

IN HYDROPONICS.
SALINITY AND THE GROWTH OF CUCUMBER Cucumis sativus
~~BY NUTRIENT FILM TECHNIQUE (NFT)~~

by

ABDULAZIZ RABEH AL-HARBI

A thesis

submitted for the degree of doctor of philosophy

WYE COLLEGE
UNIVERSITY OF LONDON
JULY 1991

ACKNOWLEDGMENT

I would like to thank my supervisor Dr. S Burrage for his helpful discussion and encouragement at all times and for reading and correcting the scripts. It was a great source of inspiration to be associated with him.

I am indebted to the Saudi Arabia government and King Saud University, Riyadh for granting me study leave and financial support during the period of my study.

I would like to thank the staff of Horticulture department and the glasshouse unit at Wye college for their help and technical assistance during this study. Mrs S Brocklehurst for her continuous assistance when carrying out the chemical analysis. I would also like to acknowledge the support of my family and my friends in Saudi Arabia, especially my brother Naser, for their support throughout the period of my study.

Finally, I wish to express my sincere gratitude to all my friends at Wye college for encouragement and constant support.

To my parents

CONTENTS

ABSTRACT	8
LIST OF TABLES	10
LIST OF FIGURES	15
LIST OF PLATES	22
LIST OF APPENDICES	23
ABBREVIATIONS	24
 CHAPTER ONE: GENERAL INTRODUCTION	 26
 CHAPTER TWO: REVIEW OF LITERATURE	 30
2.1 Introduction	31
2.2 Effect of salinity on plant growth and yield	31
2.2.1 Osmotic effect of salinity	34
2.2.2 Specific ion effect	36
2.2.3 Calcium effect on plant salt tolerance	40
2.3 Effect of salinity on plant water relations and photosynthesis ..	42
2.4 Effect of root temperature on plant growth and physiology ...	46
2.5 Conclusion	47
 CHAPTER THREE: GENERAL MATERIALS AND METHODS	 48

3.1 Plant material	49
3.2 Experimental layout	49
3.3 Cultural technique	50
3.4 Growth media	50
3.5 Measurement of vegetative growth	51
3.6 Plant water status	52
3.6.1 Relative water content (RWC)	52
3.6.2 Water potential	53
3.7 Gas exchange measurements	53
3.8 Yield measurement	53
3.9 Chemical analytical procedures	54
3.10 Experimental design and statistical analysis	55

CHAPTER FOUR: THE INFLUENCE OF NUTRIENT SOLUTION CONCENTRATION ON CUCUMBER GROWTH, WATER RELATIONS, NUTRIENT ABSORPTION AND YIELD. . 56

4.1 EXPERIMENT A: THE EFFECT OF NUTRIENT SOLUTION CONDUCTIVITY ON THE GROWTH OF CUCUMBER PLANTS.	57
4.1.1 Introduction	57
4.1.2 Experiments and results	58
4.1.2.1 Stem growth	59
4.1.2.2 Leaf growth	61
4.1.2.3 Water uptake and relative water content (RWC)	61
4.1.2.4 Plant water potential	65
4.1.2.5 Transpiration rate and stomatal conductance	67
4.1.2.6 Photosynthetic rate	67
4.1.2.7 Plant analysis	68

4.1.2.8 Yield measurement	70
-------------------------------------	----

4.2 EXPERIMENT B: THE EFFECT OF HIGH LEVEL OF SALINITY ON THE GROWTH OF CUCUMBER PLANTS. . . . 71

4.2.1 Introduction	71
4.2.2 Experiments and results	71
4.2.2.1 Stem growth	72
4.2.2.2 Leaf growth	75
4.2.2.3 Root measurement	77
4.2.2.4 Water uptake and relative water content (RWC) . . .	81
4.2.2.5 Plant water potential	83
4.2.2.6 Transpiration rate and stomatal conductance	83
4.2.2.7 Photosynthetic rate	88
4.2.2.8 Plant analysis	88
4.2.2.9 Yield measurements	92

4.3 DISCUSSION 93

CHAPTER FIVE: EFFECT OF MANIPULATING NUTRIENT SOLUTION SALINITY ON CUCUMBER PLANT GROWTH IN NFT . 105

5.1 Introduction	106
5.2 Experiments and results	106
5.2.1 Vegetative growth measurement	107
5.2.2 Root measurements	113
5.2.3 Plant water relations	114
5.2.3.1 Water uptake and relative water content	114
5.2.3.2 Water potential	116
5.2.3.3 Transpiration rate and stomatal conductance	116
5.2.4 Photosynthetic rate	121

5.2.5 Plant analysis	121
5.2.6 Yield measurements	123
5.3 Discussion	125

CHAPTER SIX: THE INTERACTION EFFECT OF SALINITY AND ROOT TEMPERATURE ON THE CUCUMBER GROWTH AND WATER RELATIONS. 131

6.1 Introduction	132
6.2 Methods and results	132
6.2.1 Vegetative growth measurements	134
6.2.2 Root measurements	138
6.2.3 Plant water relations	138
6.2.3.1 Water uptake and relative water content (RWC)	138
6.2.3.2 Plant water potential	141
6.2.3.3 Transpiration rate and stomatal conductance	141
6.2.4 Photosynthetic rate	142
6.2.5 Plant analysis	147
6.2.6 Yield measurements	150
6.3 Discussion	152

CHAPTER SEVEN: THE INFLUENCE OF SALINITY AND SODIUM / CALCIUM RATIO ON THE CUCUMBER GROWTH AND ION UPTAKE. 157

7.1 Introduction	158
7.2 Methods and results	159
7.2.1 Vegetative growth and root measurements	160
7.2.2 Water uptake and relative water content	166
7.2.3 Transpiration rate, stomatal conductance and photosynthetic	

rate	166
7.2.4 Plant analysis	172
7.3 Discussion	182
CONCLUSION	185
REFERENCES	188
APPENDICES	210

ABSTRACT

Cucumber plants *Cucumis sativus* L. cv. Farbiola were grown using the nutrient film technique (NFT) under a wide range of nutrient solution salinity (from 1.0 to 8.5 mS cm⁻¹). Nutrient solution salinity was increased from 1.0 to 2.5 mS cm⁻¹ by adding stock nutrient solution. Higher levels of salinity were achieved by adding NaCl to the basic nutrient solution (2.5 mS cm⁻¹).

Plant growth and yield were not affected by increasing solution salinity from 1.0 to 2.5 mS cm⁻¹. The plant water uptake and water potential were decreased with decreasing the osmotic potential of the nutrient solution by the addition of salts.

Increasing solution salinity from 2.5 to 8.5 mS cm⁻¹ reduced the plant growth and yield. It had a significant effect on plant water relations and on ion uptake. Plant water uptake, relative water content, plant water potential, transpiration rate and stomatal conductance were significantly reduced by increasing solution salinity. Photosynthesis rate was not affected by nutrient solution salinity.

Ion uptake was significantly affected by solution salinity. Ca²⁺ and K⁺ levels were reduced with increasing accumulation of Na⁺ and Cl⁻ in the plant tissue.

Applying different levels of salinity day and night showed that growth reduction depended on the time and duration of exposure to saline conditions. The growth of 8.5/2.5 mS cm⁻¹ (day/night) plants was less than those of 2.5/8.5 mS cm⁻¹ (day/night). The results of the plant water status measurements reflected the stress at the time of measurement. Generally the plant growth was related to the water uptake.

Heating the nutrient solution did not increase growth of the plant possibly

due to the small range of solution temperatures used in this experiment.

Increasing the Ca^{2+} concentration in the nutrient solution did not affect the plant growth or water relations. The percentage of Na ion in the leaves was low at low $\text{Na}^+/\text{Ca}^{2+}$ ratio in the nutrient solution. It suggested that increasing Ca^{2+} under saline conditions interact with the nutritional effects of salinity rather than the salinity effect on plant water relations.

LIST OF TABLES

Table 1.1	Soil salinity and crop response	27
Table 4.1	Treatments	59
Table 4.2	Effect of the nutrient solution Ec on stem growth	59
Table 4.3	Correlation coefficient (r) of different treatments relating leaf breadth and area	63
Table 4.4	Effect of nutrient solution Ec on leaf growth	63
Table 4.5	Effect of nutrient solution Ec on plant water uptake and relative water content	65
Table 4.6	Effect of nutrient solution Ec on stomatal conductance (mmol/m ² /s), transpiration (mmol/m ² /s) and photosynthetic rates (μmol/m ² /s)	67
Table 4.7	The effect of Ec of the nutrient solution on ion levels in the root (% in the dry weight)	69
Table 4.8	The effect of Ec of the nutrient solution on ion levels in the leaves (% in the dry weight)	69
Table 4.9	The effect of the nutrient solution Ec on fruit yield	70
Table 4.10	Treatments	72
Table 4.11	The effect of salinity on plant height, stem diameter, fresh and dry weight of the stem	73

Table 4.12 Correlation coefficient (r) of different treatments relating leaf breadth and area	75
Table 4.13 The effect of salinity on leaf area, fresh weight and dry weight percentage in the petiole and lamina	77
Table 4.14 The effect of nutrient solution salinity on the plant root	78
Table 4.15 The effect of nutrient solution salinity on total fresh and dry weight and root:shoot ratio	78
Table 4.16 Effect of solution salinity on plant water uptake and relative water content	81
Table 4.17 The effect of salinity on ion levels in the root (% dry weight)	90
Table 4.18 The effect of salinity on ion levels in the leaves (% dry weight)	90
Table 4.19 The effect of nutrient solution salinity on fruit number/plant, fruit weight (g), total yield (g/plant), dry weight % in the fruit, total soluble solids (TSS) and titratable acidity (TA).	92
Table 5.1 Treatments	107
Table 5.2 The influence of diurnal changes in salinity on stem growth	108
Table 5.3 Correlation coefficient (r) of different treatments relating leaf breadth and area	110
Table 5.4 The effect of fluctuating salinity on leaf growth	110

Table 5.5 The effect of fluctuating salinity on shoot fresh and dry weight	111
Table 5.6 The effect of the treatments on root growth and root:shoot ratio	113
Table 5.7 The effect of the treatments on relative water content and total water uptake	114
Table 5.8 The effect of the treatments on ion levels in the root (% dry weight)	122
Table 5.9 The effect of the treatments on ion levels in the leaves (% dry weight)	123
Table 5.10 The influence of fluctuating salinity on fruit yield and quality	124
Table 6.1 Treatments	133
Table 6.2 Correlation coefficient (r) of different treatments relating leaf breadth and area	134
Table 6.3 Effect of salinity and nutrient solution temperature on plant growth	137
Table 6.4 Effect of salinity and nutrient solution temperature on total water uptake	140
Table 6.5 Effect of salinity and nutrient solution temperature on ion levels in the root tissue (% dry weight)	147

Table 6.6 Effect of salinity and nutrient solution temperature on ion levels in the leaf tissue (% dry weight)	148
Table 6.7 The effect of salinity and nutrient solution temperature on fruit yield	152
Table 7.1 Treatments	159
Table 7.2 Effect of salinity and external Ca^{2+} concentration on plant growth	163
Table 7.3 Correlation coefficient (r) of different treatments relating leaf breadth and area	164
Table 7.4 The effect of the treatments on dry matter % in different plant parts	164
Table 7.5 Effect of salinity and external Ca^{2+} concentration on plant water uptake and relative water content (RWC)	172
Table 7.6 Effect of salinity and external Ca^{2+} concentration on Ca^{2+} levels in the root and in the leaves (% dry weight)	173
Table 7.7 Effect of salinity and external Ca^{2+} concentration on K^{+} levels in the root and in the leaves (% dry weight)	173
Table 7.8 Effect of salinity and external Ca^{2+} concentration on P levels in the root and in the leaves (% dry weight)	177
Table 7.9 Effect of salinity and external Ca^{2+} concentration on Mg^{2+} levels in the root and in the leaves (% dry weight)	177

Table 7.10 Effect of salinity and external Ca^{2+} concentration on Na^+ levels in the root and in the leaves (% dry weight)	178
---	-----

Table 7.11 Effect of salinity and external Ca^{2+} concentration on Cl^- levels in the root and in the leaves (% dry weight)	178
---	-----

LIST OF FIGURES

Figure 4.1 Changes in the stem length (A) and diameter (B) as influenced by the nutrient solution Ec	60
Figure 4.2 Leaf area as influenced by the nutrient solution Ec	62
Figure 4.3 The plant water uptake as affected by the nutrient solution Ec	64
Figure 4.4 Effect of the nutrient solution Ec on plant water potential	66
Figure 4.5 Changes in stem length (A) and diameter (B) as influenced by nutrient solution salinity	74
Figure 4.6 Effect of nutrient solution salinity on leaf area	76
Figure 4.7 Plant water uptake as affected by nutrient solution salinity ...	82
Figure 4.8a Diurnal variation on plant water potential as influenced by nutrient solution salinity	84
Figure 4.8b Plant water potential as influenced by nutrient solution salinity	84
Figure 4.9 Diurnal variation in the transpiration rate at different levels of radiation as affected by solution salinity	85
Figure 4.10 Diurnal variation in stomatal conductance at different levels of radiation as affected by solution salinity	86
Figure 4.11 Changes in transpiration rate as influenced by salinity level in the nutrient solution	87

Figure 4.12 Effect of the nutrient solution salinity on stomatal conductance	87
Figure 4.13 Diurnal variation in the photosynthetic rate at different levels of radiation as affected by solution salinity	89
Figure 4.14 Na% and Cl% in the leaf as influenced by increasing nutrient solution salinity	91
Figure 4.15 Na% and Cl% in the root tissue as influenced by increasing nutrient solution salinity	91
Figure 4.16 The relationship between plant water uptake and nutrient solution Ec	96
Figure 4.17 The relationship between plant water uptake and leaf area ..	96
Figure 4.18 The relationship between leaf area and shoot dry weight	99
Figure 4.19 The relationship between shoot fresh weight and total fruit yield	99
Figure 4.20 The relationship between Na% and K% of the dry matter of the leaf	101
Figure 4.21 The relationship between Na% and Ca% of the dry matter of the leaf	101
Figure 4.22a Na% in the root tissue related to the nutrient solution salinity	103
Figure 4.22b Na% in the leaf tissue related to the nutrient solution salinity	103

figure 4.22c Cl% in the root tissue related to the nutrient solution salinity	104
Figure 4.22d Cl% in the leaf tissue related to the nutrient solution salinity	104
Figure 5.1 Changes in the stem length (A) and diameter (B) as influenced by the treatments	109
Figure 5.2 The influence of the treatments on leaf area	112
Figure 5.3 Plant water uptake as influenced by the treatments	115
Figure 5.4 Diurnal measurement for the plant water potential 30 days after starting the treatments	117
Figure 5.5a Transpiration rate at different levels of radiation as influenced by the treatments	118
Figure 5.5b Changes in transpiration rate as influenced by the treatments	118
Figure 5.6a Stomatal conductance at different levels of radiation as influenced by the treatments	119
Figure 5.6b Changes in stomatal conductance as influenced by the treatments	119
Figure 5.7a Transpiration rate of the old and new leaves as influenced by different treatments	120
Figure 5.7b Stomatal conductance of the old and new leaves as influenced by the treatments	120

Figure 5.8 Plant shoot fresh weight related to the total water uptake	126
Figure 5.9 The relationship between plant water uptake and leaf area . . .	126
Figure 5.10 The relationship between total water uptake and total fruit yield	128
Figure 5.11 The relationship between the plant fresh weight and total fruit yield	128
Figure 5.12 The relationship between water uptake and dry matter% in the fruit	129
Figure 6.1 Changes in the stem length (A) and diameter (B) as affected by the treatments	135
Figure 6.2 The influence of the treatments on leaf area	136
Figure 6.3a Plant water uptake as affected by salinity levels in the nutrient solution	139
Figure 6.3b Plant water uptake as affected by the nutrient solution temperature	139
Figure 6.4a Relative water content as affected by salinity levels in the nutrient solution	143
Figure 6.4b Relative water content as affected by the nutrient solution temperature	143
Figure 6.5a Diurnal variation in the plant water potential as affected by the nutrient solution salinity	144

Figure 6.5b Plant water potential as affected by nutrient solution salinity .	144
Figure 6.6a Transpiration rate as affected by salinity levels in the nutrient solution	145
Figure 6.6b Transpiration rate as affected by the nutrient solution temperature	145
Figure 6.7a Stomatal conductance as affected by salinity levels in the nutrient solution	146
Figure 6.7b Stomatal conductance as affected by the nutrient solution temperature	146
Figure 6.8 The effect of the nutrient solution salinity and root temperature on Ca% of the root dry matter.	149
Figure 6.9 The effect of nutrient solution salinity and root temperature on P% of leaf dry matter	149
Figure 6.10 The effect of the nutrient solution salinity and root temperature on Na% of root dry matter.	151
Figure 7.1 Changes in the stem length (A) and diameter (B) as affected by salinity and external Ca^{2+} concentration	161
Figure 7.2 The influence of nutrient solution salinity and external Ca^{2+} concentration on leaf area	162
Figure 7.3 The effect of salinity and Ca^{2+} concentration on the nutrient solution on the dry matter % in the leaves	165

Figure 7.4 The influence of nutrient solution salinity and external Ca^{2+} concentration on the plant water uptake	167
Figure 7.5 The effect of salinity and external Ca^{2+} concentration on relative water content	168
Figure 7.6a Transpiration rate as affected by salinity levels in the nutrient solution	169
Figure 7.6b Transpiration rate as affected by external Ca^{2+} concentration	169
Figure 7.7a Stomatal conductance as affected by salinity levels in the nutrient solution	170
Figure 7.7b Stomatal conductance as affected by external Ca^{2+} concentration	170
Figure 7.8 Transpiration rate of the old and new leaves as affected by the nutrient solution salinity and external Ca^{2+} concentration	171
Figure 7.9 Stomatal conductance of the old and new leaves as affected by the nutrient solution salinity and external Ca^{2+} concentration	171
Figure 7.10 $\text{Ca}\%$ of the dry matter of the fully expanded leaves as affected by nutrient solution salinity and external Ca^{2+} concentration	175
Figure 7.11 $\text{K}\%$ of the dry matter of the young leaves as affected by the nutrient solution salinity and external Ca^{2+} concentration	176
Figure 7.12 $\text{P}\%$ of the dry matter of the young leaves as affected by the nutrient solution salinity and external Ca^{2+} concentration	176
Figure 7.13 $\text{Na}\%$ of the dry matter of the old leaves as affected by the nutrient	

solution salinity and external Ca^{2+} concentration	180
Figure 7.14 Na% on the dry matter of the fully expanded leaves as affected by the nutrient solution salinity and external Ca^{2+} concentration . .	180
Figure 7.15 Na% of the dry matter of the matter of the young leaves as affected by the nutrient solution salinity and external Ca^{2+} concentration	181
Figure 7.16 Cl% of the dry matter of the root as affected by the nutrient solution salinity and external Ca^{2+} concentration	181

LIST OF PLATES

Plate 4.1 Cucumber plants grown at high salinity compared to the
controls 79

Plate 4.2 Root matt of cucumber plants grown at different levels of
salinity 80

LIST OF APPENDICES

Appendix Figure 1. Diagram of the experiment layout	211
Appendix Table 2. Chemical composition of Wye solution. (Varley and Burrage 1981)	212
Appendix Figure 3. Connection of the Infra-red gas analyzer (LCA2) during the leaf gas exchange measurement.	213
Appendix plate 4. Cucumber plants grown under high salinity (8.5 mS cm ⁻¹) compared to the control plants (2.5 mS cm ⁻¹)	214
Appendix plate 5. Cucumber fruits grown under different salinity regimes	215
Appendix Table 6. Chemical composition of Wye tap water used in the experiments	216

ABBREVIATIONS

BST	British Standard Time
Ca ²⁺	calcium ion
°C	degree centigrade
CF	conductivity factor
Cl ⁻	chloride ion
cm	centimetre
Ec	electrical conductivity
Fig.	figure
g	gram
GMT	Greenwich Mean Time
h	hour
IRGA	Infra-Red Gas Analyzer
K ⁺	potassium ion
l	litre
LSD	least significant difference
m	metre
Mg ²⁺	magnesium ion
ml	millilitre
mM	millimolar
mmol/m ² /s	millimole per square metre per second
MPa	Megapascal
mS	millisiemens
n	normal
Na ⁺	sodium ion
NFT	Nutrient film technique
ns	not statistically significant
P	phosphorus
PEG	polyethylene glycol
ppm	parts per million
RWC	relative water content

r	correlation coefficient
RLER	relative leaf expansion rate
T	Treatment
TSS	Total soluble solids
$\mu\text{mol/m}^2/\text{s}$	micro mole per square metre per second
W m^{-2}	Watts per square metre

CHAPTER ONE: GENERAL INTRODUCTION

Salinity is often defined as the presence of an excess concentration of soluble salts in the root media sufficient to suppress plant growth (Maas and Nieman 1978). It is considered as one of the oldest environmental problems. Salinity can arise either from one or the interaction of several different factors which may include water quality, climate, soil properties and irrigation management. Salinity is an increasing problem in the arid and semi-arid regions where it is caused mainly by the deposition and accumulation of salt from the irrigation water during the process of evaporation. The salinity level of the irrigation water may be below the threshold for most sensitive crops but salt accumulation from both irrigation and ground water sources can increase salinity rapidly to a level, which can reduce the yield of even the most tolerant crops.

There are many ways of measuring the soil salinity. The most common way is by measuring the soil solution electrical conductivity (Ec). Electrical conductivity (Ec) of the nutrient solution is a measure of the total salt concentration and gives an indication of the level of fertility. It is mainly affected by the macro elements, trace elements only have a small effect on electrical conductivity. Crop growth reduction increases with increasing Ec of the soil solution (Table 1.1).

Table 1.1 Soil salinity and crop response.

Ec mmhos cm ⁻¹	Crop response
0-2	salinity effect on yield negligible
2-4	very sensitive crop reduced
4-8	yield of many crops reduced
8-16	only tolerant crops yield satisfactorily
>16	only very tolerant crops yield satisfactorily

(From Withers and Vipond, 1974)

Salinity in general reduces plant growth. Salt stress consists of two influences: osmotic stress caused by increase in external osmotic pressure of the soil solution due to the high concentration of salt and the physiological / biochemical effect of cation and anion balance in the plant cell (Munns and Termaat 1986).

Plants vary in their response to salinity level of the root media depending on their ability to adjust osmotically their cell structure. Osmotic adjustment allows some plants to continue the uptake of water in saline conditions and therefore to maintain turgor. Generally the plants can be divided in two groups, glycophytic plants, those which can only tolerate relatively low concentration of soluble salts and halophytes, those which can tolerate relatively high concentrations.

There are many other factors, which may affect the plant tolerance to high salinity, these include species, climate and growth stage. Most of the research on the effect of salinity on crop production has been carried out using hydroponic culture. This has the advantage of precise control of nutrient uniformity enabling nutrients to be supplied equally to all parts of the root zone. Hydroponics also give us the ability to control pH in the root zone.

Nutrient film technique (NFT) is one of the most advanced hydroponic systems. In NFT, the plants are grown in a shallow stream of recirculating solution in which are dissolved all the elements required for growth. The ability to control the root environment precisely makes NFT an ideal technique for studying the crop response to salinity.

OBJECTIVES:

The objective of this study was to evaluate the response of cucumber plants to salinity in the nutrient solution and to examine the possibility of alleviating the negative effects of salinity by manipulating the root environment.

CHAPTER TWO: REVIEW OF LITERATURE

2.1 INTRODUCTION:

Salinity is a limiting factor to agricultural productivity particularly in arid climates. It causes changes in plant growth and physiology. These changes are an adaptation to the influence of ions on the water activity of the soil solution. It is principally an osmotic effect resulting from competition for water between soil and the plant. This affects the plant water status, the transfer of the ions into the plant and the ion balance. The ions also affect the physiological and biochemical function of the cell (Hasegawa *et al* 1986).

The literature on the salt tolerance of plants and crop production under saline condition is extensive. This review presents a synopsis of the aspects of salinity as it affects plant growth and yield with particular reference to the studies undertaken in hydroponics.

2.2 THE EFFECT OF SALINITY ON PLANT GROWTH AND YIELD:

Plant response to increased salt concentration in the root medium varies among species and under different environmental conditions (Gale 1975; Pasternak 1987). Salinity generally stunts plant growth and reduces leaf area. The leaves look a darker green and are thicker (Bernstein 1975; Schwarz 1985). These changes usually occur without obvious signs of injury such as wilting, chlorosis or necrosis (Maas and Nieman 1978).

Salinity induced growth reduction has been observed on different crops; Onion (Wannmaker and Pike 1987) ; Tomato (Massey *et al* 1983); Pepper (Hoffman *et al* 1980). Jones (1984) found a reduction in the shoot length and dry

weight of cucumber when salinity increased from 8 to 120 mS cm⁻¹. Muskmelon fruit fresh weight and whole plant dry weight were decreased with increasing osmotic potential of the solution culture (Nukaya *et al* 1983).

Meiri *et al* (1970) grew bean plants, *Phaseolus vulgaris* in a culture solution in plastic pots. Salinity of the growing media was increased gradually in two ways. Firstly equal amounts of concentrated NaCl solution were added to the substrate twice a day. Secondly a concentrated NaCl solution was added continuously by a streaming system designed to give a linear increase of salt concentration in the substrate. They found that the bean plant growth was retarded under fluctuating regimes of salinity, the retardation being dependent on the rate of salinization, the final level of salinity and duration of exposure to the higher levels of salinity. Transfer of the plant from saline to non-saline medium resulted in a transient burst of growth.

Adams (1988a) investigated the effect of NaCl on tomato plants grown in NFT. He found that the leaves of the plants became progressively darker as the concentration of NaCl in the solution increased. No foliar symptoms developed to suggest that the plant had absorbed excessive amounts of Na⁺ or Cl⁻ at 65-67 mM Na⁺. Ramani *et al* (1989) investigated the response of three species of *Sesbania* to 0, 50 and 100 mM NaCl in hydroponic culture. They found that shoot growth, fresh and dry weight decreased with increasing salinity.

Salinity is generally reported to decrease shoot:root ratio. This is due to the suppression of top growth more than root growth when the plants are grown in saline media (Hoffman *et al* 1980; Schwarz 1985; Ramani *et al* 1989).

The response to salinity varies in each stage of growth (Schwarz 1985; Maas and Hoffman 1977). Most plants are more sensitive to salinity stress during the early stage of growth than at a later stage. This is reported for tomato and cucumber (Schwarz 1985), muskmelon (Nukaya *et al* 1984) and wheat (Hampson

and Simpson 1989).

Dumbroff and Cooper 1974 investigated the effect of salinity of the nutrient solution at different stages of tomato growth. They found that the negative effect of stress on vegetative growth generally decreased with an increase in the age of the plants at time of exposure.

The highest yield of cucumber was obtained when the solution conductivity was between 2.5 and 4.0 mS cm⁻¹ (Graves and Hurd 1983). Attenburrow and Waller (1980) examined the effect of NaCl on nutrient uptake and crop yield of tomato grown in NFT. They found that the yield of tomato was reduced when make-up water contained 200 mg/l NaCl. A further reduction was found when the NaCl concentration increased from 400 to 800 mg/l. Fruit quality, measured as total soluble solids (TSS) and titratable acidity (TA), was improved while the fruit size declined as NaCl concentration increased.

Improvement in fruit quality with increasing salinity has been observed by many workers (Hobson and Adams 1988; Mizrahi 1982). Mizrahi and Pasternak (1985) investigated the effect of salinity on the quality of various agricultural crops including melon and tomato. They reported that salinity improved the taste of melon fruit and increased the total soluble solids and acidity of tomato fruit. Adams (1988a) also reported that the proportion of Class 1 tomato fruit and the dry matter content of the fruit were improved by increasing Na⁺ level (as sodium chloride) in the nutrient solution. Sugar content and titratable acidity also increased with Na⁺ levels. Jones (1984) reported that increasing salinity reduced the cucumber fruit yield but no effect was found on fruit quality.

2.2.1 OSMOTIC EFFECT OF SALINITY:

The effect of increasing osmotic potential of nutrient solution is to decrease the water potential of growth media or soil. Different salts may have different effects on the plant growth (Bernstein 1975). Hampson and Simpson (1989) germinated spring wheat at six osmotic potentials (-0.3 to -1.8 MPa) at three temperatures and with different salt solutions including chloride and sulphate or polyethylene glycol (PEG). They found that growth reduction and injuries to seedlings grown in saline solution cannot be attributed to low osmotic potential alone since iso-osmotic solution of salt and PEG had different effects. The individual salts also differed from each other in their capacity to affect growth. In iso-osmotic solutions, sulphates of Na^+ and K^+ suppressed growth slightly more than chloride and growth was severely inhibited even at low concentrations of Mg^{2+} salt.

Cerda *et al* (1979) grew wheat and tomatoes in a greenhouse in tanks filled with 110 litres of nutrient solution containing low to excessive concentrations of NaCl. They found that the leaf water potential and osmotic potential decreased significantly with decreasing solution potential. Clipson *et al* (1985) reported that the leaf osmotic potential of *Suaeda maritima* was lower (more negative) the higher the salt concentration of the solution and lowest in the youngest leaves and stem apices producing a gradient of decreasing osmotic potential towards the apex of the plant.

The increase in dry matter of the shoot appear to reflect the osmotic stress applied on the roots after a period of time (Meyer and Gingrich 1966). Leaf elongation of barley and maize was reduced by decreasing the water potential of the root solution. This reduction in growth was followed by a subsequent resumption in growth at a much slower rate, suggesting possibly adjustments in the ability of cell to expand or the solute concentration (Acevedo *et al* 1971;

Matsuda and Riazzi 1981).

The import of salts to leaves of plants grown in saline solution contributed towards the more negative osmotic potential within the plant compensating for the reduction in osmotic potential of the external media. Lloyd *et al* (1987b) reported that salt accumulation in the leaves of Valencia oranges grown in saline media contributed to more negative osmotic pressure in the cells and the maintenance of turgor at or above the level in the control plants.

This osmotic adjustment, defined as an increase in osmotic potential of the cell sap, results from an increase in the solute molecules per cell rather than from lower cell volume (Munns 1988). Na^+ and Cl^- accounted for about 30% of the osmotic adjustment that was observed and 65% of the total solutes that were measured in cells adapted to 428 mM NaCl (Hasegawa *et al* 1986). Delane *et al* (1982) found that the Cl^- and $\text{Na}^+ + \text{K}^+$ concentration accounted for about 50% of the osmotic pressure of the elongation tissues at different NaCl concentration. They concluded that most of the osmotic adjustment of elongation leaf tissue was probably a result of reduced growth.

An early report by Bernstein (1961) indicated that a decreased osmotic gradient for water uptake such as might occur in plants unadjusted to the increased osmotic pressure of the medium could not be responsible for impaired growth of the adjusted plants in saline media since the osmotic pressure of all plant parts appears to increase with increasing osmotic potential of the root medium. This adjustment seems to be a precondition for development. He concluded that the osmotic adjustment itself is a likely limiting factor for growth under saline conditions by making osmotic cell enlargement dependent on accumulation of solutes to requisite higher osmotic level. Salt tolerance may therefore be defined in this case as the degree to which osmotic adjustment can be made without significant sacrifice of growth (Bernstein 1961).

The inhibitory effect of salinity on plant growth is generally attributed to the increase on their osmotic pressures and to the associated reduction in the water uptake (Schwarz 1985). Water deficit in the expanding tissue was once believed to limit the growth on saline media, through the restriction of water uptake thus placing the plant under stress. Some salt-sensitive species are more susceptible at low than at high humidity (Greenway and Munns 1980).

Delane *et al* (1982) and Munns *et al* (1982) studied the growth of salt tolerant barley grown at high external NaCl concentration. They concluded that the growth was reduced by water deficit in the elongate tissue rather than from adverse effects of ions on metabolism. This was indicated by resumption of the growth of plants after they were transferred from high to low saline media, despite the presence of high Cl^- and $\text{Na}^+ + \text{K}^+$ concentrations in the elongate tissue and fully elongated tissue. This hypothesis was ruled out by Termaat *et al* 1985. They grew the plants in a saline soil encased within a pressure chamber and applied a pressure to the soil, which rapidly raised the shoot water potential by the same amount as the applied pressure. This rise in shoot water potential initially caused an equal rise in shoot turgor pressure, but growth was not improved, so they concluded that turgor and therefore the process generating turgor were not limiting growth.

Munns and Termaat (1986) reported that leaf expansion is probably regulated by a message from the root rather than a water deficit in the expanding leaves or any process related to it including the production of osmotic solutes for turgor maintenance. Munns (1988) also suggested that the turgor does not control stomatal conductance or cell expansion and the osmotic adjustment might be adaptation for surviving stress rather than for growing during it.

2.2.1 SPECIFIC ION EFFECTS:

Salinity has two primary effects on the plant, direct toxicity due to excessive accumulation of ions in the tissue and nutritional imbalance caused by an excess of some particular ion (Pasternak 1987). Ion excess is defined by Greenway and Munns (1980) as a condition where high internal ion concentrations reduced growth. This was indicated in some experiments where the inhibitory effect of some isosmotic concentration of nonpermeating salt (PEG) was smaller than that of NaCl or CaCl₂ (Kawasaki *et al* 1983a,b; Ben-Hayyim *et al* 1987). Jones (1981) reported that the salt tolerance of glycophytes and even halophytes to NaCl has been correlated with their ability to exclude Cl⁻ and/or Na⁺ from the shoot. These exclusion mechanisms are more affective at low or moderate levels of salinity (Hasegawa *et al* 1986).

Lauchli (1986) reported that many crops are salt excluders when exposed to low salinity and suffer from an osmotic effects because of the lack of the ability for sufficient osmotic adjustment. Ion toxicity is a widespread salinity response in very salt-sensitive crops. It was also found in salt excluder plants exposed to very high levels of salinity that the mechanisms of ion exclusion broke down. Attenburrow and Waller (1980) investigated the effect of sodium chloride on nutrient uptake and crop yield of tomato in NFT. They found that the reduction in plant growth was associated with an increase in Na⁺ and Cl⁻ uptake by the plants.

Ion specific effects can occur at the cell membrane, leading to impaired ion transport and interference with mineral nutrition of the plant (Lauchli 1986). Certain injury signs can be attributed to Na⁺ or Cl⁻ toxicity. Greenway and Munns (1980) reported that in several species, the salt sensitivity of certain varieties is due to the absorption of relatively high amounts of Cl⁻ and/or Na⁺, so these varieties suffer from ion excess in expanded leaves. This is supported by Munns and Termaat (1986) who grew wheat, barley, white clover and Egyptian clover at

isosmotic concentration of NaCl and concentrated macronutrients for up to 30 days. They found that after four days there was no difference in growth with or without NaCl at the same osmotic potential. But by 11 days it was clear that the plants in NaCl were growing less than those in concentrated nutrients. They concluded that the long term response of reduction in growth in saline condition could be attributed to an excessive uptake of salt by the old leaves. The premature death of these leaves reduces the photosynthetic area of the plant sufficiently so that it can no longer produce enough carbohydrate to support continued growth.

The ion uptake into the whole plant involves ion uptake into the root, transport of ions through various tissue and finally their accumulation in the leaves. The overall effect of salinity is due to any possible combination of these processes. Ramani *et al* (1989) grew three *Sesbania* species hydroponically at different levels of NaCl concentration in the root media. They found that the uptake of Na^+ increased with increasing concentration of NaCl, but the translocation was much less than the uptake, most of the Na^+ was retained in the root. The uptake of Cl^- was about one third of the Na^+ but the translocation to shoot was relatively greater.

Chloride uptake is reported to produce succulence in the leaves (Jennings, 1976). It also induces larger epidermal cells, fewer stomata per unit surface area and a poorly developed xylem system (Maas and Nieman 1978). High Cl^- concentration in expanded leaves of certain species is associated with chlorosis and death, these injuries occur even when Na^+ in the leaves is low (Greenway and Munns 1980).

Growth reduction of non-halophytes grown in nutrient solution is often due to the effect of ion imbalance rather than the osmotic potential (Kawasaki *et al* 1983b). This is due to the inhibition effect of salinity on the uptake of certain ions. High sulphate concentration may promote the uptake of sodium, leading to

sodium toxicity and a decrease in the uptake of calcium leading to calcium deficiency. It may also interfere with potassium uptake (Schwarz 1985).

Calcium deficiency induced by high salinity has been reported for different crops (Kawasaki *et al* 1983a; Kent and Lauchli 1985; Maas and Grieve 1987). Sonneveld (1988) reported that the supply as well as the distribution of calcium may be affected by salinity. Most of the negative effects of salinity on the quality of glasshouse produce are related to calcium deficiency. This reduction in calcium uptake leads to calcium deficiency symptoms such as blossom end rot in tomato and peppers, black heart of celery, and internal browning (tipburn) of lettuce especially in high sulphate growing media (Schwarz 1985).

Calcium deficiency increased with increasing $\text{Na}^+:\text{Ca}^{2+}$ ratio in the root media (Maas and Grieve 1987). LaHaye and Epstein (1969) showed that Ca^{2+} and Na^+ interaction takes place at the plasmalemma. They suggested that Na^+ acted by displacing Ca^{2+} from the membrane leading to an increase in membrane permeability and intercellular Na^+ concentration. Excess of Na^+ often harms nonhalophytes by displacing Ca^{2+} from the root membranes and thus changes their integrity and ion-transport regulation (Cramer *et al* 1985). It may also be due to a high $\text{Na}^+:\text{K}^+$ ratio, which is accompanied by a reduction of protein synthesis and enzymatic activities (Silberbush *et al* 1988).

The uptake of some ions such as K^+ , P, and Mg^{2+} are reported to be affected by NaCl concentration in the root media (Kawasaki *et al* 1983a,b; Kent and Lauchli 1985; Ben-Hayyim *et al* 1987). Silberbush and Ben-Asher (1989) investigated the effect of NaCl concentration in uptake rate of NO_3^- , K^+ and orthophosphate-P by Peanut (*Arachis hypogaea* L.) in a solution culture. They found that the reduction of ion influx was greatest for K^+ , followed by NO_3^- , while phosphate influx was not affected by NaCl. They concluded that low concentrations of NaCl disturbed the nutritional balance of plants, mainly by $\text{Na}^+ - \text{K}^+$ competition in uptake and to a smaller degree by $\text{Cl}^- - \text{NO}_3^-$ interaction.

The competition between Na^+ to K^+ influx seems to be either by direct competition of the excess to the influx channels in 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). Ben-Hayyim *et al* (1987) grew Shamouti Orange salt tolerant cells, under low water potential condition induced by PEG, NaCl and CaCl_2 . They reported that K^+ concentration was reduced in all the treatments and growth capacity was determined by the combination of $\text{Ca}^{2+}/(\text{Na}^+)^2$ ratio and the absolute external concentration of NaCl. Also Kawasaki *et al* (1983a), in a short term absorption experiment using a tracer technique, found a reduction in K^+ , Ca^{2+} , and Mg^{2+} plant content with increasing NaCl concentration; which was more severe than the reduction caused by the PEG treatment.

This ionic imbalance may not be the only factor responsible for the growth reduction of the plants under high levels of salinity. The internal concentration of Na^+ and Cl^- could not be directly correlated with growth (Walker *et al* 1988; Ben-Hayyim *et al* 1987). Munns *et al* 1988 grew barley plants in a solution containing 0, 100 or 175 mol m^{-3} NaCl from emergence until anthesis. They found that Na^+ and Cl^- concentrations were high in expanding tissues and much lower in the dividing tissues particularly Cl^- . In both cases it did not correlate with the growth rate and development rate of the tissue. They concluded that the growth of the shoot is not directly controlled by local concentration of Na^+ or Cl^- of the growing tissues, but by some influence originating elsewhere in the plant.

2.2.3 CALCIUM EFFECT IN PLANT SALT TOLERANCE:

Salinity interaction with nutrient uptake by the plant has been demonstrated. One of the main elements reported to be affected by high salinity

is calcium, which is an important factor in maintenance of membrane integrity, ion-transport regulation and for K^+/Na^+ selectivity (Hanson 1984).

Calcium has been reported to enhance the plant cell-tolerance (LaHaye and Epstein 1969; Kawasaki *et al* 1983a; Kent and Lauchli 1985). Increasing Ca^{2+} concentration in the nutrient solution mitigated the adverse effect of NaCl on bean plants by inhibition of Na^+ uptake (Greenway and Munns 1980). Ehret *et al* (1990) found that the Ca^{2+} concentration in the nutrient solution had a marked effect on the relative salt tolerance of the wheat. Maas and Grieve (1987) showed that corn plants grown in nutrient solution salinized with 86.5 mol m^{-3} NaCl exhibited severe Ca^{2+} deficiency symptoms at the four leaf stage. The symptoms disappeared when part of the NaCl was replaced with 10 mol m^{-3} $CaCl_2$ (Na^+/Ca^{2+} molar ratio = 5.7). They also found that as the Na^+/Ca^{2+} ratio in the solution decreased, Ca^{2+} levels were increased and Na^+ levels were decreased in the leaves and sheaths.

Subbarao *et al* (1990) reported that decreasing Na^+/Ca^+ ratio in the growth medium at 6 and 8 mS cm^{-1} salinity level increased the shoot dry matter of pigeonpea. A similar trend was observed for the leaf area and root dry matter. Supplemental Ca^{2+} in the saline nutrient solution mitigated the reduction in root growth of cotton (Cramer *et al* 1986) and completely protected the root of maize from salt stress (Cramer *et al* 1988). Barley seedling root and shoot fresh weight was improved by addition of 10 ml m^{-3} Ca^{2+} to the growth medium when it was exposed to 150 mol m^{-3} NaCl 9 days after germination (Cramer *et al* 1989).

Kawasaki *et al* (1983b) reported that the inhibition of K^+ and P absorption by high concentrations of NaCl was reversed in the presence of Ca^{2+} especially the absorption and translocation of P. Cramer *et al* (1985) showed that the displacement of Ca^{2+} by Na^+ in the membrane sites and increased K^+ efflux with increasing NaCl concentration were mitigated by increased Ca^{2+} in the solution culture. Entrance of Na^+ into the cytoplasm is probably the most important

primary reaction of salt-stressed cells. External Ca^{2+} reduces the plasmalemma permeability to Na^+ and protects the cell from the salt effect (Katsuhara and Tazawa 1988). Kent and Lauchli (1985) reported that the addition of supplemental Ca^{2+} offset the reduction in cotton seedling growth caused by NaCl. They concluded that the beneficial effect of high Ca^{2+} concentration on the root growth of cotton seedlings in saline environment may be due to maintenance of K^+/Na^+ selectivity and adequate Ca^{2+} status in the root. Nakamura *et al* (1990) found that external Ca^{2+} has an important effect on the permeability to K^+ of plasma membranes of mung bean roots.

2.3 EFFECT OF SALINITY ON PLANT WATER RELATIONS AND PHOTOSYNTHESIS:

Salinity causes changes in water uptake and balance, gas exchange, transpiration, photosynthesis and respiration. A reduction in photosynthetic rate with increasing salinity is reported in all species recorded, but the concentration at which the photosynthetic rate is severely reduced varies greatly in different plant species (Gale 1975).

The primary effect of salinity is to reduce the osmotic potential of the soil solution. This reduces the water uptake by the plants through the effect on the turgor and subsequent stomatal closure. High salt concentration in the root media has been reported to decrease the water potential of the plants (Cerdea *et al* 1979 ; Hoffman and Rawlins 1971; Lloyd *et al* 1987a). Cerdeia *et al* (1979) reported that leaf water potential and its components osmotic and turgor pressure potential decrease as salinity levels increased. Leaf stomatal diffusion resistance to water vapour ($r_{\text{H}_2\text{O}}$) and carbon dioxide (r_{CO_2}) and calculated values of mesophyll resistance (r_m) of tomato plant increased significantly as salinity increased. They

concluded that photosynthesis may significantly be reduced by the increased r_{CO_2} as a result of lowering solution osmotic potential, and increase in $r_{\text{H}_2\text{O}}$ would lead to decreased transpiration.

Reduction in the transpiration rate with increasing salinity levels in the root media was reported by (Gale and Poljakoff-Mayber 1970; Hoffman and Phene 1971). Meiri *et al* (1970) showed that transpiration of bean plants was reduced in proportion to the salinity level in the root media. Transferring the plant from saline to non-saline medium resulted in an increase in transpiration rate, but not to the level of the control plants.

Plant productivity is determined by the area of leaf and activity of the photosynthetic tissue. The plant capacity for carbon accumulation is determined by the rate of leaf extension as well as by rate of photosynthesis and respiration (Papp *et al* 1983). Reduction in the photosynthetic rate is one of the main factors influencing growth reduction under saline conditions. Moderate salinity affects photosynthesis by reducing stomatal aperture, even when there is a full adjustment of the internal osmotic concentration and turgor is high (Schwarz 1985).

Hoffman and Phene (1971) investigated the effect of salinity on the water use efficiency of beans and cotton. They found that net photosynthesis per unit leaf area and transpiration rate were reduced and respiration rate was increased with increasing salinity. Seemann and Critchley (1985) showed that the ambient photosynthetic rate per unit leaf area of *Phaseolus vulgaris* L. declined by approximately 75% over the range of 0-300 mM leaf chloride. This reduction in photosynthesis was associated with similar reduction in stomatal conductance, expressed as H_2O conductance, with increasing leaf Cl^- concentration. They concluded that the effect of salt on photosynthetic processes could be categorized as, 1. the response of stomata to salinization of the plant, 2. the effect of salt on the capacity of the plant for CO_2 fixation independent of altered diffusion

limitations.

Schwarz and Gale (1984) investigated the plant response to salinity under high levels of CO₂. They found that CO₂ supplementation increased salt tolerance for different species (especially the C3 species). This result supported the hypothesis that under low levels of salinity growth may be limited by a shortage of photosynthate. Downton (1977) grew rooted cuttings of grapevine in sand culture and irrigated with nutrient solution containing 1-125 mM NaCl. He attributed the reduction in the vine growth under saline conditions to a decrease in photosynthetic activity. This could be largely attributed to increased residual (mesophyll) resistance to CO₂ fixation. Gale and Poljakoff-Mayber (1970) reported that the mesophyll resistance to CO₂ uptake, of salt bush plant *Atriplex halimus* L., was decreased by low concentrations of NaCl and increased by high concentrations of NaCl and by all concentrations of Na₂SO₄. Lloyd *et al* (1987a) grew grafted orange trees on soil culture under controlled environmental conditions. The soil was salinized by adding NaCl to the nutrient solution in increments of 5 mol m⁻³ per day to a final concentration of 50 mol m⁻³. They concluded that CO₂ assimilation was more sensitive to high foliar salt levels than stomatal conductance.

The reduction of plant growth under low salinity can be related to the increase of maintenance respiration. Schwarz (1985) reported that under saline conditions the plants suffered from a shortage of assimilates due to a reduction of photosynthesis and increase of maintenance respiration. Schwarz and Gale (1984) reported that salt tolerance in representative species from four physiological groupings was correlated with the extent to which maintenance respiration increased during salinity stress.

Photosynthesis reduction has been correlated by some workers with increasing level of chloride in the leaves (Downton 1977; Seemann and Critchley 1985). Yeo *et al* (1985) suggested that the inhibition of net photosynthesis in rice

Oryza sativa L. by salinity is mediated by water deficit in the leaf cell due to accumulation of salt in the apoplast while Munns *et al* (1988) found that the concentration of Cl^- and Na^+ in the expanding regions and fully expanded leaf cells did not correlate with expansion and photosynthesis.

Nieman (1962) and Walker *et al* (1988) found that photosynthetic rate per unit area of leaf did not decreased with increasing salinity. Reduction in plant growth was brought about by the influence of salinity on leaf expansion. Increasing salinity reduced leaf area and therefore reduced total photosynthetic area of the plant. Papp *et al* (1983) grew sugar beet *Beta vulgaris* L. in nutrient solution containing 0.5 to 500 mol m^{-3} NaCl. He found that respiration per unit leaf area was not affected by salinity while photosynthesis per unit area was reduced only at the highest levels of salinity (350 and 500 mol m^{-3}). Even at highest levels of salinity photosynthesis per unit area may not limit carbon accumulation. He suggested that salinity effects on carbon accumulation in *Beta vulgaris* L. are mediated primarily via effect on leaf extension.

Rawson and Munns (1984) manipulated the carbon availability for growth of sunflower plants grown in solution culture, by changing salt levels and use of a photosynthesis inhibitor DCMU. The results showed that the leaves of the control plants expanded faster during the day than the night, while the plants grown in salt had an almost consistent relative leaf expansion rate (RLER) throughout the 24 hours. This indicated that salt influences the rate of utilization of assimilates independently of their production. The same result was shown by Kriedemann (1986). He concluded that utilization rather than generation of photosynthesis substrate appears to be the key determinant of salt tolerance in expanding tissues on two grounds, 1. Soluble carbohydrates actually accumulating during salt stress. 2. An upward adjustment in maintenance respiration, which accompanies acclimatization to salinity stress appears to carry functional significance.

2.4 THE EFFECT OF ROOT TEMPERATURE ON PLANT GROWTH AND PHYSIOLOGY:

Plant growth is reported to increase with increasing root temperature up to an optimal level. This could be due to the increase in the water and nutrient uptake by the root system (Adams 1988b). In an effort to reduce heating costs in glasshouse production of crops, air temperature has been lowered. In an attempt to reduce the overall effect this has on yield, root temperature is increased, the net effect can be a reduction in energy consumption without a great loss of yield (Gosselin and Trudel 1983a). Hurd and Graves (1985) also reported that lower night temperature and high root temperature would increase the profitability of tomato crops.

The early growth and nutrient uptake of cucumber were increased by heating the nutrient solution to 30°C (Starkey 1977). Moorby and Graves (1980) showed that optimum root temperature for tomato was in the region of 25°-30°C. The greater growth is associated with larger leaf and dry matter production. Adams (1988b) grew tomato plants at four root temperatures 14°, 18°, 22° and 26°C for ten weeks. The results showed that increasing root temperature between 14°-22°C stimulated early growth. The further increase in weight at 26° C was small. The optimum root temperature for dry matter production in tomatoes may therefore be near 26°C. Water usage increased with increasing tomato root temperature over the range of 12°-30°C (Abdelhafeez *et al* 1971) and 13°-28°C (Moorby and Graves 1980).

Transpiration rate was reported to be affected by the root temperature. Abdelhafeez *et al* (1971) who observed that the reduction of transpiration rate at low temperature could be a result of increasing viscosity of water and therefore a decrease in the root permeability. Moorby and Graves (1980) showed that high

root temperature reduced the size of the root cortex and increased the size of the xylem vessels. This they considered would reduce the resistance to water flow through the root and increased the rate of transpiration.

