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Adaptation to salt and water stress by pulses tolerant to environmental stresses of high altitude deserts

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General abstract .

Emergence studies of chickpea were conducted in small pots in controlled environment emerging chambers. They compared the effects of soil water content on four cultivars, and the effects of soil salinity and sodicity on one cultivar. In all studies the final emergence percentage (survival test parameter), and the emergence rate and seedling lengths and weights (rate test parameter) were determined. Reduced soil water content reduced the final emergence percentage and emergence rate, and aggravated the effects of salinity on emergence. Water stress cased a greater reduction of shoot growth and salinity had more effect on root growth of young seedlings. Soil ESP and gypsum showed no significant effects on emergence and seedling growth.

Growth and production studies of chickpea under drip irrigation were conducted in a field with 22 treatments in the north-west Negev of Israel. The study investigated the effects on the cv. Hadas of the following four variables of salinity and water stress: residual soil salinity from previous years, water salinity, length of non-irrigated period and planting date. All tested variables affected growth and yield. Initial soil salinity higher than 2.8 dS m^{-1} reduced yield mainly by reducing seed number. A longer period without irrigation mainly reduced the seed number, and higher water salinity reduced yield mainly by reducing seed size. Seed size decreased when seed number increased and shoot size and vitality decreased. Water stress reduced shoot size and enhanced senescence more than salt stress. Stored soil water could not satisfy the crop water requirement for a long time, as the plants did not extract much water from deeper than 0.6 m.

Growth of whole chickpea plants and individual pods were followed in four treatments. The variables were: three levels of initial soil salinity, two levels of water salinity, and two periods of no irrigation. The non-determinate plant produced new vegetative and reproductive organs, and the drastically changing conditions modified the growth and function of each organ according to its growth or development stage at the time of stress. Two intermittent samplings show good correlation between shoot size and pod number but not with seed size. Mean yield parameters obtained from whole plant or whole plot data are not suficient to explain the temporal stress effects. The explanation needs also the distribution of the fruit measured parameters that can be obtained from individual pod and seed data. The practical way to follow the development of all fruit was to measure simultanuously representative fruits at different development stages and to use the relation between response and development stage to estimate the effects on other fruit. The number

of fruits in each development stage can be deduced from the fruit envelope and seed weights and dry matter contents of destructively sampled plants The pod position on the plant indicates the time when it developed. Water stress had a large effect on pod number and small effect on pod size. Salinity stress reduced pod size and had little effect on pod number. The salt stress was milder in its effects than the water stress, and the saline wet treatment allowed balanced vegetative and reproductive growth over a long time. Resumption of irrigation after long water stress was not able to start the development of many new pods nor to increase the shoot vitality needed to support the development of large pods on the early stressed plants.

Consideration of the time when each fruit grows and its response to water and salt stress should guide the control of temporary stresses to obtain optimal yield as measured by the means and variances of the yield parameters. Irrigation should stimulate initial shoot growth and avoid water stress during the early reproductive growth stage. Irrigation water with electrical conductivity (EC_i) below 3 dS m^{-1} can elevate water stress. Water with EC_i of 5.5 or higher should be avoided.

General introduction.

Many irrigated areas in arid and semi-arid zones, specifically deserts, face the choice between saline irrigation and water shortage. The use of saline water should increase yield in comparison with no irrigation, or have economic advantages over the use of fresh water. Typical of deserts is limited leaching by rain and carryover of salinity effects from year to year (Rhoades et al. 1989), in the form of soluble salts in the soil solution and exchangeable sodium in the exchange complex. Using only a saline sodic water resource for a given field will aggravate the carryover effects, while seasons of irrigation with fresh water will leach the soluble salts and reduce sodicity by exchange with natural calcium in the soil (Meiri and Plaut 1985; Meiri 1990; Rhoades et al. 1989).

Chickpeas are an important protein source, planted in late winter and suitable for warm and dry regions under irrigation. Like most pulses, chickpeas are salt sensitive (Maas 1990). The overall crop response depends on the seasonal integrated stress and the synchronization of the differential stress level with the salt tolerance of the crop during ontogenesis (Meiri 1990).

