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FINAL REPORT

COORDINATED USE OF MARGINAL WATER RESOURCES IN ARID AND DESERT AREAS

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TABLE OF CONTENT

Subject	Page
Executive Summary	I
Coordinated use of marginal water resources in arid and desert areas	3
Introduction	3
Research Objective	3
Site Locations	4
The response of above ground biomass production of *Acacia saligna* to several watering regimes and water quality	6
Material and Methods	6
Results and Discussion	9
Leaf Water Potential measurements	15
Introduction	15
Results	16
Evaluation of the efectiveness of Run-off in leaching salts in soils irrigated with brackish water in the Negev	19
Abstract	19
Introduction	19
Material and Methods	20
Results and Discussion	21
References	23
Physiological studies on the response of Acacia salignato salinity and nitrogen	25
Biomass production as affected by Nitrate	25
Salt tolerance to Nitrogen	26
Leaf area	28
N_2 fixing nodules	28
Transpiraion rate during growth	29
Effect of salinity, nitrate and Molybdenum on biomass production and Nitrate assimilation in trees of *Acacia saligna*	31
Introduction	31
Plant material	31
Chemical analysis	32
Results	32
Conclusions	40
Studies of Acacia plants under hydroponic conditions	41
Effect of Runoff and suplemental irrigation using brackish water On growth and some gas exchange parameters of *Acacia Saligna* in Arid North West Kenya	46
Introduction	46
Material and Methods	47
Results	50
References	55
Summary	57

Executive Summary

Overgrazing and tree felling are among the leading causes of desertification in the arid and semi-arid zones of developing countries Precipitation in these areas is usually low and erratic However, large volumes of runoff water can frequently be harvested, conveyed to and trapped in dike surrounded plots in which the water infiltrates Trees planted in these plots after flooding grow well and high yields may be attained Unexpected large gaps between rainfall and runoff events may occur and towards the end of such periods the trees may have absorbed all the water stored in their root zone and die Providing the trees with even a moderate amount of water during unexpected dry spells may ensure tree survival during the early growth stages, and/or minimum biomass productivity for adult trees

Shallow underground brackish water sources are frequently present in arid zones The high salt content usually precludes their use for the irrigation of traditional crops However, the sporadic application of brackish water to relatively resistant trees may be feasible, particularly in the case of runoff irrigated trees, in which case the salts may be leached during the flooding of the plot

Within the framework of project C11-133 "Coordinated use of marginal water resources in arid areas " we carried out field trials in Kenya and in Israel and the physiological response to brackish water was studied in pot trials in Israel We used Acacia saligna a leguminous multiple purpose fast growing shrub in all our trials In Israel we carried out controlled field trials in which the interactions between winter runoff, two levels of salinity and two irrigation frequencies were studied Brackish water (EC= 6 dSm^{1})was obtained by adding NaCl to the fresh water Cross sectional area was monitored as an indicator of biomass production The latter was always positively affected by the application of runoff No effect of brackish irrigation was evident for the two irrigation frequency treatments We added two well-watered treatments (fresh and brackish) for comparison and it these treatments we found a significant difference between fresh and brackish treatments The relation between Predawn leaf water potential (which was used for irrigation scheduling) and total amount of water in the soil was affected by salt addition, indicating that the osmotic effect in the root zone may be of importance under field conditions

The addition of NaCl to the irrigation water decreased the hydraulic conductivity of the soil surface layer The conductivity increased after flooding but not to the level it had prior to application of the salt The level which it regained after flooding after the

second irrigation year was lower than for the previous year indicating that prolonged irrigation with brackish water will irreversibly damage the hydraulic properties of the soil The area affected by salts was limited to the wetted area close to the trunks but the overall percolation of runoff water (flooding of the whole plot) proceeded at essentially the same rate for all plots Salt concentration was also monitored in the soil profile to a depth of 1 m and at three distances from the row Samples were obtained prior to and immediately after flooding Electrical conductivity and the concentration of Ca, Mg and Na were determined In all treatments irrigated with brackish water the highest concentrations were found close to the tree rows Flooding leached the salt to deeper horizons

In the Turkana area in Kenya the trial was carried out with natural brackish water pumped from a shallow acquifer Some selected physiological parameters were monitored and it appears that mid-day stomatal closure is an important water conservation strategy of the shrub studied Irrigation changed the observed pattern and no mid-day depression was observed Transpiration measurements indicated that is regulated by stomatal aperture during the drought periods and by vapour pressure deficit when water is available in the soil No effect of water quality on the measured parameters was observed

The effect of salt on some physiological processes showed that the effect of salinity can be offset, in pot trials, by the addition of nitrogen fertilizer (as nitrate) Both salinity and nitrate addition reduced nodulation The addition of Molybdenum together with Nitrate reduced even further the negative impacts of salinity in the pot grown shrubs This effect was not observed when the trial was carried out in hydroponic conditions

The results of the trials carried out in the various locations bear out our initial assumption that brackish water can be utilized to offset the severe drought which may occur between two flood events A crucial aspect of the system tested is the localized application of brackish water that allows water to percolate freely into the soil in between the salt-affected areas The long term accumulation of salts may however affect shrub response and it is therefore necessary to continue the long term monitoring of all the relevant variables

COORDINATED USE OF MARGINAL WATER RESOURCES IN ARID AND DESERT AREAS

INTRODUCTION

Overgrazing and tree felling are among the leading causes of desertification in the arid and semi-arid zones of developing countries Precipitation in these areas is usually low and erratic However, large volumes of runoff water can frequently be harvested, conveyed to and trapped in dike surrounded plots in which the water infiltrates Trees planted in these plots after flooding grow well and high yields may be attained Unexpected large gaps between rainfall and runoff events may occur and towards the end of such periods the trees may have absorbed all the water stored in their root zone and die Providing the trees with even a moderate amount of water during unexpected dry spells may ensure tree survival during the early growth stages, and/or minimum biomass productivity for adult trees

Shallow underground brackish water sources are frequently present in arid zones The high salt content usually precludes their use for the irrigation of traditional crops However, the sporadic application of brackish water to relatively resistant trees may be feasible, particularly in the case of runoff irrigated trees, in which case the salts may be leached during the flooding of the plot

The overall aim of this project was to stabilize and eventually increase the productivity of multipurpose fast growing trees (MPFGT) grown on runoff water generated from floods by adding brackish water from locally available sources during dry periods

RESEARCH OBJECTIVES

1 Assess the response of *Acacia saligna*, a multi-purpose fast growing legume shrub, to various combinations of runoff and irrigation with two levels of salt concentration

2 Assess the effect brackish water has on the physical properties of the area irrigated with brackish water

More specifically, the objectives of this project were to

1 Assess the effect supplemental irrigation and water quality have on the development and productivity of the above ground parts of MPFGT

2 Assess the effect supplemental irrigation and water quality have on nitrogen fixation patterns of the tree

3 Study the effect brackish water has on the physical properties of the irrigated area and on the overall infiltration rate

4 Determine the leaching efficiency of the runoff water and the distribution of both water and salt, after flooding

In order to meet the objectives described, we planted *Acacia saligna*, a proven multipurpose fast growing legume tree, in both countries (Kenya and Israel) and imposed a number of treatments, which will be described in details later in the report

1 Irrigated only with fresh water
2 Irrigated only with brackish water
3 Simulated runoff
4 Simulated runoff supplemented with fresh water
5 Simulated runoff supplemented with brackish water

SITE LOCATION

1. North-west Kenya - TURKANA

The Turkana Region (see attached map) is in North-Western Kenya (34° 51' East and 3° 43' North, altitude ca 390 m a s l) is well suited to runoff agroforestry due to its climatic conditions and the socio-economic situation The Turkanas are pastoralists who are increasingly engaged in violent conflicts with their neighbors over dry season grazing resources and therefore in need of alternative fodder sources The rain fall in Turkana is highly variable, a phenomena which is typical for arid regions However, it apears to follow a bimodal distribution, with "long rais" falling from April to July and "short rain" period falling from September to October The turkana traditionally crop Sorghum at the beginning of the long rainy season (April)

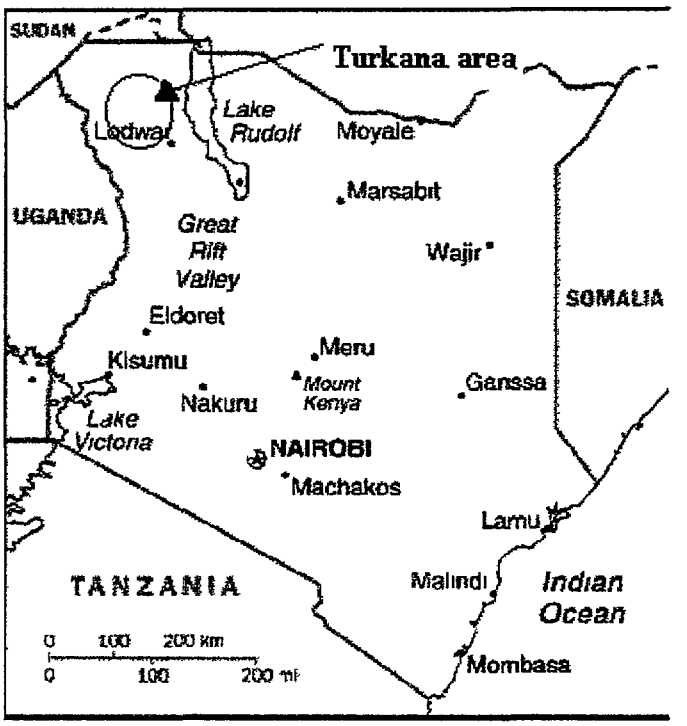
The production risk during the short rain season is regarded as too high for croping Thus the Turkana would benefit from increased prodcution and yield stability in a runoff agroforestry system

Soil characteristics will be described in the results of the Kenyan experiments

2 ISRAEL

The field trials were conducted at the Sde Boker campus (Blaustein Institute for Desert Research, Ben-Gurion University of the Negev) is situated 50 km south of Beersheva (Coordinates 30°51' North and 34°47' East)

Sede Boqer is situated within the runoff farming district in the Negev, in which many remnants are present of ancient rainwater-harvesting practices It is a hilly area largely



A map of Kenya with the site of the experiment (marked with the circle)

Sede Boqer is situated within the runoff farming district in the Negev, in which many remnants are present of ancient rainwater-harvesting practices It is a hilly area largely composed of Late Cretaceous and Early Tertiary marine carbonate rocks Altitudes in the runoff farming region ranges from 200 m in the north to about 1000 m in the south The loessial soils, shallow and stony on the slopes but one to several meters thick in the valleys, contain on the average about 15-35% fine sand, 50-65% silt, and 15-25% clay These soils form a crust, conducive to runoff production, but soils are hard when dry, but very friable and sticky when wet Nitrogen and organic matter levels are very low, typical for arid regions

The climate is very arid, the P/ETP ratio for the area ranges from 0 04 to 0 07 According to the classification of Unesco of the world distribution of arid regions the runoff farming area in the Negev borders the hyper-arid zone of the inner desert which has a P/ETP ratio below 0 03

The rainy season lasts from about October to March, while the rest of the year is almost completely dry The average annual rainfall in the area is about 90 mm

THE RESPONSE OF ABOVE GROUND BIOMASS PRODUCTION OF *ACACIA SALIGNA* TO SEVERAL WATERING REGIMES AND WATER QUALITY

P R BERLINER AND J E EPHRATH

MATERIALS AND METHODS

The soil in the experimental site is a sandy clay loam Prior to planting soil mechanical composition was determined on soil samples obtained from various locations within the experimental field Additional samples were analyzed for N, P, K, organic matter, pH, EC and ESP Results from soil analysis are presented in Table 1

Table No 1 Soil properties for the Sede Boqer experimental site Standard deviations in parenthesis (Org M total organic matter on dry mass basis, EC electrical conductivity in the saturated paste extract, CEC Cation exchange capacity on dry soil basis ESP exchangeable sodium percentage)

Depth (m)	Clay (%)	Silt (%)	Sand (%)	Org M (%)	EC (dS $^{m\ 1}$)	pH	CEC (meq/100 gr soil)	ESP
0 00-0 15	18 6	21 2	60 2	0 24 (0 04)	3 52 (1 07)	8 3 (0 12)	15 6 (1 59)	25 0 (3 11)
0 15-0 3	22 6	21 2	56 2	0 25 (0 02)	3 19 (1 29)	8 6 (0 28)	15 8 (0 65)	36 5 (7 66)
0 30-0 6	26 6	21 2	48 2	-----	8 03 (0 97)	8 4 (0 16)	14 0 (0 98)	59 0 (9 29)

Saplings of *Acacia saligna* were raised in a greenhouse and planted on March 1, 1995 Sixteen shrubs were planted per plot with a distance between rows of 4 m and 1 m distance between trees in the row Measurements were carried out on the four innermost trees with the rest acting as buffers Each treatment was replicated three times with a completely random distribution within each of the three blocks

The following treatments were implemented as from the 5 of August 1995

a) Controls

R	runoff
WW	well watered
WWB	well watered with brackish water

b) Treatments

RHF	runoff + irrigation when predawn XLWP reached -1 6 MPa
RLF	runoff + irrigation when predawn XLWP reached -2 0 MPa
RHFB	runoff + irrigation with brackish water when predawn XLWP reached -1 6 MPa
RLFB	runoff + irrigation with brackish water when predawn XLWP reached -2 0 MPa
HF	irrigation when predawn XLWP reached -1 6 MPa
LF	irrigation when predawn XLWP reached -2 0 MPa
HFB	irrigation with brackish water when predawn XLWP reached -1 6 MPa
LFB	irrigation with brackish water when predawn XLWP reached -2 0 Mpa

(XLWP xylem leaf water potential)

The plots were flooded with tap water (simulating runoff with an equivalent depth of 250 mm) once a year towards the end of the rainy season Irrigation with both water qualities was applied whenever two out of the three replicates reached the stipulated predawn xylem leaf water potential

Predawn XLWP was measured with a Schollander bomb The leaves were wrapped in a polyethylene bag, excised and stored in a cool box Potentials were measured after all leaves had been collected No differences between potentials obtained with this technique than with those that were measured immediately after excision were found in a preliminary study

The volume of water applied was computed from the deficit between water content at Field Capacity and water contents (to a depth of 1 05 m) determined on the day previous to the LWP measurements Soil water content was measured with a neutron probe Access tubes to a maximum depth of 3 m were inserted in the row mid-way between two measurement trees The depth in each plot varied according to soil conditions An almost impassable chalk layer was found at depths that varied between 2 5 and 3 m To insert the tubes a special percussion auger with a hydraulic extractor was used Well-watered plots were irrigated twice a week and the volume of water applied determined as described above

Irrigation was applied with a drip irrigation system with pressure regulated emitters Each of the four rows of trees within each plot were surrounded by a dike-like structure (made of plastic sheets) with a width of 1 m This ensured no surface water flow outside the dike Due to the relatively low hydraulic conductivity and the small distance between emitters the area bounded by the dike was usually flooded

The EC of the water for plots irrigated with water from the Israeli National Water Carrier was 0 4 dS m^{-1}, while that of the plots irrigated with brackish water was 6 0 dS m^{-1}, prepared by adding NaCl to the tap water The total amounts of water applied during the first four years are presented in Table No 2

	Irrigation Treatments						
	Control	HF	LF	HFB	LFB	WW	WWB
Irrigation (no-runoff applied)		2226	1815	2024	1755	3260	2635
Irrigation + Runoff	1066	3375	2603	2961	2675		

Table No2 Total amounts of water applied during the trial (four years)

It was not possible to estimate biomass directly due to the small number of trees Biomass was therefore estimated from trunk cross sectional area (CSA) using previously established allometric equations We tested the possible effects of brackish water on the CSA-biomass relations, The results (Fig 1) show no significant differences in the biomass-CSA regressions for trees which were irrigated with brackish water and those that had been irrigated with tap water We therefore pooled the data and used the same equation for the biomass estimations of all treatments

Infiltrability was measured before and after flooding in selected plots using a falling head permeameter Three replicate measurements per plot were carried out

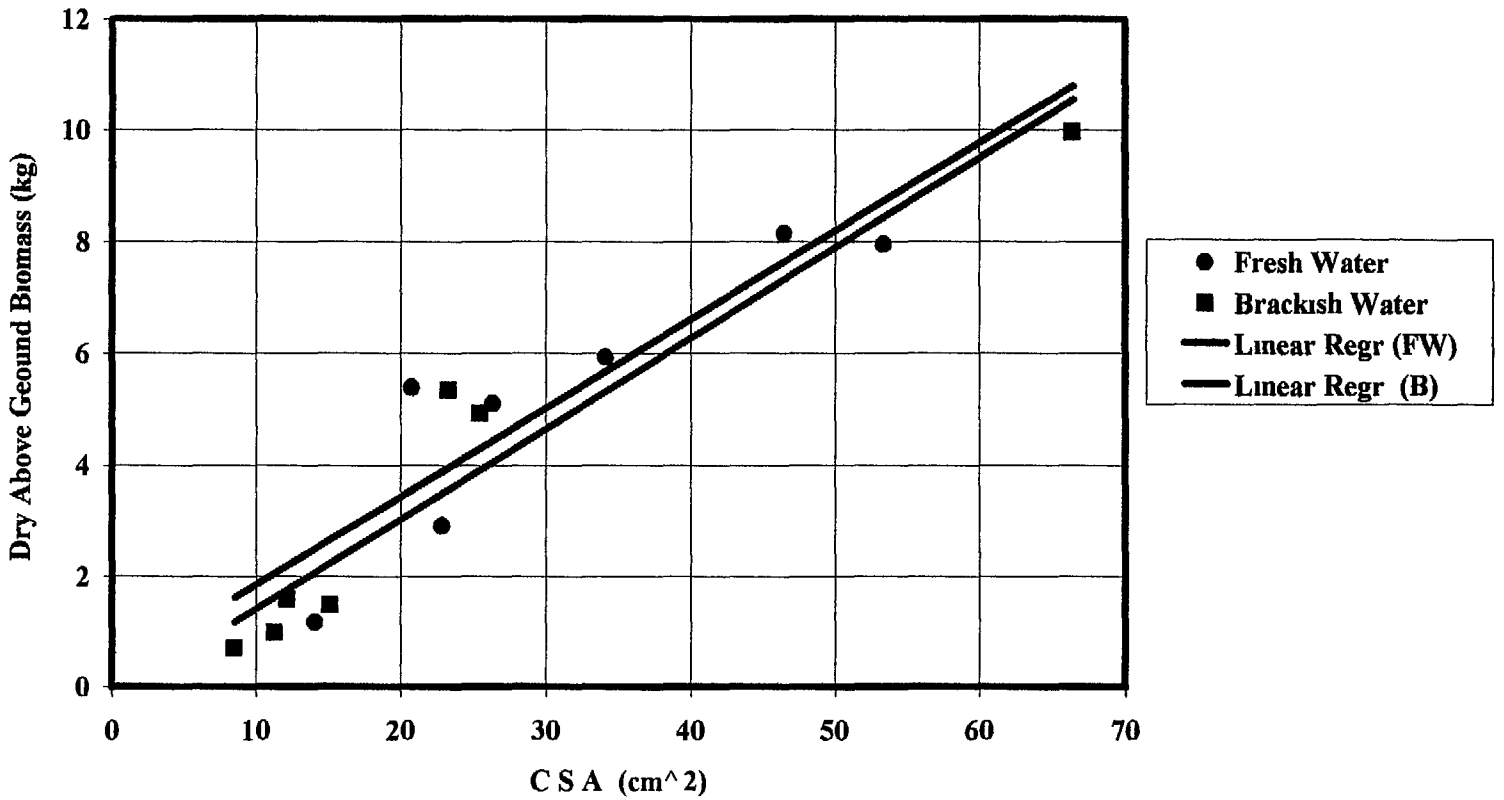


Fig 1. Above ground dry biomass as a function of CSA for *Acacia saligna* trees irrigated with fresh and brackish water

D RESULTS AND DISCUSSION

The developments of the CSA's of various treatments are presented in Figs 2-11 The decrease in biomass production due to the use of brackish water in the well-watered treatments is clear (Fig 2) The effects of irrigation frequency for both water qualities are presented in Figs 3 and 4 The fact that there was no difference in productivity for the two lower brackish irrigation frequencies is noteworthy In Fig 5 the two lowest irrigation frequencies for both water qualities are presented It is interesting to note that both treatments irrigated with brackish water performed better that LF In Figs 6 and 7 the effect of flooding and irrigation frequency (well watered, high and low) for both water qualities are presented The differences between treatments is more marked for the tap water than for the brackish water In Fig 8 the effect of runoff in addition to irrigation is presented For both frequencies runoff improves productivity The same trend is evident in Fig 9 for the corresponding brackish irrigation treatments In Fig 10 we compare the treatments which were irrigated with both water qualities at two frequency levels and received runoff The same trend that was evident in Fig 5 can be observed the CSA of R+LFB is slightly lower than that of R+HFB and the inversion between the frequencies of the brackish treatments occurs two years after flooding

The CSA data was statistically analyzed for a number of dates (319, 734, 974, 1012 and 1278 dap) The first analysis was performed on the standing biomass and the second on the biomass production in the intervals between the above mentioned dates Due to the introduction of well watered and runoff only treatments the design was non-balanced We carried out therefore a number of ANOVA's on a variety of treatment combinations Throughout the analysis the use of the word significant means significant at the 5% level

I STANDING CSA ANALYSIS

1 Fresh water irrigation only (without runoff) For DAP 319 the Low Frequency (LF) treatment yielded significantly less than High Frequency (HF) and Well Water (WW) At DAP 734, 974 and 1012 the three irrigation frequencies produced significantly different CSA's (WW>HF>LF) OnDAP1278 WW produced a significantly higher CSA than HF&LF

2 Brackish water irrigation only (without runoff) No significant differences were found for DAP319 For the rest of the dates WWB was significantly higher than HFB&LFB

3 Fresh and brackish irrigation (without runoff) On DAP319 frequency and the interaction were significant At low frequency brackish treatments produced larger CSA than the freshwater treatments At higher frequencies the opposite was true On DAP734 freq, salinity and their interactions were significant Fresh CSA's were significantly higher than brackish ones and WW was significantly higher than HF&LF Interestingly enough the interactions between factors showed that for the lowest frequency brackish irrigation resulted in larger CSA's than those irrigated with fresh water For the other two irrigation treatments (HF&WW) the opposite was true The same results were obtained for DAP974 and DAP1012 On DAP1278 only Frequency and interactions were significant The highest frequency (WW) produced significantly more than the other two treatments The same pattern of interactions as described for the previous dates was observed

4 Fresh and brackish irrigation with and without Runoff (only runoff and well watered plots excluded) On DAP319 frequency and runoff were significant factors, HF and runoff increasing CSA On the following dates the following pattern was repeated Only runoff was a significant factor (addition resulted in higher CSA's) and a significant interaction between frequency and salinity was observed For LF irrigation w/brackish water resulted in higher CSA's and the opposite was true for HF On DAP1278 only runoff was significant

II CSA PRODUCTION DURING INTERVALS

The production during four periods (DAP319-DAP734, DAP734-DAP974, DAP974-DAP1012, DAP1012-DAP1278 denominated as periods 1 through 4 respectively) was analyzed

1 Fresh and brackish irrigation (without runoff) For the first two periods both factors (frequency and salinity) were significant No salinity resulting in higher CSA's and the highest frequency (WW) resulting in higher CSA's as well The interactions between frequency and salinity resulted in the same pattern as described previously Only frequency of irrigation was significant for the third period (WW higher than the two other frequencies) and none of the factors was significant for the last period

2 Fresh and brackish irrigation with and without Runoff (only runoff and well watered plots excluded) Runoff and Freq x salinity were significant for period 1 The interaction was as described previously For period 2 frequency and runoff were significant (HF>LF and runoff higher CSA's than without) as well as the interactions between frequency and runoff The addition of runoff resulted in larger CSA's than without its addition for LF but had no effect at the higher frequency No significant factors or interactions were found for the two remaining periods

Table 1 Cross Sectional Areas (cm^2) for all plots throughout the trial period

RUNOFF	SALINITY	FREQ	REP	DAP182	DAP254	DAP319	DAP483	DAP597	DAP734	DAP767	DAP942	DAP974	DAP1012	DAP1207	DAP1263	DAP
1	0	0	1	1 1	4 5	8 0	10 2	21 5	25 7	35 6	35 7	35 9	35 7	39 1	43 4	46 0
1	0	0	2	0 9	3 3	5 9	10 1	15 0	15 6	19 3	22 6	20 5	20 8	27 7	31 5	33 5
1	0	0	3	0 8	2 4	4 7	7 7	13 7	17 8	22 3	22 1	25 9	26 1	27 3	31 2	32 7
0	0	3	1	1 4	4 6	8 2	14 6	23 3	46 4	53 2	64 8	72 7	78 1	81 7	85 9	89 5
0	0	3	2	1 2	4 6	6 5	16 0	25 7	51 1	59 2	70 1	82 1	83 5	101 8	103 7	109 1
0	0	3	3	1 0	3 2	7 0	13 7	22 2	44 4	47 5	61 2	69 3	73 8	81 9	84 9	88 6
0	1	3	1	0 9	3 6	6 8	12 1	17 1	34 2	40 8	44 4	50 6	54 1	59 2	66 9	67 4
0	1	3	2	1 0	3 3	5 7	13 4	21 2	39 2	49 5	55 5	56 9	67 3	69 7	75 6	79 7
0	1	3	3	1 6	4 2	7 2	13 0	19 2	34 1	40 5	44 8	48 3	60 0	60 3	61 7	62 8
0	0	2	1	1 2	3 6	6 4	11 6	16 1	27 9	30 8	33 6	35 0	38 0	42 9	43 8	43 4
0	0	2	2	1 7	5 1	8 2	13 4	17 3	29 4	31 1	37 9	40 6	44 9	48 8	50 0	50 3
0	0	2	3	1 2	4 7	7 5	15 5	21 4	35 0	39 0	43 0	44 8	46 8	53 6	57 7	63 2
0	0	1	1	1 7	2 7	3 8	10 4	14 9	24 5	26 7	29 4	30 6	32 6	39 1	40 5	41 0
0	0	1	2	0 6	1 7	2 7	7 4	11 2	22 8	23 1	24 5	26 1	28 7	34 8	35 8	36 9
0	0	1	3	1 1	1 9	3 3	7 5	10 7	22 3	24 3	26 6	28 5	29 0	31 7	32 7	30 9
0	1	2	1	0 8	2 7	5 0	10 4	14 6	24 5	26 2	31 0	32 5	35 9	42 6	44 7	43 3
0	1	2	2	0 9	2 9	5 4	10 6	14 5	22 4	24 9	29 1	30 5	33 1	39 3	41 3	40 7
0	1	2	3	1 0	3 7	5 7	11 5	17 3	25 7	28 5	31 9	36 7	37 8	44 2	45 3	46 5
0	1	1	1	1 3	3 0	4 2	8 8	14 8	26 7	28 0	33 4	31 6	34 9	46 3	47 4	49 0
0	1	1	2	2 5	3 6	7 2	13 7	22 5	36 9	38 0	38 6	41 5	43 6	50 6	51 8	52 4
0	1	1	3	0 6	2 3	3 6	8 6	14 6	25 0	26 4	27 1	28 3	33 1	38 4	37 1	37 6
1	0	2	1	0 8	4 1	5 7	9 5	16 8	30 0	31 3	36 5	38 3	39 7	41 9	45 1	45 6
1	0	2	2	1 1	5 8	10 1	22 5	33 9	53 6	60 2	69 0	62 2	73 9	79 1	82 5	83 0
1	0	2	3	0 8	2 5	5 6	12 0	19 4	31 6	37 9	42 3	45 0	45 8	50 4	52 9	56 9
1	0	1	1	0 9	3 1	4 6	8 7	14 3	24 6	27 7	28 8	30 3	32 1	36 8	41 1	41 4
1	0	1	2	1 0	3 6	6 0	13 2	22 5	34 5	41 4	43 7	44 3	49 2	54 0	58 8	62 0
1	0	1	3	0 8	2 9	4 4	9 9	17 3	27 0	32 7	35 4	35 5	36 8	42 6	46 0	57 8
1	1	2	1	1 5	6 2	7 7	13 9	22 1	34 0	36 5	42 0	44 6	43 2	48 3	50 9	52 2

1	1	2	2	1 5	4 6	8 1	13 6	22 1	32 3	36 0	38 8	40 7	43 1	47 8	49 5	51 3
1	1	2	3	1 3	4 3	7 7	13 9	23 8	31 1	35 8	38 8	41 9	43 1	45 6	49 7	50 5
1	1	1	1	1 3	4 8	7 5	12 7	24 4	36 0	41 4	44 4	48 8	49 8	54 9	61 8	66 1
1	1	1	2	0 7	2 9	4 5	9 2	16 4	25 5	30 5	35 0	35 8	37 6	41 6	47 0	48 7
1	1	1	3	1 2	4 3	7 8	13 9	26 0	34 3	41 2	44 0	45 3	45 6	47 0	45 5	53 5

The results of infiltrability presented in Fig 10 were obtained two and three years after the implementation of the brackish treatments The results indicate that irrigating with brackish water resulted in a decrease of the infiltrability This decrease was significant prior to flooding in 1996 Flooding in 1996 increased infiltrability which was not significantly different from the control (WW) The same trend was observed for 1997, but even though the infiltrability levels of the brackish treatment increased after flooding they were significantly lower than those of the control The infiltrability values of the corresponding treatments that were not flooded show a continuous drop

During irrigation only a small part of the surface was wetted Infiltration rates of the remaining area were therefore unaffected by irrigation During the flooding of the plots (as happens during a runoff event) water infiltrates mainly through the area not affected by the brackish irrigation We could see no systematic differences in the time it took the ponded water to disappear in the plots that had been previously irrigated with water of different qualities

E CONCLUSIONS

1 Storing of runoff water had a positive effect on tree development

2 No detrimental effect of irrigating with brackish water on biomass production at the two lowest irrigation frequencies could be detected

Infiltrability decreased as a result of periodically irrigating with brackish water even after flooding

