Wheat produces 50% of its grain potential yield (Y_0) when irrigated with water of 5 dSI m^{-1}or approximately 50 mM NaCl. When we add to this water KNO_3 the range of electroconductivity in which normal yields are obtained may be extended from 2 to about 7 dSI m^{-1}. Since other physiological systems (such as photosynthesis or nitrate reductase) are not alleviated by adding KNO_3, yield production will cease in both cases around 9 dSI m^{-1}. In this case

we extended the full yield range of electroconductivity (EC), sufficiently to use locally abundant 5 dSl m^{-1} water, although the survival limit of the plant to salinity has not changed.

As our knowledge of the different physiological and metabolic processes affected by salinity increases, a more universal model for crop production under saline conditions will presumably be developed.

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The Effect of NaCl Concentration on NO_3^-, K^+ and Orthophosphate-P Influx to Peanut Roots

M. SILBERBUSH and J. BEN-ASHER

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

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ABSTRACT

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The effect of relatively low concentrations of NaCl on the vegetative growth of peanut (*Arachis hypogaea* L.) plants appeared to be due to its disruption to nutrient uptake. The specific effect of NaCl on the uptake rate of NO_3^-, K^+ and orthophosphate-P was studied in solution culture. The influxes of the nutrients were calculated according to their depletion in the solution, and the parameters for the Hill Kinetics for low concentrations were calculated as: $I_n = I_{max} C^h/(K^h + C^h)$, where I_n = net influx, I_{max} = maximal influx, C = concentration, K = the apparent Michaelis-Menten coefficient, and h = the Hill cooperativity index. The reduction in ion influx was greatest for K^+, followed by NO_3^-, while phosphate influx was not affected by NaCl. All three parameters of the Hill equation for K^+ influx were affected by NaCl concentration: I_{max} decreased to about one-third, while the value of K tripled and h doubled, when NaCl concentration increased from 0 to 75 mM. I_{max} of NO_3^- influx was reduced by 40% because of the same increase in NaCl concentration. The other two parameters were unaffected. The results confirm previous results that low concentrations of NaCl disturb the nutritional balance of plants, mainly by Na^+-K^+ competition in uptake, and to a smaller degree, by Cl^--NO_3^- interaction. The possible implications about the nature of ion interaction in uptake by the roots, derived from the differential effect of NaCl on the parameters of the Hill equation are discussed.

Keywords: *Arachis hypogaea* L.; Hill kinetics; nutrient uptake; peanut; salt stress; soilless culture.

Abbreviations: h = Hill cooperativity index; I_{max} = maximal influx; I_n = net influx; K = apparent Michaelis-Menten coefficient.

INTRODUCTION

Peanut (*Arachis hypogaea* L.) is classified as a salt-sensitive crop (Maas and Hoffman, 1977). Previous studies (Silberbush et al., 1985) confirmed this. However, the sensitivity of this crop to salinity appeared to be due to the sen-

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sitivity of the reproductive organs, while the vegetative growth is comparatively salt-tolerant (Silberbush and Lips, 1988). Furthermore, there is an interaction between NaCl and K^+ or NO_3^- in their effect on plant growth (Silberbush et al., 1988). Such interactions between cations in a range of species were studied for K^+ and Na^+, and Ca^{2+} and Na^+ (Epstein, 1972; Greenway and Munns, 1980; Läuchli and Stelter, 1982; Kawasaki et al., 1983; Singh and Arbol, 1985). Similarly, the interaction between Cl^- and NO_3^- was studied (Kafkafi et al., 1982).

The purpose of the present study was to quantify the effect of NaCl on the uptake rate of the three major mineral nutrients (i.e. NO_3^--N, K^+ and PO_4-P) in order to identify the sources of disturbance caused by low concentrations of NaCl to the vegetative growth of the plant.

MATERIALS AND METHODS

Peanut (*A. hypogaea* L. cultivar 'Shulamit') seeds were germinated in moist paper towels for 8 days. The tap-roots were then trimmed, leaving 6 cm of root, and each seedling was transferred to a 1-l container with nutrient solution. The growth solution contained 3 mM NO_3^-, 1 mM K^+, 2 mM Ca^{2+}, 1 mM Mg^{2+}, 0.25 mM $H_2PO_4^-$, 75 μM Fe^{2+}-diethylenetriaminepentaacetic acid (DTPA), and micronutrients according to Hoagland and Arnon (1950). The pH was adjusted to 5.5 with a $Ca(OH)_2$ solution. Five days later, NaCl was added to the salt-treated containers in daily increments of 12.5 mM. The final NaCl concentrations were 0, 25, 50 and 75 mM, in 4 replicates arrayed randomly in a growth chamber. The temperature was kept constant at 25°C, with daily photoperiods of 16 h. Illumination was achieved by a series of cool-white fluorescent tubes and incandescent bulbs. The nutrient solutions were replaced every week at the beginning, and twice a week during the last 2 weeks. The growth solutions were replaced after 29 days with 2 mM $CaSO_4$ solutions (pH 5.5) and with the corresponding concentrations of NaCl for 2 more days in continuous light; 80 μM NO_3^-, 100 μM K^+ and 20 μM $H_2PO_4^-$ were then added, and the solutions were sampled over the next 24 h. The samples were stored in 5°C overnight, and analyzed on the next day for NO_3^- (Szechrom-NAS reagent, R&D Authority, Ben-Gurion University of the Negev, Beer-Sheva, Israel), P (Murphy and Riley, 1962) and K^+ (flame-photometry). The secondary roots were separated from the shoots and the tap-roots, and their lengths were measured by the line-intersect method (Tennant, 1975). Mean radii were calculated from the fresh weight and the root length, assuming the roots to be smooth cylinders and the fresh weight to equal the volume (i.e. root density $\simeq 1$ g·cm^{-3}). Root length and mean radius were used to calculate the root surface area, which was used later to calculate the influx rates of the various ions to the root surfaces.

An additional series of 14 plants was grown under the same conditions as

the first series, but without NaCl. This second series was harvested during the growth period, and root lengths were measured as before. The root length data were used to calculate a function of root growth with time which was needed later to calculate ion influx to the roots from relatively high concentrations (Silberbush and Ben-Asher, 1987).

The shoots and the roots were then dried at 60°C and ground. Shoot samples were digested in $H_2SO_4+H_2O_2$ and analyzed for Ca^{2+}, Mg^{2+} (titration with EDTA), P (Murphy and Riley, 1962), and reduced N (Nessler reagent). Na^+, K^+ (flame photometry) and Cl^- (by titration with $AgNO_3$) were determined in hot-water extracts of both shoot and root samples.

RESULTS

When NaCl concentration increased, shoot dry weight decreased, but root dry weight was not significantly affected (Table 1). Root length, on the other hand, increased and root mean radius decreased with the increase of NaCl concentration. As a result, root surface area did not change significantly.

With increasing NaCl concentration, in the shoots N decreased, P increased, K^+ was unchanged, while Na^+ and Cl^- increased (Table 2). Concentrations of Ca^{2+} and Mg^{2+} were unchanged. In the roots, K^+ decreased and Na^+ and Cl^- increased when the plants were exposed to NaCl (Table 2).

Net influxes of NO_3^-, K^+ and PO_4-P to the roots were assumed to obey the Hill kinetics for low concentrations (Bernard, 1968):

$$I_n=\frac{I_{max}\,C^h}{K^h+C^h} \qquad (1)$$

where: I_n = net influx, I_{max} = maximal influx when the concentration C is relatively high, K = the apparent Michaelis–Menten coefficient which is equal to the concentration when $I_n=1/2I_{max}$, and h = the cooperativity (Hill) index.

TABLE 1

Shoot and root growth characteristics of peanut plants grown in different concentrations of NaCl for 32 days

NaCl (mM)	Shoot dry wt (g plant^{-1})	Root dry wt (g plant^{-1})	Root length (m plant^{-1})	Root mean radius (mm)	Root surface area (cm^2 plant^{-1})
0	2.30^b	0.35^a	42.8^a	0.22^c	577^a
25	2.00^b	0.42^a	71.5^b	0.19^b	820^a
50	1.89^{ab}	0.45^a	92.7^b	0.17^{ab}	984^a
75	1.36^a	0.36^a	78.6^b	0.16^a	764^a

Within each column, values followed by different superscripts are significantly different ($P<0.05$) according to LSD.

TABLE 2

Mineral composition of peanut plants[1]

NaCl (mM)	N	P	K	Ca	Mg	Na	Cl
0	3.71[b]	0.235[a]	1.00[b]	0.51[a]	0.41[a]	0.00[a]	0.02[a]
25	3.69[b]	0.261[ab]	0.87[a]	0.51[a]	0.36[a]	0.25[ab]	0.38[b]
50	3.68[b]	0.315[bc]	0.90[ab]	0.48[a]	0.39[a]	0.34[b]	0.62[b]
75	3.14[a]	0.363[c]	0.97[ab]	0.44[a]	0.35[a]	0.85[c]	1.25[c]

Roots

NaCl (mM)	K	Na	Cl
0	0.71[b]	0.06[a]	0.03[a]
25	0.58[a]	0.38[b]	0.45[b]
50	0.56[a]	0.74[c]	0.70[c]
75	0.58[a]	0.97[d]	0.81[c]

[1]All values measured in mol kg^{-1} dry weight unless otherwise stated.
Within each column, values followed by different letters are significantly different ($P<0.05$) according to LSD.

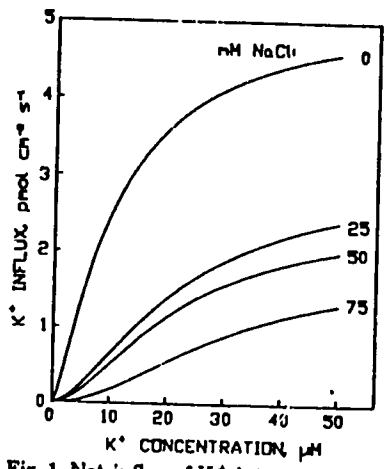
TABLE 3

The calculated parameters of the Hill kinetics for NO_3^-, K^+ and orthophosphate-P influx to peanut roots

NaCl (mM)	I_{max} (pmol cm^{-2} s^{-1})			K (μM)			h		
	NO_3^-	K^+	P	NO_3^-	K^+	P	NO_3^-	K^+	P
0	3.25[b]	5.19[c]	0.258[a]	6.79[b]	10.80[a]	3.52[a]	1.15[b]	1.31[a]	1.22[a]
25	2.33[a]	3.06[b]	0.181[a]	4.43[a]	22.52[b]	4.76[ab]	1.07[a]	1.61[b]	1.30[ab]
50	2.25[a]	2.47[ab]	0.230[a]	3.98[a]	21.86[b]	6.85[b]	1.09[a]	1.74[b]	1.57[b]
75	1.89[a]	1.80[a]	0.243[a]	4.24[a]	30.49[c]	4.89[ab]	1.08[a]	1.98[c]	1.38[ab]

Within each column, values followed by different letters are significantly different ($P<0.05$) according to LSD.

The parameters for each nutrient and NaCl concentration were calculated from the depletion data according to the procedure of Ben-Asher et al. (1980). The calculated I_{max}, K and h for NO_3^-, K^+ and P are presented in Table 3. In NO_3^- influx, there was a decrease in I_{max}, K and h. K^+ influx was more sensitive to NaCl concentration: I_{max} decreased, K tripled its value and the cooperation index h increased from about 1 to about 2, when NaCl concentration increased from 0 to 75 mM. Phosphate influx was not greatly affected by NaCl concentration. Figures 1 and 2 illustrate the calculated net-influx rates of K^+ and



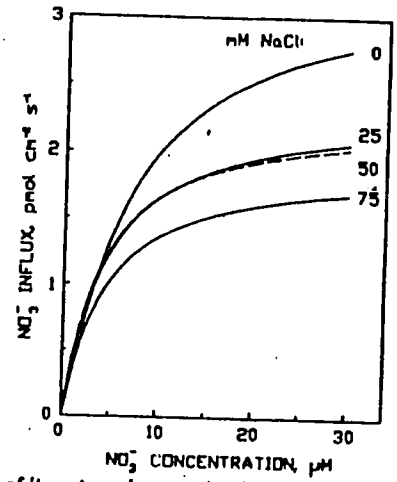


Fig. 1. Net-influx of K^+ into peanut roots as a function of its external concentration, as affected by NaCl concentration.

Fig. 2. Net-influx of NO_3^- into peanut roots as a function of its external concentration, as affected by NaCl concentration.

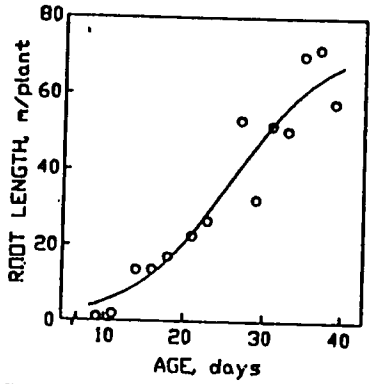


Fig. 3. Root length (measured and the fitted logistic curve) of peanut plants grown in non-saline nutrient solution.

NO_3^-, respectively, as a function of their external concentration, for each of the tested NaCl concentrations.

Root length of peanut plants grown without NaCl in the nutrient solution vs. days from germination is plotted in Fig. 3. The curve was calculated from the data by a non-linear regression to fit a logistic function:

$$L_t = \frac{L_{max}}{1 + c\exp[-k(t - t_0)]} \qquad (2)$$

TABLE 4

Mean influx of ions to peanut roots from relatively high concentration (1 mM K^+, 3 mM NO_3^-) and different concentrations of NaCl

NaCl (mM)	Mean influx (pmol $cm^{-2}s^{-1}$)			
	Na^+	Cl^-	NO_3^-	K^+
0	0.02[a]	0.03[a]	23.6[c]	6.18[c]
25	0.24[b]	0.39[b]	15.7[b]	3.47[b]
50	0.34[c]	0.57[c]	10.7[a]	2.88[a]
75	0.64[d]	0.85[d]	9.1[a]	2.56[a]

Within each column, values followed by different letters are significantly different ($P<0.05$) according to LSD.

where L=root length as a function of time t, t_0=time threshold from germination to the beginning of actual root growth (6 days), L_{max}=asymptotical value of maximal root length (73.69 m $plant^{-1}$), and c (25.67, dimensionless) and k (0.164 day^{-1}) are empirical parameters.

Influx rates of Na^+ and Cl^- were calculated according to their accumulation in the plant and the root growth data (Silberbush and Ben-Asher, 1987). Calculated net influx of Na^+ and Cl^- as a function of their concentration in the nutrient solution are presented in Table 4. Influx rates of either ion were linearly correlated with their external concentration. Chloride influx rate was somewhat higher than that of Na^+ for the same concentration. The same technique was used to calculate mean influx rates of NO_3^- and K^+ during the period in which the plants were grown in the growth solutions (i.e. 1 mM K^+ and 3 mM NO_3^-). These results are also presented in Table 4. Mean influx of NO_3^- was much higher than the I_{max} values obtained in the depletion test for low concentrations, but decreased with the increase in NaCl concentration. Influx of K^+, on the other hand, was very similar to the I_{max} values of the corresponding NaCl concentrations.

DISCUSSION

Silberbush and Ben-Asher (1987) showed that K^+ influx to cotton (*Gossypium hirsutum* L.) roots was mostly affected by NaCl concentration in the nutrient solution, while NO_3^- influx was only slightly reduced. There was also a difference between the two ions in the parameters of the Hill equation: NO_3^- influx was reduced only in its I_{max}, while K and h remained unchanged. This indicates a simple competition between ions, probably with Cl^-, without any preference by the root for the two ions. On the other hand, all the three parameters of the uptake kinetics of K^+ influx were affected, probably owing to the

competition between K^+ and Na^+. The interference of Na^+ to K^+ influx increased K, the preference parameter, which actually means that a relatively higher K^+ concentration is needed to achieve an influx rate which would equal half the I_{max} value. Since $h=1$ represents a Michaelis-Menten type kinetics, with only one agent involved in the transport across the root cell membrane, the addition of Na^+, which was associated with the increase of h from 1 to about 2, apparently introduced another agent into the influx process.

Tables 1 and 2 showed that a slight decrease in shoot growth occurred when the concentration of NaCl increased, but that there was no significant change in K^+ concentration in the shoot, although Na^+ concentration in the shoot increased. This was not the case during the depletion test, which occurred within the Mechanism I range. In this case, K^+ influx was most sensitive to the presence of Na^+ in the solution: root affinity for K^+ decreased (K increased), K^+ transport via the root membrane became more complex and therefore less efficient (h increased), in addition to the suppression of I_{max}.

The peanut plants in this experiment were grown in 1 mM K^+ which is within the range of Mechanism II (Epstein, 1972). However, the mean influx rate of K^+ during the growth period, which was calculated according to the rate of K^+ accumulation in the plants, resulted in values which were quite similar to the values of I_{max} of Mechanism I. The frequent analyses of the growth solutions for K^+ showed that the fluctuations of K^+ concentrations were rather small. Only in the last change of the nutrient solutions, before the starvation for K^+ and NO_3^-, were the solutions allowed to deplete to 0.6 mM K^+ at the least, which was reached after 3 days. The root surface areas were calculated from the final root lengths and radii which were also used to calculate the influx according to the depletion at low concentrations of K^+. The calculations of the influxes for the two concentration ranges were also based on an independent component, namely the amount of K^+ in the plant and the rate of K^+ depletion with time for the high and low concentration ranges, respectively. The agreement between the two fluxes indicates that they both represent the same mechanism, although they should be different (Epstein, 1972; Jacoby and Hanson, 1985).

The competition by Na^+ to K^+ influx seems to be either by direct competition on the excess to the influx channels on the root cell membrane, by reduction of the membrane selectivity to K^+, or by the change in the nature of the transport carrier across the membrane (Jacoby and Hanson, 1985).

Unlike the influx of K^+, NO_3^- mean influx rate increased with NO_3^- concentration (Table 4) and, like I_{max}, it was reduced by the increase in NaCl concentration.

CONCLUSIONS

The analysis of NaCl effect on the uptake of nutrients by plants, which defines it on each parameter of the kinetic equation, appeared to yield more in-

formation about NaCl interference than its effect as a whole. Even if they were determined empirically, the effect on each parameter indicates the way by which NaCl interferes with the uptake process.

Potassium influx is most sensitive to Na^+ concentration in the external solution.

The same mechanism for K^+ influx to the root seems to operate at least up to 1 mM K^+.

Nitrate uptake was affected by Cl^- concentration only by competition on influx channels, but no change was observed in the selectivity of the root cell membrane for NO_3^-.

The characterization of ion influx to roots by the ion-depletion procedure is a powerful tool, but only in low concentrations. In relatively high concentrations it yielded unreliable results because of the insensitivity of the depletion with time.

The calculated mean influx, which is based on the accumulation of the ion in question in the plant, and the pattern of root growth with time resulted in reasonably accurate estimates of ion influxes, in spite of the simplifying assumptions which were made. This approach is therefore recommended for the estimation of mean ion influx to roots from relatively high but constant ion concentrations.

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ROOT DISTRIBUTION UNDER TRICKLE IRRIGATION: FACTORS AFFECTING DISTRIBUTION AND COMPARISON AMONG METHODS OF DETERMINATION

J. Ben-Asher and M. Silberbush

The Jacob Blaustein Institute for Desert Research
Ben-Gurion University of the Negev
Sde Boqer Campus 84993, Israel

ABSTRACT

Four methods were used to characterize root distribution under trickle irrigation. These were: root weight, cation exchange capacity (CEC), uptake of ^{86}Rb, and the line intersect method. Trickle irrigated tomato plants (Lycopersicon esculentum) and peanuts (Arachis hypogeae L. var. shulamit) were grown on sandy soil (Typic Torripsamment) and their roots were used for the study. The four methods showed that most of the roots are concentrated close to the emitter. A linear correlation was found between root weight and the uptake of ^{86}Rb. This indicated that although roots near the emitter seem to be relatively old, the uptake activity is also concentrated there. Furthermore, it is apparent that the effect of the limited root distribution is even more pronounced when using CEC as an indicator for fine roots or surface area, than when using weight as an indicator. It was therefore concluded that all criteria emphasized the restricted distribution of roots as well as their activity in the wetted volume of soil beneath the emitter. When saline water was applied, more roots were found in the leached soil volume than in the saline part of the trickle irrigated hemisphere. In the fresh water irrigated soil, the roots extended also to the periphery of the wetted volume.

INTRODUCTION

The dripping system consists of a point source, from which water and solutes move in three dimensions (1-3). When the irrigation system is also used to apply soluble fertilizers, the wetted soil includes nutrients and ions originated from natural soluble salts, mainly Na and Cl ions. The extension of the wetted zone is limited by the balance between water input and losses, and is very much affected by the soil properties (4).

Root distribution under trickle irrigation is affected not only by the extension of the wetted zone, but also by the quality of the irrigation water and the distribution of nutrients within the wetted zone (5). One objective of this project was to study nutrient and saline ion distribution in a trickle-irrigated sandy soil, and their effect on root distribution and pod production of peanuts. This objective was addressed by a series of field experiments.

Furthermore, knowledge of the distribution of roots is required as input information in models that describe the soil-plant-atmosphere continuum, and in order to understand root response to environmental conditions. Direct or indirect techniques for examining root systems are known. The direct methods are usually referred to because they represent a more realistic case. However, these methods are destructive and time-consuming. On the other hand, the indirect methods which are faster and non-destructive do not always reflect the accurate behavior of the root system. Measurements of root length, weight, and surface area are among the direct methods, while measurements of water extraction and transport of tracers are indirect ones.

Root weight is probably the most commonly used method in root study. The disadvantages of this method are that many roots are lost during the soil washing process (6) and that fine roots are neglected because of their small weight. These roots are characterized by a large surface area and are therefore the most active (7). The root hairs and fine tips have thin walls of pectins and proteins that are dissociable and are the reason for the negative electrical charge of the root surface area (8). On the other hand, old root cells which exert the strongest influence on root weight are covered with uncharged wax, and therefore have small cation exchange capacity despite their large weight. There is a correlation between the surface area of the roots and their cation exchange capacity, because the root hairs and fine tips exert the most influence on the root's cation exchange capacity. The main objective of this study was to find the correlation between root measuring methods for examining the root system, i.e. root weight, cation exchange capacity, root length, and the uptake rate of radioisotopic tracers.

MATERIALS AND METHODS

The combined effect of salinity and fertilization on root distribution. Peanuts (A. hypogaea L. var. shulamit) were grown on fine dune sand (Typic Torripsamment) on the Ramat-Negev Agricultural Experiment Station, Israel (30°57' N, 34°38' E). The seeds were inoculated with rhizobium prior to sowing, in the last week of April. The field was irrigated by sprinkling with fresh water for two weeks before it was subjected to the differential experiment. The experiment consisted of a factorial array of 3 water salinities and 3 levels of fertilizer application, arranged in 6 randomized blocks. The water electrical conductivities (EC25) were 1.0 (freshwater), 4.3 (brackish well water), and 6.5 (brackish well water + NaCl) dS m^{-1}. The fertilization treatments were 3.9, 11.6, and 15.4 mM KNO_3 in the irrigation water. Each experimental plot consisted of two 2x10 m soil beds. Each bed contained four plant rows, with 8 plants per m. Two lateral lines, having 2 liter/hr tricklers spaced at 50 cm intervals (along the lateral), were used to irrigate each bed. The field was irrigated every three days with an amount of water equal to the class A evaporation pan times a ratio which varied between 0.5 in May to 0.8 in July and August, and 0.6 in September. Phosphorus (as H_3PO_4), iron (as Fe-EDDHA), and micronutrients were supplied once a week, to all the treatments.

Plant and roots were sampled three times during the growing season. The soil was excavated perpendicularly to an emitter, and soil cores (6.5 cm in diam., 5 cm long) were sampled in 25 sites, 35 cm horizontally and 40 cm vertically down from the emitter. The soil samples were weighed and stored at 5°C before further treatment. The roots were washed from soil on a fine sieve, and their length was measured by the line-intersect method (9). The soil samples were extracted using a 1:1 soil-to-water ratio, and analyzed for NO_3-N, PO_4-P, K, Na, Cl, and EC. The soil was then collected, dried at 105°C, and re-weighed to determine its original water content.

Comparison among methods of determination. Tomato plants (L. esculentum L.) were grown on sandy soil (Typic Torrisamment) and were irrigated daily with emitters having discharges of 2 liters/hour. The average amount of water applied was 140% of the evaporation from a Class A pan. The soil moisture content in all replications ranged between saturation and field capacity at depths of 0 to 50 cm below the emitter.

Root sampling: Four replications of soil samples were excavated from the soil profile at various distances from the emitter. According to the above description, the roots were washed from a volume of one liter of soil, weighed, and expressed in terms of fresh weight of roots/liter.

Tracing uptake of ^{86}Rb: ^{86}Rb was used as a tracer for evaluating the relative activity of the root and as a second method for estimating its distribution. The rubidium was buried at ten depths between 10 and 150 cm below the emitter by sliding gelatin capsules of 0.5 cm^3 through a pipe that was inserted into the desired depth. This was done in order to prevent the tracer from spreading along the hole in the soil. Each depth was represented by an average of four plants. The stem was marked 10 cm above the soil surface where a Geiger counter was used to identify the translocated tracer. The flow rate of ^{86}Rb within the plant was calculated from the ratio between the depth of its application and the time to reach the Geiger point on the stem.

Analysis of cation exchange capacity (CEC): The measurements of CEC were done according to a method suggested by Philip and Lambeth (10). For the analysis we used the same roots that were weighed earlier for the determination of root distribution according to weight. The exchange capacity was determined through the following stages:

1. Washing with H_2O and rinsing the roots with a 0.01N HCl (~pH2) solution for 5 minutes (twice), in order to remove Ca from the free space;
2. Saturating the cation exchange volume with Ca^{++} by rinsing the roots with 0.01N $CaCl_2$ solution;
3. Exchanging the Ca^{++} by rinsing with HCl (0.01N); and
4. Calculating the CEC from the amount of Ca^{++} within the HCl solution.

Root density as a function of distance and depth below the emitter was expressed as a product of CEC per unit root weight and total weight was found at the corresponding coordinate.

RESULTS AND DISCUSSION

Methods of root determination:

Root weight: The fresh weight of roots found at the first sampling volume (i.e. the closest to the emitter) was 6.4 g which is about 33% of the entire sample weight (19.3 g). In the sampling volume below it, an additional 14.5% of the total root weight was found. Deeper than these two samples, the concentration of roots decreased rapidly and at the furthest sampling corner (i.e. 30 cm from the emitter and 30 cm below the soil surface) no roots were extracted.

TABLE 1 Root Weight Distribution at Different Distances from the Emitter (g fresh root/1 liter soil and % of total)

	Distance (cm)					
	0–10		10–20		20–30	
Depth (cm)	Weight (g)	%	Weight (g)	%	Weight (g)	%
0–10	6.4	33.2	4.0	20.9	2.6	13.3
10–20	2.8	14.5	2.3	12.2	0.7	3.5
20–30	0.3	2.0	0.2	0.1	0	0

Assuming radial symmetry of root distribution around the emitter, the numbers in Table 1 represent only samples which were taken perpendicularly to the trickle laterals. In order to evaluate the total fresh root weight, one should integrate the values in the table with respect to the distance and the depth from the emitter.

Observations on the exposed roots (Fig. 1) showed that most of the weight was contributed by relatively old roots below the stem and close to the emitter. On the other hand, when the tomatoes were irrigated by sprinkling, root distribution was different. As shown in Fig. 1b, these roots are shallow and more widely spread. It was not possible to assess the weight of fine roots and therefore to relate root weight to surface area and root effectiveness. An indication of the relative importance of root weight was found through the tracing of ^{86}Rb.

Uptake rate of ^{86}Rb: The rate at which signals of ^{86}Rb from the stem were detected was plotted as a function of root weight (Fig. 2). It appears that this indica–tor is correlated linearly with weight. It should be noted that the criteria used here (i.e. the uptake rate) is not only a function of the density of the roots and the

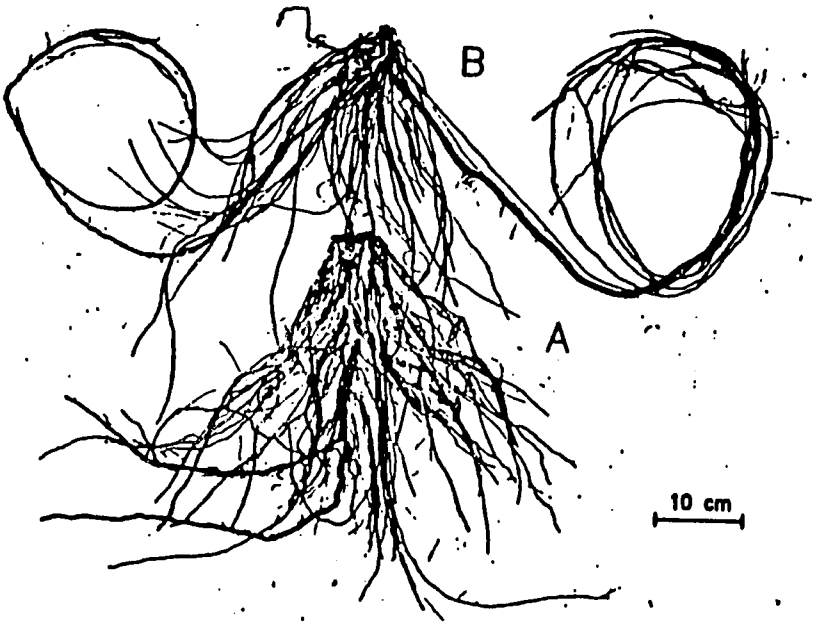

FIGURE 1 Root System of a Mature Tomato Plant under Daily Trickle Irrigation

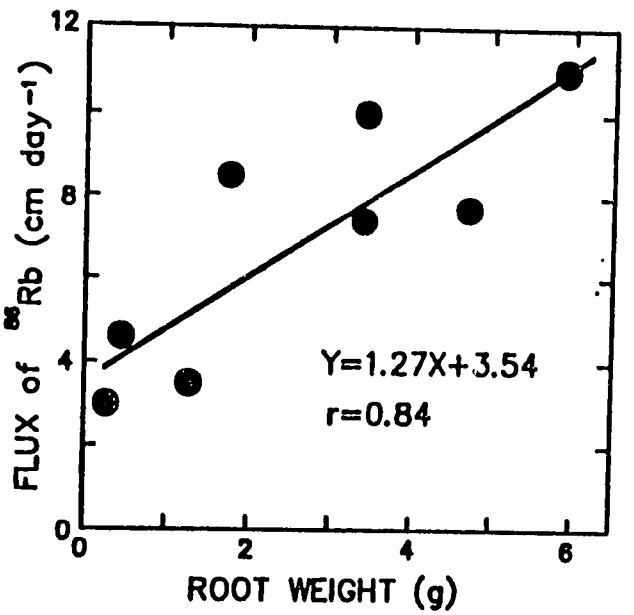

FIGURE 2 Flux of ^{86}Rb from Roots to Stem of Tomato Plants as a Function of Root Weight.

activity at the injection point, but also a function of the moisture content in the immediate vicinity of the isotope as well as the resistance of the roots to the transport of the ion. Place and Barber (11), who investigated factors influencing the flow of ^{86}Rb, found that its self-diffusion is correlated linearly with moisture content. According to their study it is possible to detect the isotope faster when its injection is close to the emitter where the moisture content is high, than far from the emitter where the moisture content is relatively low. Thus, the combined effects of roots abundance and the moisture content increase the probability of interaction between the tracer and the root. As a result, the rate of flow was determined to be faster closer to the emitter, and decreased as the distance from the emitter grew.

It was not possible to detect roots below a depth of 30 cm. This can be explained by the low density of roots at that depth and the short half-life of ^{86}Rb (i.e., 18.7 days). Low root density reduced the probability of interaction between the ion and the root, and the short half-life caused the radiation intensity to be below the sensitivity of the detector for those ions that were absorbed by the roots after a relatively long time.

These results are in agreement with those of Salter (12) who found only about 12% of the tomato roots below the depth of 30 cm, under high frequency irrigation. Jung and Otinkorang (13) used the P-32 technique to find most of the tomato roots (65%–70%) 30 cm below the stem. On the other hand, Danielson (17) found tomatoes with roots as deep as 180 cm under a different irrigation regime.

Cation exchange capacity (CEC).The third indirect criterion for root distribution was the roots' cation exchange capacity (CEC). This measurement was used as an indicator for the fine root surface area, and the results are given in Table 2. In this table, the relative density of the roots was evaluated from the product of their weight and the CEC per unit weight. The data in Table 2 show a general decrease in the CEC of the roots with distance from the emitter. In terms of per cent of total CEC found in the root zone, roots are more concentrated near the water source than far from it. Furthermore, it is apparent that the above effect with CEC is more pronounced than when using weight as an indicator for root distribution. For example, near the surface, root weight is more evenly distributed laterally (Table 1) with 33%, 21%,and 13% occurring within 10, 20, and 30 cm of the emitter, respectively. In contrast, 56%, 17%, and 5% of the total CEC occurred within the same distance. Although not identical, the two criteria for root distribution indicate

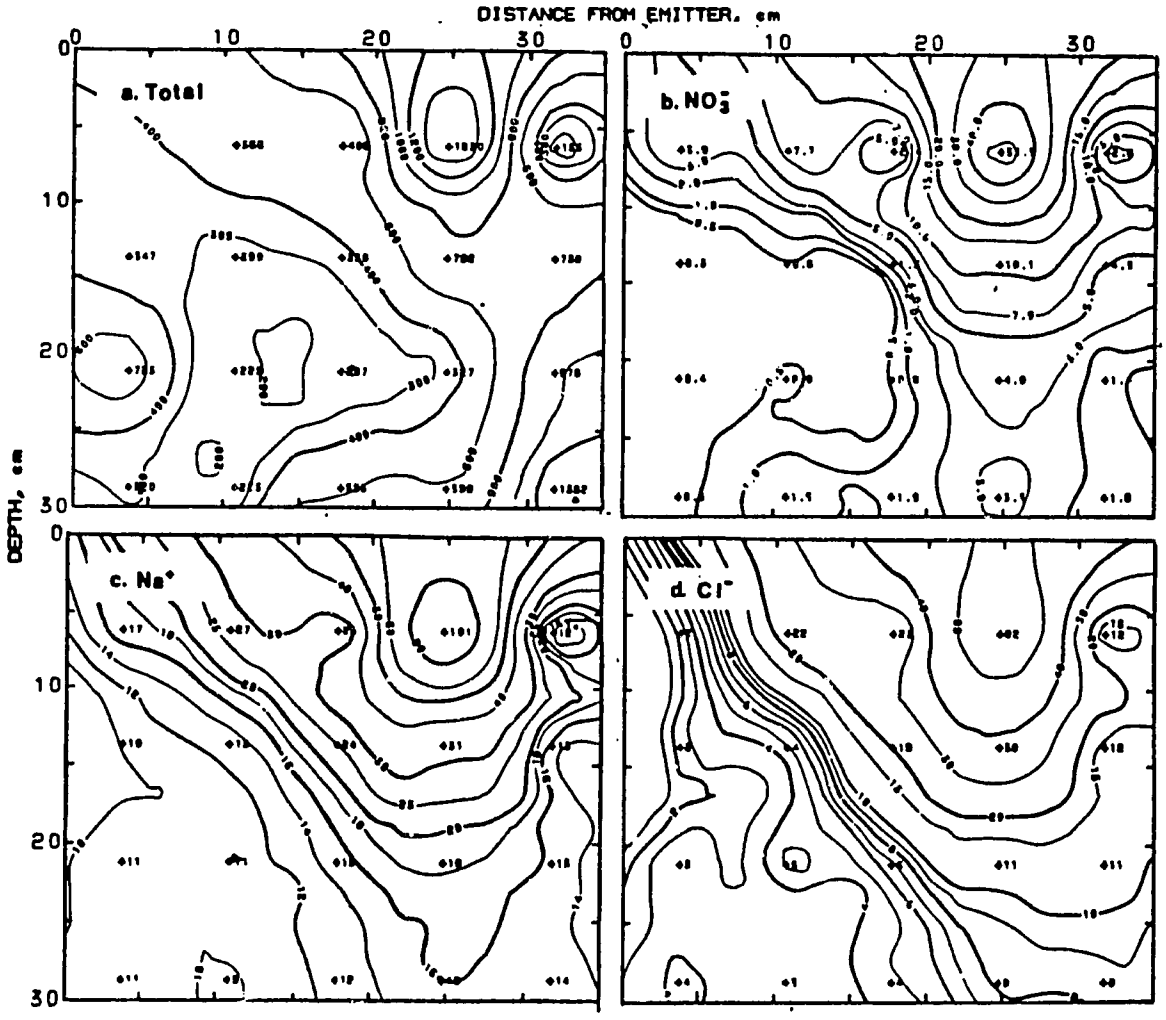

FIGURE 3 Spatial distribution in the soil profile of (a) total soluble salts concentration (me l^{-1}) in the soil solution and, in mmol kg^{-1}, (b) NO_3^-, (c) Na^+, and (d) Cl^- in dune sand under peanuts, which was irrigated by trickling with water EC of 6.5 dS m^{-1}, and 15.4 mM KNO_3.

that high concentrations near the water source can be considered for active roots as well as for old and heavy roots.