Poor stand is often a primary cause for yield reduction under saline and sodic conditions. Stand failure may reflect high sensitivity of the seed germination, but may also result from the failure of the germinating seed to emerge. The reduced shoot elongation extends the time to emergence and reduced root elongation reduces the explored soil volume while the water and salt stresses in the upper soil layer increase. Sodicity that causes crust increases the soil impedance resistance and reduces the elongation rates of the radicles. Gypsum dressing to avoid crust in sodic soils increases the soil solution salinity when the calcium ion in the gypsum acts as an exchange pump to replace the exchangable sodium (Frenkel et al. 1990, Russo 1983). This effect is expected mainly in the top layer which is the seedling root volume. Reported data show large differences between germination or emergence tolerance, on one hand, and yield tolerance, on the other hand, in many crops (Bernstein and Hayward 1958, Maas 1986). A clearer distinction is needed between germination and emergence, as the sensitive stage and quantitative discrimination is needed among the effects of salinity, sodicity and drought on emergence. Such distinctions will provide the basic inputs for soil cultivation and irrigation management during these early stages.

The final plant size and yield represent an integrated response to the durations and magnitudes of the temporal stresses imposed during different stages of growth and

development. Crop tolerance may change significantly between growth stages (Maas 1990, Meiri and Plaut 1985). The non-determinate chickpea produces new vegetative and reproductive organs over long periods, therefore the interactions of temporary stresses with the plant development stages depend on the distribution of the development stages of all individual organs. The stress timing and level can modify the relations of vegetative to reproductive growth and, through the different influence of stresses on pods at different development stages, it can modify the size distribution of the seeds. Whole plant data provide the mean values for the different organs. Data on individual pods also provide the effects of treatments on the pod size distribution. Relating these data to pod age and development scales could link the responses with the stress timing. Such relations need scales for pod age and pod development stage. If pod growth were regular pod weight could serve as a development stage index. If fruit position were in a fixed order, pod position could serve as an age index. Comparing the means and distributions will indicate whether the temporal differences in yield tolerance reflect changes at the level of individual organs or of the whole plant.

Chapter 1. Emergence of chickpeas planted in saline or sodic soils.

A. Meiri, A. Hadas and Margot Shuali

Abstract.

Experimental procedures were developed that enable to distinguish between the effects of salinity, sodicity and soil water content, on seedling emergence. The effects of these factors on the emergence of chickpeas were studied under controlled growth conditions. Low soil water content reduced the final emergence of four chickpea cultivars and reduced the seedling growth rates. The effects of soil water content and salinity, and these of soil ESP and gypsum on emergence were studied for only one cultivar. The salinity effects were stronger at lower soil water contents. Water stress reduced shoot growth more than root growth, whereas salinity reduced root growth more than shoot growth. Soil ESP and gypsum induced no significant effects on seedling emergence and growth.

Introduction.

Poor stand is often a primary cause for yield reduction under saline and sodic conditions. Stand failure may reflect high sensitivity of the young seedling during germination, i.e. during the initiation of root growth, or it may result from the failure of the germinating seed to emerge when it protrudes above the soil surface. Failure of germinating seeds to emerge can result from reduced elongation rate. Slower shoot elongation extends the period to protrude above the soil surface. Slower root elongation reduces the explored soil volume, while evaporation, under direct sun radiation, increase both water and salt stresses in this volume. Therefore, water and salt stresses that reduce elongation rates may reveal high apparent sensitivity of emergence to the stresses. Sodicity that causes crust formation reduces elongation rates of the radicles due to increased soil impedance resistance. Gypsum dressing is the most recommended practice to prevent crust. The calcium in the gypsum replaces the sodium on the soil ion-exchange sites by an exchange pump action (Frenkel et al. 1990, Russo 1983), and produce sodium sulfate salinity, even in soils from which chlorides have been leached. The large affinity of the Ca^{2+} to the

exchange sites in the soil will increase the gypsum-induced salinity mainly in the top layer which is the seedling root volume. Emergence tolerance can not be deduced from yield tolerance, since the two involve parameters of different nature: growth rate for yield, and survival for final emergence percentage. Reported data show large differences between germination or emergence tolerance and yield tolerance, in many crops (Bernstein and Hayward 1958, Maas 1986).