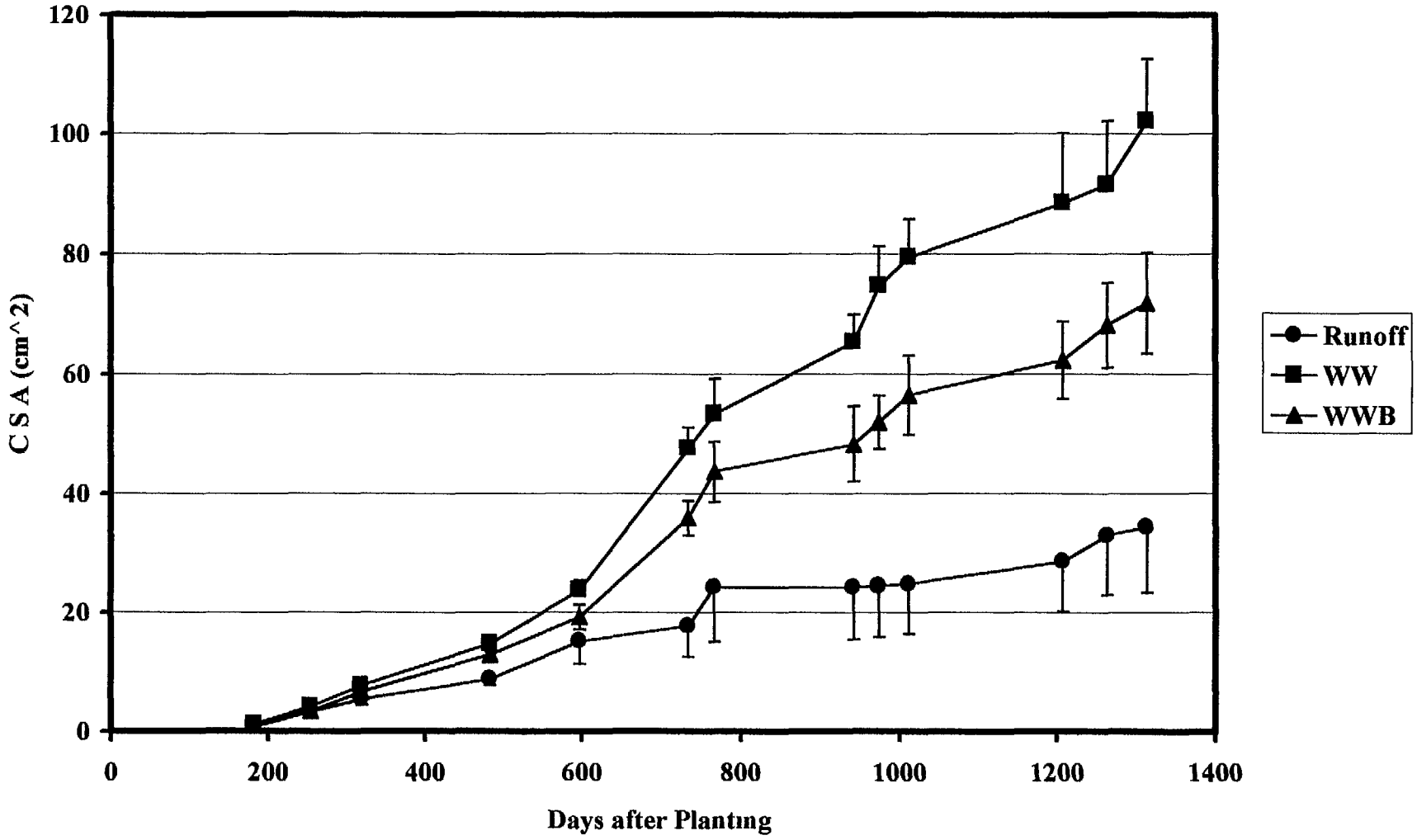


Figure 2. C.S.A. development of *Acacia saligna* of the control treatments

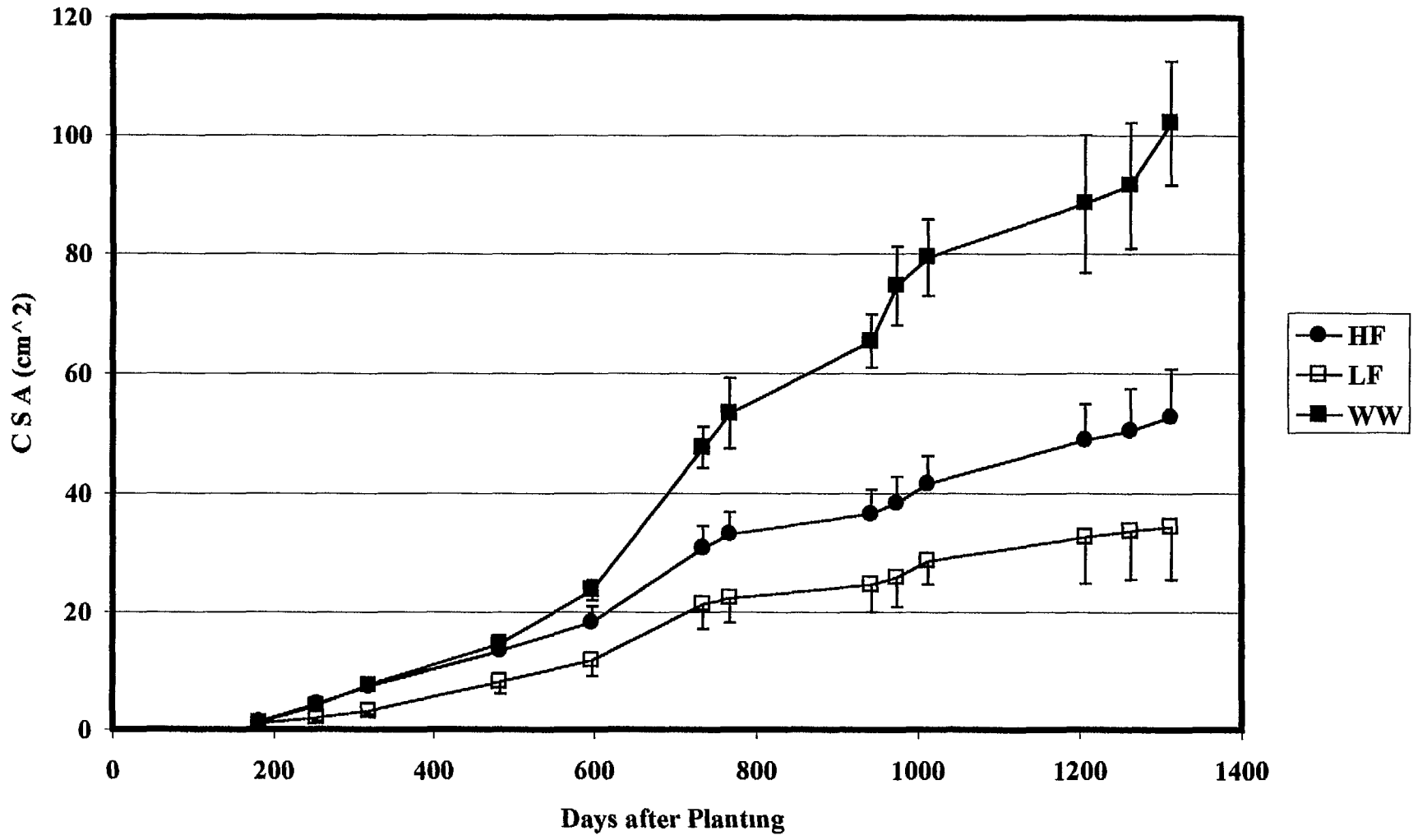


Figure 3 Effect of irrigation frequency on the C S.A. development of *Acacia saligna*

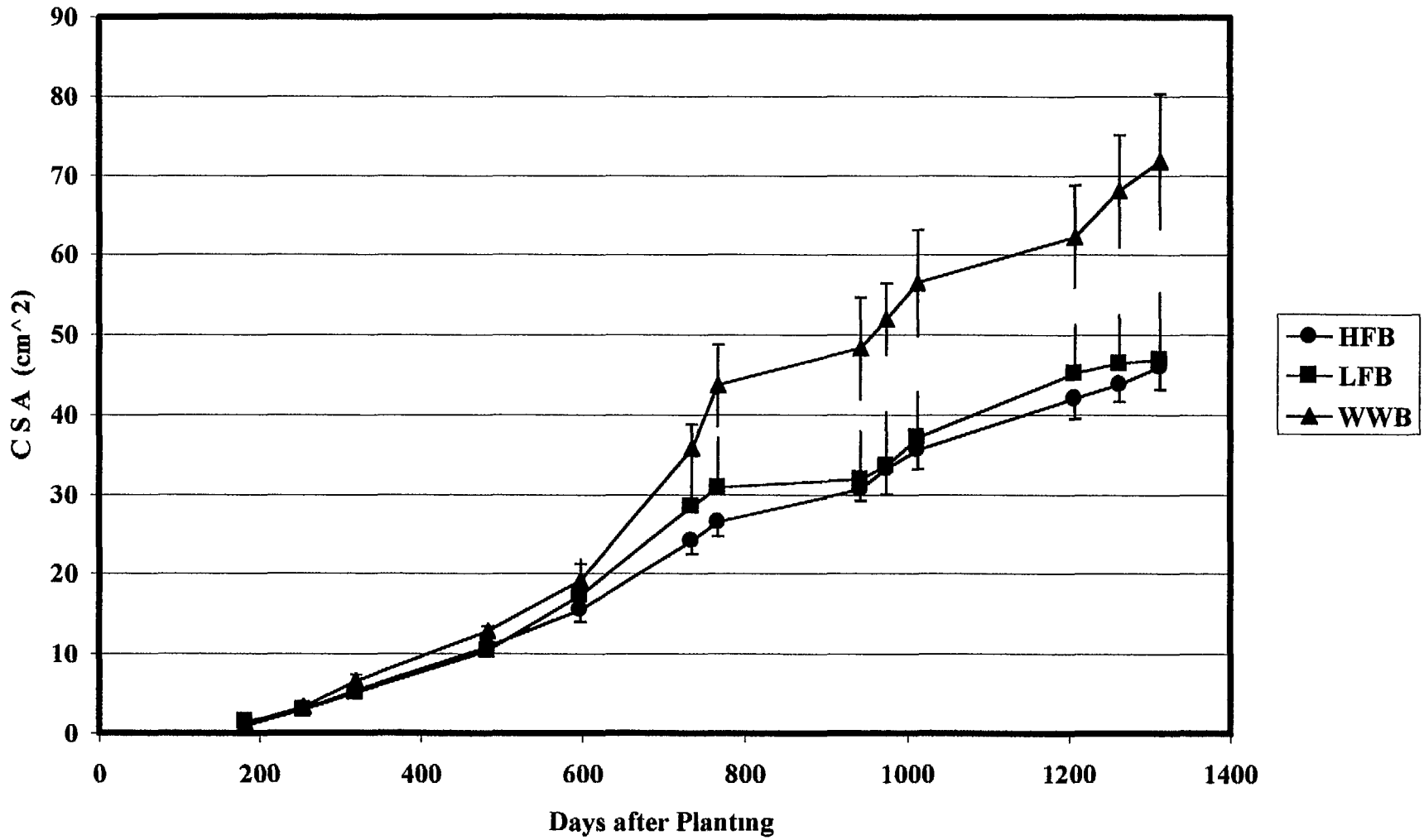


Figure 4 Effect of irrigation frequency w/brackish water on the C S A development of *Acacia saligna*

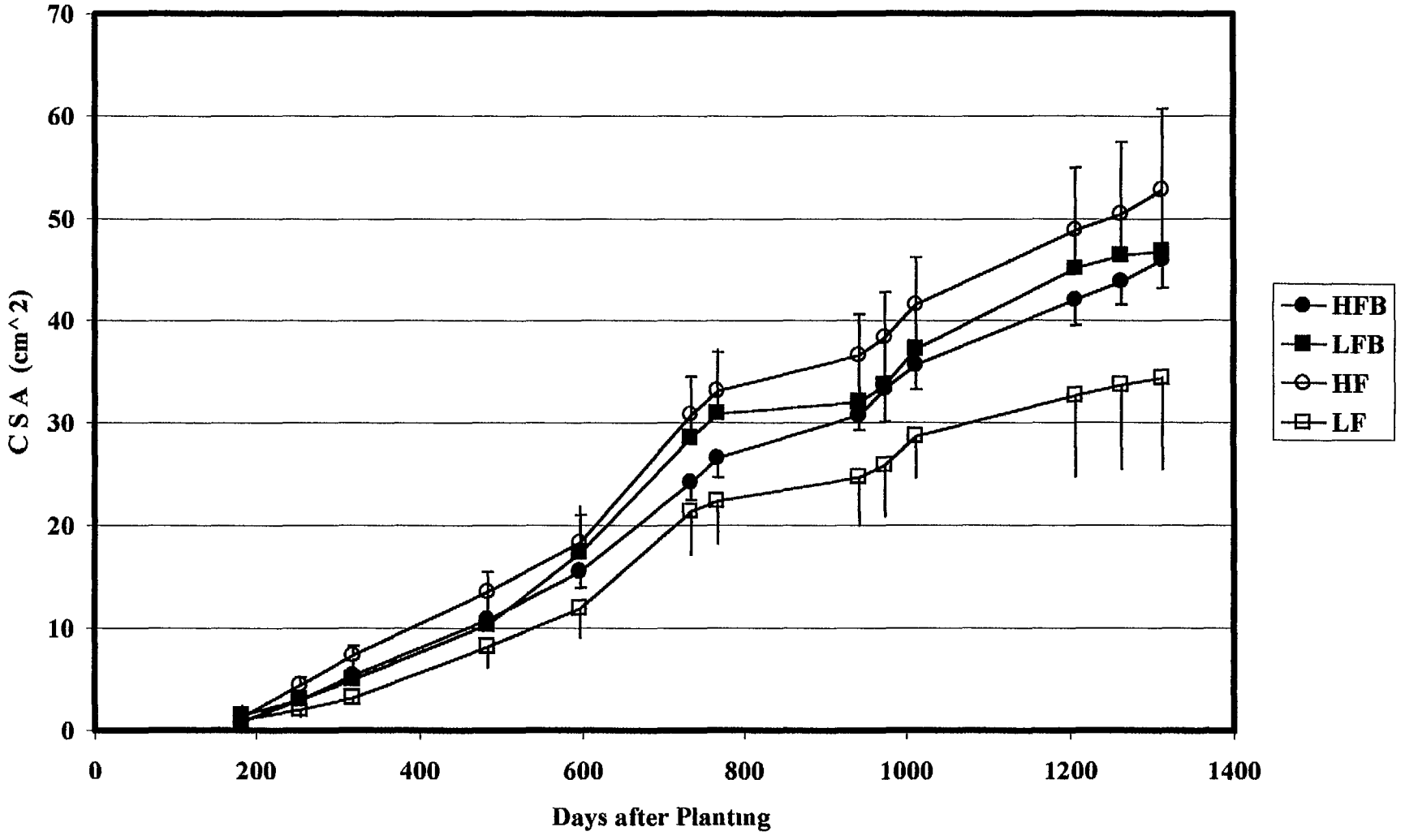


Figure 5 Effect of irrigation frequency and water quality on the C S.A. development of *Acacia saligna*

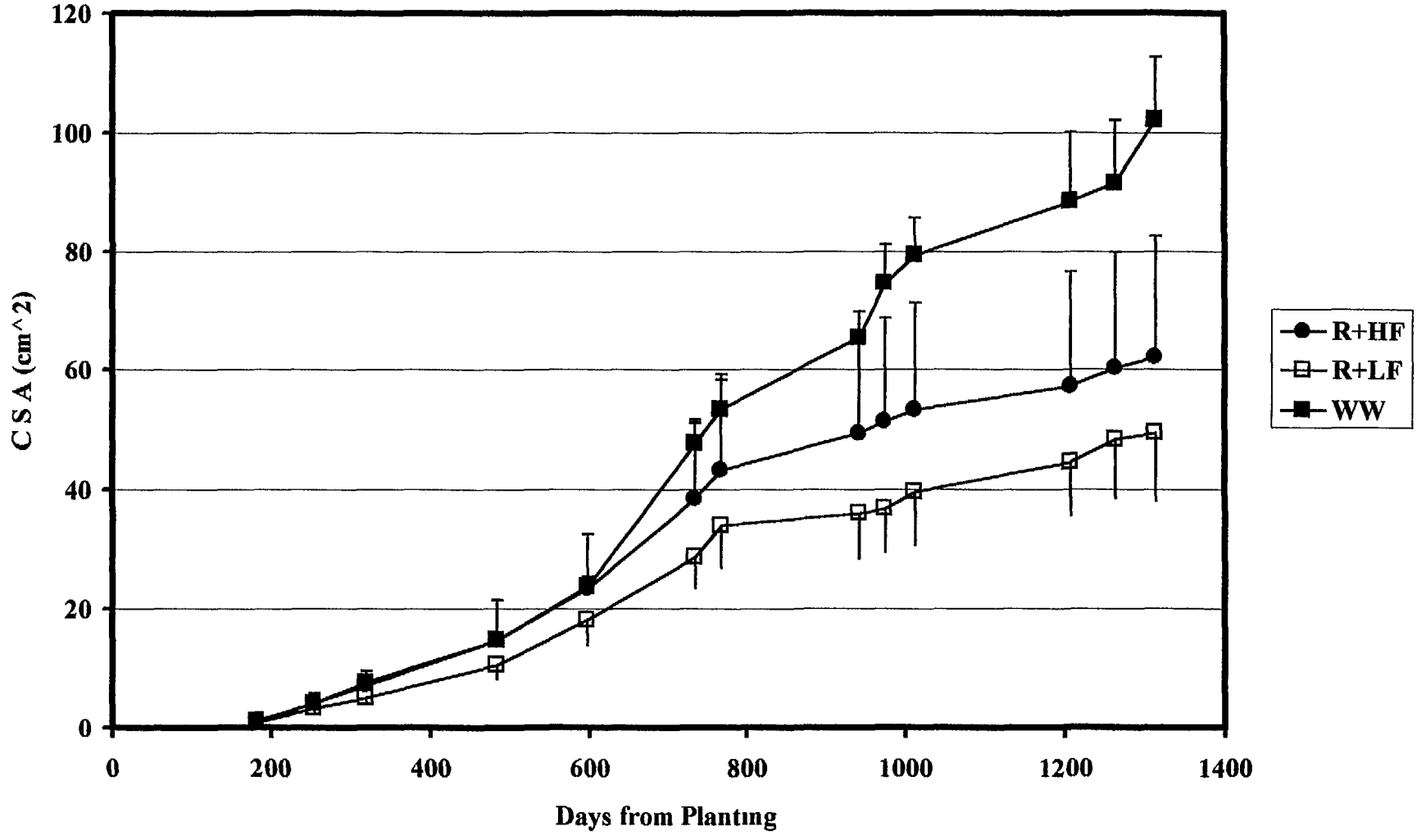


Figure 6. Effect of irrigation frequency and runoff addition on the C S.A. development of *Acacia saligna*

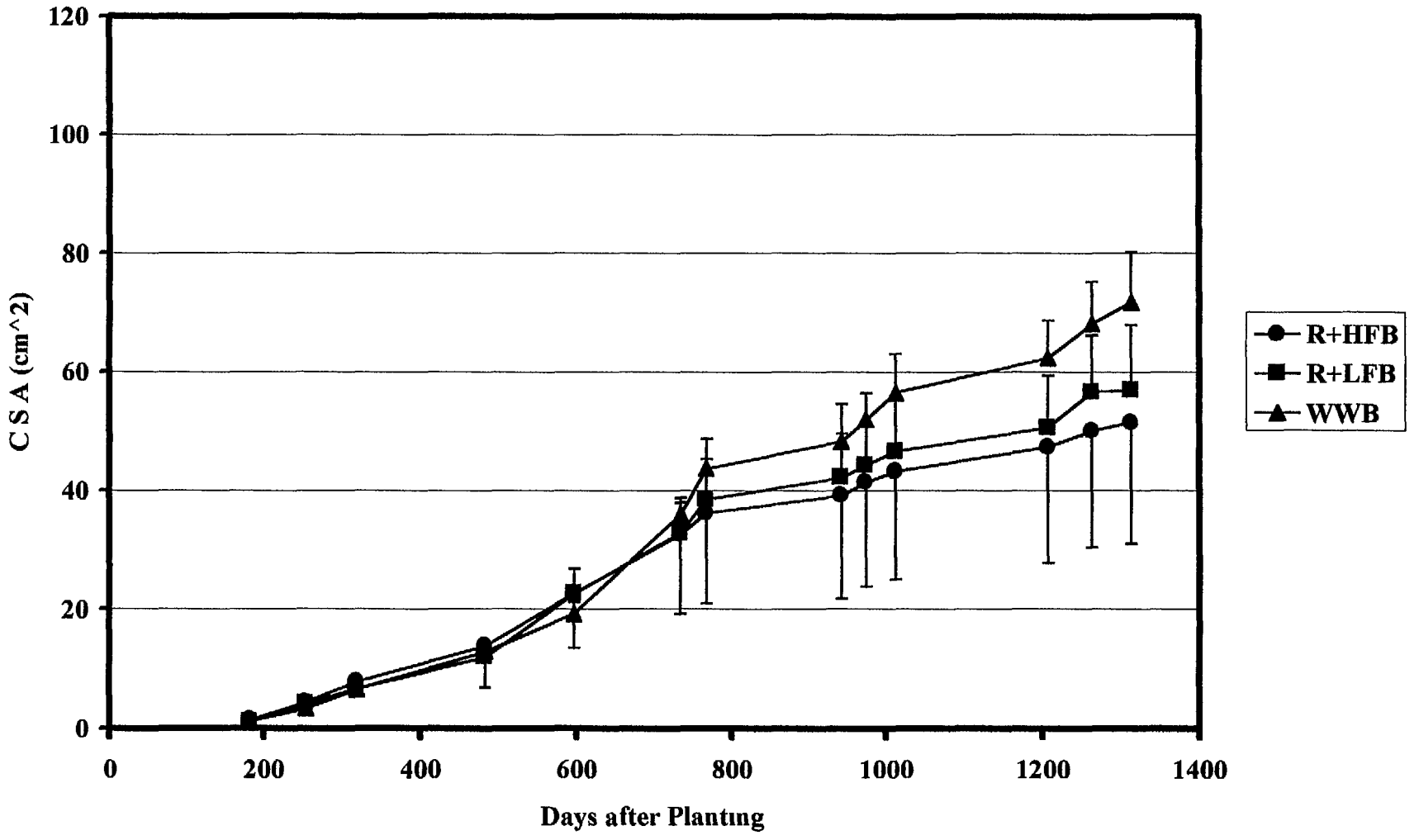


Figure 7 Effect of irrigation frequency w/brackish water and runoff on the C S A. development of *Acacia saligna*

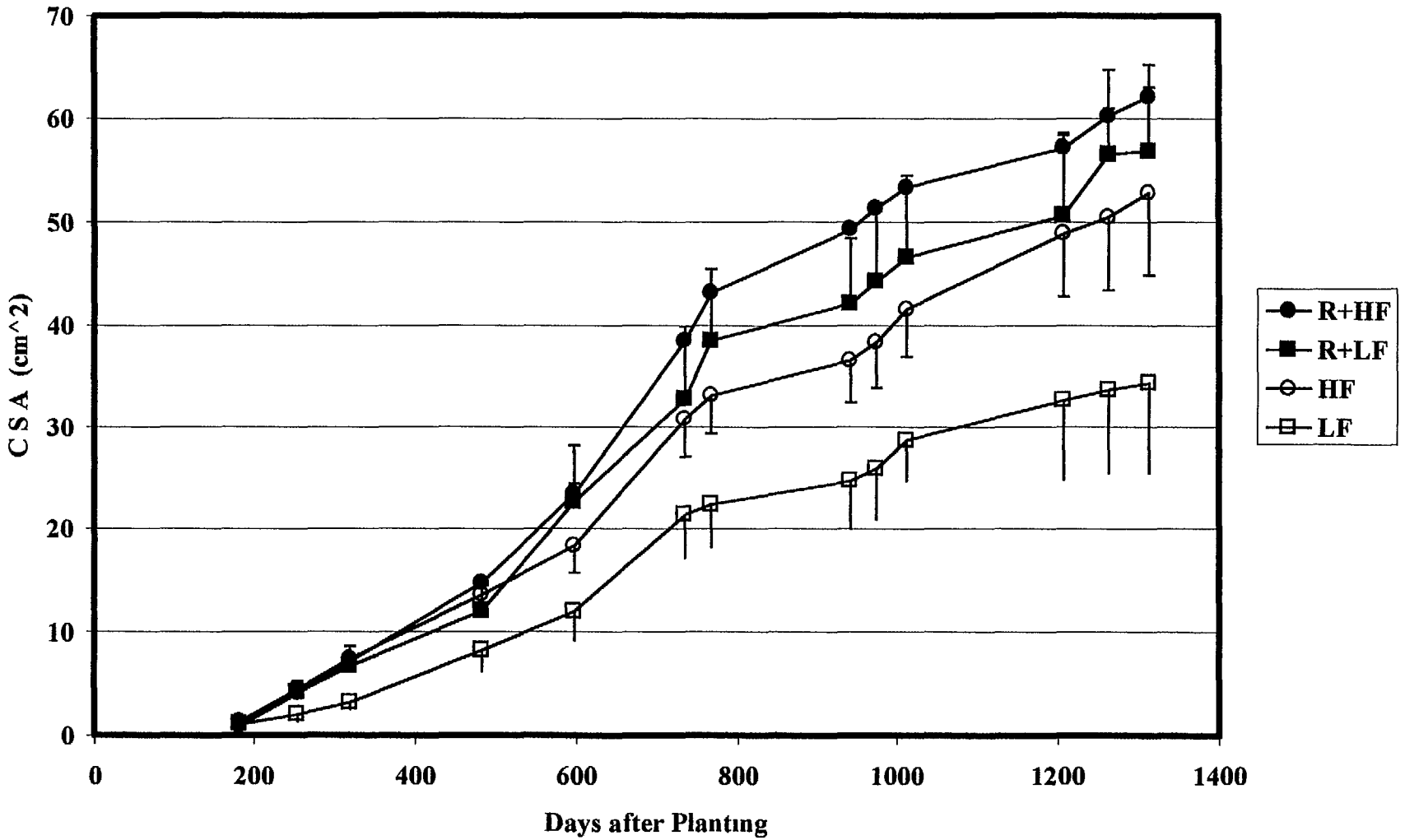


Figure 8: Effect of irrigation frequency and runoff addition on the C.S.A. development of Acacia saligna

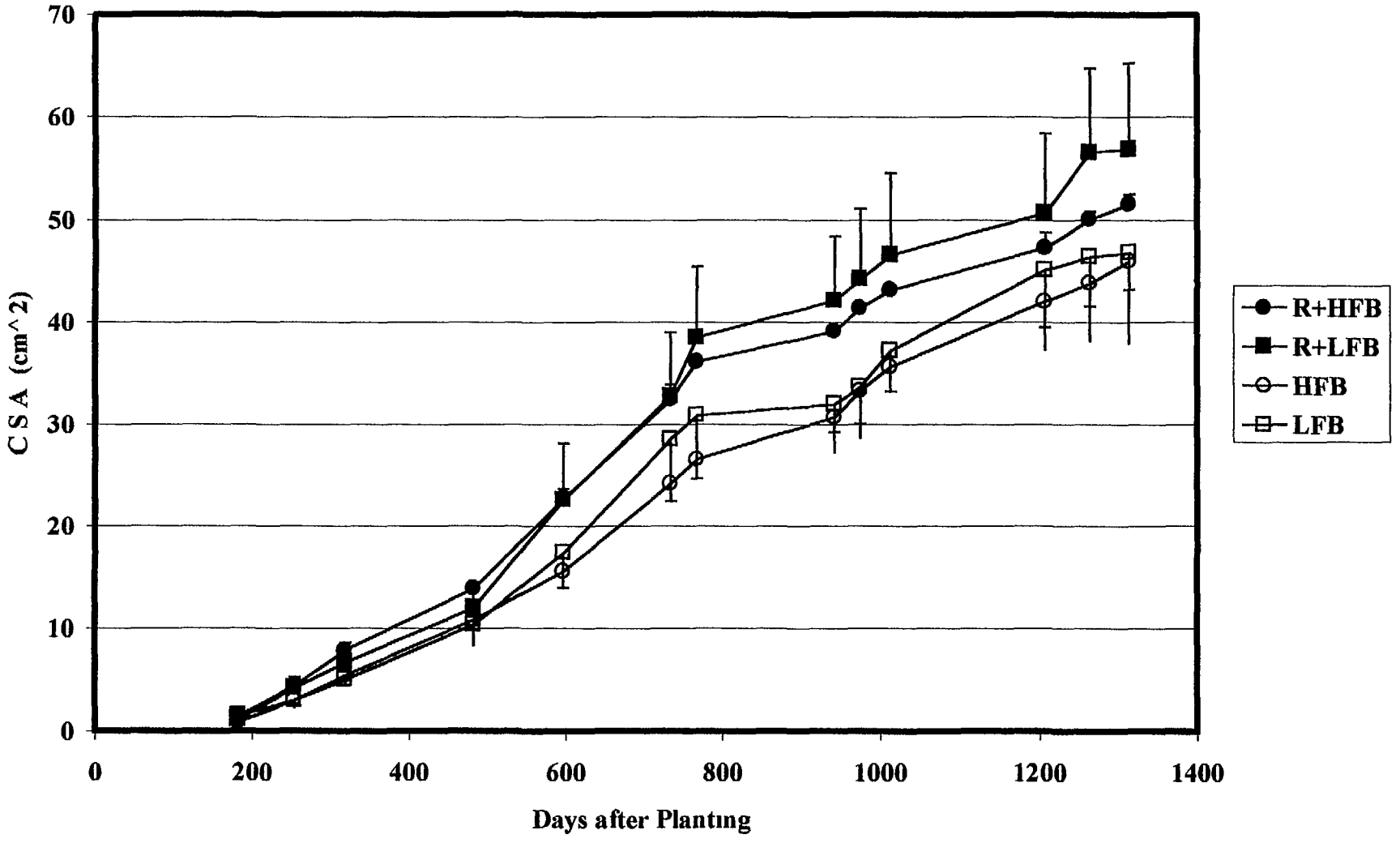


Figure 9 Effect of irrigation frequency w/brackish water and runoff on the C S.A. development of *Acacia saligna*

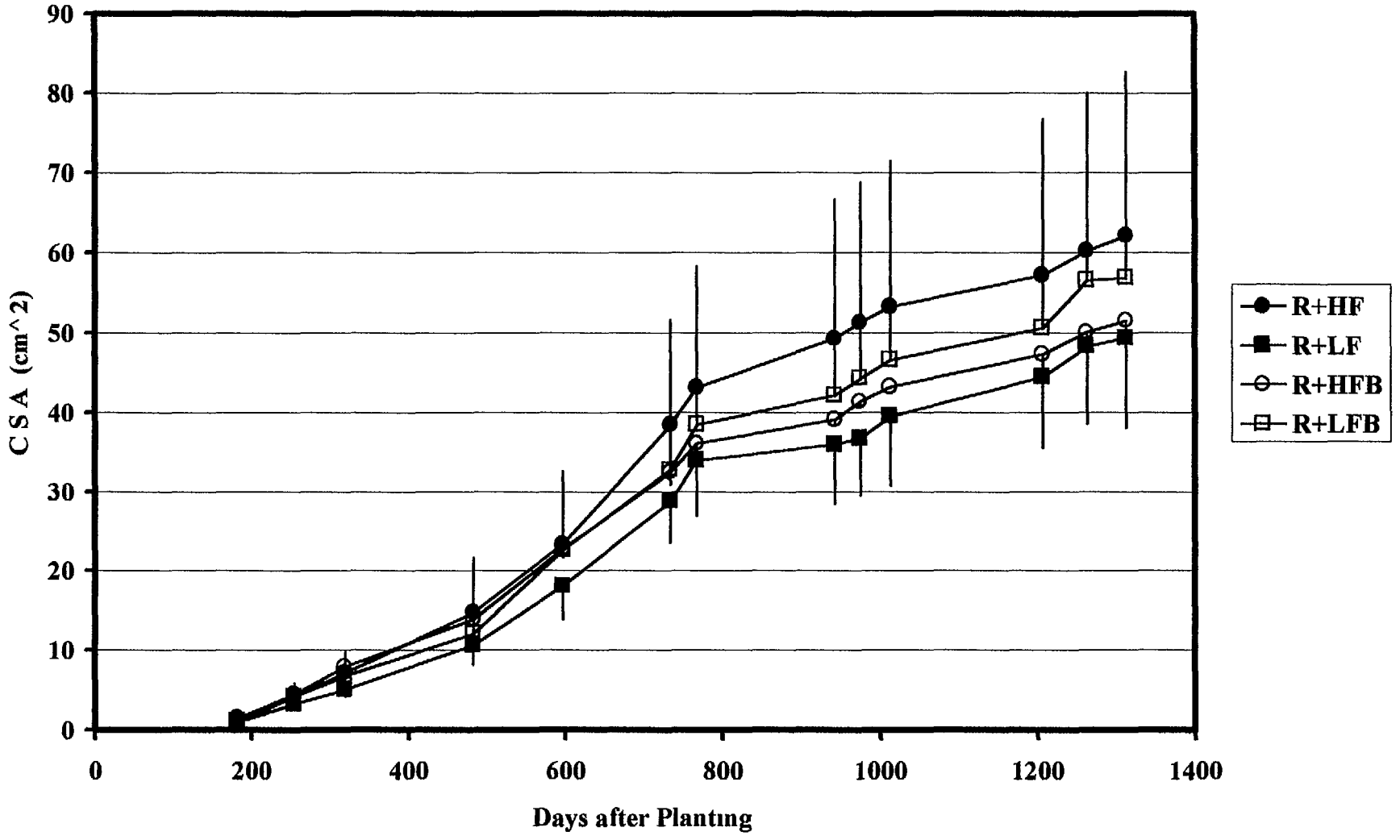


Figure 10 Effect of irrigation frequency, water quality and runoff application on the C S A. development of *Acacia saligna*