The presence of a high density of active roots near the emitter is also in agreement with results shown in Fig. 2. There, the flux of ^{86}Rb was linearly proportional to the fresh root weight which means that under these circumstances weight and activity of roots are proportional.

TABLE 2 Root Cation Exchange Capacity and its Relative Density (meq/100 g dry root)

	Distance (cm)					
	0–10		10–20		20–30	
Depth (cm)	CEC	% of total	CEC	% of total	CEC	% of total
0–10	61.6	56.1	30.2	17.3	14.4	5.3
10–20	30.6	12.1	14.9	5.0	12.5	1.2
20–30	55.5	3.0	6.6	0.0*	8.6	0.0*

* Root weight is negligible

Effect of salinity and nutrients on root distribution. Fig. 3 presents the distribution of the soluble salts in the trickle wetted soil volume which was irrigated with 6.5 dS m^{-1} and 15.4 mM KNO_3. The concentrations of the total soluble salts in the soil solution in each site along the soil profile (Fig. 3a) were calculated from the EC of the soil extract according to the equation: conc. = 10 meq.$^{-1}$ EC25 (dS m^{-1}) (15) and the measured moisture content of the soil samples (which varied between 4 to 9% by weight, with soil bulk density of 1.6 g cm^{-3}). The calculation assumed that all the ions in the extract originated from the soil solution. This assumption was based on the low content of soluble compounds (very low EC of the water extract) in the untreated sand and the low cation exchange capacity (30 mmol(+) kg^{-1} soil) of the sand. The contours in Figs. 3 and 4 were calculated and drawn using Surface II computer software (16). The data in Fig. 3 are of plants which reached their full vegetative development. Soil analyses along the whole season resulted in similar distribution in July through August, so these results presumably represent a steady-state which occurred also during the reproductive growth stage. The soluble salts were leached from under the emitter, and were concentrated in the margins of the wetted soil volume. Sodium and Cl ions (Figs. 3c and 3d, respectively)

accumulated mainly in the upper soil profile, showing similar patterns. Nitrate (Fig. 1b) also accumulated in the margins of the wetted soil volume in this treatment. The same concentration of NO_3 ion (15.4 mM) but with freshwater (not presented) resulted in a similar trend of accumulation, but the concentrations were much smaller.

Figures 4a and 4b present the distribution of roots in the wetted soil profile irrigated with freshwater and brackish water, respectively. When the soil was drip-irrigated with freshwater the roots were scattered throughout the wetted soil volume (Fig. 4a), but tended to concentrate in the margins, probably because of the abundance of nutrients (Fig. 3b) and better aeration (17). In the saline water treated soil (Fig. 4b) the roots concentrated in the leached soil volume, but avoided the margins, where the salts accumulated (Fig. 3a).

CONCLUSIONS

All the three criteria for root distribution emphasized the well recognized phenomena that the distribution of roots and their activity under trickle irrigation is restricted to the wetted volume of soil beneath each emitter. The relative density and activity decreasing with the increasing lateral and vertical distance from the emitter. Irrigation with fresh water was associated with relatively high density of roots in the periphery of the wetted soil volume, probably due to the abundance of nutrients. On the other hand, irrigation was with saline water, a relatively low root density was detected in the periphery and a high density was detected in the leached soil volume beneath the emitter. It is clear that the results of root distribution by weight and by CEC are not identical, but a good correlation was obtained between root weight and uptake of ^{86}Rb.

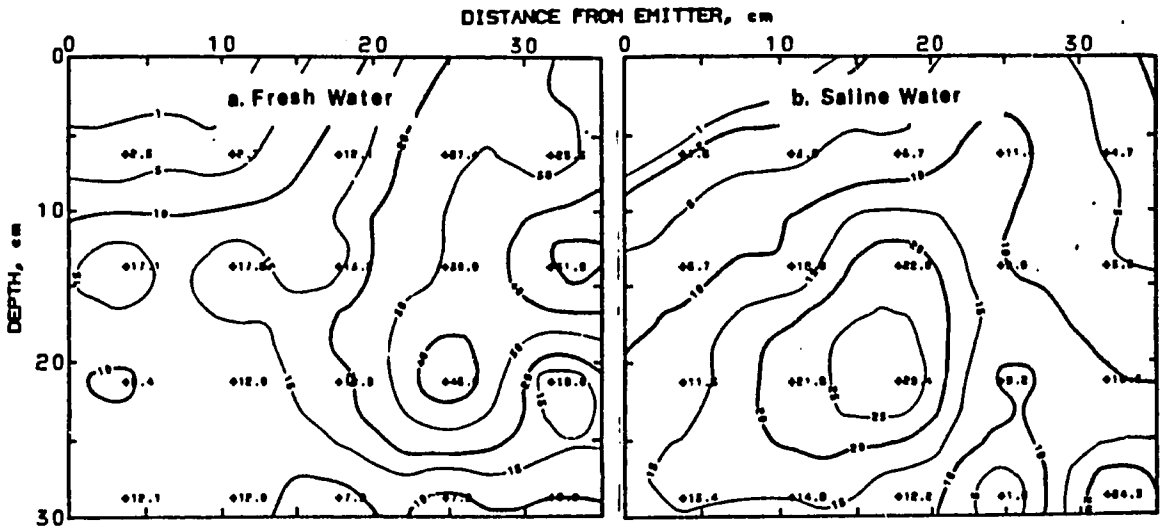

FIGURE 4 Root density (cm cm^{-3}) distribution in the soil profile of peanuts which were grown in dune sand, and irrigated with (a) fresh water and (b) brackish water with EC 6.5 dS m^{-1}.

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Wheat growth as affected by potassium, nitrogen, ammonium/nitrate ratio, and NaCl.

1. Shoot and Root growth and Mineral Composition.

M. Silberbush and S.H. Lips

Fertigation with KNO_3 as a means of reducing salinity hazards was tested with peanut plants, grown on dune sand, resulted in a reduction of plant growth and yield. The objective of this work was to study the interactions between N, K^+ and NaCl as well as effects of the NH_4^+/NO_3^- ratio on vegetative and reproductive growth. Wheat (*Triticum aestivum* L.) plants were grown in polyethylene pots with fine calcareous dune sand with different proportions of NH_4^+ and NO_3^-, under saline (60 mM NaCl) and non-saline conditions. Three replicates were harvested at the beginning of flowering, and one was grown to grain maturity. NaCl reduced shoot dry weight in all the treatments. Increasing the NH_4^+ proportion in the total of 6 mM N in the nutrient solution, increased shoot dry weight, decreased nitrogen concentration in the dry mass and increased P percentage, either with or without 60 mM NaCl. The number of tillers produced in each treatment was correlated with dry matter yield. The effect of the NH_4^+/NO_3^- ratio may be explained by alteration of the cation-anion balance on the nutrient uptake by roots, which lowered pH of the nutrient solution with increasing NH_4^+ concentration.

Additional Key words: Dune sand, Mineral nutrition, Plant production, Root growth, *Triticum aestivum* L., Water salinity.

M. Silberbush (corresponding author) and S.H. Lips, Center for Desert Agrobiology (J. Blaustein Institute for Desert Research) and Department of Biology (Faculty of Natural Sciences). Ben-Gurion University of the Negev,Sede-Boqer 84990, Israel.

Introduction

It is generally assumed that salt damage to non-halophytes is due mainly to Na^+ and Cl^- accumulation in the plant tissue and/or water deficiency in the plant. High concentrations of Na^+ and Cl^- in the nutrient medium of plants may induce accumulation of these ions in the plant tissue and consequently reduce plant growth (Greenway and Munns, 1980, Lauter and Munns, 1987). The extent of salinity inhibition of growth, however, may be affected by the nutritional status of plants (Bernstein *et al.*, 1974, Papadopoulos and Rendig, 1983). Na^+ and Cl^- ion uptake seems to interfere with uptake of other ions. NaCl suppressed NH_4^+ and NO_3^- uptake by cotton (*Gossyplum hirsutum* L.), and interfered with nitrogen metabolism (Pessarakli and Tucker, 1985). Na^+ interacts with uptake of Ca^{2+} and K^+, while Cl^- interferes with uptake of NO_3^- (Kafkafi *et al.*, 1982). The form of nitrogen in the nutrient solution may affect also plant response to salinity (Cerda and Martinez, 1988; Silberbush and Lips, 1988). The NH_4^+/NO_3^- ratio in the growth medium affects the pH of of the nutrient solution as a result of the plant pH regulation systems (Ben Zioni *et al*, 1971; Lips *et al*, 1971; Breteler, 1973; Cox and Seeley, 1984). Interactions between pH and temperature may affect P and NO_3^- uptake rate (Barber, 1984, Ganmore-Neumann and Kafkafi, 1980a). At a temperature of 25° C and pH 6, NH_4^+ was taken up at twice the rate of NO_3^- (MacDuff and Hopper, 1986). Since plants differ in their response to Na^+ or to Cl^- (Lauter and Munns, 1987), the NH_4^+/NO_3^- ratio could affect plant sensitivity to NaCl (Lips *et al.*, 1987; Cerda and Martinez, 1988).
The effect of NaCl, N and K^+ concentrations in the presence of different NH_4^+/NO_3^- ratio on wheat growth and productivity were studied. Part 1 of this work analyses the effects of these treatments on shoot and root growth as well as on the mineral composition of the plants.

Materials and methods

Six wheat (*Triticum aestivum* L. cv 'Barkol') plants were grown in black polyethylene bags containing 10 kg fine sand (Calcic, Typic Torripsamment), layered over 3 kg gravel, to insure adequate drainage of nutrient solutions. The experiment al layent was based on a factorial design of 2 salinity levels (0 and 60 mM NaCl) (1), 2 nitrogen concentrations (2 and 6 mM), 4 NH_4^+/NO_3^- ratios (0:1, 1:1, 3:1, and 1:0), and 2 K^+ concentration (0.5 and 5.0 mM). Each treatment had 4 replications. Ca^{+2} (3 mM), Mg^{+2} (1 mM), P (0.5 mM as $H_2PO_4^-$), Fe (40 mg Fe-EDDHA l^{-1}), and microelements (Hoagland and Arnon 1950) were included in the nutrient solutions used. The pots were arrayed in 4 randomized blocks in the greenhouse. The seeds were germinated for 7 days over a nutrient solution containing 2mM nitrogen as NO_3^- and 0.5 mM K^+. After this time period, seedlings were subjected to the different treatments. NaCl in the salt treatments was applied stepwise, in order to avoid osmotic shock: an initial application of 25 mM which was raised two days later to the final 60 mM salt used in the saline treatments.

(1) The nutrient solutions were prepared with tap-water, which already contained 10 mM Cl^-.

The plants were irrigated every two days with fresh nutrient solution added in excess of the field capacity of the soil in the experimental bags in order to displace residual, partly depleted, nutrient solution in the soil. The leachates were monitored for electro-conductivity to determine irrigation schedules and to avoid salt accumulation. Day temperatures varied during the growth period between 9° and 25° C, night temperatures between 1° and 12° C.

At the 44th day of growth, when the tillers started to elongate prior to flowering, plants of three blocks were harvested while a fourth block was left until grain maturity (Silberbush and Lips, 1990). The shoots were separated from the roots and divided into primary and secondary tillers, of which stems and leaves were collected separately. Fresh weight of each plant fraction was recorded. The plant fractions were then dried at 60° C, reweighed and ground to pass a 40-mesh screen. Roots were separated from the sand by floating in water and collected on a screen, blotted thoroughly and weighed for fresh weight. Samples of these roots, weighing about 1 g, were taken to determine root length (Tennant, 1975). The remaining root material was then oven-dried and the total length of the plant root system was calculated according to the dry weight ratio of the sample to the whole root. Plant samples were digested in $H_2SO_4 + H_2O_2$ and analyzed for total reduced nitrogen, P, Ca^{+2} and Mg^{+2}. Water extracts of the dry plant samples were used for assays of Na^+, K^+, Cl^- and NO_3^-.

Results

Vegetative growth

The analysis of variance revealed no significant effect of K^+ concentration on any of the measured vegetative parameters. Consequently, the two K treatments were grouped together in the results shown here. The form of nitrogen fed to the plants did not affect dry biomass production when applied at a concentration of 2 mM (Fig. 1). When 6 mM nitrogen were supplied in the nutrient solution, dry biomass production was increased in response to an increase in the NH_4^+ proportion of nitrogen in the nutrient solution, both with or without 60 mM NaCl.

Nitrogen concentration had no significant effect on root length (Fig. 2), therefore the results of 2 and 6 mM N were grouped together in the graph. Unlike shoot dry biomass (Fig. 1), root length, either with or without 60 mM NaCl, reached its maximum at the NH_4^+/NO_3^- ratio of 1:1.

The analysis of variance of the mineral compounds in the leaves (Table 1) shows only the 2-way interactions since higher interactions were not significant. There was no significant effect of the treatments on leaf Mg^{+2} concentration. Plant total nitrogen and NO_3^- contents were affected by N and NaCl concentrations in the nutrient solution, but not by the $NH4^+/NO^-3$ ratio.

Phosphorus

P concentration in the leaves was significantly affected by several experimental treatments, but not by K^+ concentration in the nutrient solutions (Table 1). P concentrations in the leaves of the primary and secondary tillers were affected by N concentration in the nutrient solution and by NH_4^+/NO_3^- ratio, as well as by NaCl concentration in the medium. P concentration was somewhat higher in the secondary than in the primary tiller (Fig. 3a, b). NaCl caused an increase in

leaf P. With the increase on the NH_4^+ fraction in the medium N we observed also an increase on leaf P, except for the treatment receiving 2 mM N and 60 mM NaCl, which did not follow this rule. This trend of P concentration changes in the treatment with low N and salinity is similar to the changes on shoot dry mass of the plant growing on it, so that the decrease in P concentration in the leaves cannot be a result of a dilution effect.

Potassium

K^+ concentration in the leaves was significantly affected by nitrogen, K^+, and NaCl concentrations in the nutrient solution. The distribution of K^+ between main and secondary tillers was not affected by NH_4^+/NO_3^- ratio (Table 1). Leaf K^+ concentration was reduced by NaCl, but increased with nitrogen and K^+ concentration in the medium (Fig. 4). As in the case of leaf phosphorus, K^+ in the secondary tillers was somewhat higher than in the primary shoot.

Calcium

Ca^{+2} concentration in the plant parts was not affected by NaCl or K^+ concentrations in the nutrient solution (Table 1), but was significantly affected by nitrogen levels in the medium and by the NH_4^+/NO_3^- ratio (Fig. 5). Calcium concentration was higher in plants grown on 6 mM nitrogen than on 2 mM nitrogen; it decreased however with increasing NH_4^+ proportion of the nitrogen in the medium.

Sodium and Chloride

The NH_4^+/NO_3^- ratio in the medium significantly affected leaf Cl^- as well as the distribution of Cl^- between primary and secondary tillers (Table 1). Leaf Na^+, on the other hand, was affected by nitrogen, K^+ and NaCl concentrations in the growth medium (Table 1). Na^+ concentration in the leaves of the secondary tillers was markedly higher than in the primary shoot (Figs. 6a and 6b). Increasing K^+ and nitrogen concentrations in the medium brought about a decrease in leaf Na^+, as did the increased proportion of NH_4^+ in the nutrient solution. Cl^- in the plants was not affected by the NaCl concentrations used in these experiments.

Discussion

Wheat plants grew better on NH_4^+ than on NO_3^- in this experiment. The number of tillers and the total dry mass increased with increasing the NH_4^+/NO_3^- ratio. Nitrogen concentration in the shoot was not affected by this ratio; phosphorus concentration, however, increased with the concentration of NH_4^+ in the medium. In a similar study with peanut plants (*Arachis hypogaea* L.) (Silberbush and Lips, 1988), both P and N concentrations in the plant shoot increased as the NH_4^+/NO_3^- ratio changed from 0:1 to 1:0. These effects may be a result of the unequal uptake of cations and anions by the roots, which may induce significant pH changes at the soil-root interface. The soil originally contained about 6.5% crystalline $CaCO_3$ which, in a calcite-water-$CO_{2(g)}$ should balance the soil solution pH at about 8.3. When NO_3^- was the only nitrogen source in the nutrient solution, it probably induced an increase in soil pH at the vicinity of the root. The low

buffering capacity of the soil may allow pH increases of up to 2 units (Schaller, 1987), which could reduce the NO_3^- uptake rate (Barber, 1984). In addition, such an increase in soil pH would reduce phosphate solubility and Ca^{+2} concentration in the soil solution. A higher concentration of NH_4^+ would bring back the NO_3^--induced increase in soil pH to 7 or even less, and allow a higher uptake rate of Ca^{+2} and phosphorus by the plant. Plant roots actively lower the pH in the growth medium when it is too high, or when phosphorus supply is too low (Breteler, 1973; Hedley *et al.*, 1983), but in order to do this roots require an adequate carbohydrate supply. Even if the plants prevented the medium pH from rising, and NO_3^- influx to the roots would not decrease, their dry mass production would be smaller than that of plants grown on NH_4^+ due to the increased allocation of carbohydrates on energy-consuming ion-balancing mechanisms of the root. Similar effects were reported by Cox and Seeley (1984) who used nutrient solutions with different NH_4^+/NO_3^- ratios in the presence of $CaCO_3$, and by Scherer and Mengel (1986) in soils with weakly-fixed NH_4^+. Barker et al. (1988) also showed decreased plant growth with increasing Ca^{+2} concentration in the nutrient solution of radish (*Raphanus sativus* L.) plants fed NH_4^+, but with NO_3^- the plant root growth increased when Ca^{2+} concentration in the shoot was higher. Similar results were obtain by Lewis *et al.* (1989) with maize (*Zea mays*, L.) grown with or without 60 mM NaCl.
Root length was curvilinearly correlated to the NH_4^+/NO_3^- ratio with an optimum ratio of about 1:1, either with or without 60 mM NaCl in both the nitrogen concentrations used in this experiment. Similar results were also reported by Ganmore-Neumann and Kafkafi (1980b). These authors expressed root development by means of root weight, which is not as sensitive measure as root length (Barber, 1984). Furthermore, roots grown on NO_3^- were longer and poorly branched compared to NH_4^+-grown roots. It may be concluded, therefore, that the effect of NH_4^+/NO_3^- ratio on root development is a combination of the effects on root length and on root branching. The curvilinear response of root lenght to the increase in NH_4^+/NO_3^- ratio may explained therefore by the role of Ca^{2+} in root elongation. In low NH_4^+/NO_3^- ratio there is a positive reaction of root growth to Ca^{2+} in the plant. When the proportion of NH_4^+ increased, this reaction of root growth had the opposite effect. But since Ca^{2+} concentration in the shoot continuosly decreased while changing N- form from NO_3^- to NH_4^+, the effect on root growth was curvilinear.

Acknowledgment

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Table 1

Analysis of Variance of mineral ions concentrations in leaves of wheat plants, grown in different concentrations of N(N conc), K^+ and NaCl(S), and with different NH_4^+/NO_3^- ratios(N Form).
*,**,***- significance of the F-value at 0.05, 0.01, 0.001, respectively. ns- not significant. Degrees of Freedom for the Error=150.

Source of Variation	df	N	P	K	NO_3^-	Ca	Mg	Na	Cl
N Conc(NC)	1	***	***	***	***	***	ns	***	ns
N Form(NF)	3	ns	***	ns	*	***	*	***	***
K	1	ns	ns	***	ns	ns	ns	*	ns
NaCl(S)	1	***	***	***	*	ns	ns	***	ns
Tillers(T)[1]	1	ns	***	***	ns	ns	ns	***	***
Blocks(B)	2	***	ns	ns	***	ns	ns	ns	ns
NCxNF	3	ns	***	ns	**	ns	ns	ns	ns
NCxK	1	ns	ns	***	*	ns	ns	ns	ns
NCxS	1	ns	ns	**	ns	ns	ns	***	***
NCxT	1	ns	ns	*	ns	ns	ns	**	ns
NCxB	2	ns	ns	ns	ns	ns	ns	ns	ns
NFxK	3	*	**	ns	ns	ns	ns	ns	ns
NFxS	3	ns	ns	ns	ns	*	ns	**	ns
NFxT	3	ns	ns	ns	ns	ns	ns	ns	*
NFxB	6	ns	ns	ns	ns	ns	ns	ns	ns
KxS	1	ns	ns	ns	ns	ns	ns	ns	ns
KxT	1	ns	ns	ns	ns	ns	ns	ns	ns
KxB	2	ns	ns	ns	ns	ns	ns	ns	ns
SxT	1	ns	ns	ns	ns	ns	ns	***	***
SxB	2	ns	**	ns	ns	ns	ns	ns	ns
TxB	2	ns	ns	ns	ns	*	ns	***	*

[1] - Primary and secondary tillers.

CAPTIONS FOR THE FIGURES

Figure 1 Dry wt in shoots of 6 wheat plants per pot, grown on different concentrations of NaCl and N, and different NH_4^+/NO_3^- ratios. Bars with the same letter are not significantly different ($p<0.05$) according to the paired t-test.

Figure 2 Root lengths of 6 wheat plants after 44 days of growth as affected by NaCl concentration and NH_4^+/NO_3^- ratio in the nutrient solution. Bars with the same letter are not significantly different $p<0.05$) according to the paired t-test

Figure 3 Distribution of P concentration in leaves between (a) primary tillers and (b) secondary tillers of wheat plants grown on different concentrations of NaCl, N, and NH_4^+/NO_3^- ratios (NH_4^+ fraction) in the nutrient solution.

Figure 4 Concentration of K^+ in leaves of primary and secondary tillers of wheat plants grown on different concentrations of NaCl, N and K^+. In each group, the vertical bar represents LSD value at $p=0.05$.

Figure 5 Ca^{+2} concentration in leaves of wheat plants as affected by N concentration and NH_4^+/NO_3^- ratio (NH_4^+ fraction) in the growth medium.

Figure 6 Na^+ concentration in leaves of (a) primary tillers and (b) secondary tillers of wheat plants grown on 60 mM NaCl, different concentrations of N and K^+, and on various NH_4^+/NO_3^- ratios (NH_4^+ fraction) in the growth solution.
Within each group, the vertical bar represents the LSD value at $p=0.05$.

Fig. 1, part 1.

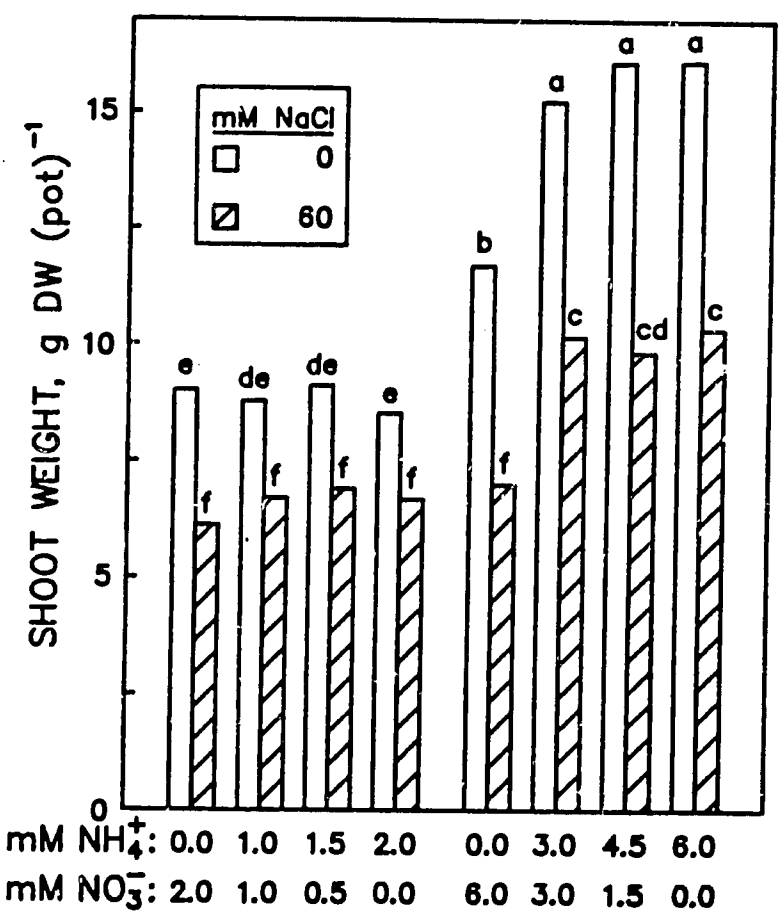

SHOOT WEIGHT, g DW (pot)$^{-1}$
15
10
5
0
mM NaCl
0
60
e
f
de
f
de
f
e
f
b
f
a
c
a
cd
a
c
mM NH_4^+: 0.0 1.0 1.5 2.0 0.0 3.0 4.5 6.0
mM NO_3^-: 2.0 1.0 0.5 0.0 6.0 3.0 1.5 0.0

Fig. 2, part 1

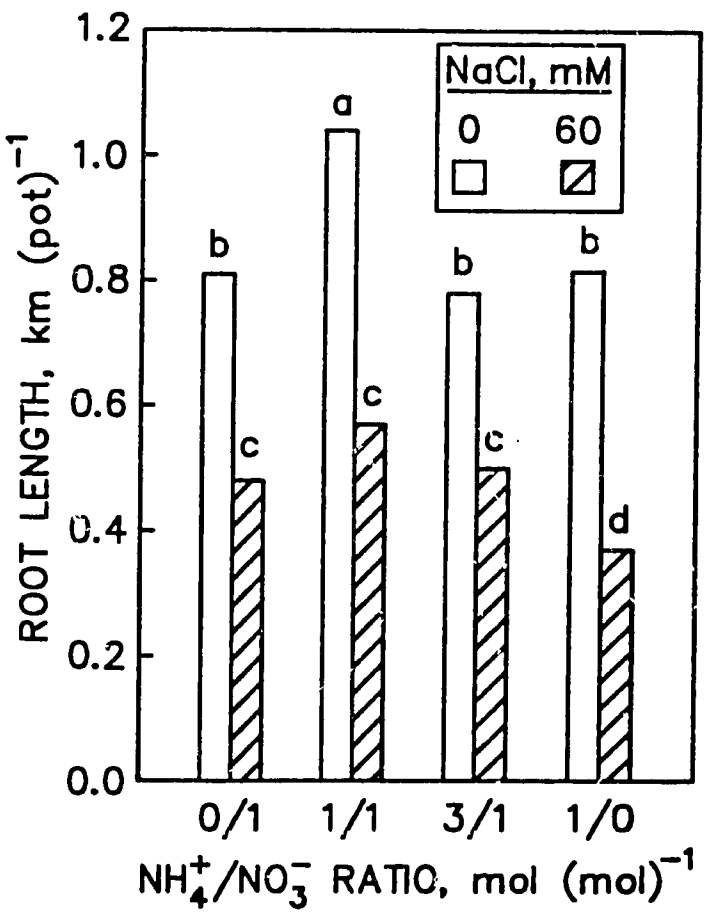
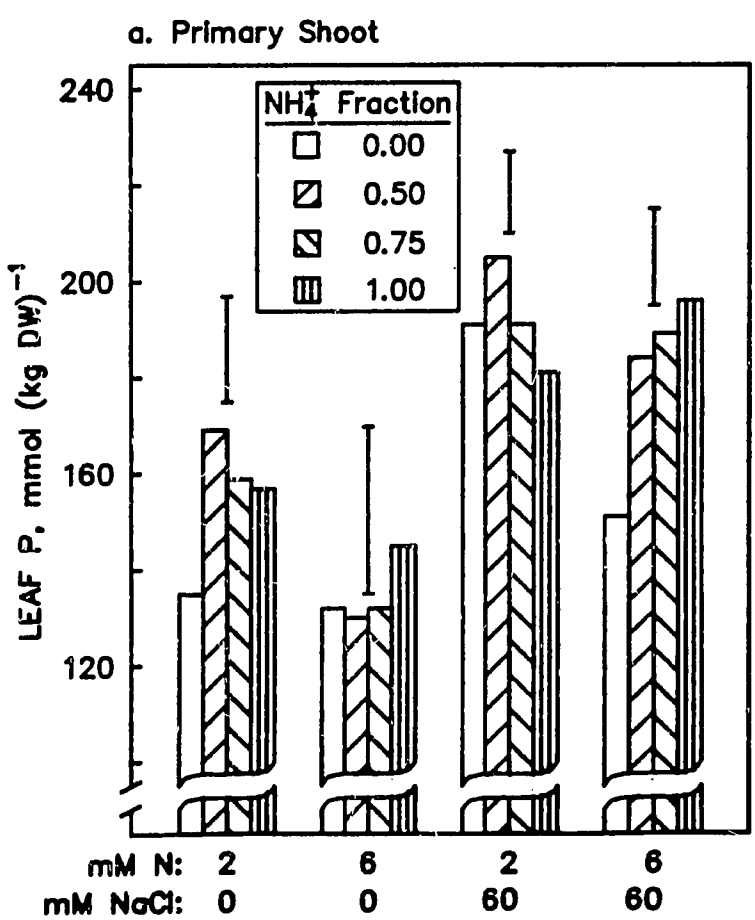

NaCl, mM
0
60
ROOT LENGTH, km (pot)$^{-1}$
1.2
1.0
0.8
0.6
0.4
0.2
0.0
a
b
c
b
c
b
c
b
d
0/1
1/1
3/1
1/0
NH_4^+/NO_3^- RATIO, mol (mol)$^{-1}$

Fig. 3a, part 1


a. Primary Shoot
NH_4^+ Fraction
0.00
0.50
0.75
1.00
LEAF P, mmol (kg DW)$^{-1}$
240
200
160
120
mM N: 2 6 2 6
mM NaCl: 0 0 60 60

Fig, 3b, part 1

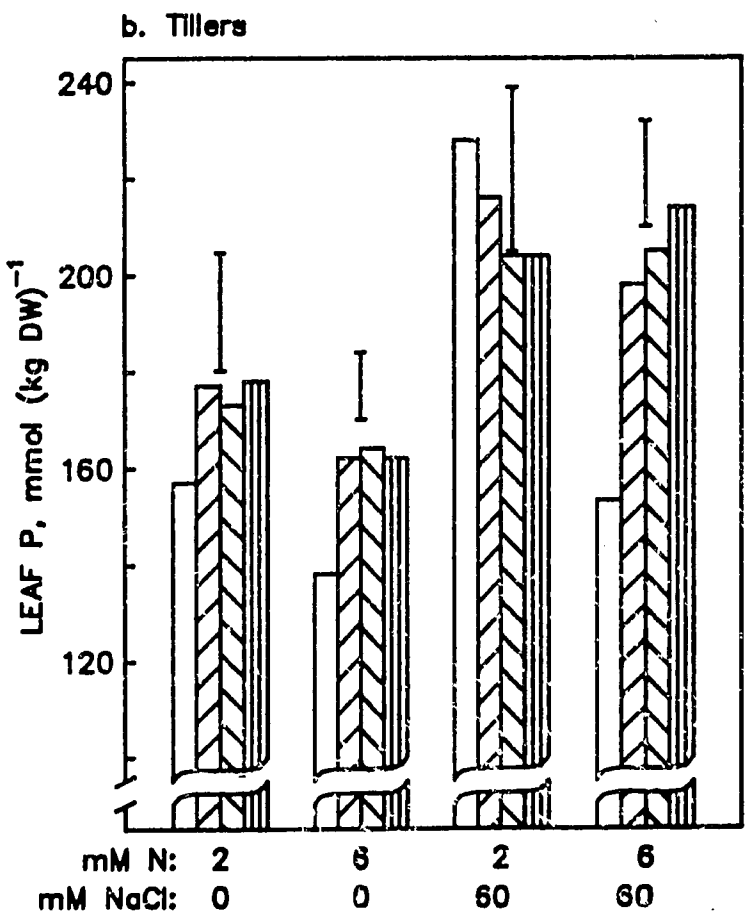

b. Tillers
240
200
160
120
LEAF P, mmol (kg DW)$^{-1}$
mM N: 2 6 2 6
mM NaCl: 0 0 60 60

Fig. 4, part 1

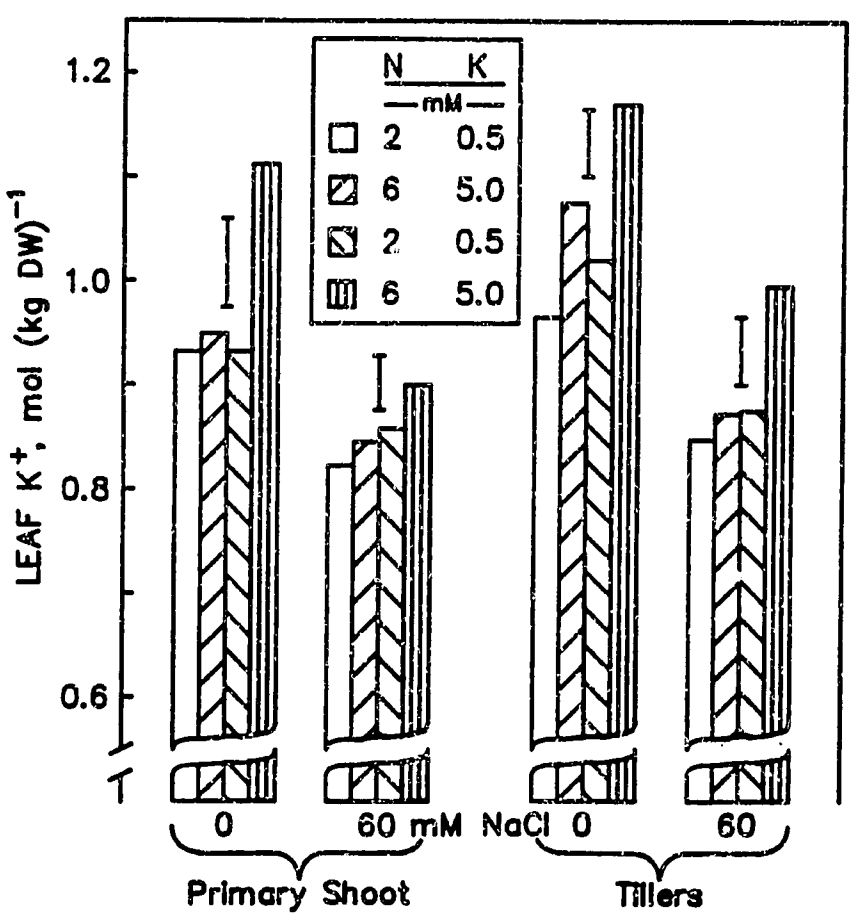

N K
mM
2 0.5
6 5.0
2 0.5
6 5.0
1.2
1.0
0.8
0.6
LEAF K+, mol (kg DW)-1
0
60 mM NaCl 0
60
Primary Shoot
Tillers