A clearer distinction is needed between germination and emergence as the sensitive stage, and quantitative discremination is needed among the effects of salinity, sodicity and drought on emergence. Such distinctions will provide the basic inputs for soil cultivation and irrigation management during these early stages.

Chickpeas, like other pulses, have large seeds and relatively thick hypocotyl, epicotyl and roots. This mean large sources and sinks for metabolites and minerals and a large demand for water during emergence. We compared the emergence of four chickpea cultivars under four soil water content levels. The effects of soil salinity and sodicity on emergence were studied with only one cultivar. In all studies the final emergence percentage (survival test parameter), and the emergence rate and seedling lengths and weights (rate test parameter) were determined.

Materials and Methods.

The emergence studies were conducted with a loess soil from the top soil layer of a non-saline-irrigated field in the Gilat experimental farm. Soils of five different salt contents were prepared by leaching soil subsamples by solutions having a sodium adsorption ratio (SAR) of about 5 and total salt ($NaCl+CaCl_2$) concentrations of 10, 50, 100, 150 and 200 meq l^{-1}. Soils of different ESP were prepared via two leaching steps: initial leaching of the soil volumes with a 1-M solution having the intended SAR (10, 20, 40 and 60) followed by leaching these subsamples with solutions of total salt concentration 10 mM and the same SAR values. Leaching stopped when the outflow water approached the inflow water in concentration and composition, and did not change with additional leaching. The saline and sodic soils were air dried, ground and sieved through a 2-mm sieve. Then they were gently sprayed with half- strength Hoagland solution under continuous mixing, to obtain uniform moisture distribution. Soil-water-content treatments were defined by nutrient solution volume. The equivalent of 350 g dry soil were packed in plastic pots and 15 seeds of each cultivar were planted at a depth of 2.0 cm in each pot. The pots were

then enclosed in polyethylene bags and allowed to incubate in an illuminated growth chamber regulated to 12 h at 25°C and 12 h at 20°C. Avoidance of additional water application prevented surface crust formation and salt leaching from the surface layer. The experiment design was completely random with four replications.

The number of emerging seeds was recorded at different time intervals according to the emergence rates. A seedling was considered to have emerged when the plumule came up of the soil surface. Several different harvest practices were adopted and the details will be given for each study. After harvest the fresh and dry weights, and lengths of seedlings were recorded. The dry matter was stored for chemical analysis.

Soil water content at harvest was determined gravimetrically. In some of the experiments salinity and soluble salt contents were determined in extracts of saturated paste with high water content, obtained by suction (U.S. Salinity Laboratory Staff 1954) and those of the actual soil solution at emergence, obtained by centrifugation (Elkhatib, 1987).

The ratios of the the salinity values obtained from soil solution and saturated paste extract were calculated as linear regressions (Table 1). The regressions show that in the salinity treatments the ratios of EC, Cl and Ca+Mg were nearly the reciprocal of the water content ratio (W_{ss}/W_{ex}) and SAR did not change with the dilution. In the ESP treatments only small changes in the solution composition occurred as a result of dilution.

Table 1. The parameters of the linear regression that relates soil solution to saturated paste extract solute parameters.

Parameter	a		b		r2
	mean	SE[a]	mean	SE	
Salinity treatments (W_{ss} W_{ex}^{-1} = 0.345 (0.006))					
EC dS m^{-1}	-0.93	0.95	3.86	0.11	0.991
Cl meq l^{-1}	2.81	7.8	3.47	0.15	0.991
Na meq l^{-1}	-0.33	2.55	2.61	0.18	0.976
Ca+Mg meq l^{-1}	6.40	4.92	3.91	0.12	0.996
SAR	0.93	0.52	0.99	0.31	0.677
ESP treatments (W_{ss} W_{ex}^{-1} = 0.432 (0.09))					
EC dS m^{-1}	1.13	0.50	1.31	0.07	0.980
Cl meq l^{-1}	19.8	1.43	0.74	0.35	0.361
Na meq l^{-1}	9.4	6.2	1.53	0.08	0.981
Ca+Mg meq l^{-1}	2.3	1.7	1.17	0.04	0.988
SAR	4.05	4.4	1.21	0.20	0.821

[a] SE= standard error

Study A.