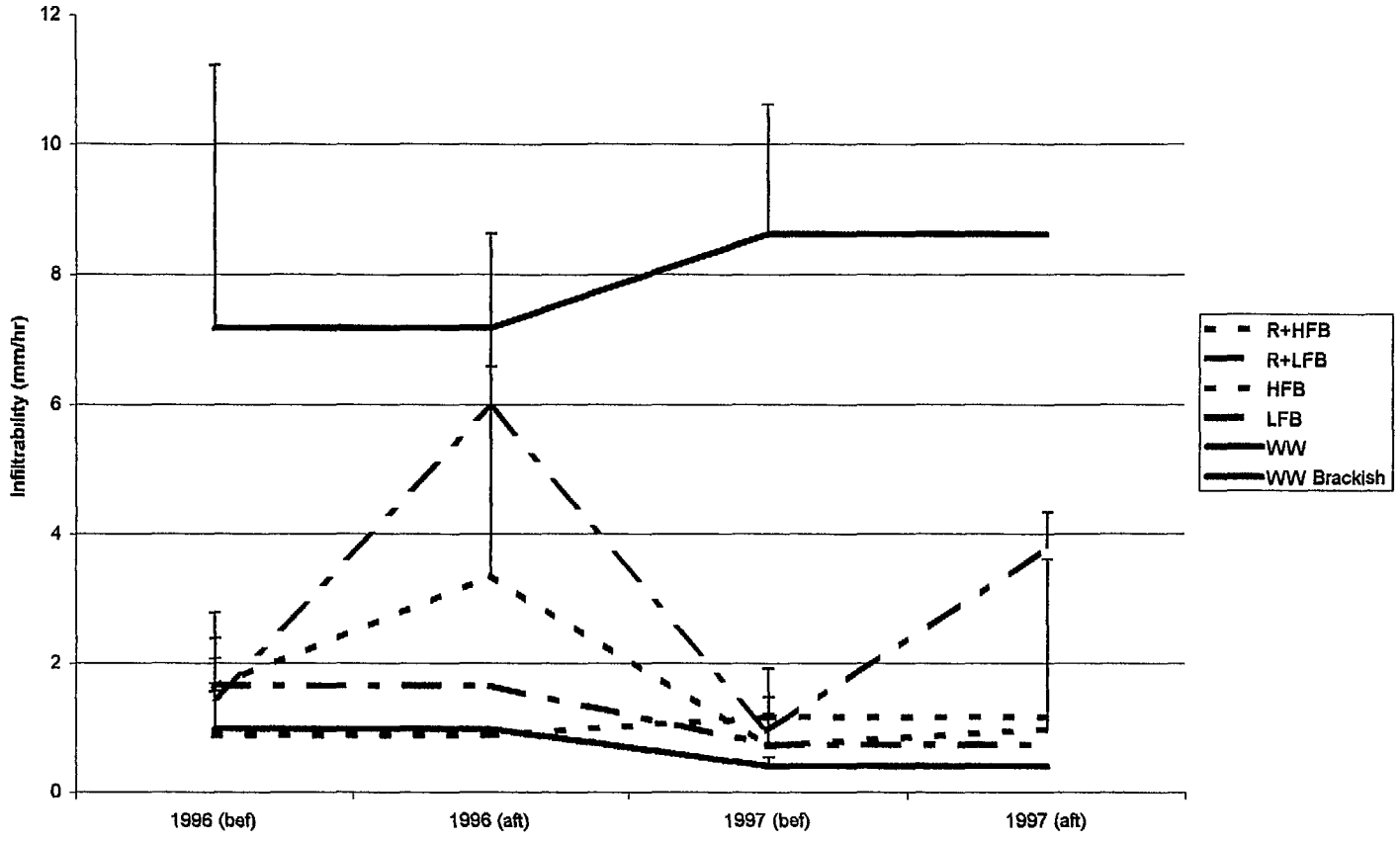


Fig 11· Infiltrability of selected treatments (bef) and (aft) denote before and after a flood (Bars indicate one Standard Deviation)

LWP MEASUREMENTS

Introduction

Leaf water potential (LWP) is used as an index of plant water status At low LWP when physiological process are damaged, the plant consider to be under moisture stress Pre-Dawn Leaf water potential (PDLWP) is the potential attained during the night prior to sunrise and is assumed to represent the intergrated soil water potential in the root zone The PDLWP which was collected throughout the three years of the experiment were used in order to decide when to irrigate

LWP was measured using two kinds of pressure chambers at the beginning of the season when the LWP values were relatively high, the ARI II pressure chamber type (*Arimad* Kfar Haruv, Israel) was used When LWP dropped to values below –3 0 Mpa, the PMS Instrument Company (Corvallis Oregon, USA) pressure chamber was used With the PMS instrument LWP values as low as -6 0 Mpa can be measured

The leaves to be measured were of the same age and size and were wrapped with an aluminum foil at the night prior to measurements This procedure was carried out in order to prevent any water loss from the time of cutting the leaves to the time of the measurements Keeping the leaves overnight covered with the aluminum foil ensured that the leaves would reach the same water potential as the soil close to root system Potentials were measured once a week in all three replicates of all treatments

Fig 1 shows data for the control (=runoff only) treatment throughout the three years of the trial A continuous reduction in PDLWP was measured throughout the growing season of each year The highest value of PDLWP was measured right after the flood and since no additional irrigation was applied the plants grew most of the season under water

stress conditions At the end of each year, PDLWP reached very low values

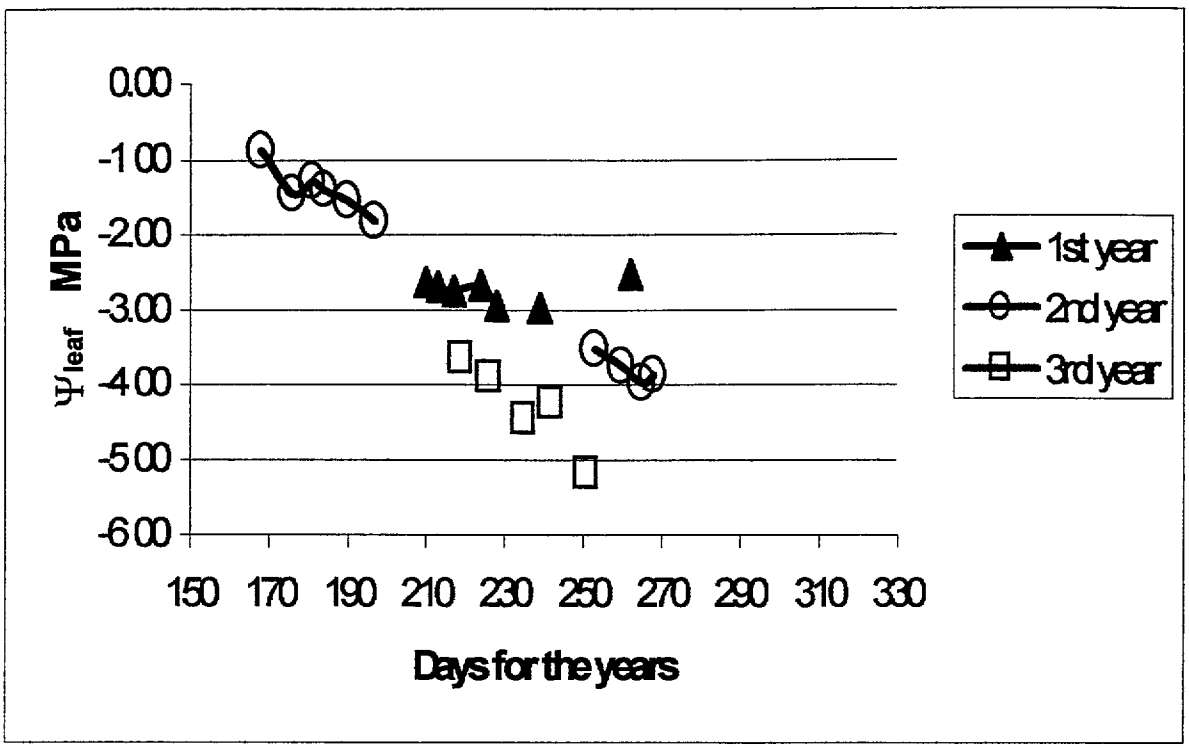


Fig 1 Pre-Dawn LWP in Treatment 1 (runoff only) throughout the growing season during the 3 years of the trial, Sede Boqer, Israel

In Fig 2 the PDLWP of treatments 2 (R+High Frequency-Fresh), 3 (R+Low Frequencyu-Fresh) and the same irrigation treatments with brackish water (Treatments 4 and 5) are presented

The comparison of Treatments 2 and 4 (Fig 2) indicates that the changes in PDLWP were more pronounced in the high quality water Since both treatments were irrigated when PDLWP reached a value of –1 6 Mpa, we can see that during the first two years of the experiment the frequency of the irrigations was higher (shown here as increase in PDLWP) in treatment 2 when compared to treatment 4

In the low irrigation frequency treatments (Treatments 3 and 5) we can see that the

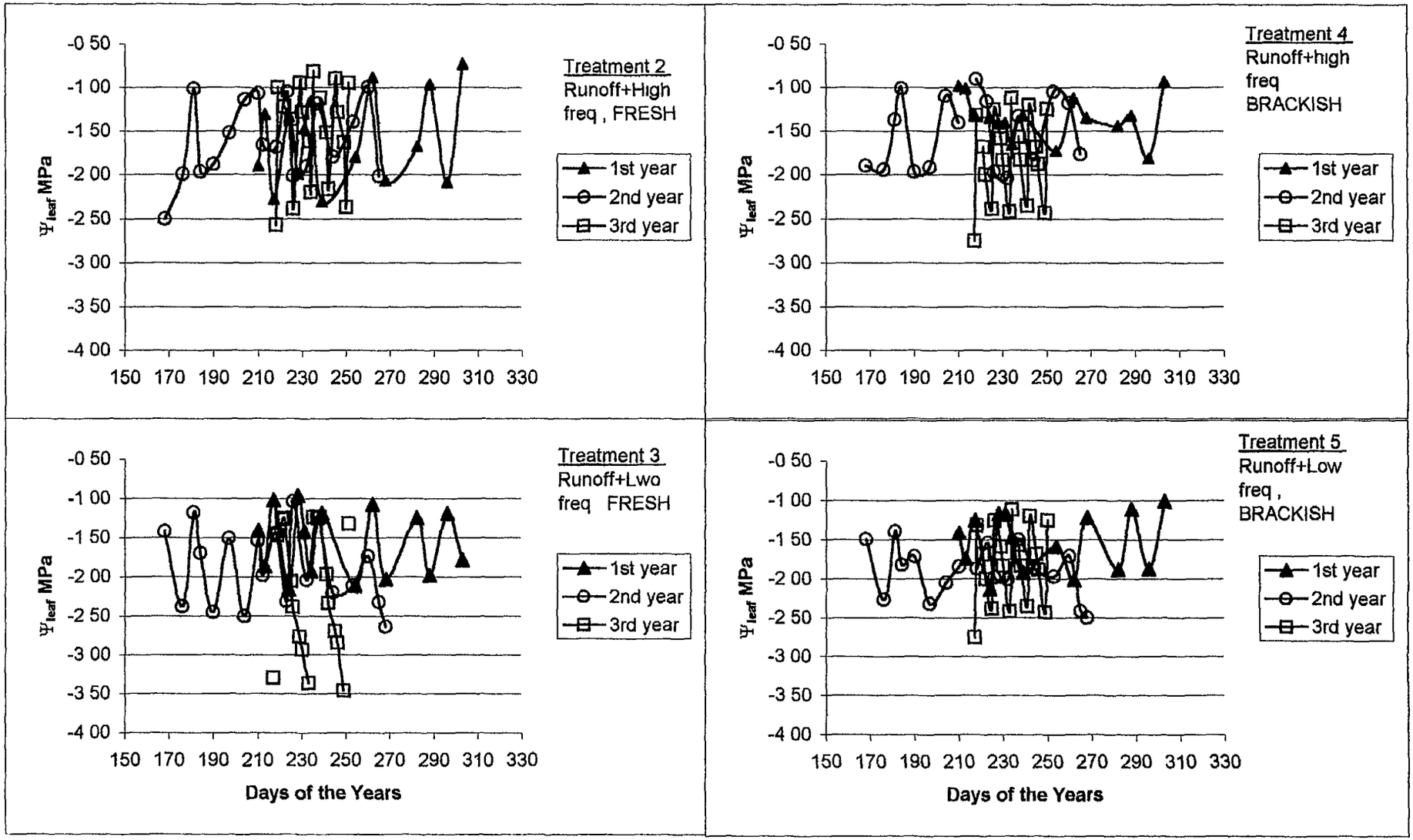


Fig 2 Pre-Dawn LWP in the 2 irrigation frequencies and 2 water qualities with runoff treatments (treatments 2-5) throughout the growing season during the 3 years of the trial, Sede Boqer, Israel

PDLWP reached lower values in comparison with treatments 2 and 4 In addition to that we also found that irrigating with fresh water of low frequency caused a lower PDLWP when compared with the same frequency of irrigation with saline water This phenomena was detected throughout the three years of the experiment

In Fig 3 the PDLWP of treatments 6-9 is presented In this treatments the irrigation scheme was identical to the first set of treatments (2-5) but without a flood at the beginning of the irrigation season

Comparing the PDLWP data of treatments 2-5 with those of treatments 6-9 shows that the frequency of irrigation was higher, or a faster reduction in LWP in the case that no flood was applied at the beginning of the irrigation season (Treatments 6-9), while in treatments 2-5, the change in LWP was slower resulting in less irrigation events

In Fig 4 there is a comparison of the results from treatments 10 (fresh water) and 11 (brackish water) which were irrigated twice a week regardless to the PDLWP levels Treatment 10 was irrigated with fresh water and treatment 11 with saline water During the 1st year the PDLWP's of treatment 10 were lower than those of treatment 11 but from the 2nd year until the end of the experiment, the PDLWP's of treatment 11 were lower, although both treatments were irrigated twice a week From the data presented in Table 1 we can also see that the amount of water applied to treatment 11 were lower when comared to treatment 10 which might indicate a smaller root system that cause a faster increase and decrease in LWP

The connection between the PDLWP and the percent of the water content in field capacity was studied during the three years of the trial Prior to sunrise the plant water potential consider to be in equilibrium with the soil in the vicinity of the roots

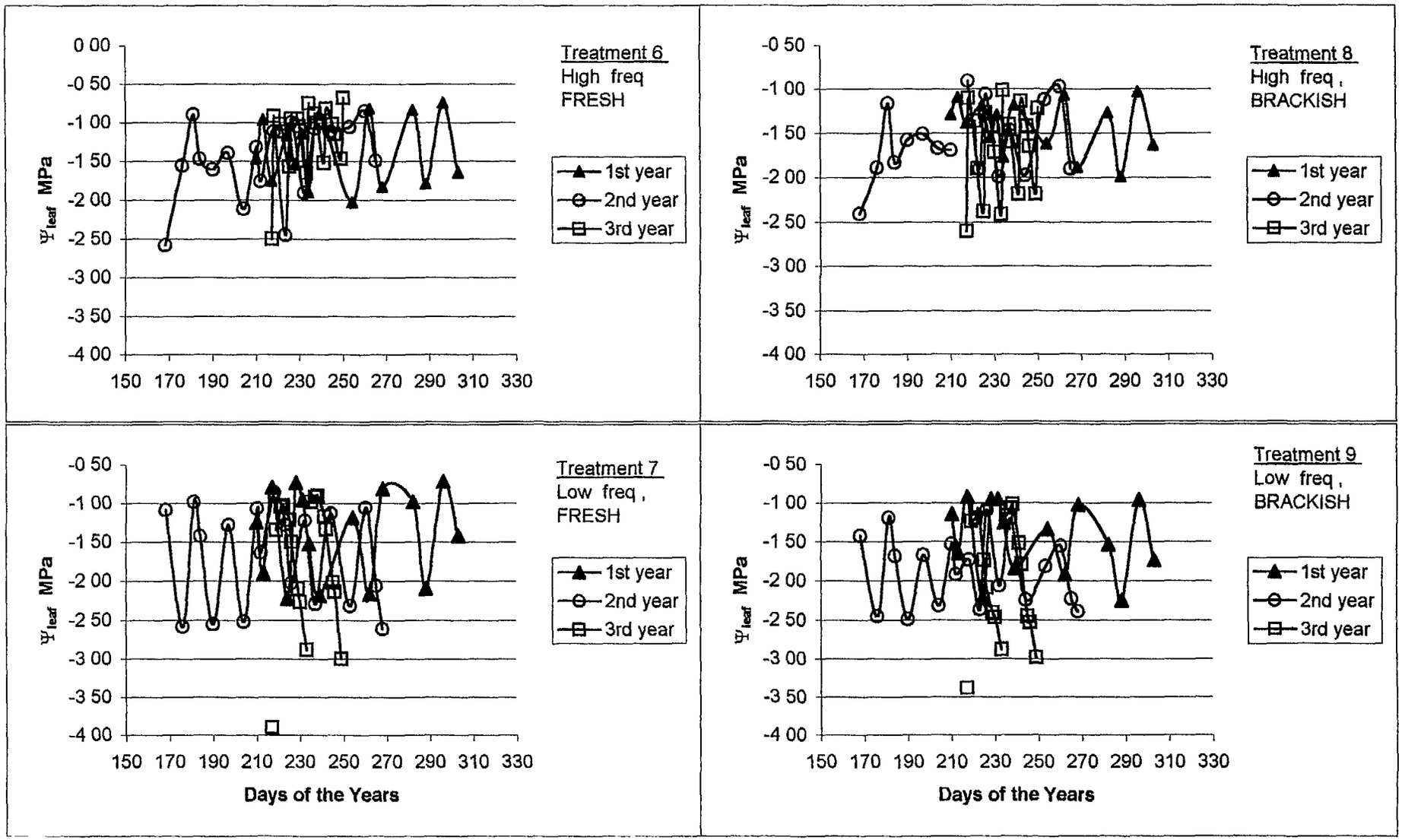


Fig 3 Pre-Dawn LWP in the 2 irrigation frequencies and 2 water qualities without runoff treatments (treatments 6-9) throughout the growing season during the 3 years of the trial, Sede Boqer, Israel

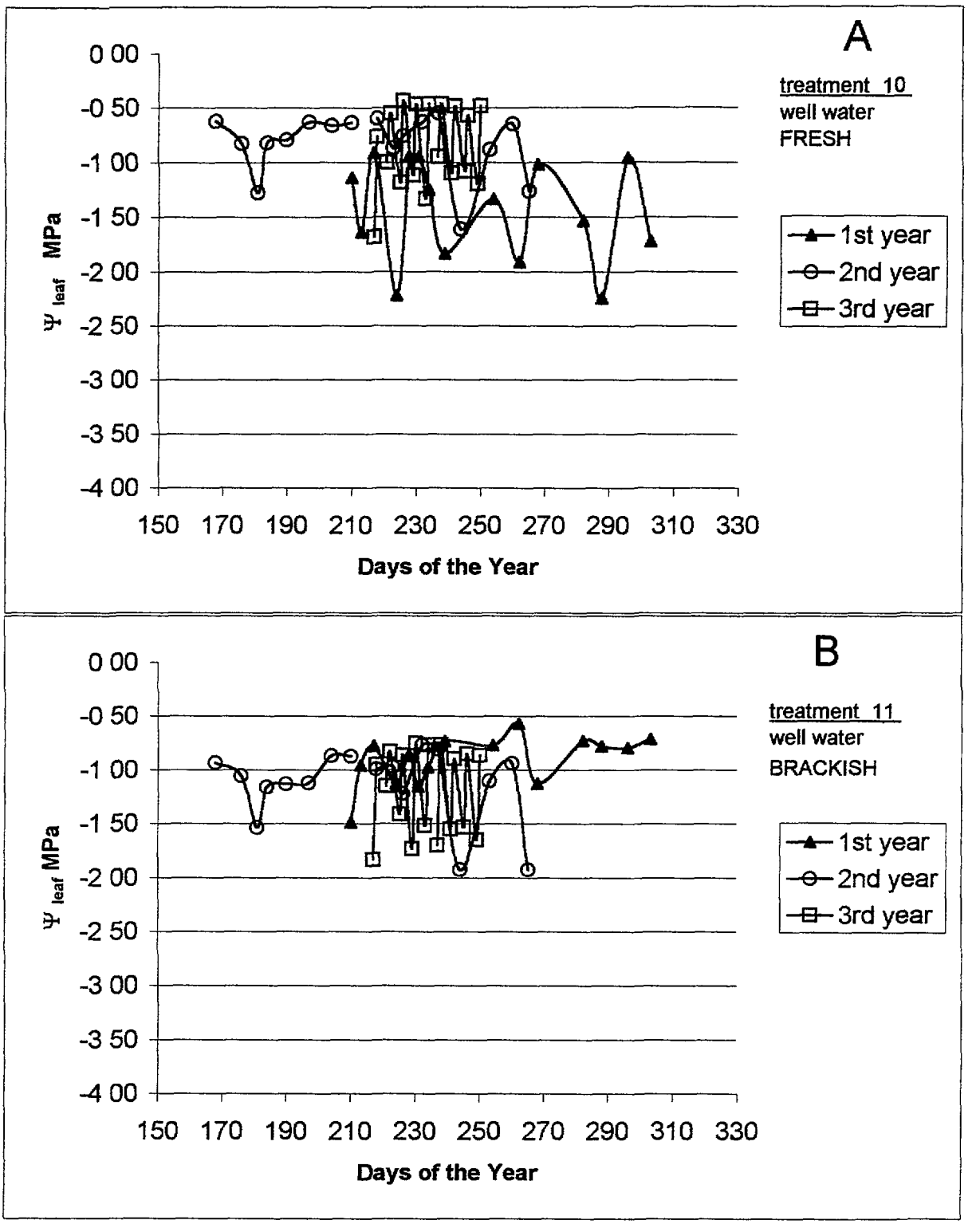


Fig 4 Pre-Dawn LWP in the well water treatments irrigated with fresh (treatment 10) or brackish (treatment 11) water throughout the growing season during the 3 years of the trial, Sede Boqer, Israel

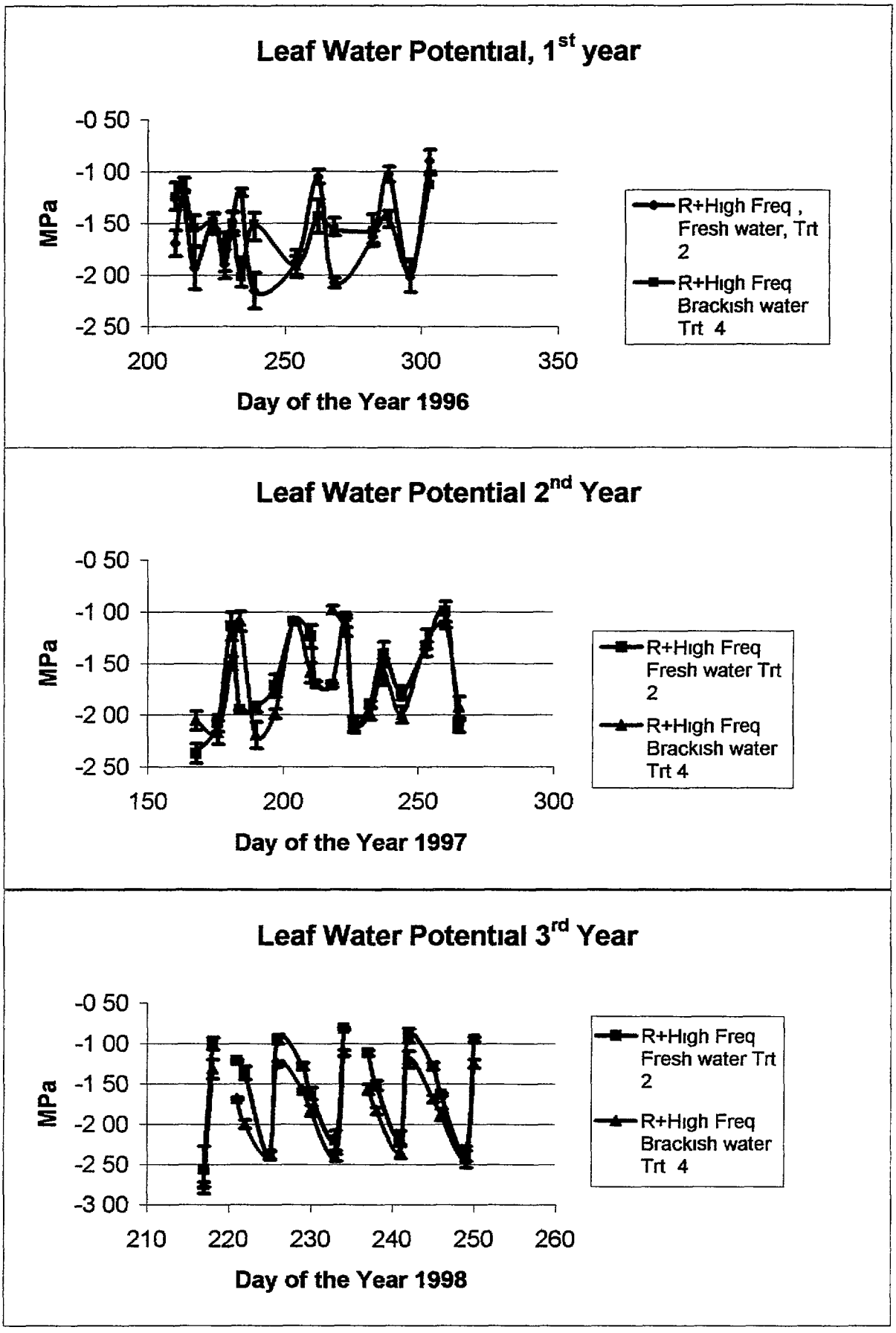


Fig 4 Comparison of Pre-Dawn LWP treatments 2 and 4 (R+HF, irrigated with fresh and brackish water respectively) throughout the growing season during the 3 years of the trial, Sede Boqer, Israel

The comparison between the PDLWP and the soil water content under irrigation with brackish or fresh water was carried out for throughout the years of the trial The results presented here are for the 2nd year (1996) of the experiment

The results (Fig 5) indicate that under the fresh water a higher leaf water potential was recorded under the same soil water content when compared to the brackish water

These results indicate that the osmotic potential which resulted from the addition of salts affected plant water ststus These effect was however not clearly expressed in the CSA's

Similar results were obtained also for the third year

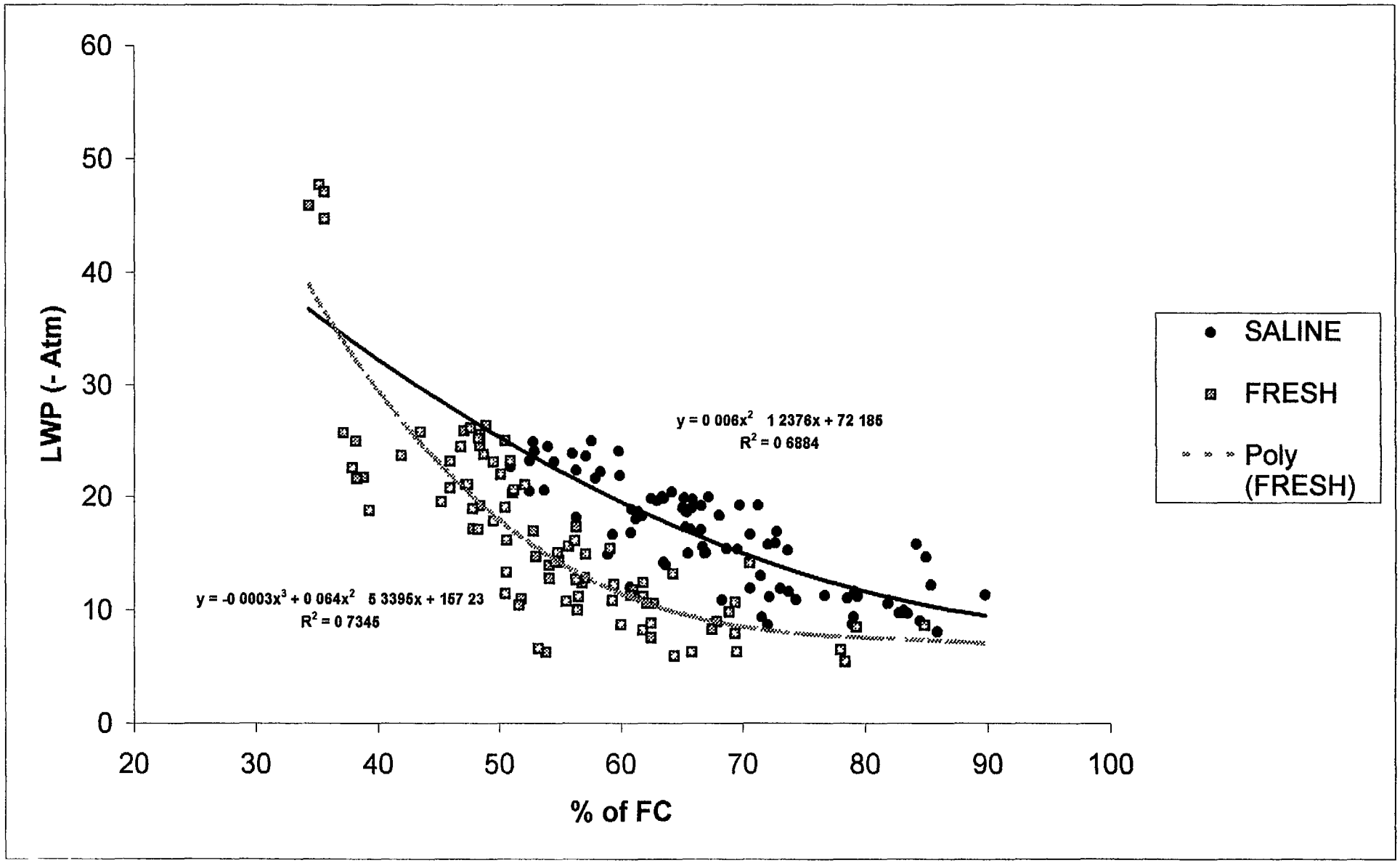


Fig 5 Pre-dawn Leaf water Potential as a function of percent of water content in Field Capacity under two water qualities in 1996, Sede-Boqer, Israel

Evaluation of the Effectiveness of Run-off in Leaching Salts in Soils Irrigated with Brackish Water in the Negev

A Musandu , J Ephrat , P Berliner , M Silberbush and C Wexler

ABSTRACT

The effectiveness of run-off on salt leaching in a soil irrigated with brackish water was evaluated in an *acacia saligna* irrigation field trial laid out on March 1995 at the Jacob Blaustein Institute for Desert Research at Sede-Boker in the Negev Desert, Israel The plots were irrigated by run-off water during the winter, and by either fresh-water or brackish water during the summer, or with fresh-water or brackish water around the year Irrigation was applied when leaf water potential decreased below –1 6 or -2 0 bar Detailed soil sampling was done in 1996, 1997, and 1998 at o, 1 and 2 m from the tree row The results indicated that salts accumulated away from the tree row, but the pattern of the accumulation varied with the flushing regime Winter flood with runoff water leached the soluble salts that accumulated during the summer away from the tree root zone In a continuous-irrigation regime with brackish water, on the other hand, the salts accumulated along the whole soil profile, but 1-2 m from the tree line, while the root zone was kept relatively with low soil salinity

INTRODUCTION

The Negev desert is short in precipitation, but has a large amount of brackish ground water There is therefore a need to develop technologies that would enable the use of this water for irrigation with minimum damage to crop yields and the soil condition (Mantell *et al* 1985, Yadav, 1991) In the Negev, both the soils and the ground water available for irrigation are often saline Different strategies were adapted to ensure that the soil and water resources in this region are used efficiently, including Growth of salt tolerant crops such as cotton (Mass and Hoffman, 1977), and the use of the drip irrigation method (Elfving, 1982) The broad objective of irrigation of agricultural crops with saline water are to leach salts down below the root zone, to reduce surface evaporation to a minimum and to ensure maximum utilization of water by the plants (Minhas and Gupta, 1992) These interventions do not address the problem of soil salinization with time when brackish water is used for irrigation Besides, most of the

research work on the use of saline water for silviculture has been restricted to the initial establishment stages (Minhas *et al* 1997)