Fig. 5, part 1

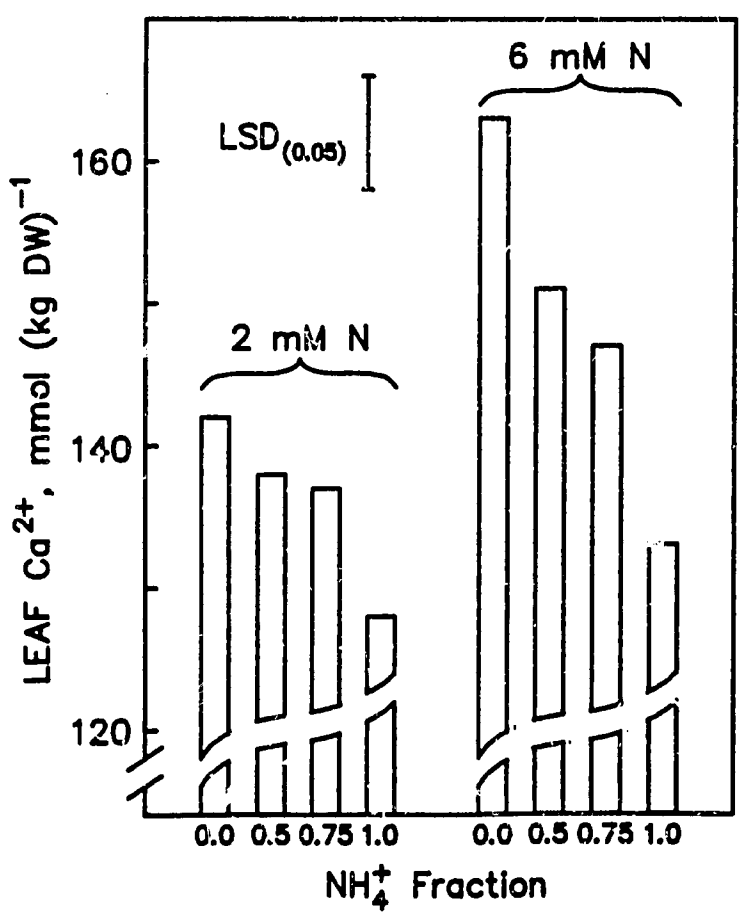

6 mM N
LSD(0.05)
2 mM N
160
140
120
LEAF Ca2+, mmol (kg DW)-1
0.0 0.5 0.75 1.0
0.0 0.5 0.75 1.0
NH4+ Fraction

Fig. 6a, part

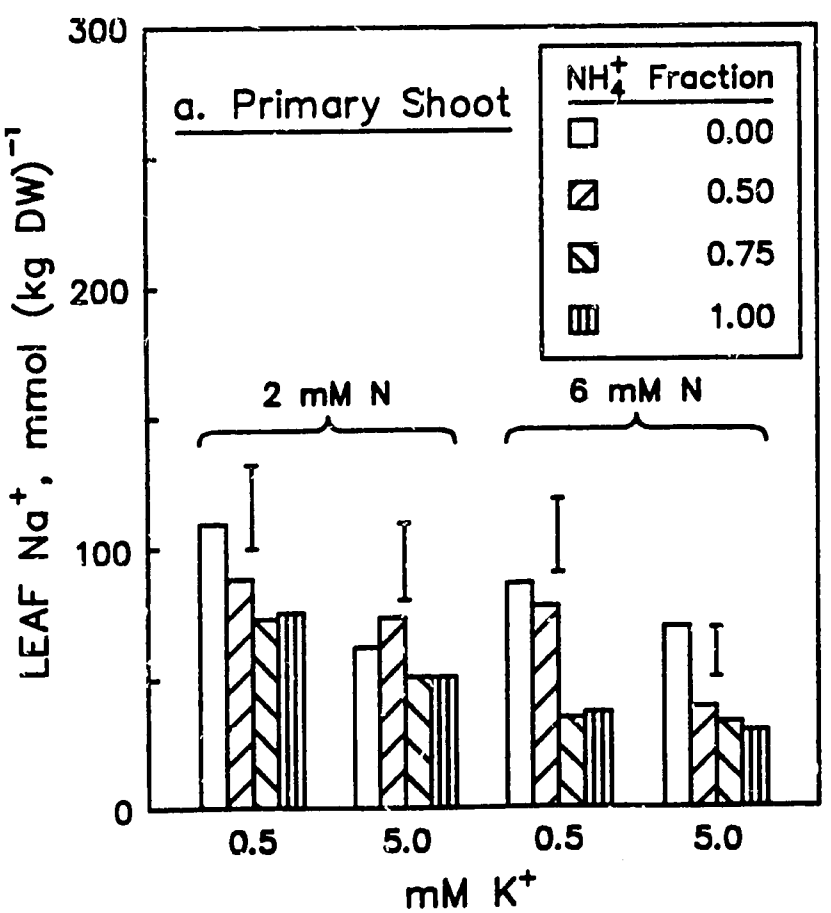
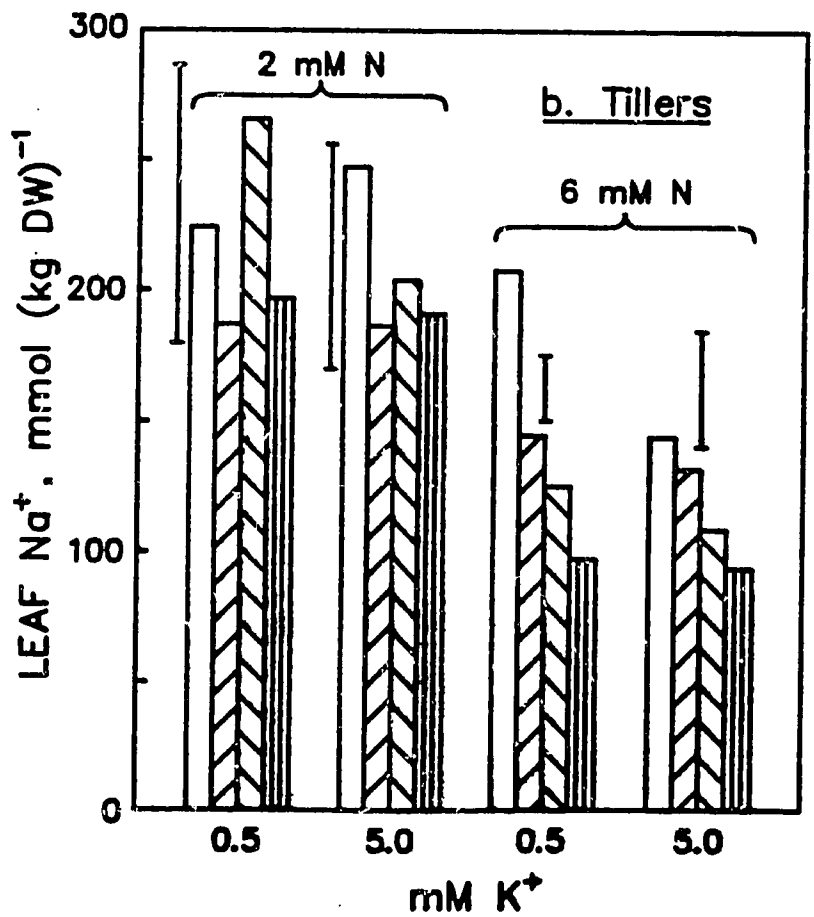

a. Primary Shoot
NH_4^+ Fraction
0.00
0.50
0.75
1.00
2 mM N
6 mM N
LEAF Na^+, mmol (kg DW)$^{-1}$
300
200
100
0
0.5
5.0
0.5
5.0
mM K^+

Fig. 6b, p. 111


300
200
100
0
LEAF Na+, mmol (kg DW)-1
2 mM N
b. Tillers
6 mM N
0.5
5.0
0.5
5.0
mM K+

Potassium, nitrogen, ammonium/nitrate eratio and sodiuim chloride effects on wheat growth.

II. TILLERING AND GRAIN YIELD.

M. Silberbushand S.H. Lips

The objectives of this project were to study the interactions between N, K^+ and NaCl and the NH_4^+/NO_3^- ratio and their effect on vegetative and reproductive growth of wheat (*Triticum aestivum* L.). Plants were grown in polyethylene pots with fine calcareous dune sand with and without 60 mM NaCl, two nitrogen concentrations (2 or 6 mM), two K^+ concentrations (0.5 or 5 mM) and four NH_4^+/NO_3^- ratios (0:1, 1:1, 3:1 and 1:0). Three replicates were harvested at the beginning of flowering, and one grown to grain maturity. Shoot and root growth, and mineral composition of the leaves, were reported in part 1 of this work (Silberbush and Lips, 1990a). Number of tillers per plant was correlated with dry matter yield. It also increased with nitrogen concentration and with NH_4^+/NO_3^- ratio, with or without 60 mM NaCl. Mean grain weight was negatively correlated with NH_4^+/NO_3^- ratio (and consequently with the number of tillers per plant). This reduction of grain weight was more pronounced with than without 60 mM NaCl. Consequently grain production of plants grown with a relatively high NH_4^+/NO_3^- ratio was more suceptible to NaCl than their vegetative yield, than plants grown with NO_3^- nitrogen only.

Additional key words: Dunes sand, Grain yield, Mineral nutrition, Plant production, *Triticum aestivum L.*, Water salinity.

M. Silberbush (corresponding author) and S.H. Lips, Center for Desert Agrobiology, J. Blaustein Institute for Desert Research and Department of Biology (Faculty of Natural Sciences), Ben-Gurion University of the Negev, Sede Boqer Campus, 84990, Israel

INTRODUCTION

It is generally assumed that salt damage to nonhalophytes is mainly due to accumulation of salt ions and/or a water deficiency in the plant. High concentrations of Na^+ and Cl^- in the nutrient medium may induce accumulation of these ions in the plant tissues and consequently inhibit plant growth (Greenway and Munns, 1980, Lauter and Munns, 1987). Modulation of the extent of salinity damage of crop production by mineral nutrients have been reported (Bernstein et al., 1974, Papadopoulos and Rendig, 1983; Silberbush and Lips, 1988). Na^+ and Cl^- ions interact with the uptake of other ions by plants. Na^+ interacts with Ca^{+2} and with K^+, and Cl^- interacts with NO_3^- (Kafkafi et al., 1982). NaCl suppressed NH_4^+ and NO_3^- uptake and interfered with nitrogen metabolism in cotton, *Gossyplum hirsutum L.* (Pessarakli and Tucker, 1985). There is no direct evidence, according to these author, as to the effect of NH_4^+/NO_3^- ratio on plant responses to NaCl (Lips et al., 1987). In part 1 of this work (Silberbush and Lips 1990), we reported on the interactions between NaCl, N and K^+ concentrations and NH_4^+/NO_3^- and the effect of these medium components on the growth and mineral composition of wheat plants. In the second part of this work, the present paper, we present the results of these growth factors on wheat grain yield and its contributing component parameters.

MATERIALS AND METHODS

The detailed experimental procedure was described in part 1 (Silberbush and Lips, 1990). Six wheat (*Triticum aestivum* L. cv. 'Barkai') plants were grown in black polyethylene bags containing 3 kg gravel at the bottom to insure good and rapid drainage;10 kg fine sand (Calcareous, Typic Torripsamment), were placed on top of the gravel layer. The experiment had a factorial design of two water salinities (0 and 60 mM NaCl), two nitrogen concentration (2 and 6 mM), four NH_4^+/NO_3^- ratios (0:1, 1:1, 3:1, and 1:0), and two K^+ concentration (0.5 and 5.0 mM).
After 44 days of growth, when the stems started to elongate but before flowering, three of the four blocks were harvested (see part 1). The remaining block was allowed to grow to maturity. Ears and grains of each individual spike were collected separately, counted, and weighed.

RESULTS AND DISCUSSION

Potassium had no effect on the extent of tillering and on shoot dry mass, according to the analysis of variance (see part 1), so the results of the two K levels were grouped together in Fig. 1. Number of tillers per pot (6 plants) increased with the increase in NH_4^+/NO_3^- ratio, but only in the higher (i.e. 6 mM) nitrogen concentration (Fig. 1). A similar pattern was observed on shoot dry mass (Silberbush and Lips, 1990), since shoot dry mass and number of tillers were significantly correlated

(Fig. 2) even tillers of plants grown with 60 mM NaCl were somewhat smaller than those grown without NaCl.

Fig.3 presents grain weight frequencies of wheat plants grown either with NO_3^- or NH_4^+, and in the two NaCl and two K^+ concectrations. The comparisons between the means of grain weight at each treatment showed a decrease in mean grain weight with increasing nitrogen concentration. At the higher nitrogen concentration (i.e. 6 mM), mean grain weight decreased also with increasing NH_4^+/NO_3^- ratio. Grain yield characteristics were correlated actually to one vegetative factor, which is the number of tillers per plant. Since the number of leaves in a tiller and the number of grains in a spike are constant, the number of tillers determines the plant vegetative and reproductive yields (Bulman and Hunt, 1988, Shaviv and Hagin, 1988), Heberer and Below, 1989). While the total grain yield was correlated with the number of tillers (Fig.4), mean grain weight decreased with that growth factor (Fig. 5). But while plants grown with NO_3^- produced similar number of grains per pot (6 plants) when grown with or without 60 mM NaCl, this number was smaller in plants grown with NH_4^+ (Fig. 3). This effect can be also seen in Fig. 5, where plants with a greater number of tillers, i.e. grown with a relatively higher NH_4^+/NO_3^-, produced smaller grains. A similar response to NH_4^+/NO_3^- by wheat plants was reported by Heberer and Below (1989), however they observed the effect on tillering and number of spikes per plant, but not a reduction in grain size. The sum of these two effects is presented in Fig. 4: plants grown with relatively high NH_4^+/NO_3^- ratio produced more tillers, but those grown with 60 mM NaCl did not produce a higher yield because they were more suceptible to salinity.

The youngest tillers of ammonium-fed plants had the smallest grains, which were responsible for the poor correlation between grain yield and number of tillers of plants grown in the presence of NaCl (Fig.4). The reason for this reduction in the development of young tillers is presented in Fig. 7 of part 1 (Silberbush and Lips, 1990): Na^+ was excluded from the older tillers toward the younger ones, where it accumulated and retarded growth. This seems to be the mechanism by which this species (and maybe other cereals) may partially avoid salinity hazards to the primary shoot and early tillers.

The explanation seems to lay with the effect on assimilate translocation and supply: the results indicate that NH_4^+- fed plants are stimulated to invest carbohydrate reserves in vegetative growth (i.e. new tillers), which may have no time to ripen. The assimilater invested in those unripe tillers are a loss in behalf of the grain-production economy of the plant. Nitrate- fed plants do invest most of their carbohydrate reserves in grain production. Plants grown without NaCl seem to have limited carbohydrate resources to divert to the developing grains. The addition of NaCl to the growth medium caused a larger stress in NH_4^+ -fed plants than in NO_3^- -fed plants, which interfered with the translocation of assimilates to the grains.

Sensivity of crops to salinity cannot be defined therefore by a single ter m(Maas and Hoffman, 1977), but may vary according to the yield component used as an index. Different growth phases may be affected to different extents by salinity. Screening for salt tolerance among genotypes

cannot be limited, therefore, to the early growth stage. In the case of wheat this screening should be carried out until grain maturity.

ACKNOWLEDGMENT

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FIGURES CAPTIONS

Figure 1 Number of tillers of wheat plants as affected by N and NaCl concentrations, and by the NH_4^+/NO_3^- ratio (NH_4^+ fraction) in the nutrient solution culture.

Figure 2 The relationships between shoot dry matter and number of tillers of 6 wheat plants grown on different concentrations of NaCl, K^+ and N, and NH_4^+/NO_3^- ratios (*** - significance of 0.001 for the correlation coefficient).

Figure 3 Distribution of grain weight frequencies of 6 wheat plants per pot grown with NH_4^+ or NO_3^- nitrogen of 2 concentrations, with 0 or 60 mM NaCl, and with 2 K^+ concentrations.

Figure 4 Relation between grain yield and number of tillers of 6 wheat plants grown on different concentrations of NaCl, K and N, and with different NH_4^+/NO_3^- ratios.

Figure 5 The relationships between mean grain wt and No. of tillers of 6 wheat plants grown with different concentrations of NaCl, K^+ and N, and with different NH_4^+/NO_3^- ratios.

Fig. 1, part 2

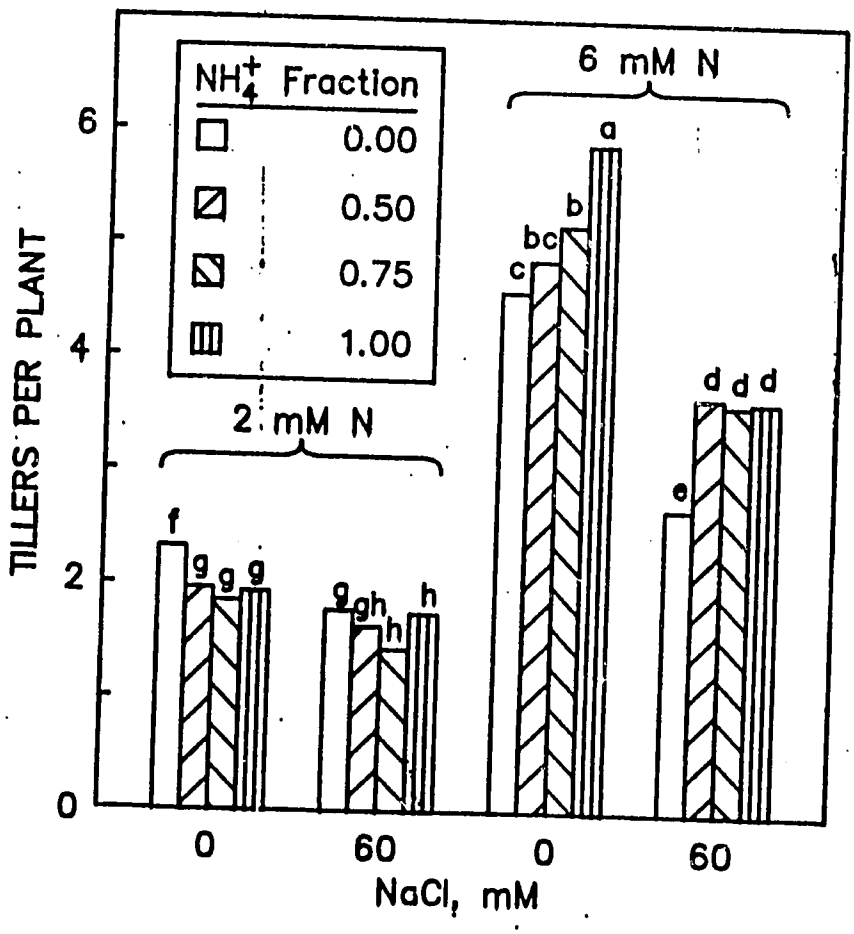
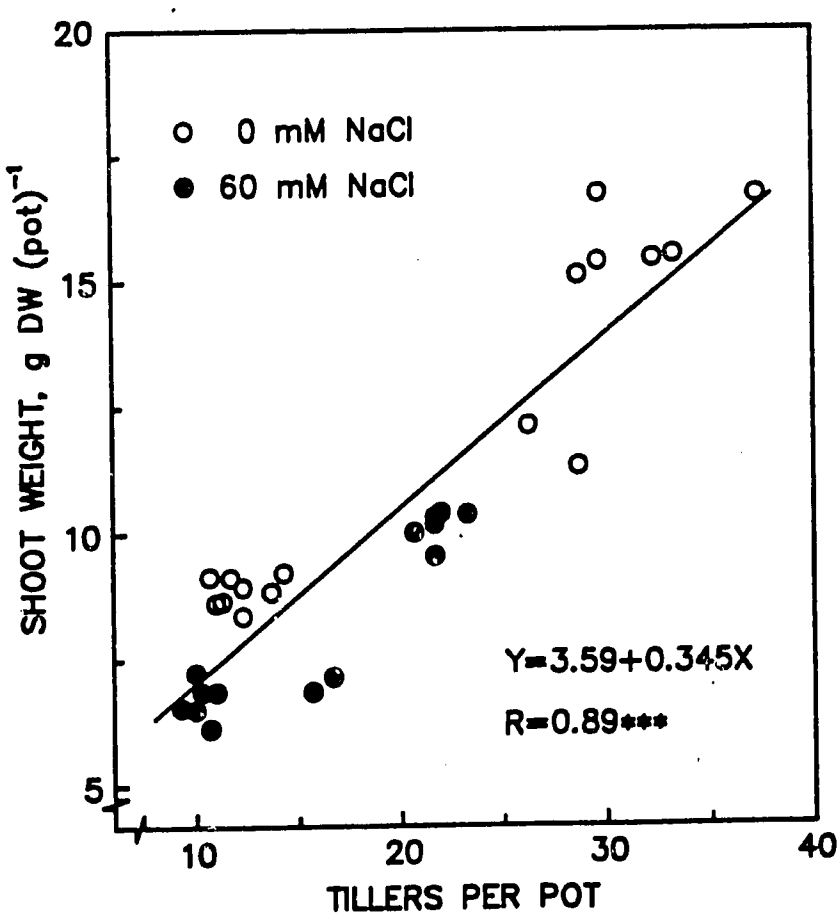
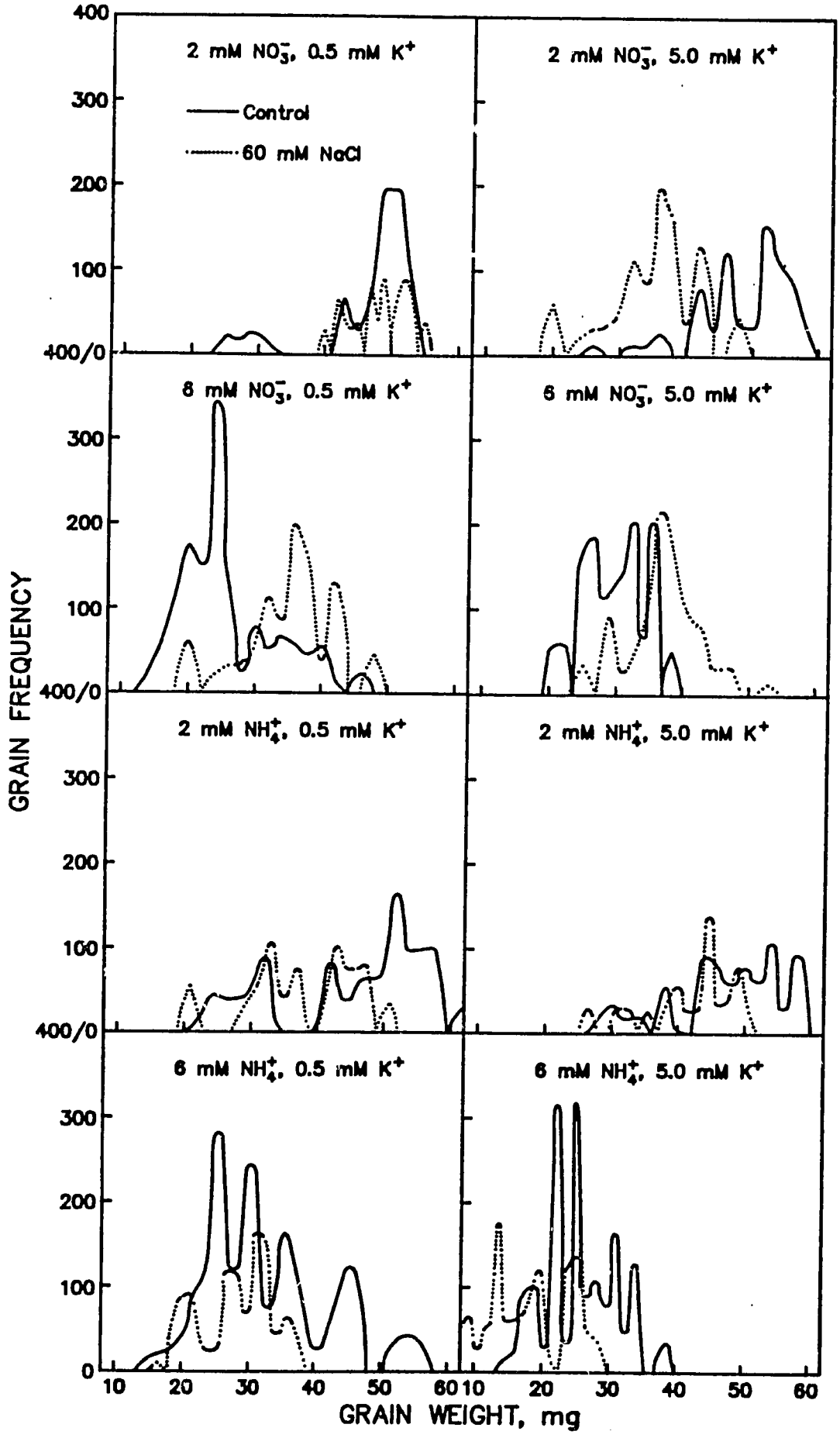

NH4+ Fraction
0.00
0.50
0.75
1.00
6 mM N
2 mM N
TILLERS PER PLANT
0
2
4
6
f
g g g
g gh h h
c bc b a
e d d d
0
60
0
60
NaCl, mM

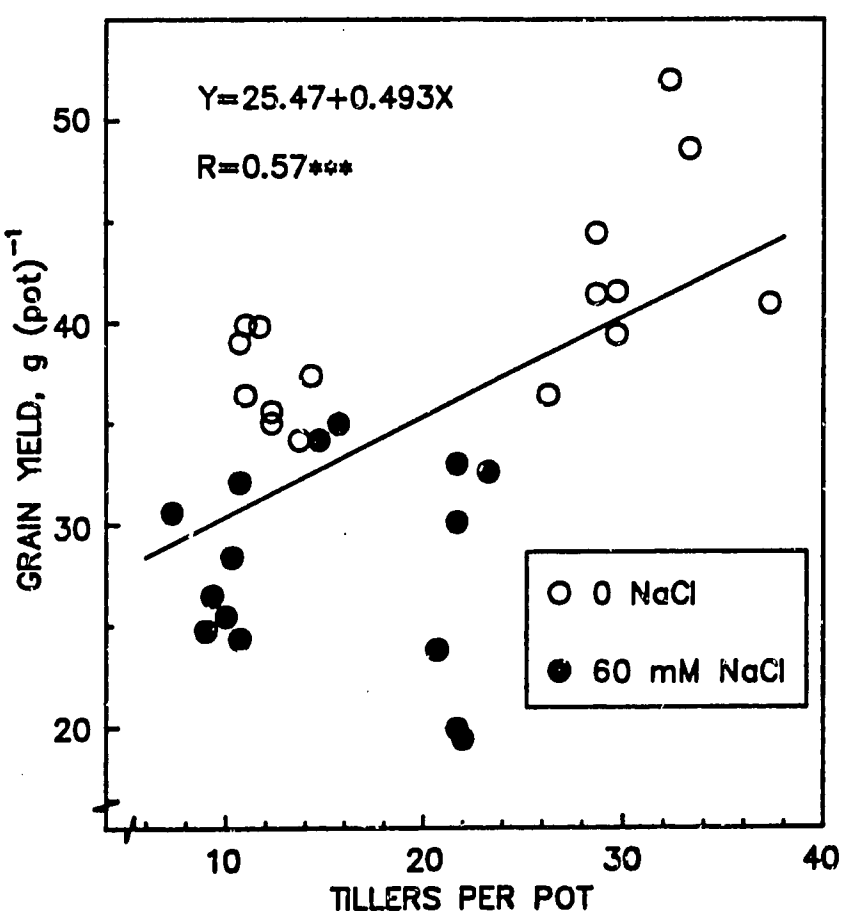
Fig. 2, plot 2


20
15
10
5
SHOOT WEIGHT, g DW (pot)$^{-1}$
0 mM NaCl
60 mM NaCl
Y=3.59+0.345X
R=0.89***
10
20
30
40
TILLERS PER POT

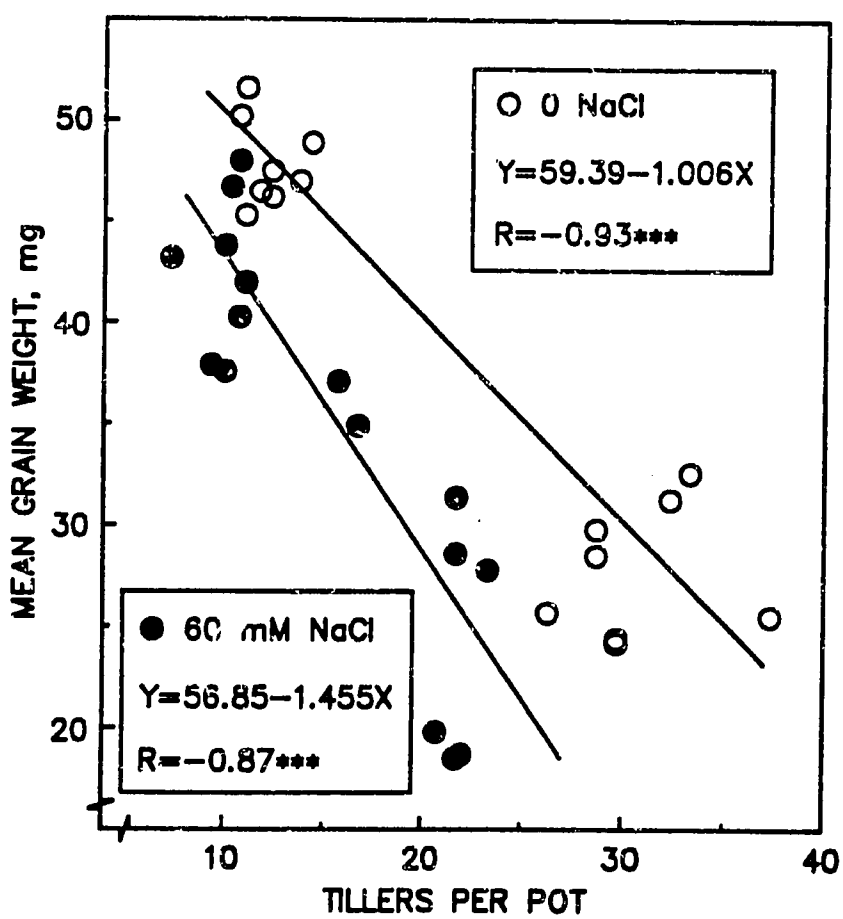

2 mM NO_3^-, 0.5 mM K^+
Control
60 mM NaCl
2 mM NO_3^-, 5.0 mM K^+
6 mM NO_3^-, 0.5 mM K^+
6 mM NO_3^-, 5.0 mM K^+
2 mM NH_4^+, 0.5 mM K^+
2 mM NH_4^+, 5.0 mM K^+
6 mM NH_4^+, 0.5 mM K^+
6 mM NH_4^+, 5.0 mM K^+
GRAIN FREQUENCY
GRAIN WEIGHT, mg
400
300
200
100
400/0
0
10
20
30
40
50
60

part 2, Fig. 3

Part 2, Fig. 11


Y=25.47+0.493X
R=0.57***
GRAIN YIELD, g (pot)$^{-1}$
50
40
30
20
10
20
30
40
TILLERS PER POT
0 NaCl
60 mM NaCl

part 2, Fig. 5


O 0 NaCl
Y=59.39−1.006X
R=−0.93***
● 60 mM NaCl
Y=56.85−1.455X
R=−0.87***
MEAN GRAIN WEIGHT, mg
50
40
30
20
10
20
30
40
TILLERS PER POT

PHYSIOLOGICAL ASPECTS OF AMMONIUM AND NITRATE FERTILIZATION

S. H. Lips, E. O. Leidi[1], M. Silberbush, M.I.M. Soares and O. E. M. Lewis[2]

Center for Desert Agrobiology (J. Blaustein Institute for Desert Research) and Dept. of Biology (Faculty of Natural Sciences). Ben Gurion University of the Negev. Sede Boqer 84990. Israel.

ABSTRACT

Various physiological effects of ammonium, nitrate and mixed ammonium-nitrate nutrition of plants have been studied in this laboratory during the last years. Some of the characteristic distinctions observed between plants growing on these nitrogen sources will be described and discussed. Biomass production of ammonium-grown plants increased with K^+ concentration in the nutrient medium between 0.1 to 3 mM, while nitrate-fed plants reached maximal growth around 0.25 mM K^+. The water use efficiency (WUE) of ammonium-fed plants was lower and also more dependent on K^+ than that of plants receiving nitrate. At low K^+ levels (0.1 mM) in the medium, plants growing on ammonium-N spent nearly twice as much water through transpiration per unit mass than nitrate-fed plants. WUE of plants receiving NH_4NO_3 was poor at low K^+ (similar to ammonium-fed plants) but at high K^+ this plants grew even better than nitrate-grown plants. Overall transpiration per plant was little affected by K^+ levels in the medium. Consequently, the main effect of K^+ was on the overall photosynthetic capacity of the shoot.

Similar studies were carried out on the efficiency of the plants to convert inorganic nitrogen taken up from the nutrient media to organic nitrogen compounds in the plant (NUE). At low K^+ levels in the medium, ammonium-fed plants assimilated into organic compounds only between 20% and 30 % of the nitrogen taken up from the solution. NUE of nitrate-fed plants was much higher (about 100%) regardless of the K^+ levels in the medium.

In additional studies to characterize the preferential growth rate of plants fed mixed ammonium and nitrate sources, we examined root respiration rates, oxidation of ^{14}C-labeled assimilates by the root, balance between root respiration and leaf net photosynthesis, patterns of assimilate allocation and effect of CO_2 level.

1 - Estacion Experimental del Zaidin, Granada, Spain.
2 - Department of Biology, Cape Town University, South Africa.

INTRODUCTION

Interest on the physiological responses of plants to different forms of nitrogen, from its reduced stage (ammonium) to its most oxidized stage (nitrate), developed simultaneously in two scientific areas: (a) the molecular and physiological studies of nitrogen uptake and assimilation and their relationship to plant growth and development; (b) the agricultural interest on the practical aspects of nitrogen use applications in intensive field production with daily fertigation.

The physiologists would like to understand why do plants generally grow better in the presence of nitrate than in that of ammonium and, even better, in that of mixed ammonium-nitrate (1). This fact is surprising considering that the actual assimilation of nitrogen into organic compounds is carried out as ammonium, a product of nitrate reduction. The uptake of nitrate requires energy and so does the reduction of nitrate to ammonium, making nitrate use by the plants far more demanding energetically. Most of the nitrogen we add as fertilizers to well aerated and warm soils is rapidly oxidized to nitrate. However, the increasing addition of fertilizer to irrigation water makes the direct effect of different forms of nitrogen fertilizers on plants, of great agricultural interest.

Nitrate enters the roots essentially by active, energy-requiring uptake systems. Net NO_3^- uptake into the roots is the balance between influx (2). Reduction of nitrate is closely associated with uptake into the cell taking place either during or immediately following its transport across the cell membrane (3).When nitrate uptake by the plant is larger than its reducing capacity , the unreduced nitrate taken up accumulates in the plant. Regulation of nitrate reduction by leaves is mediated to a large extent by the flux of nitrate into the metabolic pool (4). Although there is seemingly functional advantage for the linkage of energy-demanding nitrate reduction to photosynthesis by leaves, nitrate reduction to ammonia is not necessarily a metabolic event depending directly on light since very similar rates of nitrate reduction have been observed both in the dark and in the light by freshly detached leaves (5,6). These results put in doubt the role of chloroplasts as direct suppliers of reducing equivalents for the reduction of nitrite to ammonium.

Ammonia enters the roots, to a large extent, by passive diffusion of NH_3 at neutral and basic pH (7). Ammonium ions seem to be toxic and their assimilation into amino acids constitutes, therefore, a detoxification process. The resulting amino acids are transported as amides from the root to the shoot where they are incorporated into organic nitrogen (8). Ammonium-feeding gave rise to higher levels of proteins, among them RuBPCO, the main leaf protein.

Although physiological responses to nitrate and ammonium ions by different plants can vary greatly (9,10), work published during the last years has been the basis for the emergence of more consistent and general response patterns. Some of these experimental approaches will be described in this paper.