Nutrient absorption by the plant was affected by changing the root temperature N, P, and K^+ absorption increasing with increasing root temperature (Moorby and Graves 1980; Adams 1988b; Gosselin and Trudel 1983b). Moustafa and Morgan (1984) grew chrysanthemums hydroponically at two air temperatures and at various solution temperatures ranging from ambient to 29.4°C. They found that root zone warming of 24°C increased tissue levels of K^+ and P^+ . But the levels of N, Ca^{2+} , and Mg^{2+} were not affected. Adams (1988b) reported that the uptake of Ca^{2+} and Mg^{2+} by tomato plants increased with increasing solution temperature up to 22°C. The N, P, K^+ , Ca^{2+} and Mg^{2+} content of leaves did not increase with increasing temperature above 22°C. In contrast, Papadopoulos and Tiessen (1983) found little response of plant nutrient content to root temperature between 12°-27°C. They attributed the differences in the plant response to the root temperature to variation in the aerial environmental conditions and also to the genetic variation between the experimental material used.

2.5 CONCLUSION:

Increasing salinity in general inhibits plant growth and productivity. This reduction could be due to water stress or specific salt effect or both. The plant in a saline environment also suffers from shortage of assimilate. It is not very clear whether this shortage is caused by a reduction in the photosynthetic rate induced by water deficit or via the reduction in the leaf area.

There is variability in the published reports regarding the plant response to salinity. This could be due to the interactions with some other environmental factor such as humidity or genetic variation between the plants. The aim of this work is to investigate different aspects of salinity on the growth of cucumber plants.

CHAPTER THREE: GENERAL MATERIALS AND METHODS

3.1 PLANT MATERIAL:

Cucumber *cucumis Sativus L.* CV. Farbiola was used in all the experiments. This variety is the most widely grown in the United Kingdom for heated cropping. Generally it has high yield with a moderate growth rate and vigour. It has been used as the standard variety in other English trials (Ministry of Agriculture, Fisheries and Food 1983).

3.2 EXPERIMENTAL LAYOUT:

Nutrient Film Technique was used in all of the experiments. Each gully was 2 m. long and 0.3 m wide. The gullies were constructed from 500 gauge black and white polyethylene strip. The polyethylene was folded and stapled along the edges to form an enclosed channel. The channels were laid on benches, with a slope of 1 in 50. Polystyrene sheets were laid upon the benches to support and insulate the channels. A 25 litre (l) plastic container was used as a catchment tank for each gully (Appendix 1). The nutrient solution was pumped from the catchment tank by means of non-submersible pump to the inlet at the top end of the gully. The solution then flowed due to gravity down the trough at approximately 2.5 l min^{-1} back to the catchment tank. It was aerated as it fell into the catchment tank. Intermittent solution recirculation was used in all experiments. The flow of the solution was controlled by a time-clock, giving circulation for 45 minutes in any hour.

3.3 CULTURE TECHNIQUE:

For all the experiments seeds were incubated on moist filter paper in petri dishes at a constant temperature of 27°C for one day before being transplanted to Jiffy-7 blocks. The Jiffy-7 blocks were sprayed with fungicide (Ridomil 25 wp - 4 grams (g) in 1 litre (l) to protect the seedlings. After germination the seedlings were transferred to the glasshouse. Day temperature was set at 21°C and night temperature at 19°C. Automatic ventilation was given at 27°C.

When the roots just emerged from the Jiffy-7 block, the seedlings were selected for uniformity and transferred to 100 cm³ rockwool cubes. At the second leaf stage the seedlings were selected and transferred to the gullies. Each gully contained four plants. Tap water was circulated through the gullies for one or two days to encourage root development before imposing the treatments.

The plants were trained to single stem and supported with a string to an overhead wire. *Encarsia formosa* was used to control the whitefly *Trialeurodes vaporariorum*. Fungicides and insecticides (Benlate, Nimrod and Ridomil) were sprayed on the plants in some experiments to control white fly, mould and Phytophthora.

3.4 GROWTH MEDIA:

Wye solution, developed by Varley and Burrage 1981 was used as stock solution in all the experiments (Appendix 2). Appropriate nutrient solution concentration was achieved by diluting equal amounts of solution A and solution B in water. Different levels of salinity were obtained by adding NaCl to the basic

nutrient solution. The solution pH was maintained at 5.5 - 6.5 by using 5% acid mixture of nitric acid and orthophosphoric acid (3:1).

The solution conductivity and pH were measured and adjusted daily using Wye-NFT meter. The nutrient solution conductivity was maintained at the required level by adding equal amounts of solution A and B. When NaCl was used, conductivity was corrected by adding NaCl to maintain the correct chloride concentration in the solution, then the solution conductivity was corrected to maintain the original nutrient solution salinity using stock solution A and B. The solution was changed on the second occasion the conductivity dropped below the required level.

3.5 MEASUREMENT OF VEGETATIVE GROWTH:

Plant height and stem diameter were measured once a week for four weeks after imposing the treatments. Leaf area was measured at two days interval for two weeks after imposing the treatments. Leaf area was estimated nondestructively by using a regression equation for each treatment relating leaf breath and area. At the end of each experiment plants were cut at the cotyledons and divided into stem, petiole and leaves. Final leaf area was determined using a leaf area meter (Delta-T, Cambridge, UK). Fresh weight was determined and representative samples from each part of the plant were taken and oven dried at 80°C for 72 hours. The dry weight percentage, total dry weight for different parts and the total dry and fresh weight of the shoot were calculated.

The roots were left to be air-dried for 1-2 hours and sometimes squeezed to remove the remaining water. The fresh weight was recorded and representative samples were placed in the oven at 80°C for 72 hours to determine the dry weight

percentage and total dry weight. The stem length was recorded as final plant height. Stem diameter was measured at the 12th internode.

3.6 PLANT WATER STATUS:

The two basic parameters which describe the degree of water deficit are the water content and the energy status of the water in the cell (Turner 1981). The water status in the plant was determined by measuring the water content, expressed as relative water content and the energy status of the water, which is expressed as water potential.

3.6.1 RELATIVE WATER CONTENT (RWC):

In all the experiments ten leaf discs, one centimetre (cm) in diameter were punched with a borer from each of the treatments. The fresh weight was obtained. The discs were then floated for 24 hours in distilled water in covered petri dishes at 20°C. The discs were then surface dried and reweighed to obtain the turgid weight. Finally the leaf discs were oven-dried at 80°C for 12 hours and weighed for the dry weight. The same weighed vial was used for the same replicate during the measurement. The relative water content was calculated using the equation:

$$RWC = \frac{FW - DW}{TW - DW} \times 100$$

3.6.2 WATER POTENTIAL:

A pressure bomb was used to measure the water potential. Due to the difficulties of getting the large cucumber leaves into the pressure bomb chamber, all the measurements were carried out on tendrils. In this technique a tendril was cut and placed in a pressure chamber with the cut end just protruding from the chamber. The pressure in the chamber was increased gradually using compressed nitrogen from a cylinder. The reading was recorded at the point when bubbles of sap appeared at the cut end of the tendril.

3.7 GAS EXCHANGE MEASUREMENTS:

The gas exchange measurements were carried out using a battery operated portable infra-red gas analyzer (LCA2), supplied by ADC Hoddesdon, Herts, UK (Appendix 3). Transpiration rate, stomatal conductance and photosynthetic rate were simultaneously measured on fully expanded leaves. The readings were repeated several times during the experiment. During the measurements data was stored in the logger; later the measurements were printed out using an Epson HX-20 computer.

3.8 YIELD MEASUREMENT:

The fruits were pruned from the first five nodes to improve vigour. The yield was compared in the next ten nodes. Harvesting started when the first two

fruits were at least 30 cm in length. The second harvest started when the next two fruits reach 30 cm and the final harvest approximately one week later. Fresh weight and fruit length and diameter were measured immediately. Total soluble solids (TSS) and titratable acidity (TA) were subsequently analyzed. A representative sample was weighed and oven-dried at 80°C for 48 hours. The dry weight percentage and total dry weight were calculated.

3.9 CHEMICAL ANALYTICAL PROCEDURES:

Plant analyses are expressed as percentage of dry matter for Ca^{2+} , K^+ , Mg^{2+} , P and Na^+ and as parts per million (ppm) for Cl⁻. Each sample was prepared for the determination of P, K^+ , Ca^{2+} , Na^+ and Mg^{2+} by dry ashing. A sample of 0.2 gram dry material was ashed in a muffle furnace at 480°C. Then cooled and the ashed tissue dissolved in one millilitre (ml) of concentrated HCl. The solution was filtered and made up to 100 ml. using deionized water and subsequently diluted if required.

Ca^{2+} , K^+ and Na^+ plant material content were determined using a Corning Flame photometer 410. P content was estimated by Pye Unicam SP6-500 spectrophotometer. Ammonium molybdate-sulphuric acid and Stannous chloride reagents were used (Allen 1989). Mg^{2+} content was determined using Pye Unicam SP9 atomic absorption spectrophotometer with air-acetylene flame.

The chloride in the solution sample was measured after dilution by using chloride selective electrode (EIL Model 4002-2). Plant tissue chloride content was measured (as described by Zayed 1987). 0.2 grams of dry material was suspended in 20 ml. of 0.2N HNO_3 . Then 2.25 ml. of 2N NaOH was added to bring the pH into the range of 5 to 7. The chloride concentration was measured in the

suspension using the electrode.

3.9 EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS:

All of the experiments were carried out in a randomized block design. Each treatment replicated four times. Data statistical analysis was carried out using a Genstat program in the computer centre at Wye college - University of London. F test was used throughout all the experiments to compare the treatment means.

**CHAPTER FOUR: THE INFLUENCE OF NUTRIENT SOLUTION
CONCENTRATION ON CUCUMBER GROWTH, WATER
RELATIONS, NUTRIENT ABSORPTION AND YIELD.**

Plant growth is dependant on the fertility of the growing media. Fertility level decreases when the essential nutrient concentration is below or higher than the optimal level (Hansen, 1980). The nutrient concentration also affects the plant water supply by altering the water potential difference between the root and the growth media.

The effect of nutrient solution conductivity on the plant growth was investigated in two experiments. Both involved increasing the conductivity of the recirculating solution. Firstly by adding different amounts of stock solution, secondly by the addition of different levels of sodium chloride to a basic level of nutrient solution.

4.1 EXPERIMENT A: THE EFFECT OF NUTRIENT SOLUTION CONDUCTIVITY ON THE GROWTH OF CUCUMBER PLANTS.

4.1.1 INTRODUCTION:

Most NFT crops are grown in a solution of electrical conductivity ranging from 2.0 to 3.0 mS cm⁻¹ (Cooper 1982). Steiner 1980 reported that over a wide range of nutrient ratios in the nutrient solution, the mutual ratio in which the plants take ions is not influenced by the mutual ratio of these ions within the solution.

Workers have reported different values for the optimal solution conductivity for growing cucumbers. Graves and Hurd (1983) reported that the highest yield of cucumber was obtained when the solution conductivity was between 2.5 and 4.0 mS cm⁻¹. Whereas Sonneveld (1981) found a decline in the yield of cucumber grown in rockwool as the conductivity was increased from 1.0 to 4.0 mS cm⁻¹. An electrical conductivity range of 2.0 - 2.5 mS cm⁻¹ was recommended by Voogt (1981) for cucumbers grown on rockwool matting with a drip-fed nutrient solution. He found that at low values there were signs of deficiencies in N and K⁺ whereas at the higher levels no increase in the crop yield was found.

The aim of this experiment was to find the optimal range of solution conductivity for growth of cucumber grown in NFT and the effect of nutrient solution Ec on water and nutrient uptake.

4.1.2 EXPERIMENTS AND RESULTS:

Cucumber (*Cucumis sativus* L. Cultivar farbiola) seeds were germinated in an incubator at a constant temperature of 27°C. The seedlings were transplanted to the channels at the 5 leaf stage on 3.9.88. Tap water was circulated for the first two days to encourage development of the root. Initial measurements were taken for plant height and stem diameter to ensure the uniformity of the seedlings before starting the treatments. Four treatments were used in this experiment (Table 4.1). The solution levels in the catchment tanks were corrected daily by adding tap water and the solution conductivity was corrected by adding equal amounts of solution A and B as required. The solution pH was maintained between 5.5 - 6.5. The experiment was carried out in randomized block design. Each treatment was replicated four times.

Table 4.1 Treatments.

Treatments	Nutrient solution conductivity (mS cm^{-1})
T1	0.8-1.0
T2	1.3-1.5
T3	1.8-2.0
T4	2.3-2.5

4.1.2.1 STEM GROWTH:

The changes in the plant height and stem diameter were measured weekly for four weeks from the start of the treatments. A final measurement was made after harvesting the plants. The effect of the treatments on the stem length, diameter, fresh weight and dry weight percentage are summarized in Table 4.2.

Table 4.2 Effect of the nutrient solution Ec on stem growth.

Nutrient solution Ec (mS cm^{-1})	Stem diameter (cm)	Plant height (cm)	Fresh weight (g/plant)	Dry weight %
1.0	1.07	307.5	331.1	5.83
1.5	1.04	307.8	332.6	5.47
2.0	1.01	315.7	301.5	5.33
2.5	0.97	303.6	255.0	5.75
LSD 0.05	ns	ns	42.59	ns
LSD 0.01	ns	ns	61.20	ns

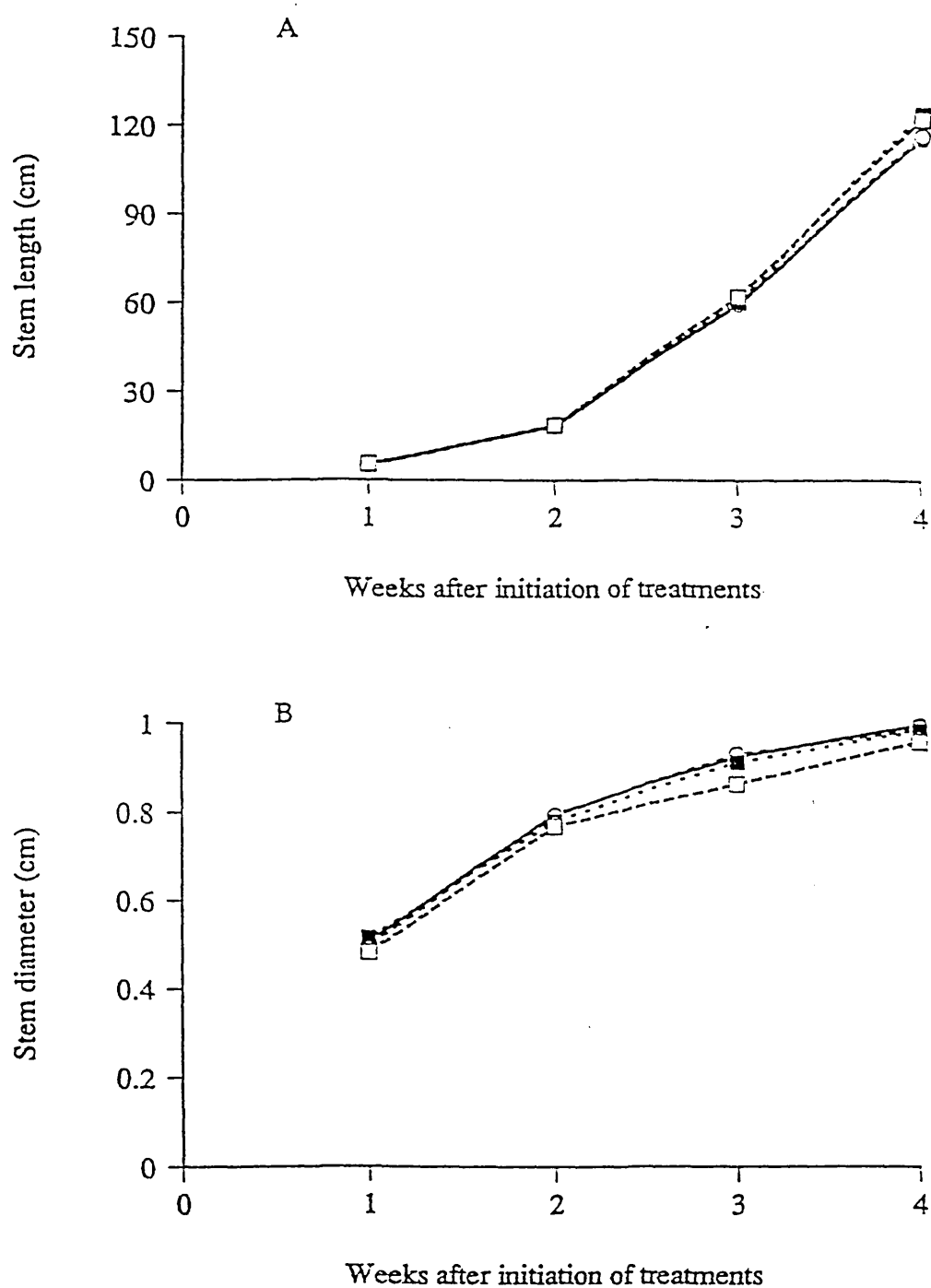


Fig. 4.1 Changes in the stem height (A) and diameter (B) as influenced by the nutrient solution Ec

- T1=0.8-1.0 mS/cm
- T2=1.3-1.5 mS/cm
- T3=1.8-2.0 mS/cm
- T4=2.3-2.5 mS/cm

Increasing nutrient solution concentration from 1.0 to 2.5 mS cm⁻¹ had no significant effect on the stem growth rate (Figure 4.1).

The final plant height and stem diameter were not affected by the treatments. There was a tendency for the stem diameter to decreased with increasing nutrient concentration but this was not significant. The stem fresh weight was slightly reduced when the nutrient solution Ec was increased up to 2.0 mS cm⁻¹. A further increase up to 2.5 mS cm⁻¹ caused a significant ($P=0.01$) reduction in the stem fresh weight compared to the 1.0 and 1.5 mS cm⁻¹ plants. No significant difference was observed on the dry matter % between the treatments.

4.1.2.2 LEAF GROWTH:

Leaf area was measured in the first two weeks after imposing the treatments (Figure 4.2). The leaf breadth was measured each two days and the leaf area was estimated by using a power regression equation for each treatment (Table 4.3). There was no significant effect on the leaf area. The leaf fresh weight and dry weight percentage were also not affected significantly by the treatments. Leaf fresh weight of T2 plants were slightly higher than all the other treatments.

4.1.2.3 WATER UPTAKE AND RELATIVE WATER CONTENT (RWC):

The plant water uptake was measured weekly. Increasing nutrient solution Ec gradually reduce the plant water uptake. The result is presented in Figure 4.3.

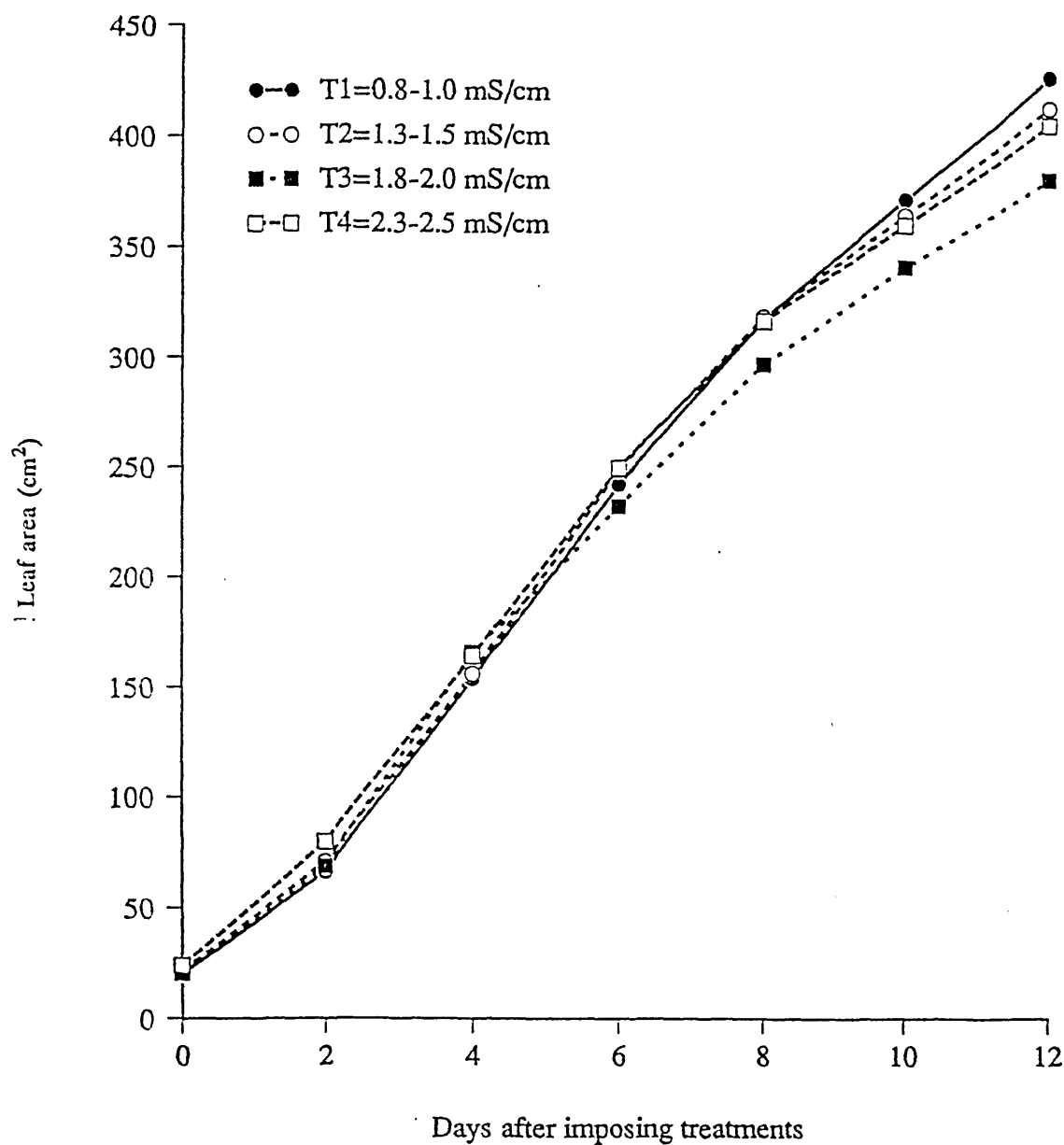


Fig. 4.2 Leaf area as influenced by the nutrient solution Ec

Table 4.3. Correlation coefficient (r) of different treatments relating leaf breadth and area.

Treatments	Regression equation	Correlation coefficient (r)
T1	$0.359 * x^{2.18}$	0.997
T2	$0.456 * x^{2.102}$	0.974
T3	$0.329 * x^{2.195}$	0.952
T4	$0.396 * x^{2.175}$	0.998

Table 4.4 Effect of nutrient solution Ec on leaf growth.

Nutrient solution Ec (mS cm ⁻¹)	Leaf fresh weight (g/plant)	leaf dry weight (g/plant)
1.0	776	7.09
1.5	868	7.45
2.0	729	6.63
2.5	621	6.85
LSD 0.05	ns	ns
LSD 0.01	ns	ns

Table 4.5 summarizes the average water uptake as a ml/plant/day (ml/p/d) and the relative water content. The result shows a significant (P=0.01) reduction on the plant water uptake with increasing solution conductivity.

The RWC was measured 28 days after starting the treatments. The RWC was slightly reduced with increasing nutrient solution Ec up to 2.0 mS cm⁻¹. A significant (P=0.01) reduction was observed when the nutrient solution Ec was increased up to 2.5 mS cm⁻¹.

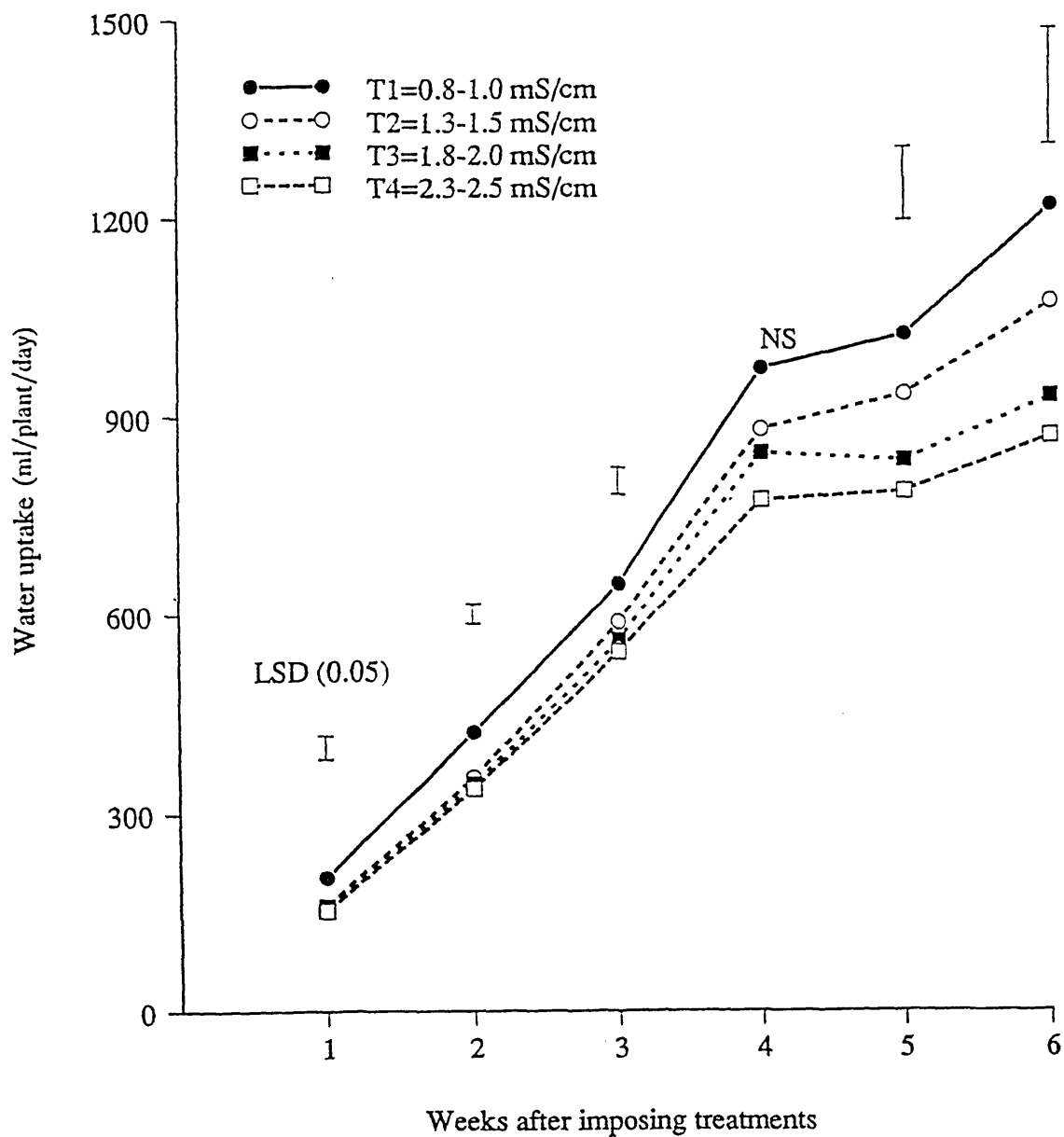


Fig. 4.3 The plant water uptake as affected by the nutrient solution Ec

Table 4.5. Effect of nutrient solution Ec on plant water uptake and relative water content.

Nutrient solution Ec (mS cm^{-1})	Average water uptake (ml/plant/day).	Relative water content %
1.0	746.98	93.65
1.5	664.13	93.75
2.0	611.43	91.24
2.5	576.60	87.51
LSD 0.05	64.92	4.21
LSD 0.01	93.27	6.04

4.1.2.4 PLANT WATER POTENTIAL:

Plant water potential was measured in the tendril using the pressure bomb as described in the material and methods at 3, 4, 5 and 6 weeks after starting the treatments (Figure 4.4). The measurements were carried out between 14:00 and 16:00 hours. The result shows no consistent changes in the first five weeks. In the 6th week the plant water potential was found to be significantly ($p=0.05$) higher in the 2.5 mS cm^{-1} plant compared to the 1.0 mS cm^{-1} plant.

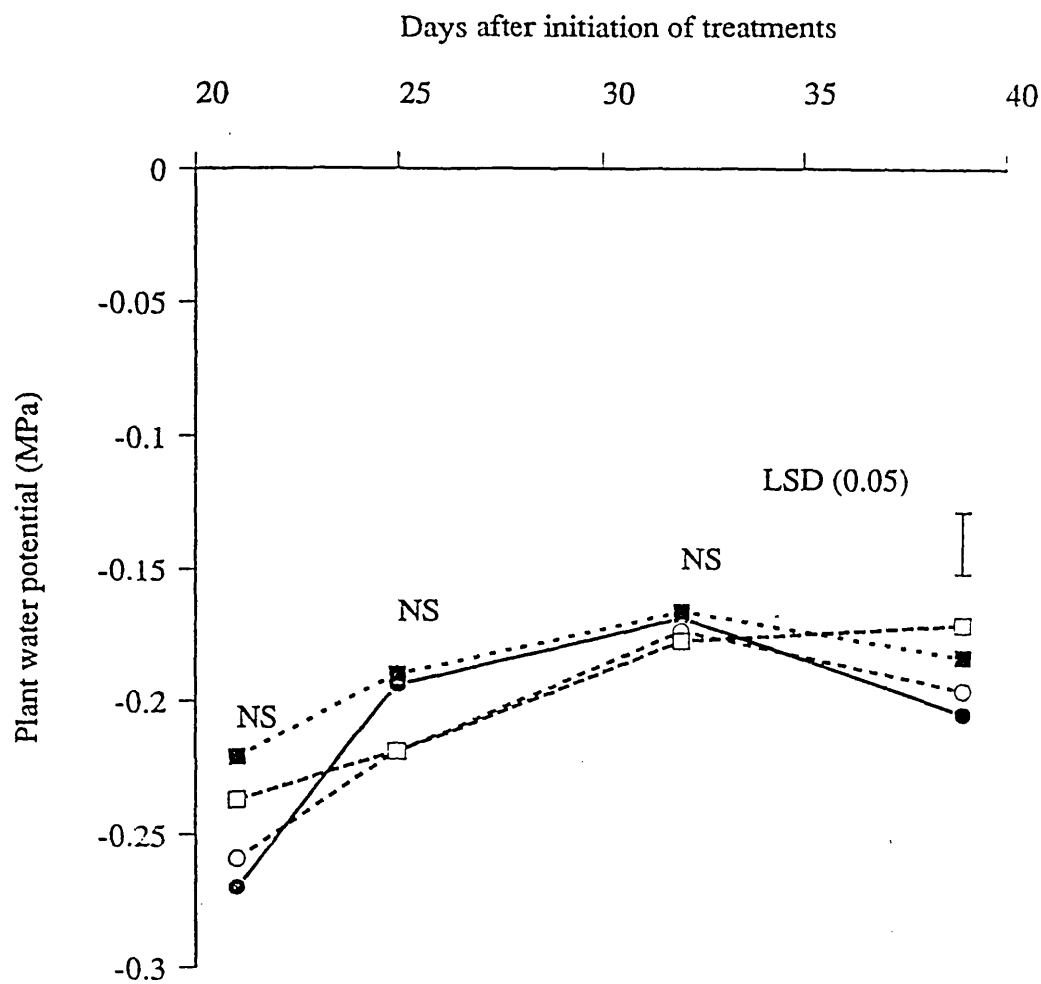


Fig. 4.4 Effect of the nutrient solution Ec on plant water potential

- T1=0.8-1.0 mS/cm
- T2=1.3-1.5 mS/cm
- T3=1.8-2.0 mS/cm
- T4=2.3-2.5 mS/cm

4.1.2.5 TRANSPIRATION RATE AND STOMATAL CONDUCTANCE:

The effect of nutrient solution E_c on the transpiration and stomatal conductance at 5 days and 40 days after starting the treatments is presented in Table 4.6. The results show a slight increase in transpiration rate and stomatal conductance with increasing E_c at 40 days after starting the treatments but no statistical difference was found between the treatments.

Table 4.6. Effect of nutrient solution E_c on the stomatal conductance ($\text{mmol/m}^2/\text{s}$), transpiration ($\text{mmol/m}^2/\text{s}$) and photosynthetic rate ($\mu\text{mol/m}^2/\text{s}$).

Nutrient solution E_c (mS cm^{-1})	Transpiration rate		Stomatal conductance		Photosynthetic rate	
	5 days	40 days	5 days	40 days	5 days	40 days
1.0	10.95	9.02	696	693	3.55	3.27
1.5	11.10	9.05	704	712	4.81	4.28
2.0	11.74	9.66	849	743	5.68	6.68
2.5	10.40	9.77	634	752	6.62	7.32
LSD 0.05	ns	ns	ns	ns	ns	1.365
LSD 0.01	ns	ns	ns	ns	ns	1.961

4.1.2.6 PHOTOSYNTHETIC RATE:

Photosynthetic rate per unit leaf area was measured 5 and 40 days after starting the treatments. The measurements are presented in Table 4.6. There was

a gradual increase in the rate of photosynthesis per unit area of leaf with increasing solution Ec. The difference was significant ($P=0.01$) only at 40 days after starting the treatments.

4.1.2.7 PLANT ANALYSIS:

Ion concentration generally increased in the root and the leaves in proportion to the nutrient solution concentration. Ca^{2+} , P, Na^+ , K^+ and Mg^{2+} concentration on the root and the leaves of the plant are presented in Table 4.7 and 4.8. Accumulation of some nutrient elements such as Ca^{2+} and K^+ were influenced by increasing nutrient concentration. Ca^{2+} level in the root was significantly ($P=0.01$) increased when the solution Ec was increased from 1.0 to 1.5 mS cm^{-1} but not when the solution Ec was further increased to 2.5 mS cm^{-1} . No consistent change was found in Ca% in the leaf tissue with increase the nutrient solution Ec from 1.0 to 2.5 mS cm^{-1} . The result showed a gradual increase in the leaf K^+ content with increasing Ec of the nutrient solution ($P=0.01$).

There were no consistent changes in the phosphorus and magnesium concentration in the root and in the leaves with increasing nutrient solution concentration. Na^+ level increased significantly in the root ($P=0.05$) and leaves ($P=0.01$) with increasing nutrient solution concentration. At 1.5 mS cm^{-1} sodium concentration in the root and leaves reached it's highest level.

Table 4.7. The effect of Ec of the nutrient solution on ion levels in the root (% dry weight).

Nutrient solution Ec	Ca	P	Na	K	Mg
1.0	0.220	1.019	0.285	2.31	0.121
1.5	0.401	1.075	0.440	6.65	0.184
2.0	0.363	1.350	0.367	3.89	0.149
2.5	0.381	1.231	0.386	4.50	0.149
LSD 0.05	0.0814	ns	0.098	0.706	ns
LSD 0.01	0.117	ns	ns	1.014	ns

Table 4.8. The effect of Ec of the nutrient solution on ion levels in the leaves (% dry weight)

Nutrient solution Ec	Ca	P	Na	K	Mg
1.0	5.31	0.488	0.206	3.6	0.4172
1.5	5.35	0.606	0.312	5.07	0.4627
2.0	4.17	0.741	0.3085	5.98	0.4032
2.5	5.64	0.553	0.3015	6.05	0.4872
LSD 0.05	0.961	ns	0.055	1.138	0.056
LSD 0.01	ns	ns	0.079	1.635	ns

4.1.2.8 YIELD MEASUREMENT:

Increasing the Ec of the nutrient solution from 1.0 to 2.5 mS cm⁻¹ had no effect on the fruit yield (Table 4.9). Fruit number per plant and dry weight percentage in the fruit were slightly increased with increasing nutrient concentration but this was not significant. Total yield per plant was not affected significantly by the treatments, although the value at 1.5 mS cm⁻¹ was slightly higher than in the other treatments. The result also shows that increasing nutrient solution Ec from 1.0 to 2.5 mS cm⁻¹ had no significant effect on the TSS in the fruit.

Table 4.9. The effect of nutrient solution Ec on fruit yield.

Nutrient solution Ec (mS cm ⁻¹)	Fruit number/ plant	Total yield (g/Plant)	Dry weight % in the fruit	TSS in the fruit
1.0	3.44	1356	2.935	2.525
1.5	3.19	1514	2.910	2.375
2.0	2.94	1287	2.838	2.875
2.5	2.88	1132	2.724	2.312
LSD 0.05	ns	ns	ns	ns
LSD 0.01	ns	ns	ns	ns

4.2 EXPERIMENT B: THE EFFECT OF HIGH LEVELS OF SALINITY ON THE GROWTH OF CUCUMBER PLANTS.

4.2.1 INTRODUCTION:

High levels of salinity in the root media have an adverse effect on the plant growth. Growth retardation can be attributed to the effect on plant water relations, nutritional disorders and specific ion toxicities. The interaction of different processes in the plant make it difficult to find out the main cause of growth reduction.

The results of the last experiment showed that increasing the E_c of nutrient solution from 1.0 to 2.5 $mS\ cm^{-1}$ had no significant effect on plant growth and fruit production. The aim of this experiment was to determine the effect of high salinity levels on the plant growth, water relations, physiology and nutrient absorption by the cucumber plant grown in NFT.

4.2.2 EXPERIMENTS AND RESULTS:

Cucumber seeds were germinated on 14.02.89 in an incubator at a constant temperature of 27°C. The seedlings were transplanted to the gullies in 3.3.89. Tap water was circulated for two days before imposing the treatments. Four treatments were studied in this experiment (Table 4.10). The basic solution conductivity was achieved by adding equal amount of stock solution A and B to give 2.5 $mS\ cm^{-1}$. The levels of salinity were obtained by adding sodium chloride

to the basic nutrient solution. The solution level in the catchment tank was corrected daily by adding tap water. The nutrient solution was changed on the second occasion the conductivity dropped below the required range.

Table 4.10. Treatments.

Treatments	Nutrient solution conductivity (mS cm ⁻¹)
T1	2.0-2.5 (control)
T2	4.0-4.5 (+ NaCl)
T3	6.0-6.5 (+ NaCl)
T4	8.0-8.5 (+ NaCl)

The conductivity of the control solution was corrected by adding the required amount of stock solutions A and B. In the saline treatments the Ec was corrected by adding NaCl to the required chloride level and then Ec was corrected by adding equal amounts of stock solutions A and B. Solution pH was maintained between 5.5-6.5. The normal cultural practices of deflowering and deleafing were followed.

4.2.2.1 STEM GROWTH:

The stem growth rate was measured as the changes in the stem length and diameter in the first four weeks after starting the treatments. The results shows

a significant ($P=0.01$) reduction in the stem growth with increasing salinity levels in the nutrient solution (Figure 4.5). At the end of the experiment the final plant height was measured from the cotyledon to the top of the plant and stem diameter was measured at the 12 th node. The effect of increasing salinity on the length, diameter, fresh weight and dry weight in the stem are presented in Table 4.11.

There was a significant ($P=0.01$) reduction in the length and diameter with increasing solution salinity from 2.5 to 8.5 mS cm^{-1} . The stem fresh weight measured as gram per plant (g/plant) significantly ($P=0.01$) decreased with increasing nutrient solution salinity. The results show a 16.9, 34.3 and 55% reduction in the stem fresh weight compared to the control when the nutrient solution salinity was increased to 4.5, 6.5 and 8.5 mS cm^{-1} respectively. The dry weight percentage in the stem was not affected by the treatments.

Table 4.11. The effect of salinity on final plant height, stem diameter, fresh and dry weight of the stem.

Solution Ec (mS cm^{-1})	Plant height (cm)	Stem diameter (cm)	Fresh weight (g/Plant)	Dry weight %
2.5	285.1	0.950	268.6	6.2
4.52	273.1	0.925	223.2	6.74
6.5	241.2	0.781	176.6	6.47
8.5	209.9	0.727	123.3	6.56
LSD 0.05	28.7	0.15	28.50	ns
LSD 0.01	41.3	0.21	40.95	ns

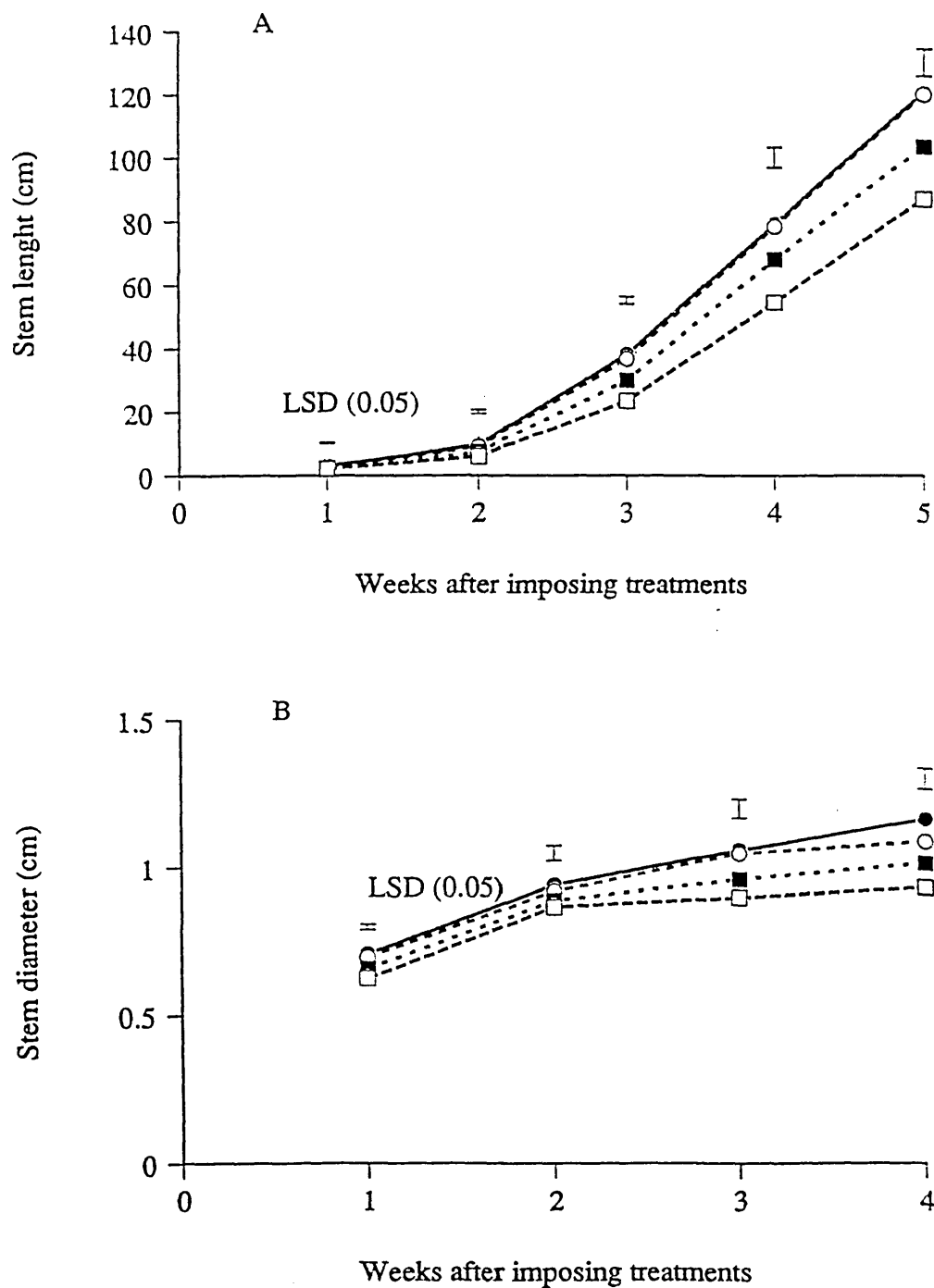


Fig. 4.5 Changes in stem length (A) and diameter (B) as influenced by nutrient solution salinity

- T1=2.0-2.5 mS/cm
- T2=4.0-4.5 mS/cm
- T3=6.0-6.5 mS/cm
- T4=8.0-8.5 mS/cm

4.2.2.2 LEAF GROWTH:

Leaf area was measured at two day intervals during the first two weeks after imposing the treatments. It was estimated from leaf breadth, using a simple regression equation for each treatment (Table 4.12). The result shows a significant ($P=0.01$) reduction on the leaf area with increasing salinity (Figure 4.6).

Table 4.12. Correlation coefficient (r) of different treatments relating leaf breadth and area.

Treatments	Regression equation	Correlation coefficient (r)
T1	$-259.74 + 30.85x$	0.967
T2	$-208.51 + 27.52x$	0.967
T3	$-193.16 + 26.2x$	0.948
T4	$-149.47 + 22.16x$	0.971

A final leaf area measurement was carried out on a sample of four leaves from each replicate. The result is presented in Table 4.13. There was a significant ($P=0.01$) reduction in the leaf area with increasing salinity in the nutrient solution. Final leaf area was reduced by 10.7, 29.6 and 48.8% compared to the control when the solution salinity increased to 4.5, 6.5 and 8.5 mS cm^{-1} .

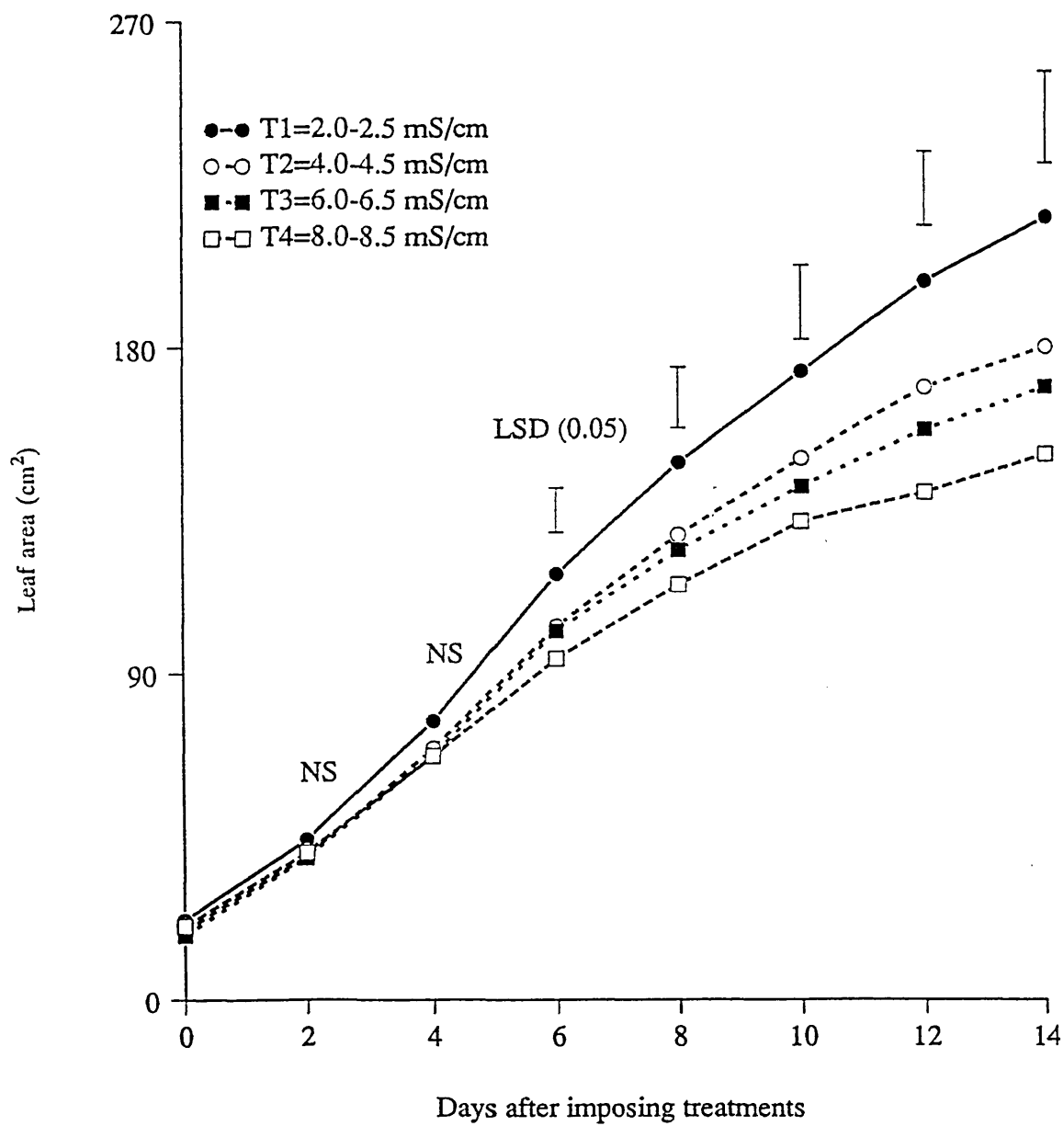


Fig. 4.6 Effect of nutrient solution salinity on leaf area

Table 4.13. The effect of salinity on leaf area, fresh weight and dry weight percentage in the petiole and lamina.

Solution Ec (mS cm ⁻¹)	Final leaf area (cm ²)	Petiole		Lamina	
		Fresh weight (g/plant)	Dry weight %	Fresh weight (g/plant)	Dry weight %
2.5	914	388.3	4.124	458.4	12.07
4.5	816	344.3	4.004	405.3	11.45
6.5	643	233.7	4.338	302.4	12.15
8.5	468	154.8	4.503	231.7	11.37
LSD 0.05	96.81	29.41	ns	38.48	ns
LSD 0.01	139.1	42.25	ns	55.28	ns

The effect of increasing salinity on the fresh weight and dry weight percentage of the petioles and laminae are presented in Table 4.13. The result shows a significant ($P=0.01$) reduction in the fresh weight of the petioles and laminae with increasing salinity, while dry weight percentages were not affected.

4.2.2.3 ROOT MEASUREMENT:

At the end of the experiment the root mat was air dried for a 1-2 hours before measuring the fresh weight. A representative sample was then taken from each treatment and oven dried for 48 hours at 80°C to find the dry weight percentage. The results are presented in Table 4.14. These shows a significant

chapter 4

reduction in the root fresh weight ($P=0.05$) and dry weight ($P=0.01$) with increasing solution salinity. The total root dry weight (g/plant) was not affected when the solution salinity was increased to 4.5 mS cm^{-1} . A further increase up to 6.5 and 8.5 mS cm^{-1} resulted in 30.3 and 53% reduction in the total root dry weight when compared to the control Plate 4.2.

Table 4.14. The effect of nutrient solution salinity on the plant root.