In this study, the effectiveness of run-off water on leaching salts in a soil irrigated with brackish water was measured, and the long-term risks of the use of brackish water were evaluated

MATERIALS AND METHODS

Detailed soil sampling was done in an *Acacia saligna* irrigation field trial laid out by the Run-off Agriculture Research Group at the Jacob Blaustein Institute for Desert Research at Sede-Boker on March, 1995 The treatments in the *Acacia* irrigation trial were

1 Irrigation with run-off only (control),
2 Irrigation with run-off during winter and irrigation with fresh water throughout the summer,
3 Irrigation with run-off at winter and irrigation with brackish water throughout the summer,
4 Irrigation with fresh water twice a week, throughout the year
5 Irrigation with brackish water twice a week, throughout the year

The irrigation treatments at (2) and (3) were applied either when the leaf water potential rose up to 1 6 bars for one level, or 2 0 bars for the second level

Run-off was simulated by flooding the plots with 250 mm of fresh water of the National Water Carrier, which is equivalent to annual precipitation at the Northern Negev The treatments were arrayed in a split-plot, completely randomized design, and replicated three times Run-off treatments were in the main plots and the different water qualities and irrigation timing in the sub-plots Plot dimensions were 5 by 8 m, each with four rows of four trees The inter-row distances between trees were 1 m, and 2 m between rows, a 1-m path separated neighbored plots

Soil samples for the reported part of the study were taken with a hand auger down to 100 cm, from two contrasting treatments The soil sampling was done at 0, 1 and 2 m from the tree row in each plot Soil sampling was done in two treatments only Plots

throughout the year than those plots which were irrigated with altered water salinity, The slope of the former is close to 10, as would be expected according to US Salinity Laboratory Staff (1954) charts Other factors but Na apparently resulted in the ECe of those plots that were flushed with non-saline water during the winter, as may be learned from the correlation of ECe and the extract sodium adsorption ratio (SAR, Fig 2) The 1996 ECe data, obtained from 1 1 soil water extracts (Fig 3a-c), showed an accumulation of soluble salts in the top 15 cm of soil profile This accumulation occurred within the tree line before the flood (they apparently were flushed by the flood), and in the plots which received only brackish water by irrigation throughout Similar accumulation of salts in the topsoil after irrigation has also been observed by Bajwa et al (1984) Salt accumulation in the topsoil occurred after the irrigation when the soil was subjected to evaporation, leading to upward movement of soluble salts The amount of salt that moved upwards depends on the salt quantity present in that part of the soil profile, so it is affected by the quality of the irrigation water used (Miyamoto et al , 1986) Flooding resulted in the leaching of salts from the topsoil to the lower horizons, in the non-flooded plots, at 1 and 2 m from the tree line, the soluble salts accumulated in the deep soil profile The lateral and vertical movement of water from the drip emitters also affected salt distribution in the soil profile

The 1997 ECe data (Figs 4a-c) showed that flooding caused relatively more leaching of salt from the 1- and 2-m distances from the tree line than within the tree line Irrigation with brackish water only also caused some leaching of salts down the soil profile, but there was a substantial increase in salt accumulation with depth The 1998 ECe profile (Figs 5a-c) of soil samples taken before the flood showed that there was salt accumulation in the top soil associated with the position 1-m away from the tree line, but not at 2-m distance Flooding had the same effect on leaching down the salts as in 1997 The no-flood plot showed a greater salt accumulation in the topsoil either at the 1- or 2-m positions from the tree line Due to the 3-dimensional pattern of lateral and vertical distributions of water and salts with the drip irrigation system, a build up of salinity occurred in the soil profile along the tree line, away from the tree - maximum salinity was observed close to the surface Similar trends in soil salinity build up as a result of using poor quality irrigation waters was also reported by Elagbaly and Naguib (1965) and Bajwa et al (1983) In our study, there was an agreement between Na concentration

distribution in the soil profile both in 1997 and 1998 (Figs 6a-c and 7a- c) and the corresponding ECe data (Figs 4a-c and 5a-c), respectively

Magnesium concentration varied within a wider range than that of calcium The observed accumulation of both Ca (Figs 8a-c) and Mg (Figs 10a-c) in 1997 with increase in depth in the soil profile on the tree line could be attributed to their roles as accompanying cations during leaching In 1998, the pattern of Ca and Mg distributions (Figs 9a-c and 11a-c, respectively) in the soil profile was similar to that observed for Na and ECe Some of the leaching observed in 1998 could have been caused by the 1997 winter rains The values of SAR at the 1- and 2-m distances from the tree line were similar, but lower than the values for those positions at the tree line (Figs 14a-c and 15a-c, respectively) This was true in all cases except than after the flood in 1997 when they were higher deeper than 20 cm The profiles obtained when $\sqrt{[(Ca+Mg)/2]}$ concentration (in me/l) ratio data (Figs 12a-c and 13a-c, respectively) were plotted against depth were similar to the ECe profiles

This study has shown that flooding can be used to effectively leach salts to deeper horizons in the soil profile and that Na concentration in the saturated extract and the ECe are good indicators of the leaching accomplished

REFERENCES

1 Bajwa, M S , G S Hira and N T Singh 1983 Effect of sodium and bicarbonate irrigation waters on sodium accumulation and on maize and wheat yields in northern India Irrig Sci 4 191

2 Bajwa, M S , A S Josan, G S Hira and N T Singh 1986 Effect of sustained saline irrigation on soil salinity and crop yields Irrig Sci 7 27-35

3 Elagbaly, M M and N M Naguib 1965 Effect of depth and salt concentration of ground water on salinization of soil Proc , Symp Sodic Soils Budapest, Hungary, pp 369

4 Elfving, D C 1982 Crop response to trickle irrigation Hort Rev 4 1

5 Maas, E V and G H Hoffman 1977 Crop salt tolerance-current assessment ASCE J Irrig Drain Div 103(IR2) 115

6 Mantell, A , H Frenkel and A Meiri 1985 Drip irrigation of cotton with saline-sodic water Irrig Sci 6 95-106

7 Minhas, P S and R K Gupta 1992 Quality of irrigation water Assessment and Management Information and Publication Section New Delhi Ind Coun Agric Res , pp 68

8 Minhas, P S , Y P Singh , O S Tomar , R K Gupta and R J Gupta 1997 Effect of saline irrigation and its schedules on growth, biomass production and water use by *Acacia nilotica* and *Dalbergia sissoo* in a highly calcareous soil J Arid Environ 36 181-192

9 Miyamoto, S , T Riley, G Gobran and J Petticrew 1986 Effect of saline water irrigation on soil salinity, pecan tree growth and nut production Irrig Sci 7 83-95

10 US Salinity Laboratory Staff 1954 Diagnosis and improvement of saline and alkali soils USDA Agric Handbook 60 US Gov Print Office Washington, DC

11 Yadav, J S P 1991 Problems and potentials of reforestation of salt affected soils of India Reg Wood Energy Dev Prog Asia CGP/RAS/III/NET Field Document No 14 Bangkok FAO, pp 54

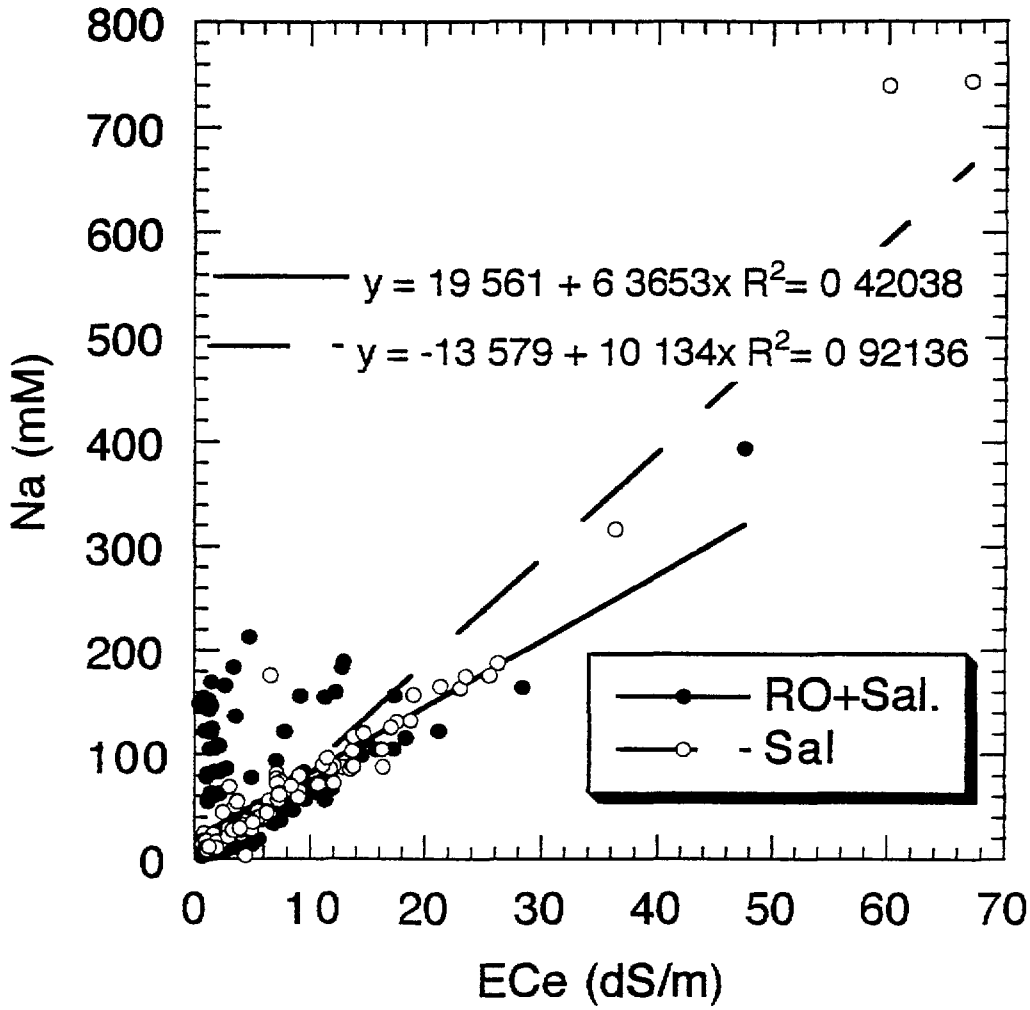


Fig 1 Correlation between Na concentration and electrical conductivity of the soil saturated paste extract RO – irrigation with Runoff water during the winter; Sal – Irrigation with saline water during the summer

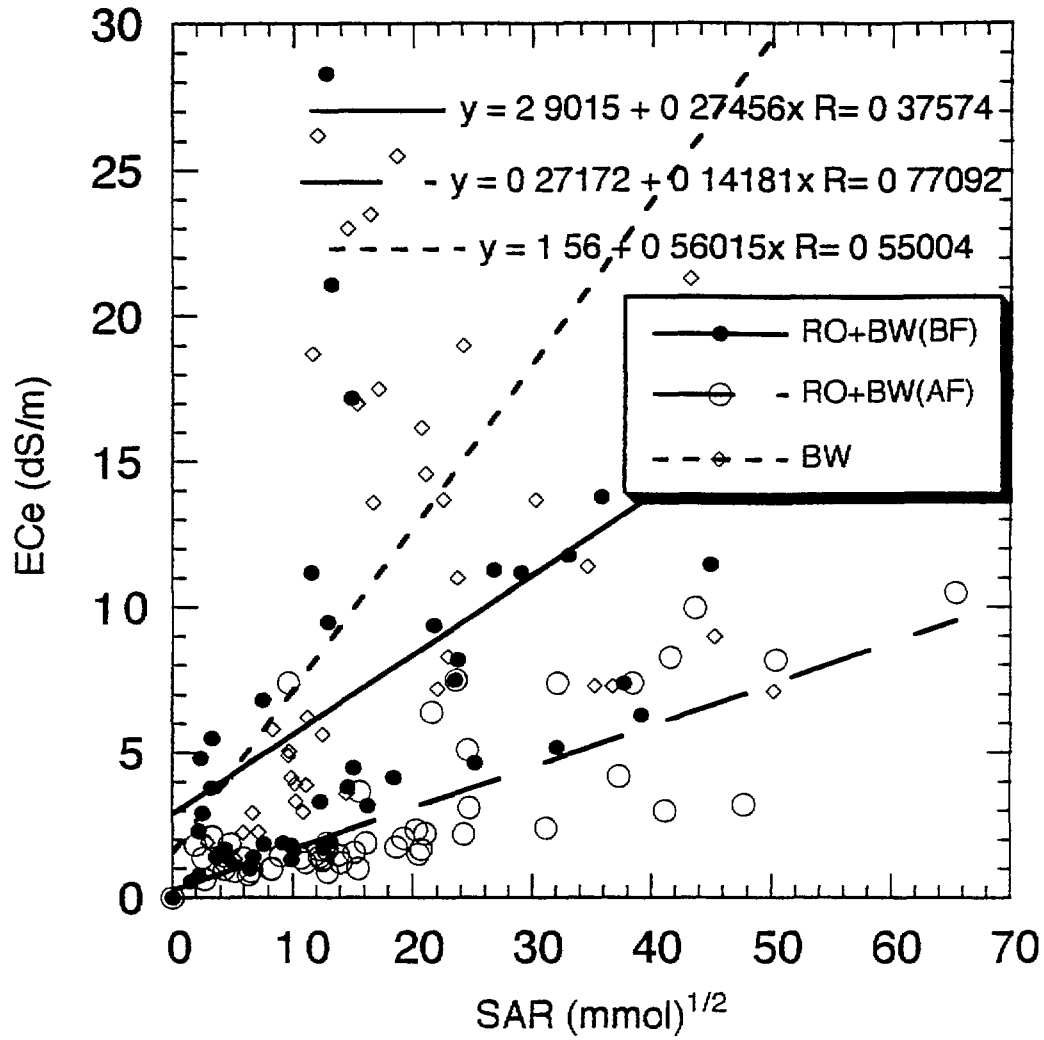


Fig 2 Correlation between the electrical conductivity and the sodium adsorption ratio of soil saturated paste extract determined in three irrigation treatments RO- irrigation by run-off water during the winter, BW – irrigation with brackish water during the summer, BF – before the flood, AF – after the flood

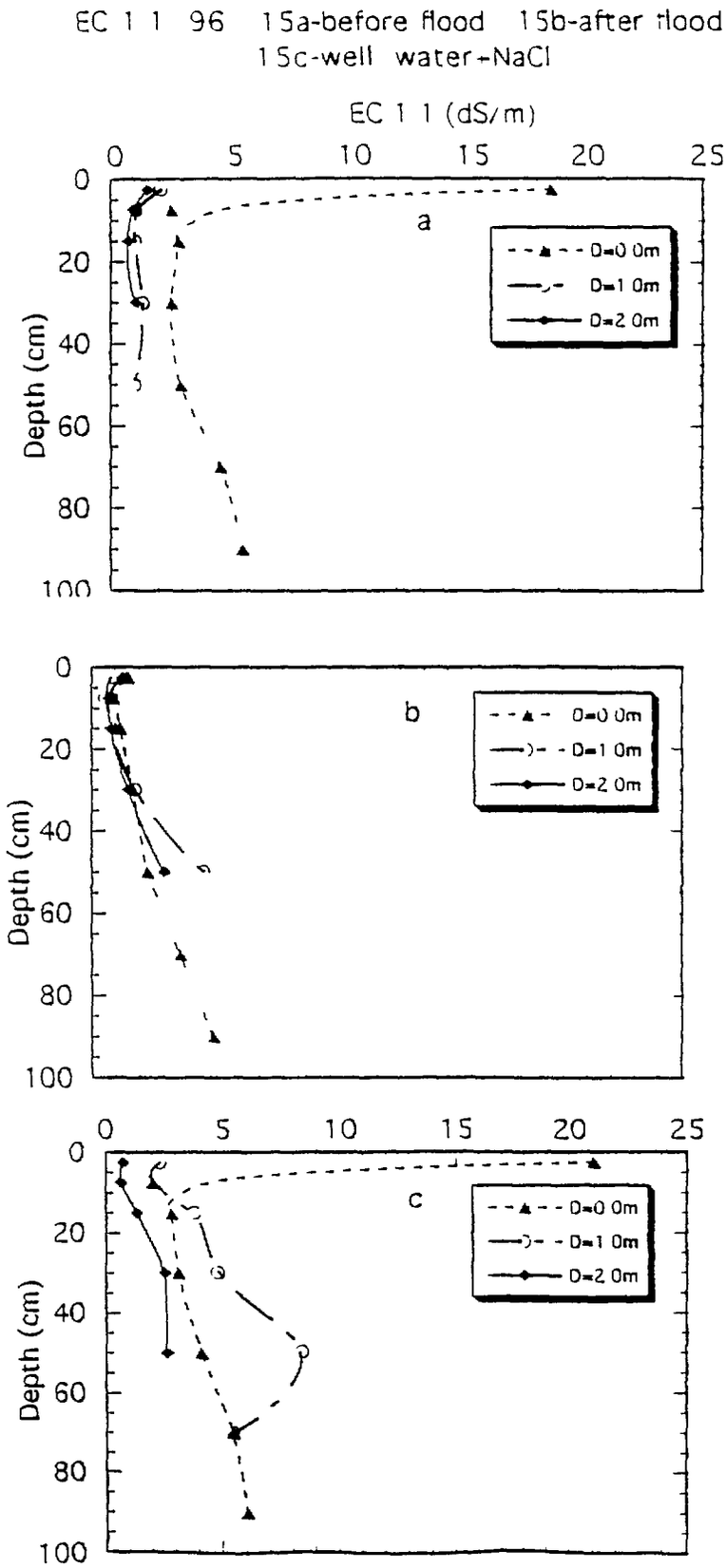


Fig 3 Electrical conductivity of the 1 1 soil water extract (a) before the flooding (12 3 1996) (b) after flooding (17 6 1996) and (c) continuously with brackish water throughout the year (sampled on 11 3 1996) Samples were taken down the soil profile at distance (D) 0 1 and 2 m from the tree row

ECe, 1997 3a-before flood, 3b-after flood, 3c-well water+NaCl

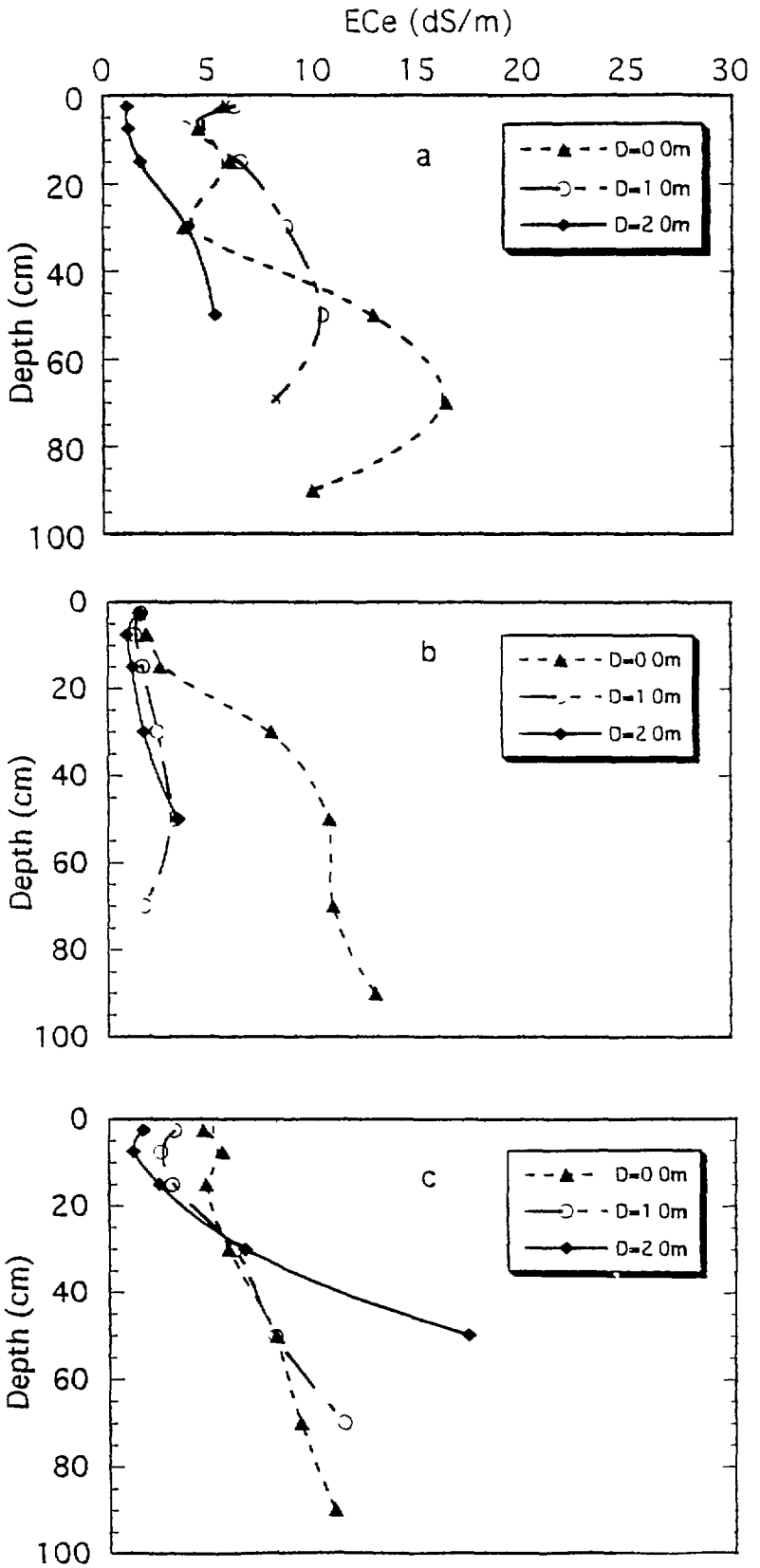


Fig 4 Electrical conductivity of the saturated paste soil water extract (a) before the flooding (2 4 1997), (b) after flooding (29 5 1997) and (c) continuously with brackish water throughout the year (sampled on 1 4 1997) Samples were taken down the soil profile at distance (D) 0 1 and 2 m from the tree row

ECe, 1998 4a-before flood, 4b-after flood, 4c-well water+NaCl

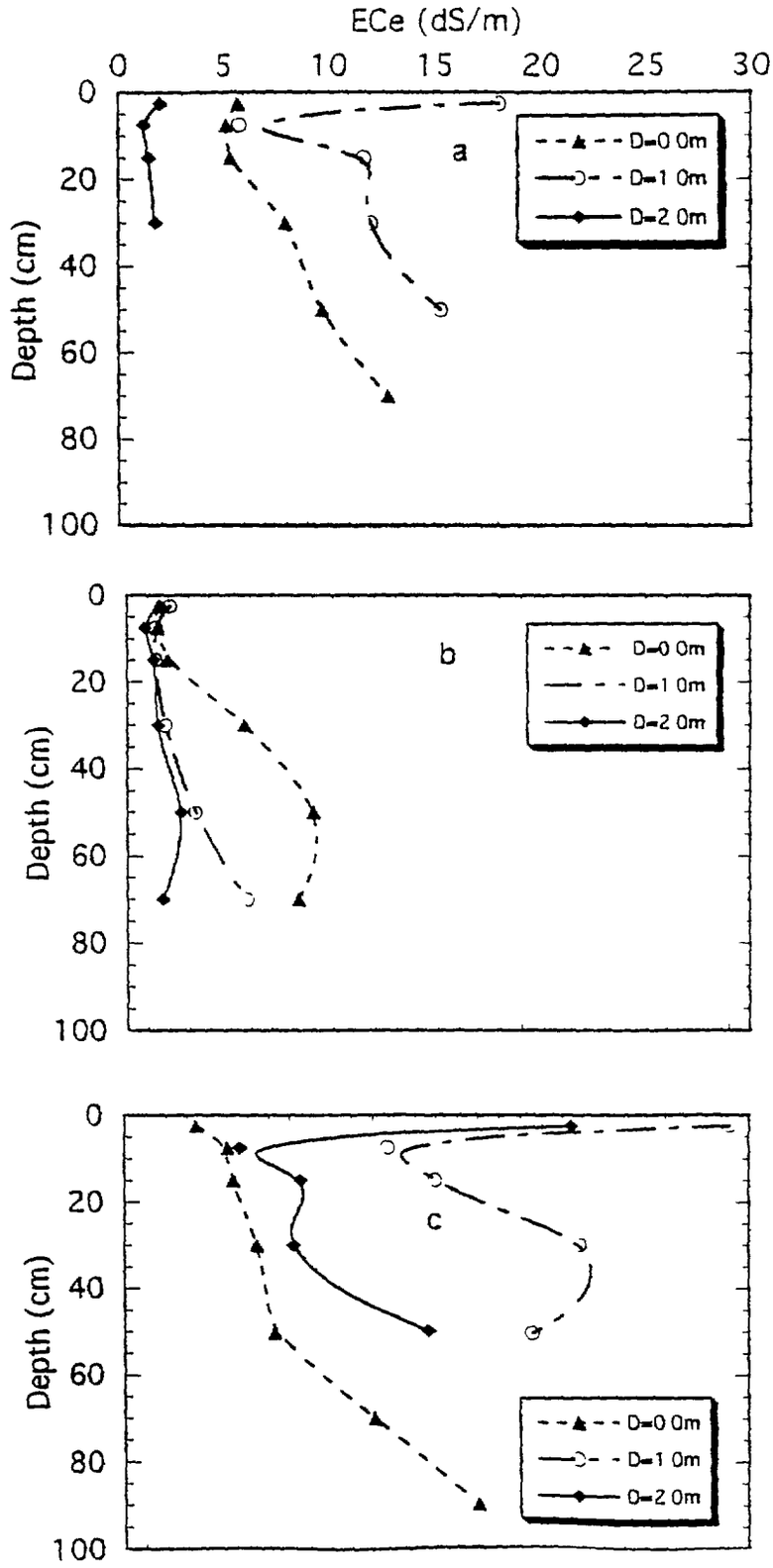


Fig 5 Electrical conductivity of the saturated paste soil water extract (a) before the flooding (8 11 1997), (b) after flooding (11 5 1998) and (c) continuously with brackish water throughout the year (sampled on 10 10 1997) Samples were taken down the soil profile at distance (D) 0 1 and 2 m from the tree row

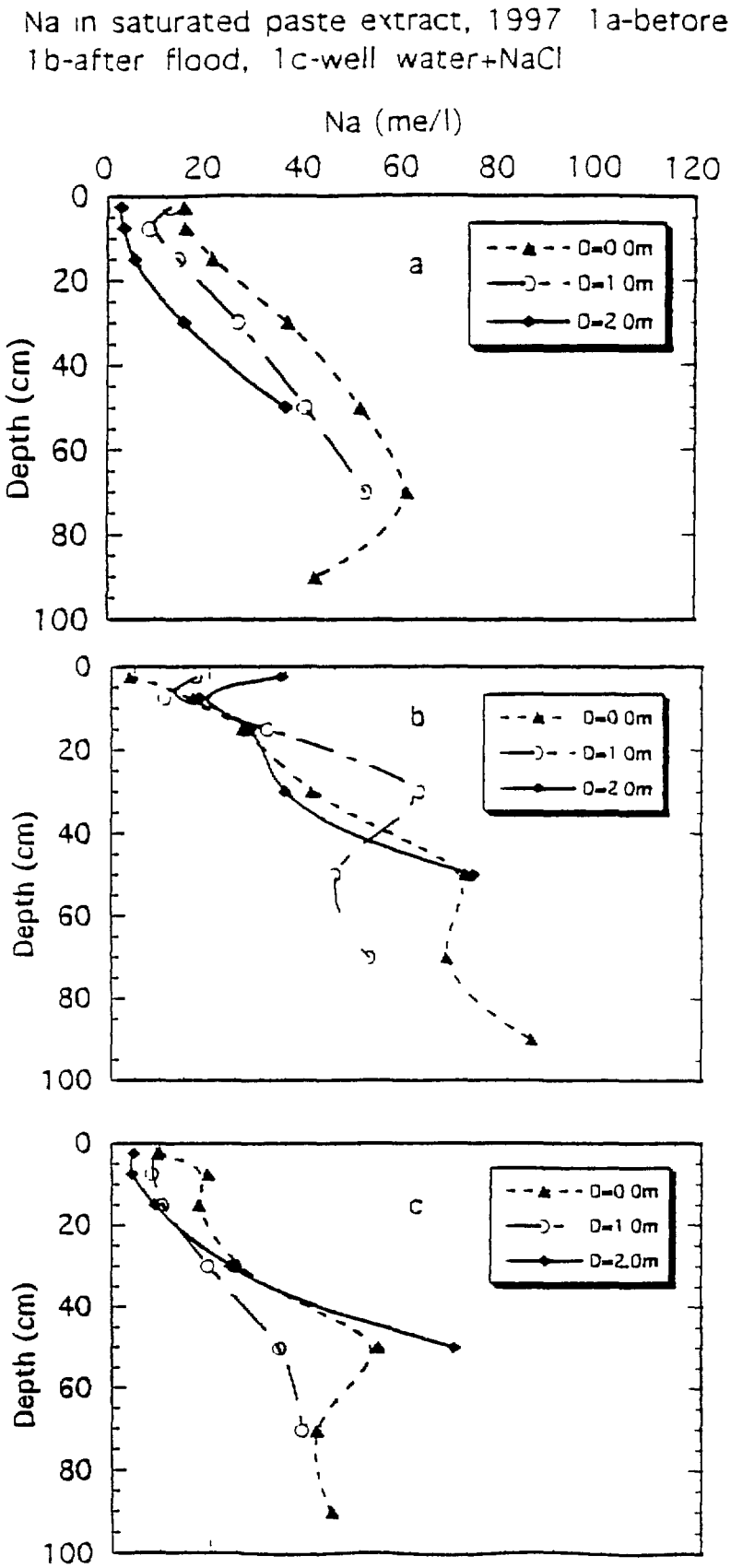


Fig 6 Sodium concentration in the saturated paste soil water extract (a) before the flooding (2 4 1997) (b) after flooding (29 5 1997) and (c) continuously with brackish water throughout the year (sampled on 1 4 1997) Samples were taken down the soil profile, at distance (D) 0 1 and 2 m from the tree row

Na in saturated paste extract, 1998 2a-before flood 2b-after flood, 2c-wellwater+NaCl