MATERIALS AND METHODS

The studies reported here were carried out in wheat (*Triticum aestivum*, L.) and tomato (*Lycopersicum esculentum*, Mill.). Plants were grown in aerated nutrient solutions of the Long Ashton type suitably modified to contain the different forms of nitrogen used. Tomatoes were grown in half strength Hoagland nutrient solutions. Nutrient solutions were replaced every two days. Ammonium was supplied as $(NH_4)_2SO_4$and nitrate as $Ca(NO_3)_2$. Potassium was added to the nutrient solutions as K_2SO_4. Nitrogen concentration in the solutions was generally 4 mM.

CO_2 gas exchange during shoot photosynthesis and root respiration was measured with an ADC infrared gas analyzer (IRGA) and total organic nitrogen was determined with the standard Kjeldhal technique. $^{14}CO_2$ pulses for 15-20 min were carried out with single leaves in a closed circuit air circulation maintained by a peristaltic pump.

Transpiration during the growth of wheat plants was measured as the loss of water from the pots with plants (evapo-transpiration) less the loss of water from pots with nutrient solutions without plants (evaporation).

Results given are the average of 3-4 replicates. Standard deviation was in the range of 4-10%.

RESULTS AND DISCUSSION

Biomass production

Dry biomass production of nitrate-fed 21-day old wheat plants was relatively low and dependent on the concentration of K^+ in the nutrient medium (Fig. 1). Biomass production by plants grown on nitrate was always greater than that of ammonium-fed plants and achieved maximal values at very low K^+ concentrations. Wheat plants grown in ammonium-nitrate (1:1 ratio) behaved essentially as the ammonium-grown plants at low K^+ concentrations in the medium. At the high K^+ concentration , however, biomass production of plants receiving a mixed nitrogen feeding was even greater than that of nitrate-fed plants. It appears therefore that the enhancing effect of nitrate on ammonium-fed plants was highly dependent on the level of K^+ in the nutrient media (Fig. 1).

Transpiration and water use efficiency

Transpiration of wheat plants grown on ammonium was higher than that of nitrate-fed plants, when calculated on a whole plant basis (Fig. 2A). The size of the plants did not markedly affect the extent of water transpired during the growth period, except for plants growing at the lowest K^+ concentration. When transpiration was expressed per unit mass (Fig. 2B), it became apparent that the amount of water transpired per gram dry weight was highest for ammonium-fed plants at low K^+ levels. The lower water use efficiency (WUE) of ammonium-fed plants was equally evident in a second experiment (Fig. 3A) with wheat. WUE was lowest for ammonium-fed plants but improved considerably with increasing K^+ concentration in the medium. Nitrate fed plants were the most efficient users of water in relation to dry biomass production at low K^+ . WUE of ammonium-nitrate-grown plants improved very rapidly with increasing concentrations of K^+ (Fig. 3B). The differences on WUE between plants grown on different nitrogen sources is due to a relatively higher transpiration rate by ammonium-fed plants as well as to a relatively higher photosynthesis rates by nitrate-fed plants. Since shoot photosynthesis rate of ammonium-nitrate grown plants is the highest as compared with plants fed with other forms of nitrogen (Fig. 6A) and they transpire less than ammonium-fed plants (Fig. 3A), their WUE turned out to be the highest (Fig. 3B)

Nitrogen use efficiency

The total organic (Kjeldhal) nitrogen content of nitrate-fed plants was relatively independent of the concentration of K^+ in the medium (Fig. 4A). However, the organic nitrogen content of ammonium-grown plants increased markedly in response to medium K^+ . In general terms, ammonium-fed plants were richer in organic nitrogen than nitrate-fed plants. Similar responses were obtained when

we studied interactions of medium K^+ level with different sources of nitrogen (Fig. 4B).

Ammonium-fed wheat plants took up far more nitrogen per g dry weight than plants grown on nitrate (Fig. 5A). Rates of nitrate uptake per g dry weight were essentially indifferent to the levels of K^+ used in this experiments. As K^+ concentration in the nutrient medium increased, ammonium-fed plant took up about a constant amount of nitrogen from the nutrient solution, on a whole plant basis. However, since the resulting biomass of these plants increased with K^+ concentration, the rate of ammonium uptake from the solution on a unit mass basis, decreased (Fig. 5A).

The patterns of assimilation efficiency of inorganic nitrogen taken up from the media into organic nitrogen compounds (NUE) were very similar (Fig. 5B) to that observed for WUE. NUE of ammonium-fed plants improved from 22% to 63% when K^+ levels in the nutrient media increased from 0.1 to 5 mM. This implies that much of the ammonium ions taken up by the plants was not recovered as organic nitrogen compounds. Nitrate-fed plants, on the other hand, showed a NUE of about 90% - 100% throughout the entire range of K^+ concentrations used. We have no definite explanation for the apparent low NUE of ammonium-fed plants, especially at low K^+ concentration. No loss of ammonia through the leaves was detected. The possibility of nitrogen being secreted back to the nutrient solutions in a form other than ammonium ions was not tested in these experiments and it is presently under study.

Photosynthesis

Biomass production was the result of the difference between rates of assimilation and respiration of carbon as well as the differences between nitrogen uptake and its loss back to the environment. Measurements of leaf photosynthesis and root respiration were carried out in order to obtain a quantitative balance between the major inputs and outputs of biomass production of plants growing on different nitrogen sources. Increasing medium K^+ had a marked effect on leaf expansion of plants grown on a 1:1 ammonium-nitrate mixture . The enhanced leaf expansion of ammonium-nitrate fed plants resulted in a remarkable increase of shoot photosynthesis (6A). When we express photosynthesis rates, as measured by IRGA, on a unit mass basis (g dry weight), increasing K^+ concentration in the medium caused a slight decrease of photosynthesis rates in plants growing on all nitrogen sources studied (Fig. 6B). Consequently, we concluded that the type of nitrogen source given to the plants affected their rates of cell or leaf expansion more than the photosynthetic capacity of their chloroplasts.

High atmospheric CO_2

Exposing sunflower plants to 1200 ppm CO_2 stimulated biomass production of nitrate-grown plants to an extent similar to that of ammonium-fed plants (Fig. 7A, B). Exposing these plants to relatively mild salinity (50 mM NaCl) caused a remarkable enhancement of biomass production under high CO_2 atmospheric concentrations. Even after adding 100 mM NaCl to the nutrient solutions, biomass production of ammonium-fed plants was not affected by high CO_2 as compared to controls. Obviously, NaCl is not always a plant hazard. Under conditions of very intensive growth in the presence of high CO_2 atmospheric concentrations, the availability of K^+ to this plants may be limiting, in which case Na^+ may partially replace K^+ on the maintenance of turgor necessary for cell and leaf expansion.

Root respiration

Root respiration of wheat plants was measured as CO_2 evolution from the nutrient solutions (pH 7) with and ADC-IRGA. Highest rates of respiration per root were observed on nitrate-fed plants while the lowest rates were seen in ammonium-fed plants (Fig. 8A). Root respiration rates of plants growing on ammonium-nitrate were slightly higher than those of ammonium-fed plants. The higher respiration rate of nitrate-fed plants reflected not only their larger size but also the extent of carobhydrate oxidation to sutisfy the energetic cost of nitrate uptake. The low rate of ammonium nitrate-fed plants was probably a result of enhanced uptake of ammonium, whose influx into the roots is achieved mainly by passive diffusion.

When we expressed the rates of root respiration on the basis of a unit mass (g dry weight), the picture obtained from overall root respiration remained unchanged (8B). Nitrate-grown plants exhibited the most intensive root respiration while plants with ammonium in their nutrient media showed the lowest root respiration per gram dry weight of root. This is presumably due to the fact that nitrate uptake, contrary to that of ammonium uptake, is an active, energy demanding process. The low rate of root respiration by plants fed ammonium-nitrate is an additional indication that ammonium is the main species taken up from the mixed nitrogen source.

The rates of whole root respiration were compared with overall photosynthesis rates of the shoot (Fig. 8C). Nitrate-fed plants spent the highest percentage of their shoot production on the uptake of nitrogen from the medium and on root growth. Ammonium-fed plants were energetically more economical, presumably because a very large proportion of the carbohydrates delivered by the shoot to the root were used for ammonium assimilation and subsequently reexported as amides to the shoot. A relatively small fraction of the carbohydrates arriving to the ammonium-nitrate roots was used to obtain metabolic energy for active uptake or for root growth. The most efficient plants in this balance between shoot assimilation and root respiration, were plants grown on ammonium-nitrate, whose root respiration was relatively low and similar to that of ammonium-fed plants, while their photosynthesis was even higher than that of nitrate-grown plants.

Root respiration and assimilate translocation from shoot to root may be a function of the composition of the nutrient medium of the plant. Tomato plants were grown in a complete Hoagland (H) nutrient medium from where they were transferred after one month for three days to either 0.5 mM $CaSO_4$ or 1 mM KNO_3. One leaf of each plant was exposed to $^{14}CO_2$ for 20 minutes. Air was passed through the medium containing the plant roots and the $^{14}CO_2$ released by root respiration was collected in a 4 N KOH trap solution. Aliquots taken from the trap solutions were assayed for radioactivity in a liquid scintillation counter. Significantly more $^{14}CO_2$ was released by the roots in KNO_3 than in $CaSO_4$, indicating a larger allocation of recently synthesized carbohydrates to roots (Fig. 9).

Leaf to grain translocation

In another experiment wheat plants were grown throughout their complete life cycle. Plants were grown in polyethylene bags containing 3 kg gravel at the bottom to insure rapid drainage. This bottom layer was then topped with 10 kg of fine dune sand. Two levels of salinity were used, 0 and 60 mM NaCl. Nutrient solutions contained two levels of either nitrate or ammonium (2 and 6 mM) and two levels of K^+ (0.5 and 5 mM). Nutrient feedings were added once a week in a volume about 50% larger than field capacity to insure complete removal of the residue of the previous feeding and to avoid build up of salinity. As the plants

developed and their water consumption increased, small amounts of deionized water were added between nutrient solution changes to the pots.

Salinity has been shown to increase the relative amount of freshly synthesized carbohydrates from the flag leaf to the grain (12). Salinity caused a decrease in the number of grains produced by wheat plants regardless of their nitrogen source. However, the translocation of assimilates from the leaves to the grains was larger in nitrate-fed plants (Fig. 10A, B). This phenomenon was evident on the production of larger individual grains by nitrate-fed plants, compensating almost totally for the decrease in the number of grains produced. More detailed studies on this matter were carried out supplying ^{15}N to wheat plants in the form of either $^{15}NH_4^+$ or $^{15}NO_3^-$ (8). Although they gave an insight on assimilate partitioning at the time of grain filling, the limitation of these studies and those described in this paper with $^{14}CO_2$ is that they followed translocation of only the recently assimilated nitrogen or carbon. The impact of ammonium and nitrate feeding, as affected by salinity and other mineral nutrients, on the hydrolysis of leaf components and their mobilization to the filling grains is still largely unknown.

Sink priority

$^{14}CO_2$ pulses were applied to wheat leaves for 15 minutes during the grain filling stage of wheat plants grown on either ammonium or nitrate. Salinization in one third of the pots was started 2 weeks after germination (0d) while in another third the same level of salinity was applied 70 days after germination and before ears emerged (70d). The remaining third of the pot did not receive salt (CONT). Twenty four hours after the radioactive pulse, the plants were harvested and separated into distinct anatomical parts: young tillers, leaves of the main tiller, stem of the main tiller, ears and roots. The harvested plant material was oven-dried and finely ground. The radioactivity in the powder was measured in a liquid scintillation counter. Ammonium-fed plants diverted the largest part of the radioactive assimilates to the developing tiller (Fig. 11A) while nitrate-fed plants diverted their assimilates preferentially to the developing ears (Fig. 11B). We do not understand yet why plants grown on different nitrogen sources established different sink priorities for assimilate allocation. The different location of the main nitrogen assimilation centers, the root for ammonium plants and the shoot for nitrate plants, may be determining factors on the allocation of carbohydrates to developing sinks. We have observed that in wild varieties of wheat in controlled greenhouse experiments, ammonium nutrition enhanced tillering and shoot development while nitrate-fed plants gave a higher priority to assimilate allocation to the filling grains (13). Ammonium-fed plants invested a considerable amount of assimilates in late season young tillers which did not have time to flower and produce grain.

CONCLUSIONS

It may be concluded that nitrate and ammonium assimilation by plants show effects far beyond the immediate energy cost of uptake and assimilation of these ions. The influx of these nitrogen compounds into the plants evokes physiological responses which determine the extent of biomass production, grain yield and salinity resistance of the plants.

Much of the influx of ammonium into the roots in alkaline soils (pH 7-8) is by passive diffusion. The plant has to detoxify the incoming ammonia by assimilating it into organic compounds, a processes which requires a supply of carbohydrates from the shoot to the root to furnish carbon skeletons for the assimilation of ammonium. Carbohydrate supply from to the root may be impaired by limited photosynthesis or translocation when other physiological processes (osmoregulation, high maintenance respiration, ion uptake, root growth) increase the demand for assimilates, required for growth and the

generation of metabolic energy . Under these circumstances the root of an ammonium-fed plant may, at best, copes with ammonia assimilation at the expense of root development and this will eventually affect overall biomass production. At worst, it may limit assimilation of only part of the ammonium entering the root while drastically arresting biomass production.

The large dependence of ammonium-fed plant to medium K^+ as compared to nitrate-grown plants is presumably related to the operation of the K^+-shuttle in plants (14). Since this K^+-recirculating system operates exclusively in nitrate-fed plants, its absence in ammonium-grown plants may explain the larger demand of these plants for K^+.

The observed improved development of plants receiving mixed ammonium-nitrate may be due to a nitrate-enhanced supply of carbohydrates to the roots (15). Studies currently conducted by Martins-Louçao (personal communication) seem to indicate that plants in mixed ammonium-nitrate readily absorb first ammonium and then nitrate. This is evident by following uptake of these nitrogen compounds from the nutrient medium. The medium pH drops initially, indicating preferential uptake of ammonium, and rises later with the subsequent uptake of nitrate. Additional support for this view may be found in several results shown in this paper (Figs. 3 and 9) in which plants fed ammonium or ammonium-nitrate at low external K^+ concentrations are very similar.

As agriculture in Israel becomes more intensive, with the use of greenhouses and soilless culture with daily fertigation, the need to rely on a more sophisticated use of different forms of nitrogen becomes more pressing. Advanced fertilization in general and the use of nitrogen and potassium in particular, control priority to either vegetative or reproductive growth, control more effectively timing and quality of seed production and increase the protein content of the crop produced.

Understanding the physiological responses to ammonium and nitrate nutrition may be important not only in advanced intensive agricultural systems but also in irrigation with marginal water resources such as brackish and waste water as well as for dry land agriculture in arid and desert areas. Better use of nitrogen fertilizers may significantly increase salt tolerance of many crops traditionally defined as salt-sensitive (16,17,18).

We have also learned that the selective use of different combinations of nitrogen and potassium fertilizers may be an important factor for increased production of non-irrigated crops in arid and desert areas. Advanced fertilization under these harsh environmental conditions can improve utilization of soil moisture by controlling root development (19), increasing water and nitrogen use efficiency, boosting a more efficient translocation of assimilates from vegetative to reproductive parts of the plants, etc.

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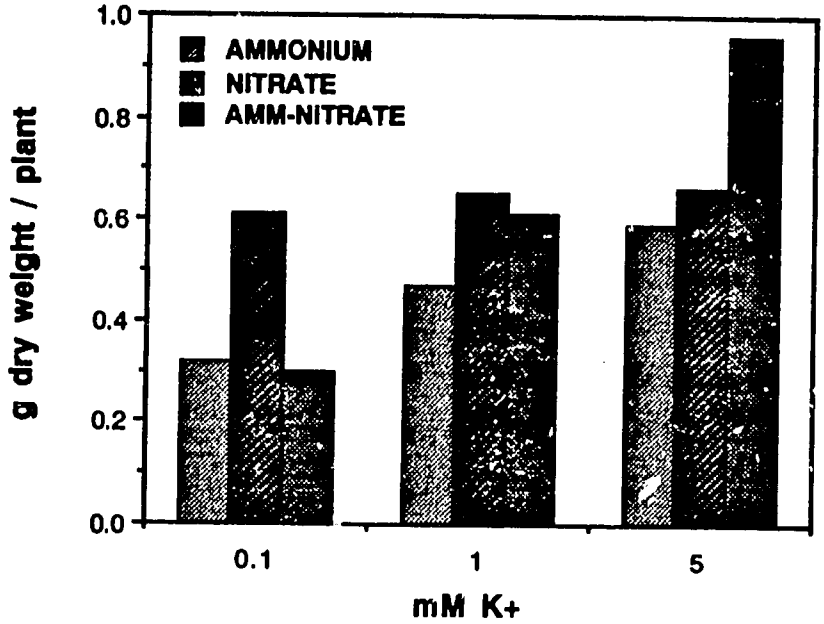


Figure 1: Biomass production of wheat seedlings grown for 21 days on nutrient solutions containing 4 mM nitrogen in the form of ammonium, nitrate or ammonium nitrate. Three levels of K were used - 0.1, 1.0 and 5.0 mM.

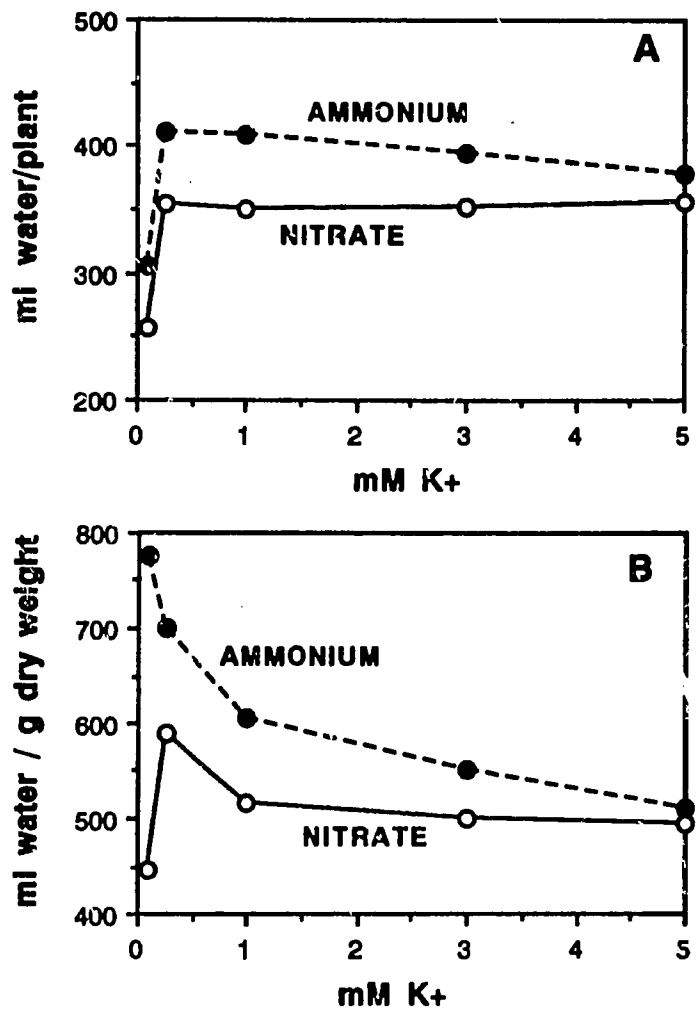


Figure 2: Transpiration of 21 day-old wheat plants grown on 4 mM ammonium- or nitrate-nitrogen in the presence of different concentrations of K^+.
A - Transpiration (ml water) per plant shoot
B - Transpiration (ml water) per g dry weight

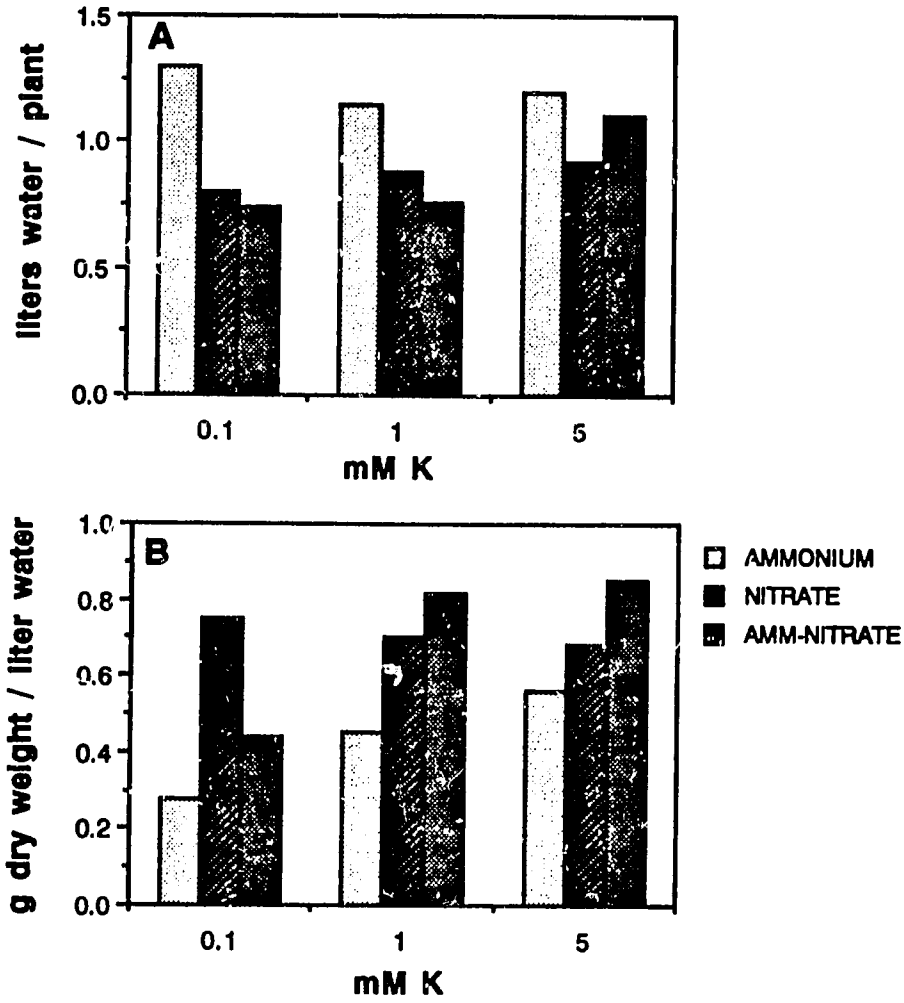


Figure 3: Water use efficiency of 21 day-old wheat plants grown on 4 mM nitrogen suppledl either as ammonium, nitrate or ammonium-nitrate in the presence of different concentrations of K^+.

A - Transpiration (liters water) per plant

B - Water use efficiency - g dry weight/liter water

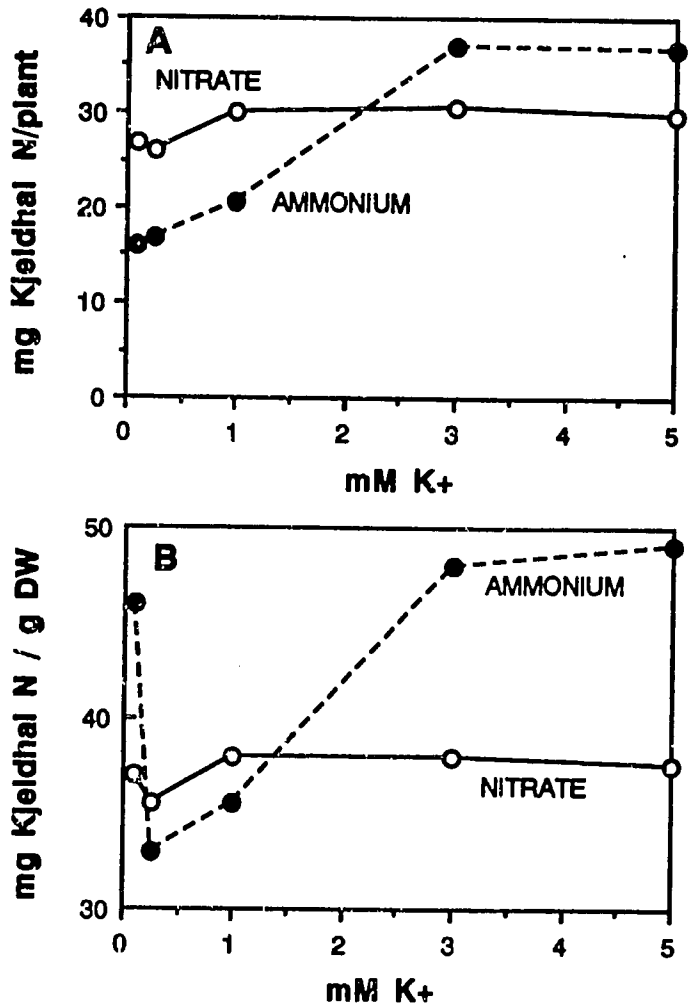


Figure 4: Organic (Kjeldhal) nitrogen content of 21 day-old wheat plants grown on 4 mM nitrogen supplied either as ammonium or nitrate with different levels of K^+ in the nutrient solutions.

A - Organic nitrogen in whole plants

B - Organic nitrogen concentration in plants

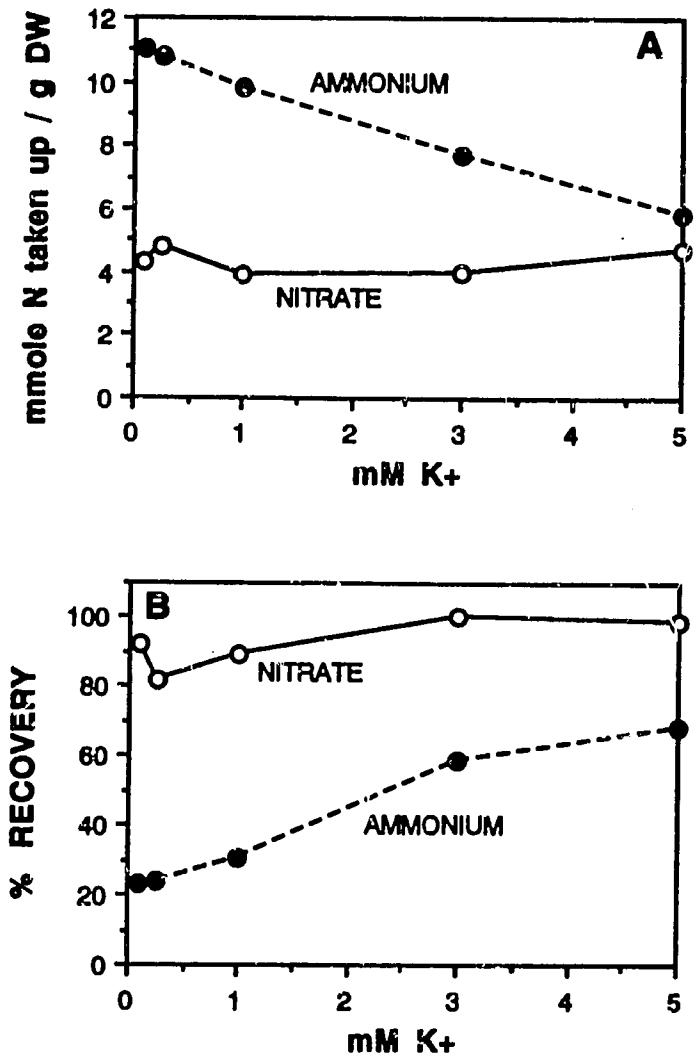


Figure 5: Nitrogen uptake and its assimilation to organic nitrogen compounds in 21 day old wheat plants grown on 4 mM of either ammonium or nitrate nitrogen and different concentrations of K^+ in the nutrient solutions.

A - Uptake of nitrogen per g dry weight of roots

B - Percent nitrogen taken up recovered in plant as organic nitrogen.

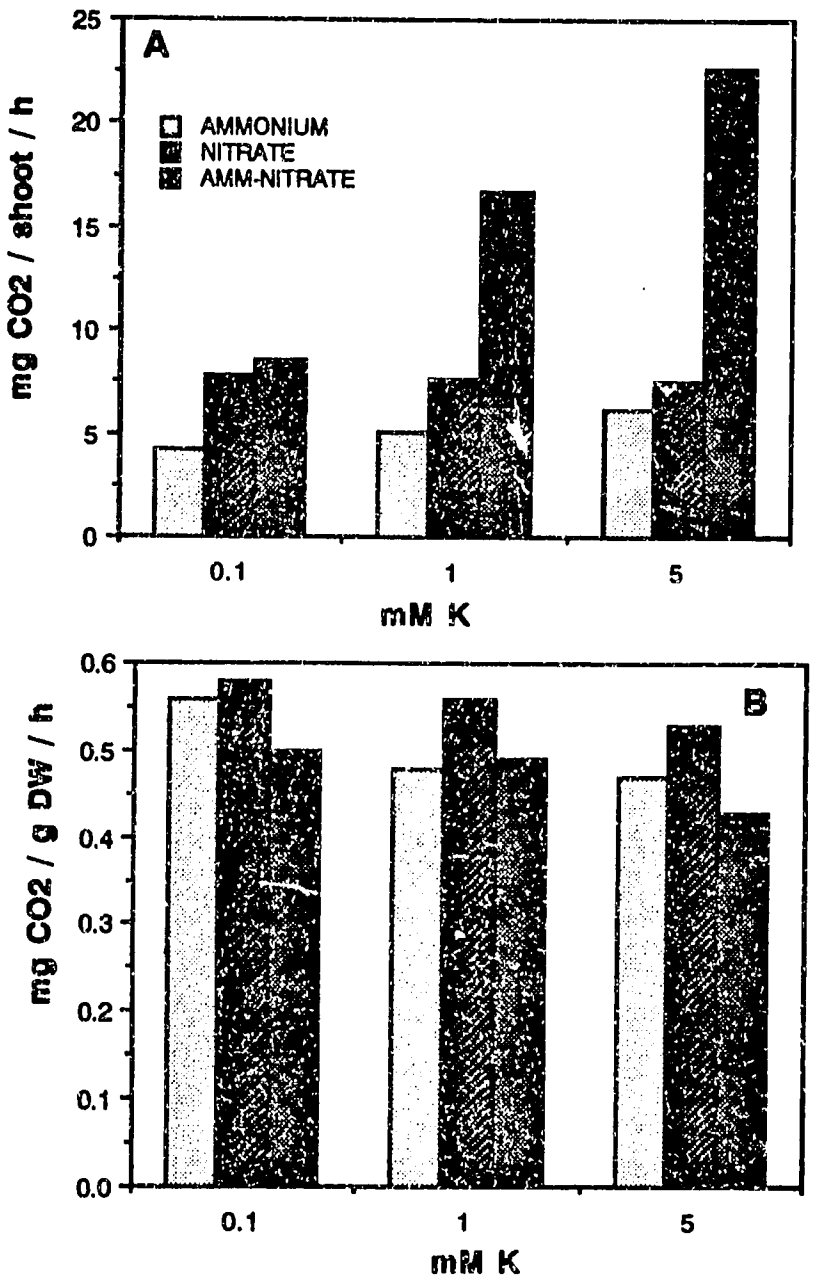


Figure 6: Photosynthesis rates per hour of wheat plants grown on either ammonium, nitrate or ammonium nitrate nitrogen and different concentrations of K^+ in the nutrient medium.

A - Photosynthesis of the entire shoot

B - Photosynthesis per gram dry weight of shoot

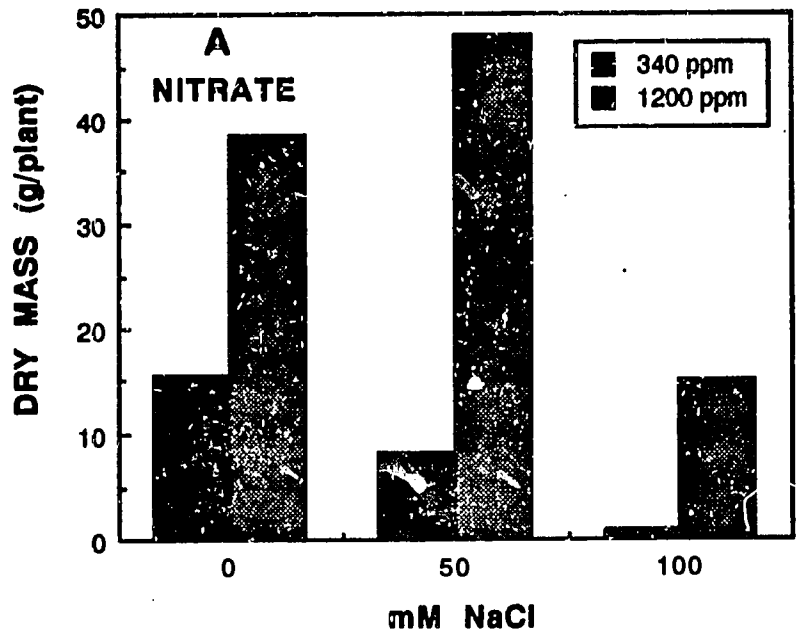


Figure 7: Biomass production of sunflower plants grown on 4 mM nitrogen. Two initially identical batches of plants were grown under low (340 ppm) and high (1200 ppm) CO_2 in the presence of of 0, 50 and 100 mM NaCl.
A - Nitrate supplied to nutrient solution.
B - Ammonium supplied to nutrient solutions.

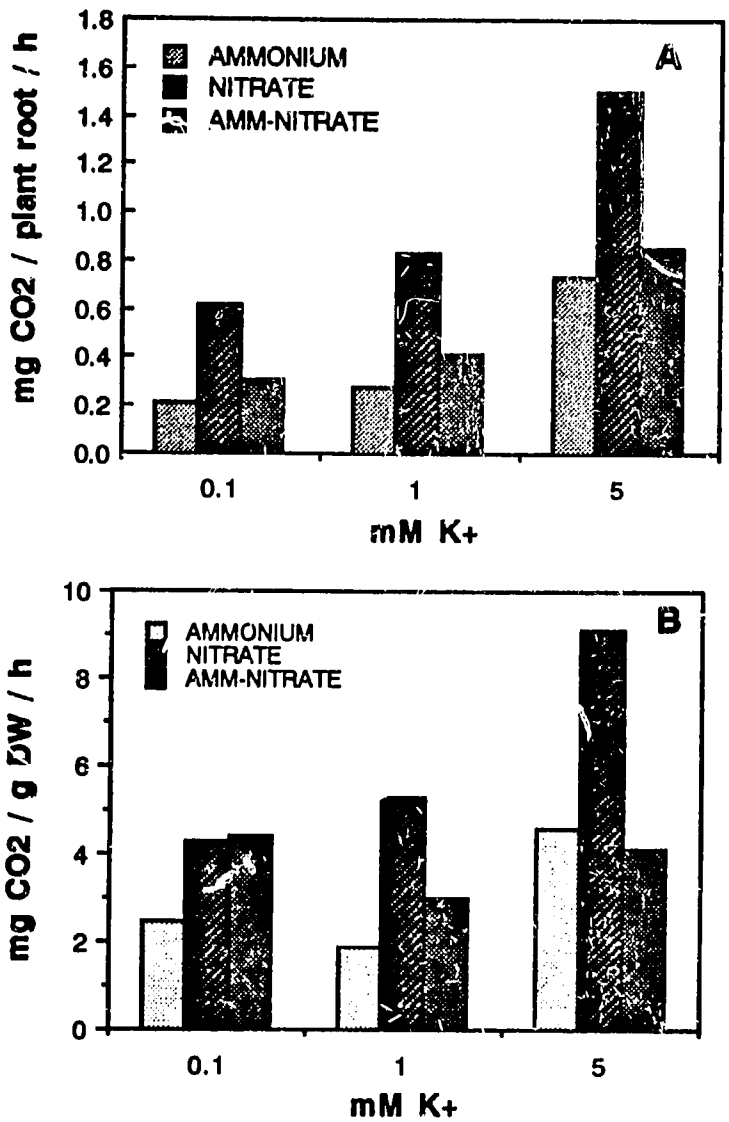


Figure 8: Respiration (CO_2 evolution) rate of roots of wheat plants grown on either ammonium, nitrate or ammonium-nitrate nitrogen and different concentrations of K^+ in the nutrient medium.

A - CO_2 evolution by whole roots per hour.