Nutrient solution salinity (mS cm^{-1})	Fresh weight (g/plant)	Dry weight %	Total dry weight (g/plant)
2.5	135	12.6	15.94
4.5	104	14.93	15.45
6.5	107	10.98	11.11
8.5	71.1	11.79	7.4902
LSD 0.05	42.07	2.099	3.805
LSD 0.01	ns	ns	5.467

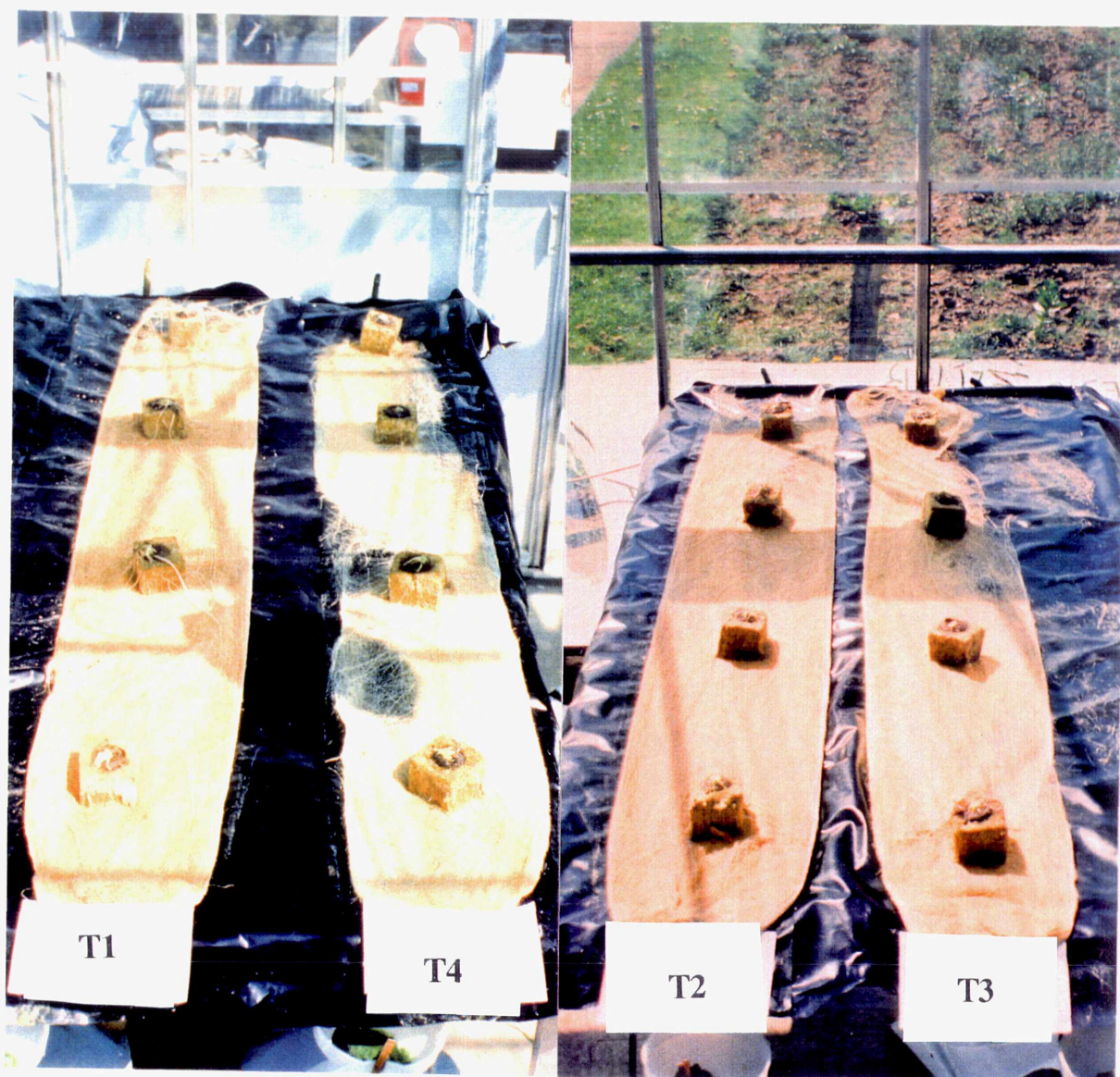
Table 4.15. The effect of nutrient solution salinity on total fresh and dry weight and root:shoot ratio.

Nutrient solution Salinity (mS cm^{-1})	Total shoot fresh weight (g/plant)	Total shoot dry weight (g/plant)	Root:shoot ratio (Dry weight)
2.5	1152.25	87.608	0.198
4.5	972.735	75.1563	0.206
6.5	712.66	58.2975	0.189
8.5	510	42.249	0.166
LSD 0.05	88.23	8.23	ns
LSD 0.01	126.75	11.83	ns

Plate 4.1 Cucumber plants grown under high salinity compared to the control.



Plate 4.2 Root matt of cucumber plants grown under different levels of salinity.



T1 = 2.0 - 2.5 mS cm⁻¹

T2 = 4.0 - 4.5 mS cm⁻¹

T3 = 6.0 - 6.5 mS cm⁻¹

T4 = 8.0 - 8.5 mS cm⁻¹

4.2.2.4 WATER UPTAKE AND RELATIVE WATER CONTENT (RWC):

The average water uptake is presented in Figure 4.7. The result shows a gradual reduction in the average water uptake with increasing solution salinity. The water uptake (ml/plant/day) and the RWC are presented in Table 4.16. The result shows a significant ($P=0.01$) reduction on the water uptake with increasing nutrient solution salinity.

RWC was measured at 20 and 40 days after initiation of the treatments. A consistent decline in RWC was observed with increasing salinity in both measurements and the difference between the treatments was significant ($P=0.01$) (Table 4.16).

Table 4.16. Effect of solution salinity on total plant water uptake and relative water content.

Nutrient solution Ec (mS cm ⁻¹)	Total water uptake (ml/plant/day).	Relative water content (RWC) %	
		20 days	40 days
2.5	592.6	72.51	96.03
4.5	556.8	70.44	95.95
6.5	382.5	64.04	93.43
8.5	270.4	60.24	88.65
LSD 0.05	42.07	2.1	3.8
LSD 0.01	60.45	3.0	5.5

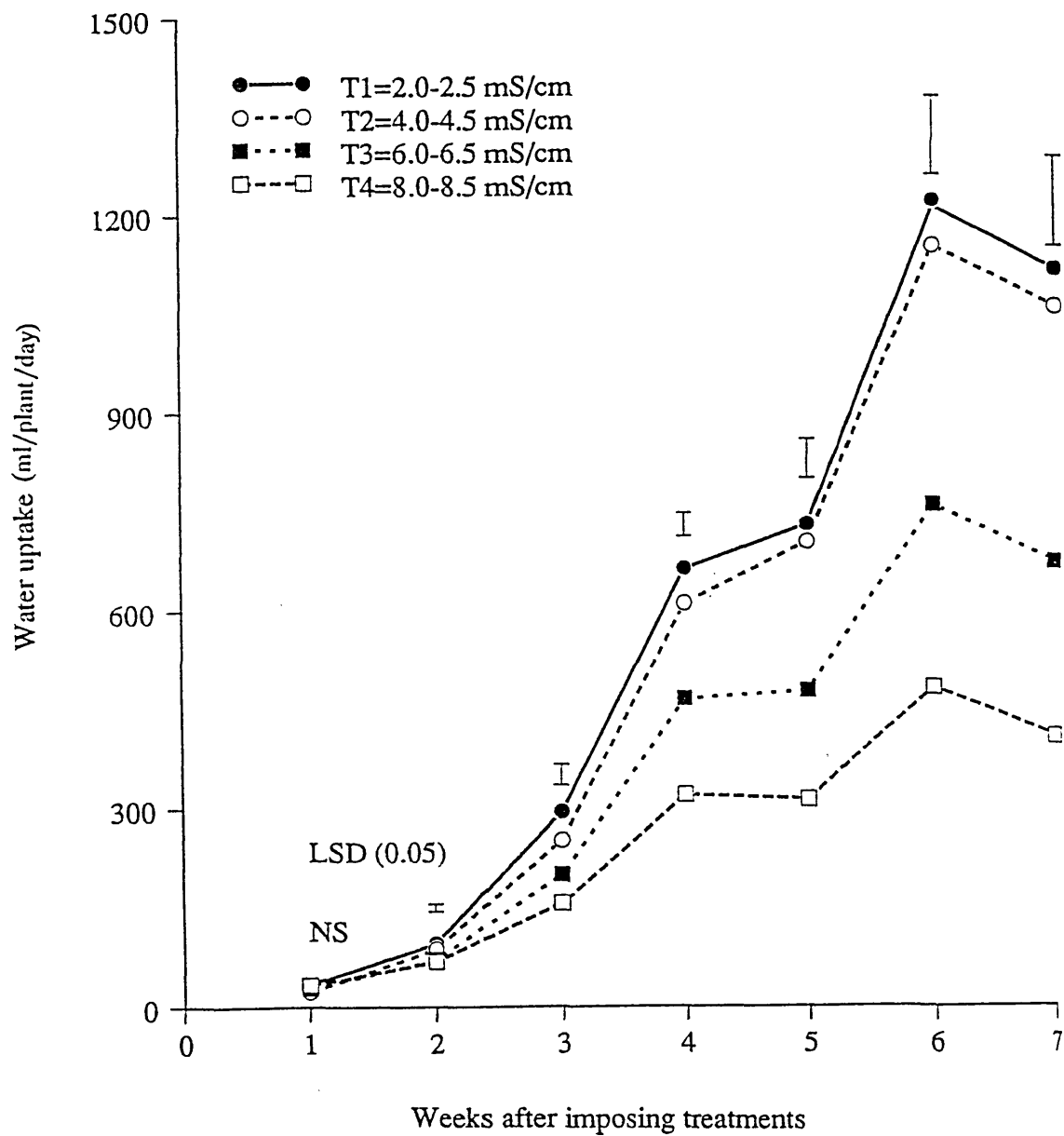


Fig. 4.7 Plant water uptake as affected by nutrient solution salinity

4.2.2.5 PLANT WATER POTENTIAL:

Plant water potential was measured several times during the experiments at different levels of radiation. Generally the water potential tended to decrease with increasing solution salinity. Figure 4.8a,b shows the diurnal pattern of plant water potential measured 25 days after starting the treatments. The salt stressed plant generally had a lower water potential but the difference was only significant ($P=0.01$) in measurements carried out between 13:00 h and 16:30 h (Figure 4.8a).

4.2.2.6 TRANSPIRATION RATE AND STOMATAL CONDUCTANCE:

Measurements of transpiration rate were carried out several times during the experiment. The fluctuation of the transpiration rate and stomatal conductance, from 07:00 - 17:00 BST, 20 days after applying the treatments are shown in Figure 4.9 and 4.10, along with concurrent variations in radiation. The results show that transpiration rate was generally reduced with increasing solution salinity but the reduction was only significant in the measurements carried out between 12:00 and 17:00 h. The transpiration rate of the control plants increased with increasing radiation, the maximum transpiration rate occurring after the radiation level began to decline at 12:00 h. The transpiration rate of T4 plants started to decline at 10:00 h.

The stomatal conductance was consistently higher in the control plants compared to the salt-treated plants. Stomatal conductance gradually reduced with increase in solution salinity (Figure 4.10 and 4.12). These results show a significant reduction in the stomatal conductance between 12:00 h and 14:00 h. The maximum value was recorded at 8:00 h in the 2.5 mS cm^{-1} plants and the minimum value was recorded at 17:00 h in the 8.5 mS cm^{-1} plants.

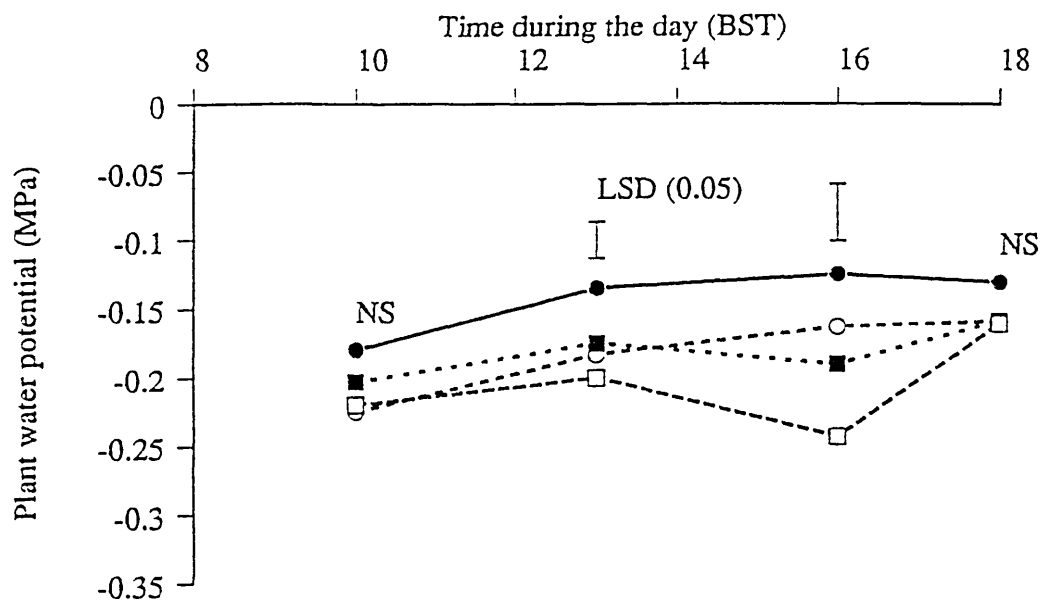


Fig. 4.8a Diurnal variation in plant water potential as influenced by the nutrient solution salinity

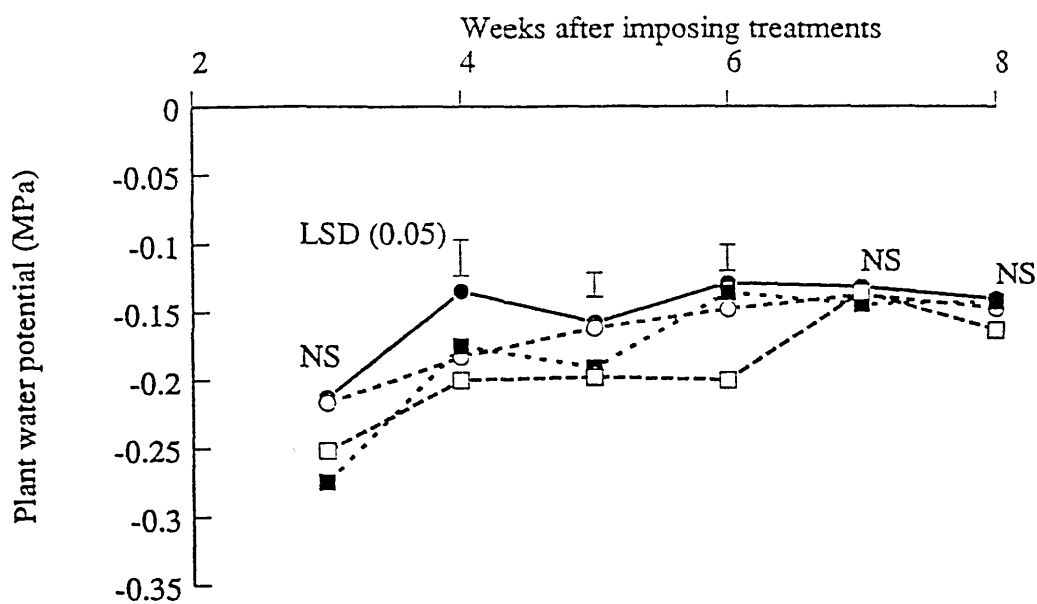


Fig. 4.8b Plant water potential as influenced by nutrient solution salinity

- T1=2.0-2.5 mS/cm
- T2=4.0-4.5 mS/cm
- T3=6.0-6.5 mS/cm
- T4=8.0-8.5 mS/cm

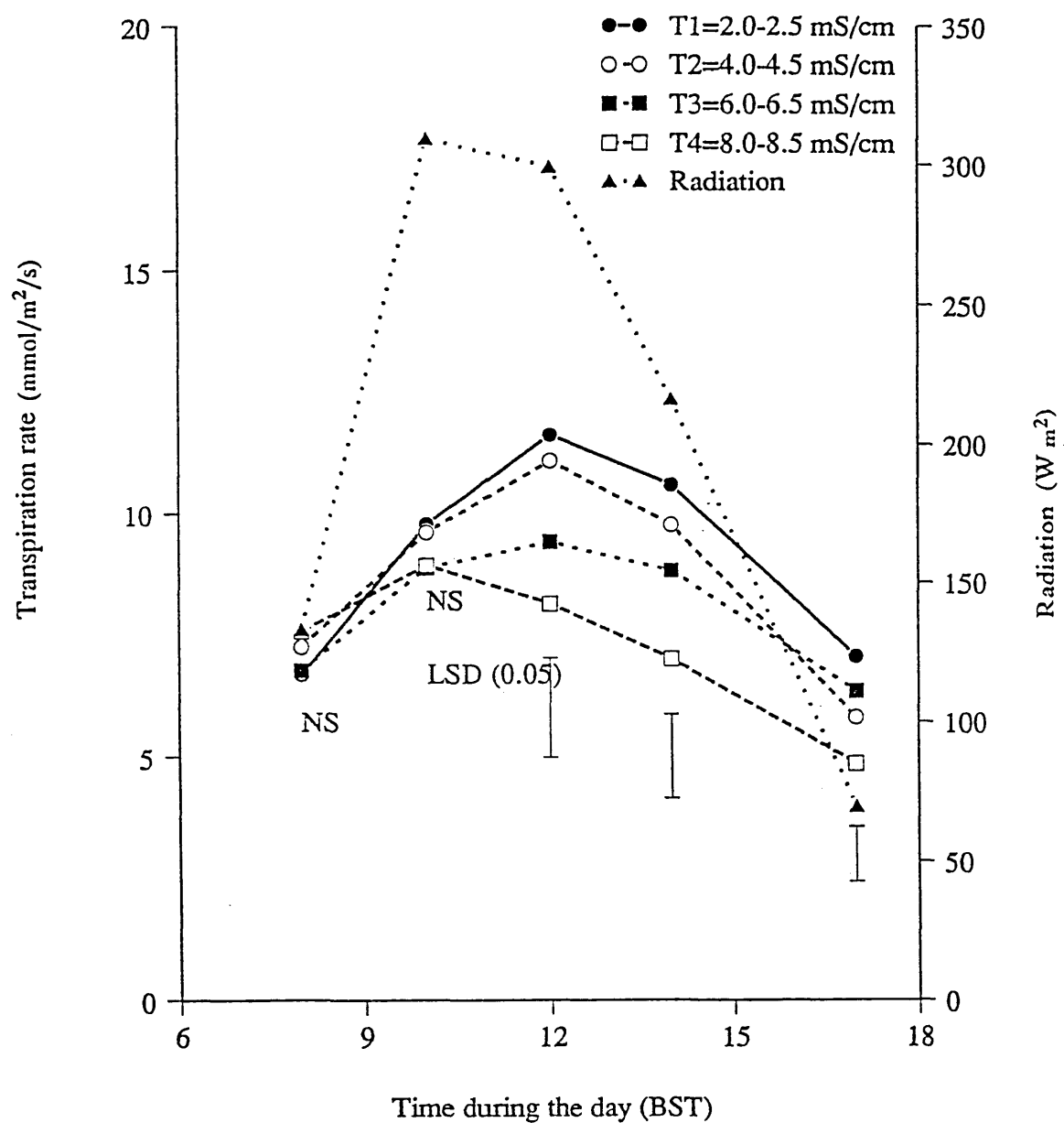


Fig. 4.9 Diurnal variation in the transpiration rate at different levels of radiation as affected by solution salinity

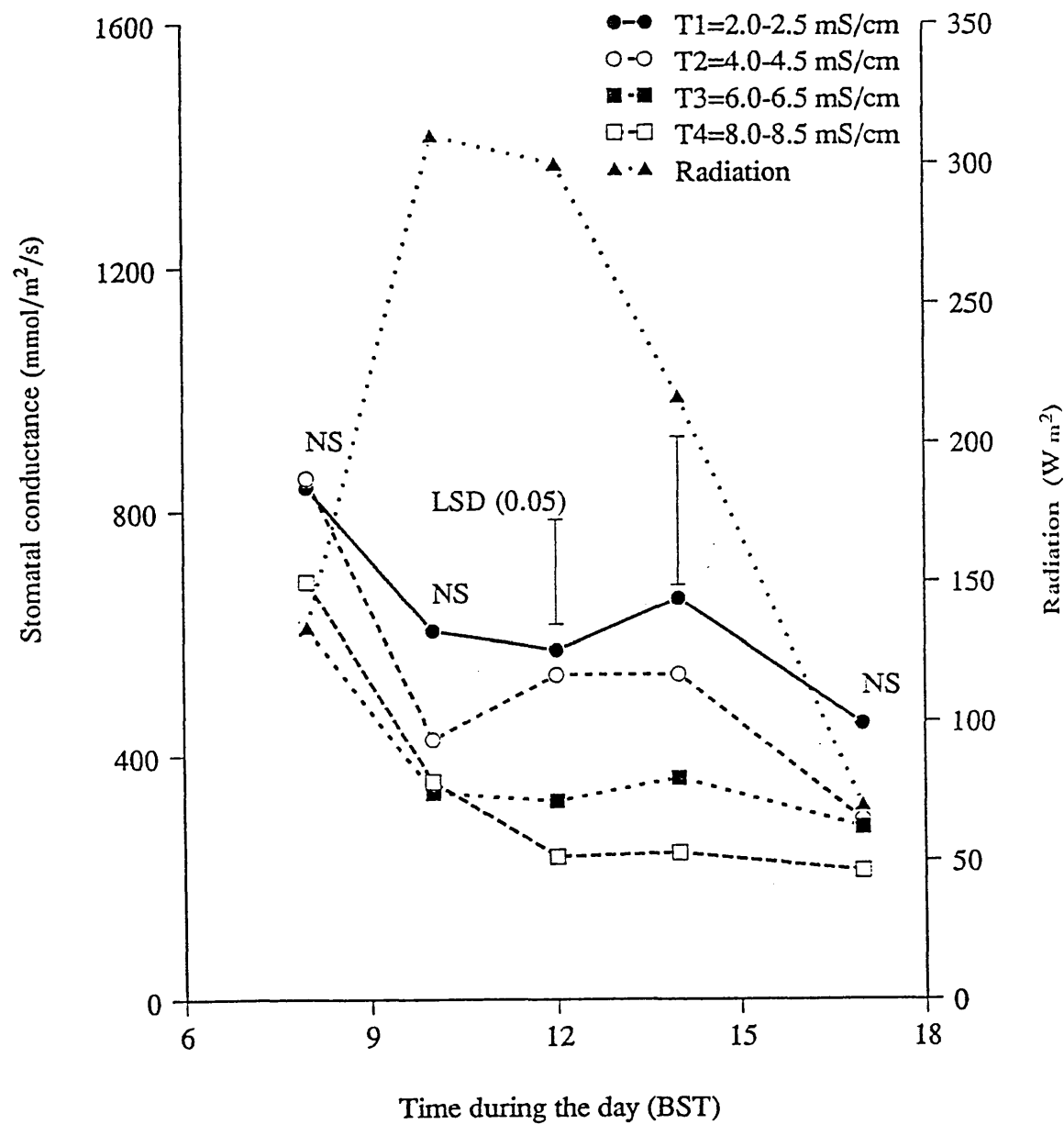


Fig. 4.10 Diurnal variation in stomatal conductance at different levels of radiation as affected by solution salinity

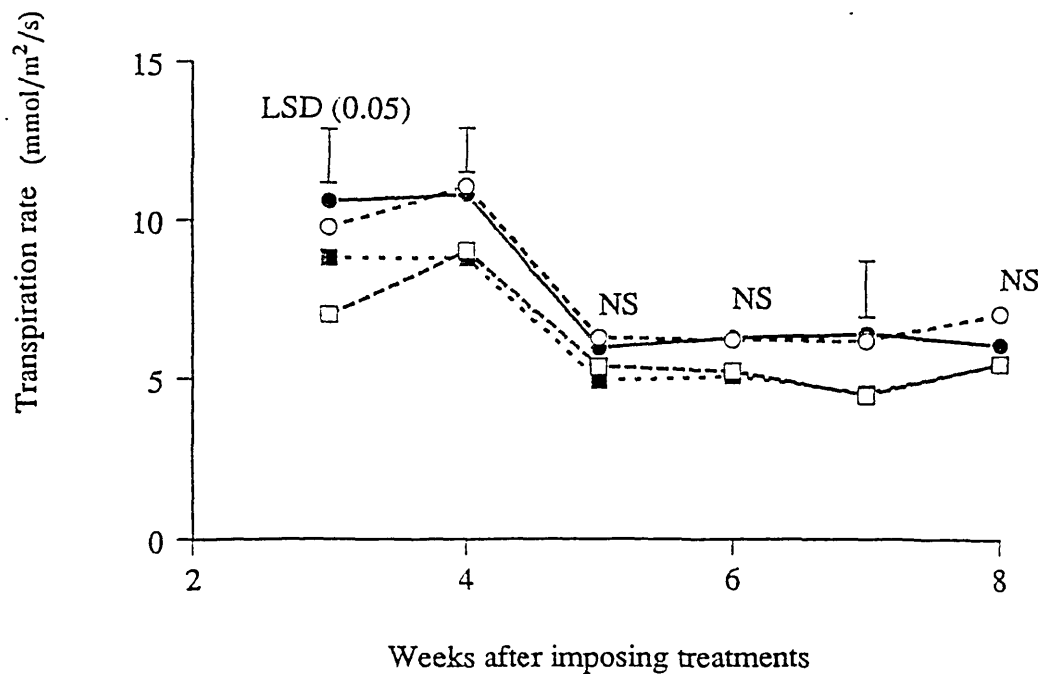


Fig. 4.11 Changes in transpiration rate as influenced by salinity level in the nutrient solution

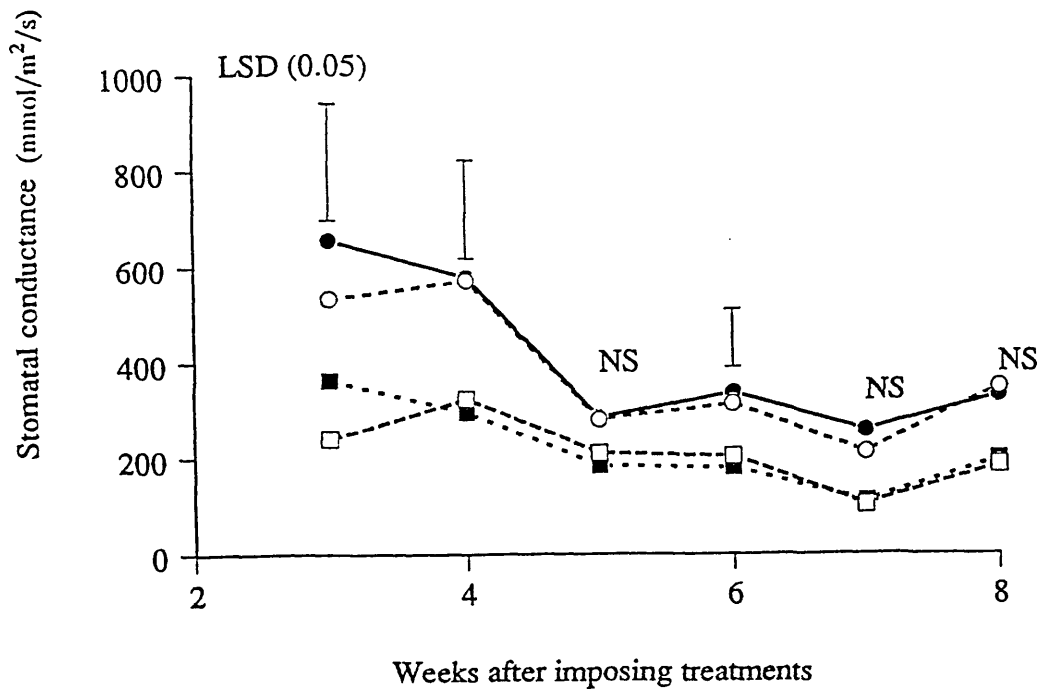


Fig. 4.12 Effect of the nutrient solution salinity on stomatal conductance

- T1=2.0-2.5 mS/cm
- T2=4.0-4.5 mS/cm
- T3=6.0-6.5 mS/cm
- T4=8.0-8.5 mS/cm

4.2.2.7 PHOTOSYNTHETIC RATE:

The photosynthetic rate per unit leaf area was slightly reduced by salinity. The difference between the treatments however was not significant. The fluctuation in the photosynthetic rate 20 days after initiation of the treatments is presented in Figure 4.13 along with concurrent radiation. The photosynthetic rate increased with increasing level of radiation. The maximum photosynthetic rate was found in the 2.5 mS cm⁻¹ plants at 12:00 h.

4.2.2.8 PLANT ANALYSIS:

The effect of salinity in the nutrient solution on the concentration of different nutrient elements on the root and leaves including Ca²⁺, P, K⁺, Mg²⁺, Na⁺ and Cl⁻ are presented on Table 4.17 and 4.18. No consistent changes were found in the Ca% in the root tissue. No significant difference was found in the Ca% in the leaves when the nutrient solution salinity was increased up to 4.5 mS cm⁻¹. A further increase in the solution salinity to 6.5 and 8.5 mS cm⁻¹ resulted in a significant (P=0.01) reduction on the Ca% in the leaves.

Phosphorus level in the root was slightly reduced with increasing solution salinity. No consistent change was found on the P% in the leaves. Increasing solution salinity caused a significant reduction on the K²⁺ levels on the root and leaves (Table 4.17 and 4.18). K% in the leaves was inversely related to the salt concentration on the root media. Increasing solution salinity from 2.5 to 6.5 mS cm⁻¹ had no significant effect on the Mg% in the root and leaves. Further increase in the solution salinity up to 8.5 mS cm⁻¹ caused a significant (P=0.05) increase in the Mg% in the root and leaves.

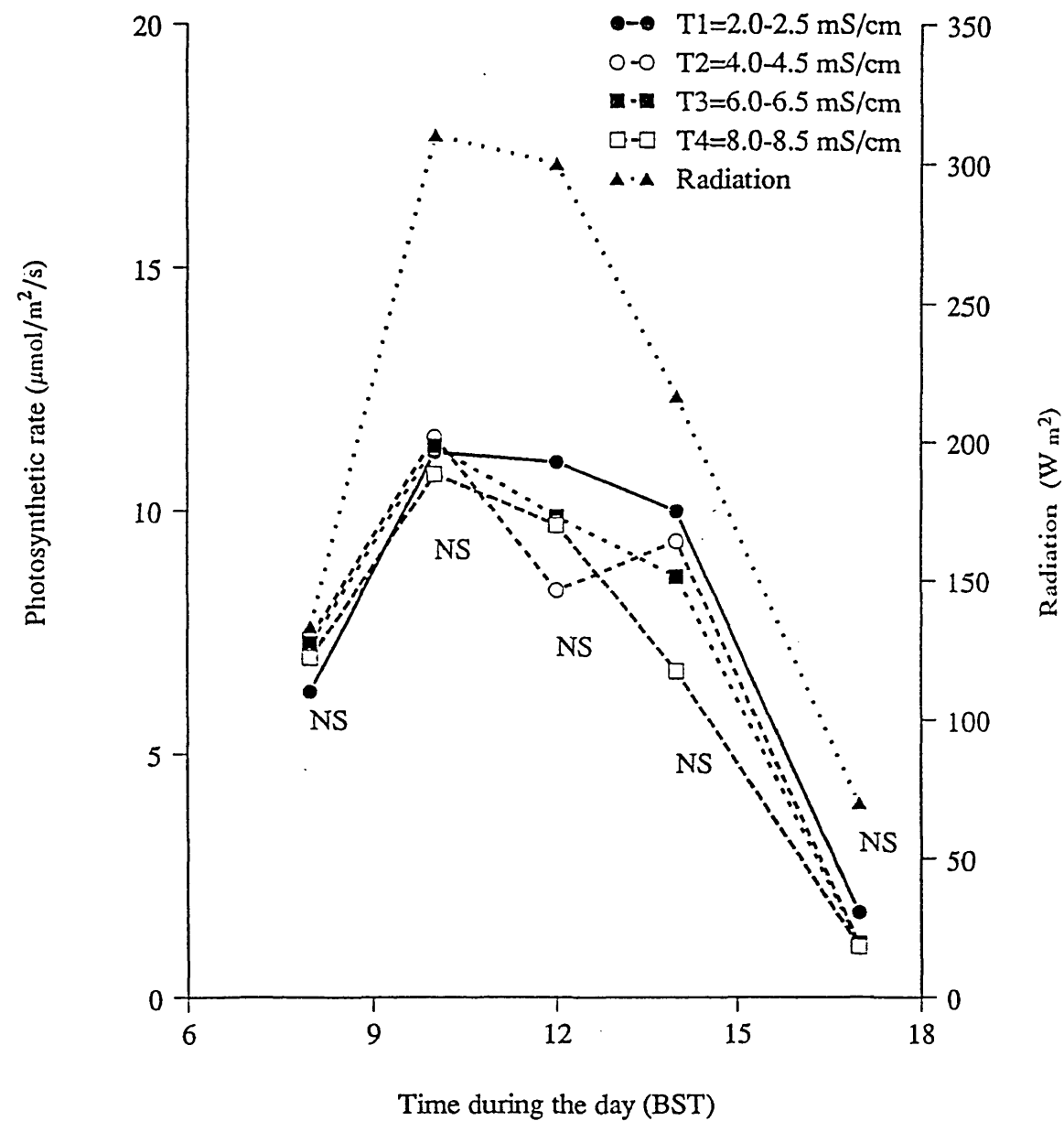


Fig. 4.13 Diurnal variation in the photosynthesis rate at different levels of radiation as affected by solution salinity

Increasing salinity in the nutrient solution led to substantial increase in the Na% and Cl% in the leaves and root (Figure 4.14 and 4.15). Na% and Cl% level in the root and leaf increased, almost linearly, with increasing external solution salinity.

Table 4.17. The effect of salinity on ion levels in the root (% dry weight).

Solution Ec (mS cm ⁻¹)	Ca	P	K	Mg	Na	Cl
2.5	.0696	1.462	5.512	0.0945	0.220	1.12
4.5	0.688	1.477	3.865	0.0882	2.717	3.78
6.5	0.613	1.360	3.882	0.0932	3.922	5.92
8.5	0.639	1.374	4.339	0.1088	5.108	8.52
LSD 0.05	0.066	0.101	0.561	0.0136	0.335	0.9862
LSD 0.01	ns	ns	0.807	ns	0.483	1.417

Table 4.18. The effect of salinity on the ion levels in the leaves (% dry weight).

Solution Ec (mS cm ⁻¹)	Ca	P	K	Mg	Na	Cl
2.5	5.67	0.457	4.7	0.4392	0.153	0.606
4.5	6.23	0.380	3.76	0.4032	1.057	1.738
6.5	4.21	0.512	3.55	0.4537	1.930	3.248
8.5	2.89	0.527	2.89	0.4926	2.774	5.254
LSD 0.05	1.249	0.088	0.823	0.0534	0.327	0.352
LSD 0.01	1.794	ns	1.183	ns	0.470	0.506

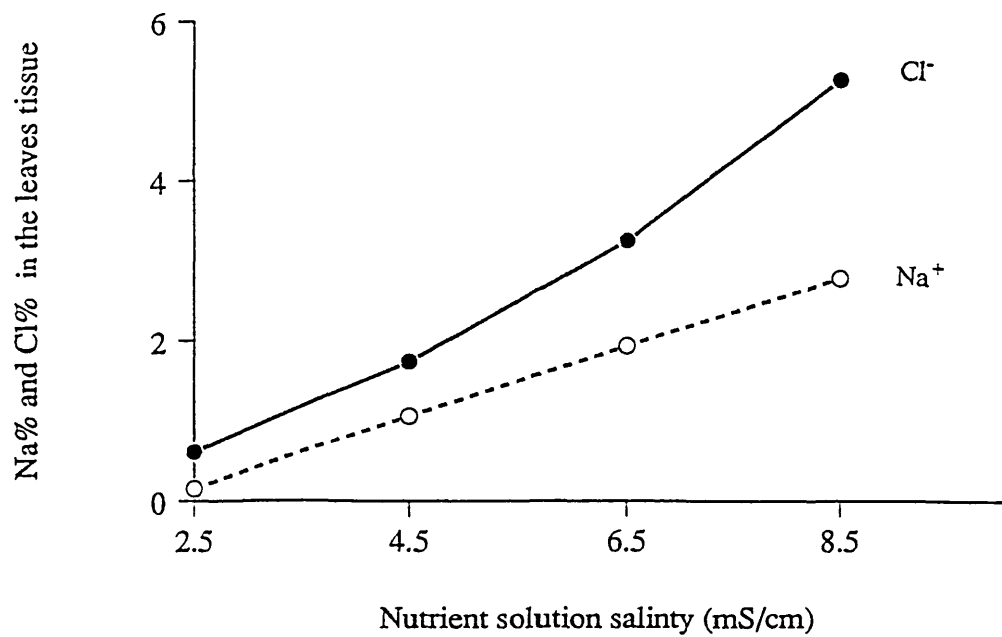


Fig. 4.14 Na% and Cl% in the leaf tissue as influence by increasing nutritet solution salinity

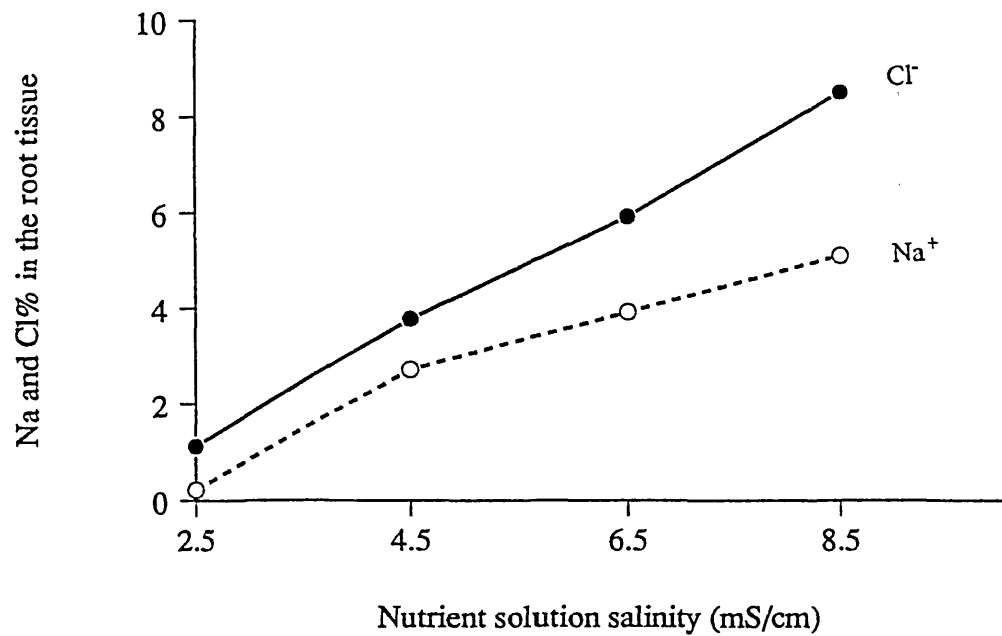


Fig. 4.15 Na% and Cl% in the root tissue as influnced by increasing nutrient solution salinity

4.2.2.9 YIELD MEASUREMENTS:

The results presented in Table 4.19 show the effect of the nutrient solution salinity on the fruit yield. Increasing solution salinity from 2.5 to 4.5 mS cm⁻¹ did not have a significant effect on the fruit number per plant. A further increase in solution salinity up to 6.5 and 8.5 mS cm⁻¹ resulted in a significant ($P=0.01$) reduction in the fruit number per plant. Average fruit weight also was not affected by increasing solution salinity up to 4.5 mS cm⁻¹. At 6.5 mS cm⁻¹ the average fruit weight was significantly ($P=0.01$) reduced. A further reduction on the fruit weight was found when the nutrient solution salinity was increased to 8.5 mS cm⁻¹.

The total fruit yield measured as gram per plant (g/plant) was gradually decreased with increasing solution salinity (Table 4.19). No significant difference in the fruit yield was observed between 2.5 and 4.5 mS cm⁻¹ plants. Increasing solution salinity up to 6.5 and 8.5 mS cm⁻¹ significantly ($P=0.01$) reduced the fruit yield. The reduction was 54% and 71% in the 6.5 and 8.5 mS cm⁻¹ plants respectively compared to the control.

Table 4.19. The effect of nutrient solution salinity on fruit number/plant, fruit weight (g), total yield (g/plant), dry weight % in the fruit, total soluble solids (TSS) and titratable acidity (TA).

Solution Ec (mS cm ⁻¹)	Fruit number/plant	Fruit weight (g)	Total yield (g/plant)	Dry weight % in the fruit	TSS	TA
2.5	5.82	516	2546	2.970	2.875	.537
4.5	5.37	485	2341	3.025	2.812	.575
6.5	3.04	301	1170	3.927	3.562	.627
8.5	2.20	266	731	3.811	3.667	.629
LSD 0.05	1.018	71.027	350.38	0.451	0.283	ns
LSD 0.01	1.463	102.05	503.43	0.648	0.406	ns

The dry matter percentage and the total soluble solid (TSS) were not affected significantly when the solution salinity increased to 4.5 mS cm^{-1} . A further increase on the solution salinity to 6.5 mS cm^{-1} resulted in a significant increase ($P=0.01$) in both dry matter% and TSS of the fruit. Increasing solution salinity up to 8.5 mS cm^{-1} had no further increase in the dry matter% and TSS of the fruit. Titrable acidity (TA) was slightly increased with increasing solution salinity but the difference was not significant.

4.3 DISCUSSION:

The results in experiment A showed that increasing nutrient solution salinity from 1.0 to 2.5 mS cm^{-1} had no significant effect on the plant growth and yield. The results indicate that cucumber could be grown in a wide range of solution conductivity without affecting the plant growth and productivity. There was however a negative, linear correlation ($R=-0.982$) between water uptake and nutrient solution E_c (Figure 4.16). This supports the close relationship found between the nutrient solution osmotic potential and the plant water uptake (Schwarz 1985; Clipson *et al* 1985). A significant reduction in the relative water content (Table 4.5) was also found with increasing solution E_c .

The plant water potential, measured 40 days after imposing the treatments, at 14:00 hour, was generally found to increase with increasing solution conductivity (Figure 4.4). A lower water potential (-0.205 MPa) was recorded for plants grown in a solution at 1.0 mS cm^{-1} than for the plants grown at 2.5 mS cm^{-1} (-0.171 MPa). This result supports the findings of Burrage and Varley (1980). They found that the water potential of lettuce plants grown in solutions at 1.1 mS cm^{-1} was reduced from -0.25 to -0.6 MPa between 9:00 and 11:00 hours whereas the water potential of plants grown in a solution at 2.5 mS cm^{-1} was reduced from

-0.25 to -0.35 MPa during the same period. They suggested that the high evaporative demand during the midday period created short term stress. The greater reduction at the 1.1 mS cm⁻¹ plant suggested a greater sensitivity or response capability to this short term stress. Black (1979) also found a transient decrease in leaf water potential when the evaporative demand was increased by a rapid reduction of relative humidity. This was subsequently accompanied by an increase in stomatal resistance.

The gas exchange measurement shows a significant increase in the photosynthetic rate with increasing solution conductivity (Table 4.6). This increase in the photosynthesis rate was accompanied by a slight increase in the stomatal conductance. It seems likely that high radiation level at the time of measurement (397.2 W m⁻²) subjected the plants to a short term stress. This caused a rapid increase in the evaporative demand by changing the humidity gradient between the leaf and the air which may have caused stomatal closure and depression the photosynthesis rate. The 1 mS cm⁻¹ plants show more sensitivity to this short term stress than the 2.5 mS cm⁻¹ plants. This is also suggested by the water potential data (Figure 4.4). Hall and Kaufmann (1975) found that with increasing humidity gradient between leaf and air, leaf resistance was increased while the mesophyll resistance remained relatively constant. They suggested that the changes in the leaf resistance were caused by stomatal aperture and that non-stomatal aspects of photosynthesis and respiration were not influenced by variation in the humidity gradient.

The results presented in experiment B in general confirmed the detrimental effect of salinity on the plant growth. Stem growth was reduced with increasing salinity (Table 4.10). Increasing water potential of the nutrient solution would restrict the water uptake, therefore subject the plants to a water stress resulting in a reduction in stem growth (Ismail 1989). Molz and Klepper (1972) related the growth in the stem diameter to the changes in the leaf water potential. They found a positive correlation between the stem diameter and leaf water

potential.

Leaf expansion rate (Figure 4.6) and final leaf area (Table 4.13) were markedly reduced with increasing nutrient solution salinity. The reduction has been considered as the major cause of growth reduction by reducing the photosynthetic area (Papp *et al* 1983; Rawson and Munns 1984). Schwarz 1985 concluded that the inhibition effect of salinity on the plant growth could be generally attributed to the osmotic effect and associated reduction on plant water uptake.

The reduction in the leaf growth might be attributed to water deficit induced by the high salinity in the root media (Ismail 1989). This is indicated by the positive correlation ($R=0.9137$) between the average water uptake and the final leaf area (Figure 4.17). Delane *et al* (1982) and Munns *et al* (1982) attributed the growth reduction of barley plant grown at high external NaCl to salinity induced water deficit in the growing tissue. The rapidity with which the growth inhibition occurs reflects the sensitivity of leaf elongation to the changes in the water potential. A slight decrease in the water potential was reported to reduce the leaf growth (Acevedo *et al* 1971). Matsuda and Riazi (1981) reported that the growth reduction is proportional to the osmotic potential of the root media. A similar result is indicated here in figures 4.16 and 4.17.

The salinity induced water deficit is indicated by the reduction of plant water uptake (Figure 4.7) and the reduction in relative water content (Table 4.16). Reduction in the plant water uptake by salt-stressed plant has been reported by many investigators (Frota and Tucker 1978; Pessarakli and Tucker 1988; Pessarakli *et al* 1989). They attributed the low water uptake by the plant to a reduction in the root permeability (expressed as hydraulic conductivity of the root system) under salt stress. The plant water potential of the salt-stressed plants was more negative than the controls (Figure 4.8a,b) as a result of decreasing the osmotic potential of the nutrient solution.

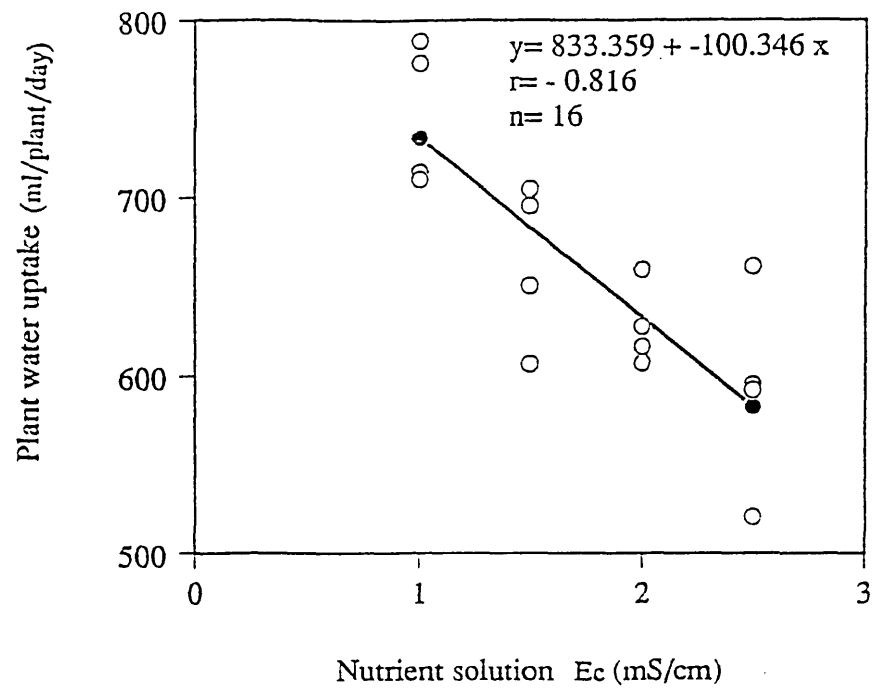


Fig. 4.16 The relationship between plant water uptake and nutrient solution E_c

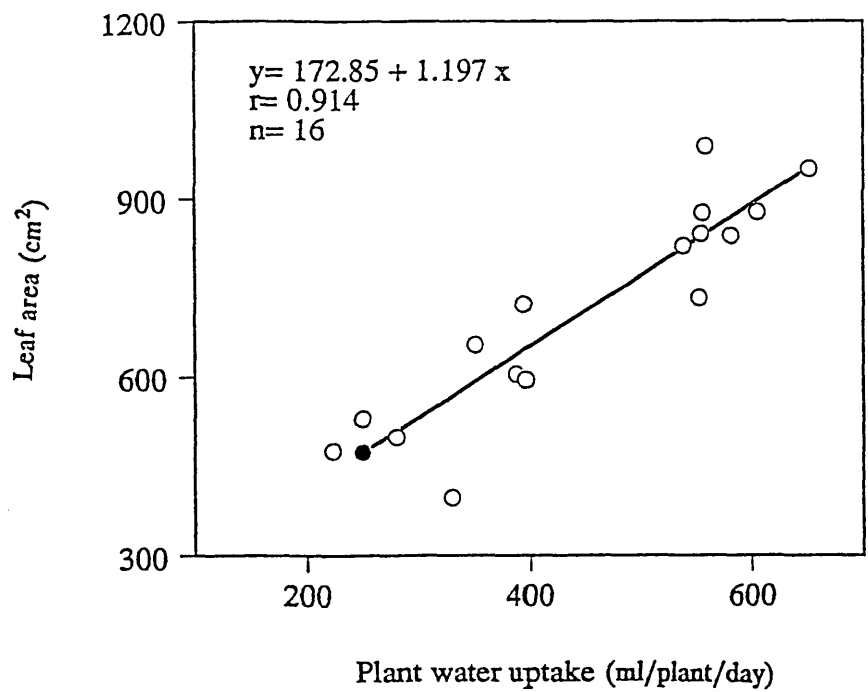


Fig. 4.17 The relationship between plant water uptake and leaf area

The hypothesis that a leaf water deficit is limiting leaf growth was ruled out by Termaat *et al* (1985) in their studies to manipulate the leaf turgor. Munns and Termaat (1986) and Munns *et al* (1988) concluded that leaf growth is influenced by a hormone produced in the old leaves or root and that it is here that NaCl exerts its effect influencing indirectly leaf growth. Although they consider that to be the main effect, it is still possible that the reduction of leaf growth is a result of decreasing leaf turgor induced by decreased water potential. Recently, Neumann *et al* (1988) reported that salinity affects leaf growth by a decrease in cell turgor rather than cell wall extensibility. Flowers and Yeo (1989) suggested that growth reduction might be a consequence of local water deficit and a reduction in the leaf turgor caused by a rapid ion accumulation in the leaf apoplast. They concluded that whether the leaf growth reduction is led by changes in hormone levels or turgor, the consequences are a reduction in leaf photosynthesis and transpiration, which reduce growth and ion import.