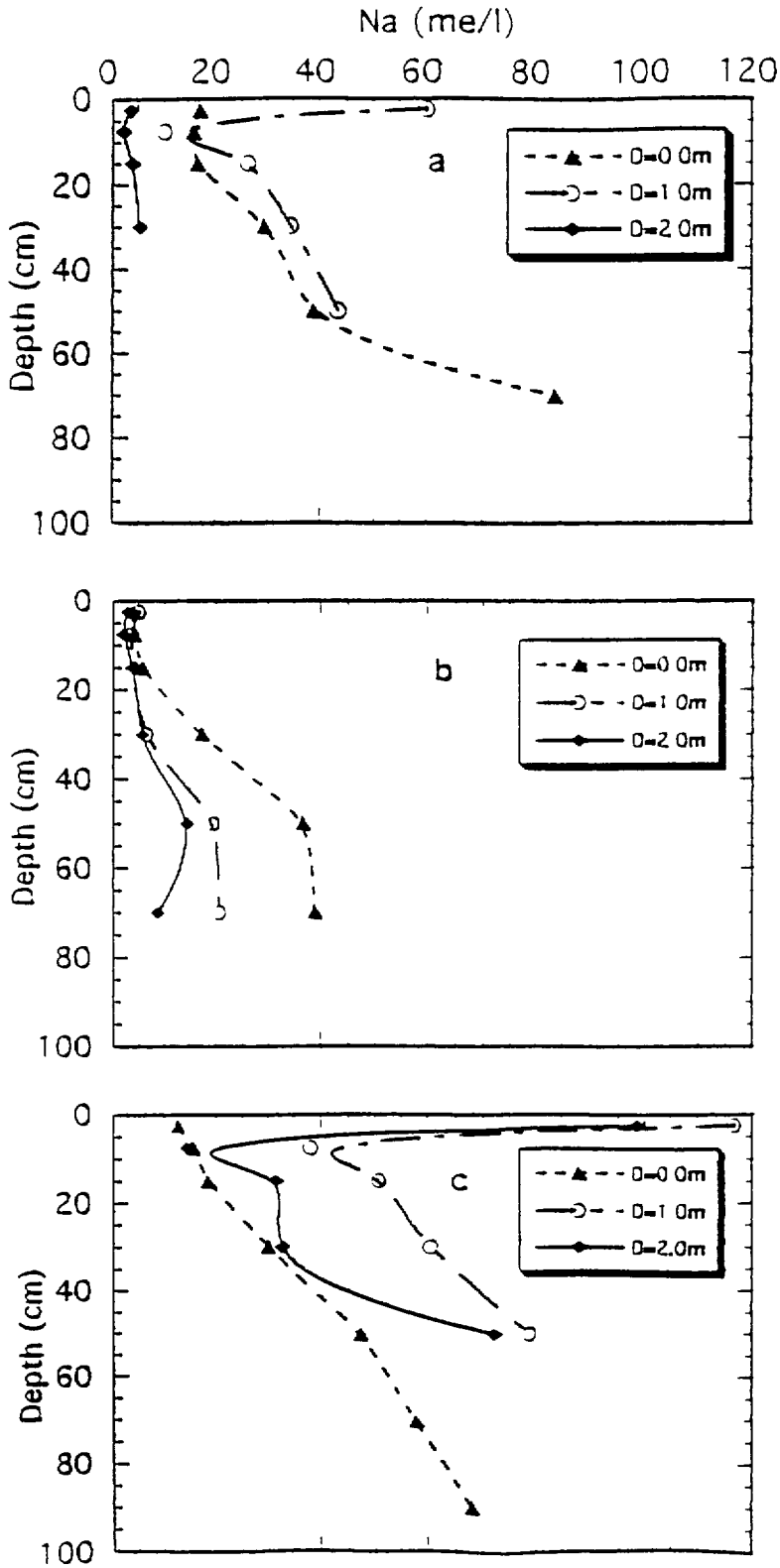


Fig 7 Sodium concentration in the saturated paste soil water extract (a) before the flooding (8 10 1997) (b) after flooding (11 5 1998) and (c) continuously with brackish water throughout the year (sampled on 10 10 1997) Samples were taken down the soil profile at distance (D) 0 1 and 2 m from the tree row

Ca in sat Extr , 97 7a-before flood, 7b-after flood, 7c-wellwater+NaCl

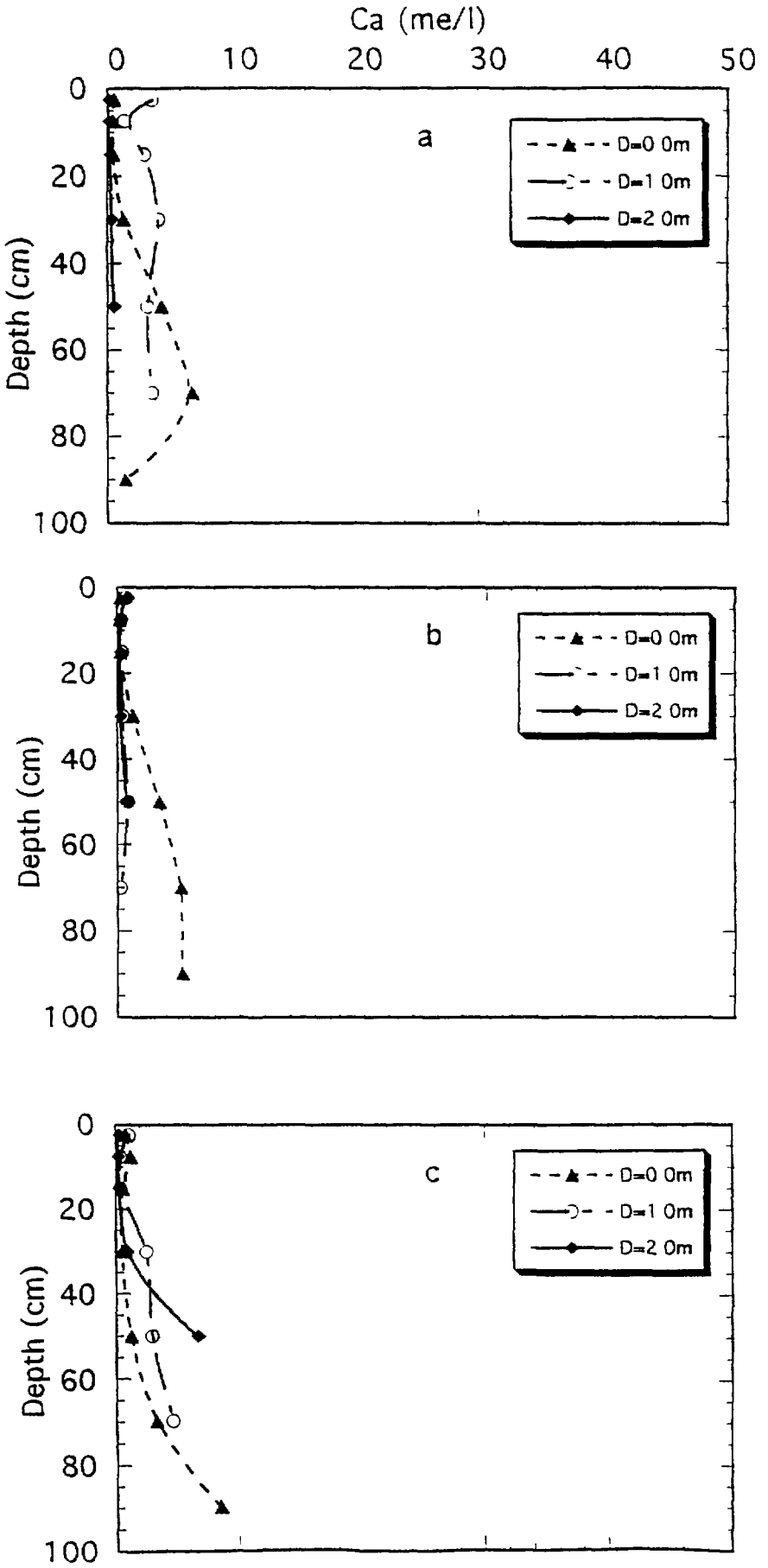


Fig 8 Calcium concentration, determined in the saturated paste soil water extract (a) before the flooding (2 4 1997), (b) after flooding (29 5 1997) and (c) continuously with brackish water throughout the year (sampled on 1 4 1997) Samples were taken down the soil profile, at distance (D) 0, 1 and 2 m from the tree row

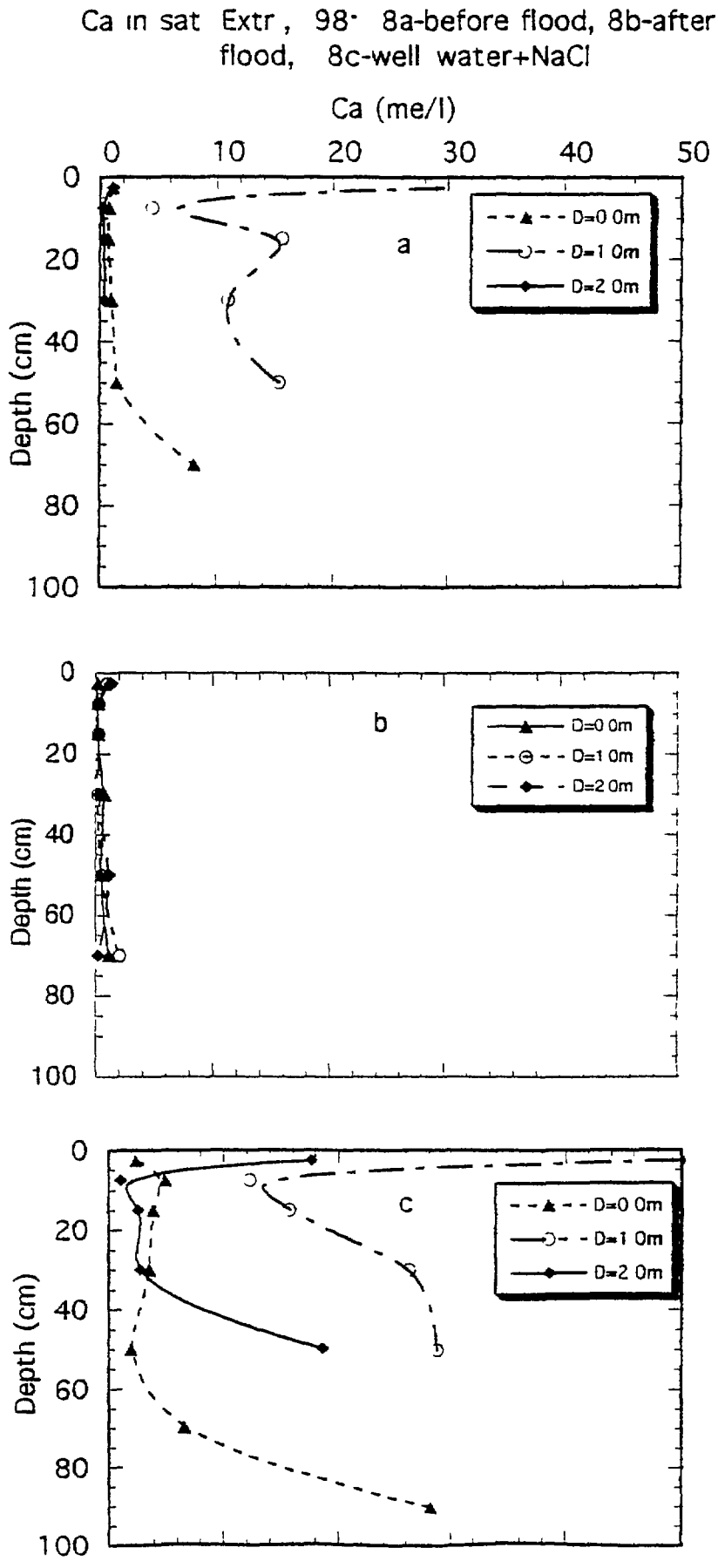


Fig 9 Calcium concentration determined in the saturated paste soil water extract (a) before the flooding (8 10 1997), (b) after flooding (11 5 1998) and (c) continuously with brackish water throughout the year (sampled on 10 10 1997) Samples were taken down the soil profile at distance (D) 0, 1 and 2 m from the tree row

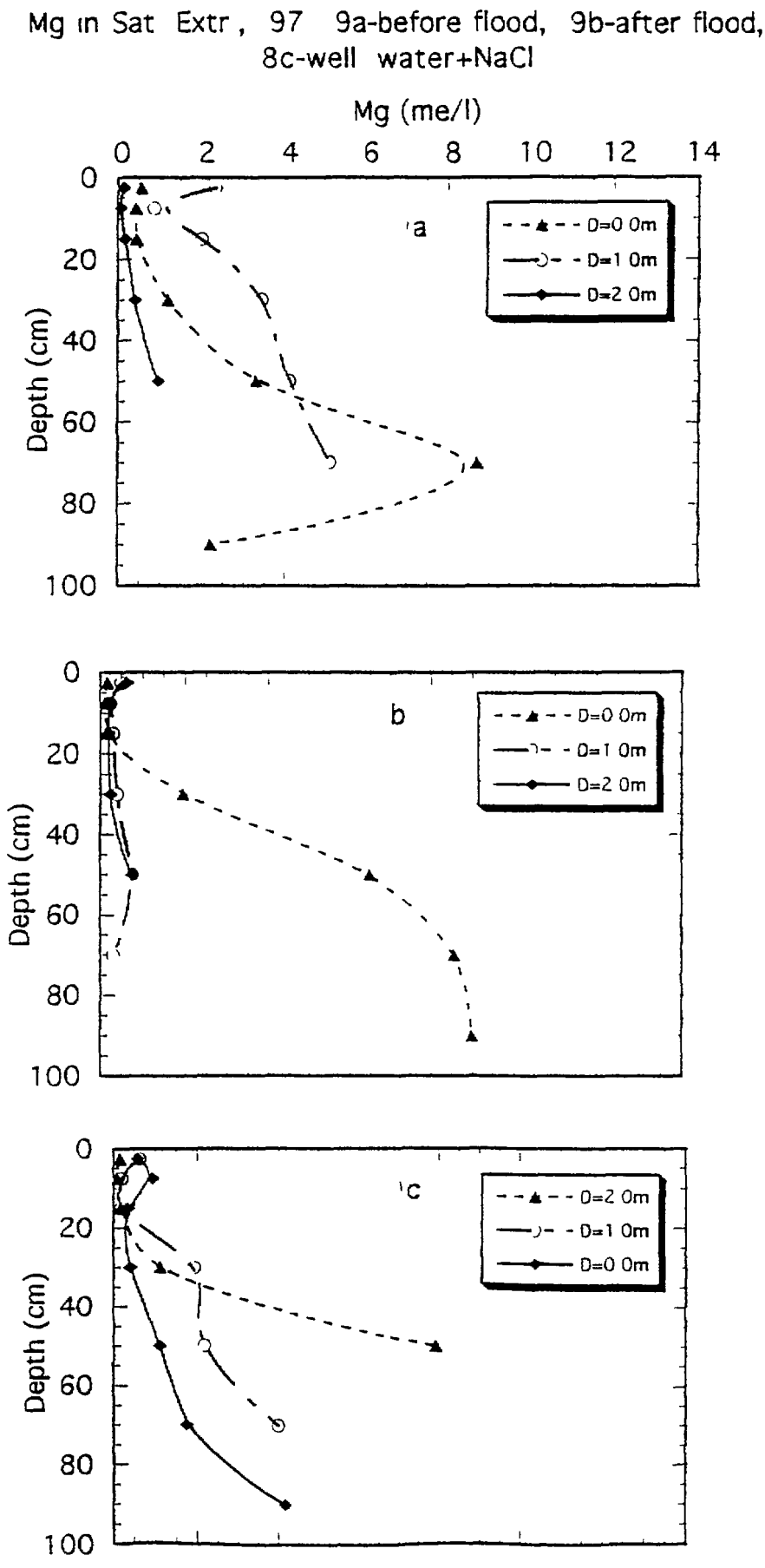


Fig 10 Magnesium concentration, determined in the saturated paste soil water extract (a) before the flooding (2 4 1997), (b) after flooding (29 5 1997) and (c) continuously with brackish water throughout the year (sampled on 1 4 1997) Samples were taken down the soil profile, at distance (D) 0, 1 and 2 m from the tree row

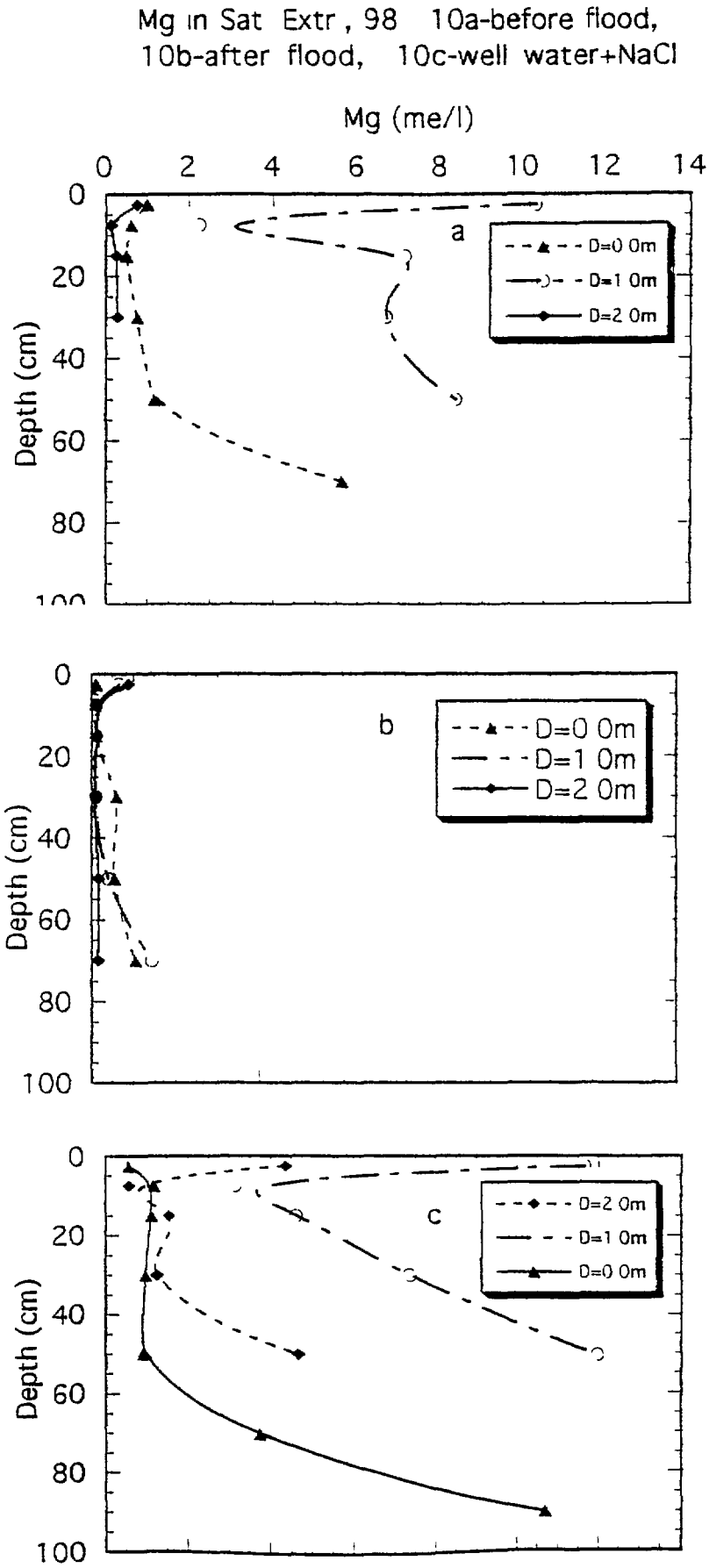


Fig 11 Magnesium concentration determined in the saturated paste soil water extract (a) before the flooding (8 10 1997), (b) after flooding (11 5 1998) and (c) continuously with brackish water throughout the year (sampled on 10 10 1997) Samples were taken down the soil profile, at distance (D) 0 1 and 2 m from the tree row

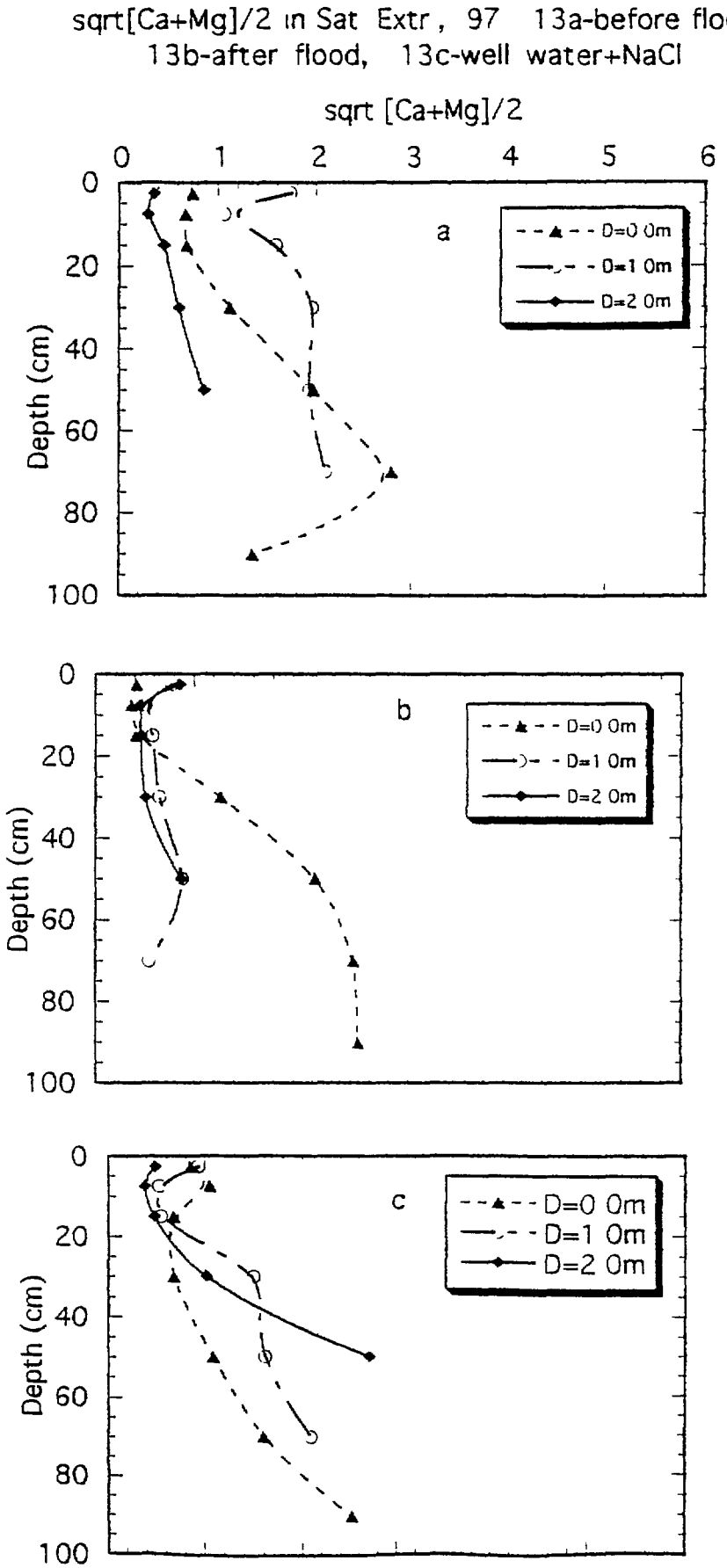


Fig 12 Sum of divalent cations' concentration equivalent, determined in the saturated paste soil water extract (a) before the flooding (2 4 1997), (b) after flooding (29 5 1997) and (c) continuously with brackish water throughout the year (sampled on 1 4 1997) Samples were taken down the soil profile at distance (D) 0 1 and 2 m from the tree row

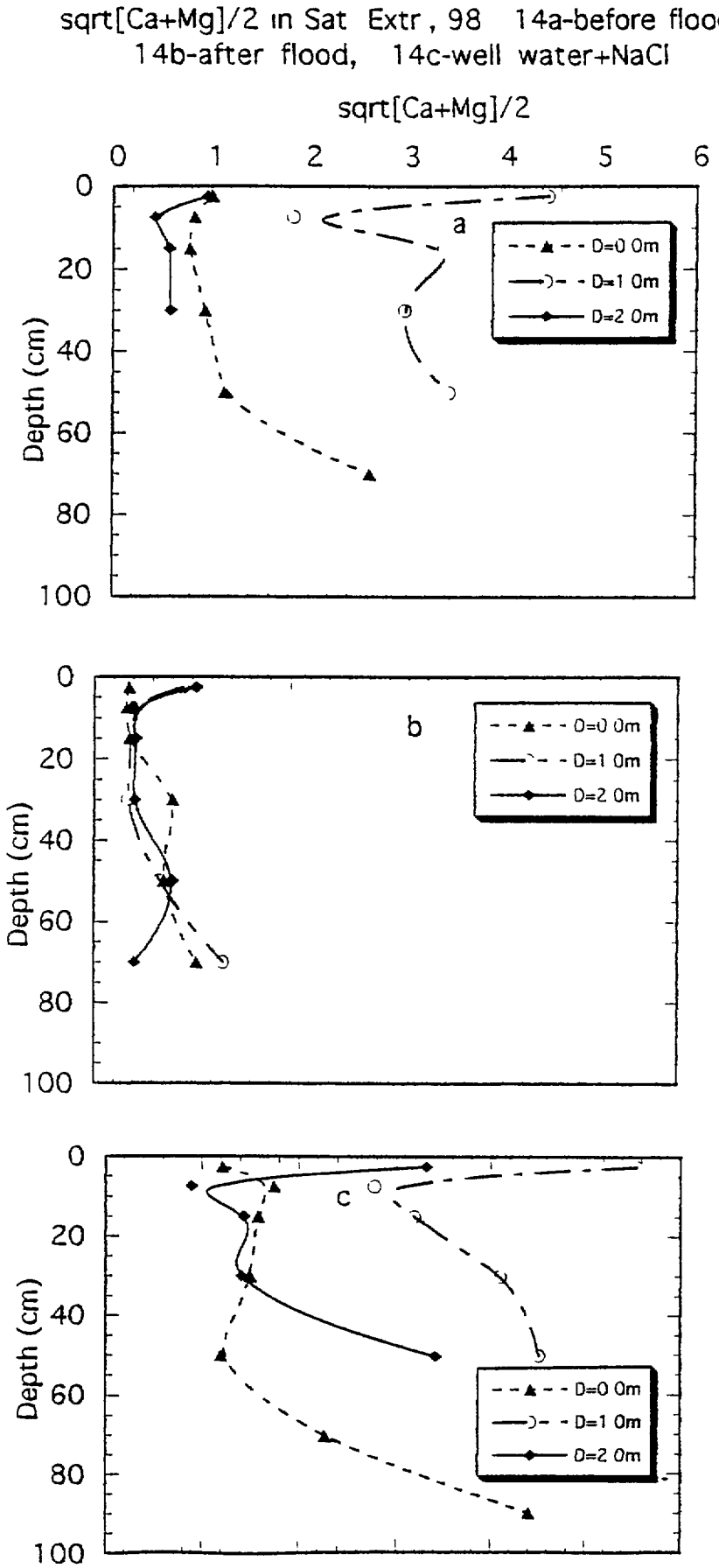


Fig 13 Sum of divalent cations' concentration equivalent, determined in the saturated paste soil water extract (a) before the flooding (8 10 1997), (b) after flooding (11 5 1998) and (c) continuously with brackish water throughout the year (sampled on 10 10 1997) Samples were taken down the soil profile at distance (D) 0 1 and 2 m from Fig 8 Sodium adsorption ratio levels, determined in the saturated paste soil water extract (a) before the flooding (2 4 1997) (b) after flooding (29 5 1997) and (c) continuously with brackish water throughout the year (sampled on 1 4 1997) Samples were taken down the soil profile at distance (D) 0 1 and 2 m from the tree row

SAR of Sat Extr, 97 5a-Before flood, 5b- after flood, 5c-well water+NaCl

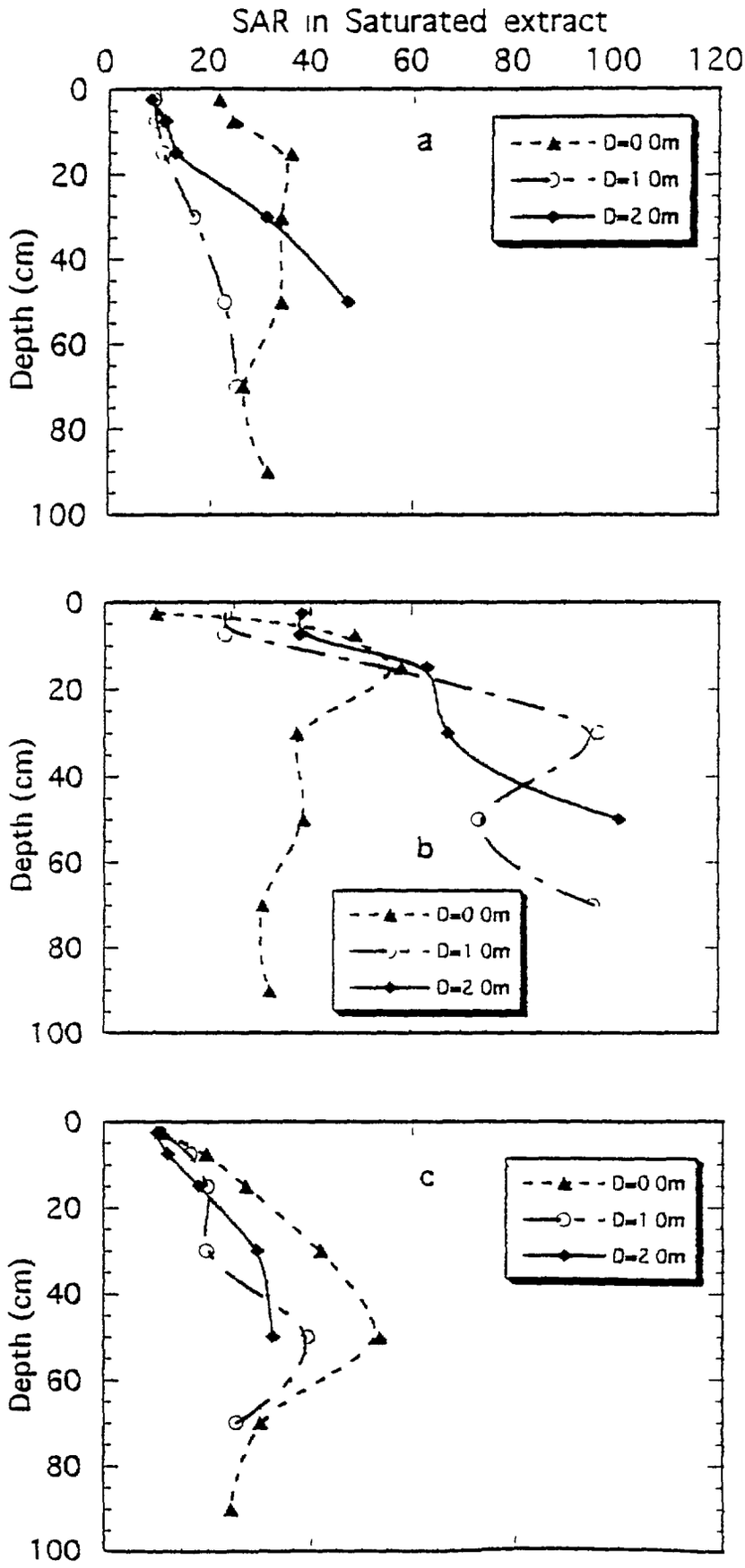


Fig 14 Sodium adsorption ratio levels, determined in the saturated paste soil water extract (a) before the flooding (2 4 1997) (b) after flooding (29 5 1997) and (c) continuously with brackish water throughout the year (sampled on 1 4 1997) Samples were taken down the soil profile, at distance (D) 0 1 and 2 m from the tree row