B - CO_2 evolution per g dry weight root per hour

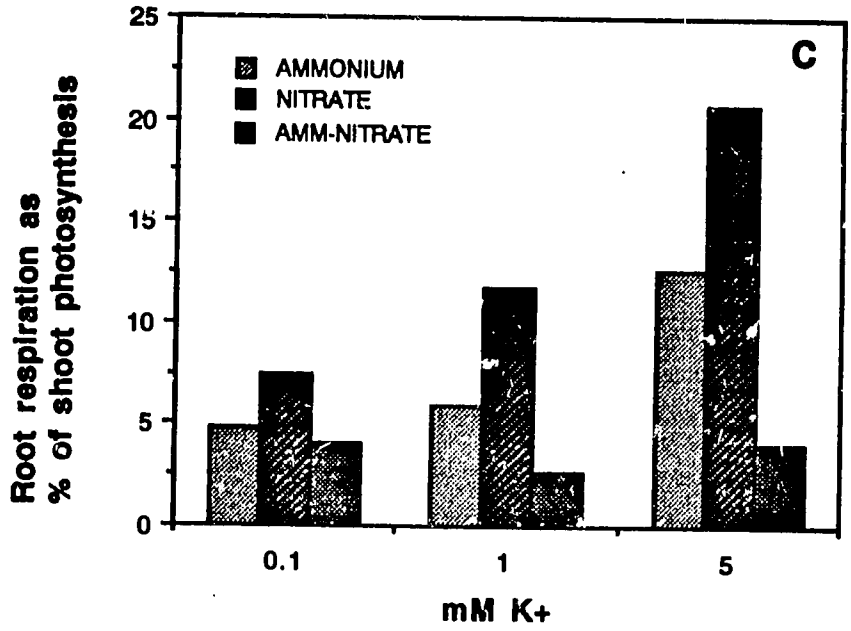


Figure 8c: Root respiration expressed as percentage of shoot photosynthesis. Wheat plants grown on either ammonium, nitrate or ammonium-nitrate and different concentrations of K^+ in the nutrient medium.

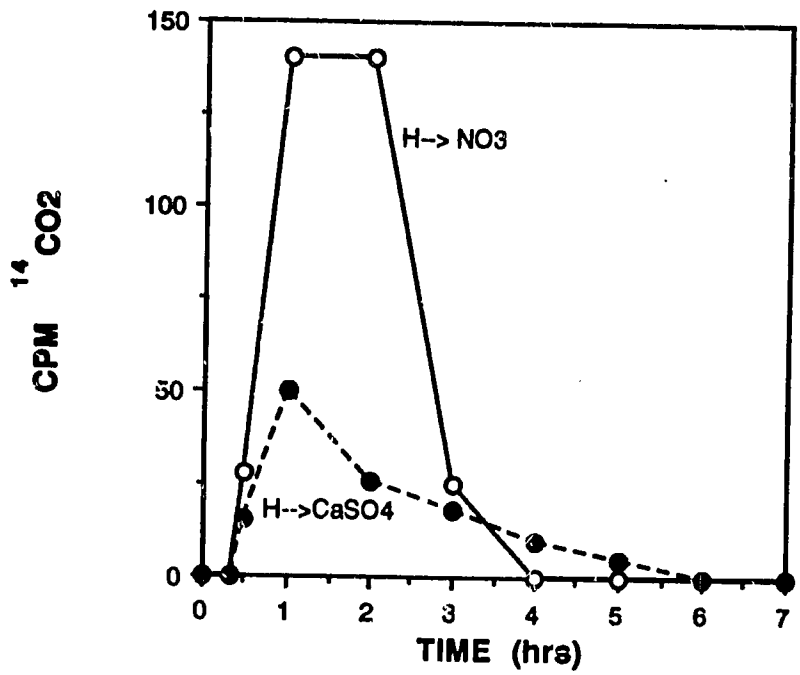
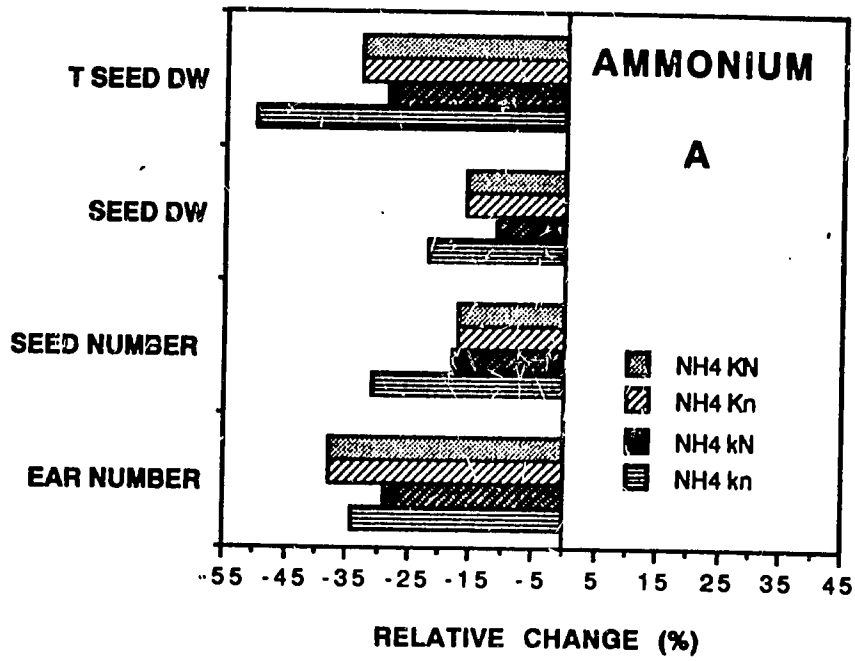


Figure 9: Respiratory $^{14}CO_2$ evolution from roots following $^{14}CO_2$-pulse to photosynthesizing leaf of tomato plant. Plants were grown in Hoagland nutrient solutions (H) and transfered to either NO_3^- or $CaSO_4$ for three days prior to pulse.



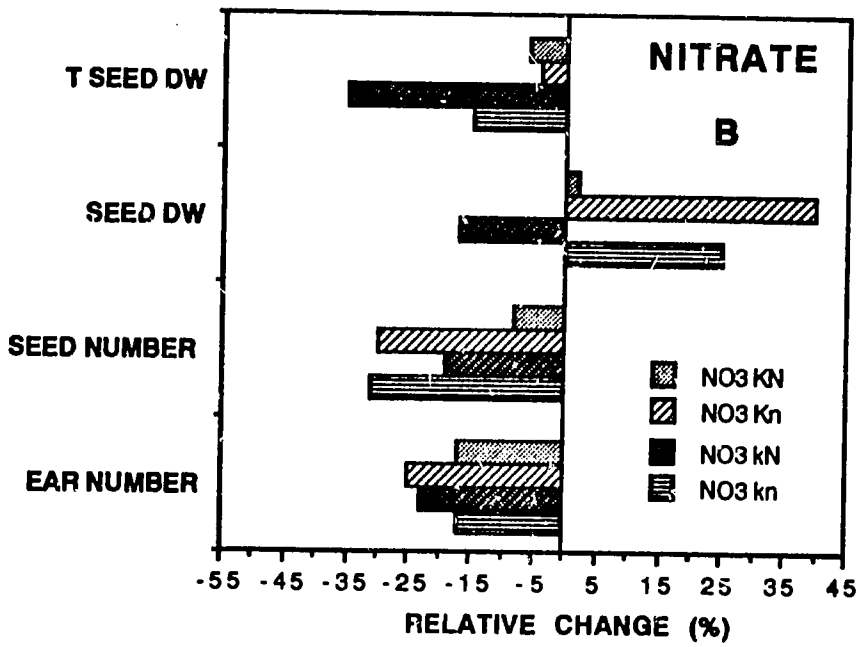


Figure 10: The relative effect of 60 mM NaCl on different parameters of the reproductive growth of wheat fed different concentrations of nitrogen (A - ammonium, B - nitrate) and potassium.

k, K - 0.5 and 5 mM K^+ in nutrient solution, respectively.
n, N - 2 and 6 mM nitrogen in nutrient solution, respectively
T SEED DW, total dry weight of seeds harvested.
SEED DW, individual average grain dry weight in treatment.

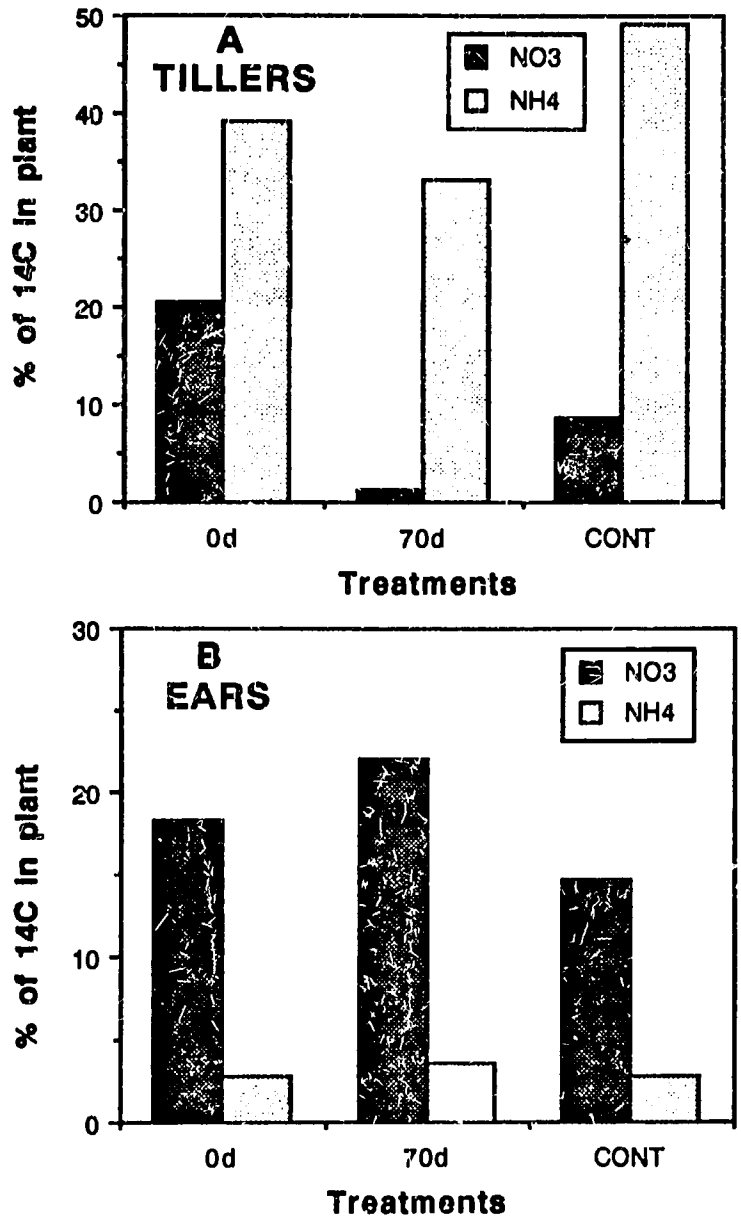


Figure 11: Radioactivity allocation in young wheat plant parts as percentage of total radioactivity, 24 hours after $^{14}CO_2$ pulse. Three groups of wheat plants grown on either ammonium or nitrate where exposed to 60 mM NaCl from the beginning of the experiment (0d), after 70 days growth (70d) or not at all (CONT).
A - Radioactivity in tillers as % of total label in plant
B - Radioactivity in ears as % of total label in plant

FOLIAR FERTILIZATION OF PLANTS IRRIGATED WITH BRACKISH WATER

Giskin M. L., R. Shaked and S. H. Lips
Plant Adaptation Research Unit, J. Blaustein Institute for Desert Research, Ben-Gurion University of the Negev. Sede Boqer, Israel.

Introduction

In the past several decades heavy and often indiscriminate applications of fertilizers, herbicides and pesticides to highly enriched soils have frequently caused heavy damage to our environment. This is seen notably in the contamination lakes, rivers and aquifers (Jackson, 1982). Also, energy and other inputs have increased in cost and, this in turn, has raised the outlay for agricultural production (Neilsen and MacKenzie, 1977). The combination of these ecological and economical considerations have brought on the realization that further, significant contributions to world food production must come from crops grown in relatively nutrient-poor and problematic soils and where limited resources and irrigations water are available.

In some circumstances, foliar fertilization may be the only or the most effective means for applying essential nutrients. This is the case of saline lands or lands irrigated with brackish water. Enhanced nitrogen fertilization of plants irrigated with saline water brought about a decrease in salinity damage to peanut (Silberbush and Lips, 1989) and wheat plants (Leidi, Silberbush and Lips, 1989). Experiments with maize have shown that the alleviation effects is greater with sprinkler than with trickle fertigation (Magnusson, Ben Asher and Lips, 1989). The use of foliar fertilization, rather than sprinkler fertigation was not directly assessed in these experiments.

In recent years the foliar application of essential nutrients (alone or in combination) has increased and has been used for a variety of purposes. These have included:

1. Increasing yields of maize, soybean and other field and row crops (Garcia and Hanway, 1976; Giskin and Efron, 1986).

2. Correction of specific macro and micronutritional deficiencies (Lauer, 1982).

3. Improving the storage characteristics of fruits (Yogaratnam and Sharples, 1982).

4. Increasing the quality and sugar content of muskmelon (Giskin and Nerson, 1984).

In view of the results reported by Magnusson *et al* (1989) which point to a nitrogen uptake system extremely sensitive to NaCl in the root system of maize, the convenience to bypass this sensitivity by supplying essential mineral nutrients through the leaves, became evident. It was proposed to study the effect of foliar application of NPK on the development of maize plant irrigated with brackish water.

Material and methods

A pot experiment was initiated on the grounds of the Blaustein Institute for Desert Research. There were five concentrations of foliar fertilizer solutions of NPK: 0, 2, 3, 4, and 5 per cent. The ratio of NPK in the foliar solutions was 7:1:1. The solutions were prepared from APP (ammonium polyphosphate), urea and K_2SO_4. Dune sand was used as the growth medium. To create a saline substrate, a 60 mM solutions of NaCl was applied to the dune sand. When needed, the sand was fertilized with salt solutions normally used in hydroponics. Ten kg of dune sand were placed over 3 kg of gravel in black polyethylene bags. The experimental crop was maize (*Zea mays* L., var. Jubilee). The four substrate treatments and five foliar treatments were as described in table 1.

TABLE 1: Soil and foliar fertilizer treatments used

Treatments	Application to soil	Foliar application % NPK
A	Fertilizer + 60 mM NaCl	
B	Fertilizer only	
C	60 mM NaCl	
D	Control	
1		0
2		2
3		3
4		4
5		5

Four seeds were sown to each container. Germination took place within 4 days at which time the containers were thinned to two plants per container. Substrate treatments (A to D) were carried out at five weekly intervals, beginning 4 days after germination.

Foliar applications were initiated at the 4-leaf stage. There were three applications which took place on days 14, 21 and 31 after germination. All foliar applications were carried out at dusk. Transpiration rates, photosynthesis and stomatal conductance of individual plants in all treatments were measured on day 26 after germination (Figures 3, 3a, 3b). The harvest was carried out 40 days after germination, at which time transpiration, photosynthesis and stomatal conductance were determined once more (Figure 4, 4a, 4b) prior to the harvest. Samples for fresh (Figure 1) and dry weight (Figure 2) were also determined at this time.

Results and discussion

Ten days after germination and three days prior to the first foliar fertilization application, the following observations were recorded regarding plant development:

(1) All plants receiving soil fertilization only (treatment B) were developing normally.

(2) Plants without substrate fertilization (treatment D) were smaller and thinner and there was yellowing of the leaf edges.

(3) No effect of salinity (60 mM NaCl) was visually evident upon plant growth. Plants receiving substrate fertilization plus salinity (treatment A) or fertilization without salinity (treatment B) had similar development. This held true for plants which did not receive substrate fertilization with (treatment C) or without (treatment D) addition of salt.

Additional plant development observations on the day of the last foliar fertilizer application showed the following:

(1) The plants which did not receive substrate application of fertilizer had begun to recover after having received half the amount of fertilizer given to the plants in the fertilizer treatment. The application had been carried out 19 days after germination.

(2) The effect of the salinity on plant development is now seen. In all cases, plants having received 60 mM NaCl were smaller in size than those without salt.This held true for the treatments with and without substrate fertilizer application. Other than being smaller in size,

no other effects on plant development were noticeable.

The foliar application of a 4 or 5 percent solution of NPK, regardless of the substrate treatment, in the majority of the cases increased the rates of photosynthesis, stomatal conductance and transpiration. This was most noticeable in treatments C (includes 60 mM NaCl) and D (control, no additions). With time the positive influence of the foliar fertilizer applications decreases. By the date of harvest (40 days after germination), the stubstrate treatment was more influential than it had been at an earlier growth stage.

The fresh and dry weights of the maize plants harvested in day 40 after germination are shown in Figures 1 and 2. It may be seen from these figures that the foliar application of NPK had little or no influence on the development of plants when they are grown in a substrate fertility level that is sub-standard (in our case zero fertilization) or a high level of salinity only. On the other hand, these same figures show that three of the foliar applications of a five percent solution of NPK results in a significant increase in the dry weights of maize plants grown on substrates having received adequate fertilization (treatment B). In addition, treatment A shows that this same significant increase in dry weight is achieved under saline conditions where the substrate has received adequate amounts of plant nutrients.

The results presented indicate that foliar fertilization may constitute an agrotechnique of significant effectiveness to obtain normal yields by salt-sensitive crops where brackish waters are used in irrigation.

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Figure 1
Fresh weight

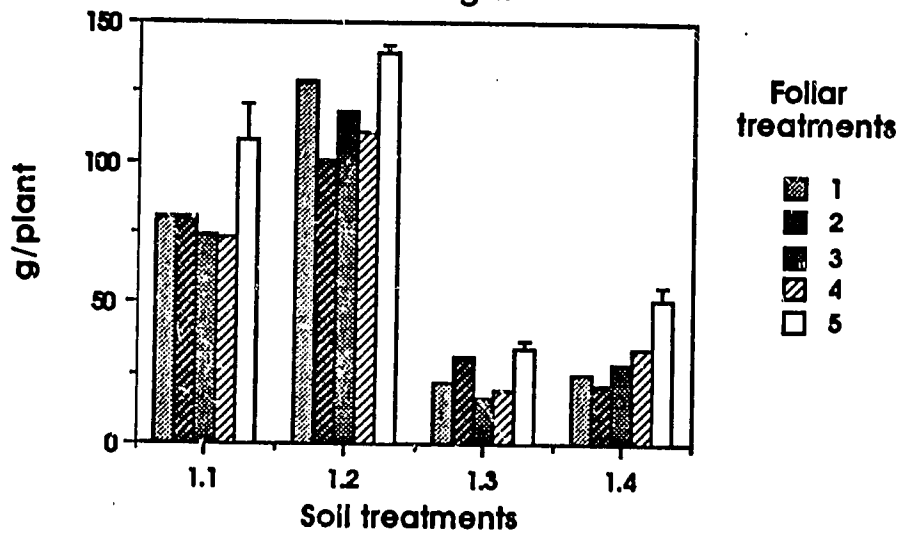


Figure 2
Dry weight

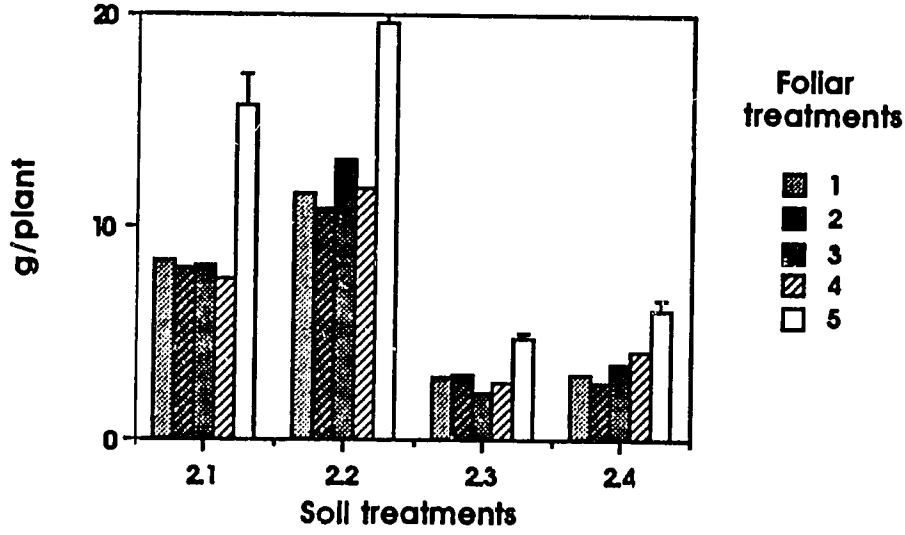


Figure 3a

Photosynthesis rate

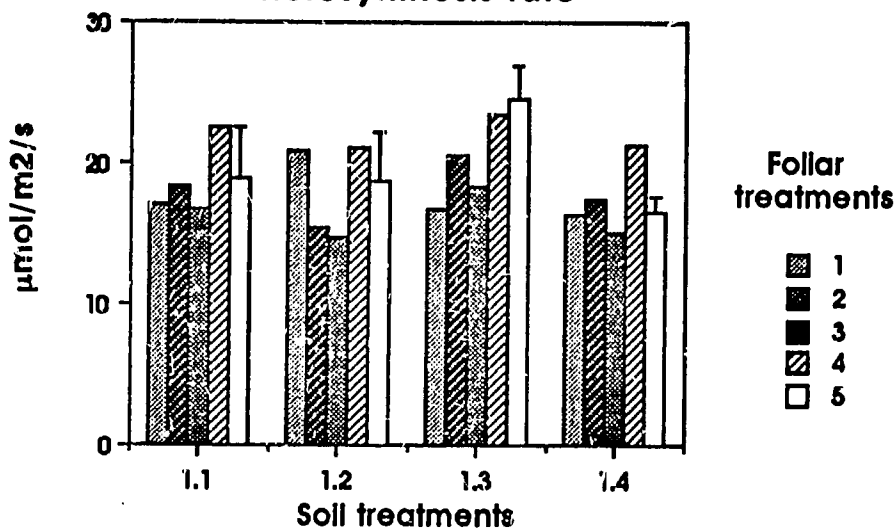
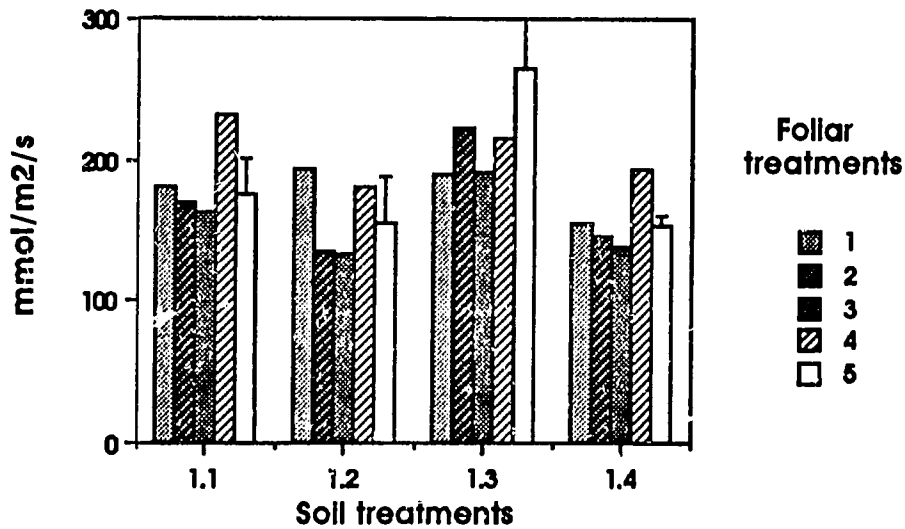


Figure 3b

Stomatal conductance



Saline Water Irrigation and KNO_3 Fertilization in Peanut

E.P. Pacardo

Institute for environmental Science and Management, University of the Philippines at Los Banos, College Laguna, Philippines.

Introduction

The deleterious effects of salinity on different growth processes have already been documented. Some of these growth processes include cell enlargement and division (Nieman, 1965), protein synthesis (Weimberg, 1975) and many others.
Experimental evidences have shown the possibility of using KNO_3 fertilizers to ameliorate the toxic effects of salinity on plants. In Israel for example, peanuts were grown successfully for two years in the sand dunes using saline irrigation water (EC= 1.6 - 6.5 mmhos/cm) mixed with various concentrations of KNO_3 applied through trickle irrigation system (Silberbush et. al, 1985). The Israeli researchers therefore arrived at a conclusion that salinity hazards in salt sensitive crops can be reduced by adequate nitrogen fertilization.
In this study, we are reporting the results of preliminary experiment on the effect of KNO_3 on peanuts grown in NaCl stressed conditions.

Materials and Methods

This experiment was laid out in a 3 x 4 factorial in randomized complete block design (RCBD) with three replications. The treatments were different concentrations of KNO_3 : 0, 75, 150 and 350 ppm and water electrical conductivity levels: 0, 4, 8 mmhos/cm at 25°C, achieved by NaCl. Treatment application started 1 month after seed sowing. The solution mixtures of NaCl and KNO_3 were applied through simulated drip irrigation system using dextrose assembly. KNO_3 application was withdrawn at the 4th month, and replaced by NH_4Cl at reproductive stage 4. The plants were harvested at the 5th month after seed sowing, and growth and yield parameters were measured.

RESULTS AND DISCUSSION

A. GROWTH DATA

No significant interaction between NaCl and KNO_3 was observed in all growth parameters, as shown in Table 1. However, different NaCl levels had highly significant effects on almost all growth parameters except of shoot dry weight (Table 1). The significant effects of KNO_3 alone was observed only on root length and shoot dry weight.

The growth response of peanut to NaCl salinity can be clearly seen in Table 2. The general trend indicates a significant decrease in growth of peanut as the level of NaCl increased.
On the other hand, significant effects of KNO_3 on shoot dry weight and root lenght are shown in Table 3. Addition of KNO_3 apparently enhanced root elongation and dry matter accumulation i shoot of peanuts grown in salt-stressed conditions. The results agree with the observation of Helal (1979) in Vicia faba (broad beans). Increasing the supply of K^+ improved the growth of the salt-stressed plants despite of the increasing osmotic potential of the medium (Helal, 1979).

B. YIELD DATA

Significant interaction between NaCl salinity and KNO_3 was observed on the pod yield of peanuts As shown in Table 4, dry pod yield generally decreased with increasing NaCl level. However, addition of KNO_3 improved the pod yield of peanuts grown in salt stressed condition. At 4 mmhos/cm, the highest yield was observed when 75 ppm KNO_3 was supplied in the growth medium. On the other hand, higher concentration of KNO_3 (150 ppm) was needed at 8.0 mmhos/cm. The results support previous observations on similar experiments in peanuts (Silberbush et al. 1985 and Reano et al. 1987).

Table 1. Summarized ANOVA results on the effect of different Levels of NaCl salinity and KNO_3 on the growth and yield of peanut. (UPLB, Philippines, 1988).

PARAMETERS	NaCl Levels (mmhos/cm)	KNO_3 (ppm)	NaCl x KNO_3
(1) Root Fresh wt (g)	**	ns	ns
(2) Root Dry wt (g)	**	ns	ns
(3) Root Lenght (cm)	**	*	ns
(4) Shoot Fresh wt (g)	**	ns	ns
(5) Shoot Dry wt (g)	ns	**	ns
(6) Shoot Lenght (cm)	**	ns	ns
(7) Dry wt. of pods (g)	**	ns	*

* = Significant at 5% Level

** = Highly significant at 1% Level

ns = Not significant.

Table 2. Effect of different NaCl Levels on the growth of peanut. (UPLB, Philippines, 1988). [1]

NaCl Levels (mmhos/cm)	Root Fresh wt (g)	Root Dry wt (g)	Root Lenght (cm)	Shoot Fresh wt (g)	Shoot Lenght (cm)
0	43.83 a	9.60 a	45.54 a	190.02 a	93.83 a
4	17.70 b	3.11 b	37.84 bc	130.41 c	77.21 b
8	6.94 c	1.77 c	33.29 c	153.70 b	58.29 c

1. Means within a column followed by common letters are not significantly different ($p \leq 0.05$) according to Duncan's Multiple Range Test.

Table 3. Effect of different KNO_3 concentrations on root lenght and shoot dry weight of peanut. (UPLB, Philippines, 1988). [1]

KNO_3 concentration (ppm)	Root Lenght (cm)	Shoot Dry Weight (g)
0	39.05 a	39.89 b
75	44.33 a	49.53 a
150	33.28 b	42.53 a
350	38.89 a	61.52 a

1. Means within a column followed by common letters are not significantly different ($p \leq 0.05$) according to Duncan's Multiple Range Test.

Table 4. Dry weight of peanut pods as affected by different levels of NaCl and KNO_3. (UPLB) Philippines, 1988). [1]

KNO_3 (ppm)	NaCl Salinity 0	Levels 4	(mmhos/cm) 8
0	39.8 a	16.7 ch	6.33 h
75	32.5 abc	33.97 ab	13.33 gh
150	31.6 ad	22.77 cg	12.77 gh
350	26.73 bc	25.97 bf	10.1 h

1. Means within a column followed by common letters are not significantly different ($p \leq 0.05$) according to Duncan's Multiple Range Test.

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Simulated water and solute distribution from a crossed triple line-source

D. A. Magnusson and J. Ben Asher

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

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Summary. Multivariable irrigation experiments are usually expensive and seldom cover the whole range of desired values. The crossed triple line-source (CTLS) was designed to provide a relatively simple and inexpensive irrigation system for creating continuous gradients of more than one variable. A computer model was developed to assist in evaluating the continuously changing multivariable levels, produced by the CTLS, given various inputs. A single sprinkler's distribution function was used in the model's development. The results of the overlapping sprinkling patterns are calculated throughout the experimental area for water depth, salinity level, and Nitrogen concentration. Measured values of irrigation water electrical conductivity (EC_i) and Nitrogen concentration were in good agreement with predicted values.

The line-source sprinkler system (Hanks et al. 1976) is an example where controlled nonuniformity of water application is used to create a desired gradient. Lauer (1983) further developed this concept by constructing three parallel lines and injecting Nitrogen into the middle line. This triple line-source created a Nitrogen gradient on either side of the middle line, while maintaining a uniform water application. Recently, Magnusson et al. (1989) used a variation of the triple line-source to study the combined effects of salinity and Nitrogen fertilizer on corn yield. In this experiment crossed gradients of two variables (salinity and Nitrogen) were generated by the CTLS. The geometry of this system is presented in Fig. 1. The experimental area is divided into four plots. Because the two gradients are superimposed and perpendicular to one another, any point in a plot receives a different combination of salts and Nitrogen.

Numerous questions are raised when designing such a system; such as selecting the appropriate sprinklers and their spacing, evaluating the distribution of water, salts, and nutrients for each selection, and formulating the related sampling policy. Addressing all these questions by a field study would require considerable time, labor, and financial resources. Thus a model, which could simulate the distribution of the major variables of the system, becomes an attractive approach for examining these questions. Willardson et al. (1987) developed a model for selecting the best sprinkler and spacing to maximize uniformity in line-source experiments. This paper describes a computational procedure that was developed to simulate the CTLS performance, including distribution of water, salts, and Nitrogen over the experimental area.

Procedure

A preliminary test was conducted to determine the appropriate sprinkler for the irrigation system. A sprinkler was required that would produce a linear distribution and a wetting radius of 10.0–12.0 m. Catch cans were placed every 0.5 m along the radius the wetted circle of one sprinkler. Each sprinkler tested was operated for 30 minutes under four different pressures (0.20, 0.30, 0.35, 0.40 MPa) in an enclosed shed. Water amounts from each can were collected and measured. The data from the preliminary experiment for Naan sprinkler 323/92 (the one chosen for our system) are shown in Fig. 2. The water distribution functions of the experimental results are described by two linear regression equations:

$$I(d)=\begin{cases}25.1-9.11\,d; & 0.0<d\leq 1.6\\ 12.4-1.24\,d; & \text{for } 1.6<d\leq D\\ 0.0; & \text{when } d>D\end{cases} \quad (1)$$

where $I(d)$ is the application rate (mm/h) at distance d (m) from the sprinkler, and D is the wetted radius (m).

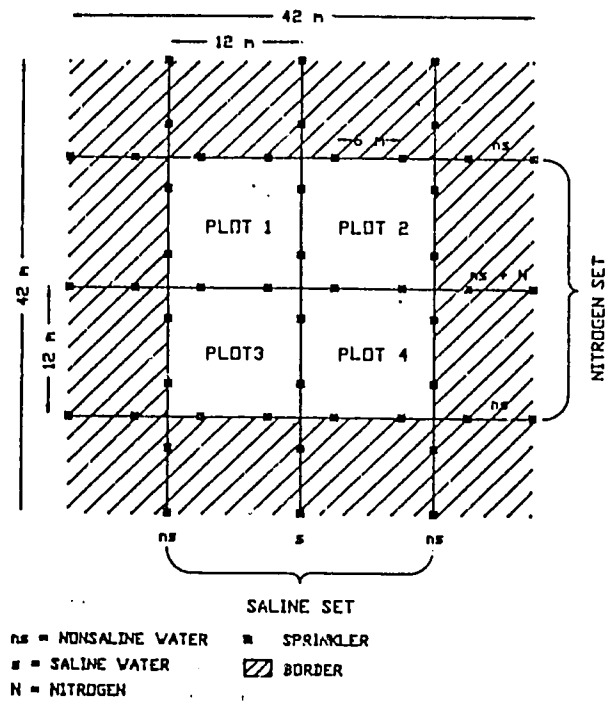

Fig. 1. Overview of the crossed triple line-source (CTLS) irrigation system

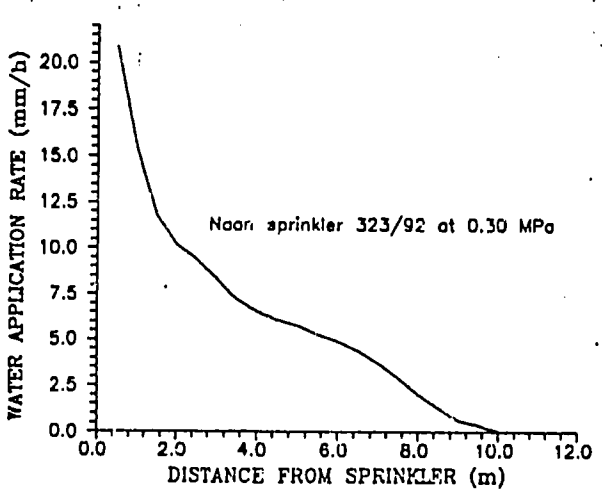

Fig. 2. Measured water distribution from a single sprinkler. Sprinkler height = 40.0 cm

The correlation coefficients of the regression lines for the two equations were 0.98 and 0.99, respectively.

Actual field measurements were taken from various locations in the experimental plot. The sampling technique was described earlier (Magnusson et al. 1989) and here only the additional details relevant to this study are mentioned. Water meters were placed on both the saline and nonsaline main lines and were read before and after every irrigation. The EC of both water sources was monitored throughout the season. The saline water had an average EC of 7.0 dS/m, whereas the nonsaline water averaged 1.0 dS/m. Ammonium nitrate was injected into the middle line of the Nitrogen set using a diaphragm injection pump. This system pulsed a predetermined amount of NH_4NO_3 solution into the middle line. Accuracy of the pump was checked by measuring the volume of the solution in the container before and after irrigations. Samples of water applied to the plot were collected from each irrigation using 10 cm diameter funnels attached to collection bottles. In order to minimize the effects of evaporation, irrigations were applied at night and the water samples were taken to the lab the following morning and measured for Nitrogen, EC, and depth of irrigation. Wind speed never exceeded 0.5 m/s during any of the reported irrigations.

An overview of the CTLS is shown in Fig. 1. This system is composed of two irrigation sets, the Nitrogen set which creates the Nitrogen gradient and the saline set which creates the salinity gradient. The experimental area created by the CTLS is divided into four plots, each plot being a mirror image of its neighbor. It is therefore sufficient to simulate the distribution pattern in one plot in order to study the concentration of nutrients and salts over the entire CTLS experimental area.