This experiment shows a reduction in the shoot and root dry weight with increasing salinity in the nutrient solution (Table 4.15). The reduction in the shoot dry weight was correlated to the reduction in the leaf area (Figure 4.18). This could be attributed to the shortage of assimilates caused by the reduction of the photosynthetic area. This result is consistent with the finding of several investigators (Dumbroff and Cooper 1974; Longstreth and Nobel 1979; Jeschke *et al* 1986 ; Al-Rawahy *et al* 1990). Jones (1984) found a reduction in shoot dry weight of cucumber with increasing solution salinity.

Root:shoot ratio was not affected by increasing solution salinity (Table 4.15). This contradicts the result reported by (Seemann and Critchley 1985 (Beans); Ismail 1989 (Tomato)). They indicated that salinity suppresses shoot growth more than root growth, leading to an increase in the root:shoot ratio. The difference here may be related to a different species with different susceptibility to saline conditions.

Transpiration rate was decreased with salinity (Figure 4.9). The reduction was very clear in measurements carried out between 12:00 h and 17:00 h. Similar results were reported by (Hoffman and Phene 1971; Cerda *et al* 1979; Eshel and Waisel 1984). Flowers (1985) reported that the increase of the external salinity decrease the rate of transpiration per unit leaf area. This reduction was shown to be due to partial closure of stomata (Gale *et al* 1967; Hoffman *et al* 1980). Flowers and Yeo (1989) suggested that this decrease occurs through an increase in the stomatal resistance. This is indicated by the reduction in the stomatal conductance with increasing salinity (Figure 4.10).

Despite the reduction in the dry matter accumulation and stomatal conductance, photosynthesis per unit leaf area was not affected by salinity levels in the root media. This result supports a previous observation by (Papp *et al* 1983 ; Zayed 1987; Ismail 1989). They attributed the reduction of the plant growth to reduction in the photosynthetic area rather than photosynthesis per unit leaf area. Walker *et al* (1988) reported that the photosynthesis is not likely to be a limiting factor in growth of salt-stressed pistachio plant, because carbon assimilation and presumably rate of net assimilate export were similar for expanded leaves of control and salt-stressed plants. In contrast, several other investigators report a decrease in the photosynthetic rate of salt stressed plants. This reduction has been correlated to an increase in the leaf sodium (Yeo *et al* 1985) and chloride levels in the leaves (Downton 1977 ; Ziska *et al* 1990). Other reports attributed the reduction of photosynthesis to the increased mesophyll resistance to CO₂ fixation (Cerda *et al* 1979; Yeo *et al* 1985; Downton 1977).

Fruit number per plant, average fruit weight and the total yield (g/p) were significantly reduced with increasing solution salinity (Table 4.19). This reduction might be a result of the reduction on the shoot growth. This is indicated by the positive correlation ($R=0.948$) between the shoot fresh weight and total yield (Figure 4.19). A similar result was reported by Ehret and Ho (1986). They found that the reduction of total fruit production with increasing salinity was

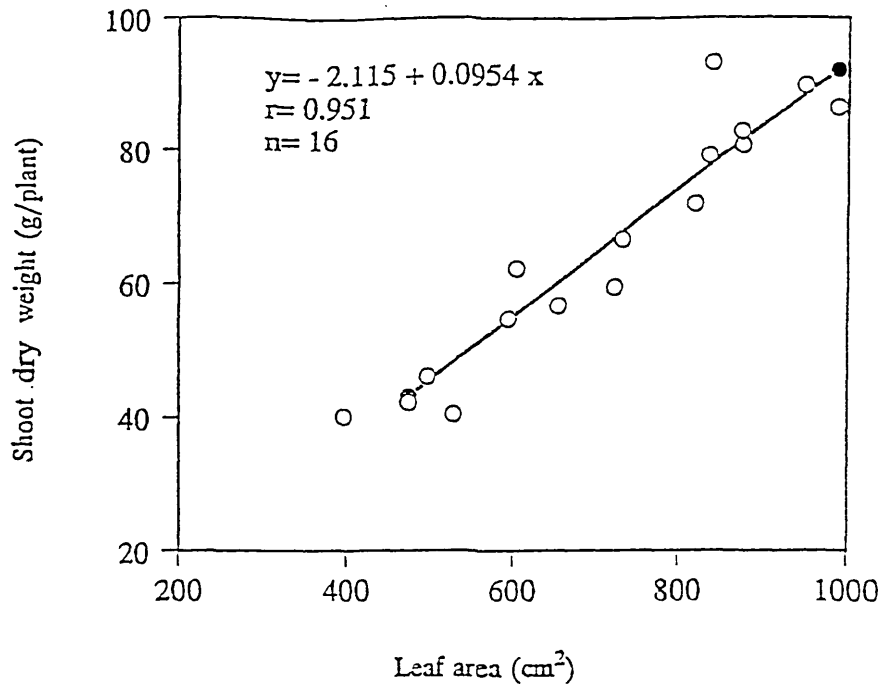


Fig. 4.18 The relationship between leaf area and shoot dry weight

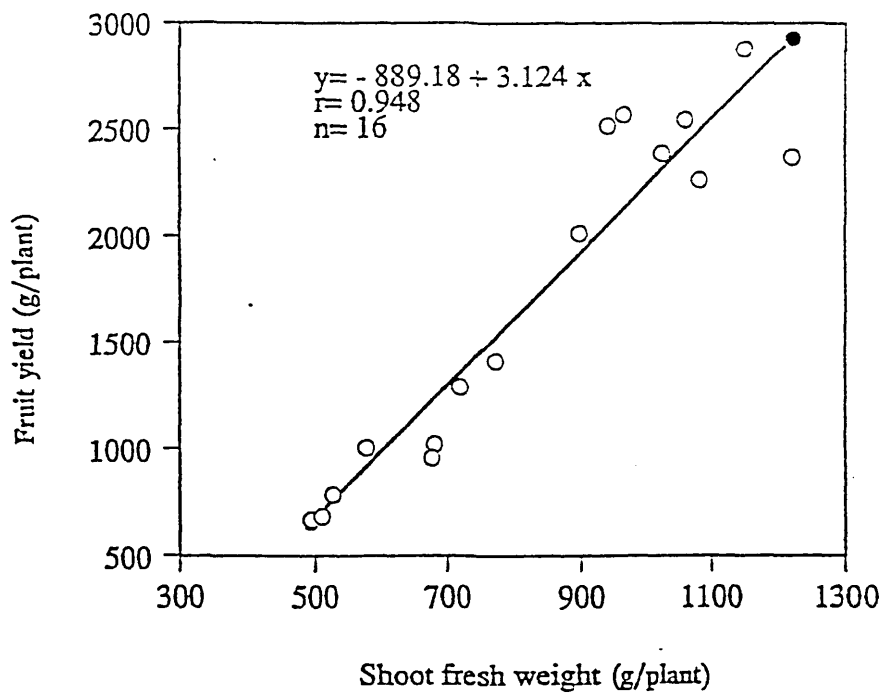


Fig. 4.19 The relationship between shoot fresh weight and total fruit

proportional to the reduction in plant growth. Jones (1984) found a reduction on fruit yield of cucumber with increasing salinity from 1.6 to 4.0 mS cm⁻¹ while the fruit quality was not affected.

The dry weight percentage and the TSS were increased in the fruit with increasing nutrient solution salinity from 4.5 to 6.5 mS cm⁻¹ (Table 4.19). This might have resulted from reduced water uptake by the plants (Mizrahi and Pasternak 1985 ; Zayed 1987; Ismail 1989). It seems from experiment B that cucumber plants can be grown at a salinity level of 4.5 mS cm⁻¹ without a significant reduction on the fruit yield. The cucumber fruit quality was improved further when the solution salinity increased up to 6.4 mS cm⁻¹ however, there was a large reduction in total yield (54%).

Salinity-induced growth reduction may be due to the nutritional effects of the salinity. These include specific ion toxicity and ion imbalance due to excess of some particular ion. The results here show that sodium and chloride levels in roots and leaves increased in proportion to NaCl concentration in the root media. The chloride level in the leaves was higher than sodium. Yang *et al* (1990) concluded that leaves appear to be more discriminatory against Na⁺ than Cl⁻. Ramani *et al* (1989) also found that the uptake of chloride by *Sesbania* grown hydroponically was about third of Na⁺, but the translocation to shoot was relatively greater.

Calcium and potassium concentrations in the roots and the leaves were negatively correlated to the Na⁺ level (Figure 4.20 and 4.21). This result supports the finding of several investigators (Kawasaki *et al* 1983a; Cramer *et al* 1985; Nakamura *et al* 1990). The reduction of Ca²⁺ with increasing NaCl concentration could be the result of displacement of Ca²⁺ from root membrane by Na⁺ and thus changing their integrity and their normal functioning (Cramer *et al* 1985). Maas and Grieve (1987) ascribed the reduction on Ca²⁺ concentration to the increase of Na⁺/Ca²⁺ in the root media, which affected the selective permeability of membrane

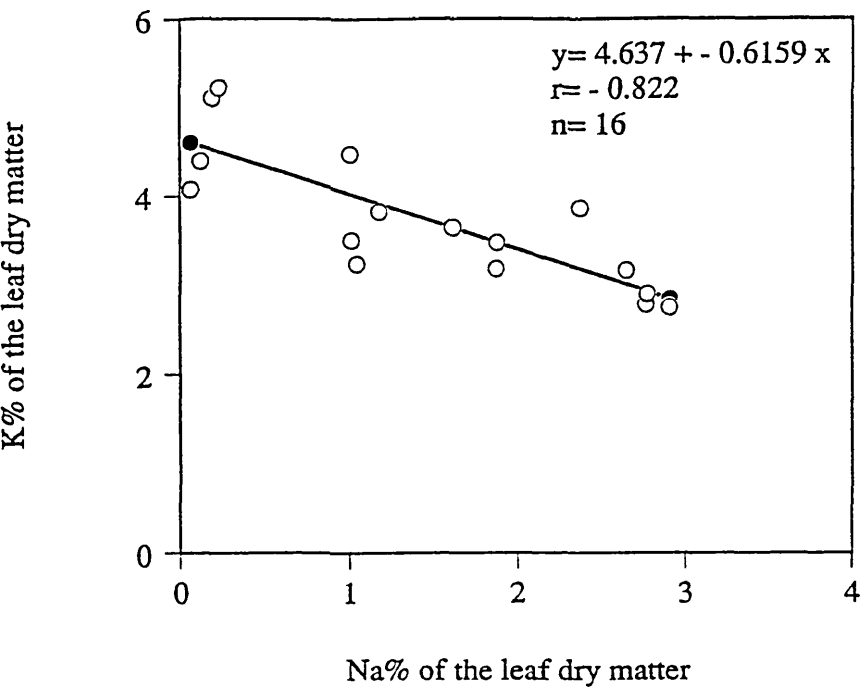


Fig. 4.20 The relationship between Na% and K% of the dry matter of the leaf

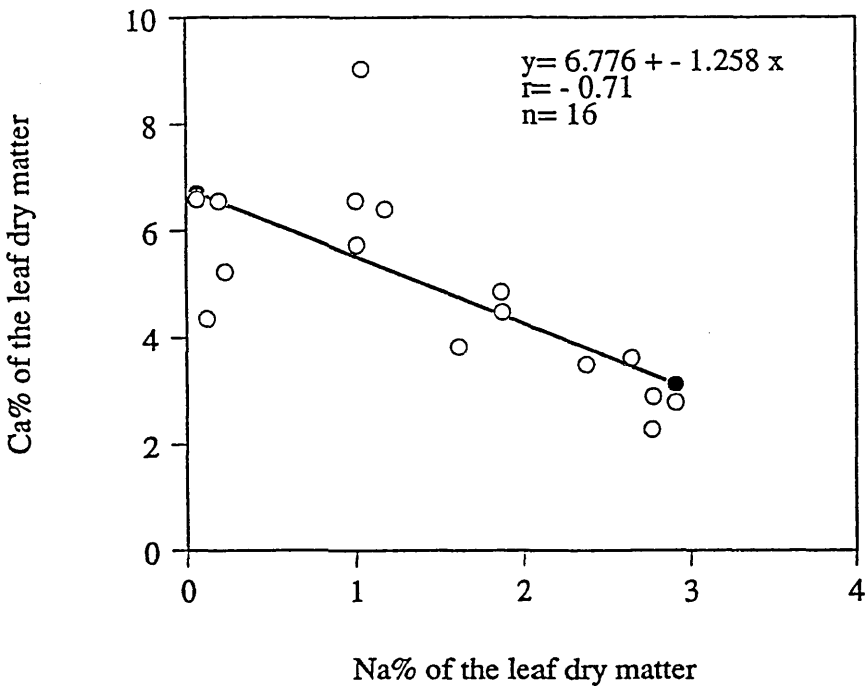


Fig. 4.21 The relationship between Na% and Ca% of the dry matter of the leaf

and induced Ca^{2+} deficiencies in salt-stressed corn.

The reduction of the K^+ is related to the effect of NaCl on the permeability of the root membrane. High Na^+ concentration in external solution reduced the influx of K^+ either by direct competition for the channels in the root cell membrane, by reduction of membrane selectivity to K^+ or by the change in the nature of the transport carrier across the membrane (Jacoby and Hanson 1985).

Silberbush and Bin-Asher (1989) concluded that K^+ influx is most sensitive to Na^+ concentration in the external solution. They also reported that in the presence of Na^+ , K^+ transport via the root membrane became more complex and therefore less efficient. High Na^+ in the external solution is reported to increased K^+ afflux from salt-stressed root (Cramer *et al* 1985). This could be related to the displacement of Ca^{2+} from the root membrane by Na^+ , since Ca^{2+} has an important role on permeability to K^+ of plasma membrane and prevents the leakage of K^+ from the root cell (Nakamura *et al* 1990). This is also indicated by the reverse effect of Ca^{2+} on NaCl induced decrease in K^+ (Shah *et al* 1990; Subbarao *et al* 1990).

Increasing salinity in the nutrient solution led to a substantial increase in the Na^+ and Cl^- in the root and leaves. Na^+ and Cl^- levels in the root and leaf were positively correlated to the level of external salinity (Figure 4.22a,b,c,d), suggesting a general excessive uptake of these ions into the plants under saline conditions.

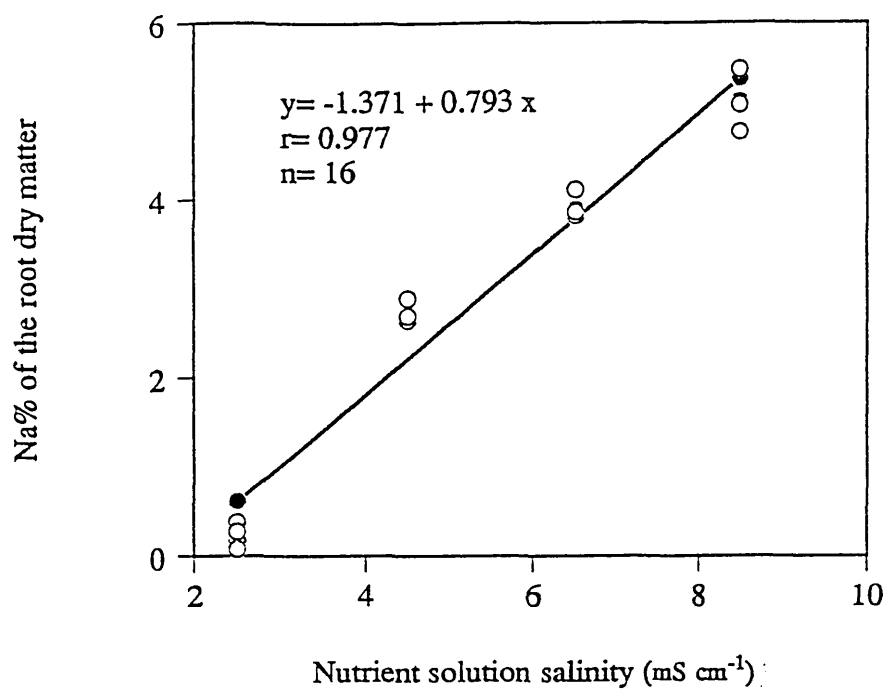


Fig. 4.22a Na% in the root tissue related to the nutrient solution salinity

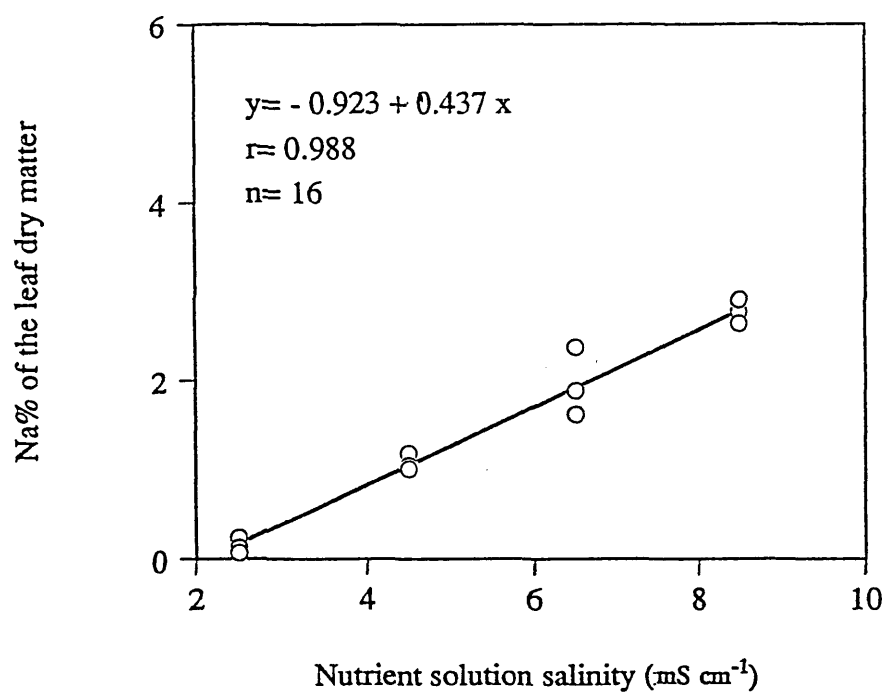


Fig. 4.22b Na% in the leaf tissue related to the nutrient solution salinity

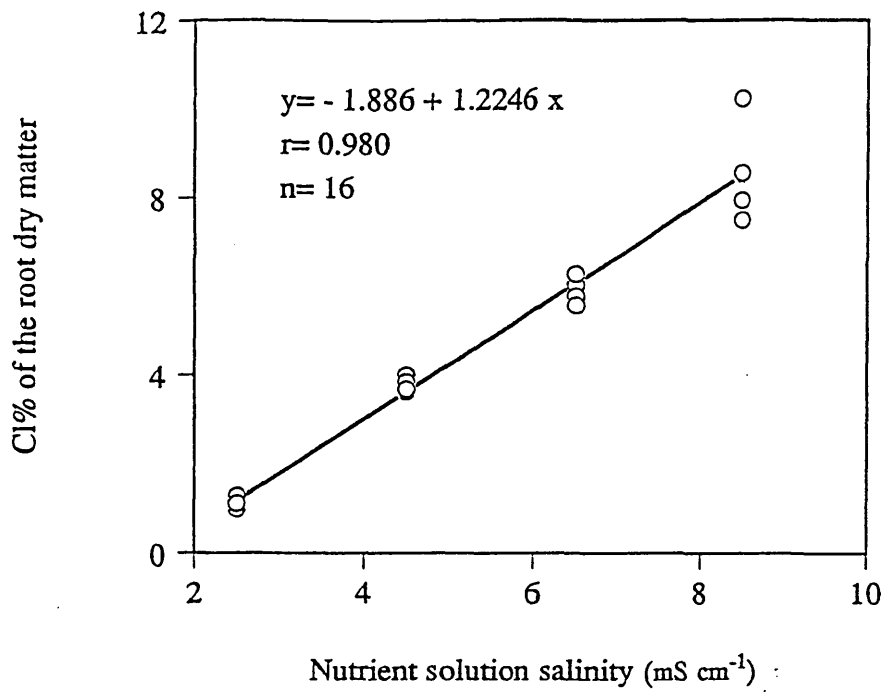


Fig. 4.22c Cl% in the root tissue related to the nutrient solution salinity

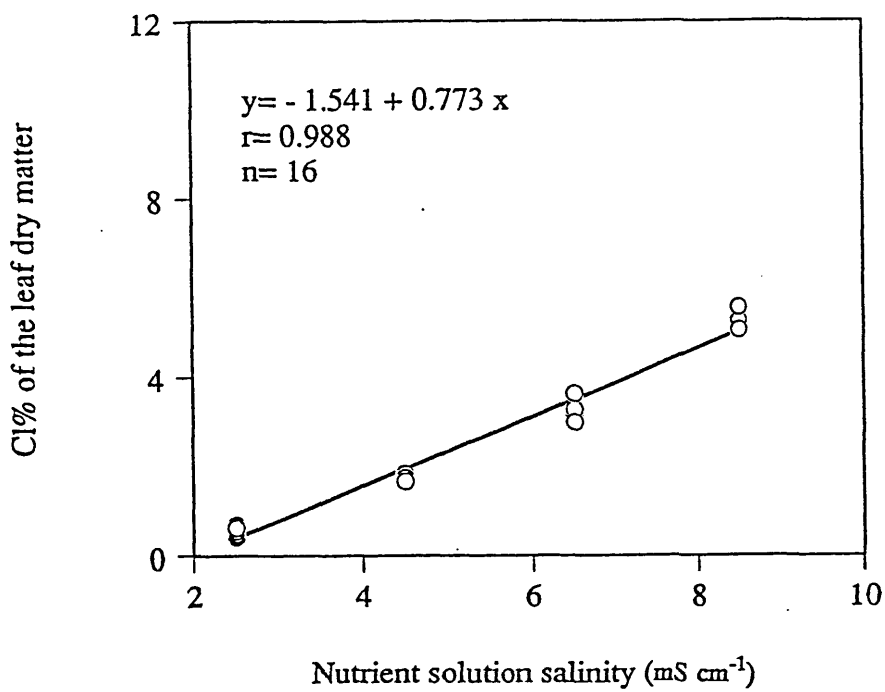


Fig. 4.22d Cl% in the leaf tissue related to the nutrient solution salinity

**CHAPTER FIVE: EFFECT OF MANIPULATING NUTRIENT SOLUTION
SALINITY ON THE GROWTH OF CUCUMBER PLANTS IN NFT**

5.1 INTRODUCTION:

The results in the previous experiment showed a reduction in the plant growth in proportion to the nutrient solution salinity. This reduction had a positive correlation with the plant water uptake. Plant water uptake is regulated by the demand and supply, the supply is mainly controlled by the difference in water potential between the root and the root media and the resistance to water flow through the plant. The effect of salinity on water supply is through the decrease in osmotic potential of the nutrient solution reducing the water flow into the root.

The negative effect of salinity on the plant water relations was very obvious during periods of high demand due to high levels of radiation. This experiment was designed to study the interaction of radiation and nutrient solution salinity on the water relations of cucumber and the influence this had on plant growth. To achieve this the plants were subjected to different day and night nutrient solution salinity regimes.

5.2 EXPERIMENTS AND RESULTS:

Cucumber seeds (cv Farbiola) were germinated on 20-06-89. Seedlings were selected and transferred to the NFT channels on 30-6-89. The experimental layout was prepared as described in the material and methods. Four treatments were compared in this experiment (Table 5.1). Each treatment was replicated four times. The nutrient solution conductivity was maintained by daily adjustment at levels of 2.0-2.5 mS cm⁻¹ and 8.0-8.5 mS cm⁻¹ at a pH of 5.5-6.5. The basic nutrient solution had an Ec of 2.5 mS cm⁻¹ achieved by diluting the stock solution in requisite amount of water. Higher solution salinity was achieved by addition of NaCl to the basic nutrient solution.

Table 5.1. Treatments.

Treatments	Nutrient solution (mS cm ⁻¹) day/night
T1	2.0-2.5
T2	2.0-2.5/8.0-8.5
T3	8.5-8.5/2.0-2.5
T4	8.0-8.5

The control plants (T1) were maintained at a constant solution concentration of 2.5 mS cm⁻¹. The T4 plants were maintained at a constant salinity in the nutrient solution of 8.5 mS cm⁻¹. The T2 and the T3 treatment plants were supplied alternately from two tanks containing nutrient solutions of 2.5 and 8.5 mS cm⁻¹. Each time the nutrient solution was drained out of the channel, before changing to a solution with a different Ec. In T2 plants received 2.5 mS cm⁻¹ solution during the day (6:00 am - 8:00 pm) and 8.5 mS cm⁻¹ solution during the night (8:00 pm - 6:00 am). In the T3 plants received 8.5 mS cm⁻¹ solution during the day and 2.5 mS cm⁻¹ solution during the night. The day time (14 hours) and the night time (10 hours) were kept constant throughout the experiment. The details of plant cultivation have been described in the material and methods. The experiment was terminated on 18-8-89.

5.2.1 VEGETATIVE GROWTH MEASUREMENT:

Plant growth seemed to be affected by the day time nutrient solution salinity more than night time. Figure 5.1 shows the stem growth rate measured as

changes in the plant height and stem diameter. The 2.5/8.5 mS cm⁻¹ plants had a higher growth rate compared to 8.5/2.5 mS cm⁻¹ plants while the constant salinity treatment had the lowest stem growth rate. Measurements at the end of the experiment shows that the plant height and stem diameter of the plants, which were exposed to salinity during the night time only was not significantly affected. High salinity during the day and constant high salinity significantly reduced both the plant height and stem diameter compared to the control (Table 5.2).

Leaf area was measured as described in the previous experiment. It was estimated from the breadth of leaf using a simple regression equation for each treatment (Table 5.3). The growth rate pattern of the leaves for different treatments is presented in Figure 5.2.

Table 5.2 The influence of diurnal changes in salinity on stem growth.

Nutrient solution Ec (mS cm ⁻¹)	Plant height (cm)	Stem diameter (cm)	Fresh weight (g/plant)	Dry weight %	Total dry weight (g/plant)
2.5	274.1	1.167	248.3	9.715	24.10
2.5/8.5	264.3	1.115	214.8	10.422	22.38
8.5/2.5	195.1	1.025	150.3	11.932	17.91
8.5	211.8	0.887	137.2	12.160	16.64
LSD 0.05	35.197	0.104	26.013	0.578	2.477
LSD 0.01	50.57	0.150	37.375	0.830	3.559

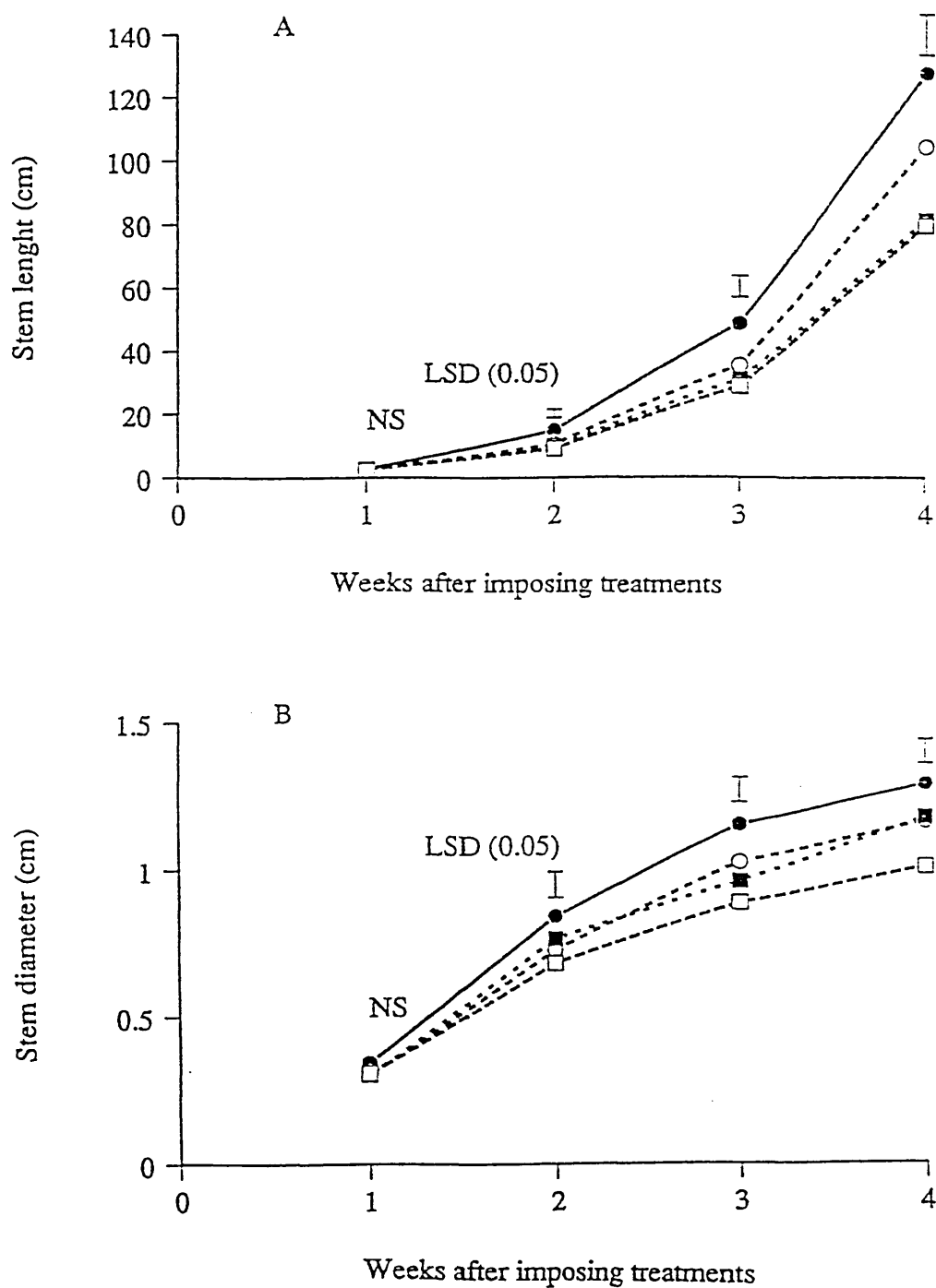


Fig. 5.1 Changes in the stem length (A) and diameter (B) as influenced by the treatments

- T1=2.5 mS/cm
- T2=2.5/8.5 mS/cm
- T3=8.5/2.5 mS/cm
- T4=8.5 mS/cm

Table 5.3. Correlation coefficient (r) of different treatments relating the leaf breadth and area.

Treatment	Regression equation	Correlation coefficient (r)
T1	$-207.246 + 28.01 x$	0.930
T2	$-182.659 + 25.34 x$	0.953
T3	$-183.628 + 22.78 x$	0.887
T4	$-125.97 + 19.55 x$	0.829

Table 5.4 The effect of fluctuating salinity level on leaf growth.

Nutrient solution E_c ($mS\ cm^{-1}$)	Leaf area (cm^2)	Petioles			Lamina		
		Fresh w. (g/plant)	Dry weight %	Total dry weight (g/plant)	Fresh weight (g/plant)	Total Dry weight (g/p)	Dry weight %
2.5	828	362.8	7.31	26.54	468	72.4	15.5
2.5/8.5	668	271.9	7.73	21.06	385	59.6	15.45
8.5/2.5	589	202.4	10.22	20.68	261	42.9	16.34
8.5	457	167.3	11.01	18.37	249	40.3	16.19
LSD 0.05	103.2	43.81	0.819	3.594	65.15	10.72	ns
Lsd 0.01	148.2	62.95	1.177	5.164	93.6	15.41	ns

Table 5.5 The effect of fluctuating salinity on shoot fresh and dry weights.

Nutrient solution Ec day/night	Total shoot fresh weight (g/plant)	Total shoot dry weight (g/plant)
2.5	1079	123.1
2.5/8.5	872	103.1
8.5/2.5	613	81.5
8.5	554	75.3
LSD 0.05	123.05	14.590
LSD 0.01	176.8	20.963

The leaves of 2.5/8.5 mS cm⁻¹ plants had a higher growth rate than the 8.5/2.5 mS cm⁻¹ plants but were lower than the control. The final leaf area determined at the end of the experiment is presented in Table 5.4. The results reflect the difference in the leaf expansion rate between the treatments. The leaf area of 2.5/8.5 mS cm⁻¹ plants were reduced by 19.32% compared to the control while the reduction was 28.86% and 44.81% for 8.5/2.5 and 8.5 mS cm⁻¹ plants.

Total shoot fresh weight and dry weight are summarized in Table 5.5. All the treatments had a significant effect on the total shoot fresh and dry weight compared with the control. Feeding the plants with 8.5 mS cm⁻¹ solution during the day caused 43.19% reduction in the fresh weight and 33.79% in the dry weight compared with the control. Plants receiving 8.5 mS cm⁻¹ solution during the night were less affected. The reduction was 19.18% in the fresh weight and 16.24% in the dry weight.

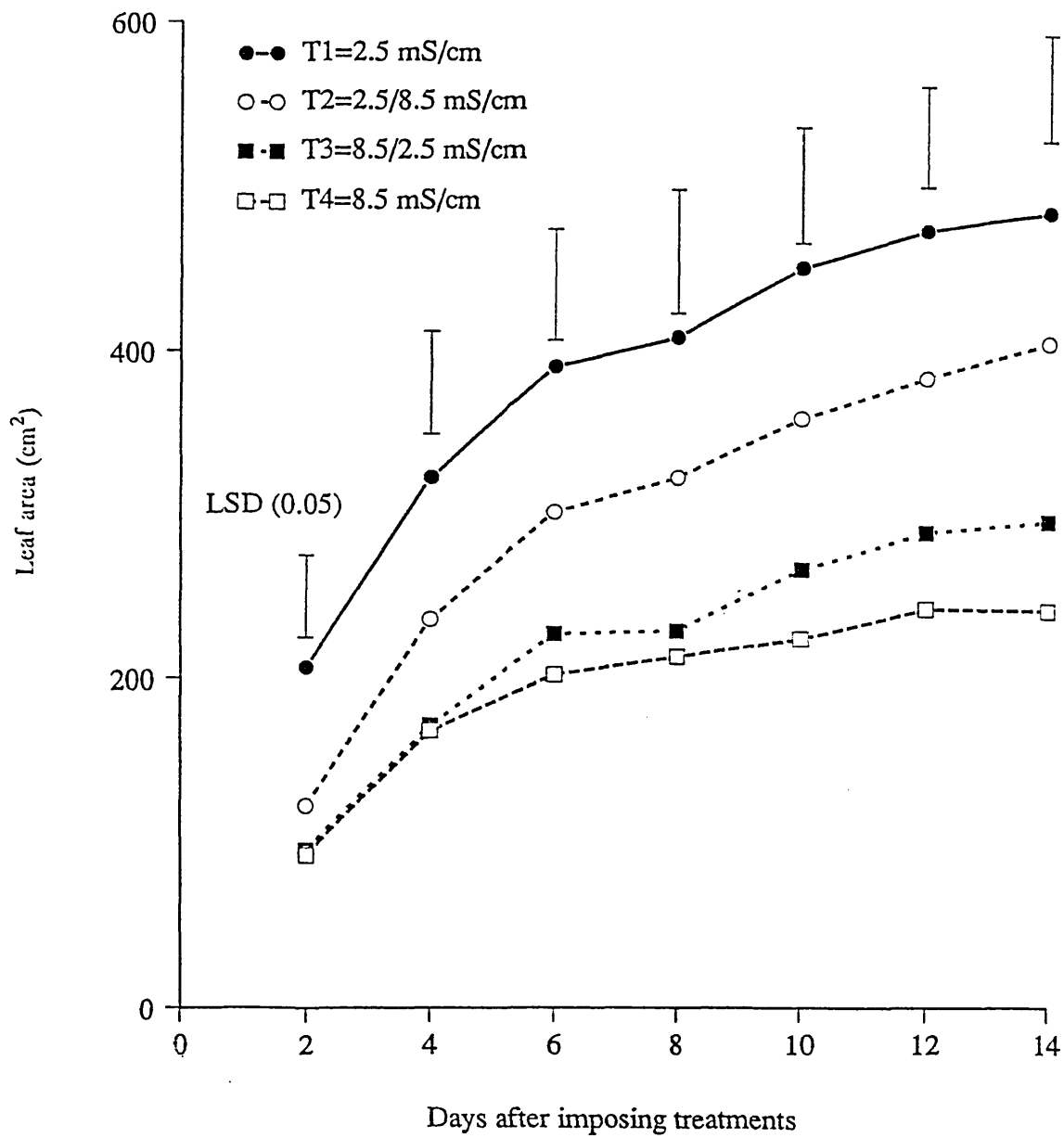


Fig. 5.2 The influence of the treatments on leaf area

5.2.2 ROOT MEASUREMENTS:

The night time high nutrient solution salinity (8.5 mS cm^{-1}) had no significant effect on the root fresh weight. There was a significant ($P=0.01$) reduction of root fresh weight when the plant was exposed to 8.5 mS cm^{-1} solution during the day and continuous high salinity solution around the root (Table 5.6). The dry matter percentage in the root was increased significantly ($P=0.05$) in $2.5/8.5 \text{ mS cm}^{-1}$ compared to the control, while there was no significant difference between $2.5/8.5$, $8.5/2.5$ and 8.5 mS cm^{-1} . The total root dry weight (g/p) was not affected by high salinity during the night, while it was markedly decreased by the day time salinity and continuous high salinity.

The root:shoot ratio was slightly increased in $2.5/8.5 \text{ mS cm}^{-1}$ plants compared to the control but the difference was not significant. The difference was significant between control and $8.5/2.5 \text{ mS cm}^{-1}$ ($P=0.05$) and 8.5 mS cm^{-1} ($P=0.01$) plants.

Table 5.6. The effect of the treatments on root growth and root:shoot ratio.

Nutrient solution Ec (mS cm^{-1})	Fresh weight (g/plant)	Dry weight %	Total dry weight (g/plant)	Root:shoot ratio
2.5	290	7.42	21.19	0.1712
2.5/8.5	206	10.22	19.52	0.1927
8.5/2.5	113	10.46	11.72	0.1435
8.5	66	10.94	7.24	0.0962
LSD 0.05	89.35	2.730	4.743	0.0448
LSD 0.01	128.38	3.887	6.82	0.0644

5.2.3 PLANT WATER RELATIONS:

5.2.3.1 WATER UPTAKE AND RELATIVE WATER CONTENT:

The total water uptake was significantly lower for all the plants receiving saline treatments than in non-saline treated control. It was also significantly lower for the plants of continuous salinity than in those, which were exposed to salinity during the day or night time only. A weekly average of daily water uptake is presented in Figure 5.3. The total water uptake was reduced by 20.05% and 47.66% compared to the control for the 2.5/8.5 mS cm⁻¹ and 8.5/2.5 mS cm⁻¹ plants respectively.

The relative water content (RWC) was measured during the day, 12 days after starting the treatments. The results presented in Table 5.7 show that RWC was affected by the salt stress at the time of measurement. It also shows a significant ($P=0.05$) reduction in the RWC of 8.5/2.5 mS cm⁻¹ and 8.5 mS cm⁻¹ plants compared to the control and 2.5/8.5 mS cm⁻¹ plants.

Table 5.7. The effect of the treatments on relative water content and total water uptake.

Nutrient solution Ec (mS cm ⁻¹)	Relative water content %	Total water uptake (ml/plant)
2.5	71	54222.8
2.5/8.5	69	43353.1
8.5/2.5	60.3	28378.2
8.5	62.2	21755.5
LSD 0.05	8.0301	3899.21
LSD 0.01	ns	5602.32

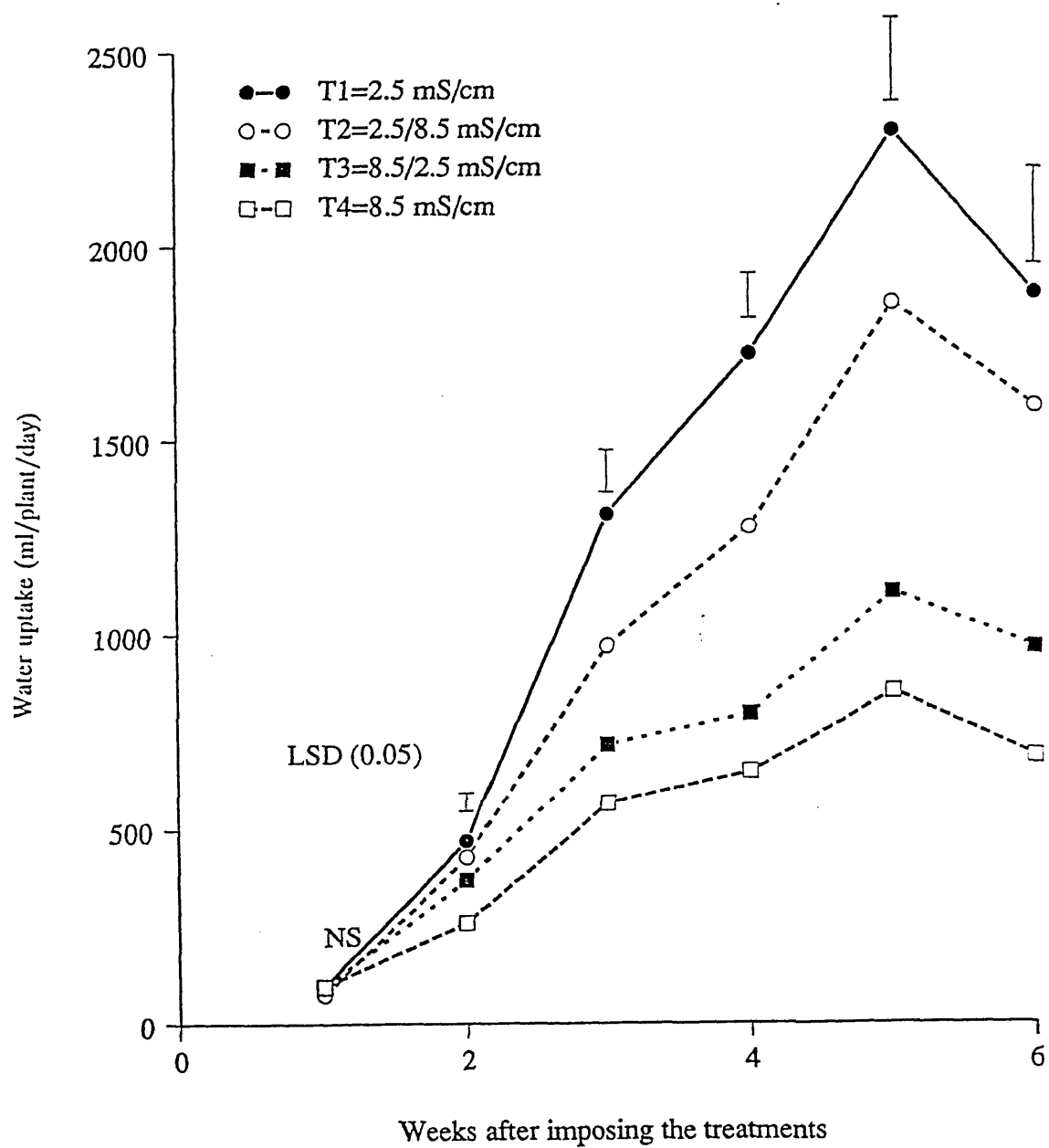


Fig. 5.3 The plant water uptake as influenced by the treatments

5.2.3.2 WATER POTENTIAL:

A diurnal measurement for plant water potential carried out 30 days after starting the treatments is given in Figure 5.4. The result shows the rapid response of the plant water potential to a change in nutrient solution salinity. The measurement started immediately after changing the nutrient solution for the fluctuating salinity treatments (06:00 h). In the first measurement the water potential of 2.5/8.5 mS cm⁻¹ plants and 8.5 mS cm⁻¹ plants could not be differentiated and both were significantly lower than 8.5/2.5 mS cm⁻¹ plants ($P=0.01$) and the control ($P=0.05$). During the day the water potential of 2.5/8.5 mS cm⁻¹ plants increased and of 8.5/2.5 mS cm⁻¹ plants decreased. By midday the water potential of the 2.5/8.5 mS cm⁻¹ plants were to the same level as the control. At 15:30 hour the water potential of 8.5/2.5 mS cm⁻¹ plants was decreased to the level of 8.5 mS cm⁻¹ plants and both were significantly ($P=0.01$) lower than the control and 2.5/8.5 mS cm⁻¹ plants.

5.2.3.3 TRANSPIRATION RATE AND STOMATAL CONDUCTANCE:

The measurements of transpiration rate and stomatal conductance were carried out several times during the experiment. Figure 5.5 and 5.6 show transpiration rate and stomatal conductance at different levels of radiation, 14 days after the treatments were imposed. The transpiration increased with increasing radiation level but no significant difference between the treatments was observed. The stomatal conductance of the plants receiving saline treatments tend to be lower than the control. A significant reduction was found in the stomatal conductance of the 8.5/2.5 mS cm⁻¹ and 8.5 mS cm⁻¹ plants compared with the control and 2.5/8.5 mS cm⁻¹ plants.