SAR of Sat. Extr , 98 6a-before flood, 6b-after flood, 6c- well water+NaCl

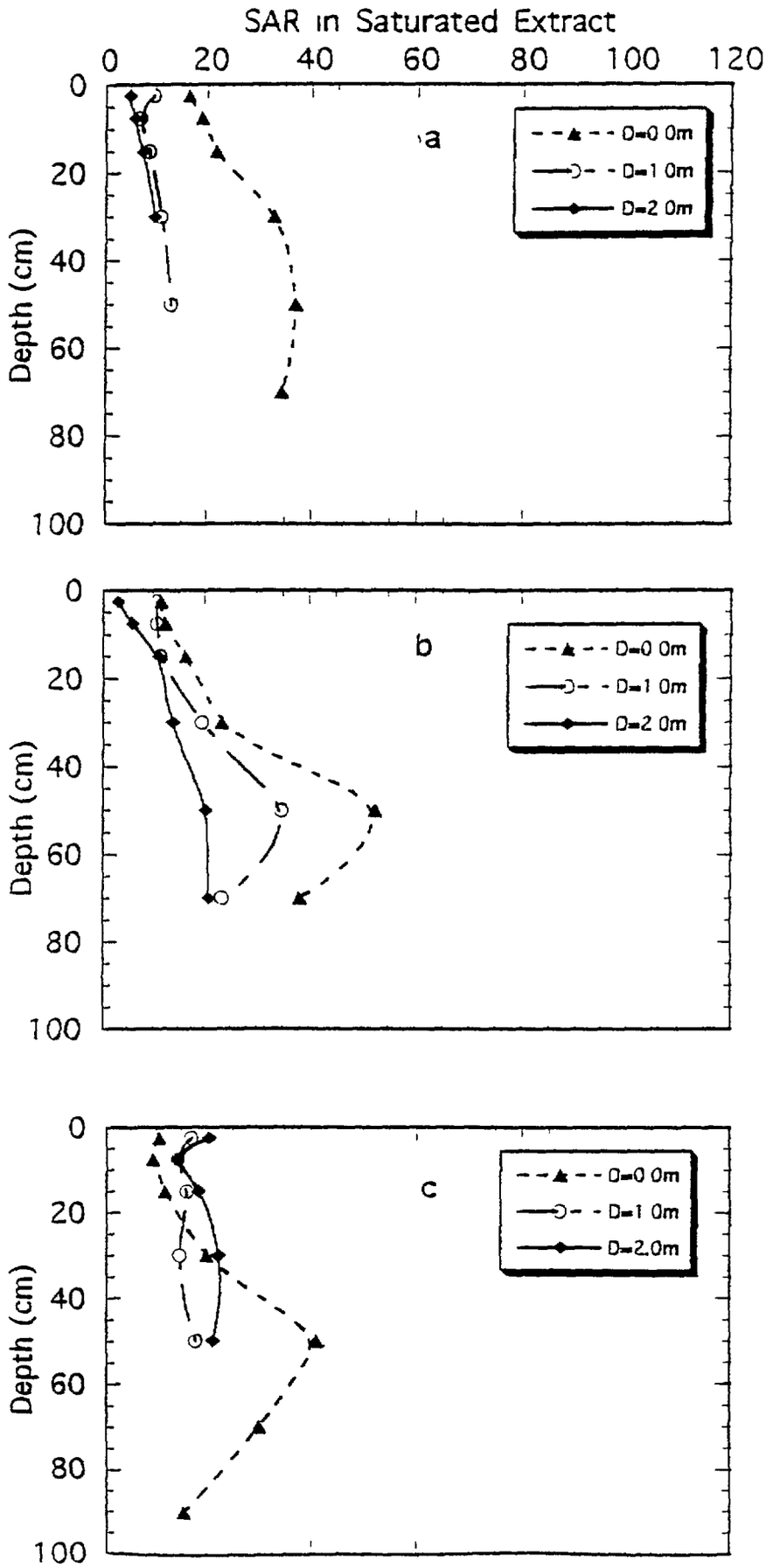


Fig 15 Sodium adsorption ratio levels determined in the saturated paste soil water extract (a) before the flooding (8 10 1997) (b) after flooding (11 5 1998) and (c) continuously with brackish water throughout the year (sampled on 10 10 1997) Samples were taken down the soil profile at distance (D) 0 1 and 2 m from the tree row

Physiological studies on the response of Acacia salignato salinity and nitrogen

S H Lips

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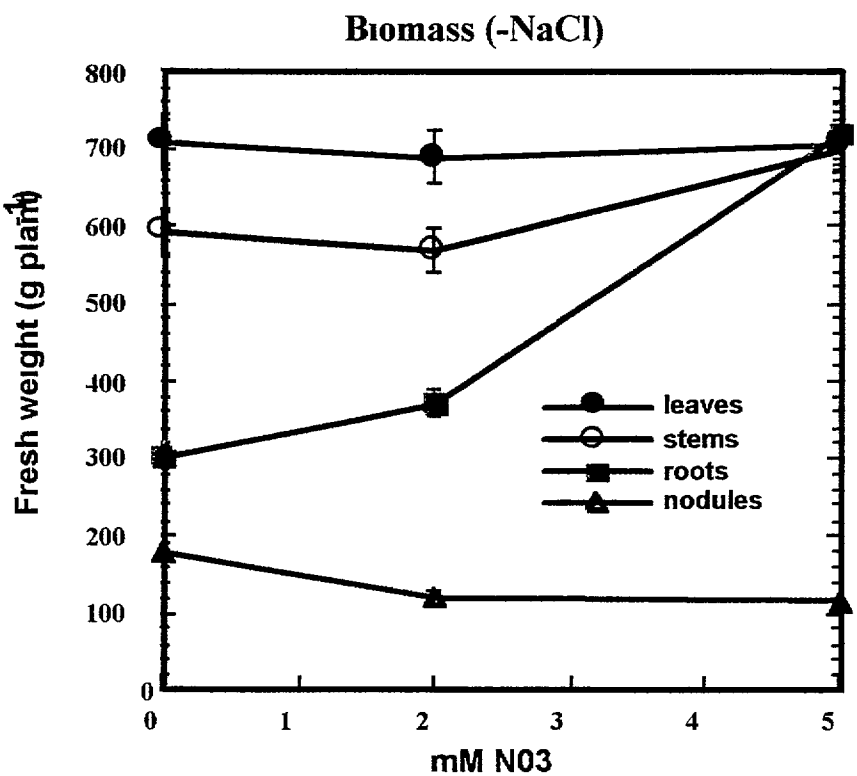
The following studies were carried out to assess the potential response of Acacia young trees to different concentrations and sources of nitrogen under various salinity levels, to establish simple techniques to increase biomass production under stress

Plant material used in the initial experiments were seedlings obtained from local seeds However, it was observed that the variability in the development of the seedlings as well a some of their responses to experimental treatments was considerable Several propagation methods were tested until we were able to produce a reliable methodology to obtain homogenous young plants From this point on time, all the experiments were carried out using plants developed from cutting taken from a single tree in Sede Boqer

A number of experiments extending for short (4-8 months) to long (1-3 years) times were performed and some of the more significant results are shown here Most of the material is in preparation for publication in relevant scientific journals

Biomass production as affected by nitrate

Young acacia plants were grown in the presence of three levels of nitrate 0, 2 and 5 mM The effect of nitrogen level was followed on the biomass production of leaves, stems, roots and nodules (Fig I) The plant part most affected by nitrate was root biomass Nitrate is known to enhance root

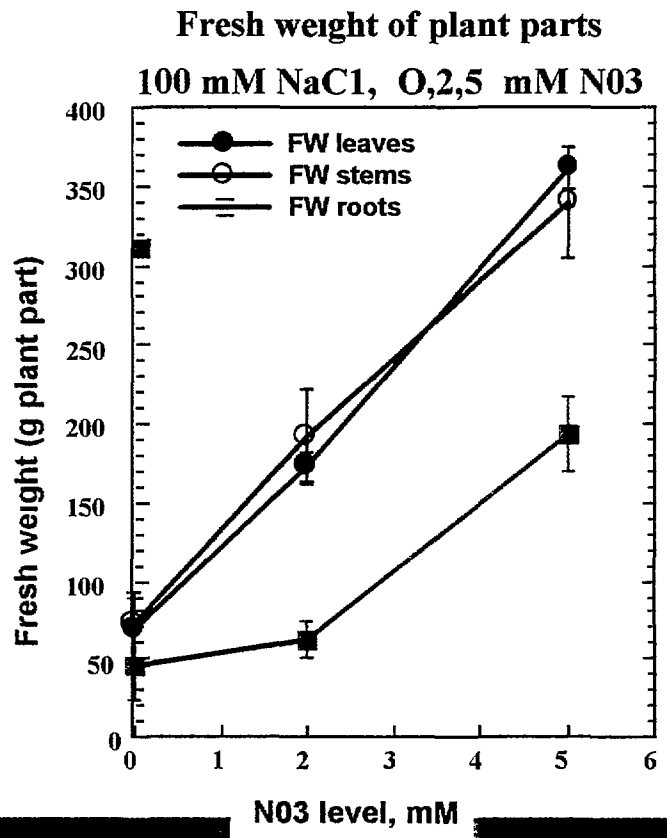


development of plants in generally, specially branching and formation of lateral roots This seems to be the case also with Acacia and should be used increase root proliferation in deep zones of the soil, to increase the possibilities of the tree to tap these zones when the upper layers dry up during the dry season

One should consider the convenience of spreading nitrate between the trees prior to runoff accumulation or brackish water irrigation The fact that nitrate is washed down through the soil profile with the water, should enhance root proliferation in deep soils

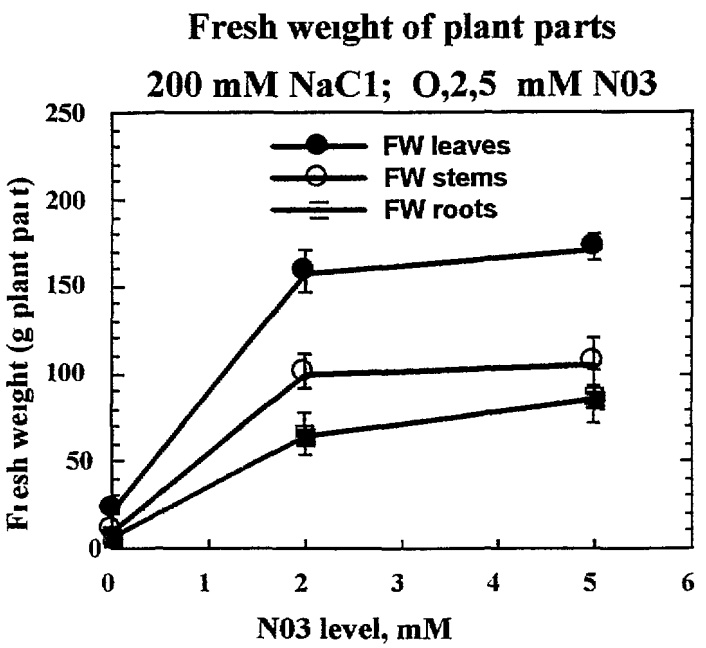
Salt tolerance and nitrogen

Salinity affected the biomass production of Acacia plants However, increased supply of nitrogen (nitrate) allowed the plant to sustain biomass production in the presence of 100 mM NaCl (Fig II)



In this experiment, the main impact of added nitrate was on the biomass production of leaves and stems They were not only larger in size but also more numerous There is no doubt that brackish water irrigation should be accompanied by increased supply of nitrate, as was well documented for a large number of crops in projects C5-001 and C8-131

Acacia plants exposed to 200 mM NaCl showed also enhanced tolerance to salt in the presence of nitrate (Figure IIb) In this case, even roots showed improved growth when "fortified" with 2 5 – 5 mM nitrate



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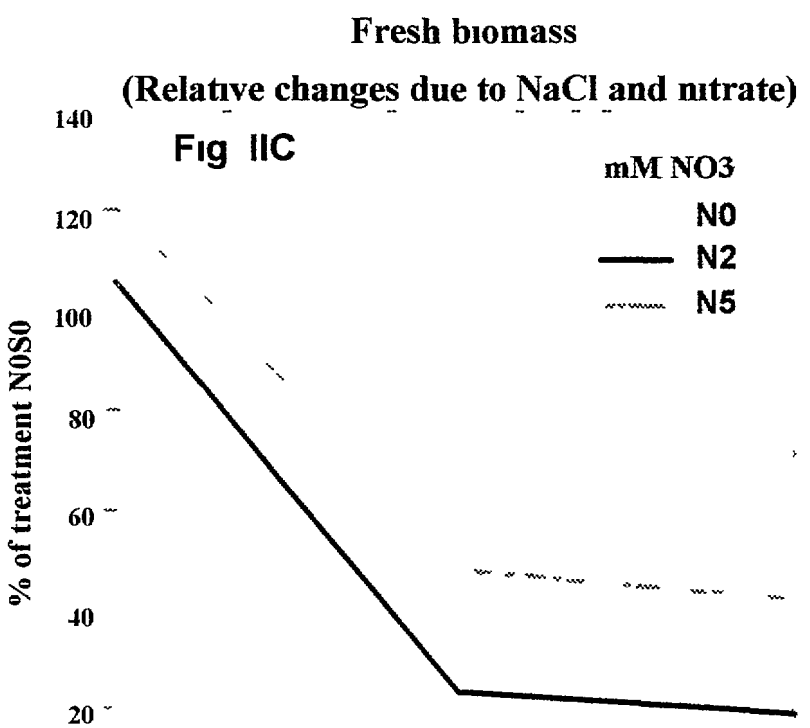
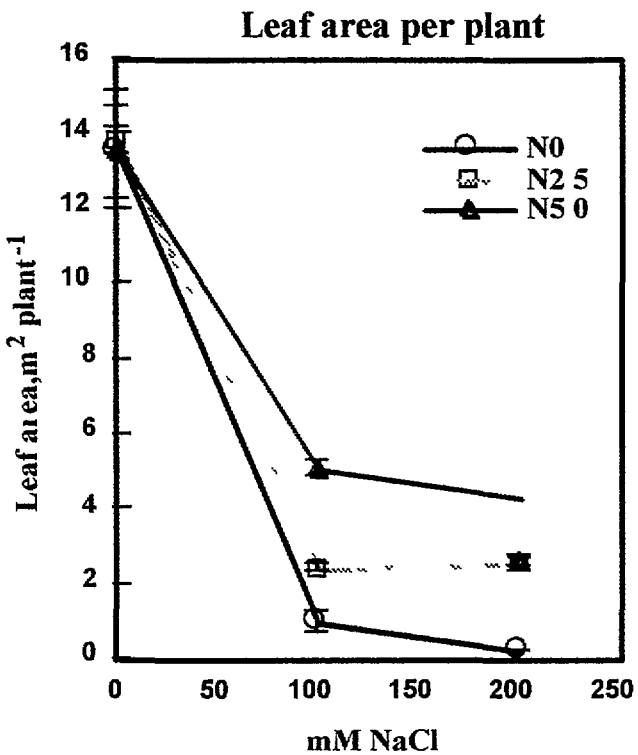
The overall effect of Acacia growth as affected by NaCl and NO_3 concentrations in the irrigation medium is summarized in Figure IIC



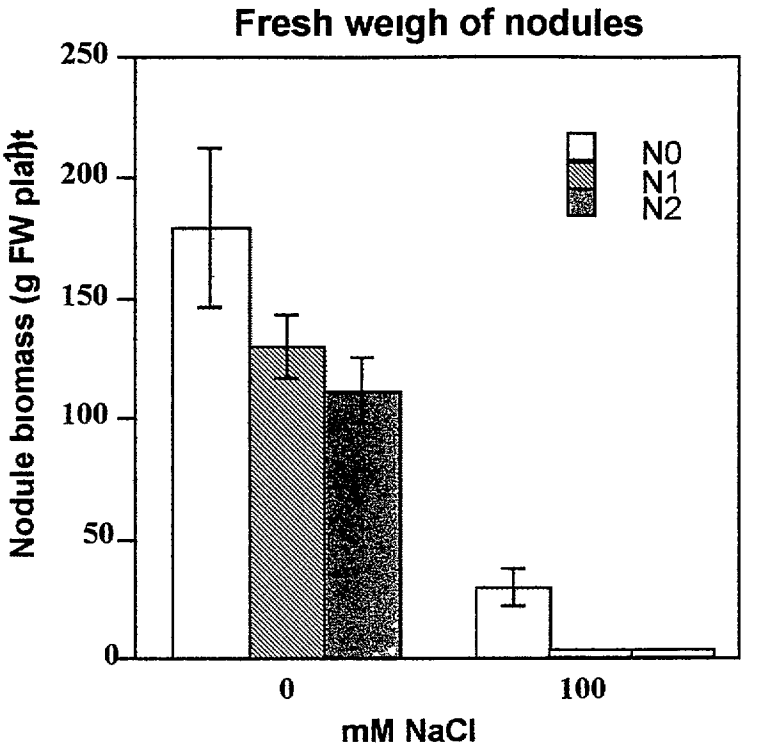
Leaf area

Leaf area of the plant determines not only its transpiration area but its photosynthetic capacity as well Leaf area of Acacia decreases in plants exposed to salinity as compared to non-stressed plants The stress induced reduction of leaf area was due mainly to a reduction in the width rather than the length On the other hand nitrogen promoted leaf width Plants grown in hydroponics in very high nitrate concentration were very broad, almost round Stressed plants produced the well known elongated leaves



N_2 fixing nodules

The acacia plants were grown in the greenhouse in a mixture of sand and local soil These plants formed considerable amounts of nodules in the absence of NaCl nor NO_3 (Fig IV) However, both salinity (100 mM) and nitrate inhibited the number and activity of these nodules Inhibition of about 85% took place in the presence of 100 mM NaCl When this level of salinity was applied in the presence of 2 or 5 mM nitrate, nodules did not develop Nitrate at a concentration of 5 mM inhibited no more than 38% the biomass of nodules formed by control plants This fact suggest that applications of nitrate to the soil before irrigation may promote root growth in deep soil layers without affecting too much the formation of N_2-fixing nodules in the upper soil layers



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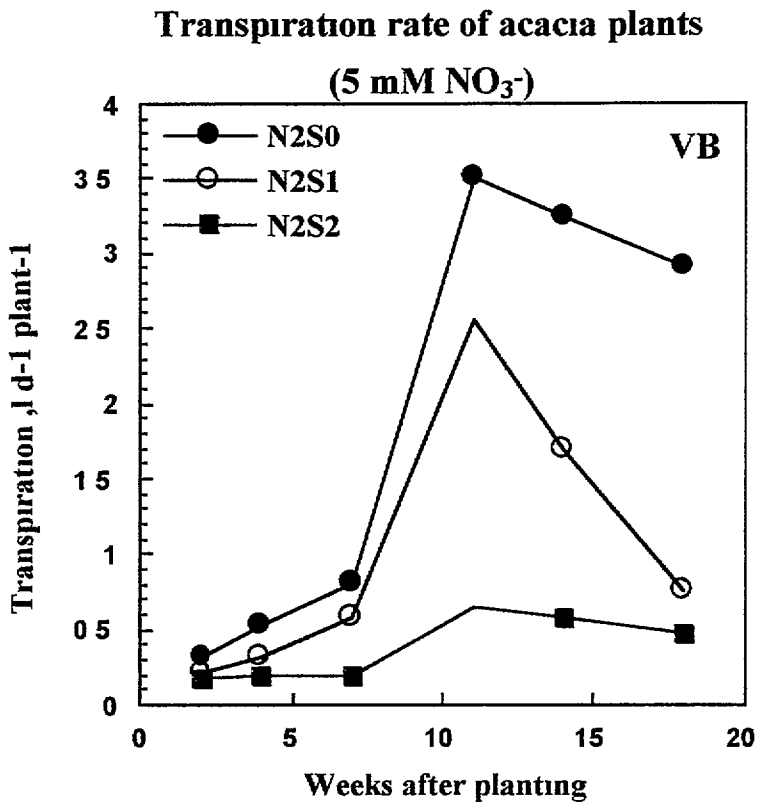
Transpiration rates during growth

Plant transpiration was monitored during their development and was determined by the difference between water applied less water collected in leaching less evaporation (Fig V) These measurements were carried out with all treatments but only two will be shown here Plants grown in the absence of nitrate (Fig VA) and plants receiving 5 mM nitrate (Fig VB)

The development of the young plants was very slow initially, as may be observed (Fig VA) during the first 7 weeks of growth, in which transpiration of the plants in all the treatments was very low From there onwards, a rapid development was observed in plants without salinity Transpiration is also an expression of the development of leaf area and good growth conditions This phenomenon seems to be related to the development pattern of acacia plants that invested all its resources on the promotion of root growth during the first two months Once this initial tap root development was completed, assimilates were allocated also to shoots (leaves and stem growth) This later development was greatly inhibited by salinity, apparently due to the lack of nitrogen required for the production of additional leaves
The initial preferential allocation of assimilates to root growth was observed also in plants subjected to the same level of salinity but in the presence of 5 mM NO_3 There is no doubt that shoot growth was stimulated mainly when the level of salinity was 100 mM NaCl (S1), but even when salinity was as high as 200 mM NaCl – addition of nitrogen enhanced shoot growth The later decline in growth after 12 weeks seems to be unrelated to the treatments and affects even the controls This later decline was prevented by using much larger pots for the acacia plants


Transpiration rate of acacia plants
(5 mM NO3-)
N2S0
N2S1
N2S2
VB
Transpiration ,l d-1 plant-1
Weeks after planting
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0 5
1
1 5
2
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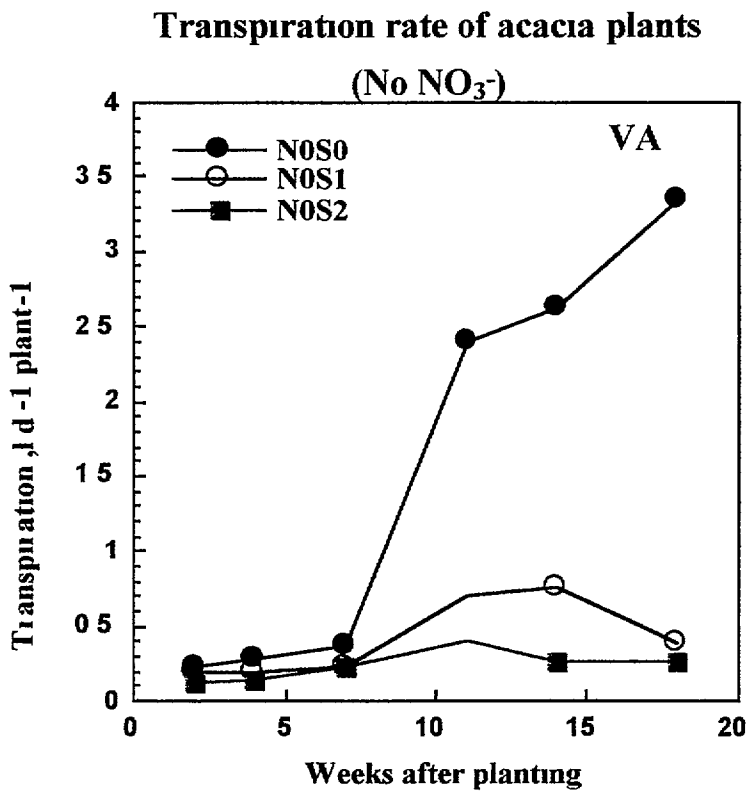
Transpiration rate of acacia plants
(No NO3-)
N0S0
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Weeks after planting
0
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2
2 5
3
3 5
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5
10
15
20

Effect of salinity, nitrate and molybdenum on biomass production and nitrate assimilation in tree of *Acacia saligna.*

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Introduction

Acacia saligna (*cyanofilla*) is a small nitrogen fixing fast growing tree (an average height 6 2 m (Bolland 1989) native to the south-west of Western Australia *Acacia saligna* is cultivated in north Afric and in the middle East for fodder, fuelwood, sand stabilisation and as a wind break The tree is tolerant o drought, light frost, alkalinity and salt (Simmons 1981) It can grow on very poor sandy soils because o ability to fix atmospheric nitrogen

The color of nodules indicates the presense of leghemoglobin which is necessary for effective functioning of N-fixation machinary Leghemoglobin with its high affinity for oxygen can facilitate the supply o oxygen required for vigorous respiration, phosphorylation and the fixation of nitrogen under conditions of extremly low oxygen tension in bacteroids of nodules (Appleby,1984) It plays a key role of in nitroger fixation which requires a great deal of ATP

The experiment was conducted to investigate response of *Acacia saligna* plants to salinity, differen nitrate levels and application of Mo on nodulation, nitrogen fixation and growth parameters

Plant material

Seeds of *Acacia saligna* were germinated by immersing them for 5 min in boiling water followed b placing on wet paper in Petri dishes and grown in green house for 4 months Then seedlings were selected for uniformity and transferred into 25 L plastic pots filled with mixture of soil taken unde Acacia saligna trees in field and perlite (1/4, V/V) Plant nutrients were initially provided with half strength Long-Ashton nutrient solution (Hewitt, 1966) After two months of growing Acacia trees were irrigated with normal Long-Ashton solution The experiment included 6 treatments

1 Control without salinity and nitrogen (solutions were prepared with DDW)

2 5 mM $N0_3$ without salinity

3 5 mM $N0_3$ + 2 µmol Mo

4 100 mM NaC1 without nitrogen

5 100 mM NaC1 + 5 mM $N0_3$

6 100 mM NaC1 + 5 mM $N0_3$ + 2 µmol Mo

In 3 month after transfer first two treatments were grown on saline water (100 mM NaC1)

The width and length of 20 leaves of each tree were measured in August when difference between treatments became pronounced Measurements of all branches were taken during experiment

Chemical analyses

Nitrogenase activity of nodules was assayed indirectly by gas chromatography method based on the reduction of acetylene to ethylene (Burris 1967)

Nitrate was determined by reduction to nitrite (Mc Namara et al 1971)

Nitrate reductase was determined according to Hageman and Reed (1980)

Results

Leaf expansion

The measurements of width and length of 20 developed leaves were taken from 6 months-old plants The difference in length of the leaves between treatments was less pronounced than width The correlation between applied nitrogen and width expansion of the leaves was found

Nodulation and nitrogen fixation were severely inhibited under salinity and lack of transported nitrogen to the leaves suppressed leaf expansion The leaves of *Acacia saligna* trees grown without mineral nitrogen on saline water were for 22% more narrow than control leaves The difference between length of the leaves in both free-nitrogen treatments was negligible

Nitrate in stressed and non-stressed plants stimulated leaf (both parameters) Mo considerably increased the width of the leaves in non-stressed plants (21%) In salinity stressed plants this difference was not so pronounced The length of the leaves was practically not affected by Molybdenum (Table 1)

Table 1 Leaf dimensions as affected by different treatments

Treatments	Leaf width cm	Leaf length cm	Leaf width %	Leaf length %
0 mM NaC1				
N-0	3 28±0 3	22 60±1 9	100	100
N-1	3 65±0 1	25 81±0 3	112	114
N-1+Mo	3 97±0 2	26 09±1 7	121	115
100 mM NaC1				
N-0	2 56±0 1	22 16±1 1	78	98
N-1	3 73±0 1	25 13±1 4	114	111
N-1+Mo	3 87±0 3	23 31±0 7	118	112

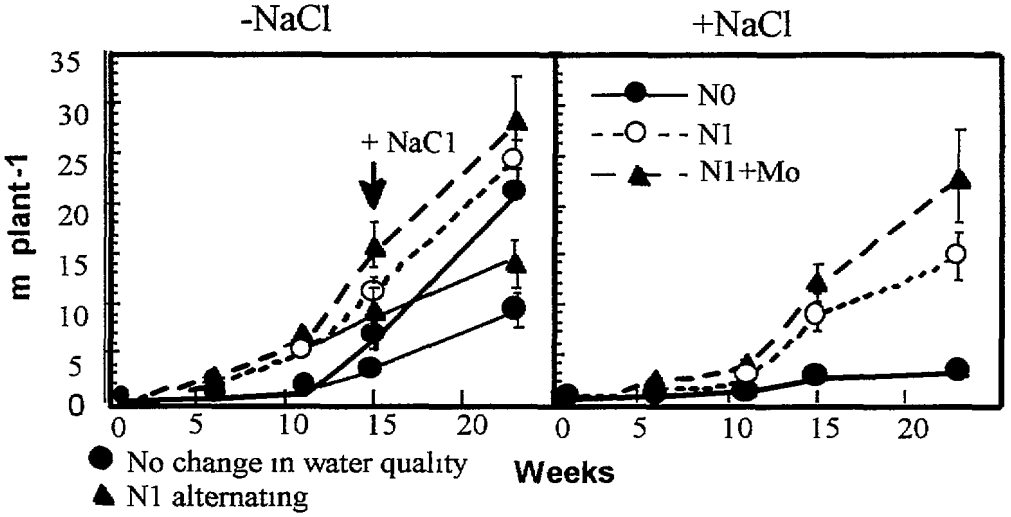
Length of branches

There was no significant difference between trees grown without nitrogen on different levels of salinity (0 mM and 100 mM NaC1) during 3 months after transfer of plants to big pots Nitrogen fixation at early stages was not sufficient for normal growth of plants

Mineral nitrogen increased 4-fold length of branches and in combination with Mo 5-fold compared with control in non-stressed plants

Salinity in all the treatments was a limiting factor and plants grew slower compared with the same treatments without adding NaC1 100 mM NaC1 inhibited for 90% branches length and lack of nitrate only 26% The best results were obtained on the level with adding nitrate supplemented with Mo Mo was more efficient under saline conditions and increased 30% growth of branches, while in non-stressed

Figure 1 **Branches length**



plants only - 12%

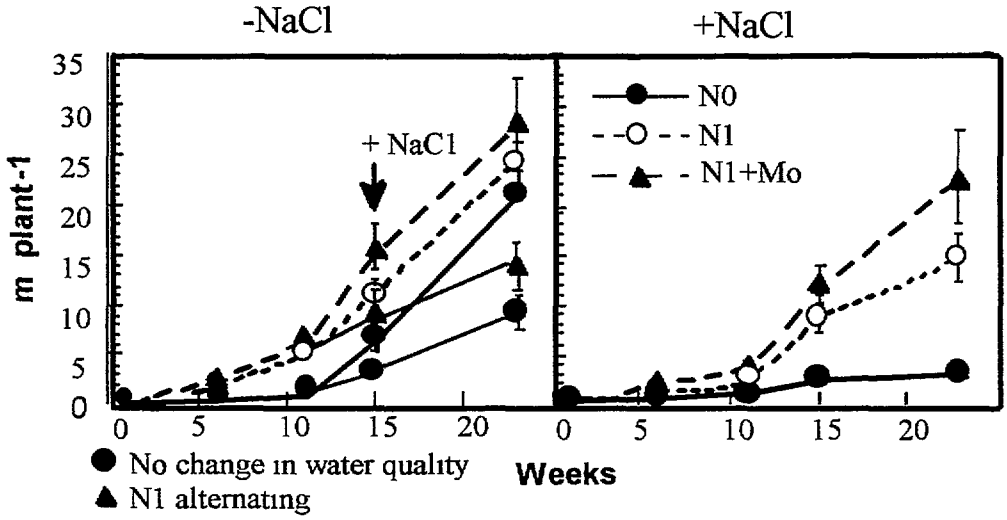
Alternation of salinity in 3 months led to strong decrease of the growth of branches (Fig 1)

Total biomass production

The total biomass production per pot in non-saline treatments was found to be 26% more with N03 added in nutrient solution and 56% more with N03 supplemented with Mo

100 mM NaC1 applied from the early stages of *Acacia* plants had detrimental effect on growth rate The biomass of salinity stressed plants grown without mineral nitrogen in the media was almost 90% less than

Figure 1 **Branches length**



that observed in control

Nodulation and nitrogen fixation were completely inhibited by combination of N03 and salt 5 mM N03 was not sufficient for developed trees As a result, total biomass of stressed N03-grown plants was about 30% less than that in control Mo practically did not increase the total biomass under saline conditions In early stages when nitrate was not limiting factor effect of molybdenum was more pronounced Alternation of salinity significantly decreased biomass production The total biomass of plants grown with 5 mM N03 on alternative salinity and on saline water was found to be practically the same (30% less than control) On the contrary, the plants grown without mineral nitrogen in the media were affected by salt stress and decreased total biomass production more than 60% (Fig 2)

Root shoot ratio

The results indicate that saline water with adding N03 had detrimental effect on formation of shoots Root growth was less affected by salinity The plants grown on fresh water and the plants grown under alternative saline conditions had the same biomass of roots (the ratio root shoot 0,26 and 0,47) This is typical response of non-halophytes to salinity (M Nabil 1995) The plants grown under alternative saline conditions without nitrate in the growth medium formed relatively small root system (0 22) to compare with control treatment (0 26) Mo relatively increased biomass production of roots under saline and non-saline conditions (Table 2)