The effect of soil water content on emergence of four cultivars of chickpeas.

The effects of four soil water content levels on the emergence rates and seedling size of four chickpea cultivars were studied. The soils were leached to equilibrium with a solution of 10 mM salt concentration and SAR of 5. Subsamples were gently sprayed with half-strength Hogland nutrient solution to reach the soil water contents of 15, 18, 21 and 24 % by weight. The cumulative emergence over time is presented in Figure 1, and the seedling growth parameters are presented in Table 2.

At low water content the emergence rates and final emergence percentages were reduced to different levels for the different cultivars (Figure 1).

Emergence rates did not correlate with the seed sizes of the different cultivars. The cv. Bulgarian with the smallest seeds emerged first. Faster emergence was mainly the result of greater uniformity among the soil water content treatments, in emergence. Reduced soil water content reduced the elongation or emergence rates and final emergence percentages of all cultivars (Figure 1, Table 2).

Table 2. The influence of water content in non-saline soil on emergence of four chickpea cultivars.

cv.	Soil water content	DAP	Plant length mm		Elongation rate		Plant	Plant dry weight	Seed	Seed mean weight
	weight%		mean	SE	mean	SE	%DW	g	%DW	g
Spanish	15	17	30.6	3.37	1.881	0.212	0.14	0.027	0.42	
	18	15	32.0	3.45	1.924	0.207	0.17	0.026	0.43	
	21	13	39.7	3.36	2.648	0.224	0.13	0.031	0.39	
	24	10	40.9	2.38	4.009	0.265	0.13	0.032	0.31	0.521
Bulgarian	15	12	40.4	3.42	3.336	0.291	0.12	0.014	0.39	
	18	9	34.3	2.88	3.821	0.320	0.12	0.009	0.42	
	21	9	34.9	3.68	3.886	0.409	0.14	0.012	0.38	
	24	10	51.7	2.82	5.281	0.332	0.11	0.025	0.37	0.251
Hadas	15	13	28.1	3.40	2.170	0.252	0.15	0.018	0.45	
	18	10	32.7	3.34	3.316	0.351	0.21	0.029	0.41	
	21	10	38.8	3.27	4.091	0.359	0.13	0.020	0.37	
	24	13	37.2	3.47	3.721	0.347	0.13	0.019	0.29	0.416
Ayelet	15	16	28.8	3.23	1.800	0.201	0.16	0.023	0.46	
	18	13	34.7	4.39	2.644	0.310	0.14	0.016	0.42	
	21	13	30.7	3.67	2.403	0.295	0.14	0.018	0.40	
	24	13	53.5	10.1	4.085	0.703	0.11	0.030	0.30	0.422

Figure 2 compares the tolerance to reduced soil water content of the final emergence and the elongation rates of the four cultivars. Cvs. Spanish and Ayelet were more sensitive to water stress than cvs. Hadas and Bulgarian. Among the two tolerance criteria relative

final emergence decreased less than relative seedling elongation rate with the decrease in soil water (figure 2). This apparently larger tolerance of final emergence arises from the use of non-comparable parameters. The emergence fraction is the result of a binary test of yes or no for each seed and it is strongly influenced by the non-emerging seeds, whereas elongation rate is a continuous variable and is measured only for the emerging seeds. Thus, the comparison is between different populations and the test for final emergence is less sensitive than than for elongation rate. Seedling elongation rate, plant length and plant weight increased and plant dry matter content decreased as the in soil water content increased. These observations indicate that the limiting factor for growth was tissue extensibility and not metabolites supply. To determine whether the change in extensibility was the result of lower turgor or of smaller plastic extensibility we need measurements of plant water relations, i.e., tissue water potential, sap osmotic potential and P/V ratios. The seed water content increased with increasing soil water content. Most of the seed water is imbibition water and its increase corresponds to diminished water retention forces in the soil.