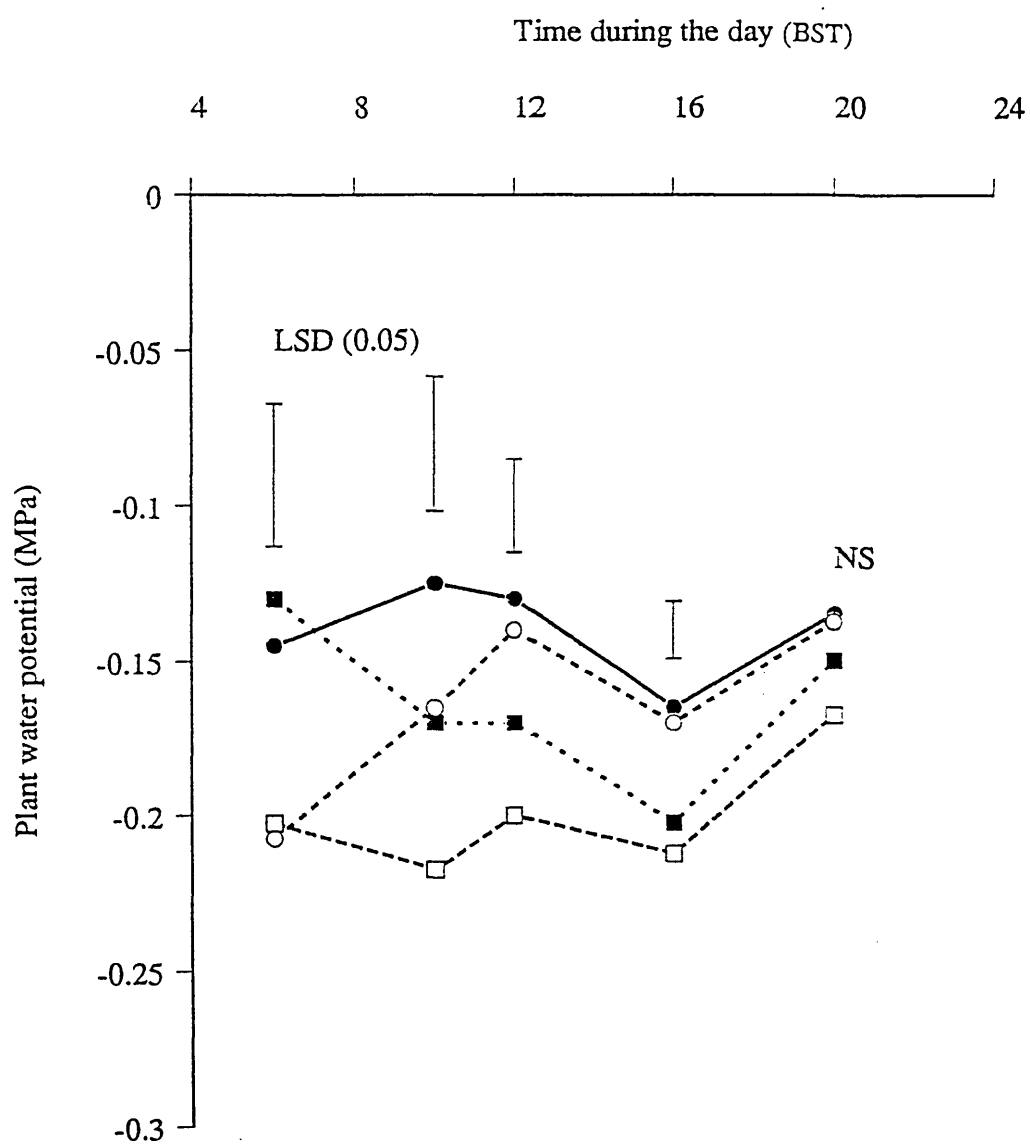


Fig. 5.4 Diurnal measurement for the plant water potential 30 days after starting the treatments

- T1=2.5 mS/cm
- T2=2.5/8.5 mS/cm
- T3=8.5/2.5 mS/cm
- T4=8.5 mS/cm

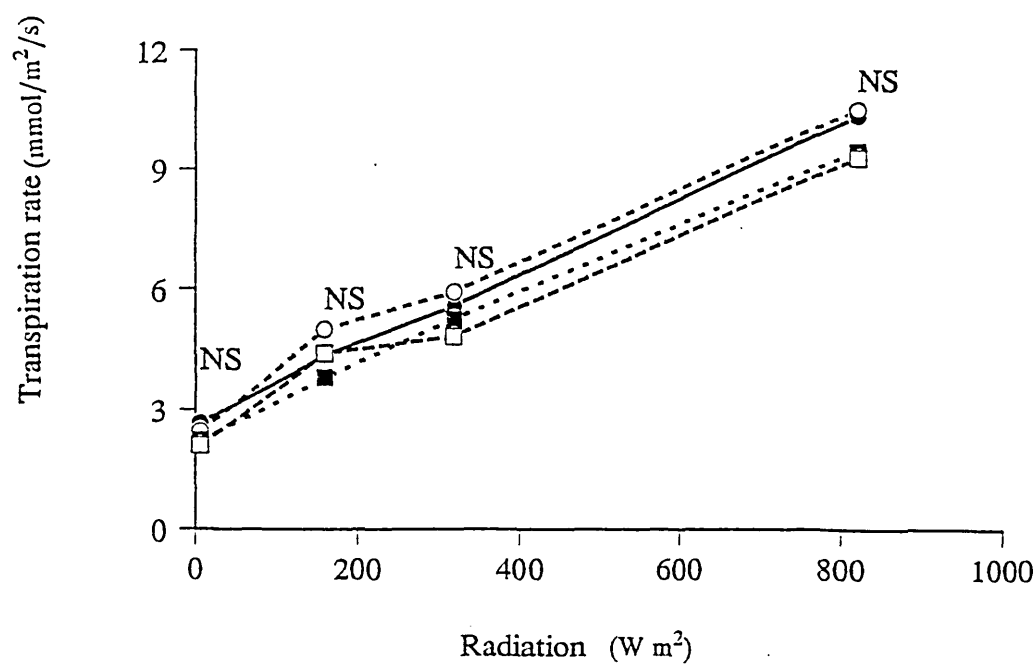


Fig. 5.5a Transpiration rate at different levels of radiation as influenced by the treatments

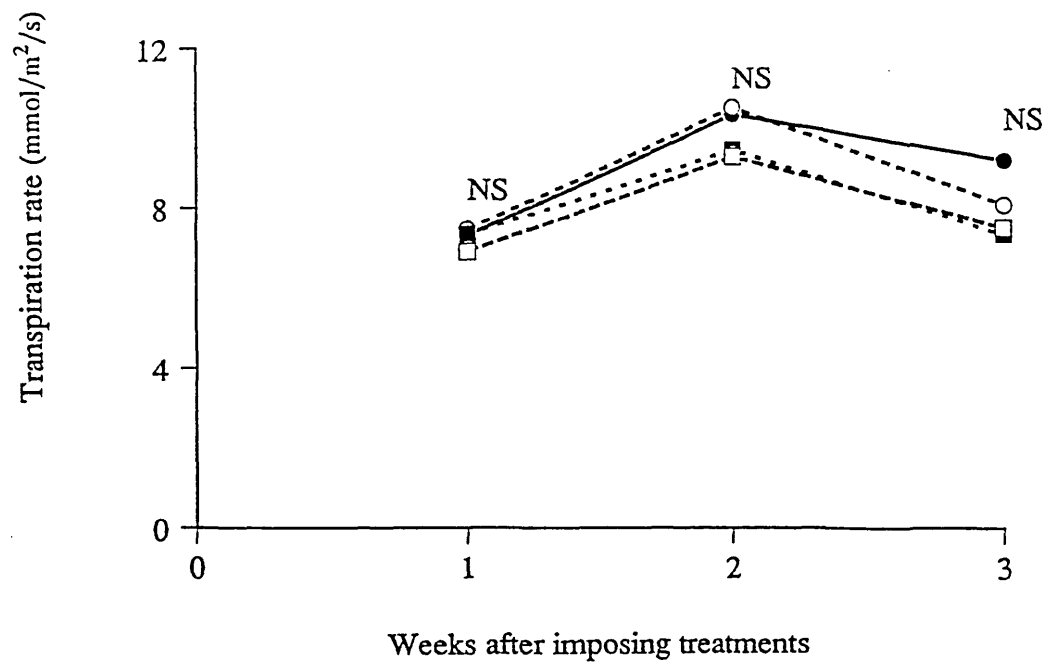


Fig. 5.5b Changes in transpiration rate as influenced by the treatments

- T1=2.5 mS/cm
- T2=2.5/8.5 mS/cm
- T3=8.5/2.5 mS/cm
- T4=8.5 mS/cm

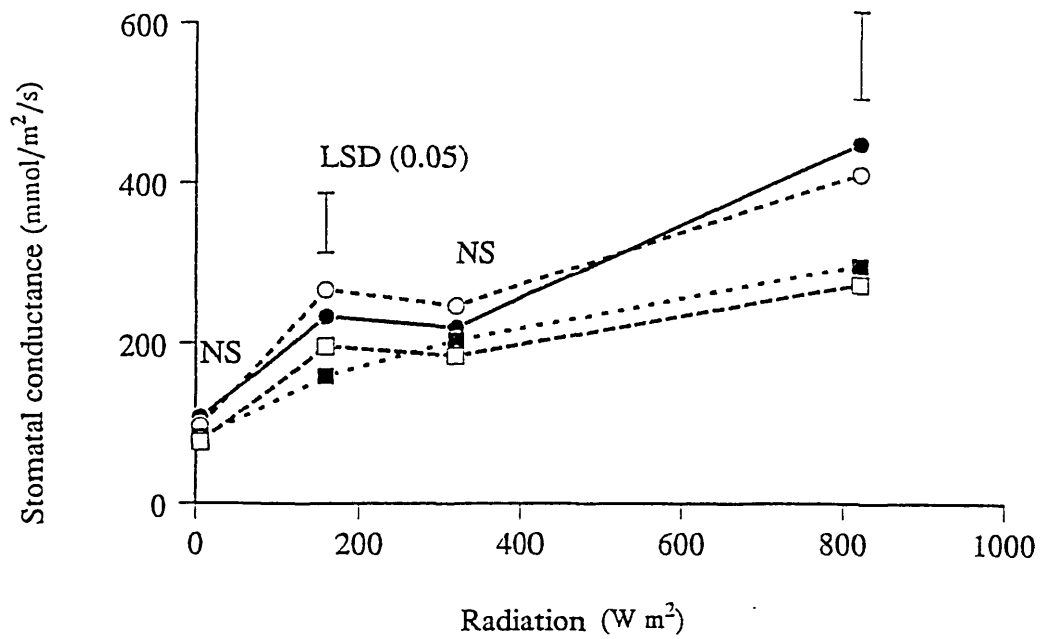


Fig. 5.6a Stomatal conductance at different levels of radiation as influenced by the treatments

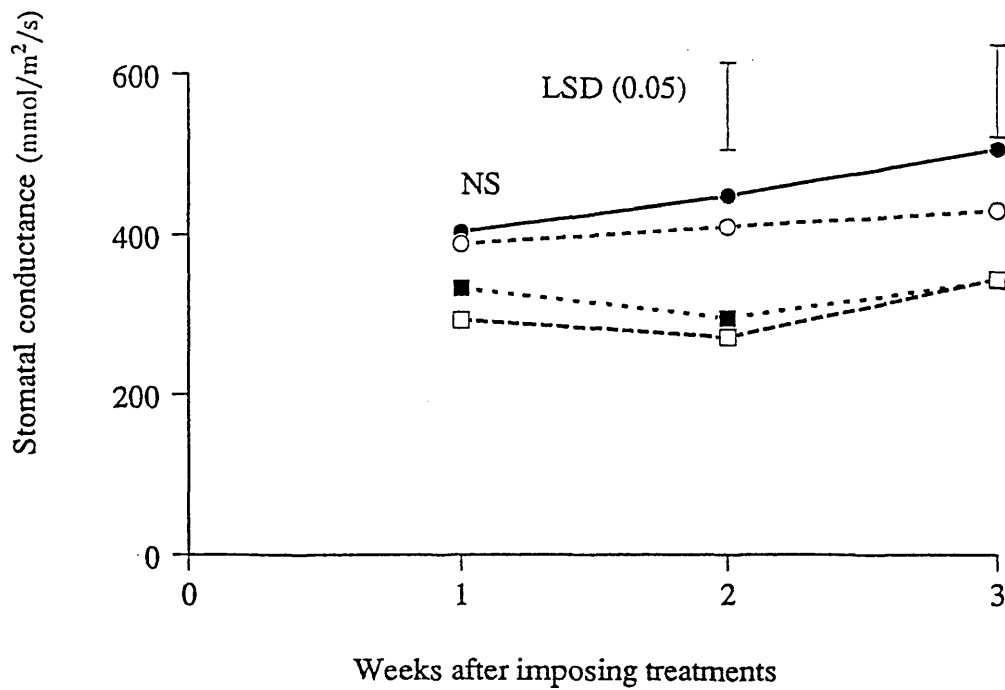


Fig. 5.6b Changes in stomatal conductance as influenced by the treatments

- T1=2.5 mS/cm
- T2=2.5/8.5 mS/cm
- T3=8.5/2.5 mS/cm
- ◻ T4=8.5 mS/cm

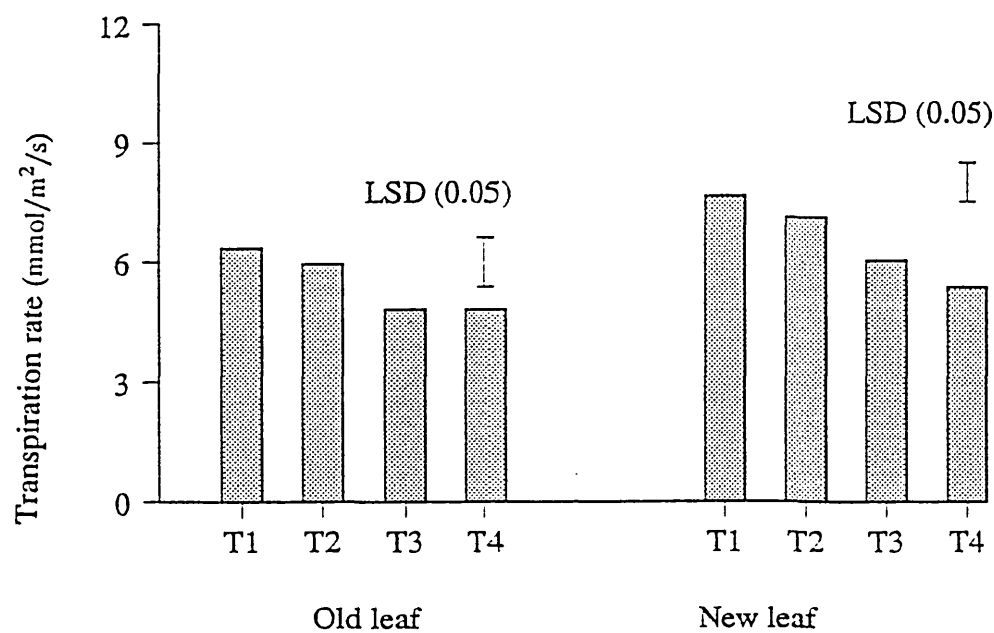


Fig. 5.7a Transpiration rate of the old and new laeves as influenced by different treatments

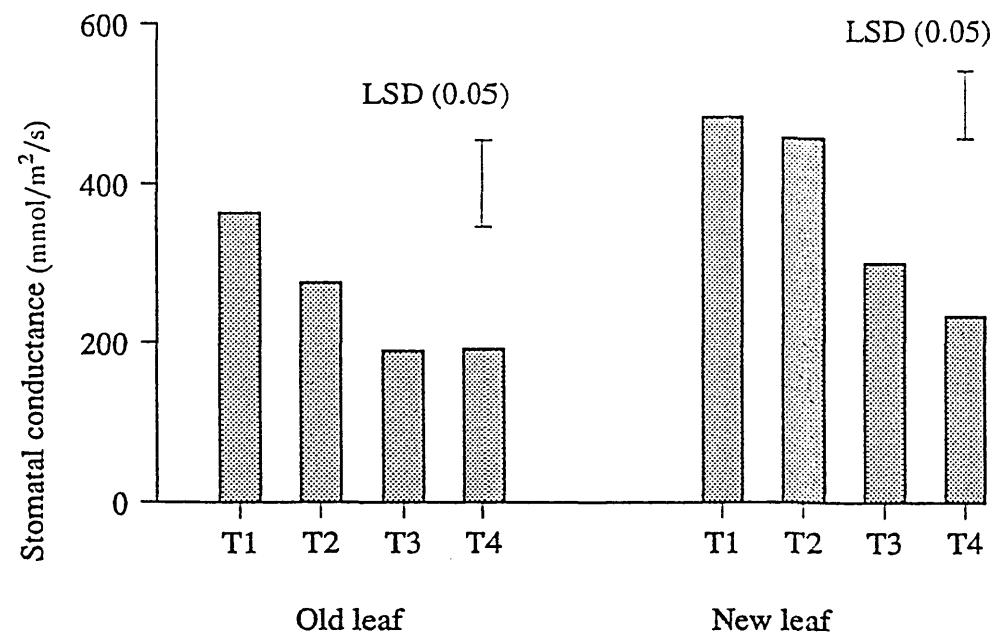


Fig. 5.7b Stomatal conductance of the old and new leaves as influenced by the treatments

The final measurements carried out showed that transpiration rate and stomatal conductance of the plants under salt stress were significantly reduced both for old leaves ($P=0.05$) and new leaves ($p=0.01$) (Figure 5.7a,b).

5.2.4 PHOTOSYNTHETIC RATE:

Photosynthetic rate was measured 14 days after starting the treatments. The results show that photosynthesis rate increased with radiation but no consistent difference between treatments was observed.

5.2.5 PLANT ANALYSIS:

The treatments effect on the nutrient content of the root and leaf tissue is summarized in Table 5.8. and 5.9. Calcium level in the root tissue was not affected by the treatments. Ca^{+2} level in the leaves of the 2.5/8.5 mS cm^{-1} plants was not affected, while there was a significant reduction in the leaves of 8.5/2.5 mS cm^{-1} ($P=0.05$) and 8.5 mS cm^{-1} ($P=0.01$) treatments compared to the 2.5/8.5 mS cm^{-1} treatment. The reduction was 31.58% and 56.09% for 8.5/2.5 and 8.5 mS cm^{-1} respectively.

Phosphorous concentration was found to be higher in the root than in the leaves. The level in the root and leaf tissue was not influenced by the treatments (Table 5.8 and 5.9). Na% in the root and shoot was significantly increased in the salt treated plants. The results show that Na% in the dry matter of the root and leaf tissue of 8.5/2.5 mS cm^{-1} plants were not different from 8.5 mS cm^{-1} plants

and both were significantly ($P=0.01$) higher than that in $2.5/8.5 \text{ mS cm}^{-1}$.

K% in the dry matter of the root and shoot was significantly ($P=0.01$) reduced in the salt treated plants compared with the control (Table 5.8 and 5.9). The reduction of K^+ level in the root tissue of the $8.5/2.5 \text{ mS cm}^{-1}$ was greater than the $2.5/8.5 \text{ mS cm}^{-1}$ treatment. The difference between these treatments was statistically significant ($P=0.01$). No significant difference was observed between $8.5/2.5 \text{ mS cm}^{-1}$ and 8.5 mS cm^{-1} treatments in K% either in the root or in the leaves.

No consistent changes were observed on the Mg% in the root and leaves. Na^+ and Cl% in the root and leaves were markedly increased by salinity. These values were significant ($P=0.01$) when compared with the controls.

Table 5.8. The effect of the treatments on ion levels in the root (% dry weight).

Solution Ec (mS cm^{-1})	Ca	P	Na	K	Mg	Cl
2.5	0.906	0.432	0.449	4.59	0.1960	0.74
2.5/8.5	0.750	0.491	2.322	2.49	0.0797	3.52
8.5/2.5	0.743	0.460	3.687	1.46	0.1080	4.59
8.5	0.689	0.448	3.782	1.99	0.0772	5.28
LSD 0.05	ns	ns	0.4228	0.6809	0.0602	1.4070
LSD 0.01	ns	ns	0.6074	0.9783	0.0865	2.0215

Table 5.9 The effect of the treatments on ion levels in the leaves (% dry weight).

Solution Ec (mS cm ⁻¹)	Ca	P	Na	K	Mg	Cl
2.5	5.95	0.226	0.26	4.52	0.831	0.46
2.5/8.5	6.65	0.2342	1.76	1.852	0.581	2.96
8.5/2.5	4.55	0.2172	2.44	1.462	0.509	3.96
8.5	2.92	0.2417	2.682	1.397	0.599	5.89
LSD 0.05	1.635	ns	0.2533	0.4341	0.1418	1.056
LSD 0.01	2.350	ns	0.364	0.6237	0.2038	1.518

The chloride levels in the root and leaf tissue of 8.5/2.5 mS cm⁻¹ plants were slightly higher than those of 2.5/8.5 mS cm⁻¹ plants but the difference was not significant.

5.2.6 YIELD MEASUREMENTS:

Fruit number per plant was significantly ($P=0.01$) reduced for the 8.5/2.5 mS cm⁻¹ and 8.5 mS cm⁻¹ treatments compared to the control and 2.5/8.5 mS cm⁻¹ treatment. No significant difference was observed between the control and 2.5/8.5 mS cm⁻¹ treatment. Also no significant difference was found between 8.5/2.5 mS cm⁻¹ and 8.5 mS cm⁻¹ treatments. Fruit weight was not affected by 2.5/8.5 mS cm⁻¹ treatment, while the 8.5/2.5 mS cm⁻¹ treatment substantially decreased the fruit weight compared to the control (Table 5.10). All the treatments had a significant effect on the total plant yield. The total yield was decreased by 24.66%, 59.48% and 76.23% for 2.5/8.5, 8.5/2.5 and 8.5 mS cm⁻¹ treatments respectively.

2.5/8.5 mS cm⁻¹ treatment significantly ($P=0.05$) increased the dry matter percentage in the fruit compared with the control. A further increase was caused by 8.5/2.5 mS cm⁻¹ treatment but the value statistically was not significant compared with the 2.5/8.5 mS cm⁻¹ treatment. The highest dry matter percentage in fruit was observed in the 8.5 mS cm⁻¹ plants. The difference was significantly ($P=0.01$) greater than the rest of the treatments. The TSS in the fruit was slightly increased with increasing time of exposure to high salinity (Table 5.10) but the difference was not significant

Table 5.10 The influence of fluctuating salinity on fruit yield and quality.

Nutrient solution Ec (mS cm ⁻¹)	Fruit number /plant.	Fruit weight	Dry matter % in the fruit	TSS in the fruit	Total yield (g/plant)
2.5	8.75	526	3.44	3.0	3946
2.5/8.5	8.0	369	3.825	3.38	2973
8.5/2.5	5.88	274	4.07	3.56	1599
8.5	5.13	187	4.692	3.94	938
LSD 0.05	0.853	157.89	0.3481	ns	684.03
LSD 0.01	1.225	226.85	0.500	ns	982.8

5.3 DISCUSSION:

The effect of continuous high salinity on the plant growth was similar to the previous experiment. The stem and leaf growth rate were less affected by the high night-time nutrient solution salinity than by high day-time salinity (Figure 5.1a and 5.1b). The final plant height and stem diameter were significantly reduced in 8.5/2.5 mS cm⁻¹ and 8.5 mS cm⁻¹ plants when compared to the controls. Also greater reduction in the leaf area, fresh and dry weight of the root and shoot was found in plants, that were exposed to salinity during the day time (14 h) compared to those expose to salinity during night time (10 h) (Table 5.4 and 5.5). The plant growth seems to be affected by the factors influencing the total water uptake by the plants such as the time and duration of exposure. This was indicated by the positive correlation between the total water uptake by the plant and total shoot weight and leaf area (Figure 5.8 and 5.9) regardless of the treatment. Meiri and Poljakoff-Mayber (1970) reported that the reduction on the bean plants growth under salt stress was correlated to time of exposure to salinity. Meiri *et al* (1970) found no significant difference between day-time and night-time salinity on the final leaf area and dry and fresh weight of bean plants. They concluded that the duration of exposure to salinity was the decisive factor. Root:shoot ratio was significantly ($P=0.01$) reduced by continuous high salinity. A similar result was reported and discussed in the previous experiment.

The results of the previous experiment showed that the nutrient solution concentration was negatively correlated to the plant water uptake. Increasing the osmotic potential of the nutrient solution on the root media caused an immediate reduction in the plant water uptake (Falk 1966; Janes 1968). The RWC measurements, carried out during the day, seem to be affected by the nutrient solution salinity at the time of the measurement (Table 5.7).

The diurnal measurements of the plant water potential (Figure 5.4) showed that the plant water status was rapidly affected by the changes in the root osmoticum. Decreasing the osmotic potential of the recirculating solution

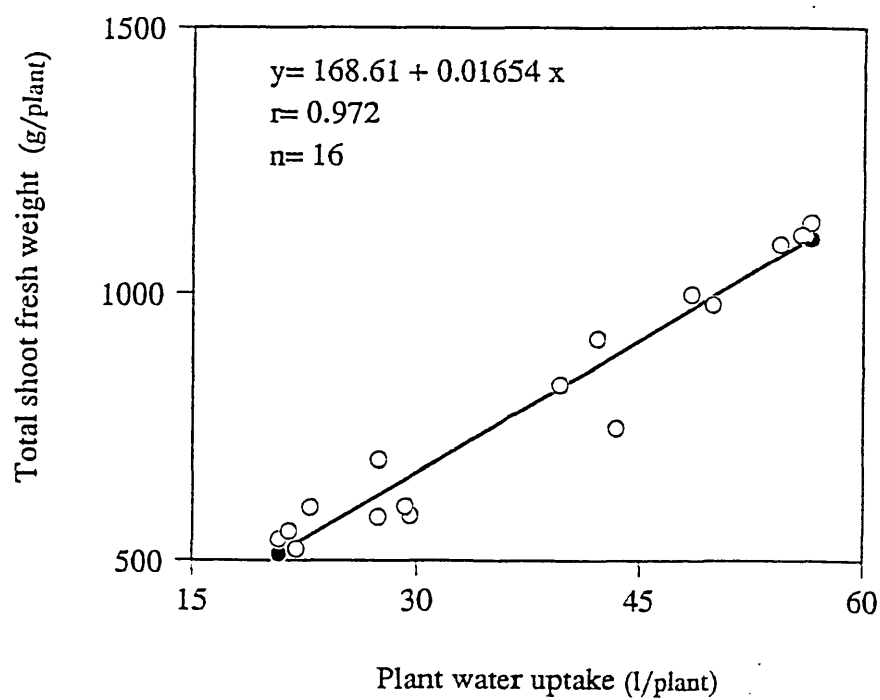


Fig. 5.8 Plant shoot fresh weight related to the total water uptake

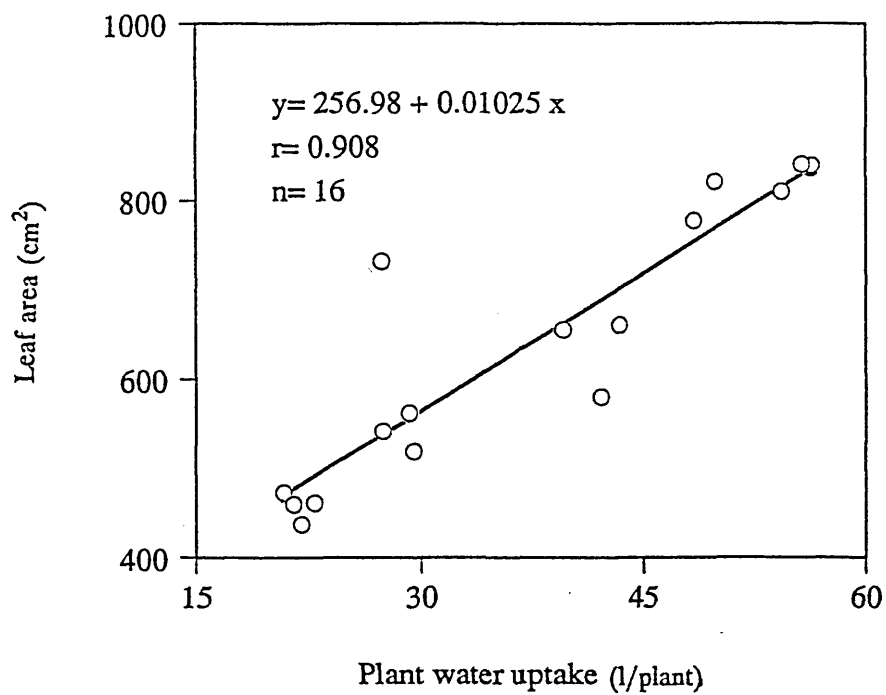


Fig. 5.9 The relationship between plant water uptake and leaf area

decreased the plant water potential in a matter of 2 - 4 hours. Increasing the solution osmotic potential increased the plant water potential over a similar period.

The same result was reported by Acevedo *et al* (1971) and Matsuda and Riazi (1981). The rapidity of response was explained by the fact that the water in the xylem is acting as a hydraulic unit to bring about immediate changes in leaf water status when the water potential of the root medium was changed (Raschke 1970 ; Hsiao *et al* 1970). Matsuda and Riazi (1981) attributed the decrease in the leaf water and osmotic potential of salt stressed young barley seedlings to the osmotic adjustment not to major losses of water.

Transpiration rate has been reported to respond rapidly to any changes in the osmotic potential of the root media (Janes 1968; Meiri and Poljakoff-Mayber 1970). In this experiment the transpiration rate and stomatal conductance measurements were made during day and there was a tendency for a decrease in transpiration and stomatal conductance for the plants under stress at the time of measurement although this was not significant. The photosynthetic rate per unit leaf area was not affected by the treatments. The same result was reported and discussed in chapter 4, experiment B.

The fruit number per plant, fruit weight and total yield per plant was reduced in the same pattern as vegetative growth. The control plants had the highest yield and continuous salinity treatment had the lowest. The fruit yield production of 8.5/2.5 mS cm⁻¹ plants was significantly ($P=0.01$) lower than the total yield of 2.5/8.5 mS cm⁻¹ plants. This may be due to the dominating effect of the high salinity (8.5 mS cm⁻¹) during the day. The total fruit yield was correlated positively to the water uptake (Figure 5.10). This reduction may also be due to the reduction in leaf growth, which caused a reduction on the photosynthetic area. This is indicated by the positive correlation between the shoot and leaf fresh weight and total yield (Figure 5.11).

The dry matter % in the fruit was increased in the salt treated plants. This was correlated negatively to the plant water uptake (Figure 5.12). Ho and Picken (1985) reported that the fruit weight of tomato grown in media of high salinity

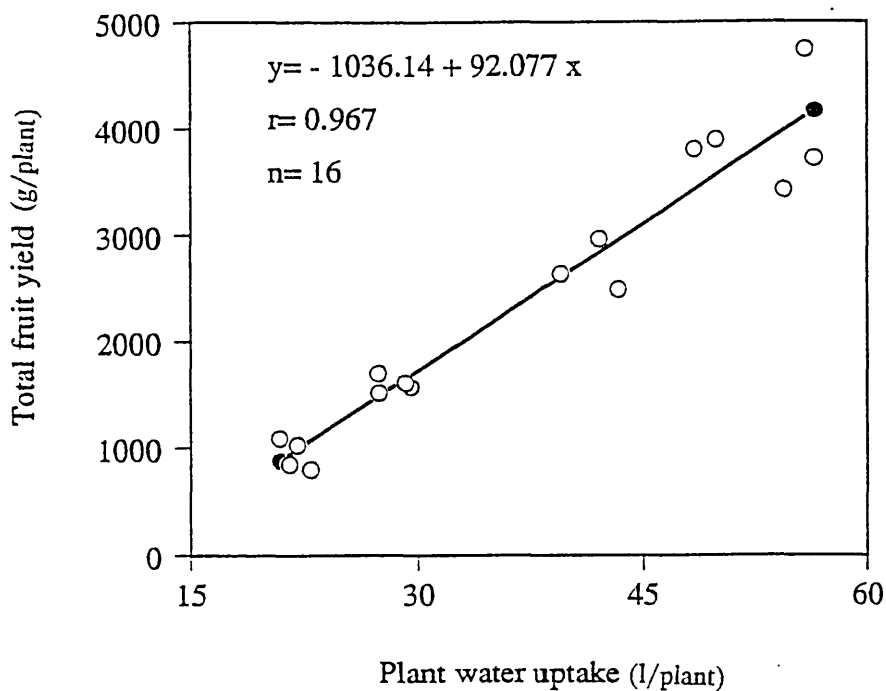


Fig. 5.10 The relationship between total water uptake and total fruit yield

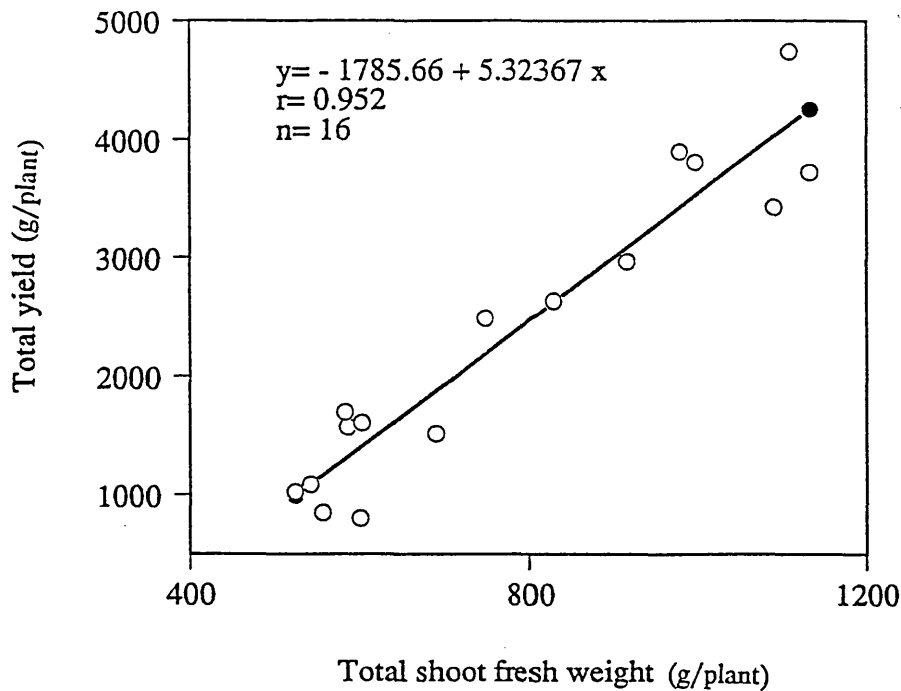


Fig. 5.11 The relationship between the plant fresh weight and total yield

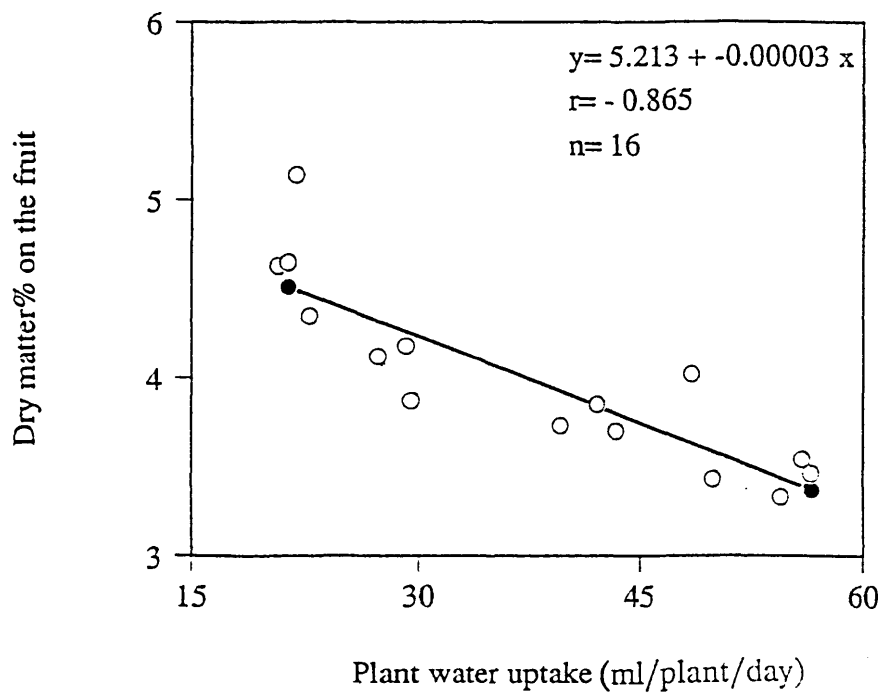


Fig. 5.12 The relationship between water uptake and dry matter% in the fruit

reduced as a result of lower uptake of water rather by reduced accumulation of dry matter. The total soluble solids (TSS) was not affected significantly by the treatment in this experiment. The effect of salinity on the TSS was discussed in the previous chapter, experiment B.

Different day and night time nutrient concentration had an effect on the absorption of some nutrients, for example calcium. Bradfield and Guttridge (1984) reported that calcium uptake of tomato fruit was affected by night time nutrient concentration. Guttridge *et al* (1981) also reported that calcium concentration in the emerging leaves was affected by night time but not by day time nutrient concentration. They suggested that the positive root pressure at night promotes transport of Ca^{2+} into the tissues and organs that have restricted transpiration. The result shows that the calcium level in the leaves of all the salt treated plant was reduced compared with the control regardless of whether the salt stress was applied during the day or night. The continuous high salinity (8.5 mS cm^{-1}) plants had the lowest Ca^{2+} in the leaves. $\text{Ca}^{2+}\%$ in the leaves was gradually reduced with increasing the time of exposure to the salt stress (Table 5.9). Ho and Adams (1989) reported that the reduction of Ca^{2+} uptake by tomato fruit at 8 mS cm^{-1} during the day (10-16 h) was not compensated for by an enhancement of Ca^{2+} uptake at 3 mS cm^{-1} at night (6-12 h). They also indicated that the expected short term effect on transpiration may have been nullified by the long term effect of salinity on the plant development. Phosphorus level was not affected by the treatment while the potassium level was reduced for all the salt treated plants. The $\text{Na}\%$ and $\text{Cl}\%$ in the root and shoot were gradually increased with the time of exposure to the high salinity. The mechanism of the salinity effect on the nutrient concentration in the plant tissue was discussed in the last experiment.

The results of this experiment show a greater effect for the high salinity during the day than during the night, which indicates clearly that salinity acts through its effect on water uptake by the plant. This is supported by the positive correlations between water uptake and shoot and leaf fresh weight (Figure 5.8), leaf area (Figure 5.9) and yield (Figure 5.10).

**CHAPTER SIX: THE INTERACTION EFFECT OF SALINITY AND ROOT
TEMPERATURE ON THE CUCUMBER GROWTH
AND WATER RELATIONS.**

6.1 INTRODUCTION:

Increasing root temperature may have a beneficial effect on plant growth. Increasing root temperature is associated with the production of large leaves, increasing photosynthesis per unit leaf area and increased translocation of the nutrients (Graves 1983). High root temperature also increases the water uptake through a reduction in the root cortex and the formation of large xylem vessels reducing the resistance to the water flow through the root (Moorby and Graves 1980).

The results of the previous experiments have showed the extent of growth reduction caused by salinity. The reduction was found to depend on the level of salinization, the time and the duration of exposure to salinity.

The objective of this study was to investigate the interactive effect of nutrient solution temperature and salinity on the plant growth and water relations. Also to investigate the possibility of alleviating some of the adverse effects of salinity.

6.2 METHODS AND RESULTS:

Cucumber seeds (cv Farbiol) were germinated on 27-9-89. The seedlings were at the second leaf stage when placed in the gullies on 14-10-89. Minimum air temperatures of 22°C and 19°C were maintained during day and night respectively. The treatments consisted of two levels of nutrient solution conductivity (Ec) and two different root temperatures (Table 6.1). The Ec levels were 2.0-2.5 mS cm⁻¹ and 8.0-8.5 mS cm⁻¹. The two root temperature treatments,

unheated nutrient solution in which the temperature fluctuated with the air temperature (18-25°C) and heated to a constant $27 \pm 1^\circ\text{C}$ by using a glass enclosed heater.

Table 6.1 Treatments.

Treatments	Nutrient solution Ec (mS cm^{-1})	Root temperature ($^\circ\text{C}$)
S1T1	2.0-2.5	unheated
S1T2	2.0-2.5	$27^\circ \pm 1$
S2T1	8.0-8.5	unheated
S2T2	8.0-8.5	$27^\circ \pm 1$

The basic nutrient solution (2.5 mS cm^{-1}) and the high salinity (8.5 mS cm^{-1}) were prepared as described in previous experiments. Tap water was circulated for two days before applying the treatments. The experiment was conducted in a randomized block design with two factors. Initial morphological measurement, vegetative growth and yield assessment, physiological and water relation measurement were carried out as described in the general materials and methods.

6.2.1 VEGETATIVE GROWTH MEASUREMENTS:

Plant growth was assessed by measuring the stem growth, leaf area and shoot dry and fresh weight. Shoot growth was inhibited by salinity (Table 6.3). Heating the nutrient solution to $27 \pm 1^\circ\text{C}$ had no significant effect on the plant vegetative growth. Figure 6.1a and 6.1b show the effect of salinity on the stem growth rate.

Leaf area was measured in the period of two weeks after imposing the treatments. Non-destructive measurement for the leaf area was carried out using a simple regression equation for each treatment, as described in the materials and methods. Coefficient factor (r) for each equation is presented in Table 6.2. Figure 6.2 illustrates the interaction effect of salinity and root temperature on the leaf area. Leaf area decreased in salt treated plants but this was not affected by root temperature. There was no interaction effect between salinity and root temperature on the leaf area.

Table 6.2 Correlation coefficient (r) of different treatments relating leaf breadth and area.

Treatments	Regression equation	Correlation coefficient (r)
S1T1	- 240.75 + 28.228 x	0.965
S1T2	- 228.17 + 27.477 x	0.965
S2T1	- 159.52 + 21.574 x	0.973
S2T2	- 192.86 + 22.732 x	0.986

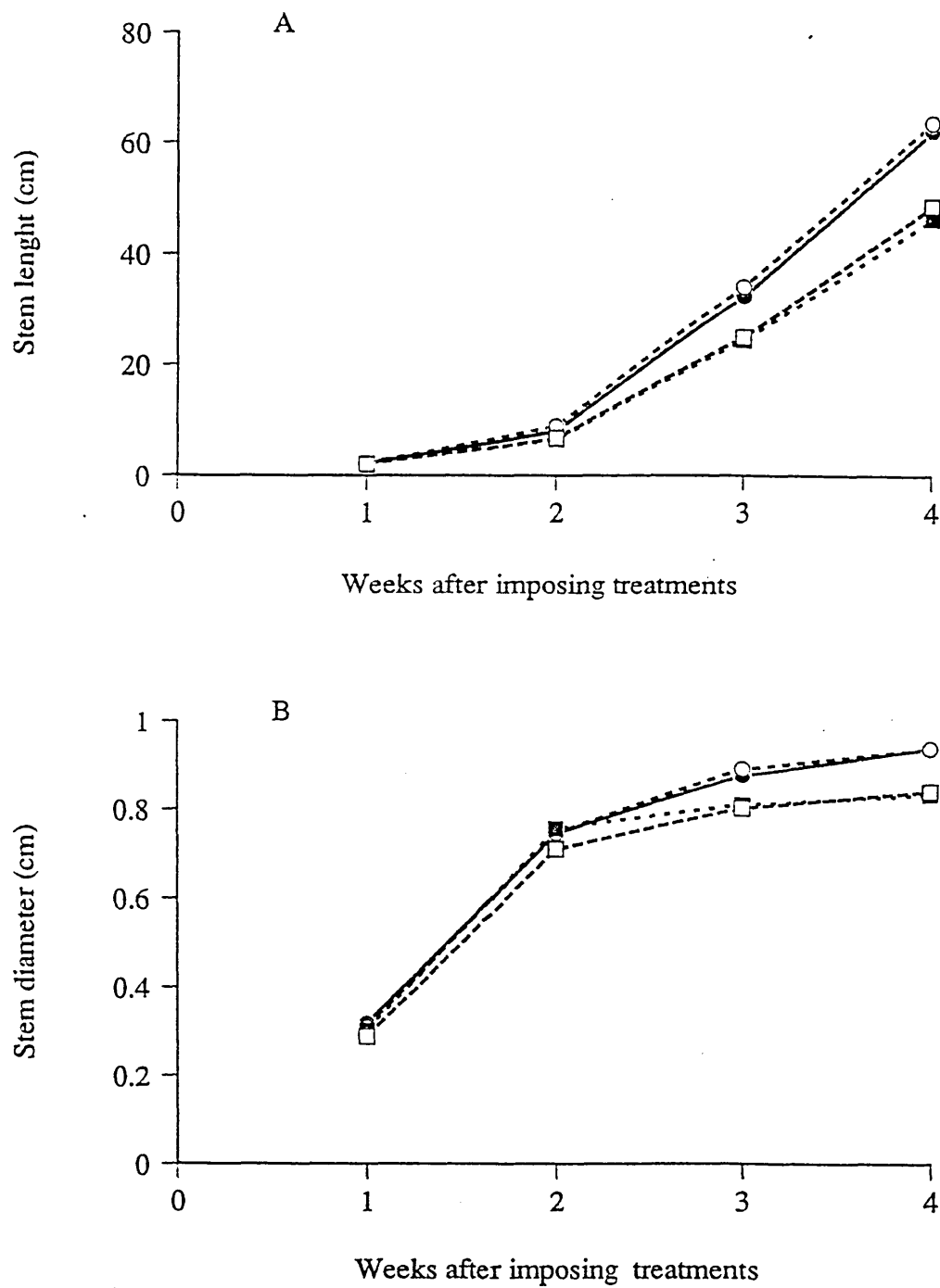


Fig. 6.1 Changes in the stem length (A) and diameter (B) as affected by th treatments

- S1T1=low salinity and low root temperature
- S1T2=low salinity and high root temperature
- S2T1=high salinity and low root temperature
- S2T3=high salinity and high root temperature

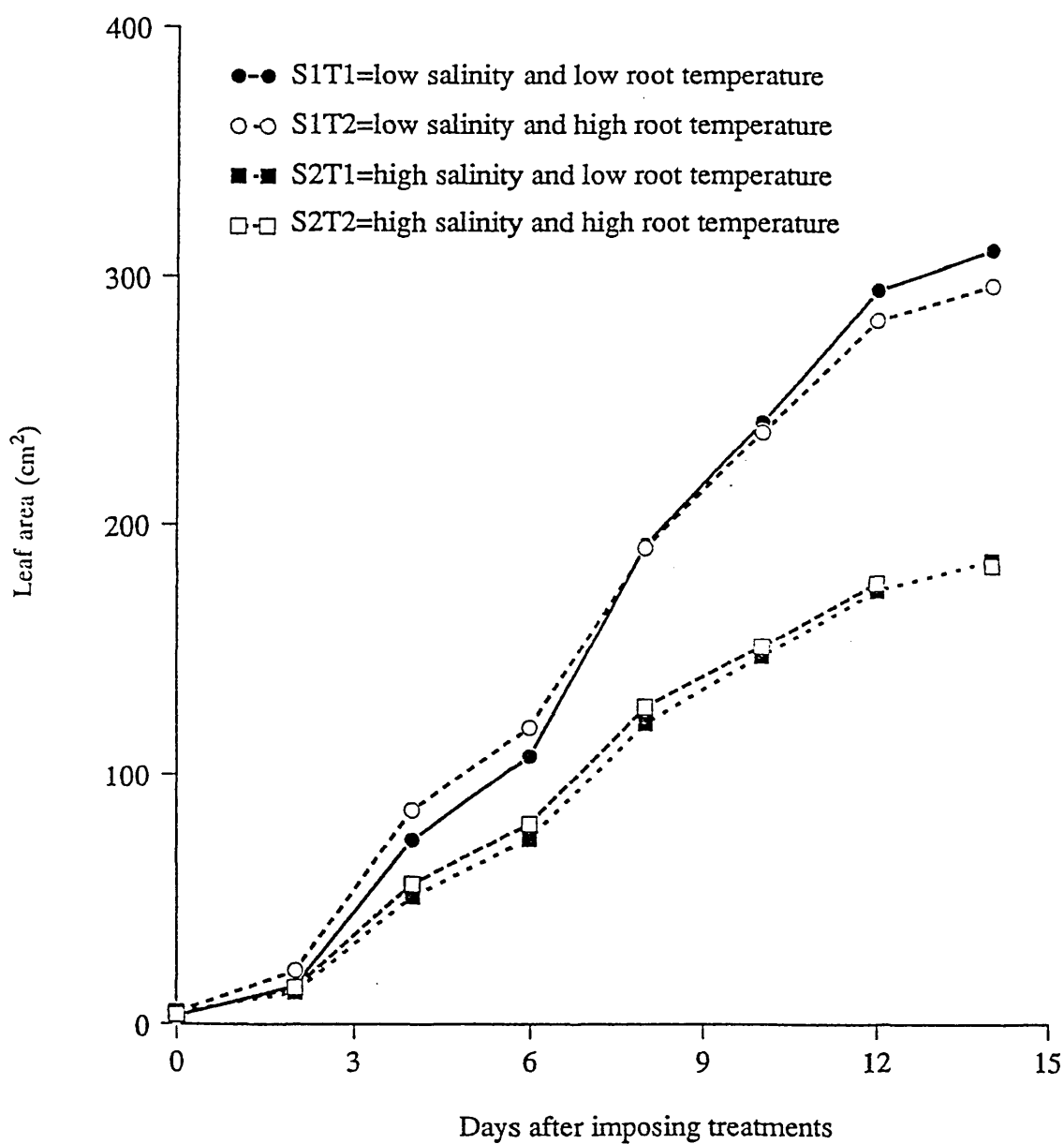


Fig. 6.2 The influence of the treatments on the leaf area

Table 6.3. Effect of salinity and nutrient solution temperature on plant growth.

Growth measurements	Salinity level (mS cm ⁻¹)		LSD	Nutrient solution temperature		LSD
	2.5	8.5		Unheated	27± 1°C	
Plant height (cm)	241.1	176.8	**	207.6	210.3	ns
Stem diameter (cm)	0.84	0.66	**	0.725	0.775	ns
Stem fresh weight (g/plant)	148.8	79.6	**	114.2	114.2	ns
Stem dry matter %	4.889	4.559	*	4.569	4.879	ns
Leaf area (cm ²)	661	389	**	518	531	ns
Petiole fresh weight (g/plant)	213	86	**	143	156	ns
Petiole dry matter %	3.199	3.091	ns	3.082	3.207	ns
Lamina fresh weight (g/plant)	254	128	**	190	192	ns
Lamina dry matter %	9.44	8.25	**	8.67	9.02	ns
Total shoot fresh weight (g/plant)	615	293	**	447	461	ns
Total shoot dry weight (g/plant)	38.24	16.7	**	26.38	28.56	ns
Root dry weight (g/plant)	4.78	2.27	**	3.55	3.49	ns
Root:Shoot ratio	0.127	0.139	ns	0.1365	0.1291	ns

ns not significant at P=0.05

* significant at P=0.05

** significant at P=0.01

Measurements at the end of the experiment show that the plant height, stem diameter and leaf area were significantly ($P=0.01$) reduced by salinity at both levels of root temperature (Table 6.3). Heating the nutrient solution up to $27\pm 1^\circ\text{C}$ did not have a significant effect on the plant vegetative growth. No interaction effect between root temperature and salinity was observed.

The variation in the total shoot fresh and dry weight was due to nutrient solution salinity. No difference due to root temperature or the interaction effect of salinity and root temperature was obtained (Table 6.3).

6.2.2 ROOT MEASUREMENT:

Root growth followed the same trend as shoot growth. Salinity caused substantial reduction in the root growth, while heating the nutrient solution up to $27 \pm 1^\circ\text{C}$ seemed to have no significant effect. Both treatments did not affect the root:shoot ratio (Table 6.3). No interaction effect between salinity and root temperature was observed on the root growth or root:shoot ratio.

6.2.3 PLANT WATER RELATIONS:

6.2.3.1 WATER UPTAKE AND RELATIVE WATER CONTENT (RWC):

The average water uptake by plant (ml/plant/day) was calculated weekly after starting the treatment. The effect of salinity, root temperature and the interaction effect on the plant water uptake is illustrated in Figure 6.3a and 6.3b. The results show a significant ($P=0.01$) reduction in the average water uptake over the period of 6 weeks of the experiment after imposing the treatments. Heating the nutrient solution up to $27^\circ \pm 1^\circ\text{C}$ significantly ($P=0.01$) increased the daily water uptake in the first four weeks. In the 5th and 6th weeks high root temperature slightly increased the water uptake but the result was not significant.

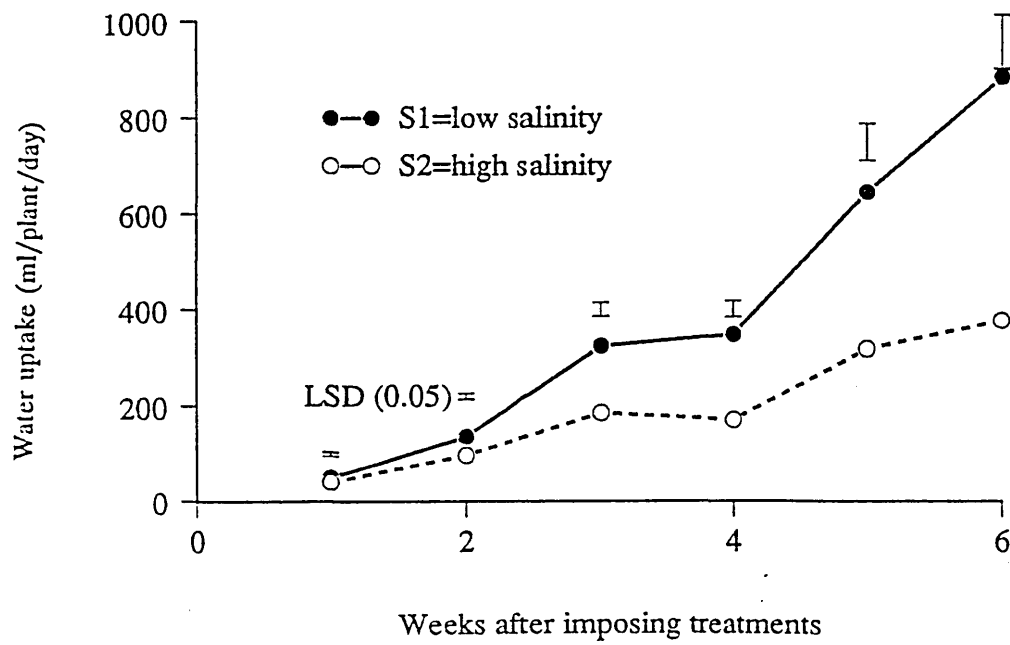


Fig. 6.3a Plant water uptake as affected by salinity level in the nutrient solution

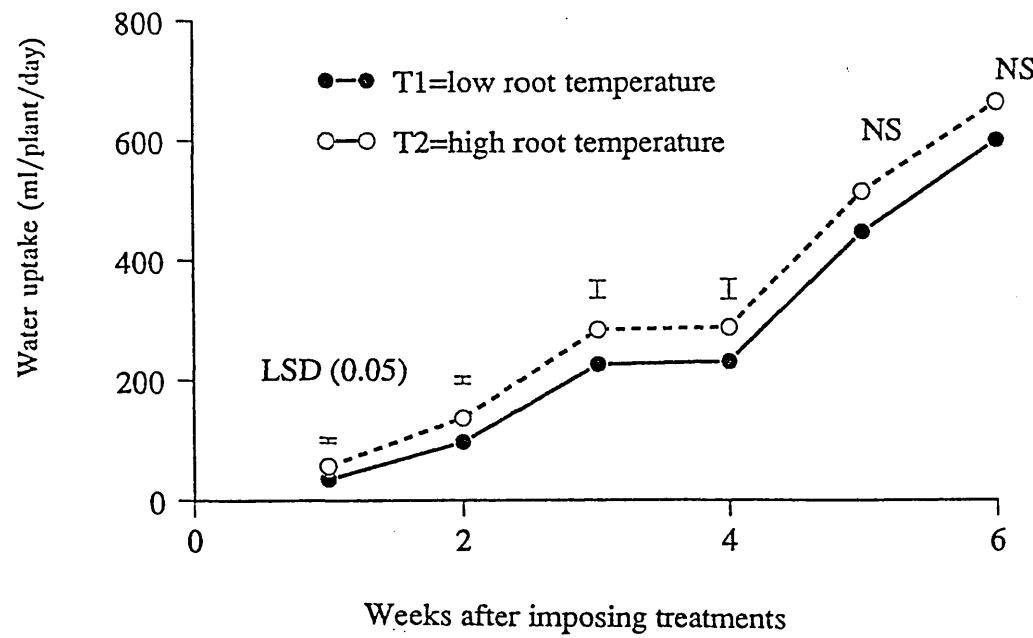


Fig. 6.3b Plant water uptake as affected by the nutrient solution temperature

Table 6.4 Effect of salinity and nutrient solution temperature on total water uptake.