Table 2 root shoot ratio

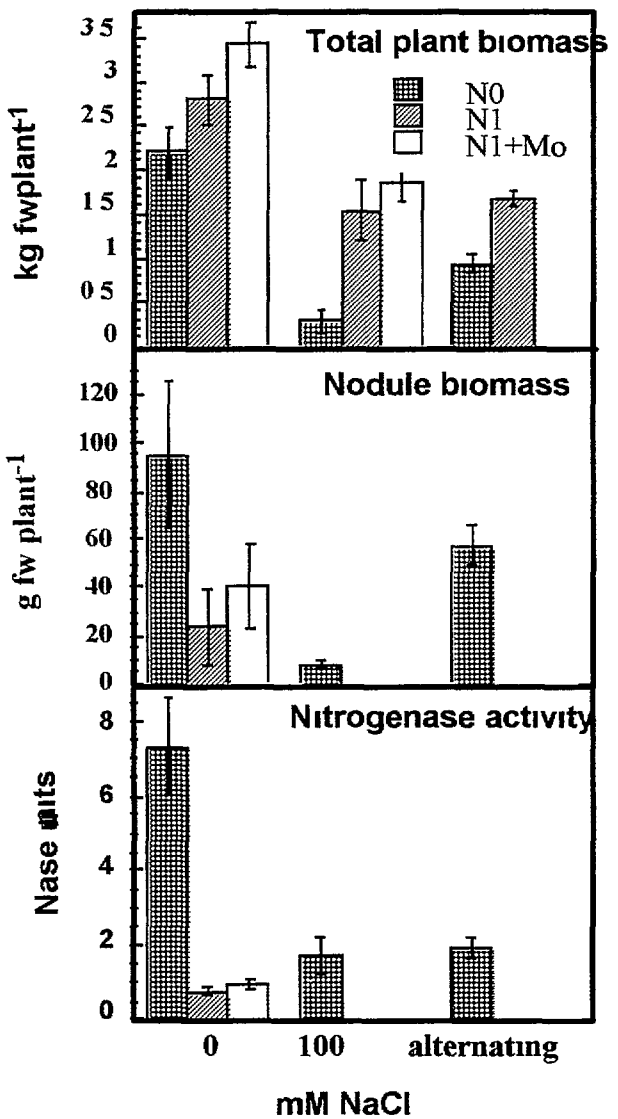
Treatment	**- N03**	**+ N03**	**N03 +Mo**
- NaC1	0 26±0 06	0 26 ± 0 05	0 34 ± 0 04
+ NaC1	0 34 ± 0 1	0 23± 0 03	0 29 ± 0 03
Alternating	0 22 ± 0 3	0 47± 0 04	-

Nodulation

Root nodules were found in all treatments except treatments with combination of salinity and nitrate The color of the nodules was brown and inside tissue reddish in all the treatments without nitrate in the media and slight reddish in the treatments with provided N03

Nitrate inhibited nodulation of the *Acacia saligna* plants grown on fresh water for about 75% while Mo considerably stimulated the nodule formation in treatments with nitrate applied (Fig 3) NaC1 which was applied at early stages severely inhibited nodules formation (about 90%) In case of alternation of fresh and saline water biomass of nodules was only 40% less than that in the control

Figure 3 Nodule productio



Nitrogen fixation activity

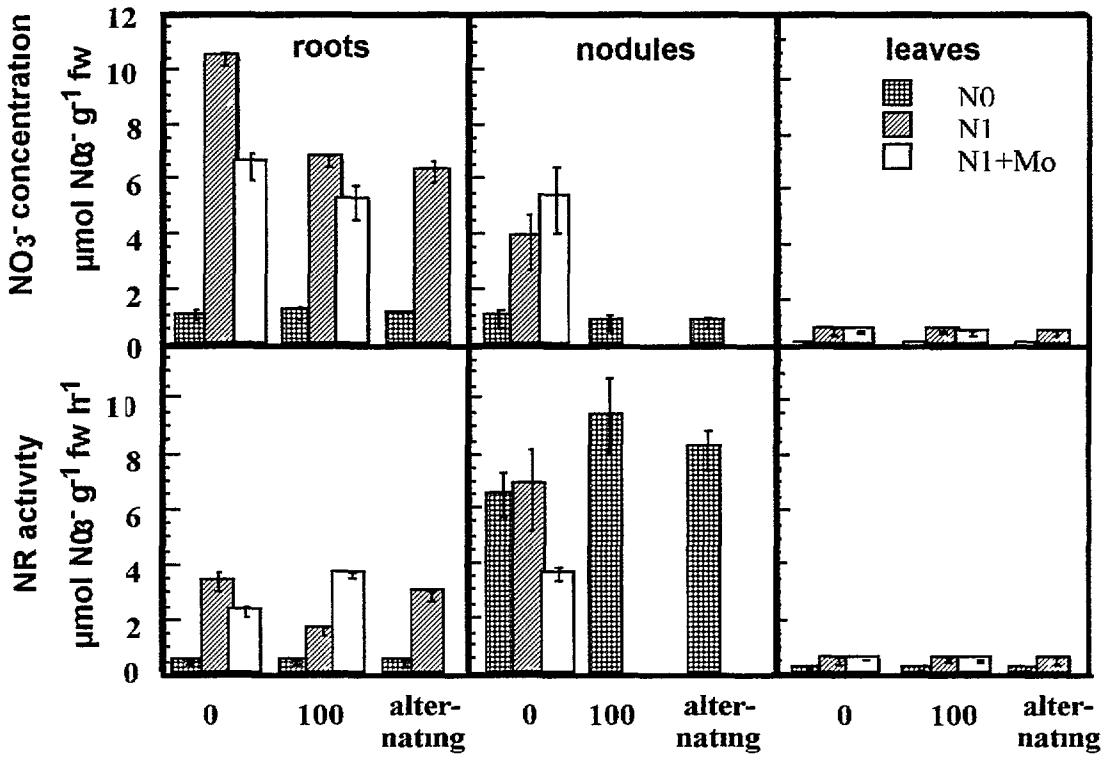
The maximum nitrogen fixation activity was observed in the control Nitrate dramatically decreased the rate of nitrogen fixation of *Acacia saligna* nodules (90%) The decrease can be probably attributed to the formation of nytrosylleghemoglobin with nitric oxide Nitric oxide, readily produced from nitrite in cell has already been identified as the main product synthesized via nitrate reductase in soybean (Dean and Harper 1986) The affinity of leghemoglobin for nitric oxide may be much higher than that for oxygen (Kanayama, Yamamoto 1990)

Salinity applied at early stages and alternative salinity severely inhibited nitrogen fixation activity estimated by means of acetylene test (80%) Mo did not stimulated relative nitrogen fixation rate(Fig 3)

In vivo NR activity

It has been found that NR activity in secondary roots considerably exceeded that in primary roots developed at earlier stages of plant growth (Fig 4) Therefore, as far as secondary root system developed only after several months of growing, proportion of nitrate reduced in shoots was greatly dependent on age of plants The plants grown on saline and fresh water without nitrate had negligible NR-activity in roots and leaves close to detection limit Nitrate-grown non-stressed plants had NR activity in roots 4 fold higher compared to shoots Salinity decreased part of nitrate reduced in roots in favor to shoots Mo stimulated activity of NR and significantly increased the amount of nitrate reduced in roots This effect

Fig. 4. NO_3^- concentration and NR activity in vivo



was more pronounced under salinity stress conditions Leaf NR was not affected by salinity, but greatly dependent on nitrate content in tissue (Fig 4) On the contrary, root NR reduced dramatically after adding NaC1

The maximum nitrate concentration in blades of the plants grown under salinity stress with adding 5 mM NO_3 was 17-fold less than that in roots In the plants grown on fresh water this difference was even more pronounced (60-70 fold) Thus, salinity stress stimulated nitrate transport to shoots (Fig 5)

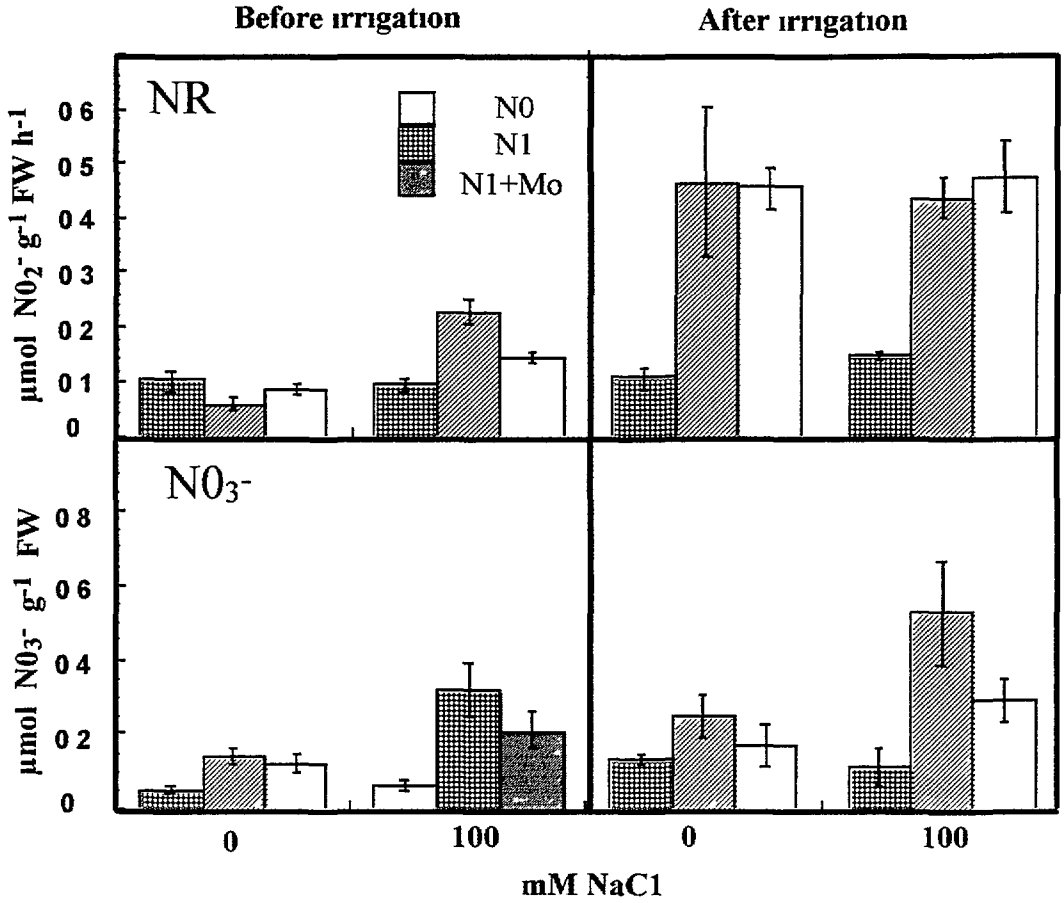
The measurements were taken before irrigation and after 7 hours Nitrate reductase in treatments without addition of NO_3 was not changed and with addition of nitrate increased up to 6-7 fold on the levels without applied salt and 2-3 fold with applied salt (Fig 4)

Nodule NR activity had different pattern Nitrate and supplemented Mo did not increase NR-activity in nodules On the contrary, salinity stimulated NR activity in nodules (Fig 4)

Chlorophyll

Total total chlorophyll concentration in early stages was not affected by salinity The plants grown without nitrate supply on saline and fresh water hadthe same concentration of total chlorophyll On the other hand, nitrate considerably stimulated accumulation of chlorophyll in leaf tissue The plants under

Figure 5: NR in vivo and N03 in blades of acacia



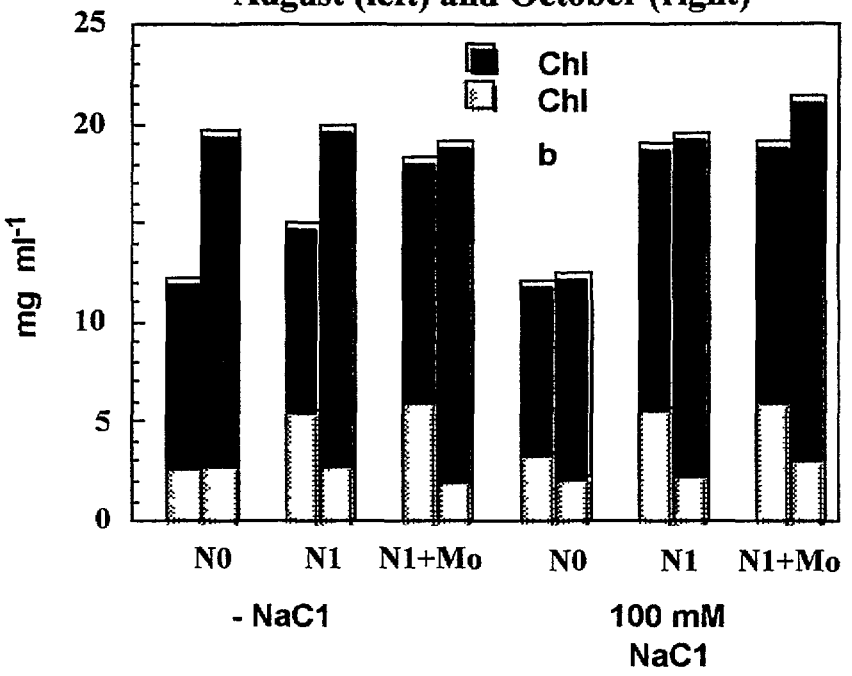
salinity stress grew slower and were not limited in nitrogen Moreover, the concentration of total chlorophyll increased for 20% by salinity when plants were grown on nitrate

The ratio between chlorophyll a and chlorophyll b was changed significantly after 8 months of plant growing compared to 5 months-old plants Nitrate and salinity reduced 40-70% chlorophyll b content in leaves and increased 1 5-2-fold chlorophyll a content Chlorophyll b content in the plants grown without nitrate on fresh water did not changed and chlorophyll a increased about 2-fold The proportion between chlorophyll b and a in the plants supplied with nitrate was 1 5-2 in August and 6-7 in October It is probable that chlorophyll b content was related to nitrate transported to the leaves and converted there into organic form (Fig 6)

Organic nitrogen

Organic nitrogen concentration in leaves practically was not changed in all the treatments free of nitrate Supplied 5 mM nitrate increased it not more than 10% The highest organic nitrogen was found in the leaves of the plants grown on fresh (more then 35%) and saline (31%) water with supplemented to nitrate Mo

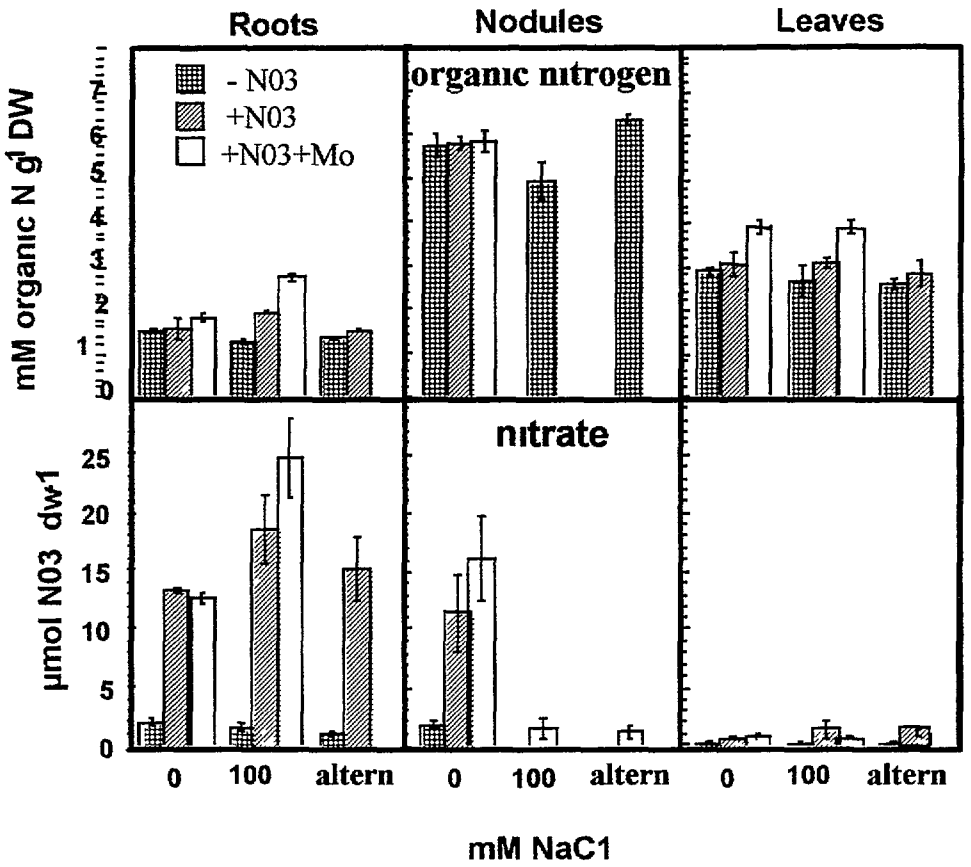
Figure 6: Chlorophyll
August (left) and October (right)



The same tendency was found in roots Nitrate and Mo practically did not increased the concentration of organic nitrogen in the roots of the plants grown on fresh water and alternation of salinity The difference between the treatments was more pronounced in the roots of the plants grown under saline stress The plants with nitrate-free medium contained 20% less organic nitrogen in roots than control plants Nitrate led to 20% increase and supplemented Mo more than 80 % increase in accumulation of organic nitrogen in roots of acacia trees under salinity conditions

Organic nitrogen of nodules was almost twice higher than in leaf tissue All non-saline treatments led to practically the same amount of organic nitrogen in nodules Nodules of the plants grown on saline water had the lowest level of organic nitrogen (20% less to compare with control)

Figure 7 Organic nitrogen and nitrate distribution in different parts of acacia



Conclusions

1 Salinity (100 mM) severely inhibited inoculation (90% less) of *Acacia saligna* roots with Rhisobium strain and decreased for about 75% nitrogen fixation activity

2 Nitrate led to less detrimental effect on nodule formation (for about 75%) but practically completely inhibited nitrogenase activity (90%)

3 The plants in the treatment with combination nitrate and salinity did not form nodules

4 Nitrate reductase activity was less sensitive to salinity than nitrogenase

5 2 µmol Mo stimulated the growth of plants on saline and fresh water Organic nitrogen content was the highest in both treatments

6 Acacia reduces almost all nitrate in the roots, the content of nitrate in leaves is negligible

Sudies of Acacia plants under hydroponic conditions

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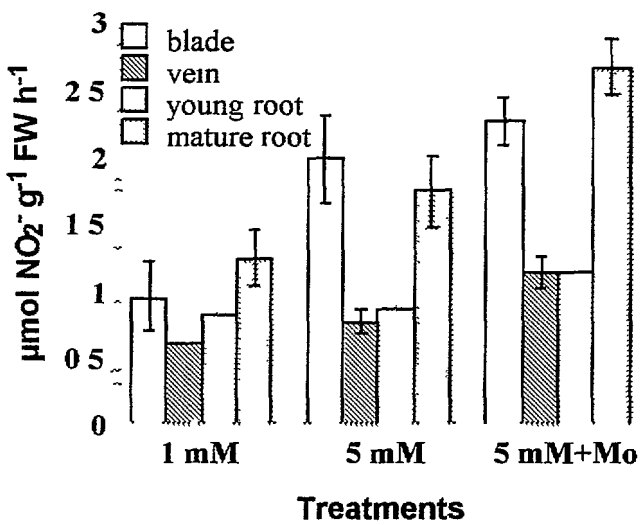
Biostress Research Laboratory

Acacia saligna plants were transferred to 100 L tanks 2 month after planting, at which time plants were 15 cm height Nitrogen was applied to nutrient solutions at concentrations of 1 mM $N0_3$, 5 mM $N0_3$ and 5 mM $N0_3$ + 2 µmol Mo These nutrients were added initially to 1/2 strength Long-Ashton nutrient solution at full strength after 2 months The solutions were changed once a week and the pH was adjusted daily

1 The first measurement of NR-activity in vivo was carried out 2 weeks after transfer Growth of secondary roots was observed at this stage NR activity was measured in the mature parts of roots (more than 10 cm from the tip) and in the younger parts (first 8 cm from the tip) Nitrate stimulated NR-activity in mature parts of roots, in blades and in veins and little in the younger part of roots NR-activity of the mature root segments with tiny secondary roots (1-2 mm) was 50% higher in plants grown with 1 mM $N0_3$, 100% higher in plants with 5 mM $N0_3$ and 130% in plants grown in the presence of 5mM $N0_3$+Mo, as compared with the younger root sections NR-activity in leaf veins was considerably less compared to that in blades 65% less in plants grown with 1 mM nitrate, 35% with 5 mM and 40% with 5 mM + 2 µmol Mo The leaves reached maximum NR activity at this growth stage Leaf blades were the major sites for nitrate reduction before the beginning of secondary roots formation Mo increased significantly NRactivity in the mature root parts as well as in veins and in blades NR-activity of the young root sections was less sensitive to Mo supplementation (Fig 1)

Figure 1: NR-activity in different parts as affected by nitrate level and Mo

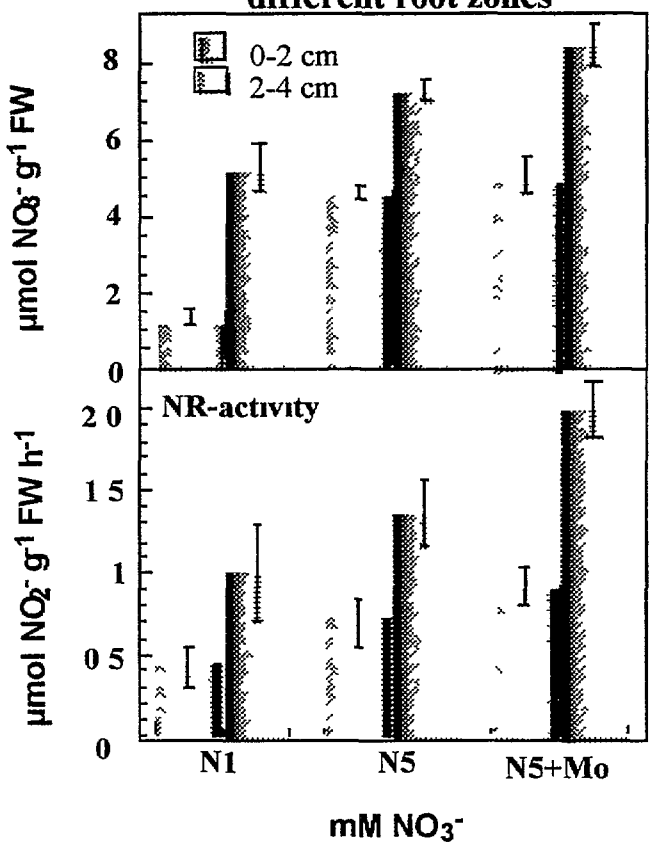


2 The next measurements were taken after 1 month, when plants formed small secondary roots (2-3 cm with 1 mM $N0_3$, 3-4 cm in 5 mM $N0_3$ and 5 mM NO_3 +2 µmol Mo) Nitrate

cell multiplication takes place and the region of elongation and differentiation where cell division continues to a lesser extent Probably above 2 cm there was a beginning of the maturation zone where uptake and NR-activity considerably increased (Fig 3)

2 The aim of the next experiment was to determine NR-activity and distribution of $N0_3$ in root segments (0-2, 2-4, 4-6, 6-8, 8-10 cm) of primary and secondary roots and blades on the level

Figure 3: NO3- concentration in different root zones



3 5 mM NO_3 There was the same tendency as in previous experiment - NR-activity in primary roots reached maximum in 4-6 cm segments and was steady in all the segments up to 10 cm NR-activity of segments 0-2 cm practically did not change within 2 month period On the contrary NR-activity in the blades reduced 30% during the first month and 55% during the second one It was limited by poor nitrate supply to the leaves (nitrate concentration in blades reduced more than 4 -fold) (Fig 4)

4 Nitrate supplemented by adding Mo did not lead to a better growth of branches On the contrary the lack of nitrate in the treatment 1 mM N03 declined growth of branches more than twice (Fig 5)

Figure 4: NR-activity and NO3- in different parts of the Acacia plants grown with 5 mM NO_3^-

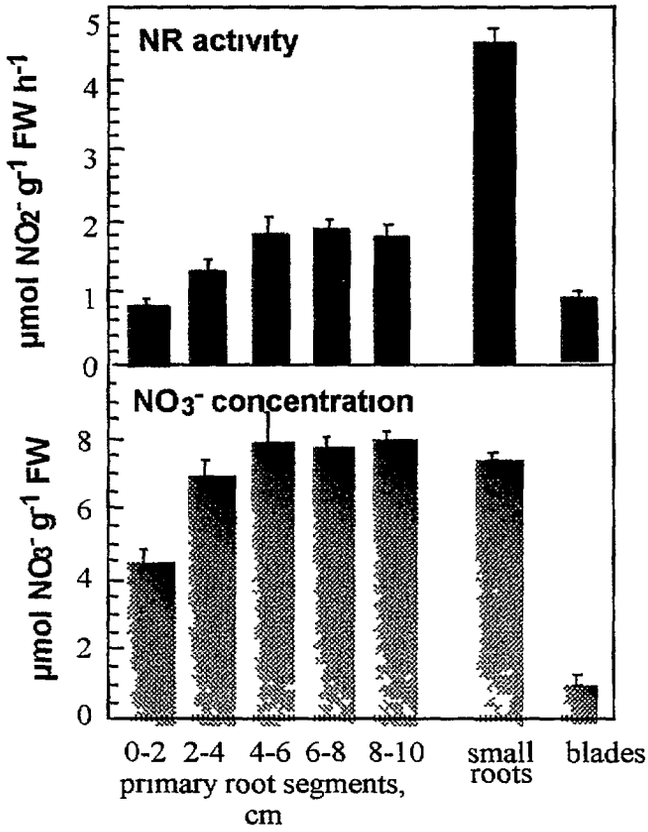
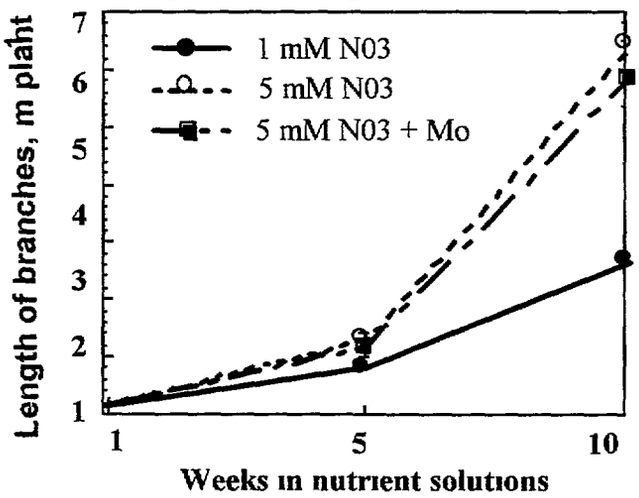


Figure 5 Length of branches



EFFECT OF RUNOFF AND SUPPLEMENTAL IRRIGATION,USING BRACKISH , ON GROWTH AND SOME GAS EXCHANGE PARAMETERS OF *ACACIA SALIGNA IN ARID N* W KENYA.

J O Nyabundi and P O Ayiecho

INTRODUCTION

One of the major problems facing the world today is that of feeding the ever increasing population from limited arable land The long-term solution to this problem lies in exploitation of under-utilized agriculturally marginal areas Arid and semi-arid lands (ASAL) comprise a large portion of such regions Worthington (1976) estimated that ASAL forms 60% of the world' s land surface In Kenya ASAL covers over 83 % of the landmass which is home for 20% of the population and 50% of the livestock (Braun and Mungai, 1981) Agricultural utilization of tropical ASAL is limited not only by the low annual rainfall, but also by its highly erratic and often excessively intensive pattern alongside all-year conditions of high evapotranspiration rates North-Western Kenya, in particular, receives a mean annuall rainfall below 200 mm which is characteristically concentrated over unpredictable short periods giving a growing period of 1 - 29 days a year (F A O , 1993) Under such conditions even the fastest maturing annual crop species/varieties would not yield a significant crop in an average year Even though trees are generally more resistant to drought, by virtue of their deep roots, their growth is greatly impaired during these long dry periods In the absence of all out irrigation which may be an expensive/uneconomic undertaking, short term localised options include use of drought tolerant species,water harvesting techniques and supplemental irrigation using ground water

Use of runoff harvesting in agriculture dates back to 4000 years in the Negev (Evenari, *et al,* 1971) In North-Western Kenya runoff farming was already being used to grow sorghum by the Turkana people in 1952 (Fallon, 1963) It has also shown promising results in Kitui and Baringo districts of Kenya (Thomas *et al,* 1989) The importance of runoff harvesting in many ASAL's stems from the fact that runoff events are common in these regions, as evidenced by upsurge of many intermittent rivers Significantly runoff may come either as a result of direct rains in an area or as surface rainwater flowing in from distant places Whatever the source, the infrequent and erratic rainfall in tropical ASAL can never ensure continued provision of runoff

water throughout any one year nor every year This calls for supplementary irrigation to cover the dry periods/years and thus enable the annual crops grow to maturity while also reducing growth and productivity checks on tree crops Unfortunately ground water available in most ASAL's is usually brackish thus posing special irrigation and/or environmental problems Nevertheless, it is conceivable that the occasional big floods, when harvested, should assist to leach the salts out of the main rooting zones

This experiment was conducted in arid North-Western Kenya to study the impact of runoff harvesting and supplemental irrigation on growth and some physiological traits of *Acacia saligna*, a fast growing tree legume that has been found to perform well in desert regions of Western Australia (Crompton, 1992), North Africa (Tiedeman and Johnson, 1992) and Negev (Degen *et al*, 1995) Two morphotypes of the species were used

MATERIALS AND METHODS

The experiments were conducted at Kakuma in the arid Turkana district of Kenya The site had deep soil (> 3 m),ideal for soil water storage and was located on an established runoff path Runoff water was collected into a liman water harvesting system The system comprised basin-like fields (limans) into which water was led by means of dykes and channels The Liman floor lay 40 cm below the surrounding ground thereby ensuring that upto 40 cm of runoff water was collected at any one flooding episode Water ponded in the limans infiltrated into the soil, save for evaporative losses, and was thus available for crop/tree growth

The field was laid out as a completely randomised block design in which each main liman (block) was divided into six smaller limans (plots) each measuring 10 m x 40 m The treatments consisted of 2 *A saligna* morphotypes distinguished as broad leaved (M1) and narrow leaved (M2) The broad leaved type also had dark green leaves and greyish-green stem The narrow leaved type conversely had bright green leaves, pinkish-brown stems and they branched more prominently to form dense bushy canopies The second set of treatments comprised 3 irrigation categories namely

(i) Irrigation with runoff water only

(ii) plus supplemental fresh water

(iii) plus supplemental brackish water

The plots on supplemental irrigation treatments normally received 40 cm of irrigation per month but this was occasionally varied to accomodate the flood episodes Characteristics of the irrigation waters are shown in Table 1

Table 1 Quality of water used for supplemental irrigation at Kakuma

Property	Brackish	Fresh
pH (H20)	7 3	6 5
Ecw dS/m 25 C	3 15	0 3
Na (meq/l)	18 7	1 13
K meq/l)	1 53	0 92
Ca (meq/l)	0 23	0 42
Mg (meq/l)	0 86	0 42
Cu (ppm)	tr	tr
Fe (ppm)	tr	tr
Zn (ppm)	tr	tr
Mn (ppm)	tr	tr
Sum Cations	**21 23**	**2 89**
OH (meq/l)	tr	tr
CO3 (meq/l)	tr	tr
HCO3 (meq/l)	11 8	3 4
Cl (meq/l)	18 65	0 5
SO4 (meq/l)	3 62	0 24
Sum anions	**34 07**	**4 14**
RSC	10 71	2 56
SAR	25 33	1 74
SAR [adj]	44 33	4 53
PI	27 91	108 04
Osm pot (KPa)	-113 4	-10 8

The fresh and brackish water supplemental treatments were started when the plants were about one year old Previously they had survived on runoff irrigation only In

fact the irrigation treatments were started in June 1997 following a very dry period during which the plants had not received any water for over six months

The following parameters were measured before beginning of the irrigated treatments in June 1997 and again in the following September after a flooding and a number of irrigation episodes

(i) Stomatal coductance

(ii) Transpiration

(iii) Leaf water potential

(iv)Vapour pressure deficit (VPD)

(v)Tree growth in terms of elongation of new shoots and increase in stem girth These measurements were taken every week throughout the growing period

Stomatal conductance and transpiration were measured on the middle leaflet of youngest fully expanded and fully exposed leaves which had been earlier tagged and were therefore known to be of comparable age Steady state porometer (LI-COR, LI-1600) was used The porometer also measured leaf temperature,air temperature and atmospheric relative humidity from which VPD was calculated Leaf water potential was measrured using the pressure bomb method (Scholander *et al* 1965) on the same type of leaves as those used for porometer measurements To monitor tree growth,stem girth at 20 cm from ground level was measured at regular intervals At the same time, growth in length of newly formed stem buds was monitored