Study B.

Interactive effects of soil salinity and water content on emergence of chickpea (cv. Bulgarian).

The treatment variables in this study were soil salinity and soil water content. Five levels of soil salinity were obtained by equilibrating the soils with leaching solutions of 10, 50, 100, 150 and 200 meq l^{-1} $NaCl+CaCl_2$, all with SAR of 5. Each soil was divided into two subsamples that were sprayed, while mixing, with half-strength Hoagland solution, to reach water contents of 18% (dry) and 21% (wet) by weight before planting. Small pots containing the equivalent of 350 g dry soil were planted with 15 chickpea seeds of cv. Bulgarian at 2 cm depth. The emergence study was conducted under continuous light and 12 h of 20°C and 12 h of 25°C air temperatures. The pots were arranged in a randomized pattern with four replications for each treatment.

To minimize differences in the size of the plants from the different treatments, the harvest of the 10 and 50 meq l^{-1} treatments were carried out 8 and 10 DAP (days after planting), and of the other three treatments at 22 DAP. Lengths of individual seedlings and combined fresh and dry weights of all seedlings in each pot were recorded.

Results.

At all salt levels the wet treatments emerged faster (Figure 3). Salinity of 50 meq l^{-1} did not reduce the final emergence; of 100 meq l^{-1} reduced it by about 50% in the dry soil and 10% in the wet soil; of 150 meq l^{-1} reduced it by about 90% and salinity of 200 meq l^{-1} caused zero emergence (Figure 3). The final emergence and the emergence rates show significant interaction between the soil water and salt contents with larger salt effects in the dry treatments (Figure 3).

The effects of soil salinity and water content on the final plants size, dry matter content of shoot root and seed, specific weight of shoot and root, and shoot elongation rates are presented in Tables 2 and 3. The treatments that had different growth rates, i.e. 10 meq l^{-1}, 50 meq l^{-1}, and 100 and 150 and 200 meq l^{-1} were sampled after 8, 10 or 22 DAP respectively, to obtain shoots of similar size (Table 2). Elongation rates, specific weight (g per cm length) and dry matter content values can be considered as normalized data. Growth was faster and seedlings were larger at lower salinities and higher soil water contents. Shoot growth was more sensitive to soil water content and root growth was more sensitive to salinity. These dfferences among stresses result in small differences between treatments of different water content at a given salinity in the ratios of shoots to roots lengths and large increases in these ratios with increased salinity. These observations contradict the common view that salinity reduces the shoot-to-root ratio. The specific weight, that can provide a first approximation to root diameter was similar for all treatments, except for 100 meq l^{-1} salinity and 21% water content, in which it was much larger than in the other treatments (Table 4). The dry matter content of shoots was not affected by salinity. Seeds that did not germinate, at high salinities, absorbed less water than those that did germinate; for those seeds that germinated the dry matter content was similar at all salinity levels.

Table 3 The effects of salinity and soil water content on growth, final size and shoot/root ratio of seedlings of chickpea (cv. Bulgarian).

Sal[1]	W[2]	no. of seedlings		elongation rate mm/seed/day						Shoot length mm		Root length mm		Shoot/ root length
				shoot			root							
meq l^{-1}	w%	mean	SE	mean	SE	tive	mean	SE	tive	mean	SE	mean	SE	ratio
10	18	10.5	0.2	4.29	0.17	0.75	12.99	0.83	1.04	34.3	3.5	75.1	8.2	0.46
10	21	14.3	0.2	5.74	0.32	1.00	12.55	0.73	1.00	45.9	3.6	95.5	9.1	0.48
50	18	13.5	0.7	3.41	0.15	0.59	6.08	0.30	0.48	34.1	3.6	55.3	6.0	0.62
50	21	14.3	0.4	5.25	0.02	0.91	7.79	0.26	0.62	52.4	3.4	77.9	5.5	0.67
100	18	8.5	0.5	1.39	0.10	0.24	0.39	0.29	0.03	30.5	4.8	33.1	2.6	0.92
100	21	6.3	0.4	2.55	0.22	0.44	3.06	0.33	0.24	56.0	6.1	60.0	4.3	0.93