Nutrient solution salinity (mS cm ⁻¹)	Total water uptake (ml/plant)
2.5	3232.8
8.5	1494.2
LSD 0.05	344.2
LSD 0.01	494.5
Nutrient solution temperature	
Unheated	2185.5
27±1°C	2541.5
LSD 0.05	344.2
LSD 0.01	ns

Total water uptake was reduced significantly ($P=0.01$) by salinity. Higher root temperature resulted in a significant ($P=0.05$) increase in the total water uptake (Table 6.4). No significant interaction effect for salinity and root temperature was observed.

RWC measurement was carried out several times during the experiment. The results show that RWC was significantly ($P=0.01$) reduced in saline treatments throughout the experiment (Figure 6.4). No significant effect for the root temperature or the interaction effect of salinity and root temperature on the RWC was obtained

6.2.3.2 PLANT WATER POTENTIAL:

Figure 6.5b shows the effect of salinity and root temperature on the plant water potential (weeks after imposing the treatments). There was a significant ($P=0.01$) reduction in the plant water potential due to salinity, except in the 4th week, where the difference was not significant. Diurnal measurement of water potential 38 days after treatment implementation is shown in Figure 6.5a. High salinity treatment resulted in a significant lowering of the water potential throughout the day.

The high root temperature plants tended to have lower water potential but the difference was not significant. Therefore no interaction effect for salinity and root temperature on the plant water potential was obtained.

6.2.3.3 TRANSPIRATION RATE AND STOMATAL CONDUCTANCE:

The measurements of transpiration rate and stomatal conductance were carried out in several times during the experiment. The main variation on the transpiration rate and stomatal conductance was due to the salinity treatment. Root temperature and the interaction effect of root temperature and salinity had no significant effect on the transpiration rate and stomatal conductance.

Figure 6.6a and 6.6b show the transpiration rate measured four weeks after starting the treatments at different levels of radiation. The transpiration rate was increased with increasing level of radiation. The salt treated plants had a significantly ($P=0.01$) lower transpiration rate. Neither root temperature nor the interaction effect of salinity and root temperature had a significant effect on the

transpiration rate. Stomatal conductance followed the same trend as transpiration rate. The results of stomatal conductance measurements are illustrated in Figure 6.7a and 6.7b. Most of the variation on the stomatal conductance was due to salinity and no significant effect due to increasing root temperature was observed.

6.2.4 PHOTOSYNTHETIC RATE:

The results of this experiment show that salinity and root temperature had no significant effect on photosynthetic rate per unit leaf area. Salt treated plants tended to have lower photosynthetic rate but the difference was not significant. Root temperature and the interaction effect of salinity and root temperature had no influence on the photosynthetic rate.

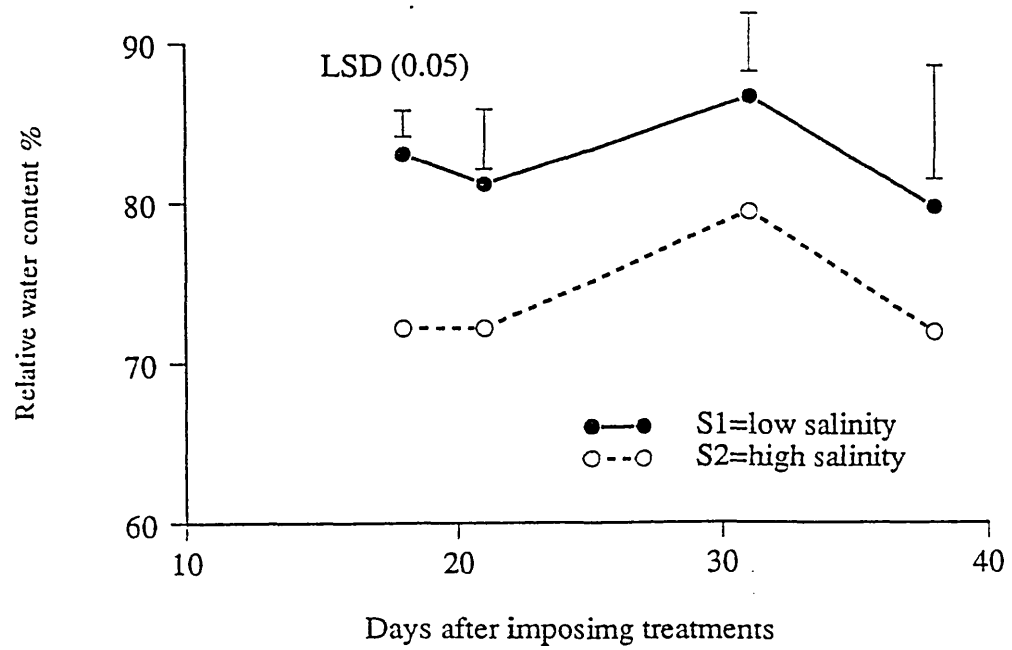


Fig. 6.4a Relative water content as affected by salinity levels in the nutrient solution

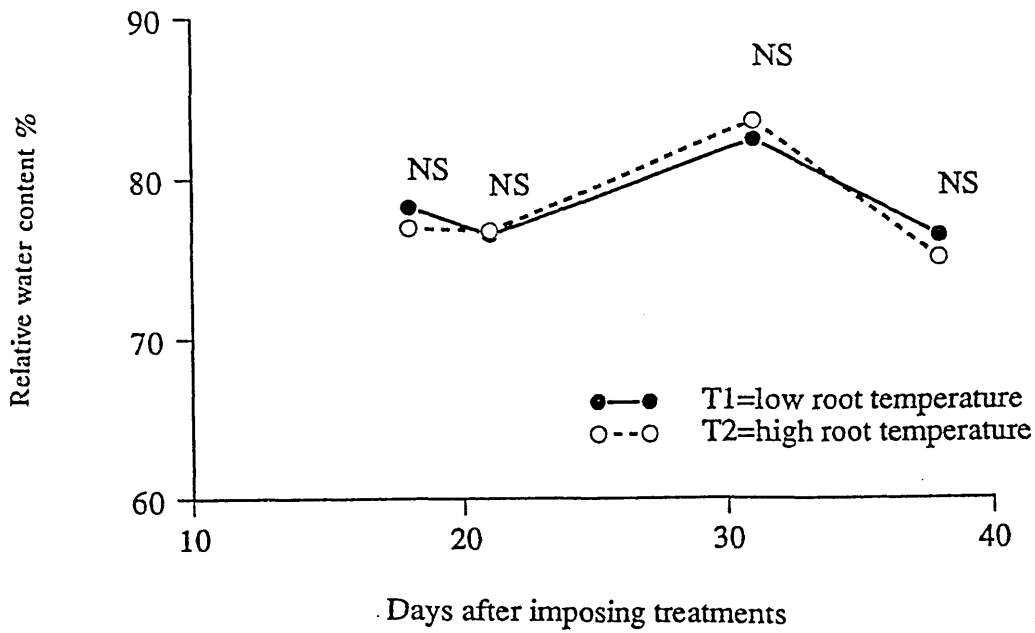


Fig. 6.4b Relative water content as affected by the nutrient solution temperature

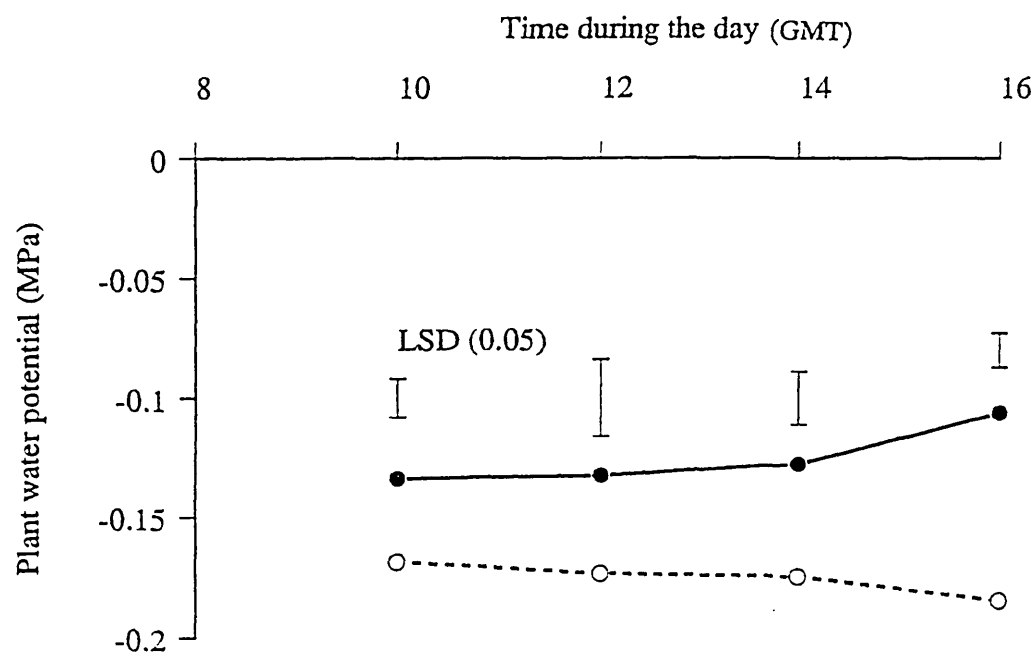


Fig. 6.5a Diurnal variation in the plant water potential as affected by the nutrient solution salinity

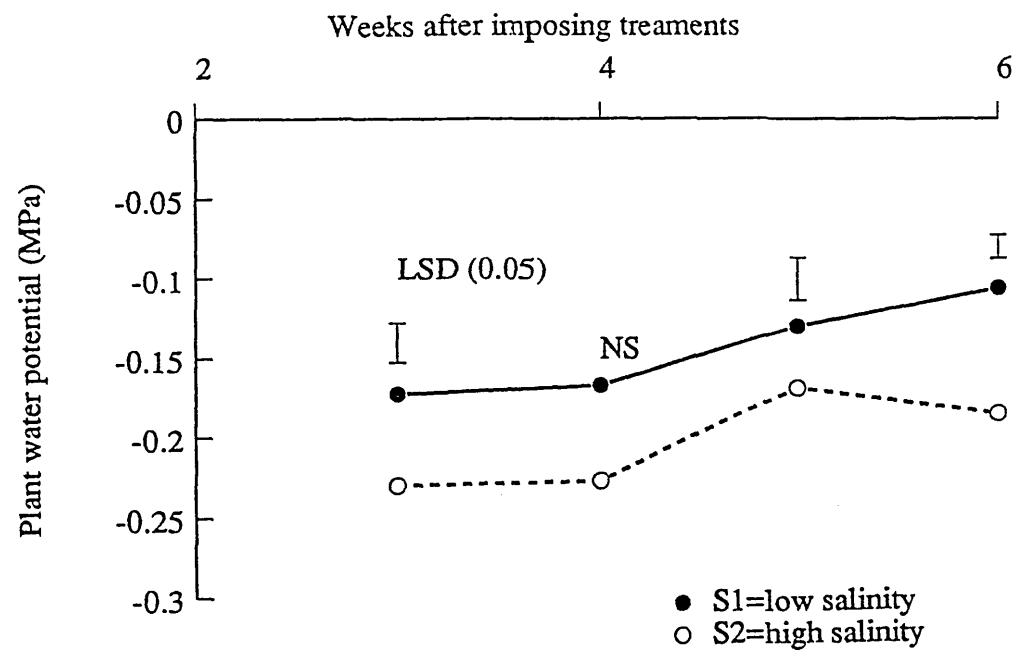


Fig. 6.5b Plant water potential as affected by the nutrient solution salinity

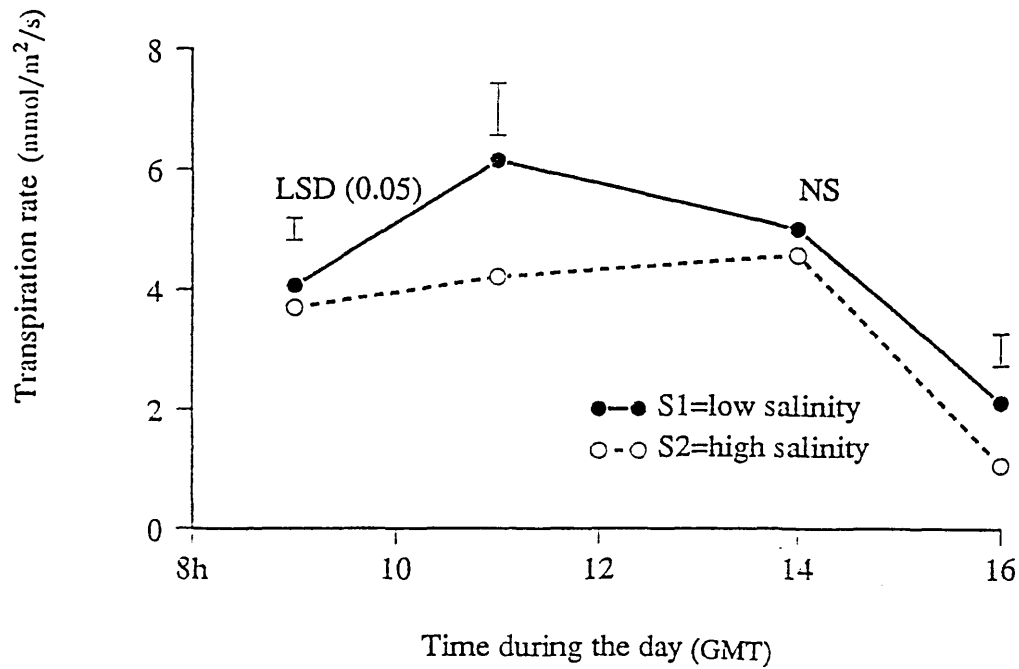


Fig. 6.6a Transpiration rate as affected by salinity levels in the nutrient solution

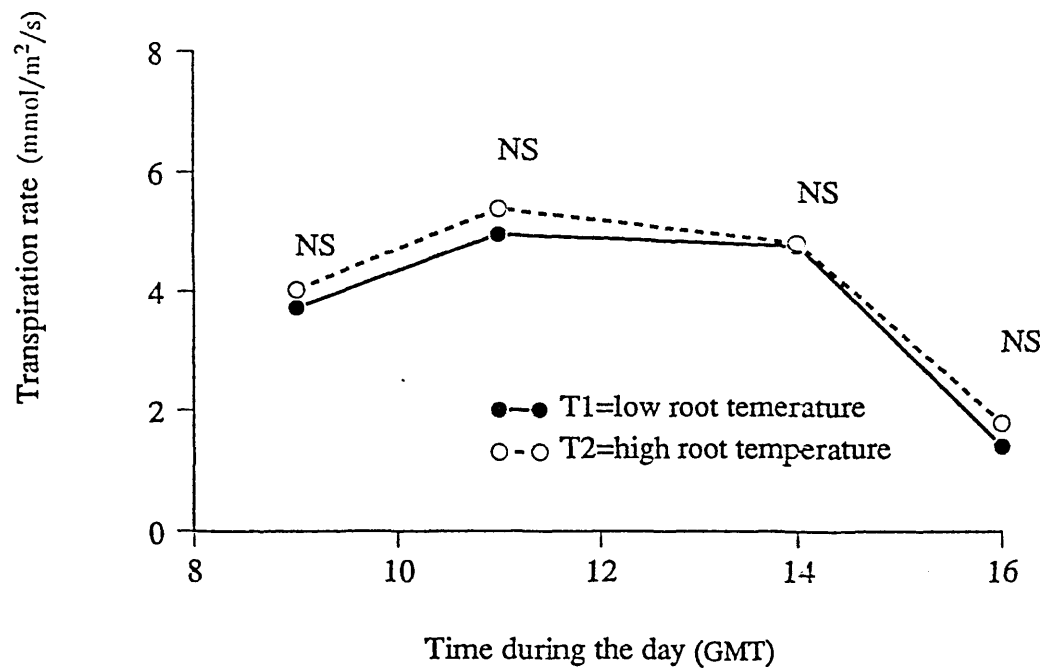


Fig. 6.6b Transpiration rate as affected by the nutrient solution temperature

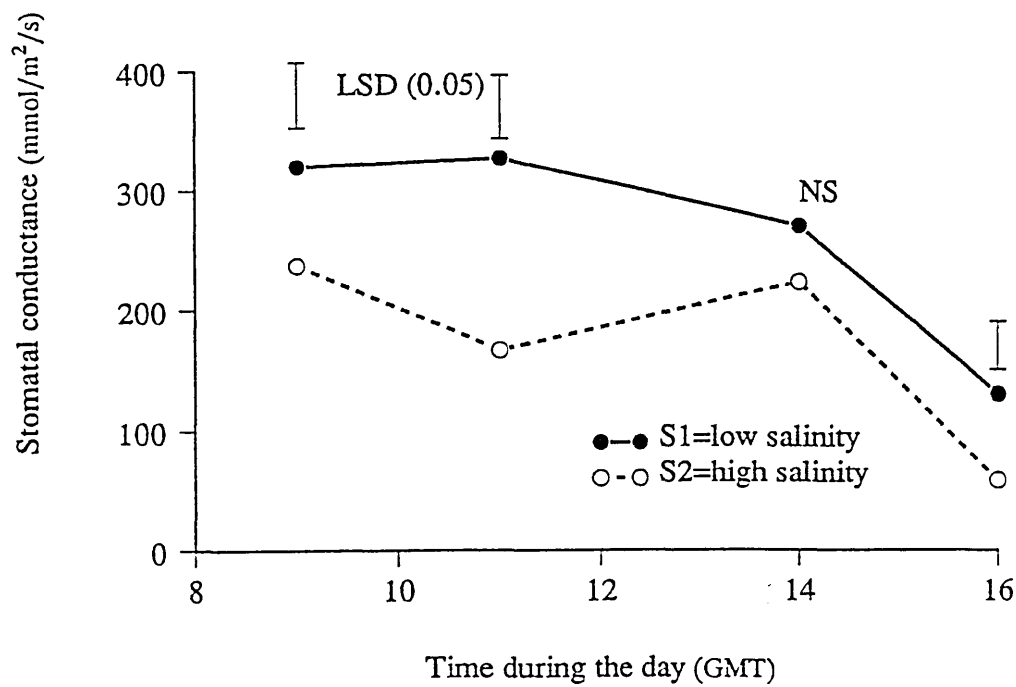


Fig. 6.7a Stomatal conductance as affected by salinity levels in the nutrient solution

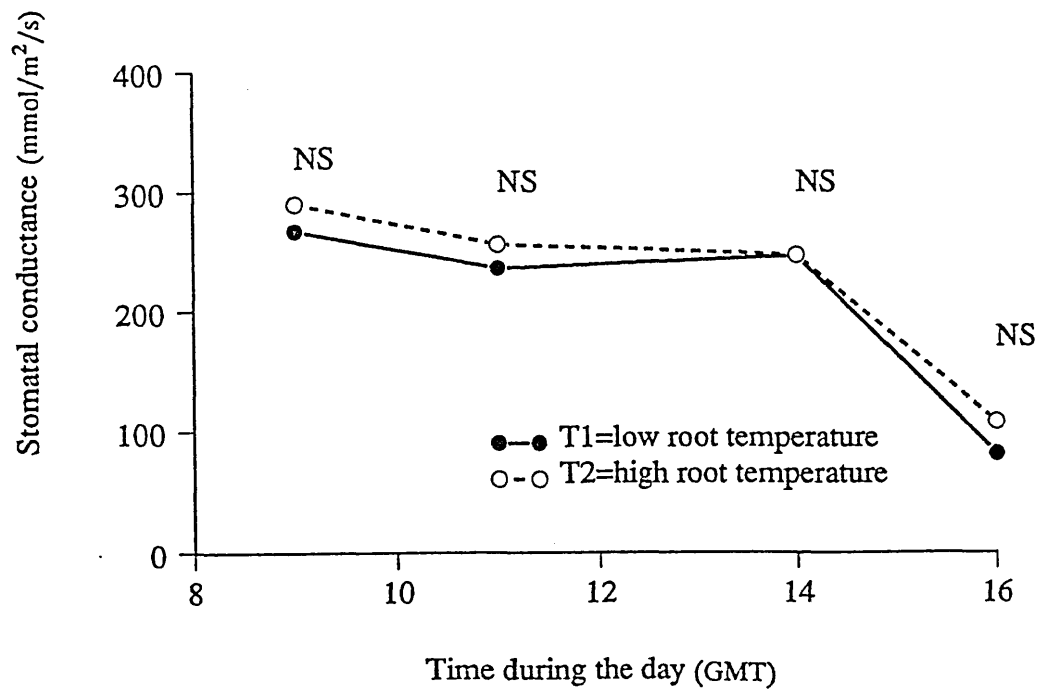


Fig. 6.7b Stomatal conductance as affected by the nutrient solution temperature

6.2.5 PLANT ANALYSIS:

Nutrient analysis was carried out on root and leaf tissue. The results presented in Table 6.5 showed that salinity significantly ($P=0.01$) reduced Ca% and K% in the root tissue and significantly ($P=0.01$) increased Na% and Cl%. Ca% in the root significantly ($p=0.01$) increased and Na% decreased ($P=0.05$) with increasing root temperature. There was a significant interaction between salinity and root temperature on the calcium percentage in the root tissue (Figure 6.8). Maximum root Ca^{2+} percentage was obtained at high salinity and high root temperature.

Table 6.5 Effect of salinity and nutrient solution temperature on ion levels in the root tissue (% dry weight).

Nutrient element	Solution salinity (mS cm^{-1})		LSD	Solution temperature		LSD
	2.5	8.5		Unheated	$27\pm 1^\circ\text{C}$	
Ca	0.6394	0.7095	**	0.6395	0.7094	**
P	0.3699	0.376	ns	0.3567	0.3891	ns
Na	0.31	4.394	**	2.514	2.19	*
K	6.22	2.77	**	4.77	4.22	ns
Mg	0.1065	0.1054	ns	0.1001	0.1117	ns
Cl	1.42	9.01	**	5.45	4.97	ns

Table 6.6 Effect of salinity and nutrient solution temperature on ion levels in the leaf tissue (% dry weight).

Nutrient element	Solution salinity (mS cm ⁻¹)		LSD	Solution temperature		LSD
	2.5	8.5		Unheated	27± 1°C	
Ca	5.09	3.19	**	4.17	4.11	ns
P	0.2917	0.2914	ns	0.2927	0.2904	ns
Na	0.318	2.554	**	1.494	1.378	ns
K	4.97	2.45	**	3.58	3.84	ns
Mg	0.802	0.769	ns	0.887	0.683	ns
Cl	1.11	8.56	**	4.53	5.13	ns

ns not significant at P=0.05

* significant at P=0.05

** significant at P=0.01

Ca²⁺ percentage in the dry matter of the leaf tissue was significantly (P=0.01) reduced by salinity. Root temperature and the interaction affect of salinity and root temperature did not influence the Ca²⁺ in leaf tissue (Table 6.6).

Salinity and root temperature did not have a significant effect on the phosphorus percentage in the root and leaf tissue. However, the combination of high salinity and high root temperature gave a low level of phosphorus in the root tissue compared to other treatments (Figure 6.9).

Salt treated plants had higher levels of Na⁺ in the root and leaf tissue. At high level of salinity Na⁺ level in the root was significantly (P=0.01) reduced by increasing root temperature (Figure 6.10). Root temperature and the interaction effect of root temperature and salinity had no significant effect on the Na⁺ level in the leaves (Table 6.6).

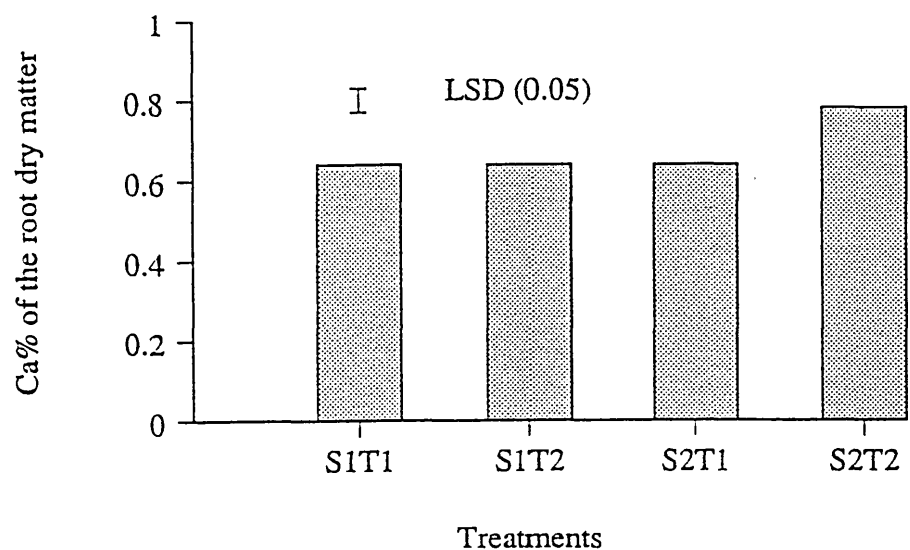


Fig. 6.8 The effect of the nutrient solution salinity and root temperature on Ca^{2+} of the root dry matter

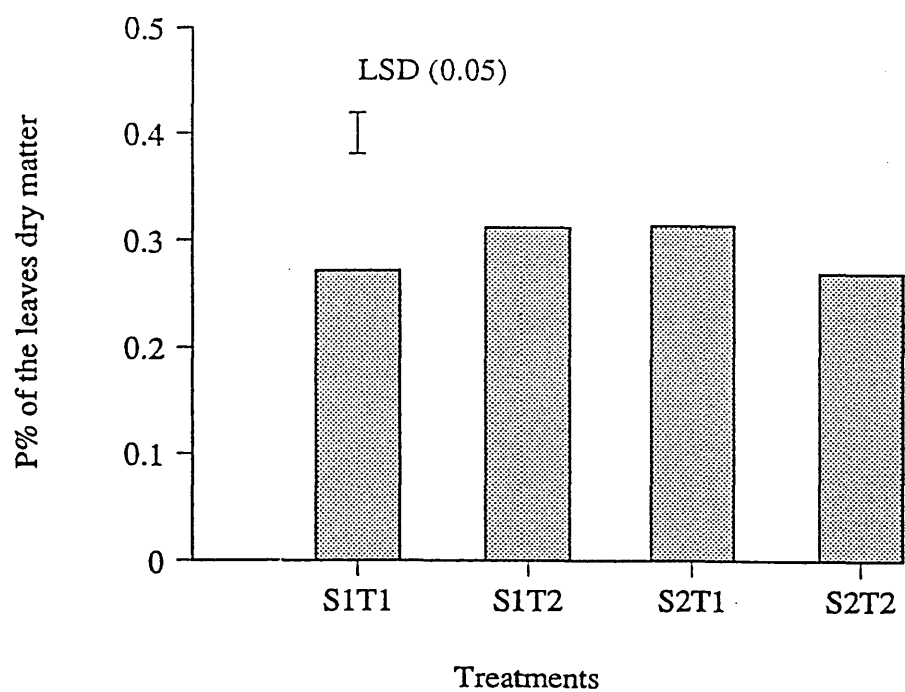


Fig. 6.9 The effect of the nutrient solution salinity and root temperature on P% of leaf dry matter.

The effect of salinity and root temperature on the potassium levels in the root and leaves are presented on Table 6.5 and 6.6. Salt treated plants had a significantly ($P=0.01$) lower level of K^+ in the root and leaf tissue. No significant effects were obtained for root temperature and the interaction with salinity on the K^+ level in root and leaves.

The results presented in table 6.5 and 6.6 show no constant changes resulting either from salinity or root temperature on the Mg^{2+} in the roots and in the leaves. Also there was no interaction effect between the treatments. High salinity significantly ($P=0.01$) increased the chloride level in the root and in the leaves (Table 6.5 and 6.6). Heating the nutrient solution to $27^\circ \pm 1^\circ C$ did not influence the Cl^- in the root and in the leaves. No interaction effect between the treatments was obtained.

6.2.6 YIELD MEASUREMENTS:

The effect of salinity and root temperature on the yield parameter is similar to the effect on vegetative growth. The variation on the fruit yield was due to salinity. High salinity caused a significant ($P=0.01$) reduction on the total yield (Table 6.7). High root temperature plants had a slightly higher fruit number per plant and total fruit yield than the unheated nutrient solution plants but the results were not significant. No interaction effect between salinity and root temperature was observed.

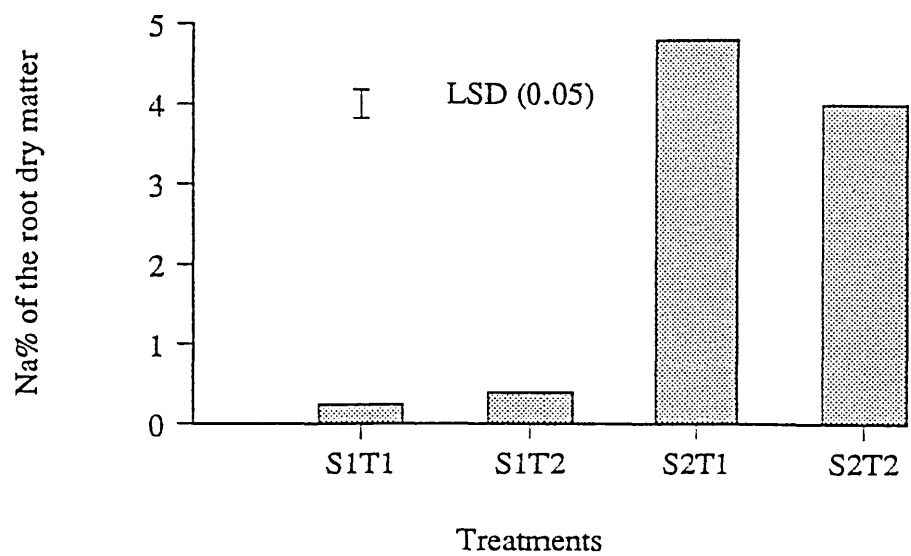


Fig. 6.10 The effect of nutrient solution salinity and root temperature on Na% of root dry matter.

Table 6.7 The effect of salinity and nutrient solution temperature on fruit yield.

Yield parameter	Solution salinity (mS cm ⁻¹)		LSD	Solution temperature °C		LSD
	2.5	8.5		unheated	27± 1	
Fruit number (f/p)	3.28	1.38	**	2.29	2.37	ns
Fruit yield (g/p)	772	444	*	544	671	ns
Dry matter % in the fruit	3.04	3.29	*	3.06	3.27	ns
Small fruit (f/p)	8.44	0.88	**	4.69	4.62	ns
Fruit failed to develop (f/p)	0.00	5.63	**	2.94	2.69	ns

ns no significant at P=0.05

* significant at P=0.05

** significant at P=0.01

6.3 DISCUSSION:

Growing the plants at low root temperatures restricts cell expansion and reduces leaf growth (Abdelhafeez *et al* 1971; Barlow *et al* 1977; Ismail 1989). This reduction of leaf growth was attributed to the restricted water uptake at low root temperatures, which resulted in a lowering of the plant water potential.

Increasing root temperature increases the total dry weight up to the optimal level. Some variation of the optimal root zone temperature was observed due to the interaction with some environmental factors, such as air temperature and light level (Gosselin and Trudel 1983a, 1984). Maximum shoot growth, leaf area and shoot dry weight were measured at 30°C root zone temperature for tomato and pepper (Gosselin and Trudel 1983a, 1984).

The measurements in this experiment indicate that a greater effect on growth is exerted by salinity than by heating the nutrient solution. Also there was no interaction effect between salinity and root temperature on plant growth. Stem and leaf growth rate were not affected by root temperature under conditions of high salinity. Leaf area and total shoot fresh and dry weight were slightly increased by heating the nutrient solution, (Table 6.3) but the result was not significant. These results are similar to those found by Yelle *et al* (1987) who found no difference in dry weight of tomato grown at root temperature of 24°C and 30°C. Adams (1988b) reported an increase in the dry weight of tomato with increasing the root temperature up to 22°C, but only a small increase in the weight was found when temperature was increased up to 26°C.

The growth of tomato root increased with heating the nutrient solution up to 25°C under 5°C and 13°C night air temperature regime and a standard day temperature of 20°C (Maher 1980). A similar result was reported by Ismail (1989) when the root temperature was increased from 12 to 22°C. Abdelhafeez *et al* (1971) and Cooper (1973) indicated that the root system is generally longer and more branched but thinner at high temperatures. The result of this study shows no significant effect on growth at the root temperatures studied and no interaction with salinity on the root growth. Newton *et al* (1988) reported a different result. They found an increase in the root dry weight of cucumber with increasing root temperature over the range 18°C - 28°C. The difference in this case may be due to the closeness of the control to the heated treatment and the closeness of the root temperature used in this experiment to the optimum root temperature for plant growth.

These results show that salinity had a significant effect on the plant water uptake. Total water uptake, RWC, and plant water potential were significantly ($P=0.01$) reduced by salinity. Salt treated plants had lower transpiration rates and stomatal conductance. The mechanism of the effect of salinity on the plant water relations was discussed in previous experiments.

Heating the nutrient solution up to $27^{\circ}\pm 1^{\circ}\text{C}$ resulted in a significant ($P=0.05$) increase in the total water uptake. This result is in agreement with the findings of several investigators (Menhett and Waring 1975; Barlow *et al* 1977; Ismail 1989). Moorby and Graves (1980) suggested that, high root temperature increases the water uptake due to a reduction in the root cortex and the formation of large xylem vessels, which reduces the resistance to flow of water through the root.

Apart from the increase in the plant water uptake, heating the nutrient solution had little effect on the plant water relations. A few investigators reported a reduction in the plant water potential at low root temperatures. Watts (1972) found that, the water potential of the *Zea mays* plants was lowered at root temperature below 5°C . The same result was reported for the corn seedling when the root temperature reduced from 28°C to 4°C (Barlow *et al* 1977). Gur *et al* (1976) found a steady increase in the apple tree water potential with increasing the root temperature from 22°C to 36°C . Menhett and Waring (1975) reported that low soil temperature affected shoot growth by several mechanisms including, altering leaf water potential and restricting cell expansion by restricting water and nutrient uptake.

Transpiration rate and stomatal conductance were not affected by root temperature or the interaction with salinity. Both treatments had no significant effect on the photosynthetic rate per unit leaf area. Gur *et al* (1976) reported a reduction in the transpiration and photosynthetic rate of apple trees with increasing root temperature. Moorby and Graves (1980) found an increase in the transpiration rate with increasing root temperature. Barlow *et al* (1977) reported that low temperature did not affect transpiration rate or photosynthesis until the plant water potential reached -1.2 to -1.3 MPa.

The weak growth response to the changes in the root temperature in this experiment could be attributed to the small temperature difference between the

unheated and heated nutrient solution, since the unheated nutrient solution temperature fluctuated with the air temperature, which ranged between 22°C to 25°C during the day. The lack of significant difference between temperature treatments could be also a result of maintaining an optimum level of air temperature throughout the experiment. According to Graves (1983) and Mongeau and Stewart (1984), the beneficial effect of solution temperature was more evident when air temperature was a limiting factor. Gosselin and Trudel (1983a) and Maher (1980) indicated that a high root temperature has more effect on shoot growth and root size at low night air temperatures.

Increasing root temperature had no significant effect on fruit yield. These results agree with those obtained by Starky (1977), Orchard (1980) and Ismail (1989). Starky (1977) grew cucumber in two different nutrient solution temperatures, ambient and heated to 30°C. He found that heating of the nutrient solution did not affect the early yield. Also he found that plants grown in solution at ambient temperatures produced a 5% increase in the total yield. Gosselin and Trudel (1986) found that high root zone temperatures (24°C, 30°C, and 36°C) promoted vegetative growth of pepper, delayed flowering and fruit set, but increased total yield. The variation on the effect of root temperature on the yield, may be due to an interaction with the radiation levels. Gosslein and Trudel (1983a) reported that soil warming resulted in only a 1% increase in yield in the winter, but a 46.7% increase in spring.

High nutrient solution salinity significantly increased the Na^+ and Cl^- levels and reduced Ca^{2+} and K^+ levels in the root and in the leaves. No consistent changes were found on the Mg^{2+} and P levels. This confirms the results of the previous experiments. High root zone temperature reported to increase calcium uptake (Davis and Lingle 1961; Moorby and Graves 1980; Hurd and Graves 1985). On the other hand, Gosselin and Trudel (1983b) and Papadopoulos and Tiessen (1983) found no effect on the calcium level, as the root temperature increased. In this experiment the level of Ca^{2+} in the roots increased with

increasing root temperature but Ca^{2+} level in the leaves was not affected. Lack of significant difference between the two may have resulted from high temperature of the unheated nutrient solution, which may have been within the optimal range of Ca^{2+} uptake. Davis and Lingle (1961) reported that concentration of Ca^{2+} reached maxima at approximately 20°C. Also Adams (1988b) found that the uptake of Ca^{2+} was increased only up to 22°C.

In this experiment under conditions of high salinity in the root media increasing root temperature reduced sodium level in the roots. High root temperature however had little effect on the Na^+ level on the leaves. Gosselin and Trudel (1983b) similarly reported a reduction on the Na^+ level with increasing root temperature. They suggested that, this reduction may compensate for the large amount of cations absorbed, to maintain the electro-osmotic equilibrium within the tissue as a result of increasing vegetative growth and nutrient uptake under high root temperature conditions.

P, K^+ , Mg^{2+} , and Cl^- levels were not affected by heating the nutrient solution constantly to $27^\circ \pm 1^\circ\text{C}$. Gosselin and Trudel 1983b reported an increase in P, K^+ , and Mg^{2+} with increasing root temperature from 12°C to 24°C. The lack of significant difference in this experiment may be due to the small temperature difference between the heated and unheated nutrient solution and the relatively high ambient temperature. Also the levels used by the previous workers may have been suboptimal for the uptake of ions. Adams (1988b) also found that P, K^+ , and Mg^{2+} content of the tomato leaves did not increase with temperature above 22°C.

The results of this experiment show that the plant does not over come the reduction in growth created by saline condition by heating of the nutrient solution at the levels of salinity and temperatures used.

**CHAPTER SEVEN: THE INFLUENCE OF SALINITY AND SODIUM /
CALCIUM RATIO ON CUCUMBER GROWTH AND ION
UPTAKE.**

7.1 INTRODUCTION:

Salt stress consists of two components, osmotic stress and the physiological and biochemical effect of cations and anions on plant cells (Munns and Termaat 1986). The results in the previous experiments have shown a marked increase in the uptake of Na^+ and Cl^- and a reduction on the uptake of Ca^{2+} and K^+ occurs with increasing solution salinity. In the saline condition Na^+ displace Ca^{2+} from the cell membrane. Removal of Ca^{2+} from the plasma membrane induces the loss of intracellular K^+ (Cramer *et al* 1985). Kent and Lauchli 1985 concluded that Ca^{2+} levels that were adequate for growth in a balanced nutrient solution proved insufficient when the $\text{Na}^+/\text{Ca}^{2+}$ ratio was increased.

Cramer *et al* (1989) reported a significant $\text{Na}^+/\text{Ca}^{2+}$ interaction between ion transport, ion accumulation and the growth of barley seedlings. The displacement of Ca^{2+} by Na^+ from the root membrane of an intact cotton root was related to the $\text{Na}^+/\text{Ca}^{2+}$ ratio in the nutrient solution (Cramer and Lauchli 1986; Cramer *et al* 1986). The ratio of $\text{Na}^+/\text{Ca}^{2+}$ in the growth medium is therefore crucial for plant growth. Numerous studies have shown that many agronomic plant species are seriously injured by a high $\text{Na}^+/\text{Ca}^{2+}$ ratio in growing media (Hyder and Greenway 1965; Nassery *et al* 1979; Kent and Lauchli 1985; Nakamura *et al* 1990). The positive growth response to Ca^{2+} under saline condition is well documented in previous studies on different crops (Hyder and Greenway 1965, *Phaseolus vulgaris*; Kent and Lauchli 1985, Cotton; Grieve and Maas 1988, Sorghum; Subbarao *et al* 1990, Pigeonpea).

The aim of this investigation was to study the effect of salinity at different levels of external Ca^{2+} concentration, on the growth and ion distribution in cucumber plants grown in NFT.

7.2 METHODS AND RESULTS:

Cucumber seeds cv. Farbiola were germinated on 5-3-90. Seedlings were selected and transferred to the NFT channels on 26-3-90. Tap water was circulated for two days before starting the treatments. The treatments consisted of two levels of nutrient solution Ec, control and high salinity, combined with two levels of calcium giving four treatments, each treatment was replicated four times. The high salinity treatment was imposed by adding NaCl to the basic nutrient solution (2.5 mS cm^{-3}).

The tap water used contained 2.55 mol m^{-3} of Ca^{2+} and 0.435 mol m^{-3} of Na^+ (Appendix 6). Ca^{2+} was manipulated in the nutrient solution by using tap water and reverse osmosis water. Na^+ level was increased by adding NaCl to the nutrient solution. Under non-saline conditions the $\text{Na}^+/\text{Ca}^{2+}$ ratio in the solution was $0/2.034$ when the reverse osmosis water was used and $0.435/4.58$ with tap water. At 8.5 mS cm^{-1} nutrient solution, the $\text{Na}^+/\text{Ca}^{2+}$ ratio was $61.61/2.034$ with reverse osmosis water and $62.045/4.58$ with tap water (Table 7.1). The experiment was conducted in a randomized block design.

Table 7.1 Treatments.

Treatments	Nutrient solution Ec (mS cm^{-1})	Ca^{2+} level in the solution (mol m^{-3})	$\text{Na}^+/\text{Ca}^{2+}$ ratio
S1Ca1	2.0 - 2.5	2.034	0/2.034
S1Ca2	2.0 - 2.5	4.58	0.435/4.58
S2Ca1	8.0 - 8.5	2.034	61.61/2.034
S2Ca2	8.0 - 8.5	4.58	62.045/4.58

The method of cultivation and growth measurements were the same as those described on the previous experiments. Nutrient analysis was carried out on the root, old, fully expanded and new leaves. The experiment was terminated in 25-4-90.

7.2 VEGETATIVE GROWTH AND ROOT MEASUREMENTS:

Salt-treated plants had lower stem and leaf growth rates. The stem and leaf growth was not affected by changing Ca^{2+} concentration in the nutrient solution (Figure 7.1a,b and 7.2). There was no significant interaction effect between salinity and external Ca^{2+} concentration on the stem and leaf growth.

The salinity effects on the root and shoot growth were similar to the results obtained in the previous experiments. Root:shoot ratio was significantly reduced by salinity (Table 7.2). Shoot and root growth was not affected by Ca^{2+} levels in the nutrient solution at 2.5 and 8.5 mS cm^{-1} salinity levels (Table 7.2). No interaction effect between salinity and Ca^{2+} levels on the root and shoot was observed.

The dry weight percentage in the root and fully expanded and young leaves was not affected by salinity and Ca^{2+} levels. High external Ca^{2+} significantly ($P=0.01$) increased the dry weight % in the old leaves (Table 7.4). There was also a significant interaction effect between salinity and external Ca^{2+} on dry weight % of the old leaves (Figure 7.3). A combination of high salinity and high external Ca^{2+} had higher dry weight percentage.

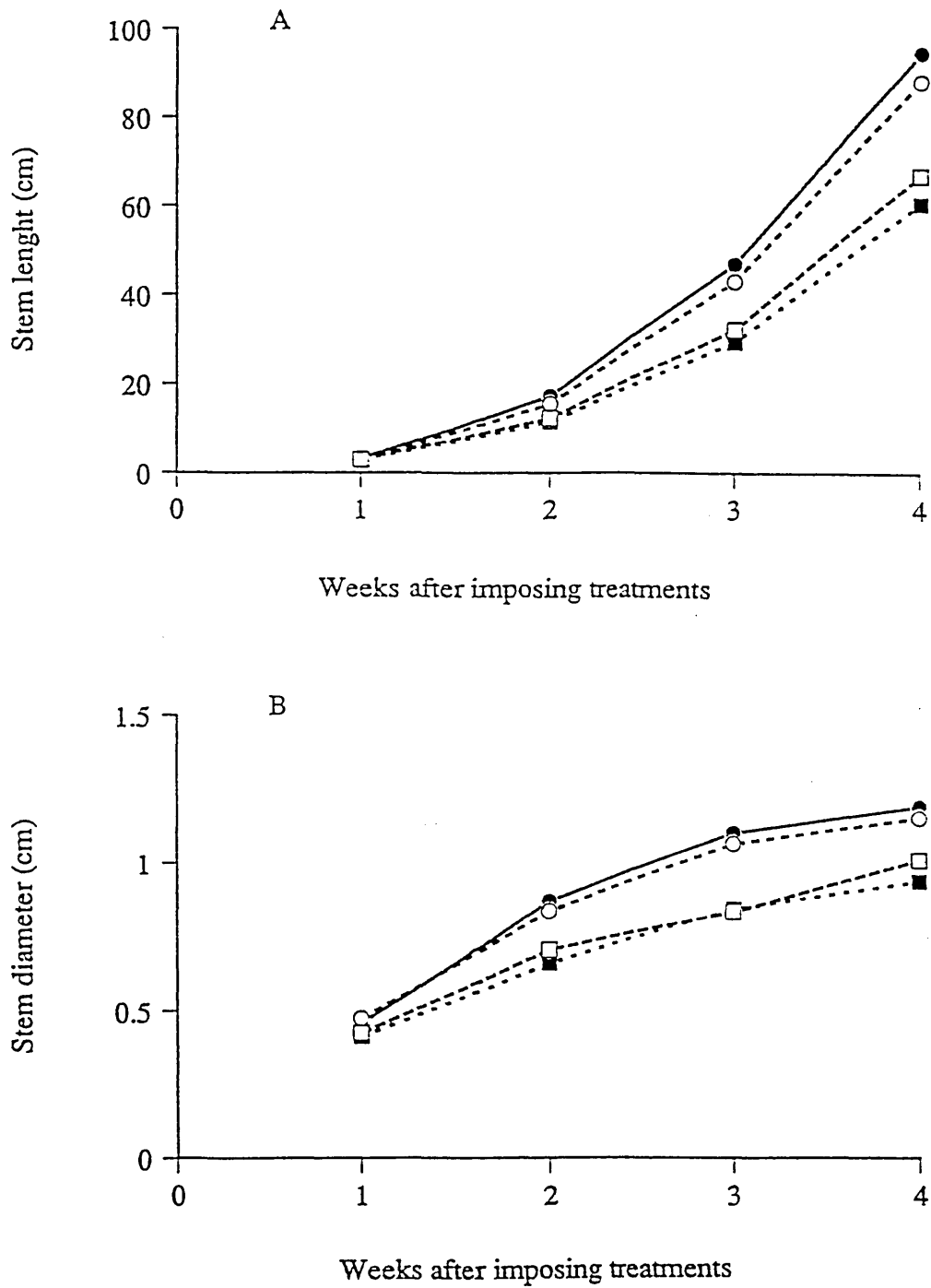


Fig. 7.1 Changes in the stem length (A) and diameter (B) as affected by salinity and external Ca^{2+} concentration

- S1Ca1=low salinity and low Ca^{2+}
- S1Ca2=low salinity and high Ca^{2+}
- S2Ca1=high salinity and low Ca^{2+}
- S2Ca2=high salinity and high Ca^{2+}

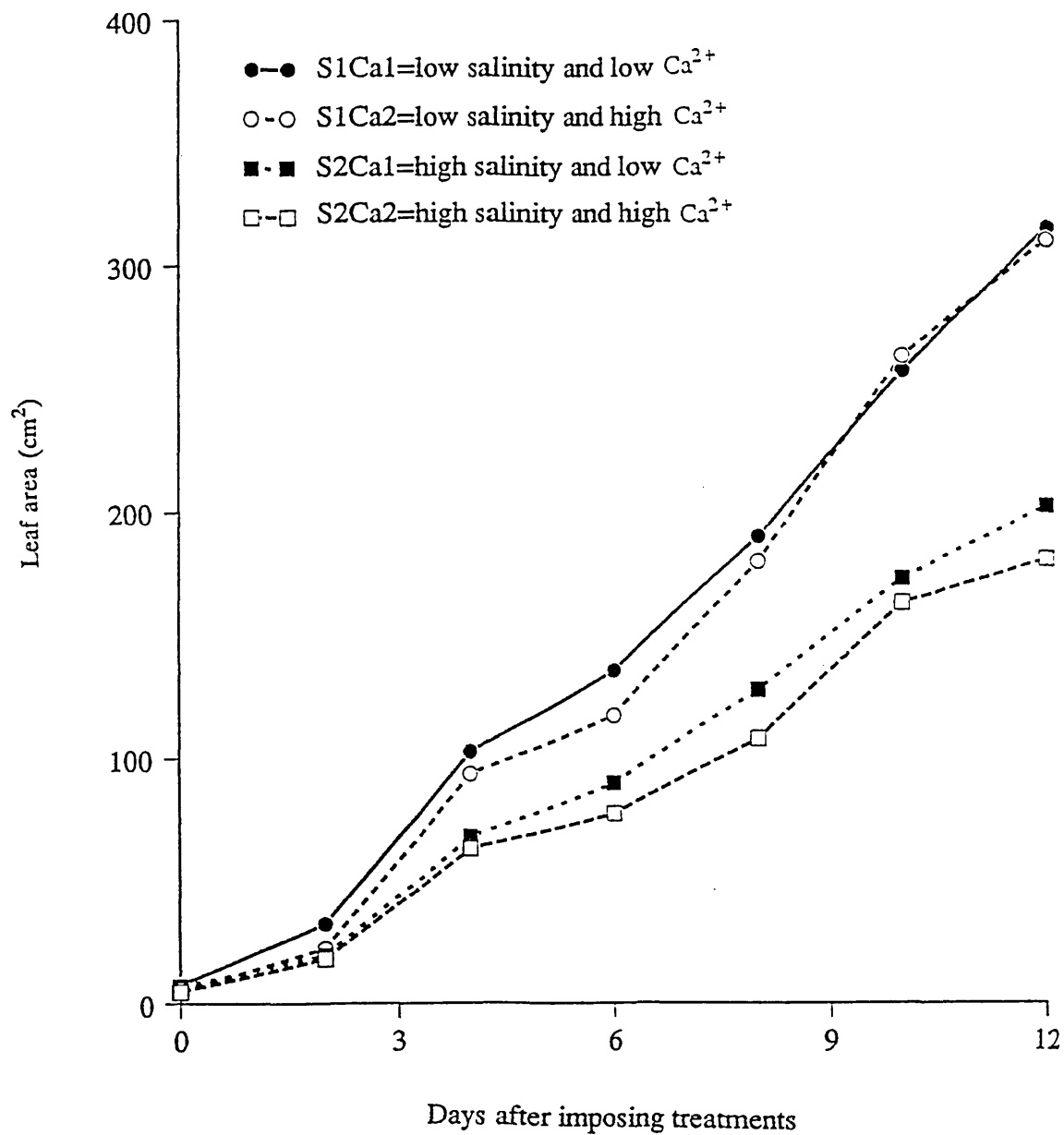


Fig. 7.2 The influence of nutrient solution salinity and external Ca²⁺ concentration on leaf area

Table 7.2 Effect of salinity and external Ca^{2+} concentration on final plant growth.