In this example irrigation was applied with the two sets separately. The saline set was operated first and applied most of the water. Only the small amount of water necessary to apply Nitrogen and rinse any salts from the leaves was given through the Nitrogen set. Thus, irrigations were given by two time sets.

Computational scheme

The boundaries of a single plot are marked by eight sprinklers (Fig. 1). The geometry of the field is described by two sets of coordinates. One set identifies sites on the field such as x_p and y_p with respect to the plain coordinates x and y. The second set of subscripts identifies this point with respect to its distance from the contributing sprinklers, x_s and y_s.

Each sprinkler (s) can be identified by its coordinates, solute concentration, and duration of irrigation as:

$$s(x_s, y_s, C_s, t_s)$$

where t is the duration of irrigation (h) and C is the solute concentration (kg/m^3). Water from all sprinkling sources is mixed at various proportions at any point p within the boundaries of the plot. The purpose of the simulation model is to predict the resultant amount of water, salts, and nutrients at p.

Table 1. Simulated output data for a typical irrigation using the CTLS. Amount of water supplied through the saline and Nitrogen sets were 40.0 and 6.0 m^3 respectively. Saline water EC = 7.0, nonsaline water EC = 1.0 (*d*S/m). (A) Total water distribution from all contributing sprinklers in one plot; (B) Resultant electrical conductivity of the irrigation water; (C) Resultant Nitrogen concentration. (NH_4NO_3 solution applied = 4.0 l, applicable to C only)

Table 1 A

Dist. from *N* line (m)	Distance from saline line (m)											
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5
	(mm)											
0.5	32.0	30.0	30.0	29.0	27.0	27.0	27.0	27.0	29.0	30.0	30.0	32.0
1.5	32.0	31.0	29.0	28.0	28.0	27.0	27.0	28.0	28.0	29.0	31.0	32.0
2.5	44.0	32.0	30.0	28.0	28.0	28.0	28.0	28.0	28.0	30.0	32.0	44.0
3.5	43.0	32.0	30.0	28.0	27.0	28.0	28.0	27.0	28.0	30.0	32.0	43.0
4.5	32.0	30.0	29.0	28.0	27.0	27.0	27.0	27.0	28.0	29.0	30.0	32.0
5.5	31.0	30.0	27.0	27.0	27.0	26.0	26.0	27.0	27.0	27.0	30.0	31.0
6.5	31.0	30.0	27.0	27.0	27.0	26.0	26.0	27.0	27.0	27.0	30.0	31.0
7.5	32.0	30.0	29.0	28.0	27.0	27.0	27.0	27.0	28.0	29.0	30.0	32.0
8.5	43.0	32.0	30.0	28.0	27.0	28.0	28.0	27.0	28.0	30.0	32.0	43.0
9.5	44.0	32.0	30.0	28.0	28.0	28.0	28.0	28.0	28.0	30.0	32.0	44.0
10.5	32.0	31.0	29.0	28.0	28.0	27.0	27.0	28.0	28.0	29.0	31.0	32.0
11.5	32.0	30.0	30.0	29.0	27.0	27.0	27.0	27.0	29.0	30.0	30.0	32.0

The distance between any sprinkler and any point p is

$$d_{sp} = SQR[(x_s - x_p)^2 + (y_s - y_p)^2]. \quad (2)$$

Water application rate at point p due to sprinkler s is a function of this distance and can be expressed as

$$I_{sp} = f\{d_{sp}\}. \quad (3)$$

However, p is subject to input from a large number of sprinklers and their additive intensity ($m^3/m^2/h$) is

$$I_p = \underset{s}{SUM}[I_{sp}]. \quad (4)$$

By including the length of time each sprinkler irrigates, the total depth of water applied at p (m^3/m^2) can be expressed as

$$Q_p = \underset{s}{SUM}[t_s I_{sp}]. \quad (5)$$

The total salt application (TS, kg/m^2) at p is

$$TS_p = \underset{s}{SUM}[C_s t_s I_{sp}]. \quad (6)$$

The expression in Eq. (6) is similar for Nitrogen with TN_p representing the total amount of Nitrogen applied (kg/m^2) at p.

Required input and generated output

Required inputs are EC of saline and nonsaline water, amount of water applied by each set, and volume of NH_4NO_3 solution applied through the system. Amount of pure Nitrogen (kg) is calculated assuming the NH_4NO_3 solution is 20.0% Nitrogen and has a specific weight of 1.26 kg/l. Since each of the three lines in the Nitrogen set applies equal water amounts, the volume of water applied by the Nitrogen source line is easily determined. The Nitrogen concentration (mg/l) in the Nitrogen source line is calculated from this information.

Generated output includes Nitrogen, salt, and water distribution, irrigation uniformity, duration of irrigation for each set, and average water depth applied throughout the plot. Point values for water, Nitrogen, and salt distribution are calculated beginning at 0.5 m from any line and are equilaterally spaced 1.0 m from one another. Thus in a single plot, 12 m by 12 m, 144 point values are calculated. Water depth is reported in mm, EC_1 in *d*S/m, and Nitrogen is displayed both as a concentration (mg/l) and as an amount (kg/ha).

Results and discussion

Table 1 shows a typical output for water amount, EC_1, and Nitrogen concentration. The data reveal a higher variation of water application near the sprinklers but more uniform distribution toward the center of the plot. Low water uniformity had a negligible effect on EC_1, as can be seen in Table 1 A and 1 B. For example, differences of 37.5% in water application amounts (see column 1 in Table 1 A) were associated with only a

Table 1 B

Dist. from *N* line (m)	Distance from saline line (m)											
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5
	(*d*S/m)											
0.5	6.2	6.2	5.7	5.1	4.6	3.9	3.2	2.4	1.7	1.1	1.0	1.0
1.5	6.3	6.2	6.0	5.5	4.8	4.0	3.1	2.3	1.6	1.1	1.0	1.0
2.5	6.5	6.3	6.0	5.6	5.0	4.1	3.2	2.2	1.5	1.2	1.0	1.0
3.5	6.5	6.3	6.1	5.7	5.0	4.1	3.2	2.2	1.6	1.2	1.0	1.0
4.5	6.3	6.3	6.1	5.6	4.8	4.1	3.1	2.4	1.7	1.1	1.0	1.0
5.5	6.3	6.3	6.1	5.4	4.7	4.0	3.3	2.5	1.7	1.1	1.0	1.0
6.5	6.3	6.3	6.1	5.4	4.7	4.0	3.3	2.5	1.7	1.1	1.0	1.0
7.5	6.3	6.3	6.1	5.6	4.8	4.1	3.1	2.4	1.7	1.1	1.0	1.0
8.5	6.5	6.3	6.1	5.7	5.0	4.1	3.2	2.2	1.6	1.2	1.0	1.0
9.5	6.5	6.3	6.0	5.6	5.0	4.1	3.2	2.2	1.5	1.2	1.0	1.0
10.5	6.3	6.2	6.0	5.5	4.8	4.0	3.1	2.3	1.6	1.1	1.0	1.0
11.5	6.2	6.2	5.7	5.1	4.6	3.9	3.2	2.4	1.7	1.1	1.0	1.0

Table 1 C

Dist. from *N* line (m)	Distance from saline line (m)											
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5
	N (mg/l)											
0.5	66.0	71.0	102.0	103.0	78.0	78.0	78.0	78.0	103.0	102.0	71.0	66.0
1.5	61.0	66.0	72.0	74.0	73.0	73.0	73.0	73.0	74.0	72.0	66.0	61.0
2.5	41.0	58.0	64.0	67.0	67.0	64.0	64.0	67.0	67.0	64.0	58.0	41.0
3.5	35.0	51.0	56.0	59.0	58.0	55.0	55.0	58.0	59.0	56.0	51.0	35.0
4.5	39.0	44.0	48.0	49.0	49.0	47.0	47.0	49.0	49.0	48.0	44.0	39.0
5.5	32.0	35.0	39.0	40.0	39.0	37.0	37.0	39.0	40.0	39.0	35.0	32.0
6.5	24.0	24.0	28.0	28.0	27.0	28.0	28.0	27.0	28.0	28.0	24.0	24.0
7.5	16.0	16.0	15.0	15.0	17.0	19.0	19.0	17.0	15.0	15.0	16.0	16.0
8.5	6.0	7.0	7.0	7.0	8.0	9.0	9.0	8.0	7.0	7.0	7.0	6.0
9.5	1.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0
10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

4.8% change in EC_i (see column 1 in Table 1 B). In this simulation, this "buffering" effect occurred because the saline set supplied the majority of the water. The relatively small amount of water received from the Nitrogen set had little affect on the final salt concentration. Thus, the same effect would be seen in Nitrogen concentration if the Nitrogen set was used to apply the majority of the water. Note however, that even though the concentrations are buffered, the actual solute amounts are not.

Although there are many different approaches to evaluating water application uniformity (Seginer 1987), the most commonly used method is still the Christiansen uniformity coefficient (U_c, Christiansen 1941), which reflects the absolute deviation of the samples from the mean value. In this paper U_c is expressed in percent.

Uniformity for each irrigation will vary according to the proportion of water each set applies. The highest uniformity is obtained by applying equal water amounts from both sets, while the lowest uniformity occurs when only one set applies water. This is because the sprinkler density increases when water is applied with two sets. Table 2 shows the range of U_c values that can be expected and the advantage gained by avoiding the 1-meter strip nearest the line. An increase in uniformity of almost 4.0% can be obtained by supplying equal amounts of water from both sets and avoiding the strip nearest the lines.

Irrigation depth and U_c derived from measured and simulated data are compared in Table 3. Simulated values were always higher than those measured. This may be due to many factors, two of the most obvious are mentioned here. First, no attempt was made to

Table 2. The simulated range of possible water application uniformities. U_c = Christiansen uniformity coefficient expressed as percent

	U_c (%)	
	All points	Only points > 1.0 m from any line
Equal water amounts from both sets	93.2	94.4
Water from only one set	90.5	92.3

Table 3. Comparison of simulated and measured values for irrigation depth and U_c

Date	Water depth (mm)		U_c (%)	
	Simulated	Measured	Simulated	Measured
6/16/88	41	36	93.3	92.2
6/18/88	36	34	93.4	91.9
6/21/88	39	36	92.9	92.1

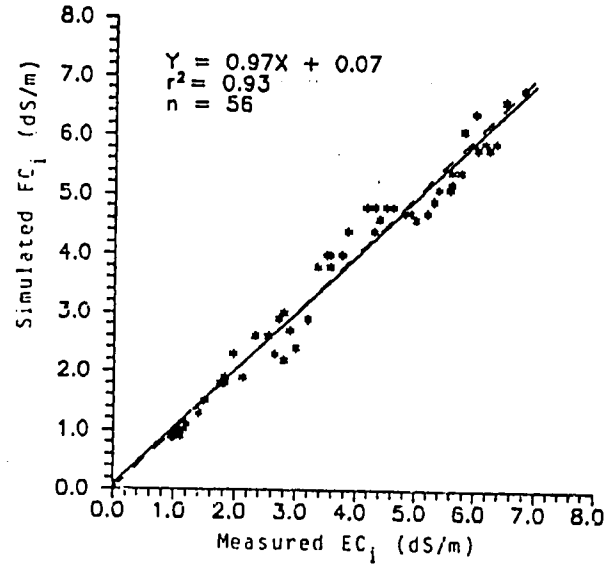

Fig. 3. Simulated and measured irrigation water EC values as created by the CTLS system. Dashed line = 1 : 1 line, solid line = regression line

program wind effects into the model, thus actual values were affected by wind while simulated values were not. Secondly, the water volumes used for these simulations were taken from water meters located outside the plots. It was assumed that all of this water was applied to the plot through the sprinklers. Water lost due to pipe drainage and leakage is not accounted for in the model. Therefore, higher values for the simulated irrigation amounts would be expected.

Simulated and measured EC_i values are compared in Fig. 3. These samples were taken from numerous irrigations throughout the growing season. The high correlation coefficient and a slope near 1.0 indicate good agreement between simulated and measured results.

The simulated versus measured values for Nitrogen concentration (Fig. 4) were very similar to the EC_i results. The Nitrogen values were distributed fairly evenly on either side of the 1 : 1 line except when Nitrogen was very low. These values represent locations farther than 10.0 m from the Nitrogen line. This is beyond the theoretical wetting radius of the sprinklers applying Nitrogen. The model assumes that the irrigation water in and of itself does not contain any Nitrogen. Actually, both saline and nonsaline water contain small Nitrogen amounts.

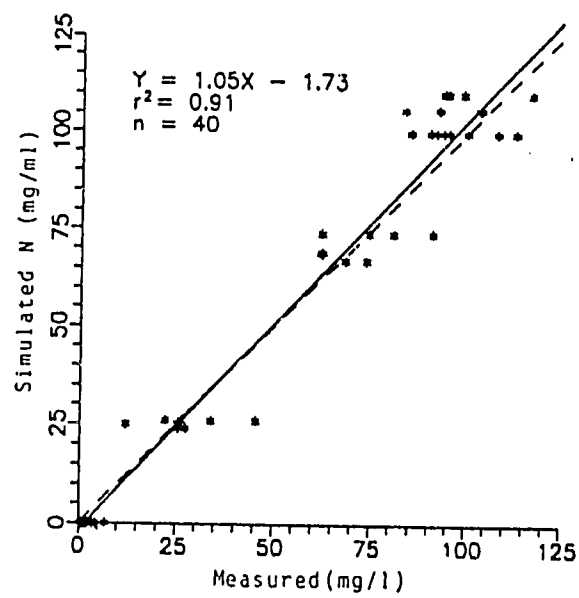

Fig. 4. Simulated and measured Nitrogen concentrations as created by the CTLS system. Dashed line = 1 : 1 line, solid line = regression line

Conclusions

The above results indicate that the model closely simulates actual salinity and Nitrogen distribution over a wide range of values. It provides a quick and accurate method for examining water and variable distribution for a single irrigation or for an entire season produced by the CTLS. The model was also helpful in determining a sampling policy by identifying areas which had undesirable high variations in water and variable amounts. It would require an extreme amount of time and effort to physically gather the same amount of

Firstly, the two sources are situated in somewhat different climates; and secondly, the wilting process at Mambedi Estates can be described as very harsh. It has been shown by van Lelyveld *et al.* (1989) that overwithering can lead to a highly significant reduction in TF values.

For the different grades of black tea, PD was significantly higher ($P \leq 0{,}05$) in TF compared with BOPF and BOP for selections 'Clone', 'MT 12' and 'SFS 204'. It appears, however, that there was a general tendency for higher TF to occur in the fine teas, with lower TF in the coarser grades. This could have resulted from a better overall fermentation in the finer grades, which gives a better exposure to the polyphenol oxidase enzyme and the browning substrates.

While the highest TF values at Mambedi Estate were obtained from 'PC 1' and 'TRI 6/8', further analysis is necessary to prove their superiority.

Acknowledgements

We wish to express our thanks to Mr A. Toerien for the statistical analysis.

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Interaction of nitrogen fertilization and irrigation water salinity on growth of maize (*Zea mays* L.) in a two-way line-source sprinkler system

R.E. Steynberg*

Department of Plant Production, University of Pretoria, Pretoria, 0002 Republic of South Africa

D. Magnusson, Y. Ben-Asher and M. Silberbush

Jacob Blaustein Institute for Desert Research, Ben-Gurion University of the Negev, Beersheva, 84990, Israel

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Maize was planted in a line-source sprinkler experiment in the Negev Desert in Israel. A double line-source system was used with one line source at right angles to the other. It was possible to create a gradient of salt concentration in one direction and a nitrogen gradient at right angles to the salt gradient. Thus the whole range of possible treatment combinations between salt and nitrogen was established in a very small area. The uniform application of irrigation water was ensured by applying non-saline water from sprinkler lines on both sides of and parallel to the salt and nitrogen source lines. The experiment proved that satisfactory results can be obtained when including two variables in a line source experiment. Higher nitrogen levels did not enhance salinity toleration of maize plants in this experiment.

Mielies is in 'n liniêre bron-sprinkelaar-eksperiment in die Negev-woestyn van Israel geplant om die wisselwerkingseffekte van soutgeaffekteerde besproeiingswater en stikstofbemesting te bestudeer. 'n Dubbele liniêre bron-sisteem is gebruik waar twee besproeiingslyne loodreg op mekaar geplaas is. Een lyn het 'n soutkonsentrasiegradient in een rigting veroorsaak en die ander 'n gradient van stikstofbemesting loodreg op die soutgradient. Die hele spektrum van behandelingskombinasies tussen sout en stikstofpeil is gevolglik in 'n baie klein area verkry. Besproeiingswater is eweredig toegedien deur gebruik te maak van varswaterbesproeiingslyne weerskante en parallel aan die sout- en stikstofbronlyne. Die eksperiment het getoon dat twee veranderlikes met gemak en akkuraatheid gebruik kan word in 'n liniêre bron-sisteem. Die sout × stikstof-interaksie was nie in hierdie eksperiment betekenisvol nie.

Keywords: Leaf area index, line source, maize, nitrogen, salinity

*To whom correspondence should be addressed

It has been estimated that a third of all irrigated soils on earth are affected by salinization (Yaron, 1981). The proportion of salt-affected soils could further increase because of the necessity to rely on poor-quality water for irrigation as fresh water sources are exhausted or diminish through intensive utilization.

There are several ways of addressing the problem of decreased agricultural production under saline conditions. Some options are to select or breed tolerant plants, apply larger quantities of irrigation water in conjunction with improved drainage to ensure leaching of salts beyond the root zone, irrigate alternately with fresh and saline water or blend fresh and saline water prior to irrigation, determine which growth stages of crops might be less sensitive to the use of saline water, promote high-frequency irrigation techniques to ensure a high soil water potential at all times and improve irrigation scheduling techniques to minimize salt importation.

La Haye & Epstein (1969) found that calcium could reduce the hazardous effects of saline conditions on plant growth. Kafkafi, Valoras & Letey (1982) demonstrated how chloride uptake was reduced by nitrate application and Silberbush, Ben-Asher, Kafkafi & Lips (1985) reported on the beneficial effects of potassium and nitrate fertilization on salt tolerance of peanuts. This paper reports on a preliminary study of interactions between nitrogen and salinity to ascertain to what extent it might be possible to reduce inhibitive effects of salinity on maize growth by increasing the level of nitrogen fertilization.

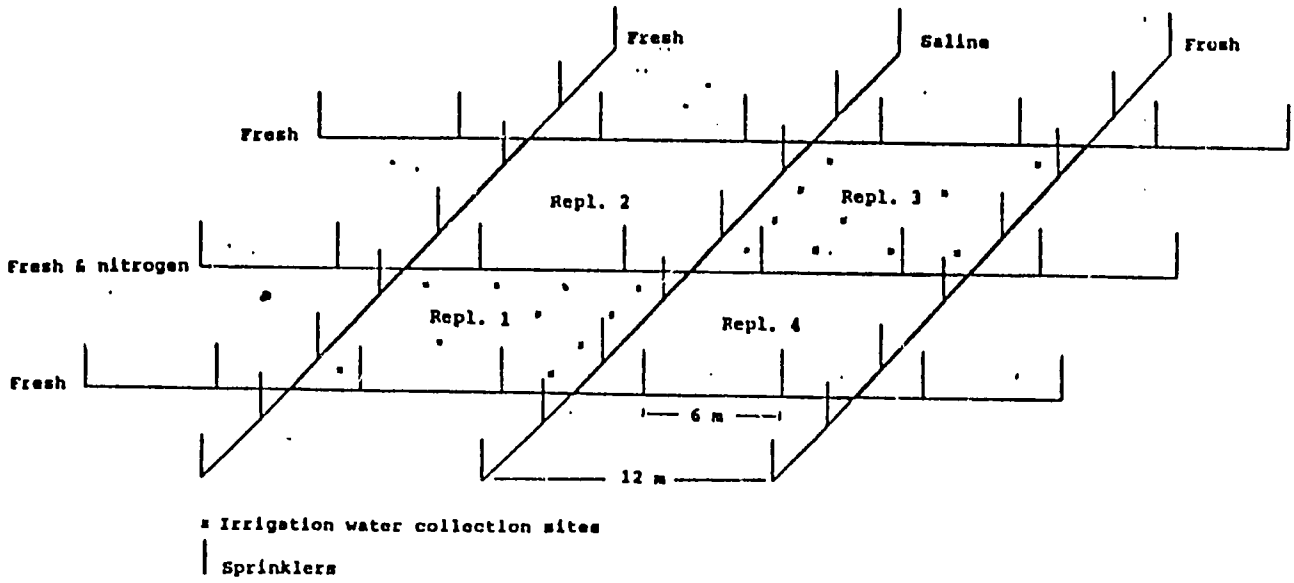

Figure 1 Lay-out of experiment.

The experiment was conducted in the Negev Desert on the Ramat Negev experimental farm south-east of Beersheva in Israel. It was conducted on a sandy loam loess soil typical of the area. Phosphorus, potassium and micro-nutrients were applied to ensure that no deficiencies of these nutrients would occur.

The line-source sprinkler system favoured by Hanks, Keller, Rasmussen & Wilson (1976) was modified to include two variables yet maintain uniform water application. One sprinkler line supplied saline water to ensure a salt gradient away from the line in two directions (Figure 1). Fresh water lines on both sides and parallel to the source line ensured uniform water application. A similar nitrogen source line was installed at right angles to the first system. Two variables were thus included to create gradients in different directions. The

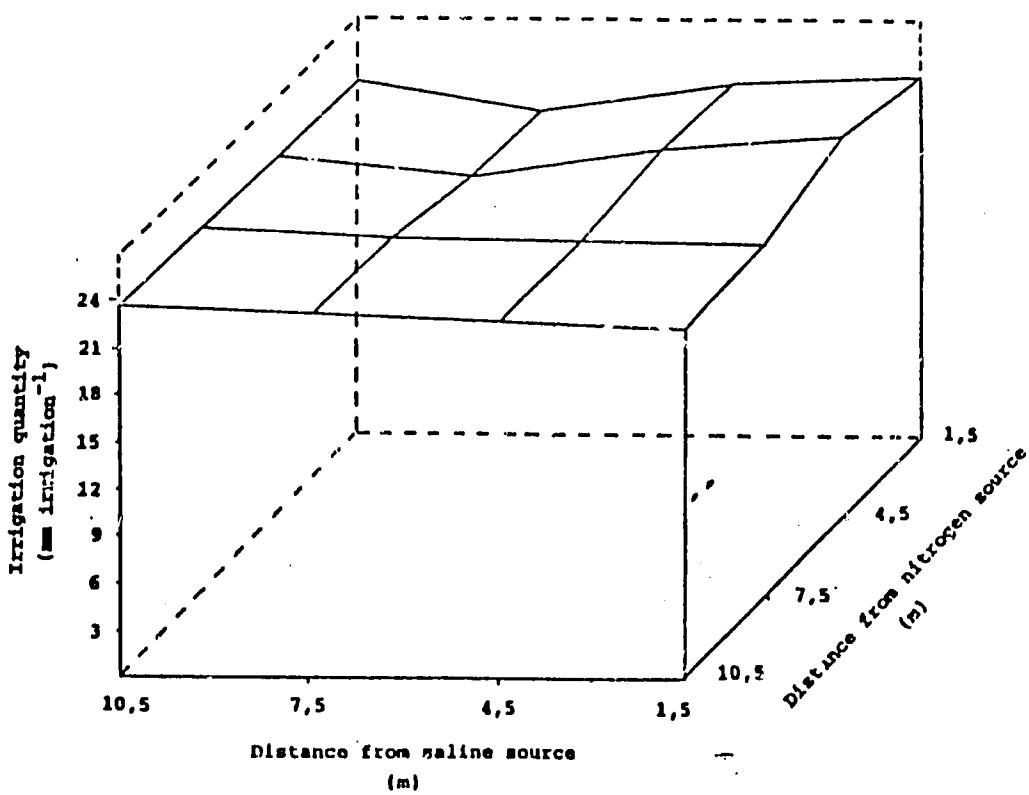

Figure 2 Variability of irrigation water quantity.

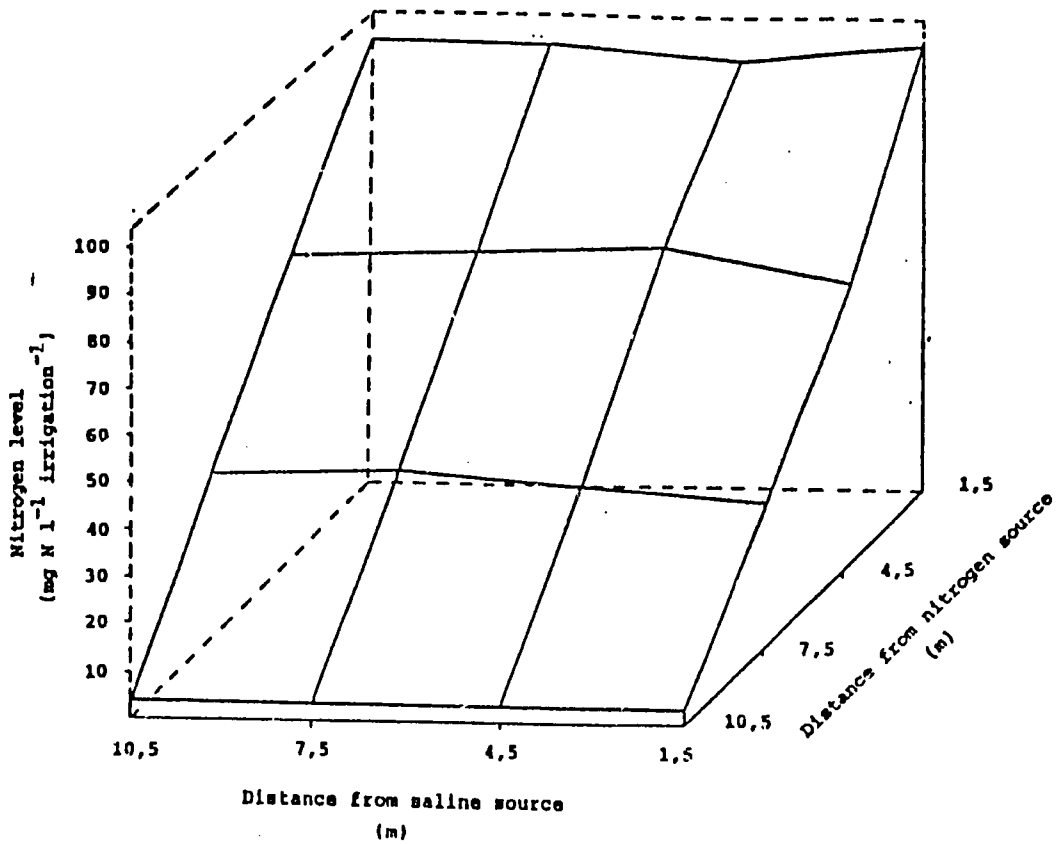

Figure 3 Nitrogen level as affected by distance from nitrogen and saline sources.

pattern was replicated four times (Figure 1).

The saline water with an electrical conductivity (Ec) of approximately 7 dS m^{-1} was obtained from a local well. The sodium and chloride concentrations were 661 and 996 mg l^{-1} respectively. Fresh water (Ec = 1 dS m^{-1}) was supplied by the national water grid. The local maize cultivar, Hazera 712, was planted on July 7, 1987 in 1 000-mm rows with a final plant population of 70 000 plants ha^{-1}.

Catch cans were installed in replicates 1 and 3 (Figure

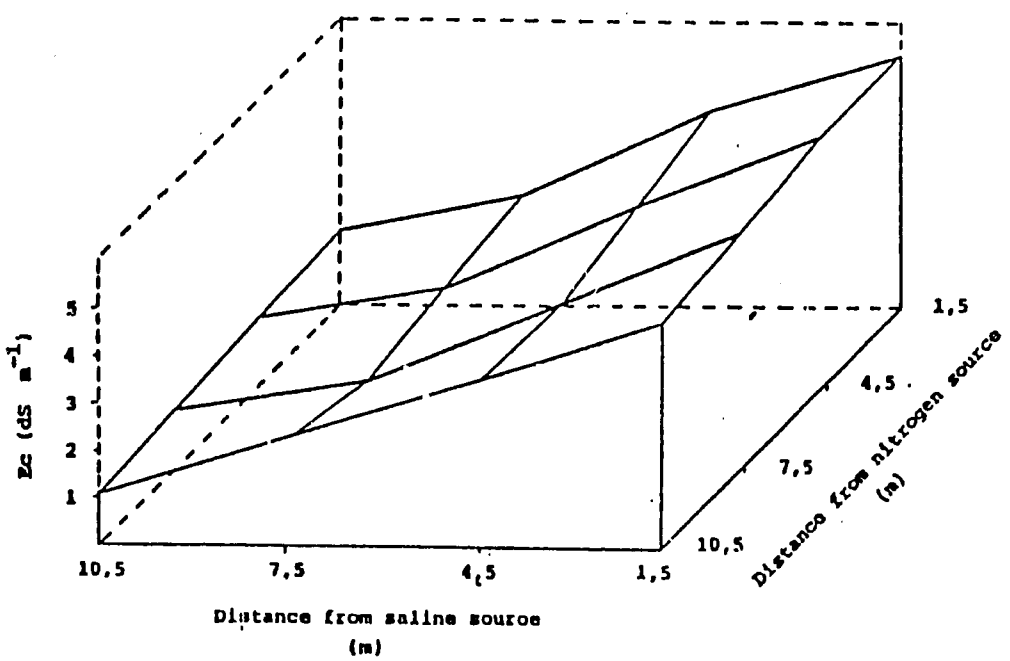

Figure 4 Electrical conductivity of irrigation water as affected by distance from nitrogen and saline source.

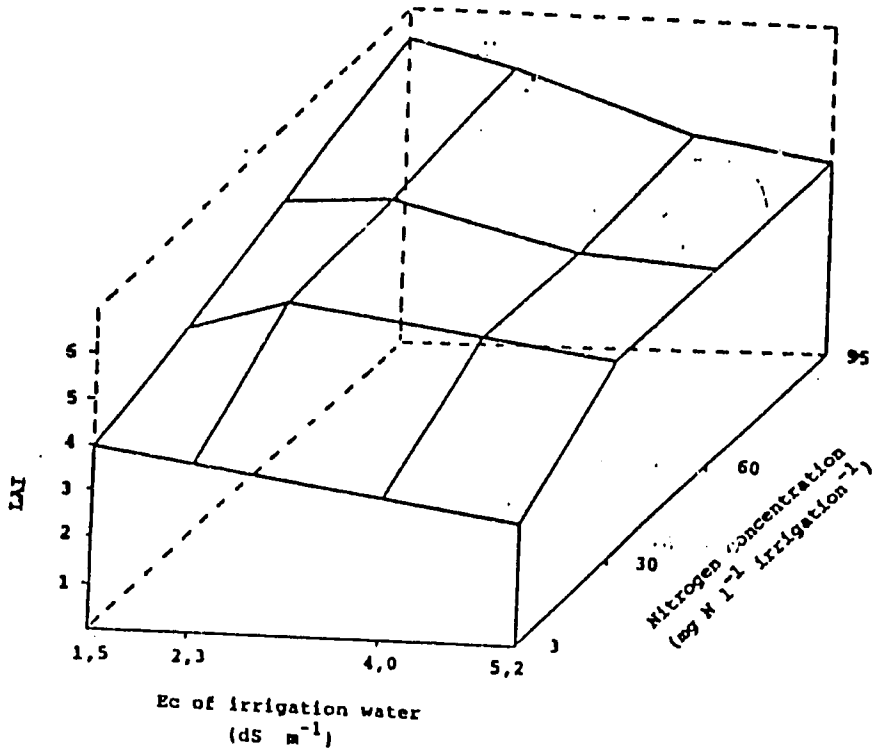

Figure 5 Leaf area index as a function of nitrogen fertilization and salinity.

1) to monitor the uniformity of irrigation. These samples were analysed for nitrate, ammonium and electrical conductivities. The site was irrigated twice per week at a rate of approximately 25 mm per irrigation to ensure a high soil water content at all times. Soil water content was monitored with a neutron probe to verify that a high soil water content was maintained. The saline line source was operated first, followed by the nitrogen line, and the fresh water lines last, to wash any salts from the foliage. Nitrogen was applied in the form of liquid ammonium nitrate (20%).

Water was applied very uniformly throughout the

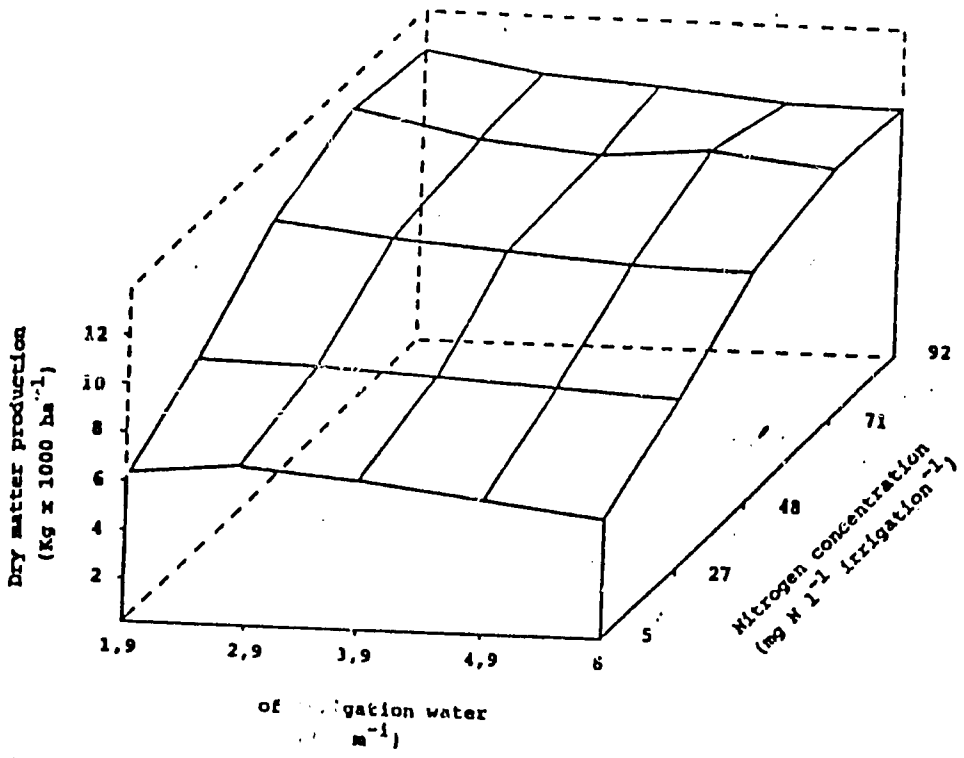

Figure 6 Dry matter production as a function of nitrogen fertilization and salinity.

experiment with a coefficient of variability of only 5,6% (Figure 2).

The average quantities of nitrogen applied during August are shown in Figure 3. The uniformity along the line was very good and nitrogen level declined linearly with increasing distance from the source line ($R^2 = 0,99$).

Figure 4 illustrates the variation in Ec of the irrigation water intercepted by soil and crop with distance from the saline and nitrogen sources. Ec declined linearly with increasing distance from the saline source ($R^2 = 0,98$). A slight but highly significant increase ($R^2 = 0,96$) along the line towards the nitrogen source was observed. It is well known that dissolved nitrogen will increase the Ec of water (Jurinak & Wagenet, 1981).

Leaf area index (LAI), determined when tassels started emerging, corresponded very well with nitrogen level and Ec. In Figure 5 it can be seen that LAI was highest where Ec was lowest and nitrogen level highest. LAI declined linearly with increasing Ec and this pattern was much the same for all nitrogen levels. Thus, it would seem that the nitrogen × salinity interaction was not significant.

The influence of salinity and nitrogen on dry matter production of the plants is illustrated in Figure 6. The tendency was similar to that observed for LAI. Dry matter production decreased linearly with increasing Ec at all levels of nitrogen.

Although results are not conclusive and more work needs to be done, the line-source concept proved to be a very useful instrument for studying interaction between two variables.