RESULTS

The data presented here are representative of extremely dry period (June, 6 1997) and a well watered irrigated situation (September, 2 1997) The June data were taken at a time when the plants had not received water for over six months The September data on the other hand were taken at a time when the plants had received 254 mm of runoff /rainfall during July In addition, the supplemental irrigation treatments had received 1600 mm from four irrigation episodes,one each in June and July and two in August The shorter irrigation interval in August was deemed necessary, for experimental purposes, to recharge brackish water back into the profile of the respective treatments following the flood in July

Under the Kakuma conditions, diurnal trend of stomatal conductance and transpiration of *A saligna* peaked between 9 00 and 10 00 a m in both highly stressed (Fig 1) and better watered plants (Fig 2) then decreased towards midday Both parameters assumed comparatively very low values in plants experiencing exreme drought (Fig 1) compared to the well watered plants (Fig 2) For example,while well watered plants of the broad leaved type exhibited peak stomatal conductance above 2 5 cm /s, the peak for highly stressed plants of the same morphotype was only 0 7 cm/s In the morning , the highly stressed plants (Fig 1) exhibited a rapid rise to the peak in both parameters followed by an almost equally precipitous drop leading to total stomatal closure around midddday The better watered plants showed an almost equally rapid increase in stomatal conductance and transpiration in the morning but the fall from the peak was much more gradual In fact,while the highly stressed plants closed their stomata around midday (13 00-15 00 Hours), stomatal conductance in the well watered plants about the same time was above 1 cm/s which was even higher than the peak for the highly stressed plants It was, however, observed that the highly stressed plants exhibited a distinct afternoon recovery in stomatal conductance and transpiration Such recovery did not come out clearly in the better watered plants (Fig 2) even though the VPD and water potential trends were quite similar between the two days (Fig 3) There was also a distinct synchrony between stomatal conductance and transpiration in the highly stressed plants (Fig 1) which,again, was not clear in the better watered plants (Fig 2) Actually peak transpiration lagged behind peak stomatal conductance in the better watered plants (Fig 2) and the transpiration rate remained

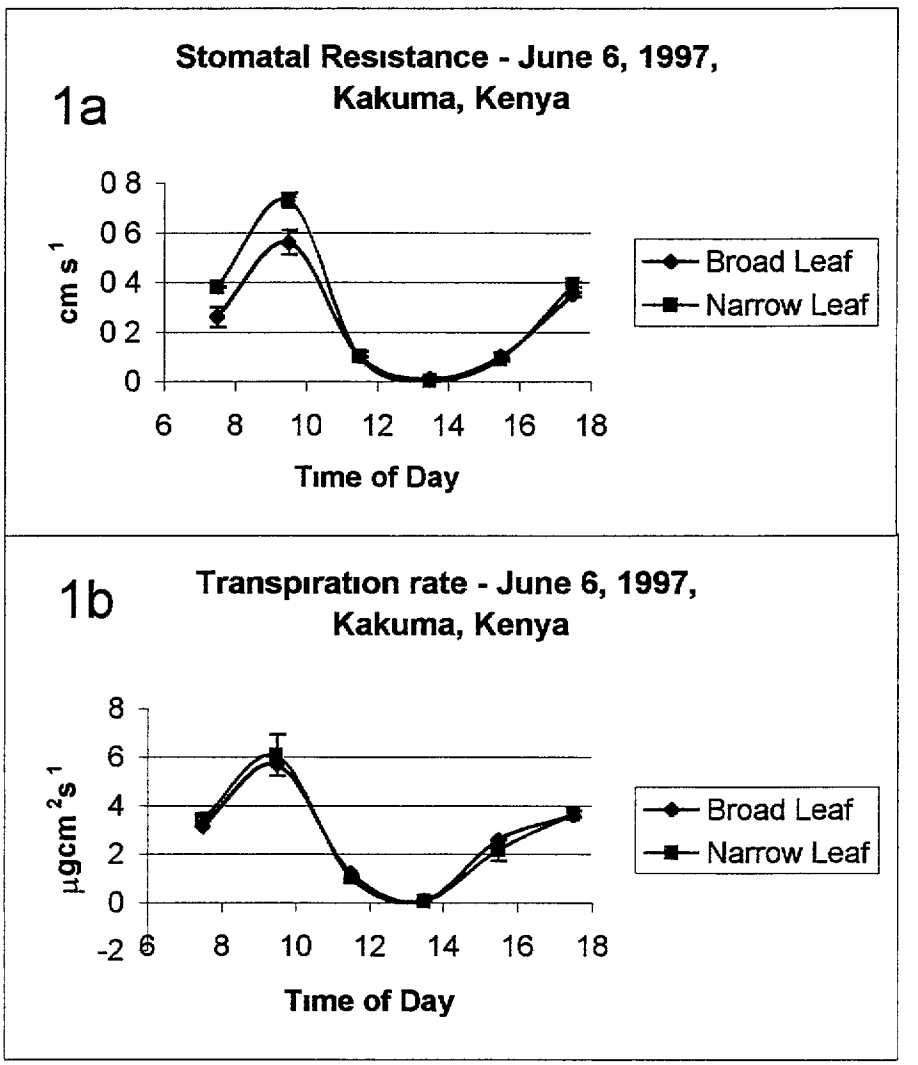


Fig 1 Stomatal resistance (1a) and transpiration rate (1b) in the broad and narrow leaves, June 6, 1997 in Kakuma, Kenya

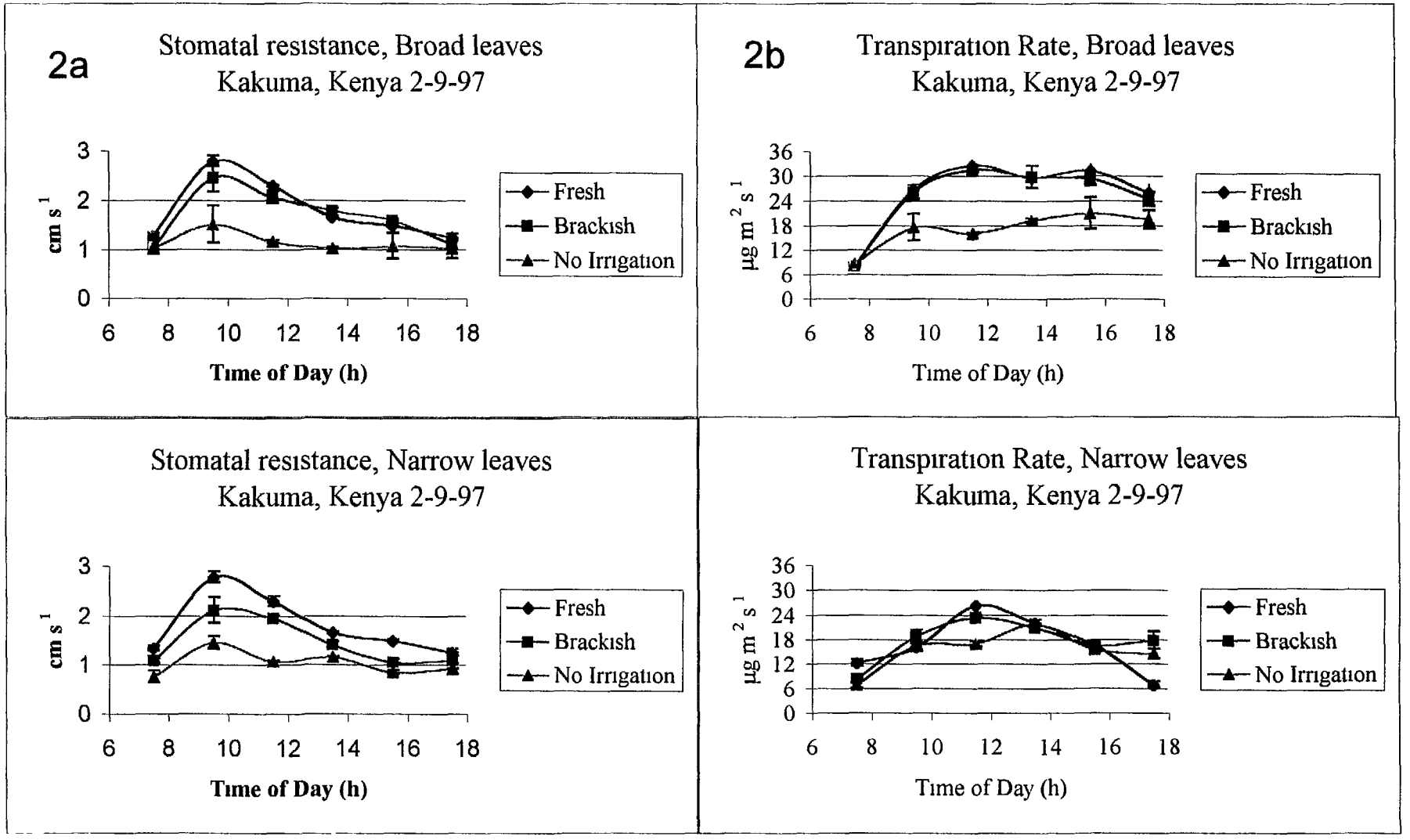
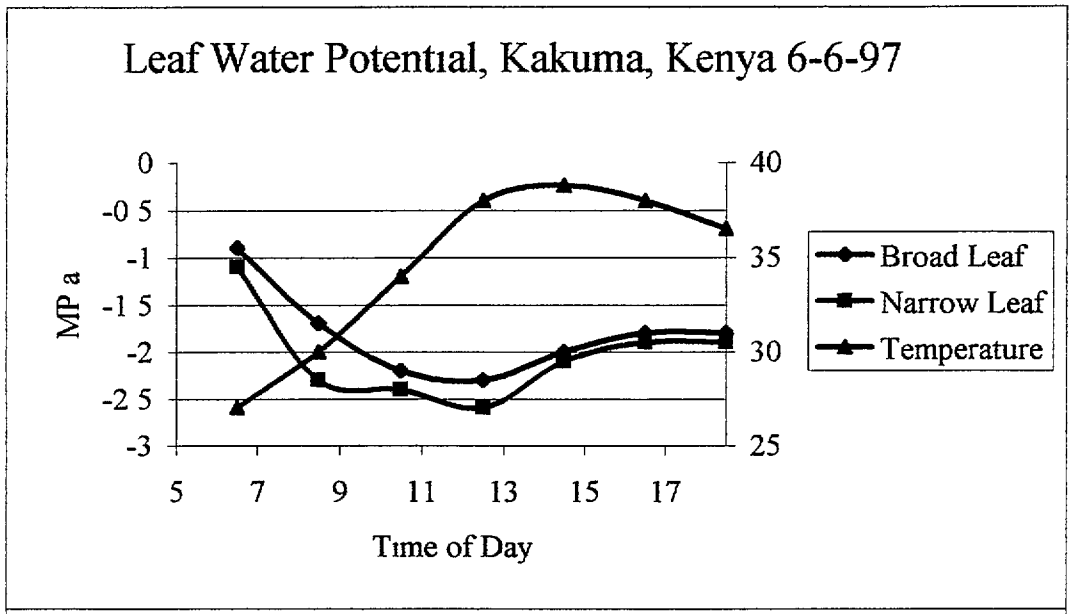


Fig 2 Stomatal resistance (2a) and transpiration rate (2b) in the broad and narrow leaves, Septebmer 2, 1997 in Kakuma, Kenya



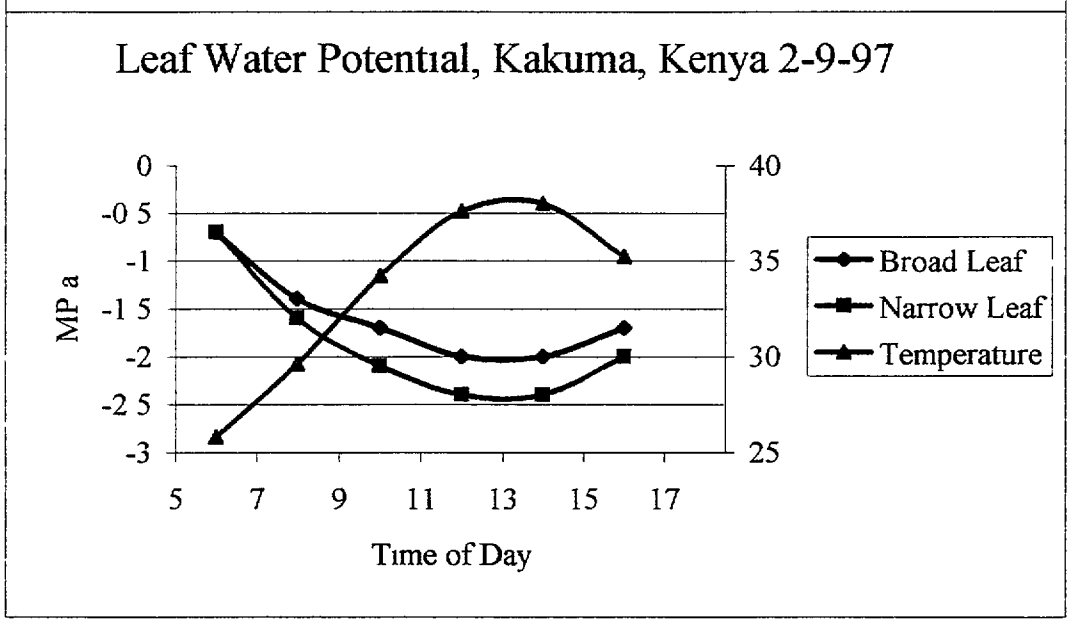


Fig 3 Leaf Water Potential and Air temperature in June (dry season) and September (rainy season) 1997 in Kakuma, Kenya

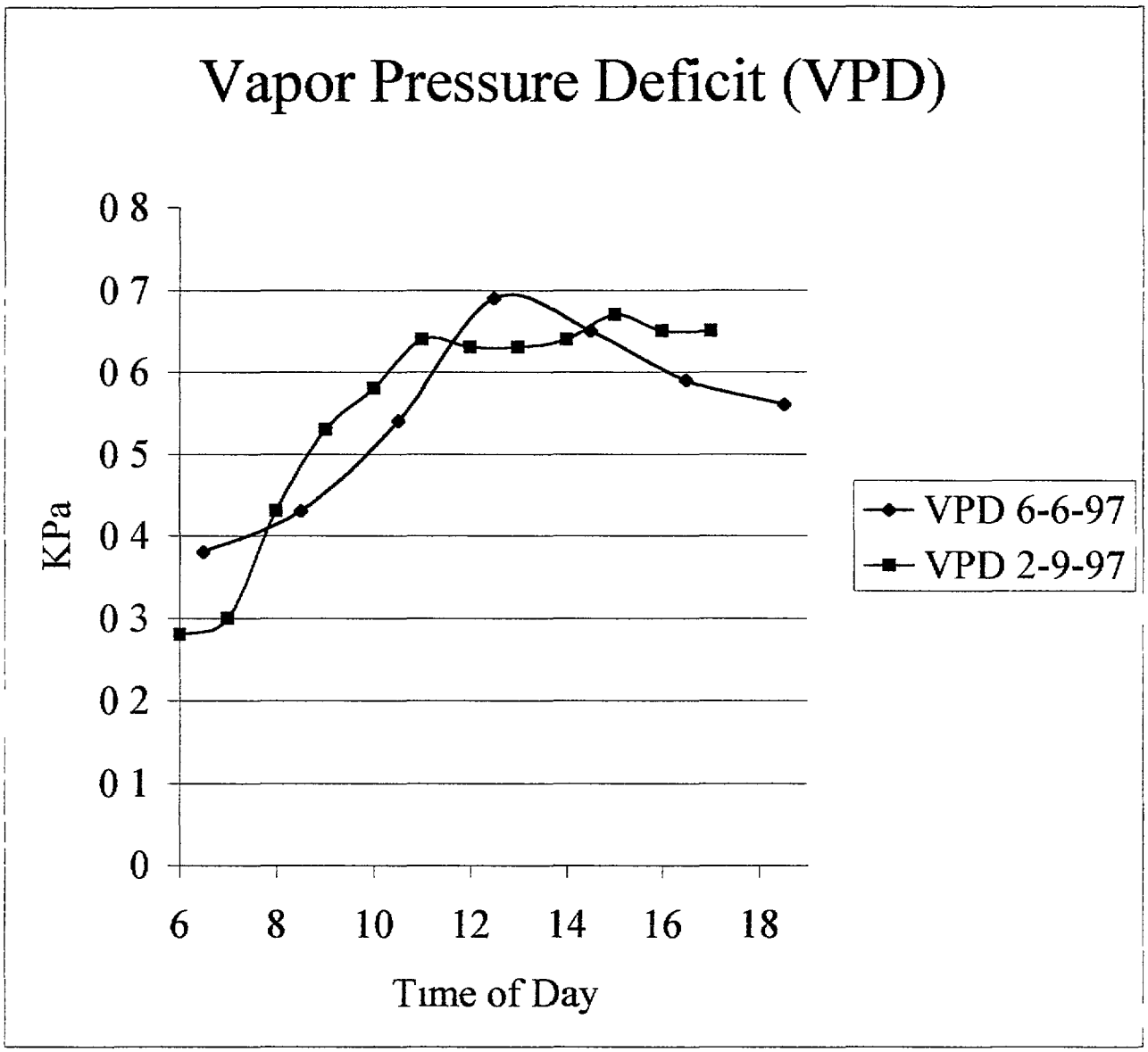


Fig 4 Vapor pressure deficite measured in June (dry season) and September (rainy season) 1997 in Kakuma, Kenya

near peak most of the day so that even though stomatal conductance had got back to the morning levels by 17 30 Hours, transpiration still remained way above the morning levels

Whereas Figures 1 and 2 compare plants under almost two extreme watering conditions, the data shown in Figure 2 in itself draws a comparison between runoff only and the use of supplemental irrigation even over short duration of drought It is clear that even with less than two months of drought, supplemental irrigation created a distinct advantage in terms of stomatal conductance and transpiration but there was no statistically significant difference between plants irrigated with fresh water and those irrigated with brackish water even though the former generally had higher numerical values

Between the morphotypes, there was no significant difference in terms of stomatal conductance and transpiration during the period of extreme drought (Fig 1)although the broad type generally had numerically higher values Similar trend was observed for stomatal conductance during the better watered period (Fig 2a) in all the irrigation treatments The broad leaved type, however, had a significantly higher transpiration rate than the narrow leaved type in the treatments which received supplemental irrigation (Fig 2b)

Diurnal trends in leaf water potential exhibited similar trends during both the very dry period (Fig 3a) and the better watered period (Fig 3b) In both cases there was a distinct midday low period followed by partial afternoon recovery The narrow leaved morphotype generally had lower leaf water potential, significantly so during the midday low periods Notably there was little difference in water potential between the very dry period (Fig 4a) and the better watered period (Fig 4b) No difference in water potential was detected between brackish and fresh water irrigation treatments There was a close but inverse relationship between VPD and leaf water potential, as the VPD increased (Fig 4) leaf water potential decreased and vice versa

Both shoot elongation rate and stem girth growth rate (Fig 5) showed a significant increase with introduction of runoff/irrigation After the low growth periods upto June,the plants picked up following the runoff/irrigion in June/July Once again there was no significant difference in growth rate between the plants which received fresh

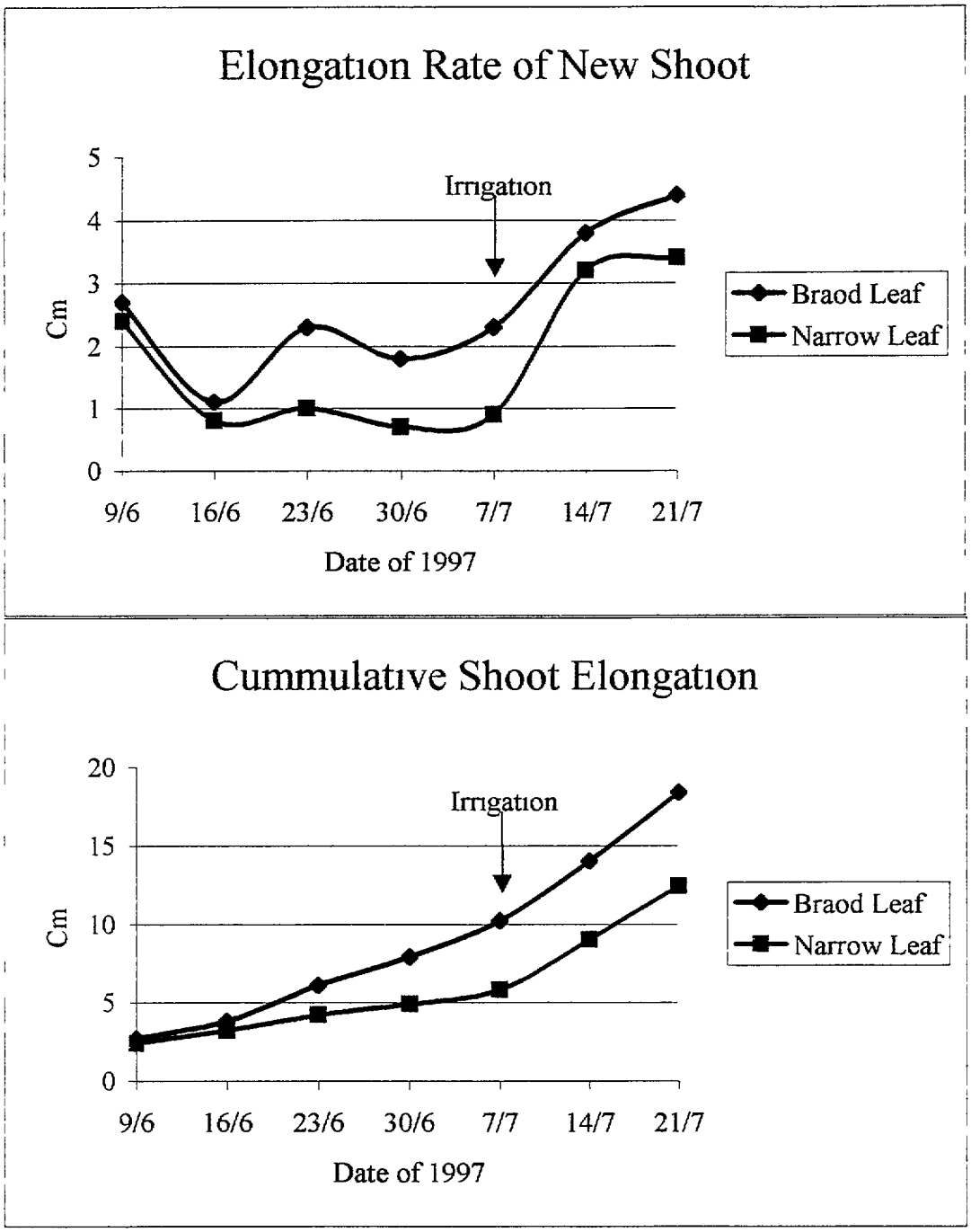


Fig 5 Shoot elongation rate (above) and Cummulative shoot elongation (below) throughout the year of 1997 in Kakuma, Kenya

water compared to those that were irrigated with brackish water but the broad leaved type had higher growth rate

DISCUSSION

The merits of runoff irrigation together with supplemental irrigation in enhancing growth and a number of specific physiological attributes of *A saligna* have been well demostrated in this study Benefits of water availability in enhancing plant growth and productivity are in no doubt Kramer (1983) noted that on a global scale water stress reduces plant growth and yield more than all other stress factors combined Hsiao (1973) observed that water stress affects almost all physiological aspects linked to plant growth with expansive growth appearing the more sensitive Inhibition of expansive growth *per se* by water stress has been considered in terms of turgor reduction (Hsiao, 1973) Increasingly, however, experimental evidence indicate that while expansive growth appears to depend on having some minimum turgor pressure, the relationship is complex depending on age of the tissue and its stress history (Kramer, 1983) Michelena and Boyer (1982), for example,reported that withholding of water from growth chamber grown maize plants inhibited leaf elongation even though there was no corresponding decrease in turgor Von Volkenburgh and Boyer (1985) reported results which indicated that reduction in expansive growth arising from water stress may be better explained in terms of decrease in cell wall extensibility rather than turgor

In this study we found that *A saligna* plants growing under highly droughted conditions exhibited low growth rate which was rapidly alleviated by application of water Nevertheless water potential data taken during the period of high soil water deficits did not differ significantly from those taken during the better watered periods While leaf water potential remains a useful thermodynamic state indicator of plant water status, its relationship to plant growth under field conditions is commonly tenuous Nyabundi (1985),for example, found a 60% decrease in biomass of water stressed field grown tomatoes but there was no significant difference in water potential between these plants and the well watered control throughout the season Water stress develops gradually under field conditions giving plants opportunity to employ adaptive measures such as reduced canopy and increased root growth which will ensure plant survival through increased ratio of water uptake water loss without

subjecting the plant tissue to excessive dehydration which may cause lethal physiological disorders The emerging concept of root-sourced signalsof plant water stress (Davis and Zhang , 1991) would allow the plant to make these adjustments without the mediation of reduced plant tissue water potential In any case leaf water potential is highly dependent on atmospheric evaporative demand which may also influence stomatal movements Vapour pressure deficit is a good indicator of atmospheric evaporative demand and our data indicated that the trend and magnitude of VPD were quite comparable during the two measuring episodes

The possible effect of leaf water potential and VPD on stomatal movements introduces the element of plant control of its water economy at the leaf/atmosphere interface During the very dry period, the *A saligna* plants not only operated at very low stomatal conductance levels but actually closed their stomata altogether during the midday periods when the evaporative demand was highest (Fig 1 also see Fig 3a) This would be viewed as a water saving mechanism mediated through atmospheric or soil signals That transpiration followed exactly same pattern as stomatal conductance is evidence that the stomata played a major part in control of water loss during this period This was not the case in the better watered period where not only did the stomata remain largely open all day (Fig 2) but there was no distinct midday depression It seems like the plant relaxed that survival mechanism when moisture was available possibly for the benefit of maximizing photosynthesis and growth The observation that transpiration remained high almost throughout the day during the better watered period , even despite decrease in stomatal conductance in the afternoon,is indication that stomatal conductance was not limiting gas exchange in the well watered plants Transpiration was therefore largely controlled by VPD the driving force for evaporation This was further supported by the observation that transpiration peak lagged behind peak stomatal conductance in the better watered period (Fig 2a and 2b) compared to almost total synchrony between stomatal conductance and transpiration in the highly droughted plants (Fig 1a and 1b) The suggestion here is that while stomata opened in the morning in response to light and peaked around 9 00-9 30 Hours, transpiration only peaked around midday (11 30-12 00 Hours) when incident radiant flux density and consequently air temperature and VPD approached their peak diurnal values As a fast growing desert plant it appears adaptively strategic that *A saligna* would minimize water loss during dry periods while

taking advantage of the short well watered episodes to maximize biomass accumulation The broad leaved morphotype had faster growth rate which may be related to its higher gas exchange rates Although CO2 exchange rates were not determined in this study the higher transpiration rates, when well watered, would suggest that the broad leaf could conceivably also have higher rate of exchange of CO2 as well although some non-stomatal factors could also be at play For example it has already been mentioned that the broad leaf had amore open canopy which could itself cause higher productivity by exposing a larger canopy leaf area to direct radiation

Since growth of *A saligna* was not affected by use of brackish water, that practice may be considered for recommendation although longer term study is necessary to monitor effects of brackish water on soil physical and chemical attributes alongside actual salt accumulation in the soil profile

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REFERENCES

Braun, H M H and D M Mungai 1981 The agroclimatic zones of Kenya's arid and semi-arid lands Paper presented at a workshop on strategies for developing the resources of the arid and semi -arid areas of Kenya Nairobi, Kenya

Crompton, H 1992 *Acacia saligna* for dryland fodder and soil stabilization NFT highlights NFTA 92-93

Davies, W J and J Zhang 1991 Root signals and the regulation of growth and development of plants in drying soil Annu Rev Plant Physiol 42 55-76

Degen, A A, K Becker, H P S Makker, N Borowy 1995 *Acacia saligna* as a fodder tree for desert livestock and the interaction of its tannins with fibre fractions J Sci Food and Agric 68 65-71

Evenari, M, L Shenan and N H Tadmor 1971 The Negev The challenge of a desert Havard University Press

Fallon, L E 1963 Water spreading in Turkana A hope for impoverished people USAID, Nairobi

F A O 1993 Agroecological assessment for national planning The example of Kenya F A O soils bulletin No 67

Hsiao, T C 1973 Plant responses to water stress Annu Rev Plant Physiol 24 519-570

Kramer, P J 1983 Water relations of plants Academic Press

Michelena, V A and J S Boyer 1982 Complete turgor maintainance at low water potentials in the elongating region of maize leaves Plant Physiol 69 1145-1149

Nyabundi, J O 1985 Biomass accumulation and partitioning in field-grown tomatoes under water stress Ph D Dissertation, University of California - Davis

Scholander, P F, H T Hammel, E A Hemmingsen and E D Bradstreet 1965 Sap pressure in vascular plants Science 148 339-346

Tiedeman, J A and D E Johnson 1992 Acacia cyanophylla for forage and fuelwood in North Africa Agroforestry Systems 17 169-180

Thomas D B, E K Biamah, A M Kilewe, L Lundgren and B O Mochoge 1986 Soil and water conservation in Kenya Proceedings of the 3RD National workshop Nairobi, Sept 1986

Worthington, E B (Ed) 1976 Aridland irrigation in developing countries Environmental problems and effects Based on International symposium hed at Alexandria Egypt in Feb 1976 Pergamon Press Egypt

Summary

Within the framework of project C11-133 "Coordinated use of marginal water resources in arid areas " we carried out field trials in Kenya and in Israel and the physiological response to brackish water was studied in pot trials in Israel We used Acacia saligna a leguminous multiple purpose fast growing shrub in all our trials In Israel we carried out controlled field trials in which the interactions between winter runoff, two levels of salinity and two irrigation frequencies were studied Brackish water (EC= 6 dSm^{1})was obtained by adding NaCl to the fresh water Cross sectional area was monitored as an indicator of biomass production The latter was always positively affected by the application of runoff No effect of brackish irrigation was evident for the two irrigation frequency treatments We added two well-watered treatments (fresh and brackish) for comparison and it these treatments we found a significant difference between fresh and brackish treatments The relation between Predawn leaf water potential (which was used for irrigation scheduling) and total amount of water in the soil was affected by salt addition, indicating that the osmotic effect in the root zone may be of importance under field conditions

The addition of NaCl to the irrigation water decreased the hydraulic conductivity of the soil surface layer The conductivity increased after flooding but not to the level it had prior to application of the salt The level which it regained after flooding after the second irrigation year was lower than for the previous year indicating that prolonged irrigation with brackish water will irreversibly damage the hydraulic properties of the soil The area affected by salts was limited to the wetted area close to the trunks but the overall percolation of runoff water (flooding of the whole plot) proceeded at essentially the same rate for all plots Salt concentration was also monitored in the soil profile to a depth of 1 m and at three distances from the row Samples were obtained prior to and immediately after flooding Electrical conductivity and the concentration of Ca, Mg and Na were determined In all treatments irrigated with brackish water the highest concentrations were found close to the tree rows Flooding leached the salt to deeper horizons

In the Turkana area in Kenya the trial was carried out with natural brackish water pumped from a shallow acquifer Some selected physiological parameters were monitored and it appears that mid-day stomatal closure is an important water conservation strategy of the shrub studied Irrigation changed the observed pattern and

no mid-day depression was observed Transpiration measurements indicated that is regulated by stomatal aperture during the drought periods and by vapour pressure deficit when water is available in the soil No effect of water quality on the measured parameters was observed

The effect of salt on some physiological processes showed that the effect of salinity can be offset, in pot trials, by the addition of nitrogen fertilizer (as nitrate) Both salinity and nitrate addition reduced nodulation The addition of Molybdenum together with Nitrate reduced even further the negative impacts of salinity in the pot grown shrubs This effect was not observed when the trial was carried out in hydroponic conditions

The results of the trials carried out in the various locations bear out our initial assumption that brackish water can be utilized to offset the severe drought which may occur between two flood events A crucial aspect of the system tested is the localized application of brackish water that allows water to percolate freely into the soil in between the salt-affected areas The long term accumulation of salts may however affect shrub response and it is therefore necessary to continue the long term monitoring of all the relevant variables