Growth measurements	Solution salinity (mS cm^{-1})		LSD	External Ca^{2+} (mol m^{-3})		LSD
	2.5	8.5		2.034	4.58	
Leaf area (cm^2)	1008	539	**	812	734	ns
Petiole fresh weight (g/p)	183.5	74.6	**	136.5	121.6	ns
Lamina fresh weight (g/p)	330.7	178.6	**	263.3	246	ns
Plant height (cm)	116.3	82.4	**	98.6	100.1	ns
Stem diameter (cm)	1.22	0.982	**	1.062	1.14	ns
Stem fresh weight (g/p)	136.2	77.9	**	109.5	104.6	ns
Total shoot fresh weight (g/p)	649.2	332.2	**	332.2	471	ns
Total shoot dry weight (g/p)	43.12	24.02	**	33.57	33.58	ns
Root fresh weight (g/p)	294.1	115.7	**	205.3	204.4	ns
Root dry weight (g/p)	15.83	6.08	**	11.12	11.12	ns
Root:Shoot	0.369	0.259	**	0.304	0.325	ns

ns not significant at $P=0.05$

* significant at $P=0.05$

** significant at $P=0.01$

Table 7.3 Correlation coefficient (r) of different treatments relating leaf breadth and area.

Treatments	Regression equation	Correlation coefficient (r)
S1Ca1	$-189.533 + 28.35 x$	0.967
S1Ca2	$-145.713 + 26.77 x$	0.982
S2Ca1	$-224.117 + 26.47 x$	0.973
S2Ca2	$-189.282 + 25.57 x$	0.963

Table 7.4. The effect of the treatments on dry matter % in different plant parts

Solution salinity (mS cm ⁻¹)	Root	Stem	Leaves		
			Old leaves	Fully expanded leaves	New leaves
2.5	5.45	11.11	16.04	20.42	33.3
8.5	5.25	10.92	15.96	19.73	35.8
LSD	ns	ns	ns	ns	ns
External Ca ²⁺ concentration (mol m ⁻³)					
2.034	5.25	10.71	15.41	19.16	34.3
4.58	5.45	11.35	16.58	20.99	34.8
LSD	ns	ns	**	ns	ns

ns not significant at P=0.05

* significant at P=0.05

** significant at P=0.01

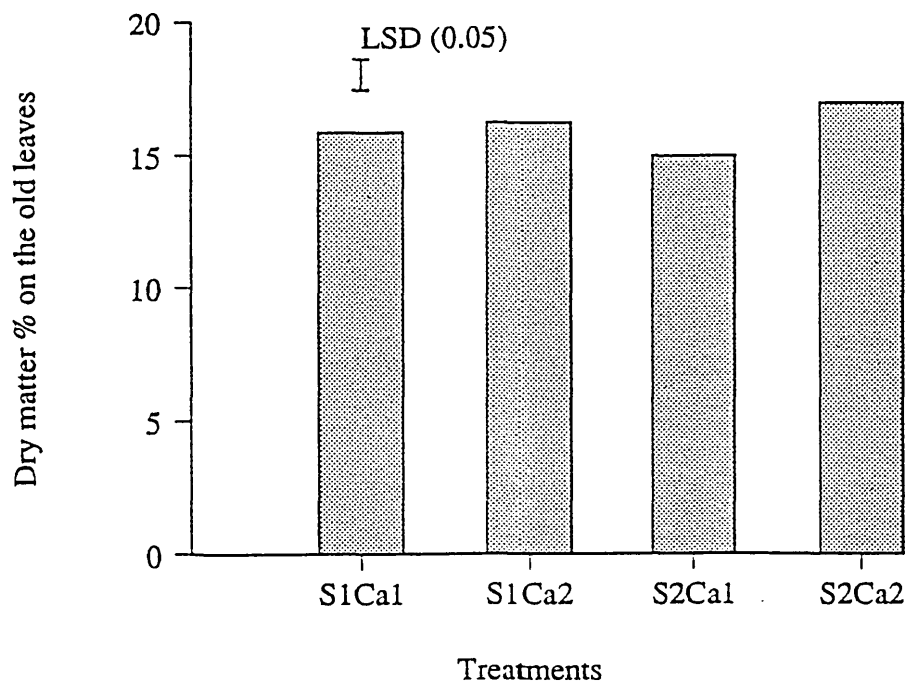


Fig. 7.3 The effect of salinity and Ca^{2+} concentration in the nutrient solution on the dry matter % in old leaves

- S1Ca1=low salinity and low Ca^{2+}
- S1Ca2=low salinity and high Ca^{2+}
- S2Ca1=high salinity and low Ca^{2+}
- S2Ca2=high salinity and high Ca^{2+}

7.2.2 WATER UPTAKE AND RELATIVE WATER CONTENT:

As in the previous experiments both weekly average water uptake (ml/plant/day) and total water uptake were reduced by salinity (Figure 7.4 and Table 7.5). Ca^{2+} level on the nutrient solution and the interaction with salinity had no significant effect on the plant water uptake. The result presented in Figure 7.5 shows a significant ($P=0.01$) interaction effect between salinity and Ca^{2+} on the RWC. The RWC of salt-treated plants was increased by reducing the external Ca^{2+} .

7.2.3 TRANSPIRATION RATE, STOMATAL CONDUCTANCE AND PHOTOSYNTHETIC RATE:

Salt-treated plants had a lower transpiration rate and stomatal conductance than plants grown in non-saline conditions (Figure 7.6a,b and 7.7a,b). Figure 7.8 and 7.9 show the effect of the treatments on the transpiration rate and stomatal conductance of the new and old leaves. External Ca^{2+} concentration and the interaction between salinity and Ca^{2+} had no significant effect on transpiration rate and stomatal conductance. The results show that both treatments had no significant effect on the photosynthetic rate per unit leaf area. Also no significant interaction between treatments was observed.

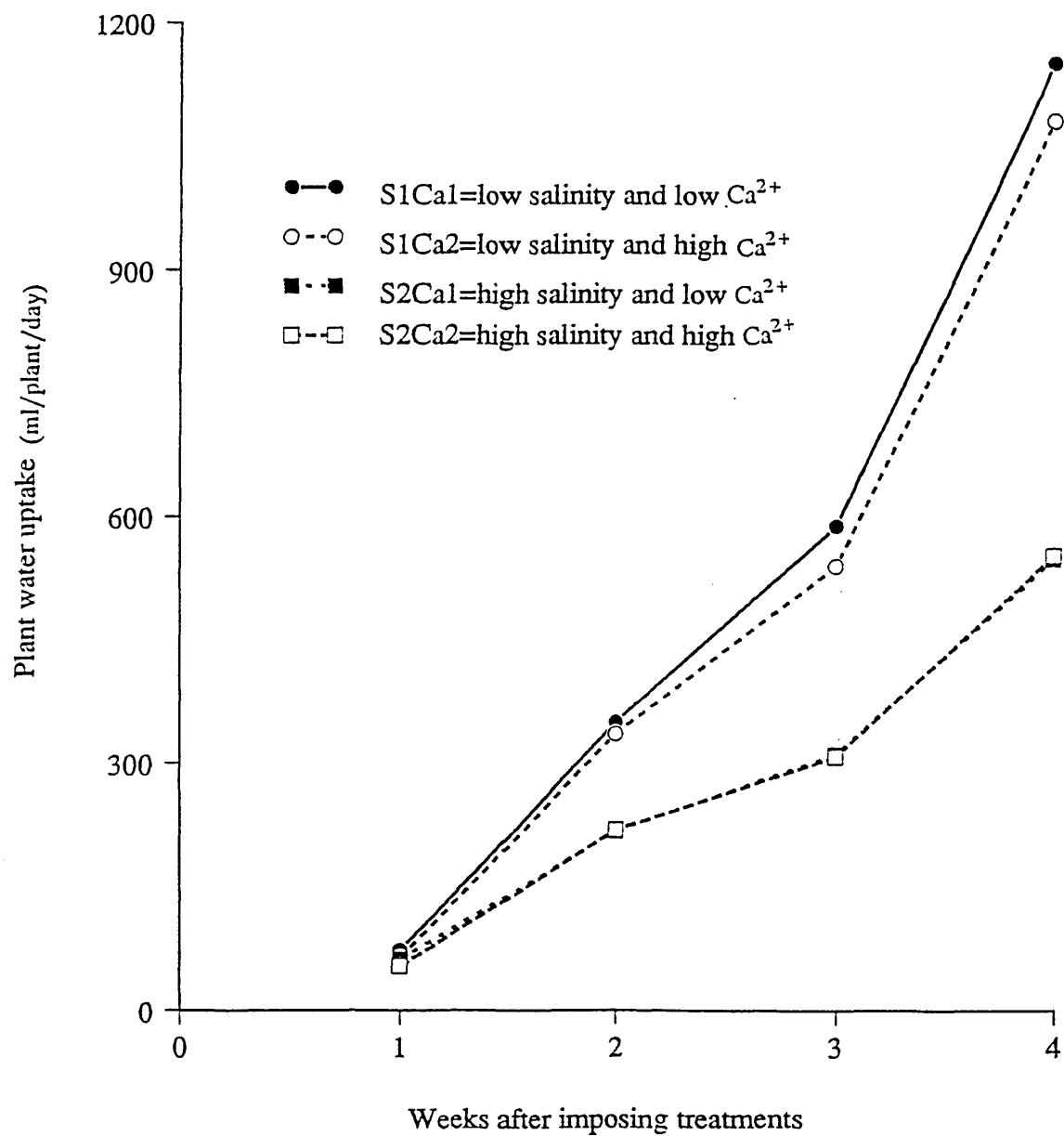


Fig. 7.4 The influence of nutrient solution salinity and external Ca^{2+} concentration on the plant water uptake

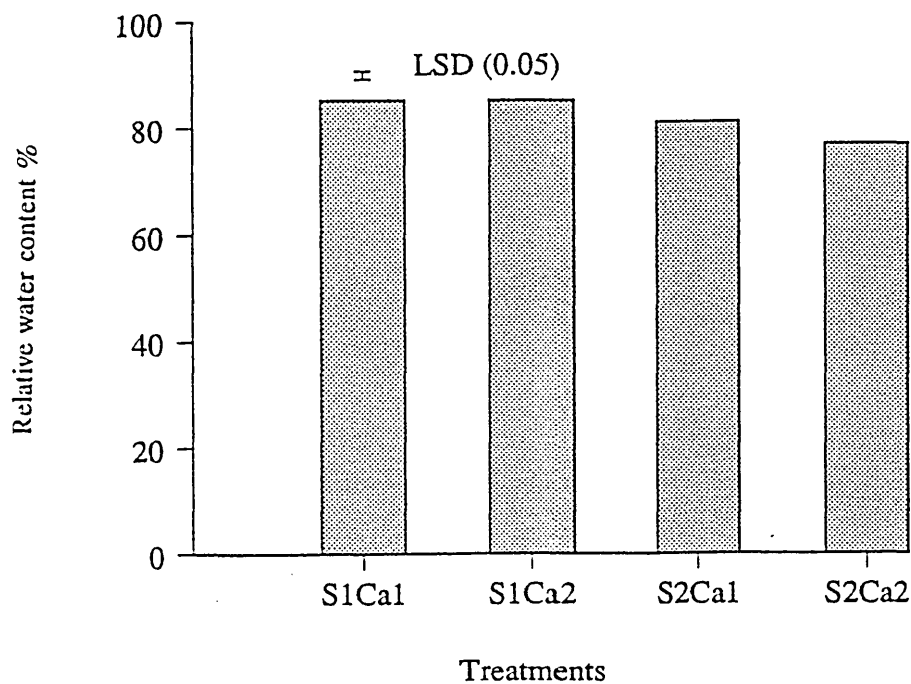


Fig.7.5 The effect of salinity and Ca^{2+} concentration in the nutrient solution on relative water content

- S1Ca1=low salinity and low Ca^{2+}
- S1Ca2=low salinity and high Ca^{2+}
- S2Ca1=high salinity and low Ca^{2+}
- S2Ca2=high salinity and high Ca^{2+}

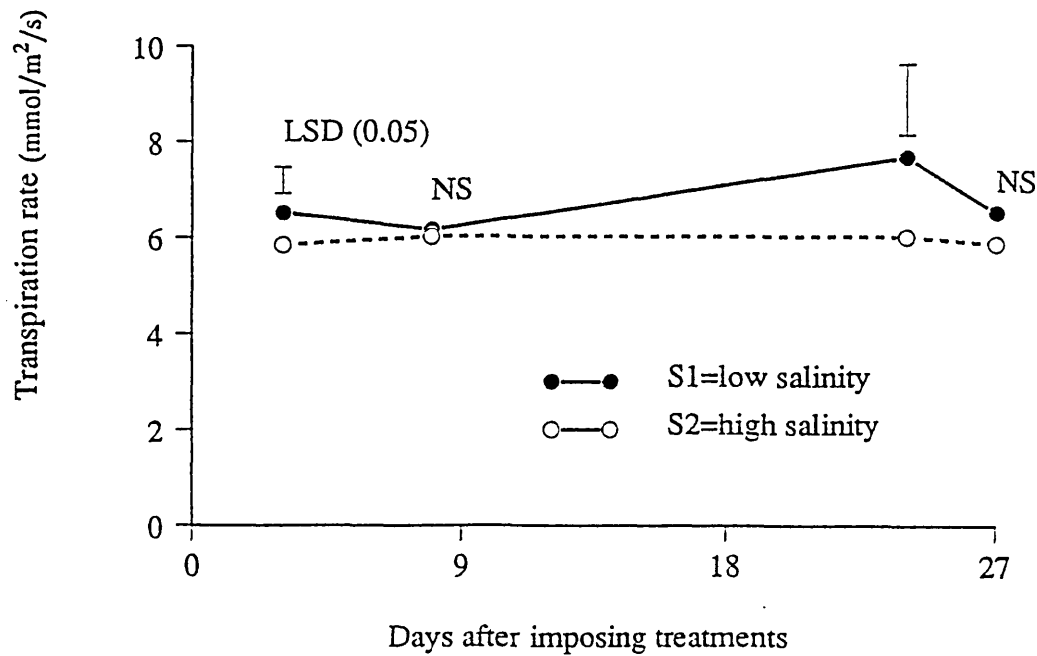


Fig. 7.6a Transpiration rate as affected by salinity levels in the nutrient solution

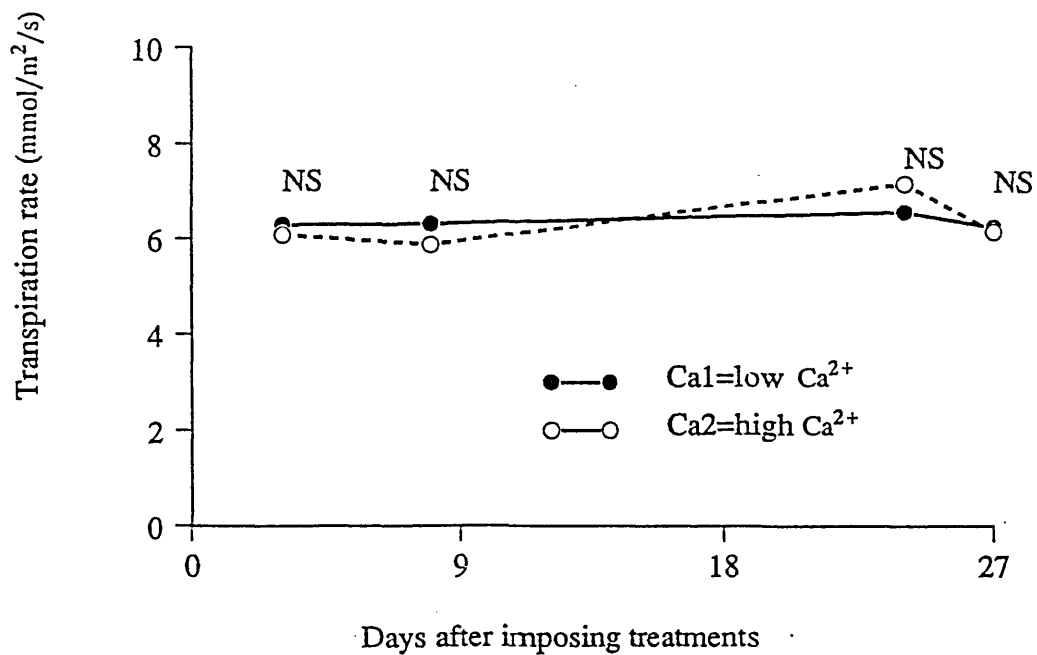


Fig. 7.6b Transpiration rate as affected by external Ca²⁺ concentration

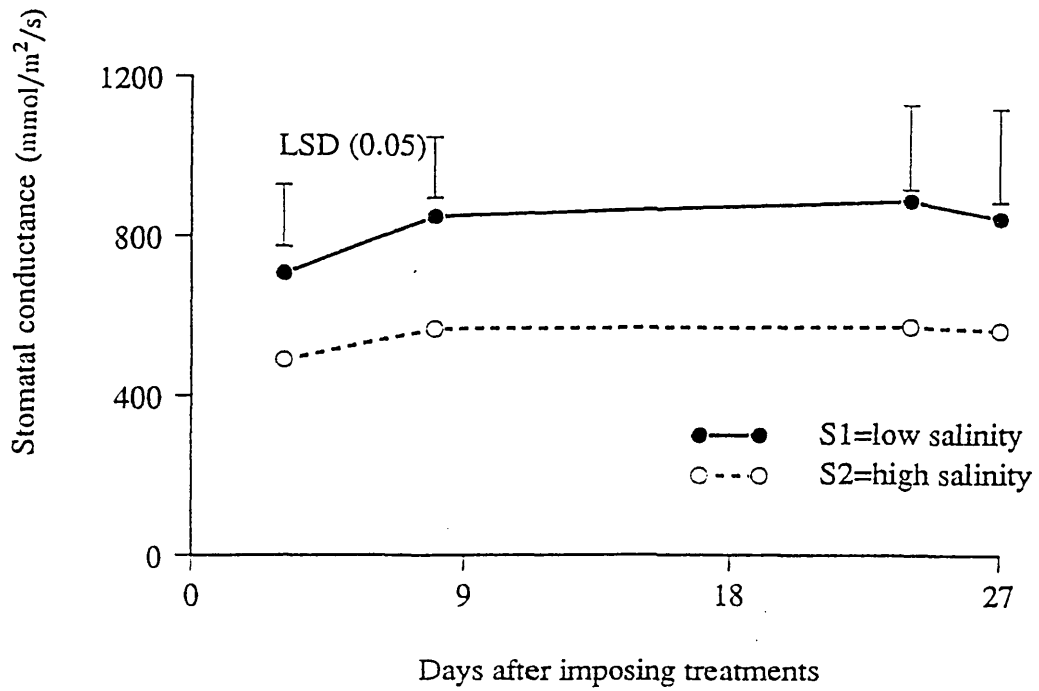


Fig. 7.7a Stomatal conductance as affected by salinity levels in the nutrient solution

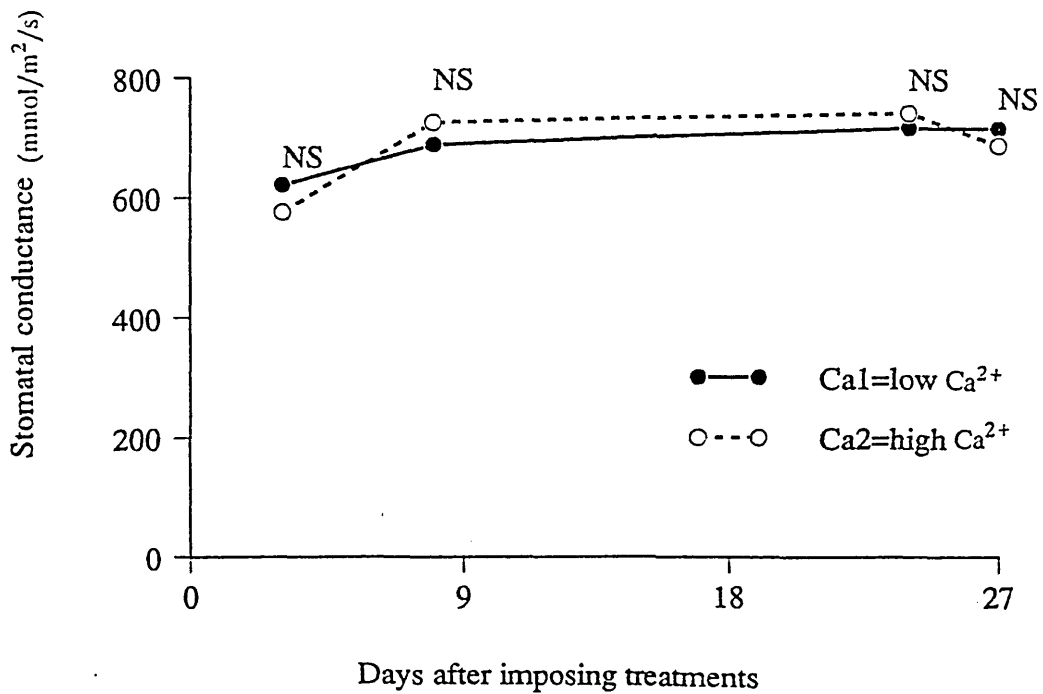


Fig. 7.7b: Stomatal conductance as affected by external Ca²⁺ concentration



Fig. 7.8 Transpiration of the old and new leaves as affected by nutrient solution salinity and external Ca^{2+} concentration

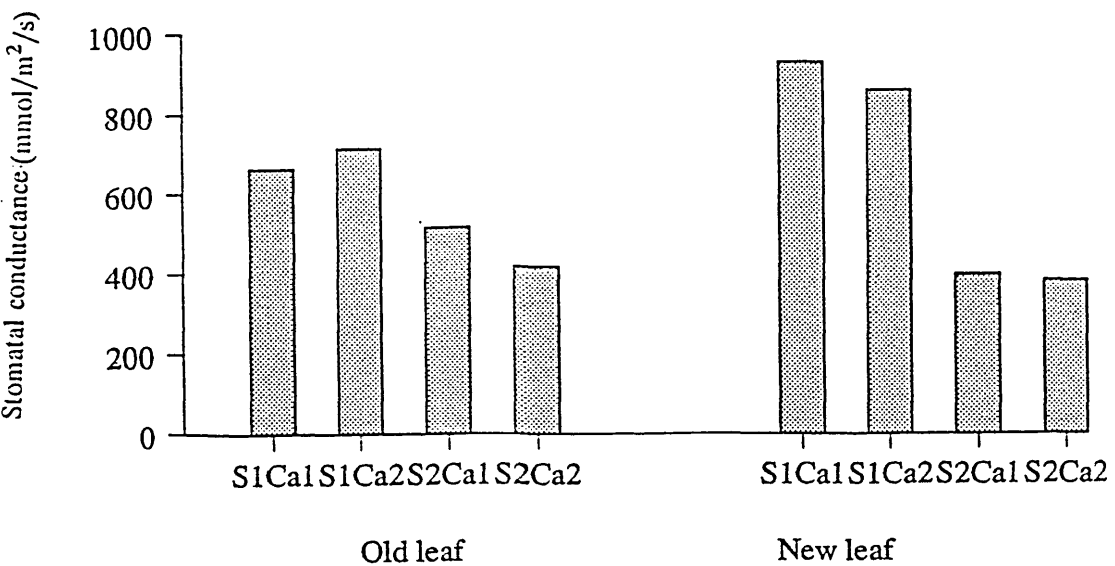


Fig. 7.9 Stomatal conductance of the old and new leaves as affected by the nutrient solution salinity and external Ca^{2+} concentration

- S1Ca1=low salinity and low Ca^{2+}
- S1Ca2=low salinity and high Ca^{2+}
- S2Ca1=high salinity and low Ca^{2+}
- S2Ca2=high salinity and high Ca^{2+}

Table 7.5. Effect of salinity and external Ca^{2+} concentration on plant water uptake and relative water content (RWC).

Solution salinity (mS cm^{-1})	Total water uptake (ml/plant)	Relative water content (RWC)
2.5	2092.34	85.17
8.5	1136.33	78.95
LSD	**	**
External Ca^{2+} concentration (mol m^{-3})		
2.034	1651.19	83.1
4.58	1577.48	83.02
LSD	ns	**

ns not significant

* significant at $P=0.05$

** significant at $P=0.01$

7.2.4 PLANT ANALYSIS:

Under saline conditions, the Ca^{2+} content of the old and fully expanded leaves were decreased, while the Ca^{2+} level in the roots and in the young leaves was not affected (Table 7.6). High external Ca^{2+} increased the Ca^{2+} level in the roots, old and fully expanded leaves. Ca^{2+} level in the young leaves was not affected (Table 7.6). Salinity and Ca^{2+} concentration in the external solution produced a significant ($P=0.05$) interaction on the Ca^{2+} level in the fully expanded leaves (Figure 7.10). High external Ca^{2+} concentration increased $\text{Ca}^{2+}\%$ in the fully expanded leaves non-saline condition. In the salt-stressed plants Ca^{2+} level on the roots and old leaves was slightly increased but the difference was not significant. The Ca^{2+} level on the fully expanded and young leaves was not affected by external Ca^{2+} concentration.

Table 7.6 Effect of salinity and external Ca^{2+} concentration on Ca^{2+} levels in the root and in the leaves (% dry matter).

Solution salinity (mS cm^{-1})	Root	Leaves		
		Old leaves	Fully expanded leaves	Young leaves
2.5	0.514	3.85	0.4785	0.3285
8.5	0.521	1.80	0.3960	0.3510
LSD	ns	**	**	**
External Ca^{2+} concentration (mol m^{-3})				
2.034	0.485	2.03	0.4110	0.3360
4.58	0.55	3.62	0.4635	0.3435
LSD	*	**	*	ns

Table 7.7. Effect of salinity and external Ca^{2+} concentration on K^+ levels in the root and in the leaves (% dry matter).

Solution salinity (mS cm^{-1})	Root	Leaves		
		Old leaves	Fully expanded leaves	Young leaves
2.5	6.58	6.23	5.036	4.197
8.5	2.70	3.67	3.012	3.639
LSD	**	**	**	**
External Ca^{2+} concentration (mol m^{-3})				
2.034	4.36	5.2	4.39	4.071
4.58	4.91	4.7	3.659	3.765
LSD	ns	ns	**	**

ns not significant at $P=0.05$

* significant at $P=0.05$

** significant at $P=0.01$

The results presented in Table 7.7 show the effect of salinity on the potassium percentage in the dry weight of roots and old, fully expanded and young leaves. K^+ level in roots and in the leaves were significantly ($P=0.01$) decreased with salinity. High external Ca^{2+} concentration did not affect K^+ in the roots and in the old leaves. In fully expanded and young leaves K^+ level was increased significantly ($P=0.01$) at low level of external Ca^{2+} (Table 7.7). The results show a significant ($P=0.01$) interaction between the treatments on the K^+ level in young leaves (Figure 7.11). K^+ level in the young leaves was reduced under non-saline conditions at high external Ca^{2+} , while it was not affected in the salt-stressed plants.

The effect of salinity and external Ca^{2+} concentration on the phosphorous percentage in the dry weight of roots and leaves are summarized in Table 7.8. The $P\%$ in the root and in the old leaves were not affected by salinity. High salinity significantly ($P=0.05$) increased $P\%$ in fully expanded and young leaves. High external Ca^{2+} concentration significantly ($P=0.01$) increased $P\%$ in the root tissue while it had no effect on $P\%$ in the leaves. Both treatments produced a significant ($P=0.01$) interaction in $P\%$ in the young leaves (Figure 7.12). Under non-saline condition $P\%$ was increased at high external Ca^{2+} . $P\%$ in the young leaves of salt treated plants was not affected by external Ca^{2+} concentration.

Table 7.9 shows Magnesium percentage in roots and leaves as affected by salinity and external Ca^{2+} . The results shows that Mg^{2+} level in the root and old leaves was not affected by salinity. In both fully expanded and young leaves, there was a marked reduction in Mg^{2+} levels at 8.5 mS cm^{-1} solution. External Ca^{2+} concentration had no significant effect on Mg^{2+} level, either in the root or in the leaves. No interaction effect between the treatments was found.

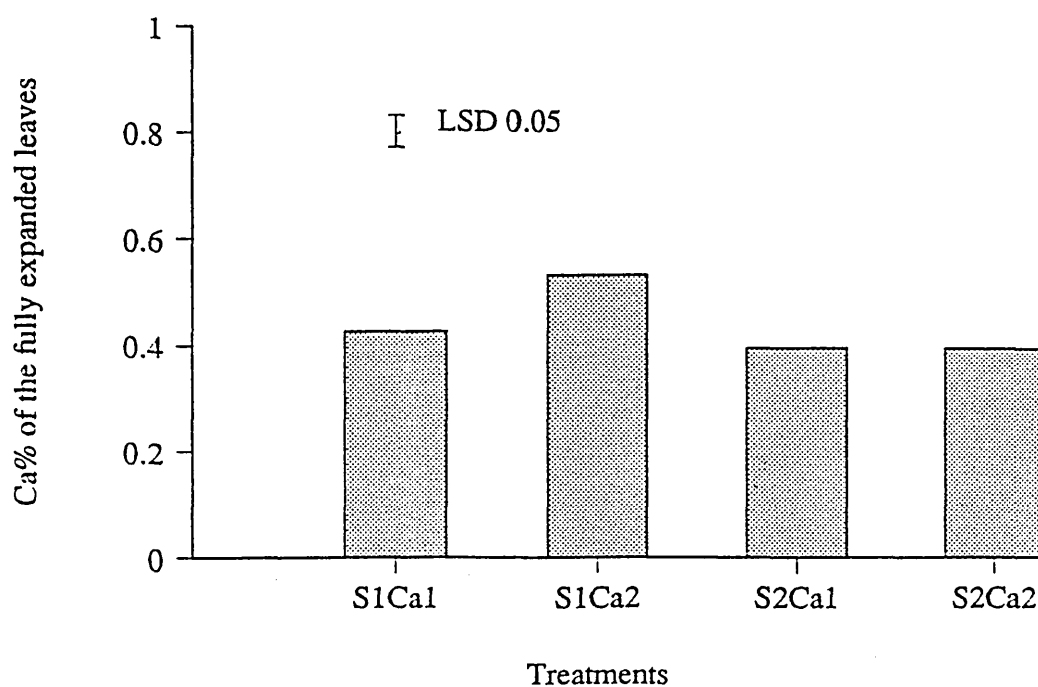


Fig 7.10 Ca% of the dry matter of the fully expanded leaves as affected by nutrient solution salinity and external Ca^{2+} concentration

- S1Ca1=low salinity and low Ca^{2+}
- S1Ca2=low salinity and high Ca^{2+}
- S2Ca1=high salinity and low Ca^{2+}
- S2Ca2=high salinity and high Ca^{2+}

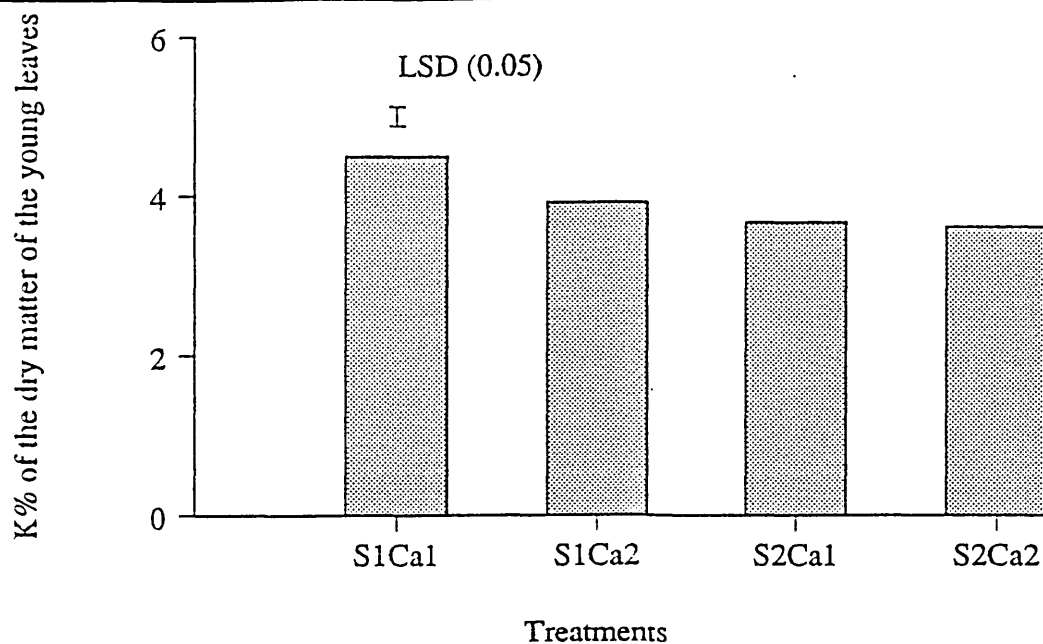


Fig. 7.11 K% of the dry matter of the young leaves as affected by nutrient solution salinity and external Ca^{2+} concentration

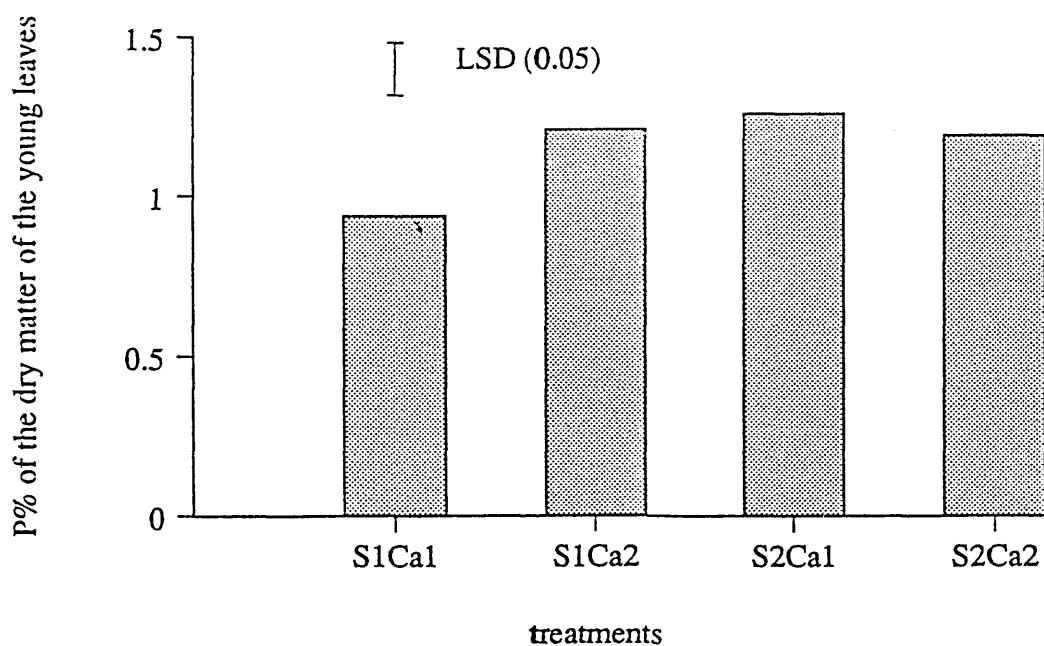


Fig. 7.12 P% of the dry matter of the young leaves as affected by the nutrient solution salinity and external Ca^{2+} concentration

- S1Ca1=low salinity and low Ca^{2+}
- S1Ca2=low salinity and high Ca^{2+}
- S2Ca1=high salinity and low Ca^{2+}
- S2Ca2=high salinity and high Ca^{2+}

Table 7.8 Effect of salinity and external Ca^{2+} concentration on P levels in root and in the leaves (% dry weight).

Solution salinity (mS cm^{-1})	Roots	Leaves		
		Old leaves	Fully expanded leaves	Young leaves
2.5	0.877	0.754	0.919	1.072
8.5	1.001	0.707	1.24	1.226
LSD	ns	ns	*	*
External Ca^{2+} concentration (mol m^{-3})				
2.034	0.807	0.723	1.090	1.098
4.58	1.071	0.738	1.069	1.2
LSD	**	ns	ns	ns

Table 7.9. Effect of salinity and external Ca^{2+} concentration on Mg^{2+} levels in the root and in the leaves (% dry weight).

Solution salinity (mS cm^{-1})	Roots	Leaves		
		Old leaves	Fully expanded leaves	Young leaves
2.5	0.237	1.073	0.433	0.457
8.5	0.362	0.813	0.324	0.323
LSD	ns	ns	*	**
External Ca^{2+} concentration (mol m^{-3})				
2.034	0.299	1.199	0.401	0.424
4.58	0.299	0.687	0.356	0.356
LSD	ns	*	ns	ns

ns not significant at $P=0.05$

* significant at $P=0.05$

** significant at $P=0.01$

Table 7.10. Effect of salinity and external Ca^{2+} concentration on Na^+ level in the root and in the leaves (% dry weight)

Solution salinity (mS cm^{-1})	Roots	Leaves		
		Old leaves	Fully expanded leaves	Young leaves
2.5	0.606	0.144	0.083	0.027
8.5	4.129	3.3	2.34	1.336
LSD	**	**	**	**
External Ca^{2+} concentration (mol m^{-3})				
2.034	2.32	1.859	1.363	0.754
4.58	2.415	1.585	1.060	0.609
LSD	ns	**	*	**

Table 7.11. Effect of salinity and external Ca^{2+} concentration on Cl^- level in the root and in the leaves (% dry weight).

Solution salinity (mS cm^{-1})	Root	Leaves		
		Old leaves	Fully expanded leaves	Young leaves
2.5	1.08	0.830	1.75	2.864
8.5	5.55	7.018	5.46	5.124
LSD	**	**	**	**
External Ca^{2+} concentration (mol m^{-3})				
2.034	3.64	3.974	3.64	4.101
4.58	2.99	3.875	3.52	3.887
LSD	ns	ns	ns	ns

ns significant at $P=0.05$

* significant at $P=0.05$

** significant at $P=0.01$

High nutrient solution salinity markedly increased sodium and chloride levels in roots and leaves (Table 7.10 and 7.11). Both treatments had a significant ($P=0.01$) main effect on Na^+ level in the leaves. Salinity and external Ca^{2+} produce a significant ($P=0.01$) interaction on Na^+ levels on the leaves (Figure 7.13, 7.14 and 7.15). Na^+ levels in the leaves of salt-treated plants declined markedly with increasing Ca^{2+} concentration from 2.034 to 4.55 mol m^{-3} . The difference was statistically significant ($P=0.01$). Under non-saline condition Na^+ level in leaves was not affected by external Ca^{2+} . Na^+ level on the root was not affected by external Ca^{2+} or the interaction effect with salinity.

Both 2.034 and 4.58 mol m^{-3} external Ca^{2+} concentration did not have a significant effect on the Cl^- in the root and in the leaves at 2.5 and 8.5 mS cm^{-1} solution salinity (Table 7.11). The results show a significant interaction ($P=0.05$) between salinity and external Ca^{2+} on Cl^- level in the roots (Figure 7.17). High external Ca^{2+} concentration significantly ($P=0.05$) reduced the Cl^- level on roots of salt treated plants. In the non-saline condition root Cl^- level was not affected by external Ca^{2+}

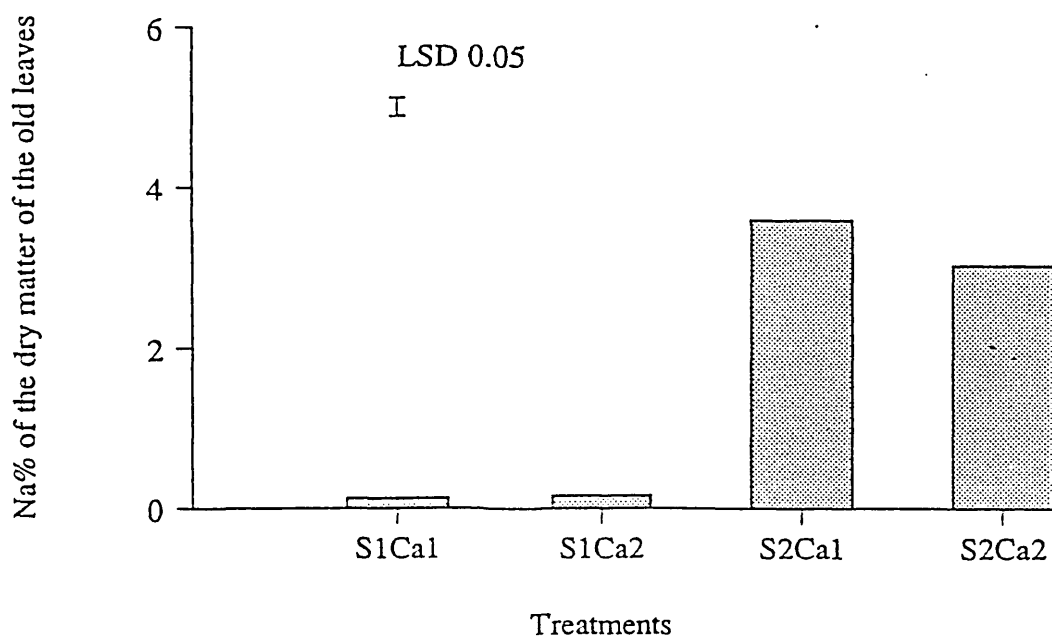


Fig. 7.13 Na% of the dry matter of the old leaves as affected by nutrient solution salinity and external Ca^{2+} concentration

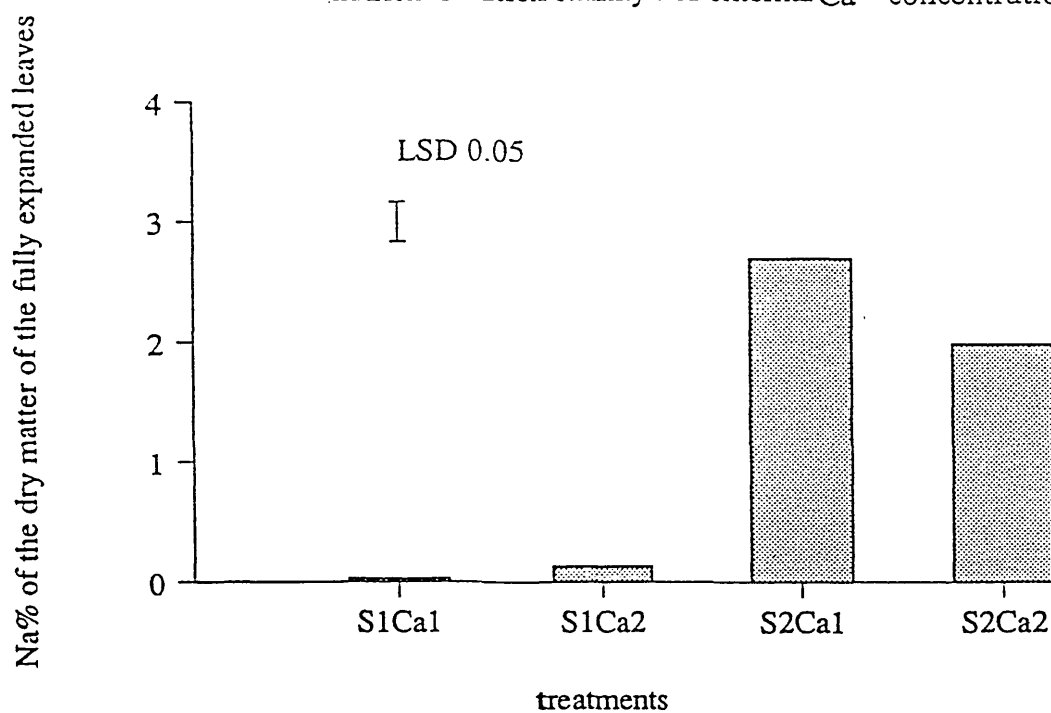


Fig. 7.14 Na% on the dry matter of the fully expanded leaves as affected by the nutrient solution salinity and external Ca^{2+} concentration

- S1Ca1=low salinity and low Ca^{2+}
- S1Ca2=low salinity and high Ca^{2+}
- S2Ca1=high salinity and low Ca^{2+}
- S2Ca2=high salinity and high Ca^{2+}

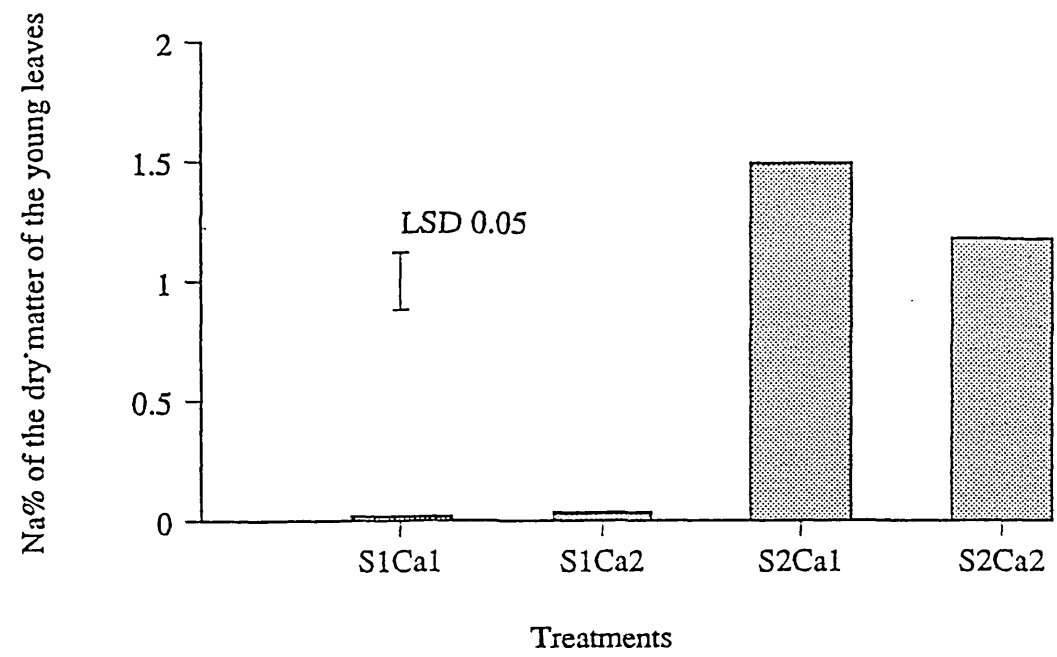


Fig. 7.15 Na% of the dry matter of the young leaves as affected by nutrient solution salinity and external Ca^{2+} concentration

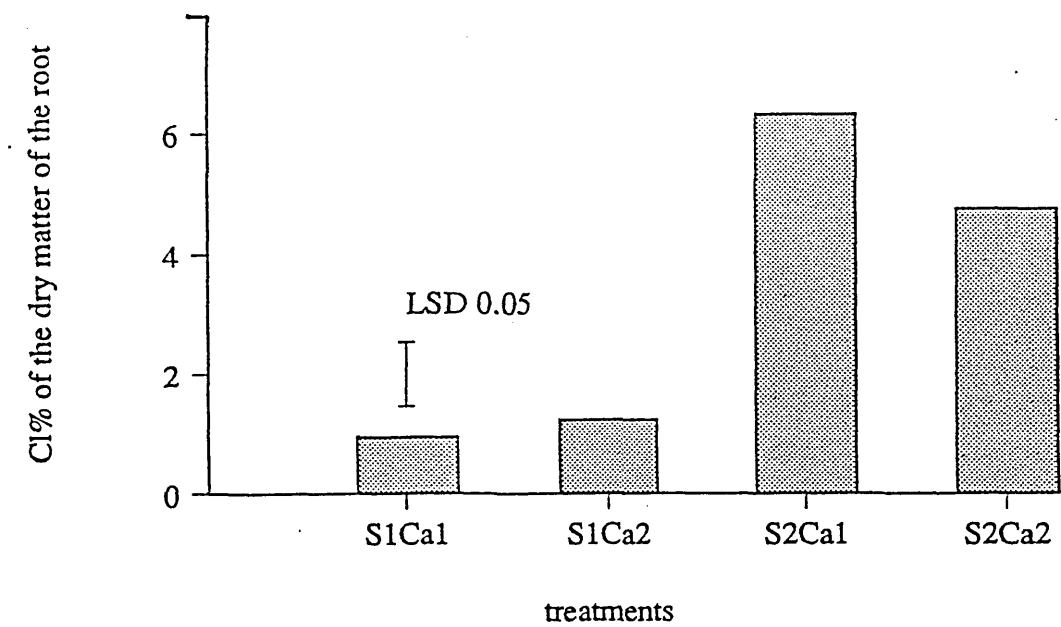


Fig. 7.16 Cl% of the dry matter of the root as affected by the nutrient solution salinity and external Ca^{2+} concentration

- S1Ca1=low salinity and low Ca^{2+}
- S1Ca2=low salinity and high Ca^{2+}
- S2Ca1=high salinity and low Ca^{2+}
- S2Ca2=high salinity and high Ca^{2+}

7.3 DISCUSSION:

Several investigators reported a positive growth response for increasing external Ca^{2+} under saline condition (Kent and Lauhli 1985; Cramer *et al* 1986; Nakamura *et al* 1990). Subbarao *et al* (1990) reported a significant increase in the shoot dry matter of Pigeonpea with decreasing $\text{Na}^+/\text{Ca}^{2+}$ ratio from 165 and 220 to 2, in the medium at 6 and 8 mS cm^{-1} salinity levels. They also observed a similar trend in the leaf area and root dry matter. In this experiment increasing Ca^{2+} concentration in the external nutrient solution from 2.034 to 4.58 mol m^{-3} did not affect the dry and fresh weight of roots and shoot produced when plant were grown at 2.5 and 8.5 mS cm^{-1} solution salinities.

Lack of positive growth response to increase external Ca^{2+} under saline condition in this experiment may be due to the already high $\text{Na}^+/\text{Ca}^{2+}$ ratio in nutrient solution. In the 8.5 mS cm^{-1} solution $\text{Na}^+/\text{Ca}^{2+}$ ratio was 30.29 and 13.55 mol m^{-3} for 2.034 and 4.58 mol m^{-3} external Ca^{2+} respectively. Ben-Hayyim *et al* (1987) indicated that the growth capacity of cultured citrus cells was determined by the combination of $(\text{Ca}^{2+})/(\text{Na}^+)^2$ ratio and the absolute external concentration of NaCl.