Acknowledgements

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Corn Response to Sprinkler Applied N Under Saline Conditions

J. Ben Asher, D.A. Magnusson
Y. De Malach, and H. Lipps

JACOB BLAUSTEIN INSTITUTE FOR DESERT RESEARCH
BEN GURION UNIVERSITY OF THE NEGEV
SEDE BOKER CAMPUS, ISRAEL 84990

ABSTRACT

Plant response to fertilization has been thoroughly studied under nonsaline conditions. However, under saline conditions the literature is often in disagreement as to the proper level of fertilizer to apply. The purpose of this study was to examine the interactive relationship of N and irrigation water salinity on the yield of corn (Zea mays; cvs. Hazera 712 and Jubliee), over a wide range of both variables.

Perpendicular gradients of salinity (approximately 1.0 to 6.3 dS/m) and N (approximately 0.0 to 1017.0 kg/ha) were produced using the crossed triple line-source (CTLS) irrigation system.

Plant growth and development rates were reduced by salinity. Leaf Cl% was clearly reduced by increasing N levels under nonsaline conditions, but not so clearly under saline conditions. Excessive N amounts did not tend to increase yields at any level of salinity. For Jubilee, the highest yields tended to be found at lower and lower N levels as the salinity increased. Thus it may be possible to obtain optimum yields under saline conditions using less N than required for nonsaline conditions.

INTRODUCTION

Salinity is an ancient, frustrating, and complex problem to those involved with irrigated agriculture. Plants suffering from salt stress face external (osmotic) as well as internal (physiological-biochemical-metabolic) obsticals (Cramer et al. 1988). Munns and Termaat (1986) listed five possible limiting factors to growth of non-halophytes in

saline soils. The list included water deficit, specific NaCl effect, nutrient deficiency, carbohydrate status, and hormonal regulation.

NaCl has been reported to reduce leaf NO_3 concentrations of some crops (e.g. wheat, Torres and Bingham 1973; ryegrass, Veen and Kleinendorst 1985). Others have reported that increasing the NO_3 concentration in the rooting environment resulted in increased growth in some crops (e.g. bermudagrass, Langdale and Thomas 1971). Thus is may appear that a N deficiency may be occurring. However other reports indicate that the beneficial effects of NO_3 are a result of lowering the Cl concentrations in the leaves rather than alleviating a N defeciency (Bernstein et al. 1974; Glass and Siddiqi, 1985).

Some have reported that N amounts above nonsaline optimum levels improves crop growth in saline conditions (Langdale and Thomas 1971, bermudagrass; Ravikovitch and Yates 1971, millet and clover). Yet, others have reported no effect (Selassie and Wagenet 1981, corn), and even negative effect of increased N (Khalil et al. 1967, corn; Langdale et al. 1971, spinach) under saline conditions. Some of the contradictory results may be due to differences in N types and different ranges of N and salinity levels examined.

In this study we examined a continuous range of both variables to determine optimum levels of NH_4NO_3 to apply under saline conditions, and if increasing NO_3 amounts, at any salinity level, would partially offset the harmful effects of NaCl.

MATERIALS AND METHODS

In 1987 and 1988 corn was grown at the Ramat Negev Experimental

Station in the Negev of Israel (30 57 N, 34 38 E). Meterological data for the area is shown in Table 1. The soil was loess (torrifluvent sandy loam containing 60-70% sand, 15-20% clay and 10-15% silt). Before the experiments were begun, the plots were leached with 150 mm of nonsaline water (1.0 dS/m), and 110 kg/ha P was applied in the form of Superphosphate. In 1988, 25 kg/ha N (NH_4SO_4) was hand applied 14 days after emergence (DAE).

Various plant parameters were measured during each season at 16 selected locations. Soil N and EC were measured periodically during the season at 20, 50, and 80 cm depths.

A local field corn (cv. Hazera 712) was planted on July 8, 1987 and the treatments were begun 24 days later. In the 1988 experiment, sweet corn (cv. Jubliee) was planted on May 12 and the treatments were begun seven days later. Seeding rate was 85,000 seeds/ha and the rows were 1.0 m apart.

Plants were harvested on October 17 and August 21 for the 1987 and 1988 experiments, respectively. Every one meter section of each row was measured seperately. This gave a harvest area of one square meter for each treatment. We did not harvest the meter closest to the irrigation lines. Thus, a total of 100 treatments per plot (10 rows with 10 one meter sections) were harvested from three replications. Ears were seperated from the stalks and fresh weights were measured immediately. Dry weights were calculated from subsamples.

Irrigations were scheduled for twice a week according to ET as determined by Class A pan evaporation times a crop coefficient. In order to achieve and maintain an uniform distribution of solutes in the

Table 1

Daily average meteorological data for Ramat Negev experimental station

	May	June	July	Aug.	Sep.	Oct.
Temp. (max)	28.7	31.4	32.4	32.1	29.8	27.4
Rel. humidity	26.2	28.6	27.8	25.3	21.6	17.1
Class A. Pan evap. (mm/day)	8.4	9.2	10.1	8.7	7.4	5.7

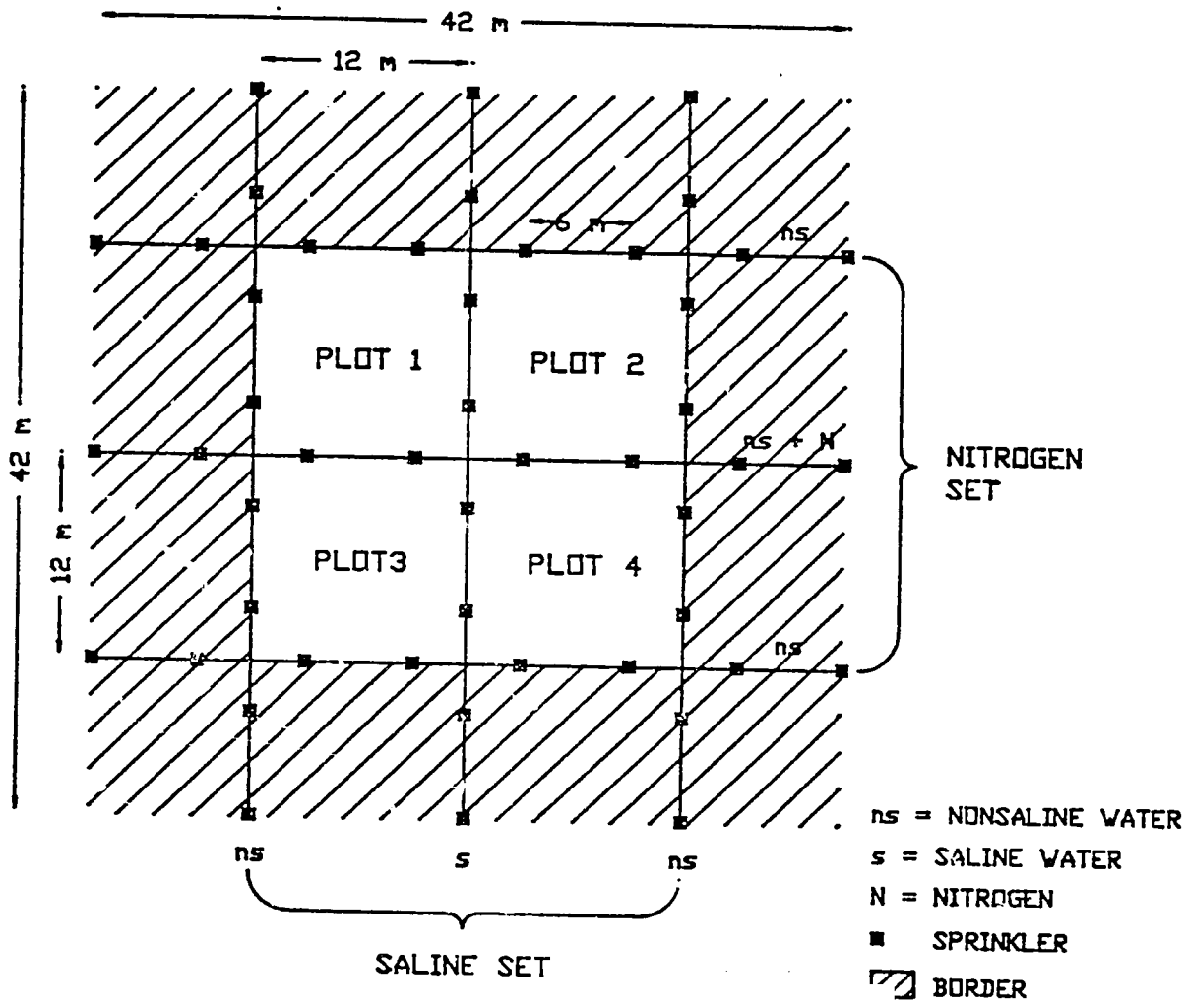

42 m
12 m
6 m
42 m
12 m
PLOT 1
PLOT 2
PLOT3
PLOT 4
ns
ns + N
ns
NITROGEN SET
ns
s
ns
SALINE SET
ns = NONSALINE WATER
s = SALINE WATER
N = NITROGEN
SPRINKLER
BORDER

fig 1

rooting profile, a leaching fraction (0.2 in 1987 and 0.5 in 1988) was also included.

The map of the experimental field and is given in Figure 1. This figure represints the geometry of the CTLS proposed by Magnusson et. al. (1989a,b). The first set of three parallel lines (saline set) provided the salinity gradient. Each of the three lines supplied equal water amounts. The middle line irrigated with water from a local well (7.0 dS/m) while the two outside lines irrigated with nonsaline water (1.0 dS/m) from the National Water Carrier (NWC).

The second set (N set) used only nonsaline water and NH_4NO_3 was injected into the middle line creating the N gradient. This set was superimposed perpendicularly to the saline set, thus creating four replications of the various combinations. As in the saline set, each of the three lines supplied equal water amounts. This design provided a uniform water application within the sampling area, yet at the same time gave a continuous gradient of N and salinity. The field measured Christiansen coefficient of uniformity was consistantly above 0.92.

The water and solute distribution for the treatment periods of both seasons is shown in Tables 2 and 3. In 1987 22.3% of the total water was applied through the N set, whereas in 1988 the N set applied only 12.7% of the total. This smaller application of water by the N set increased the average EC of the irrigation water (EC_i) near (1.5 m) the saline line from 5.8 dS/m in 1987 (Table 2b) to 6.3 dS/m in 1988 (Table 3b). However, far from the saline line (11.5 m) the EC_i was 1.0 dS/m for both years. This corresponds to an average salinity slope gradient, perpendicular to the saline line, of 0.48 and 0.53 dS/m per meter for

1987 and 1988, respectively.

In 1987 the N concentration gradient was slightly higher than in 1988 (Tables 2c and 3c). However, total N application (t/ha) was greater in 1988 (Tables 2d and 3d) because N was applied over a longer period of time.

RESULTS AND DISCUSSION

Soil Salinity

The average initial soil EC in the top 50.0 cm as determined by the saturated paste extract (EC_e) was approximately 1.6 for both years. Tables 4a and 4b present soil salinity over time and depth for both seasons.

Soil salinity increased as the irrigation water became more saline. The results of the two different irrigation water salinity gradients are also reflected in the soil EC. The final reported average EC_e, 1.5 m from the saline line in 1987, was 4.3 dS/m at the 20 cm depth. In 1988, the same corresponding depth and location had an EC of 5.1 dS/m.

In 1987 it was noted that the soil EC was still increasing at 30 DAE. In the following year we sought to achieve a "steady state" solute level in the rooting profile as quickly as possible. Therefore we began the treatments sooner and increased the leaching fraction. As a result the rooting zone EC_e values for 1988 were fairly constant. By 21 DAE the average soil salinity over all depths was 3.3 dS/m and 28 days later it was 3.4 dS/m.

Nitrogen also tended to increase the soil EC, especially in 1988. The average soil EC 1.5 m from the N line was 3.9 dS/m comparred to 3.0 dS/m at 10.5 m from the N line for the final reported measurement in 1988

Table 2

(a)

Dist. from N line (m)	Dist. from saline line (m) 0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	Avg.
	mm												
0.5	618.	596.	612.	608.	546.	534.	534.	546.	608.	612.	596.	618.	
1.5	625.	602.	575.	561.	550.	535.	535.	550.	561.	575.	602.	625.	565.
2.5	814.	610.	581.	554.	540.	540.	540.	540.	554.	581.	610.	814.	565.
3.5	812.	606.	573.	547.	536.	539.	539.	536.	547.	573.	606.	812.	560.
4.5	611.	587.	555.	541.	535.	521.	521.	535.	541.	555.	587.	611.	548.
5.5	594.	570.	534.	529.	520.	509.	509.	520.	529.	534.	570.	594.	532.
6.5	594.	570.	534.	529.	520.	509.	509.	520.	529.	534.	570.	594.	532.
7.5	611.	587.	555.	541.	535.	521.	521.	535.	541.	555.	587.	611.	548.
8.5	812.	606.	573.	547.	536.	539.	539.	536.	547.	573.	606.	812.	560.
9.5	814.	610.	581.	554.	540.	540.	540.	540.	554.	581.	610.	814.	565.
10.5	625.	602.	575.	561.	550.	535.	535.	550.	561.	575.	602.	625.	565.
11.5	618.	596.	612.	608.	546.	534.	534.	546.	608.	612.	596.	618.	
Avg.		595.	564.	546.	536.	529.	529.	536.	546.	546.	595.		554.

(b)

Dist. from N line (m)	Dist. from saline line (m) 0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	Avg.
	dS/m												
0.5	5.7	5.6	5.0	4.4	4.2	3.5	2.9	2.3	1.6	1.1	1.0	1.0	
1.5	5.7	5.7	5.4	4.9	4.3	3.7	2.9	2.2	1.6	1.1	1.0	1.0	3.3
2.5	6.1	5.8	5.5	5.1	4.5	3.7	2.9	2.1	1.5	1.2	1.0	1.0	3.3
3.5	6.1	5.8	5.6	5.2	4.5	3.8	2.9	2.1	1.5	1.2	1.0	1.0	3.4
4.5	5.9	5.8	5.6	5.1	4.4	3.7	2.9	2.2	1.6	1.1	1.0	1.0	3.3
5.5	5.9	5.8	5.6	5.0	4.3	3.6	3.0	2.3	1.7	1.1	1.0	1.0	3.3
6.5	5.9	5.8	5.6	5.0	4.3	3.6	3.0	2.3	1.7	1.1	1.0	1.0	3.3
7.5	5.9	5.8	5.6	5.1	4.4	3.7	2.9	2.2	1.6	1.1	1.0	1.0	3.3
8.5	6.1	5.8	5.6	5.2	4.5	3.8	2.9	2.1	1.5	1.2	1.0	1.0	3.4
9.5	6.1	5.8	5.5	5.1	4.5	3.7	2.9	2.1	1.5	1.2	1.0	1.0	3.3
10.5	5.7	5.7	5.4	4.9	4.3	3.7	2.9	2.2	1.6	1.1	1.0	1.0	3.3
11.5	5.7	5.6	5.0	4.4	4.2	3.5	2.9	2.3	1.6	1.1	1.0	1.0	
Avg.		5.8	5.5	5.1	4.4	3.7	2.9	2.2	1.6	1.4	1.0		3.3

Table 2 (continue)

(c)

Dist. from N line (m)	Dist. from saline line (m) 0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	Avg.
	N (mg/l)												
0.5	140.	149.	204.	206.	163.	162.	162.	163.	206.	204.	149.	140.	
1.5	131.	140.	152.	155.	153.	153.	153.	153.	155.	152.	140.	131.	151.
2.5	90.	125.	135.	142.	141.	136.	136.	141.	142.	135.	125.	90.	136.
3.5	77.	110.	119.	125.	124.	117.	117.	124.	125.	119.	110.	77.	119.
4.5	85.	94.	103.	105.	103.	100.	100.	103.	105.	103.	94.	85.	101.
5.5	68.	75.	83.	84.	83.	79.	79.	83.	84.	83.	75.	68.	81.
6.5	52.	52.	59.	59.	58.	60.	60.	58.	59.	59.	52.	52.	58.
7.5	34.	33.	32.	33.	37.	40.	40.	37.	33.	32.	33.	34.	35.
8.5	13.	16.	14.	15.	18.	20.	20.	18.	15.	14.	16.	13.	17.
9.5	1.	3.	5.	5.	4.	2.	2.	4.	5.	5.	3.	1.	4.
10.5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11.5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
Avg.		65.	70.	72.	72.	71.	71.	72.	72.	70.	65.		70.

(d)

Dist. from N line (m)	Dist. from saline line (m) 0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	Avg.
	N (kg/ha)												
0.5	864.	890.	1251.	1251.	890.	864.	864.	890.	1251.	1251.	890.	864.	
1.5	817.	842.	873.	873.	842.	817.	817.	842.	873.	873.	842.	817.	850.
2.5	733.	763.	786.	786.	763.	733.	733.	763.	786.	786.	763.	733.	766.
3.5	628	664.	683.	683.	664.	628.	628.	664.	683.	683.	664.	628.	664.
4.5	518.	552.	569.	569.	552.	518.	518.	552.	569.	569.	552.	518.	552.
5.5	405.	429.	445.	445.	429.	405.	405.	429.	445.	445.	429.	405.	431.
6.5	307.	299.	314.	314.	299.	307.	307.	299.	314.	314.	299.	307.	307.
7.5	208.	196.	177.	177.	196.	208.	208.	196.	177.	177.	196.	208.	191.
8.5	106.	95.	81.	81.	95.	106.	106.	95.	81.	81.	95.	106.	92.
9.5	10.	21.	26.	26.	21.	10.	10.	21.	26.	26.	21.	10.	21.
10.5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11.5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
Avg.		386.	395.	395.	386.	373.	373.	386.	395.	395.	386.		387.

Table 3

(a)

Dist. from N line (m)	Dist. from saline line (m) 0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	Avg.
	mm												
0.5	979.	937.	915.	907.	847.	829.	829.	847.	907.	915.	937.	979.	
1.5	999.	955.	901.	877.	861.	838.	838.	861.	877.	901.	955.	999.	886.
2.5	1345.	977.	921.	873.	851.	858.	858.	851.	873.	921.	977.	1345.	896.
3.5	1344.	973.	914.	866.	848.	857.	857.	848.	866.	914.	973.	1344.	892.
4.5	986.	941.	883.	859.	848.	825.	825.	848.	859.	883.	941.	986.	871.
5.5	958.	914.	844.	836.	823.	807.	807.	823.	836.	844.	914.	958.	845.
6.5	958.	914.	844.	836.	823.	807.	807.	823.	836.	844.	914.	958.	845.
7.5	986.	941.	883.	859.	848.	825.	825.	848.	859.	883.	941.	986.	871.
8.5	1344.	973.	914.	866.	848.	857.	857.	848.	866.	914.	973.	1344.	892.
9.5	1345.	977.	921.	873.	851.	858.	858.	851.	873.	921.	977.	1345.	896.
10.5	999.	955.	901.	877.	861.	838.	838.	861.	877.	901.	955.	999.	886.
11.5	979.	937.	915.	907.	847.	829.	829.	847.	907.	915.	937.	979.	
Avg.		952.	893.	862.	846.	837.	837.	846.	862.	893.	952.		878.

(b)

Dist. from N line (m)	Dist. from saline line (m) 0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	Avg.
	dS/m												
0.5	6.2	6.2	5.8	5.1	4.6	3.9	3.2	2.5	1.7	1.1	1.0	1.0	
1.5	6.3	6.2	6.0	5.5	4.8	4.0	3.1	2.4	1.6	1.1	1.0	1.0	3.6
2.5	6.5	6.3	6.1	5.6	5.0	4.1	3.2	2.2	1.5	1.2	1.0	1.0	3.6
3.5	6.5	6.3	6.1	5.7	5.0	4.1	3.2	2.2	1.6	1.2	1.0	1.0	3.6
4.5	6.4	6.3	6.1	5.6	4.9	4.1	3.2	2.4	1.7	1.1	1.0	1.0	3.6
5.5	6.4	6.3	6.2	5.5	4.7	4.0	3.3	2.5	1.8	1.1	1.0	1.0	3.6
6.5	6.4	6.3	6.2	5.5	4.7	4.0	3.3	2.5	1.8	1.1	1.0	1.0	3.6
7.5	6.4	6.3	6.1	5.6	4.9	4.1	3.2	2.4	1.7	1.1	1.0	1.0	3.6
8.5	6.5	6.3	6.1	5.7	5.0	4.1	3.2	2.2	1.6	1.2	1.0	1.0	3.6
9.5	6.5	6.3	6.1	5.6	5.0	4.1	3.2	2.2	1.5	1.2	1.0	1.0	3.6
10.5	6.3	6.2	6.0	5.5	4.8	4.0	3.1	2.4	1.6	1.1	1.0	1.0	3.6
11.5	6.2	6.2	5.8	5.1	4.6	3.9	3.2	2.5	1.7	1.1	1.0	1.0	
Avg.		6.3	6.1	5.6	4.9	4.1	3.2	2.3	1.6	1.1	1.0		3.6

Table 3 (continue)

(c)

Dist. from N line (m)	Dist. from saline line (m) 0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	Avg.
	N (mg/l)												
0.5	106.	114.	164.	165.	126.	125.	125.	126.	165.	164.	114.	106.	
1.5	98.	106.	116.	119.	117.	117.	117.	117.	119.	116.	106.	98.	115.
2.5	65.	94.	102.	108.	107.	102.	102.	107.	108.	102.	94.	65.	103.
3.5	56.	82.	90.	94.	94.	88.	88.	94.	94.	90.	82.	56.	90.
4.5	63.	70.	77.	79.	78.	75.	75.	78.	79.	77.	70.	63.	76.
5.5	51.	56.	63.	64.	62.	60.	60.	62.	64.	63.	56.	51.	61.
6.5	38.	39.	45.	45.	43.	46.	46.	43.	45.	45.	39.	38.	44.
7.5	25.	25.	24.	25.	28.	30.	30.	28.	25.	24.	25.	25.	26.
8.5	9.	12.	11.	11.	13.	15.	15.	13.	11.	11.	12.	9.	12.
9.5	1.	3.	3.	4.	3.	1.	1.	3.	4.	3.	3.	1.	3.
10.5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11.5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
Avg.		49.	53.	55.	55.	53.	53.	55.	55.	53.	49.		53.

(d)

Dist. from N line (m)	Dist. from saline line (m) 0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	Avg.
	N (kg/ha)												
0.5	1035.	1066.	1498.	1498.	1066.	1035.	1035.	1066.	1498.	1498.	1066.	1035.	
1.5	979.	1009.	1045.	1045.	1009.	979.	979.	1009.	1045.	1045.	1009.	979.	1017.
2.5	878.	914.	941.	941.	914.	878.	878.	914.	941.	941.	914.	878.	918.
3.5	753.	795.	818.	818.	795.	753.	753.	795.	818.	818.	795.	753.	796.
4.5	621.	661.	681.	681.	661.	621.	621.	661.	681.	681.	661.	621.	661.
5.5	484.	514.	533.	533.	514.	484.	484.	514.	533.	533.	514.	484.	516.
6.5	368.	358.	376.	376.	358.	368.	368.	358.	376.	376.	358.	368.	367.
7.5	249.	235.	212.	212.	235.	249.	249.	235.	212.	212.	235.	249.	229.
8.5	127.	114.	97.	97.	114.	127.	127.	114.	97.	97.	114.	127.	110.
9.5	11.	25.	32.	32.	25.	11.	11.	25.	32.	32.	25.	11.	25.
10.5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11.5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
Avg.		463.	474.	474.	463.	447.	447.	463.	474.	474.	463.		464.

(Table 4a). It was reported earlier that the EC_1 increased 1 dS/m for every 175 mg/l N in the irrigation water (Magnusson and Ben Asher, 1989a). Any increase in soil EC would lower the soil osmotic pressure and therefore increase the plant's difficulty in withdrawing moisture from the soil. This would be a negative factor when using high N amounts under saline conditions.

Soil N

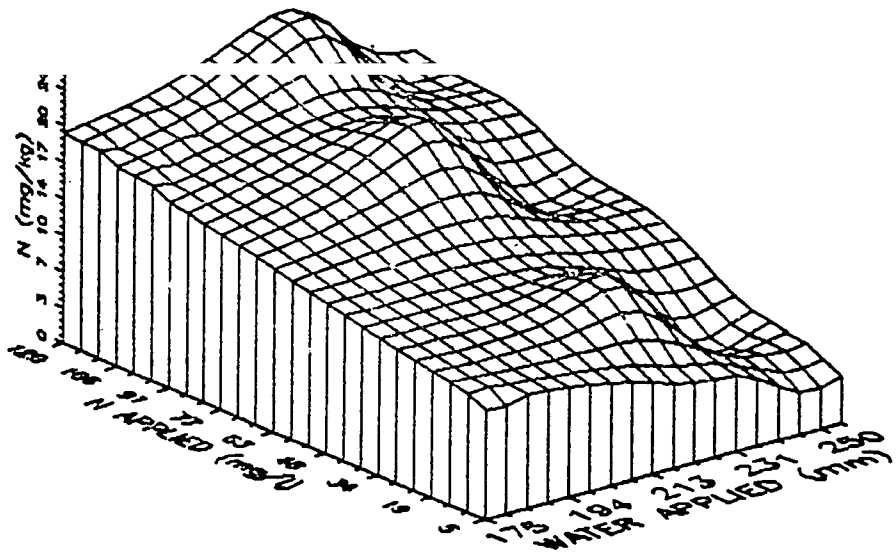
As with soil salinity, soil N increased as the irrigation water contained higher N concentrations. Initial soil $N\text{-}NO_3$ was 1.9, 1.5, and 0.9 (mg/kg) at the 20, 50 and 80 cm depths respectively. Total average soil N was slightly higher at 21 DAE than at 49 DAE in the top 50.0 cm (Table 5). However there was little change in the higher N treatments, indicating that N was sufficient in these treatments.

Soil N was also affected salt levels in the irrigation water. Higher soil N amounts were measured in the higher saline treatments. The plants in these treatments were smaller and thus may have taken up less N. This distinction is more obvious at 49 DAE when the plants were larger and were taking up more appreciable N amounts. At this date, the average soil N content 1.5 m from the saline line (i.e. highest saline treatment) was 9.7 mg/kg. At 10.5 m (nonsaline treatment) from the saline line the average soil N was 6.9 mg/kg.

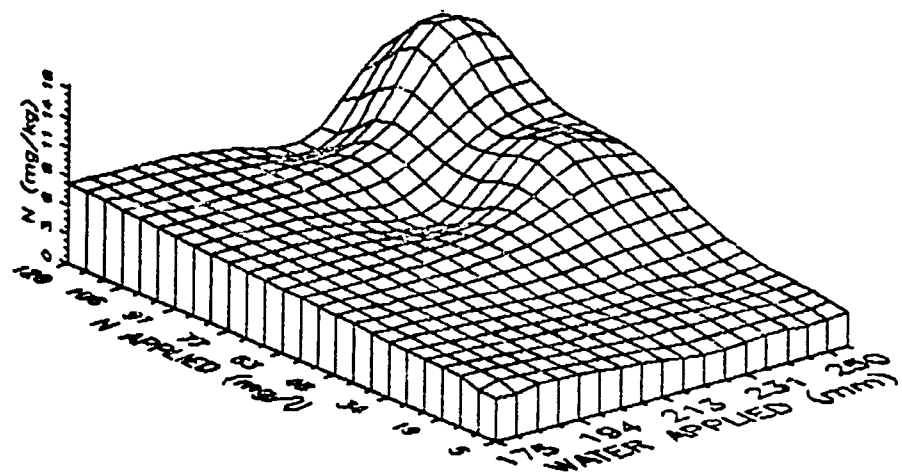
Movement of N within the soil profile is demonstrated in Figures 2a-c. It can be seen from these figures that N movement was highly affected by the amount of N and water applied. With lower water amounts, N tended to remain near the soil surface (Fig. 2a). As water amounts increased above appproximately 220 mm by this date, N was

C.

SOIL N-NO3 AT 20 CM DEPTH



SOIL N-NO3 AT 80 CM DEPTH



SOIL N-NO3 AT 50 CM DEPTH

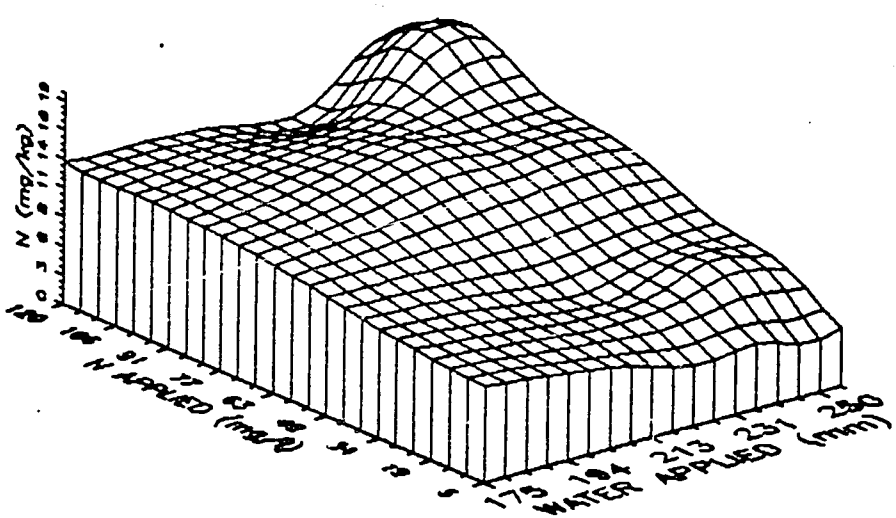


Table 4

(a)

EC_i dS/m	21 DAE 20	21 DAE 50	21 DAE Avg.	60 DAE 20	60 DAE 50	60 DAE Avg.
	Sampling depth (cm)					
	dS/m					
5.8	3.3	2.7	3.0	4.8	5.4	5.1
5.8	3.2	3.2	3.2	4.0	4.4	4.2
5.7	3.5	3.3	3.4	4.2	5.6	4.9
5.7	3.1	2.9	3.0	4.2	5.3	4.8
4.4	3.1	2.5	2.8	3.3	4.6	4.0
4.3	3.7	2.7	3.2	4.4	3.7	4.1
2.2	2.9	2.4	2.7	2.0	2.8	2.4
2.2	2.5	1.8	2.2	2.3	3.0	2.7
1.0	1.6	1.7	1.7	1.4	1.7	1.6
1.0	1.7	1.5	1.6	1.2	1.9	1.6
Avg.	2.9	2.5	2.7	3.2	3.8	3.5

(b)

EC_i dS/m	21 DAE 20	21 DAE 50	21 DAE 80	21 DAE Avg.	49 DAE 20	49 DAE 50	49 DAE 80	49 DAE Avg.
	Sampling depth (cm)							
	dS/m							
6.3	6.3	6.1	4.0	5.5	6.0	7.4	5.2	6.2
6.3	5.3	5.4	3.0	4.6	4.3	4.6	4.1	4.3
6.2	5.0	5.5	4.2	4.9	5.4	5.2	4.7	5.1
6.2	5.3	4.6	3.5	4.5	4.6	4.8	4.1	4.5
4.9	5.3	4.6	2.5	4.1	6.0	6.0	3.0	5.0
4.9	4.9	3.9	2.5	3.8	4.1	5.3	4.0	4.5
4.8	5.1	3.8	3.0	4.0	3.1	3.8	3.1	3.3
4.8	4.8	3.2	2.3	3.4	4.5	5.2	4.4	4.7
2.4	3.9	3.0	1.8	2.9	3.5	3.1	2.1	2.9
2.4	3.6	2.9	1.4	2.6	2.6	3.1	2.5	2.7
2.4	3.4	2.3	1.3	2.3	3.7	3.9	2.5	3.4
2.4	2.0	2.3	1.8	2.0	2.4	3.2	2.4	2.7
1.0	2.8	2.7	1.8	2.4	1.3	2.0	1.8	1.7
1.0	2.3	2.6	2.4	2.4	1.3	2.5	2.2	2.0
1.0	1.4	2.2	2.3	2.0	2.2	2.9	2.5	2.5
1.0	1.7	1.7	1.7	1.7	1.3	1.5	1.5	1.4
Avg.	3.9	3.6	2.5	3.3	3.5	4.0	3.1	3.6

leached into the lower levels (Figs. 2b,c). This leaching becomes more pronounced as the N concentration in the irrigation water increases. Figure 2c reveals considerable differences in the amount of N that had reached the 80.0 cm depth. These figures presents a clear senerio of how N may often be lost for crop use and contaminate ground water. It should be kept in mind that this irrigation system consistantly produced a Christiansen's uniformity coefficient of above 0.92. Therefore it is fairly reasonable to assume that leaching of solutes past the root zone is a highly spacial event that is probably often over looked and under predicted by models that only consider the average depth of applied water to a given field.

Crop Growth and Development

The effects of salinity were first noticed in plant height. As the water salinity increased the plants grew slower. Nitrogen seemed to influence plant height only when it was limiting. Excess N did not increase plant height at any salinity level.

Leaf area (Fig. 3) and leaf extension rates (Fig. 4) were also reduced by increasing salinity. Again, N had little to no beneficial affect on leaf area or leaf extension rates for except at the lowest N level.

Salinity also delayed plant development. At 63 DAE, in the 1988 experiment, it was noted that the plants in the saline treatments appeared to be gaining height on the nonsaline treated plants. Actually, the nonsaline treated plants had already reached their maximum height a few days earlier and the saline treated plants were still growing. This same effect was also noted in tassel and ear appearance

fig 3

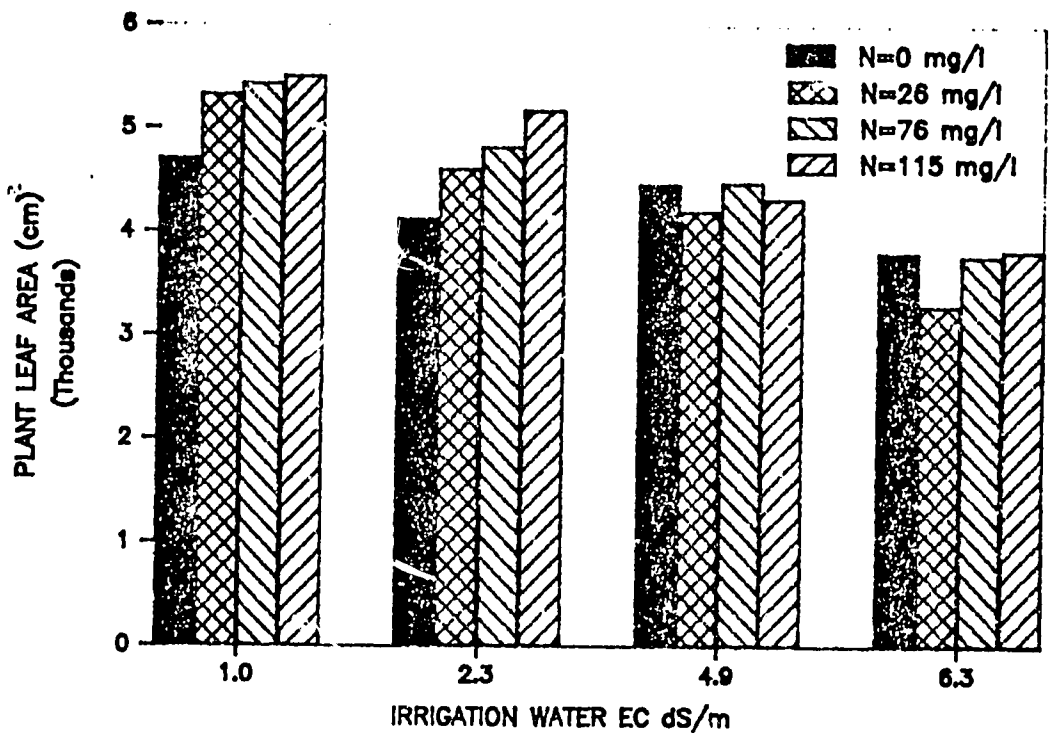
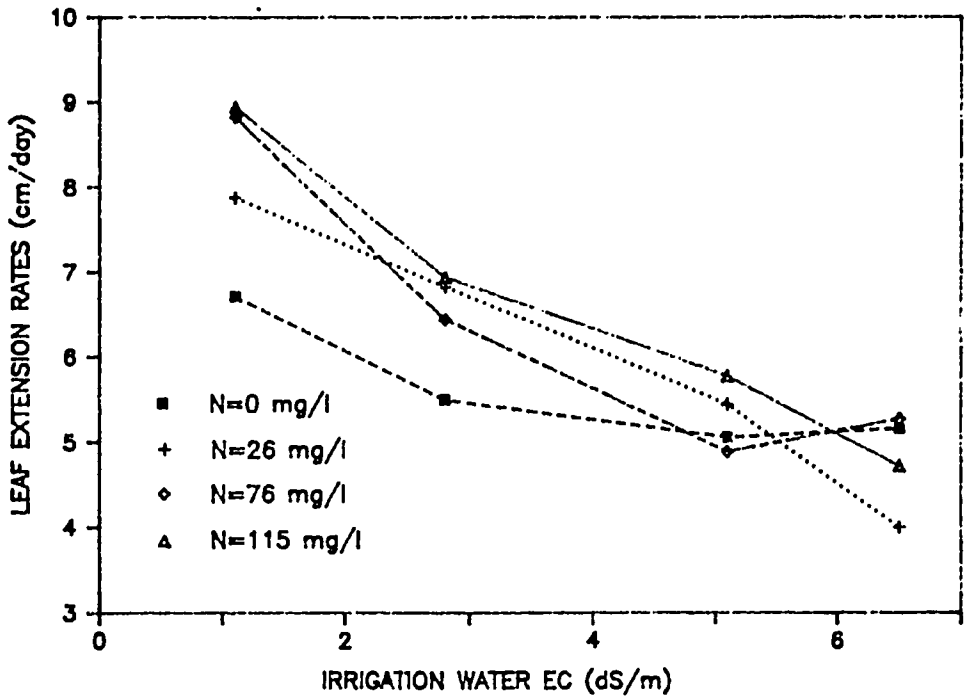

N=0 mg/l
N=26 mg/l
N=76 mg/l
N=115 mg/l
PLANT LEAF AREA (cm)²
(Thousands)
0
1
2
3
4
5
6
1.0
2.3
4.9
6.3
IRRIGATION WATER EC dS/m

fig 4


LEAF EXTENSION RATES (cm/day)
10
9
8
7
6
5
4
3
0
2
4
6
IRRIGATION WATER EC (dS/m)
N=0 mg/l
N=26 mg/l
N=76 mg/l
N=115 mg/l

where high salinity delayed development by 7-10 days.