The RWC of salt-stressed plants was increased at low external Ca^{2+} , although the water uptake by the plants was not affected. This increase may have resulted from lower calcium level in the solution affecting membrane permeability. Shah *et al* (1990) reported that increasing Ca^{2+} in the growth media did not affect the callus water content in callus culture, established from cultivars of *Medicago sativa* L.

Transpiration rate and stomatal conductance were not affected by increasing Ca^{2+} at both 2.5 and 8.5 mS cm^{-1} levels of salinity. The same result was found by Cramer *et al* (1989). They found that, increasing external Ca^{2+} from 0.4

to 10 mol m^{-3} did not affect transpiration rate. High Ca^{2+} was found to counteract the ion-specific rather than the osmotic effect of high salt concentrations on root growth (Nakamura *et al* 1990).

The data of the nutrient analysis in the plant tissue showed that the uptake rates of those ions controlling some of the processes implicated with salt tolerance are affected by external Ca^{2+} concentration. Ca^{2+} and Na^+ were significantly affected by salinity and correlated with growth in saline conditions. In this experiment the Ca^{2+} levels in the root and in the leaves of salt treated plants was not affected significantly by the external Ca^{2+} . This result does not agree with finding of Maas and Grieve (1987), Cramer *et al* (1989) and Subbarao *et al* (1990). Cramer *et al* (1991) reported that salt-treated barley with supplemental Ca^{2+} , had Ca^{2+} uptake rate comparable to those of control. This could be due to the high $\text{Na}^+/\text{Ca}^{2+}$ ratio in this experiment. Maas and Grieve (1987) found that the symptoms of Ca^{2+} deficiency caused by salinity on corn was removed, when the $\text{Na}^+/\text{Ca}^{2+}$ ratio decreased to 5.7 molar ratio. Ca^{2+} level in the old leaves remained higher than those in the fully expanded and young leaves at both levels of salinity and external Ca^{2+} . This indicates that, Ca^{2+} may be accumulated preferentially by old leaves at the expense of young leaves (Loneragan and Snowball 1969; Maas and Greive 1985).

Cramer *et al* (1985) showed that salinity significantly increased Na^+ level and decreased K^+ level in roots and in leaves, as a result of displacement of Ca^{2+} by Na^+ in the cell membranes. This induced an enhanced efflux of K^+ from the cell. The results of the present experiment show that high external Ca^{2+} had a divergent response to Na^+ uptake by salt-stressed plants. Na^+ level in the leaves of the salt-stressed plants was decreased at 4.58 compared to 2.034 mol m^{-3} external Ca^{2+} in the nutrient solution. These results are in agreement with those reported by (Jacoby and Hanson 1985; Ben-Hayyim *et al* 1987; Katsuhara and Tazawa 1988).

High external Ca^{2+} (4.58 mol m^{-3}) had no significant effect on the K^+ uptake by the salt-stressed plants. This result is not in accordance with those reported by Kent and Lauchli (1985), Nakamura *et al* (1990) and Shah *et al* (1990). They reported that high Ca^{2+} partially reversed the salt-induced decrease in K^+ by preventing the leakage of intercellular K^+ . Katsuhara and Tazawa (1988) reported that addition of external Ca^{2+} (10 mol m^{-3}) prevented the Na^+ influx in salt-treated *Nitellopsis* cells and the changes in K^+ concentration were opposite to those in Na^+ concentration. It seems that the external Ca^{2+} concentration used in this experiment may not have been high enough to reverse the negative effect of high salinity on K^+ uptake.

Cl^- levels in root and in leaves was increased at 8.5 mS cm^{-1} salinity. Increasing the external Ca^{2+} upto 4.58 mol m^{-3} did not affect the Cl^- in plants. Cl^- level in roots of salt-treated plants was reduced under high external Ca^{2+} . Subbarao *et al* (1990) reported that Cl^- level increased with decreasing $\text{Na}^+/\text{Ca}^{2+}$ at 6 and 8 mS cm^{-1} , which they attributed to the maintenance of cation-anion balance.

Generally the result of this experiment shows that the plant growth under saline condition was not affected by increasing external Ca^{2+} from 2.034 to 4.58 mol m^{-3} . This could be attributed to the high $\text{Na}^+/\text{Ca}^{2+}$ ratio that existed even at high levels of external Ca^{2+} (13.51 mol m^{-3}). The plant water status was not affected by increasing Ca^{2+} concentration under saline conditions. High external Ca^{2+} counteracts the ion-specific effect of salinity rather than osmotic effect (Nakamura *et al* 1990). Increasing Ca^{2+} concentration reduced $\text{Na}\%$ in the leaves of salt treated plants, as a result of improving cell membrane permeability and controlling the influx of Na^+ (Cramer *et al* 1985).

CONCLUSIONS

Cucumber plants (*Cucumis sativus* L.) are considered to be moderately salt tolerant (Schwarz 1985). The data presented in this thesis indicated that cucumber plants could be grown over a range of nutrient solution conductivities from 1.0 to 2.5 mS cm⁻¹ with little effect on plant growth and yield. However, there was a significant reduction in water uptake and RWC of the plant tissue when solution Ec was increased from 1.0 to 2.5 mS cm⁻¹.

Crop salt tolerance is usually expressed as the expected decrease in yield for a given level of salt concentration compared with the yield of plants grown under non-saline conditions. Assessment of plant salt tolerance was carried out by growing the cucumber plants at a range of nutrient solution salinities (4.5, 6.5 and 8.5 mS cm⁻¹), produced by adding NaCl to the basic nutrient solution. In this work cucumber plants of cv Farbiola were found to tolerate a salinity level of 4.5 mS cm⁻¹ in the nutrient solution without a significant reduction in the yield. Total yield was reduced by 10% when solution salinity increased from 2.5 mS cm⁻¹ to 4.5 mS cm⁻¹ using NaCl. According to an FAO (1985) report, cucumber yield was reduced by 25% at 4.4 mS cm⁻¹ soil salinity. The difference between the observations in the FAO report and those observed here may have been due to the different growing media used. Zayed (1987) reported that plants could tolerate higher levels of salinity in nutrient film culture than in the soil. In NFT a constant level of salinity is maintained whereas in the soil the level of salinity fluctuates with water uptake and areas of high salinity can occur close to the root system. Different environmental conditions particularly the level of plant water stress, or the cultivar and period over which harvesting was carried out, could have contributed to the difference between the two observations.

Jones (1984) reported that genetic variability for salt tolerance exists among cucumber cultivars. This makes it more difficult to draw a general statement about cucumber salt tolerance. There is therefore a need for more assessment of cucumber salt tolerance in nutrient film culture using several cultivars.

Increasing salinity further to 6.5 and 8.5 mS cm⁻¹ reduced both growth and yield. Although the cucumber fruit quality was improved with increased solution salinity, this was offset by a large reduction in the yield.

Investigation in this study revealed that plant water uptake was decreased with increasing salinity. This effect was more significant when the low osmotic potential was applied during the day time hours. The inhibitory effect of salinity on plant growth could be attributed principally to its osmotic effect on the nutrient solution and to the way this reduced water uptake. The results discussed in chapter 4 show that the plant growth was a positive function of total water uptake.

Photosynthetic rate per unit leaf area was not affected by nutrient solution salinity. However, the reduction in the leaf expansion resulted in a reduction in available photosynthetic area in saline affected plants. This is effective in reducing the availability of assimilate to generate further growth. The reduced water uptake in the saline treated plants also reduces the nutrient uptake by the plant.

The key effect of salinity appears to be its effect on the leaf area of the plant. Reduced leaf area influences radiation interception and total plant photosynthesis. It also influences the area available for transpiration and the nutrient uptake by the plant. Reduced plant photosynthetic area and reduced nutrient uptake together will result in a reduction in crop yield. High levels of radiation will increase the demand for water by the plant and, therefore are likely to increase the effect of osmotic stress. This further reduces the plant's ability to utilise optimally the radiation in photosynthesis.

Plant water status was found to respond rapidly to the changes in salinity of the root media. Within a few hours of removing the salt stress from the root media, the plant water potential within the stressed plant tissue increased to the levels found in the control plants. A few investigators have reported that leaf

growth responds rapidly to changes osmotic potential of external solution (Munns *et al* 1982; Rawson and Munns 1984). The rapid changes in water status of plant brought about by changes in solution concentration had a considerable significance in the way salinity affected plant growth even when these changes were only of a short duration.

The reduction in plant growth under saline conditions could result from the interference of Na^+ and Cl^- in metabolism in the leaves, or on the uptake and transport of essential nutrient ions such as Ca^{2+} and K^+ . As discussed in chapter 4, the Na^+ and Cl^- levels in the plant tissue increased with increasing salinity. The reduced Ca^{2+} levels found within the plant may be due not only to the substitution of Na^+ for Ca^{2+} but also to the reduction in the transfer of Ca^{2+} into the plant as a result of the decrease in water uptake.

Heating the nutrient solution continuously at $27 \pm 1^\circ\text{C}$ did not affect the plant growth and yield or influence the plant's response to saline conditions. This may have been due to several factors, firstly the air temperature may not have been a limiting factor, secondly both heated and unheated solution temperatures may have been within the optimal range for cucumber growth. More work is needed to study the interaction of salinity and solution temperature on cucumber growth in solution culture using a wider range of solution temperatures. In view of the importance of water uptake on the effect of salinity, growing plants outside the optimal root temperature range at ,say, lower root temperatures one might anticipate the negative effect of salinity would be increased. Experiments using a wider range of air and root temperature are needed before a true assessment of the interaction between root temperature and salinity can be made.

Increasing external Ca^{2+} concentration in the recirculating solution did not influence the growth of cucumber at high salinity. However, the Na^+ level in the leaves was reduced with increasing Ca^+ level in the nutrient solution. Lack of a significant effect on plant growth could be attributed to the relatively high

conclusion

$\text{Na}^+/\text{Ca}^{2+}$ ratios used in this study (30.29 and 13.55) compared with other reports. Mass and Grieve (1987) reported that Ca^{2+} deficiency symptoms were removed when the $\text{Na}^+/\text{Ca}^{2+}$ ratio was reduced to 5.7. Recently, Subbarao *et al* (1990) found a significant increase in the shoot dry matter of Pigeonpea by decreasing the $\text{Na}^+/\text{Ca}^{2+}$ ratio from 165 and 220 to 2. Lower levels of the $\text{Na}^+/\text{Ca}^{2+}$ ratio in the nutrient solution might have produce more positive effects on plant growth and nutrient uptake at high saline conditions. However, these changes were not possible in these experiments without substantial changes to the composition of the nutrient solution.

REFERENCES

references

- Abdelhafeez, A.T., Harssema, H., Veri, G. and Verkerk, K. (1971). The effect of soil and air temperature on growth, development and water use of tomatoes. *Neth. J. Agr. Sci.*, 19:67-75.
- Acevedo, C., Hsiao, T.C. and Henderson, D.W. (1971). Immediate and subsequent growth response of maize leaves to changes in water status. *Plant Physiol.* 48:631-636.
- Adams, P. (1988a). Some response of tomato grown in NFT to sodium chloride. *ISOSC proceedings. Seventh international congress on soilless culture, Flevohof, 1988*, PP. 59-71.
- Adams, P. (1988b). Some effects of root temperature on the growth and nutrient uptake of tomatoes in NFT. *ISOSC proceedings. Seventh international congress on soilless culture, Flevohof, 1988*, PP. 73-82.
- Allen, S.E. (1989). *Chemical analysis of ecological materials*. 2nd. edition. Blackwell Scientific. London.
- Al-Rawahy, S.A., Stroehlein, J.L. and Pessarakli, M. (1990). Effect of salt stress on dry matter production and nitrogen uptake by tomatoes. *Journal of Plant Nutrition* 13(5):567-577.
- Attenburrow, W.C. and Waller, P.L. (1980). Sodium chloride : its effect on nutrient uptake and crop yields with tomato in NFT. *Acta Horticulturae*. 98:229-236

references

- Barlow, E.W.R., Boersma, L. and Young, J.L. (1977). Photosynthesis, transpiration and leaf elongation in corn seedling at suboptimal soil temperature. *Agronomy Journal* 69:95-100.
- Ben-Hayyim, G., Kafkafi, U. and Ganmone-Neumann, R. (1987). Role of internal potassium in maintaining growth of cultured *Citrus* cells on increasing NaCl and CaCl₂ concentration. *Plant and Soil* 85:434-439.
- Bernstein, L. (1961). Osmotic adjustment of plants to saline media. 1. steady state. *American Journal of Botany* 48:909-918.
- Bernstein, L. (1975). Effect of salinity and sodicity on plant growth. *Ann. Rev. Phytopathol.* 25:271-291.
- Black, C.R. (1979). the relative magnitude of the partial resistances to transpirational water movement in sunflower (*Helianthus annuus* L.). *Journal of Experimental Botany*. 30:245-253.
- Bradfield, E.G. and Guttridge, C.G. (1984). Effects of night-time humidity and nutrient solution concentration on the calcium content of tomato fruit. *Scientia Horticulturae*. 22:207-217.
- Burrage, S.W. and Varley, M.J. (1980). Water relations of lettuce grown in nutrient film culture. *Acta Horticulturae* 98:79-86.

references

- Cerda, A., Bingham, F.T., Hoffman, G.J. and Huszar, C.K. (1979). Leaf water potential and gaseous exchange of wheat and tomato as affected by NaCl and P level in the root medium. *Agronomy Journal* 71:27-31.
- Clipson, N.J.W., Tomos, A.D., Flowers, T.J. and Jones, W. (1985). Salt tolerance in the halophyte *Suaeda maritima* L. Dum. *Planta* 165:392-396.
- Cooper, A.J. (1973). Root temperature and plant growth. Commonwealth Agriculture Bureaux, Slough. England.
- Cooper, A. (1982). Nutrient film technique. The English Language book society and Grower Books. London.
- Cramer, G.R., Lauchli, A. and Polito, V.S. (1985). Displacement of Ca^{2+} by Na^{+} from the plasmalemma of root cells. *Plant Physiol.* 79:207-211.
- Cramer, G.R. and Lauchli, A. (1986). Ion activities in solution in relation to Na^{+} - Ca^{2+} interaction at plasmalemma. *Journal of Experimental Botany.* 37(176):321-330.
- Cramer, G.R., Lauchli, A. and Epstein, E. (1986). Effect of NaCl and CaCl_2 on ion activities in complex nutrient solution and root growth of cotton. *Plant Physiol.* 81:792-797.

- Cramer, G.R., Epstein, E. and Lauchli, A. (1988). Kinetics of root elongation of maize in response to short – term exposure to NaCl and elevated calcium concentration. *Journal of Experimental Botany* 39(208):1513 – 1522.
- Cramer, G.R., Epstein, E. and Lauchli, A. (1989). Na – Ca interaction in barley seedling : relationship to ion transport and growth. *Plant, Cell and Environment* 12:551 – 558.
- Cramer, G.R., Epstein, E. and Lauchli, A. (1991). Effect of sodium, potassium and calcium on salt – stressed barley. II. Elemental analysis. *Physiologia Plantarum* 81:197 – 202.
- Davis, R.M. and Lingle, J.C. (1961). Basis of shoots response to root temperature in tomato. *Plant Physiol.* 36:153 – 161.
- Delane, R., Greenway, H., Munns, R. and Gibbs, J. (1982). Ion concentration and carbohydrate status of the elongation leaf tissue of *Hordeum vulgare* growing at high external NaCl. *Journal of Experimental Botany* 33(135):557 – 573.
- Downton, W.J.S. (1977). Photosynthesis in salt – stressed grapevines. *Aust. J. Plant Physiol.* 4:183 – 192.
- Dumbroff, E.B. and Cooper, A.W. (1974). Effect of salt stress applied in balanced nutrient solution at several stages during growth of tomato. *Botanical*

references

Gazette 135(3):219-224.

Ehret, D.L. and Ho. L.C. (1986). Effect of salinity on dry matter partitioning and fruit growth in tomato grown in nutrient film culture. *Journal of Horticulture Science* 61(3):361-367.

Ehret, D.L., Redmann, B.L., Harvey, B.L. and Cipywnyk, A. (1990). Salinity-induced calcium deficiency in wheat and barley. *Plant and Soil* 128:143-151.

Eshel, A. and Waisel, Y. (1984). Effect of salt and soil water status on transpiration of *Salsola kali* L. *Plant, Cell and Enviroment* 7:133-137.

Falk, S.O. (1966). Effect on transpiration and water uptake by rapid changes in the osmotic potential of the nutrient solution. *Physiologia Plantarum* 19:602-627.

FAO. (1985). Water quality for a griculture. Irrigation and Drainage Paper. 29. Rome

Flowers, T.J. (1985). Physiology of halophytes. *Plant and Soil* 89:41-56.

Flowers, T.J. and Yeo, A.R. (1989). Effect of salinity on plant growth and crop yields. In: *Enviromental stress in plants, Biochemical and physiological mechanisms* (Ed. Joe H. Cherry). ATO, ASI series. Seris G: Ecological

sciences, vol,19. Springer-Verlag.

Frota, J.N.E. and Tucker, T.C. (1978). Absorption rate of ammonium and nitrate by red kidney beans under salt and water stress. Soil Sci. Soc. Am. J. 42:753-756.

Gale, J. (1975). The combined effect of environmental factors and salinity on plant growth. In: Plant in Saline Environment (Poljakoff-Mayber Eds.) Springer-Verlag, Berlin, Heidelberg, New York : 187-192.

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

Gale, J. and Poljakoff-Mayber, A. (1970). Interrelation between growth and photosynthesis of salt bush (*Atriplex halimus* L.) grown in saline media. Aust. J. Biol.Sci. 23:937-945.

Gosselin, A. and Trudel, M.J. (1982). Influence of root-zone temperature on growth, development and mineral content of tomato plant cv. Vendor. Can. J. Plant Sci. 62:751-757.

Gosselin, A. and Trudel, M.J. (1983a). Interaction between air and root temperature on greenhouse tomato: 1. growth, development and yield J. Amer. Soc. Hort. Sci.108(6):901-905.

references

- Gosselin, A. and Trudel, M.J. (1983b). Interaction between air and root temperature on greenhouse tomato: 11. Mineral composition of plant. J. Amer. Soc. Hort. Sci. 108(6):905-909.
- Gosselin, A. and Trudel, M.J. (1984). Interaction between root-zone temperature and light levels on growth, development and photosynthesis of *Lycopersicon esculentum* Mill. cultivar 'Vendor'. Scientia Horticulturae 23:313-321.
- Gosselin, A. and Trudel, M.J. (1986). Root-zone temperature effects on pepper. J. Amer. Soc. Hort. Sci. 111(2):220-224.
- Graves, C.J. (1983). The nutrient film technique. Horticultural Reviews. 5:1-44.
- Graves, C.J. and Hurd, R.G. (1983). Intermittent solution circulation in the nutrient film technique. Acta Horticulturae. 133:47-52.
- Greenway, H. and Munns, R. (1980). Mechanisms of salt tolerance in nonhalophytes. Annu. Rev. Plant Physiol. 31:149-190.
- Grieve, C.M. and Maas, E.V. (1988). Differential effect of sodium/calcium ratio on sorghum genotypes. Crop Sci. 28:659-665.
- Gur, A., Bravdo, B. and Hepner, J. (1976). The influence of root temperature on apple trees. III. The effect on photosynthesis and water balance. Journal

- of Horticultural Science 51:203-210.
- Guttridge, C.G., Bradfield, E.G. and Holder, R. (1981). Dependence of calcium transport into strawberry leaves on positive pressure in the xylem. *Annals of Botany*. 48:473-480.
- Hall, A.E. and Kaufmann, M.R. (1975). Stomatal response to environment with *Sesamum indicum* L. *Plant Physiol*. 55:455-459.
- Hampson, C.R. and Simpson, G.M. (1989). Effect of temperature, salt and osmotic potential on early growth of wheat (*Triticum aestivum*). II. Early seedling growth. *Can. J. Bot*. 68:529-532.
- Hansen, M. (1980). Nutrition of plants according to species and water supply. *Acta Horticulturae* 98:99-102.
- Hanson, J.B. (1984). The function of calcium in plant nutrition. In *Advances in plant nutrition*, (ed. P.B. Tinker and A. Lauchli) Vol 1. PP. 159-208 Praeger Publishers, New york.
- Hasegawa, P.M., Bressan, R.A. and Handa, A.K. (1986). Cellular mechanisms of salinity tolerance. *Hortscience* 21(6):1317-1324.
- Ho, L.C. and Adams, P. (1989). Effect of diurnal changes in the salinity of the

references

- nutrient solution on the accumulation of calcium by tomato fruit. *Annals of Botany*. 64:373-382.
- Ho, L.C. and Picken, A.J.F. (1985). Routes of water import by tomato fruit during growth. In: Annual report of Glasshouse Crop Research Institute 1985. PP. 72-73.
- Hobson, G. and Adams, P. (1988). Working on the famous cherry flavour. *Grower*, 109(2):15-19.
- Hoffman, G.J. and Rawlins, S.L. (1971). Growth and water potential of root crops as influenced by salinity and relative humidity. *Agronomy Journal* 63:877-880.
- Hoffman, G.J. and Phene, J.C. (1971). Effect of constant salinity levels on water-use efficiency of bean and cotton. *Transactions of the Am. Soc. Agric. Engineers* 14:1103-1106.
- Hoffman, G.J., Shalhevet, J. and Meiri, A. (1980). Leaf age and salinity influence water relation of pepper leaves. *Physiol. Plant.* 48:463-469.
- Hsiao, T. C., Acevedo, E. and Henderson, D.W. (1970). Maize leaf elongation, continuous measurement and close dependence on plant water status. *Science*. 168:590-591.

references

- Hurd, R.G. and Graves, C.J. (1985). Some effect of air and root temperature on the yield and quality of glasshouse tomatoes. *J. Hortic. Science* 60(3)359-371.
- Hyder, S.Z. and Greenway, H. (1965). Effect of Ca on plant sensitivity to high NaCl concentration. *Plant and Soil* 23:258-260.
- Ismail, M.R. (1989). The effects of salinity and vapour pressure deficit on the growth of tomatoes (*Lycopersicon esculentum* Mill.). PhD. University of London. Faculty of Science.
- Jacoby, B. and Hanson, J.B. (1985). Controls on $^{22}\text{Na}^+$ influx in corn roots. *Plant Physiol.* 77:930-934.
- Janes, B.E. (1968). Effect of extending periods of osmotic stress on water relationships of pepper. *Physiol. Plant.* 21:334-345.
- Jennings, O.H. (1976). The effect of sodium chloride on higher plants. *Biol. Rev.* 51:243-246.
- Jeschke, W.D., Pate, J.S. and Atkins, G.A. (1986). Effect of NaCl salinity on growth , development, ion transport and ion storage in white lupin (*Lupinus albus* L. cv. Ultra). *J. Plant Physiol.* 124:257-274.
- Jones, R.W. (1984). Studies related to genetic salt tolerance in the cucumber, *Cucumis stivus* L. PhD, Texas A&M University, College Station.

references

- Jones, W.R.G. (1981). Salt tolerance. In : Physiological processes limiting plant productivity. (ed C. B. Johnson). Butterworths, 1981 pp. 271-292.
- Katsuhara, M. and Tazawa, M. (1988). Changes in sodium and potassium in *Nitellopsis* cell treated with transient salt stress. Plant, Cell and Environment 11:71-74.
- Kawasaki, T., Akiba, T. and Moritsugu, M. (1983a). Effect of high concentration of sodium chloride and polyethylene glycol on the growth and ion absorption in plant.
1. Water culture experiments in a greenhouse. Plant and Soil 75:75-85
- Kawasaki, T., Shimizu, G. and Moritsugu, M. (1983b). Effect of high concentration of sodium chloride and polyethylene glycol on the growth and ion absorption in plant.
11. Multi-compartment transport box experiment with excised root of barley. Plant and Soil 75:87-93.
- Kent, L.H. and Lauchli, A. (1985). Germination and seedling growth of cotton: Salinity -calcium interaction. Plant, Cell and Environment 10:559-564.
- Kriedemann, P.E. (1986). Stomatal and photosynthesis limitations to leaf growth. Aust. J. Plant Physiol. 13:15-31.
- LaHaye, P.A. and Epstein, E. (1969). Salt toleration by plant: Enhancement with

calcium. Science 166:395-396

Lauchli, A.(1986). Responses and adaptations of crop to salinity. Acta Horticulturae 190:243-246.

Lloyd, J., Kriedemann, P.E. and Syvertsen, J.P. (1987). Gas exchange, water relation and ion concentration of leaves on salt stressed 'Valencia' Orange, *Citrus sinensis* (L.) Osbeck. Aust. J. Plant physiol. 14:387-396.

Lloyd, J., Syvertsen, J.P. and Kriedemann, P.E. (1987b) Salinity effects on leaf water relation and Gas exchange of 'Valencia; Orange, *Citrus sinensis* (L.) Osbeck. on rootstocks with different salt exclusion characteristics. Aust. J. Plant Physiol. 14:605-617.

Longstreth, D.L. and Nobel, P.S. (1979). Salinity effect on leaf anatomy. Plant Physiol. 63:700-703.

Loneragan, J.F. and Snowball, K. (1969). Calcium requirements of plants. Aust. J. Agricultural Research. 20:465-478.

Maas, E.V. and Hoffman, G.J. (1977). Crop salt tolerance current assessment. Journal of Irrigation Drainage Division 103:115-134.

Maas, E.V. and Grieve, C.M. (1987). Sodium-induced calcium deficiency in salt-

references

- stressed corn. *Plant, Cell and Environment* 10:559-564.
- Maas, E.V. and Nieman, R.H. (1978). Physiology of plant tolerance to salinity. In: crop tolerance to suboptimal land condition, (ed. G. A. Jung), chapter 13. *Am. Soc. Agron. Spec. Publs.*, 32:277-299.
- Maher, M.J. (1980). Effect of root zone warming, flow rate and propagation system on tomato crop performance in NFT. *Acta Horticulturae*. 98:45-52.
- Massey, D.M., Hayward, A.C. and Winsor, G.W. (1983). Some response of tomatoes to salinity in Nutrient Film Culture. *Rep. Glasshouse Crops Res. Inst.* 1983, 60-62.
- Matsuda, K. and Riazi, A. (1981) Stress-induced osmotic adjustment in growing regions of barley leaves. *Plant Physiol.* 68:571-576.
- Meiri, A., Mor, E. and Poljakoff-Mayber, A. (1970). Effect of time of exposure to salinity on growth, Water status and salt accumulation in bean plants. *Annals of Botany*. 34:383-391.
- Meiri, A. and Poljakoff-Mayber, A. (1970). Effect of various salinity regimes on growth, leaf expansion and transpiration rate of bean plants. *Soil Science* 109:26-34.

references

- Menhenett, R. and Wareing, P.F. (1975). Possible involvement of growth substances in the response of tomato plants (*Lycopersicon esculentum* Mill.) to different soil temperature. J. Hort. Sci. 50:381-397.
- Meyer, R.E. and Gingrich, J.R. (1966). Osmotic stress effects on wheat using a split root solution culture system. Agronomy Journal 58:377-381.
- Ministry of Agriculture, Fisheries and Food (1983). cucumber production. ADAS. Part 1, varieties.
- Mizrahi, Y. (1982). Effect of salinity on tomato fruit ripening. Plant Physiol. 69:966-970.
- Mizrahi, Y. and Pasternak, D. (1985). Effect of salinity on quality of various agricultural crops. Plant and Soil 89:301-307.
- Molz, F.J. and Klepper, B. (1972). Radial propagation of water potential in stems. Agronomy Journal 64:469-473.
- Mongeau, R. and Stewart, K.A. (1984). Effect of solution temperature on the growth and development of lettuce cv. ostinata. ISOSC proceedings 1984. Sixth international congress on soilless culture, Lunteren PP. 387-392.
- Moorby, J. and Graves, C.J. (1980). Root and air temperature effect on growth

and yield of tomato and lettuce. *Acta Horticulturae* 98:29-45.

Moustafa, A.T. and Morgan, J.V. (1984). The effect of root zone warming and air temperature on dry matter accumulation, nutrient uptake and nutrient absorption on spray chrysanthemum in NFT. ISOSC proceeding 1984. Sixth international congress on soilless culture, Lunteren PP. 401-419.

Munns, R., Greenway, H., Delane, R. and Gibbs, J. (1982). Ion concentration and carbohydrate status of the elongation leaf tissue of *Hordeum vulgare* growing at high external NaCl. *Journal of Experimental Botany* 33(135):574-583.

Munns, R. and Termaat, A. (1986). Whole plant response to salinity. *Aust. J. Plant Physiol.* 13:143-160.

Munns, R. (1988). Why measure osmotic adjustment ? *Aust. J. Plant Physiol.* 15:717-726.

Munns, R., Gardner, P.A., Tonnet, M.L. and Rawson, H.M. (1988). Growth and development in NaCl-treated plant 11. Do Na⁺ or Cl⁻ concentration in dividing or expanding tissue determine growth in barley ? *Aust. J. Plant Physiol.* 15:529-540.

Nakamura, Y., Tanaka, K., Ohta E. and Sakata, M. (1990). Protective effect of external Ca²⁺ on elongation and the intracellular concentration of K⁺ in

references

- intact mung bean root under NaCl stress. *Plant Cell Physiol.* 31(6): 815-821.
- Nassery, H., Ogata, G. and Mass, E.V. (1979). Sensitivity of sesame to various salts. *Agronomy Journal.* 71:595-597.
- Neumann, P.M., Van Volkenburgh, E. and Cleland, R.E. (1988). Salinity stress inhibits bean leaf expansion by reducing turgor, not cell wall extensibility. *Plant Physiol.* 88:233-237.
- Newton, P., Sahraoui, R. and Sherif, M.A. (1988). The influence of nutrient solution temperature on the root growth and nutrient uptake by cucumber, cv. Corona, Grown using the nutrient film technique. ISOSC proceeding. Seventh international congress on soilless culture, Flevohof 1988. PP. 335-351.
- Nieman, R.H. (1962). Some effect of sodium chloride on growth, photosynthesis and respiration of twelve crop plants. *Botanical Gazette* 123:279-235.
- Nukaya, A., Masui, M. and Ishida, A. (1983). Salt tolerance of muskmelons as affected by various salinities in nutrient solution culture. *J. Jap. Soc. Hort. Sci.* 52(2):167-173. In: *Hort. Abstracts* 1984 Vol.54 No.8.
- Nukaya, A., Masui, M. and Ishida, A. (1984) Salt tolerance of muskmelons 5372 as affected by diluted sea water applied at different growth stage in

references

- nutrient solution culture. J. Jap. Soc. Hort. Sci. 53(2):168-175. In: Hort. Abstracts 1985 Vol.55 No.1.
- Orchard, B. (1980). Solution heating for tomato crop. Acta Horticulturae 98:19-28.
- Papadopoulos, A.P. and Tiessen, H. (1983). Root and air temperature effect on flowering and yield of tomato. J. Amer. Soc. Hort. Sci. 108(5):805-809.
- Papp, J.C., Ball, M.C. and Terry, N. (1983). A comparative study of the effects of NaCl salinity on respiration, photosynthesis and leaf extension growth in *Beta vulgaris* L. (sugar beet). Plant, cell and Enviroment 6:675-677.
- Pasternak, D. (1987). Salt tolerance and crop production - A comprehensive approach. Ann. Rev. Phytopathol. 25:271-291.
- Pessarakli, M. and Tucker, T.C. (1988). Dry matter yield and nitrogen-15 uptake by tomatoes under sodium chloride stress. Soil Sci. Soc. Am. J. 52:698-700.
- Pessarakli, M., Huber, J.T. and Tucker, T.C. (1989). Dry matter yield, nitrogen absorption and water uptake by sweet corn under salt stress. Journal of Plant Nutrition. 12(3):279-290.
- Ramani, S., Joshua, D.C. and Shaikh, M.S. (1989). Response of sesbania species to salinity when grown hydroponically. Journal of Plant Nutrition. 12(12):1-

references

447-1455.

Raschke, K. (1970). Leaf hydraulic system: rapid epidermal and stomatal response to changes in water supply. *Science*. 167:189-191.

Rawson, H.M. and Munns, R. (1984). Leaf expansion in sunflower as influenced by salinity and short-term changes in carbon fixation. *Plant, Cell and Environment* 7:207-213.

Schwarz, M. (1985). The use of saline water in hydroponics. *Soilless culture* 1(1):25-34.

Schwarz, M. and Gale, J. (1984). Growth response to salinity at high levels of carbon dioxide. *Journal of Experimental Botany*. 35(151):193-196.

Seemann, J.R. and Critchley, C. (1985). Effect of salt stress on the growth, ion content, stomatal behaviour and photosynthetic capacity of a salt-sensitive species, *Phaseolus vulgaris*, L. *Planta* 164:151-165.

Shah, S.H., Wainwright, S.J. and Merrett, M.J. (1990). The interaction of sodium and calcium chloride and light on growth, potassium nutrition and proline accumulation in callus cultures of *Medicago sativa* L. *New Phytol.* 116:37-45.

references

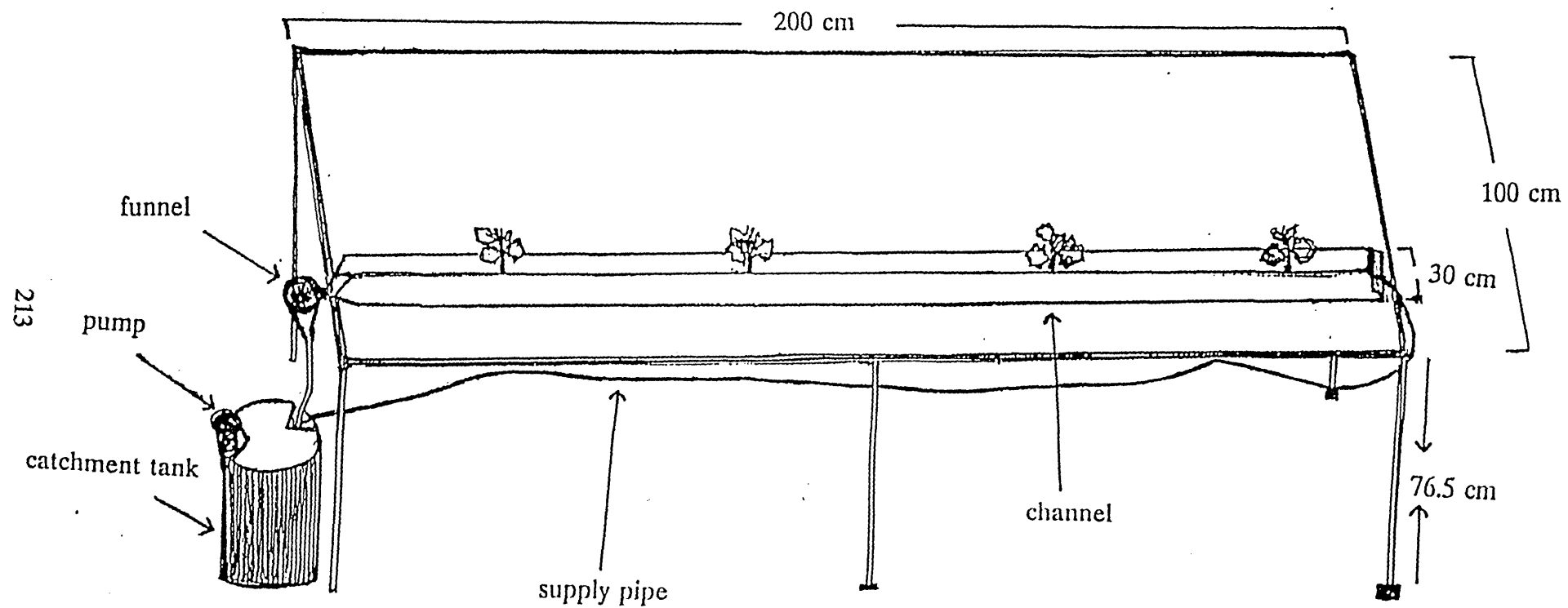
- Silberbush, M., Golan-Goldhirsh, A., Heimer, Y., Ben-Asher, J. and Lips, S.H. (1988). Response of peanuts (*Arachis hypogaea* L.) grown in saline nutrient solution to potassium nitrate. J. Plant Physiol. 132:229-233.
- Silberbush, M. and Ben-Asher, J. (1989). The effect of NaCl concentration on NO_3^- , K^+ and orthophosphate-P influx to peanut roots. Scientia Horticulturae 39:279-287.
- Sonneveld, C. (1981). Irrigation and nutrition of glasshouse cucumber in the Netherlands. Proc. Annu. Western greenhouse Veg. Growers Conf. 1981, pp 1-14.
- Sonneveld, C. (1988). The salt tolerance of greenhouse crops. Netherland Journal of Agricultural Science 36:63-73.
- Starkey, N.G. (1977). Cucumber : Nutrient film technique - Effect of solution temperature and potting media on crop performance. Lee Valley Experimental Horticulture Station. Ann. Rep. 1977 P. 20-21.
- Steiner, A.A. (1980). The selective capacity of plants for ions and its importance for the composition and treatment of the nutrient solution. Fifth international congress on soilless culture. Wageningen 1980. International society for soilless culture. pp 83 -95.
- Subbarao, G.V., Johansen, C., Jana, M.K. and Kumar Rao, J.V.D. (1990) Effect of the sodium / calcium ratio in modifying salinity response of pigeonpea

- (*Cajanus cajan*). J. Plant Physiol. 136:439-443.
- Termaat, A., Passioura, J.B. and Munns, R. (1985). Shoot turgor does not limit shoot growth of NaCl-Affected wheat and barley. Plant Physiol. 77:869-872.
- Turner, A.C. (1981). Techniques and experimental approaches for the measurements of plant water status. Plant and Soil 58:339-366.
- Varley, J. and Burrage, S. (1981). New solution for lettuce. Grower 95(15):19-25.
- Voogt, W. (1981). What electrical conductivity (EC) for cucumber in rockwool ? Groenten en fruit (1981) 36(34) 26-27 (IN,1pl) Proefstation voor de Tuinbouw onder glas, Naaldwijk, Netherlands. In: Hort. abstracts, 1981 Vol.51 No.11.
- Walker, R.R., Torokfalvy, E. and Behhoudian, M.H. (1988). Photosynthetic rates and solute partitioning in relation to growth of salt-treated pistachio plant. Aust.J. Plant Physiol. 15:787-798.
- Wannmaker, M.J. and Pike, L.M. (1987). Onion responses to various salinity levels. J. Amer. Soc. Hort. Sci. 122(1):49-52.
- Watts, W. R. (1972). Leaf extension in *Zea mays*. 1. Leaf extension and water relation in relation to root-zone and air temperature. Journal of Experimental Botany, 23:704-712.

references

- Withers, B. and Vipond, S. (1974). Irrigation, design and practice. Batsford. Academic, London.
- Yang, Y.W., Newton, R.J. and Miller, F.R. (1990). Salinity tolerance in *Sorghum*.
1. Whole plant response to sodium chloride in *S. bicolor* and *S. halepense*.
Crop Science 30:775-781.
- Yeo, A.R., Caporn, J.M. and Flowers, J. (1985). The effect of salinity upon photosynthesis in rice (*Oryza sativa* L.): Gas exchange by individual leaves in relation to their salt content. Journal of Experimental Botany 36(169):1-240-1248.
- Yelle, S., Gosselin, A. and Trudel, M.J. (1987). Effect of atmospheric CO₂ concentration and root-zone temperature on growth, mineral nutrition, and nitrate reductase activity of greenhouse tomato. J. Amer. Soc. Hort. Sci. 112(6):1036-1040.
- Zayed, A.M. (1987). The influence of sodium chloride on the ion uptake and yield of tomatoes and lettuce grown in hydroponics. PhD, University of London, Wye college.
- Ziska, L.H. Seemann, J.R. and Dejong, M.T. (1990). Salinity induced limitations on photosynthesis in *Prunus salicina*, a deciduous tree species. Plant Physiol. 93:864-870.

APPENDICES



Appendix Figure 1: Diagram of the experiment layout.

Appendix Table 2. Chemical composition of Wye solution. (Varely and Burrage 1981)

Stock solution A:

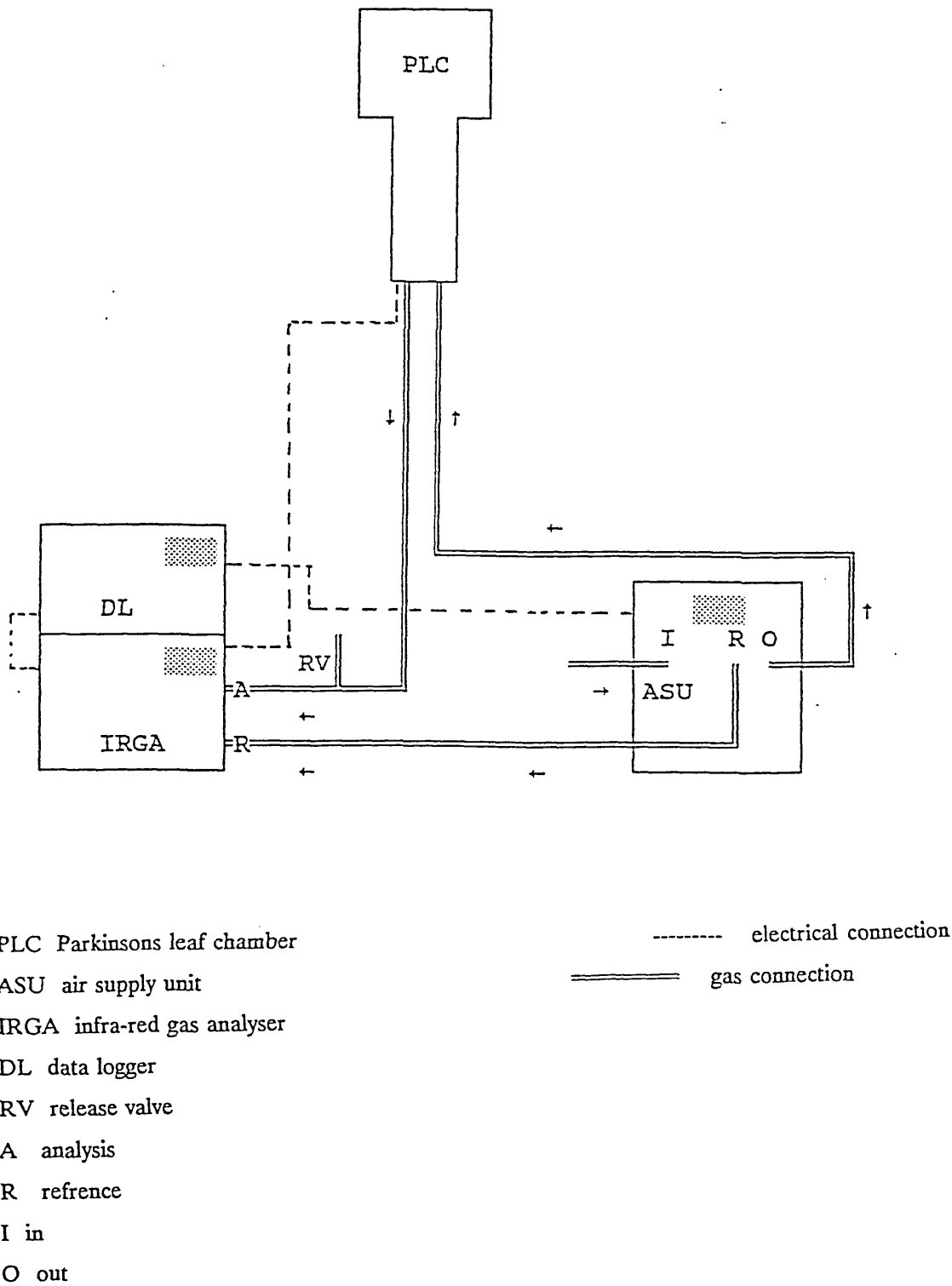
Compound	Formulae	Kg/100 litres
Potassium nitrate	KNO_3	8.295
Magnesium nitrate	$\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	3.27
Potassium dihydrogen orthophosphate	KH_2PO_4	2.070
Potassium sulphate	K_2SO_4	3.665
Iron chelate	FeEDTA	0.400
Vytel chelate Mix		0.588

Stock solution B:

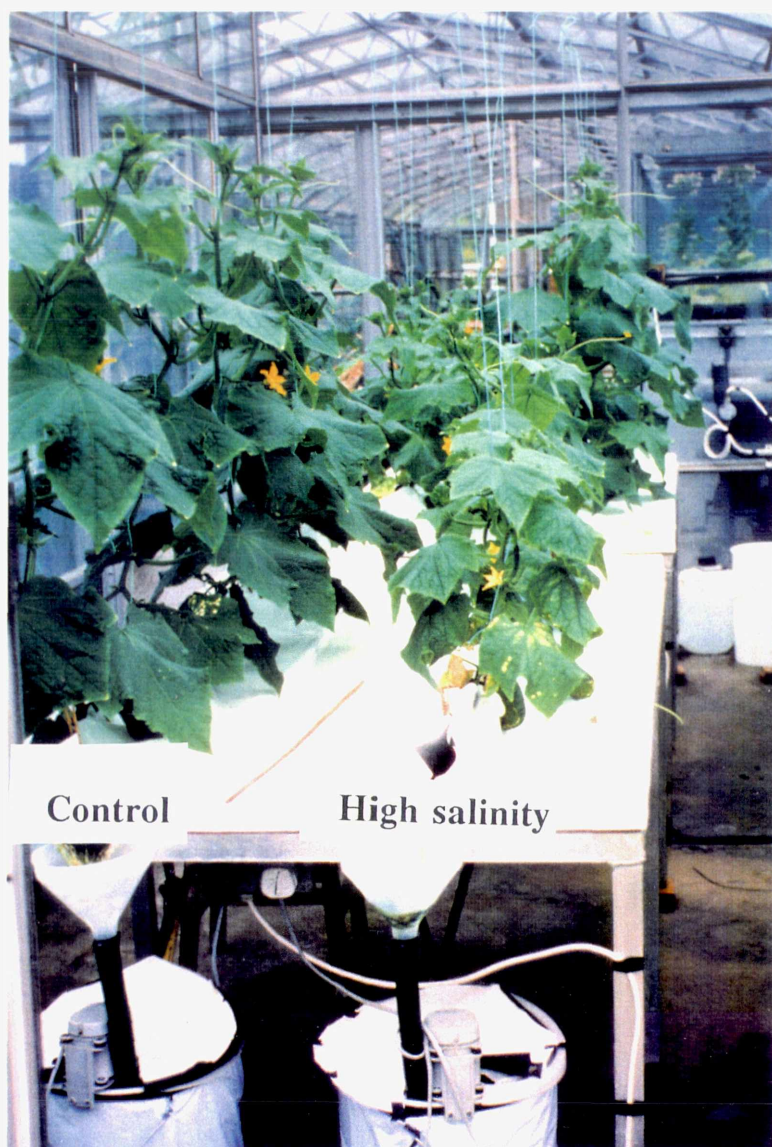
Compound	Formulae	Kg/100 litres
Calcium Nitrate	$\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$	4.33

* pH was corrected by using 5% acid mixture of nitric acid and orthophosphoric acid (3:1)

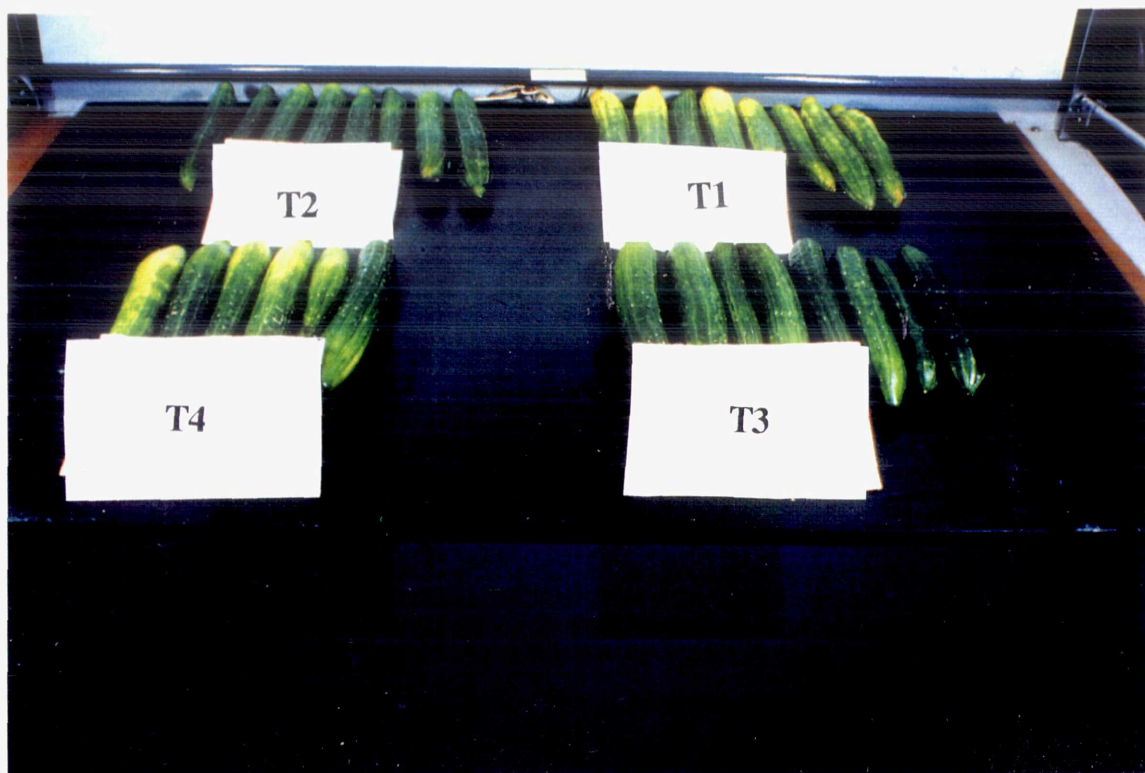
Appendix Figure 3. Connections of the infra-red gas analyzer (LCA2) during leaf gas exchange measurements.



Appendix plate 4. Cucumber plants grown under high salinity (8.5 mS cm^{-1}) compare to the control plants (2.5 mS cm^{-1}).



Appendix plate 5. Cucumber fruit of plants grown at different salinity regimes.



T1 = 2.0 - 2.5 mS cm⁻¹

T2 = 4.0 - 4.5 mS cm⁻¹

T3 = 6.0 - 6.5 mS cm⁻¹

T4 = 8.0 - 8.5 mS cm⁻¹

Appendix Table 6. Analysis of the tap water used in the experiments:

	Formula	mg/l
Alkalinity	CaCO ₃	239
Hardness total	CaCO ₃	267
Chloride	Cl	19
Nitrate	N	3.9
Sulphate total	SO ₄	10
Calcium total	Ca	102
Magnesium total	Mg	3.0
Iron 2,3 total	Fe	< 0.02
Manganese total	Mn	< 0.02
Sodium total	Na	10
Potassium total	K	1.2
pH 7.1 unit		
Conductivity 526 US/CM		

* Source: The Mid Kent Water Company

* Date 01/02/89

* Location: Wye.