The plants closest to the saline line (ie. high saline treatment) rolled their leaves as the temperature increased. This is a common sign of water stress, even though in this study water was never limiting due to irrigation. The plants that received the nonsaline water were never observed with rolled leaves.

Grain dry matter was measured at three different times during the growing season. The affects of salinity were quite clear (Fig. 5). Increased salinity tended to decrease the grain dry matter. This is most likely due to the delay in physiological maturity caused by the salinity. It is not clear from this study if grain dry matter from saline and nonsaline treated plants of the same relative physiological maturity differs. Differences in grain dry matter due to N were irregular, but the highest dry matter was found in the high N treatments.

Leaf Cl

Nitrogen tended to reduce the percent of Cl in the leaves when the irrigation water was medium to nonsaline (Fig. 6). However, at the more saline levels, no effect of N was detected. Once the EC_i was above approximately 3.5 dS/m, increasing the N concentration above 76 mg/l N appeared to have a negative effect on excluding Cl from the leaf. This effect is also reflected in the total dry weight as reported in Table 6a in the following section, although the scale is slightly different.

Crop Yield

Fresh ear weights and stover dry matter for both years are reported in Tables 6a and b. The values reported reflect an area of 2 m^2, and the

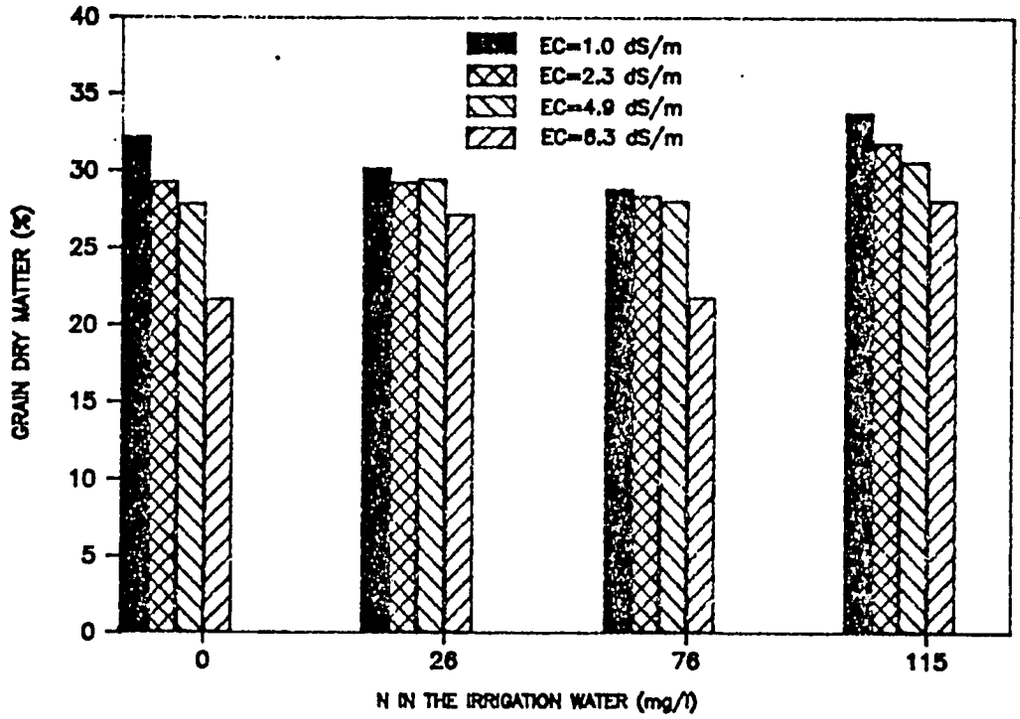
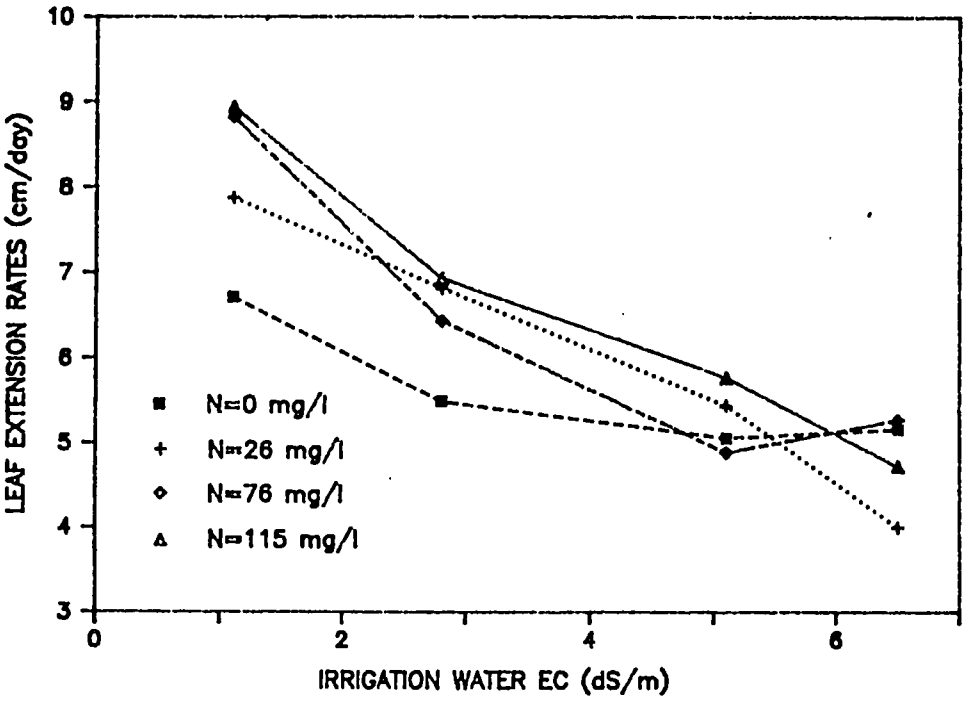

EC=1.0 dS/m
EC=2.3 dS/m
EC=4.9 dS/m
EC=8.3 dS/m
GRAIN DRY MATTER (%)
40
35
30
25
20
15
10
5
0
0
26
76
115
N IN THE IRRIGATION WATER (mg/l)

fig 5

fig 6


LEAF EXTENSION RATES (cm/day)
IRRIGATION WATER EC (dS/m)
N=0 mg/l
N=26 mg/l
N=76 mg/l
N=115 mg/l

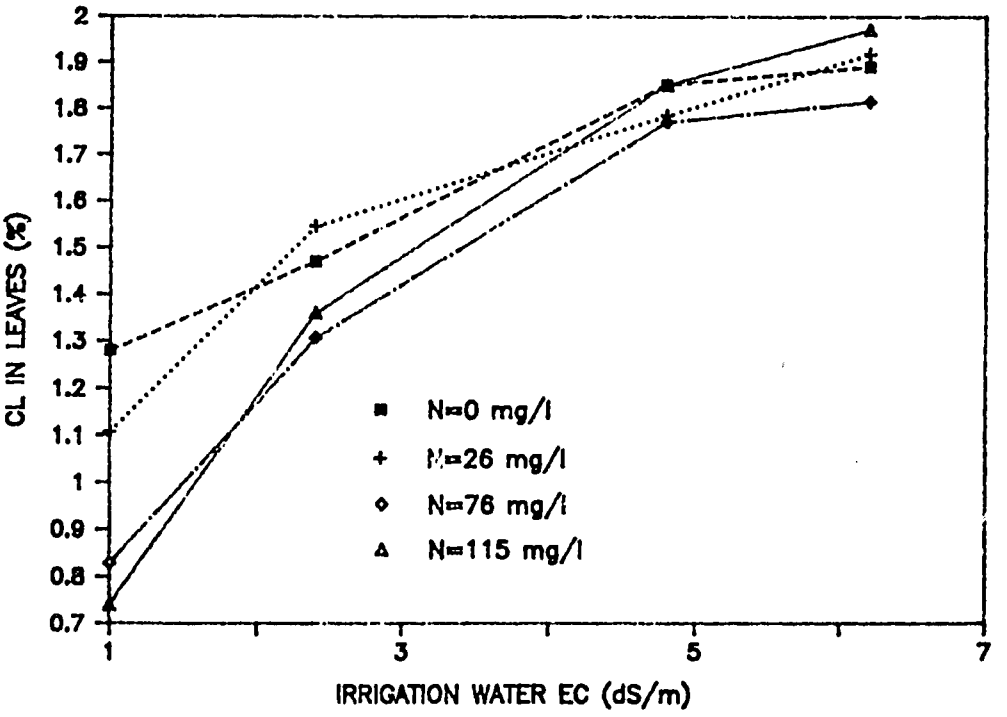

CL IN LEAVES (%)
IRRIGATION WATER EC (dS/m)
N=0 mg/l
N=26 mg/l
N=76 mg/l
N=115 mg/l

Table 5

N mg/l	EC_i dS/m	21 DAE Sampling depth (cm) 20.0	50	80	Avg.	49 DAE Sampling depth (cm) 20.0	50	80	Avg.
		mg/kg							
106.0	6.2	17.0	22.0	16.0	18.3	16.5	13.5	29.5	19.8
70.0	6.3	15.0	16.0	10.0	13.7	14.0	15.0	11.5	13.5
25.0	6.3	5.5	10.0	4.2	6.6	4.0	3.0	5.5	4.2
0.0	6.2	4.7	6.7	3.5	5.0	2.5	0.5	0.5	1.2
Avg.		10.6	13.7	8.4	10.9	9.3	8.0	11.8	9.7
117.0	4.8	22.0	10.0	6.5	12.8	16.5	22.5	15.5	18.2
78.0	4.9	21.0	19.0	5.2	15.1	15.5	12.5	6.0	11.3
28.0	4.9	17.0	11.5	5.2	11.2	5.0	3.5	7.0	5.2
0.0	4.8	7.7	5.2	3.5	5.5	2.0	1.0	0.5	1.2
Avg.		16.9	11.4	5.1	11.2	9.8	9.9	7.3	9.0
117.0	2.4	29.5	13.0	4.2	15.6	21.5	17.5	8.0	15.7
78.0	2.4	23.0	12.5	4.0	13.2	6.5	4.0	5.5	5.3
28.0	2.4	12.0	4.5	3.0	6.5	11.5	3.1	3.0	5.9
0.0	2.4	6.7	5.2	2.0	4.6	2.0	1.0	2.0	1.7
Avg.		17.8	8.8	3.3	10.0	10.4	6.4	4.6	7.1
106.0	1.0	18.0	18.0	18.0	18.0	16.0	25.5	14.0	18.5
70.0	1.0	9.2	14.0	13.0	12.1	6.5	4.0	7.5	6.0
25.0	1.0	4.7	11.0	3.2	6.3	2.0	2.0	2.0	2.0
0.0	1.0	1.7	2.0	2.2	2.0	2.0	0.5	0.5	1.0
Avg.		8.4	11.3	9.1	9.6	6.6	8.0	6.0	6.9
Grand Avg.		13.4	11.3	6.5	10.4	9.0	8.1	7.4	8.2

Table 6

(a)

N mg/l	Dry matter yield t/ha dS/m 1.2	1.9	3.3	4.8	5.7	Avg.	Fresh ear yield t/ha dS/m 1.2	1.9	3.3	4.8	5.7	Avg.
2	7.4	8.7	8.4	7.4	6.4	7.7	2.6	3.6	3.7	2.9	2.3	3.0
26	11.1	10.8	10.3	10.2	9.8	10.4	5.6	5.2	5.0	5.0	4.8	5.1
70	14.8	14.0	13.6	13.2	13.0	13.7	7.1	6.3	6.4	6.3	6.2	6.5
110	16.1	14.6	14.1	15.0	14.0	14.8	7.1	6.3	6.6	6.7	6.1	6.6
144	16.1	14.6	14.6	13.5	13.6	14.5	6.9	6.2	6.4	5.9	6.1	6.3
Avg.	13.1	12.6	12.2	11.9	11.4	12.2	5.8	5.5	5.6	5.4	5.1	5.5

(b)

N mg/l	Dry matter yield t/ha dS/m 1.1	2.0	3.7	5.3	6.2	Avg.	Fresh ear yield t/ha dS/m 1.1	2.0	3.7	5.3	6.2	Avg.
2	11.6	10.4	10.1	9.8	8.8	10.1	15.2	13.2	14.6	13.3	11.8	13.6
19	14.6	13.5	12.8	11.9	10.5	12.7	23.8	21.4	20.1	17.9	15.4	19.7
53	14.9	13.2	12.5	10.9	10.8	12.5	23.8	20.6	20.6	17.1	16.2	19.7
83	15.3	14.1	12.3	11.1	10.7	12.7	24.4	23.8	19.7	16.0	14.7	19.7
109	15.7	13.4	11.9	10.8	9.7	12.3	26.1	22.7	20.0	17.5	14.9	20.2
Avg.	14.4	12.9	12.0	10.9	10.1	12.1	22.7	20.3	19.0	16.4	14.6	18.6

corresponding treatment values are from the midpoint of each sampling area. Hazera 712 was affected more by N than by salinity. Whereas, Jubliee was more affected by salinity. This may be expected since sweet corn is known to be more sensitive to salinity than field corn. Mass and Hoffman (1977) presented equations for the relative productivity of various crops with increasing soil salinity. The relative yield reductions for both varieties, due to salinity, are in good agreement with their reported values. At the highest saline treatment, dry matter and fresh ear yields averaged across all N levels were 87.0% and 87.9% of the nonsaline treatment for Hazera and 70.1% and 64.3% for Jubliee, respectively.

Hazara dry matter yield continued to respond to N increases up to 110 mg/l N in the irrigation water, but ear yield showed little increase above 70 mg/l N. Jubilee's highest yields were at the highest N level (109 mg/l) when the irrigation water was nonsaline. Thereafter, as the EC_i increased the highest yields tended to be found at lower and lower N levels. These differences in response to N are probably partially due to initial soil N differences, varietal responses, and timing of treatment initiations.

CONCLUSIONS

From the results of this study there is no strong evidence to support the theory that high levels of N help to overcome the detrimental effects of salinity. In fact high N levels in the saline treatments tended to slightly increase soil salinity and reduce yields. An increase in EC also translates into a decreased soil osmotic potential. Evidently, the plant was more sensitive to this osmotic stress than to a

toxic effect (Cl) which N was hoped to alleviate. If this is the case fertilizers that have a low salt index should be considered. These fertilizers have less of a tendency to raise the soil osmotic pressure.

Thus it appears from this initial study, that the recommended N fertilizer rates for nonsaline water may be reduced under saline conditions without serious yield loss.

LIST OF FIGURES

Fig. 1 Experimental plot layout of the crossed triple line-source (CTLS) irrigation system designed to produce saline and N gradients.

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Fig. 3 Leaf area as affected by N and salt taken 67 DAE for Jubliee.

Fig. 4 Leaf extention rates as affeced by N and salt taken 35 DAE for Jubliee.

Fig. 5 Grain dry matter as affected by N and salt for Jubliee.

Fig. 6 Leaf Cl percent as affected by N and salt for Jubliee.

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fig 7

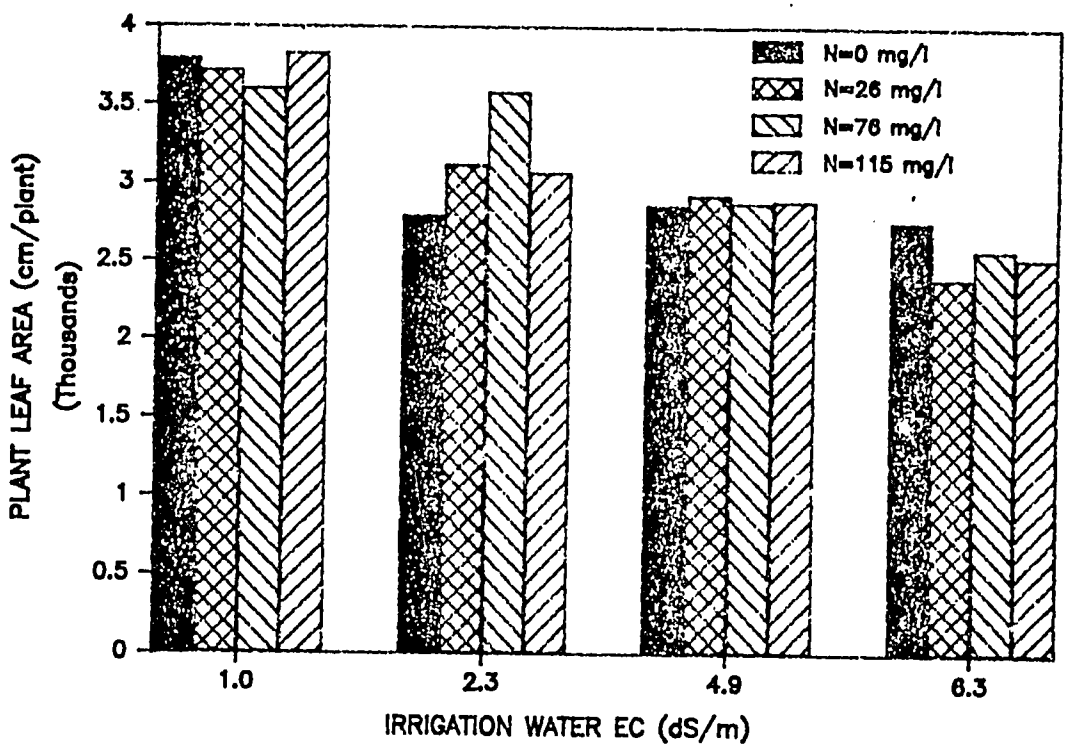
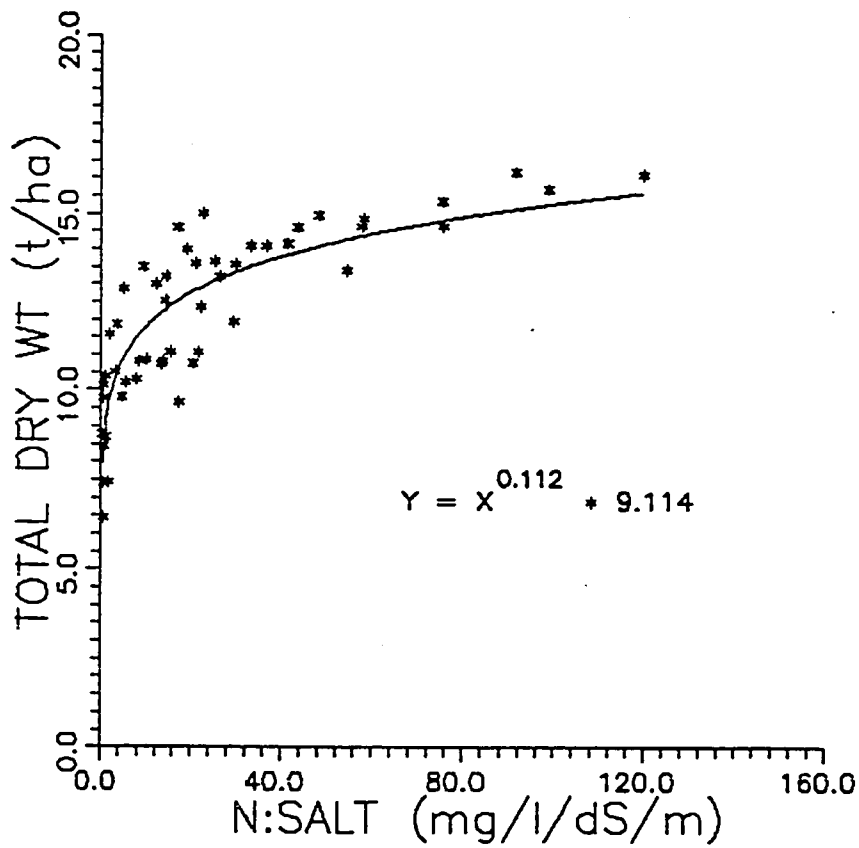

N=0 mg/l
N=26 mg/l
N=76 mg/l
N=115 mg/l
PLANT LEAF AREA (cm/plant)
(Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
1.0
2.3
4.9
6.3
IRRIGATION WATER EC (dS/m)

fig 8


TOTAL DRY WT (t/ha)
0.0
5.0
10.0
15.0
20.0
0.0
40.0
80.0
120.0
160.0
N:SALT (mg/l/dS/m)
Y = X^0.112 * 9.114

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V - Lectures and seminars

1988 **H. Lips. Primary assimilation processes and intensive agriculture.**
INIA - Instituto Nacional de Investigaçao Agraria, Oeiras. Portugal
H. Lips. New approaches in modern arid zone agriculture.
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H. Lips. Primary productivity of plants in arid areas.
Workshop on Use of Renewable Natural Resources. University of Antofagasta. Chile

1989 **H. Lips. Nitrogen assimilation under stress conditions**
2nd International Conference on Nitrogen Assimilation of Plants. Napoli. Italy
H. Lips. Crop production under saline water irrigation
University of the Philippines at Los Baños. College. Laguna. Philippines
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University of Khon Kaen. Khon Kaen. Tahiland
H. Lips. Crop production in sand dunes under saline water irrigation
Institute of Sand Dune Research. Tottori. Japan
J. Ben Asher. Saline water irrigation and fertilization studies.
University of the Philippines at Los Baños. College. Laguna. Philippines
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University of Khon Kaen. Khon Kaen. Tahiland

1990 **H. Lips. Physiological aspects of water use efficiency crops.**
Binational Workshop on Use of Water Resources in Arid Zones. Mexico City. Mexico.
H. Lips. The use of salinity to enhance crop productivity
International Workshop on Modern Agrotechnologies. Guatemala City. Guatemala
H. Lips. Physiological aspects of ammonium and nitrate fertilization
1st Symposium of ENAAG - ISRAEL. Haifa. Israel
H. Lips. A new approach to the study of salt-resistance of plants
University of Cape Town. South Africa
H. Lips. Crop production and salinity - problems and solutions
Instituto de Ciencias Biologicas - CSIR. Madrid. Spain
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J. Ben Asher. Soil-nitrogen relationships in the root zone.
University of Karlsruhe. Germany

VI - Workshops and Courses

1988 Crop Production in Arid Zones
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1988 Use of Renewable Natural Resources in Desert Areas
Workshop sponsored by Fundacion Andes and UNDP
Antofagasta. Chile

1990 Food Biotechnology and Crop Production
Workshop sponsored by the Instituto de Nutricion de Centro America y Panama, the Universidad de San Carlos and the Division of International Cooperation (Israel Ministry of Foreign Affairs). Guatemala City. Guatemala

1990 Efficient Use of Water Resources
Workshop sponsored by the Instituto Nacional de Tecnologia del Agua de Mexico, Cuernavaca. Mexico

1990 Biological and Physical Aspects of Crop Production in Arid Areas.
Two months series of courses offered by the staff of the Center for Desert Agrobiology, J. Blaustein Institute for Desert Research, Ben-Gurion University of the Negev. Attended by 20 graduate students from developing countries in Asia, Africa, Central America, the Middle East and Eeatern Europe. Sponsored by the Division of International Cooperation (Israel Ministry of Foreign Affairs)

1991 Water Use Efficiency and Crop Production in Arid Areas. (In prepration)
Two months series of courses offered by the staff of the Center for Desert Agrobiology, J. Blaustein Institute for Desert Research, Ben-Gurion University of the Negev. For 60-80 graduate students from developing countries in Asia, Africa, South and Central America, the Middle East and Eeatern Europe.

VII - Summary

The objectives originally set up for this project were:

a. To increase production of salt-sensitive crops through irrigating with saline water and enhanced fertilization.
b. To establish production of important local crops in the Philippines by the use of available saline water during the dry season in areas with no alternative water resources.

Laguna de Bay is the major natural water reservoir in the Philippines. The water of this reservoir could be used for irrigation. The electroconductivity of the lake drops during the rainy season due to influx of large quantities of runoff water from the surrounding area. Water in excess of the capacity of the lake spills over into the sea. During the dry season, however, there is a back flow from the sea into the lake increasing its salinity to 4-6 ds/m. Agricultural productivity during the dry season practically ceases, irrigation is not used to any significant extent due to the seasonal salinization of the water in Laguna de Bay. Introduction of irrigation techniques suitable for the application of moderately saline water could be the basis for the establishment of a profitable and productive dry season agriculture in this fertile area.

Shortage of water in Israel is a fact of life and the use of brackish water irrigation in the Negev desert is the only alternative to enhanced agricultural production. This situation has stimulated a large volume of relevant research on ways to use effectively brackish water. This experience has been applied to conditions in the Philippines by local scientists and agronomist with our assistance and through the financial support of AID/CDR.

This summary will described several aspects of our project. The first part includes some statistical information on the impact of the CDR/AID fund as "seed money" to attract additional financial support. It also includes some data on the international collaboration the project generated and the transfer of the know-how acquired.

The second part of this summary includes a short report on the scientific methods that we have developed through the course of our work. The last part described results of the project and a discussion on directions for future continuation of work.

To address the prescribed problem we established an international working team which was based on scientists, students and technicians from 6 countries: Israel, Philippines , Germany Portugal, USA and Spain. The total number of participants was more than 25.

Additional financial sources to this project were as described bellow:

Source	Budget (US $)
AID	150,000
Dead Sea Works	50,000
Israeli Chemicals	40,000
The Katif center	20,000
Kessel fund	50,000
Total	**310,000**

About 45 scientific reviewed papers were and will be published in more than10 reviewed journals (see detail in section "Publications"). More than 10 invited Lectures were given in the following countries: Philippines, Israel, Thailand, Guatemala, Mexico, Portugal, Italy, Spain, Chile, Germany and the U.S.A. (See detail on section "Lectures and Seminars"). Posters and lectures were presented in a large number of international and national Conferences (See detail in "Presentation at Scientific Conferences").

The basic hypothesis tested in this project suggested that salt tolerance of a given crop is a

function of environmental (climatic and nutritional) conditions as well, but not only, to its genetic salt-resistance capacity. The importance of this approach in relation to current agricultural practices, is the implication that significant yield enhancement may be obtained even with salt-sensitive plant species by enhancing their productivity with fertilization management adequate to saline conditions.

On the long run, the development of salt tolerant varieties and the establishment of a national infrastructure for the efficient utilization of water resources, constitute the ultimate solution of salinity problems in large areas. However, these elements require time and capital which are not always available. Since problems of salinity are affecting already vast areas of the world, on the short term, application of relatively simple alternative agrotechniques, especially designed to cope with salinity effects on crop production may be extremely useful. Among these agrotechniques, improved nutritional management has a potential immediate impact on the utilization of saline water for food production.

New experimental methods

During the 3-4 years duration of the present project we have established two distinct but tightly interrelated working methods for laboratory and field studies.

In the laboratory a new method for early diagnosis of mineral deficiencies which are frequently induced by stress conditions, is under development. Potassium deficiency detection is normally based on determination of total K in the soil or in the leaves. The results of these test can either confirm phenological deficiency signs and are generally too late to permit effective correctional steps.

The method developed in this project induced K deficiency is detected within 24 hours, based on the appearance of 1-2 specific proteins in the stems and petioles of sunflower as observed in experiments carried out in our laboratory. The diagnosis of K deficiency is possible at a stage when no visible difference can be seen between deficient plants and controls. This observation may serve as the basis for developing a simply and effective early diagnostic method for K^+ deficiency at a stage when physiological damage can be corrected by adequate fertilization.

Other mineral deficiencies will lead to a characteristic gene expression change in the plant through changes in the levels of specific proteins. This phenomena may serve for the development of immunological kits which could be used by any farmer to guide him on the application of fertilizers.

Physiological studies have increased our options for the utilization of saline water not only to obtain yields close to those obtained with good quality water. In numerous instances there is a clear advantage to the use of saline water irrigation. The cases described in the papers published by our group indicate that salinity stimulates:

(a) Flowering and seed production by peanut
(b) Production of larger seeds by cereals
(c) Regulation of tiller or seed production by assimilate allocation in wheat

A new method for multivariable irrigation experiments was developed and applied to field crop research. Multivariable irrigation experiments are usually expensive and seldom cover the whole range of desired values. The crossed triple line-source (CTLS) was designed to provide a relatively simple and inexpensive irrigation method to create continuous gradients of more than one variable. A computer model was developed facilitate evaluation of the continuously changing multivariable levels produced by various inputs. A single sprinkler's distribution function was used in the model's development. Results of overlapping sprinkling patterns were calculated throughout the experimental area for water depth, salinity level, and nitrogen concentration. Measured values of irrigation water electrical conductivity (EC_i) and nitrogen concentration were in good agreement with predicted values.

Results of field experiments

Work presented here describes studies of physiological mechanisms of soil-tolerance under greenhouse conditions coordinated with experimental work under field conditions. Cooperation with our Philippino colleagues has yielded interesting and important results bath in the lab and in the field. Peanut production in our joint experimental field in the Philippines is three fold higher than the local average, even when irrigating with saline water during the dry season. This has been possible by the introduction of trickle irrigation and fertilizer management adequate for saline conditions.

The highest peanut yield in the Philippines was obtained with saline water irrigation (4 dSi m^{-1}) when 75 ppm KNO_3 was supplied. About 3.4 Tones/ha were obtained with enhanced KNO_3 fertilization as compared with fresh water which yielded about 4.0 Ton/ha, but it was not significantly higher than the saline irrigated peanuts at significance level of 0.05. Saline water irrigation without enhanced fertilization yielded only 1.7 Ton/ha. These results supported previous observations on similar experiment in Israel.

Corn experiments were less promising. Examining the trends form this years data it appears that nitrogen did not contribute to overcome the harmful effects of salinity. Additional amounts of nitrogen tended to raise the soil EC. Increased soil water electroconductivity also translates into a decreased soil osmotic potential. Evidently, the plant was more sensitive to this osmotic stress than to the salt toxicity which N was expected to alleviate. If this is the case, fertilizers that have a low salt index should be used. These fertilizers raise the soil osmotic pressure to a smaller extent. The only plant parameter that benefited from increasing amounts of N was fresh stover weight, and then mainly in the low salinity treatments.

Thus, the recommended N fertilizer rates for nonsaline water can also be applied when irrigating with brackish water sweet corn. Our laboratory and greenhouse studies indicated that increasing the supply of specific forms of inorganic nitrogen (mixed ammonium nitrate) and K^+, frequently enhances the salt-tolerance of crops.

Salinity may be a tool to increase yield and yield quality of some crops. This new line of research is based on two lines of studies:

(a) Salinity enhanced flowering and consequent gynophore production by peanut plants and
(b) Salinity stimulated translocation of assimilates form leaves to filling grains of wheat.

Discussion and suggestions for further study

Growing peanuts in sand dunes it was observed that salts were leached from the vicinity of the emitter, creating a circular area of about 20 cm of leached soil. At the same time salt accumulated at the border of the wetted zone of the emitter, mainly at the soil surface. Peanut plants were located 15-20 cm from the trickling line. This profile represents actually a radial section of the soil volume wetted with a relatively high concentration of salt at the upper soil level. Gynophores in this experiment died (prior to pod production) when touching the saline soil surface due to their high sensitivity to salinity. This was the main reason for the large hay and poor pod yield for plants irrigated with brackish water.

We concluded that trickle irrigation with brackish water supplemented with nitrogen in soils with high permeability such as sand, is beneficial to peanut during the vegetative growth stage before gynophores reach the saline soil surface. During the reproductive stage, soil surface must be leached from its salt in order to enable gynophore penetration and pod production. Irrigation during the reproductive stage could be best done with sprinklers or minisprinklers.

This concept was tested successfully under green house conditions (see our annual reports) and is included in the objectives of Phase 2 in this proposal. It is relevant to the Philippines because of

the increasing interest in shifting from rainfed agriculture to irrigated agriculture during the dry season. A similar experiment was carried out in the Philippines (on heavier soil than that used in our experiments in Israel) yielding pod production, under saline conditions with KNO_3, which was three times larger than without fertilizer (see details given by Dr. E. Pacardo in this report).

The difference in results between Israel and the Philippines is due to the fact that during the reproductive period in the latter a significant amount of rainfall leached the saline soil enabling gynophores penetration and pod development. Since soil leaching during gynophore development did not take place in Israel, the results obtained in the Philippines support our conclussion that good soil surface leaching is essential for successful pod development.

The combined fertilization-saline water irrigation concept was also tested for corn (under field conditions) and wheat in Israel and for rice and wheat in Israel and in the Philippines. Much has been learned about the interactions of these crops with salts: nutrient uptake, photosynthesis and transpiration, assimilate allocation to growth sinks, sink priority determination, etc. All these studies have set the basis for field experimentation. Thus, another objective for Phase 2 is to study the applicability of the theory to several important salt-sensitive crops. Continuation of this work will allow much needed crop diversification in the Philippines, due to market demand and to justify the investment in modern irrigation systems in the fields.

Salinity problems exist in other most countries of the world. The experience obtains in these studies may be applicable to environmental conditions.

Most of proposal objectives of Phase 1 (C5-001) have been implemented:

(a) We have established a method to increase crop production with saline water irrigation by selectively enhanced fertilization. Salinity may promote increased yields as observed in greenhouse and field experiments.

(b) We have established cooperative research sites in Israel and the Philippines. Other Universities and Research Institutes in the Philippines are setting up cooperative projects with our group (La Salle University, Institute of Plant Breeding, Faculty of Agriculture of UPLB, etc.) These two experimental sited can now be used for the implementation of the objectives in Phase 2 (project submitted to AID/CDR, C11-131).

(c) We established a cooperative team of scientists in the two countries who are now working closely together in this and other joint projects. Graduate students from the Philippines are a constant component of our group where they integrate well and rapidly. They continue research on saline water irrigation when returning to the Philippines.