[1] the salinity of soil washing solution in mM

[2] initial soil water content

Table 4 The effects of salinity and soil water content on root and shoot specific weights and on dry matter content of seed and shoot of chickpea (cv. Bulgarian).

Sal[1]	W[2]	specific shoot weight gr cm^{-1}				percentage dry weight shoot		percentage dry weight seed	
		dry weight		fresh weight					
meq l^{-1}	w%	mean	SE	mean	SE	mean	SE	mean	SE
10	18	2.54	0.17	0.32	0.025	0.12	<0.00	0.43	<0.00
10	21	2.81	0.10	0.33	0.013	0.12	<0.00	0.40	<0.00
50	18	2.41	0.04	0.28	0.004	0.12	<0.00	0.45	<0.00
50	21	2.45	0.03	0.28	0.005	0.11	<0.00	0.40	0.01
100	18	2.30	0.35	0.29	0.010	0.13	0.01	0.45	<0.00
100	21	5.16	0.32	0.76	0.073	0.14	<0.00	0.42	<0.00
150	18							0.50	0.01
150	21							0.63	<0.00
200	18							0.53	<0.00
200	21							0.54	0.04

Study C.

Interactive effects of soil sodicity and water content on emergence of chickpea (cv. Bulgarian).

Table 5. The effect of soil ESP, gypsum application, and soil water content on chickpea (cv. Bulgarian) seedling size.

Treatments variables			Whole seedling weight (g)			
SAR of	W	Gypsum	Fresh		Dry	
solution	weight %		Mean	SE	Mean	SE
5	18	Without	0.293	0.015	0.0296	0.0020
20	21	Without	0.270	0.044	0.0290	0.0038
40	18	Without	0.277	0.037	0.0304	0.0014
60	21	Without	0.297	0.044	0.0259	0.0029
5	18	Without	0.289	0.015	0.0288	0.0025
20	21	Without	0.284	0.172	0.0293	0.0214
40	18	Without	0.270	0.198	0.0297	0.0093
60	21	Without	0.339	0.015	0.0296	0.0007
5	18	With	0.282	0.011	0.0294	0.0019
20	21	With	0.271	0.016	0.0280	0.0026
40	18	With	0.289	0.012	0.0287	0.0029
60	21	With	0.363	0.015	0.0311	0.0014
5	18	With	0.280	0.011	0.0317	0.0012
20	21	With	0.264	0.030	0.0275	0.0026
40	18	With	0.296	0.076	0.0279	0.0042
60	21	With	0.389	0.009	0.0345	0.0011
Factors	**means**					
		Without	0.289	0.067	0.0290	0.0055
		With	0.304	0.022	0.0298	0.0022
	18		0.292	0.024	0.0289	0.0023
	21		0.301	0.065	0.0298	0.0053
5			0.286	0.013	0.0298	0.0018
20			0.272	0.065	0.0284	0.0076
40			0.282	0.080	0.0291	0.0044
60			0.347	0.020	0.0302	0.0015

The study of the effects of soil ESP, with and without gypsum, and soil water content on chickpea emergence used the same methods as studies A and B with a modification in the planting procedure: a pressure of 1 kg cm^{-2} was applied to the soil surface after planting. to simulate the pressure of the planting machine. As a result the emerging seedlings did not penetrate but lifted the compact top layer when several seedlings reached it.

No reliable data of emergence or germination rates could be obtained. Therefor the weight of the seedlings was used as a measure for the treatments effects (Table 5). Each treatment data set, as well as the means of the main effect show only small effect of soil ESP or of gypsum on the seedlings.

Conclusions.

Water and salt stresses interact in reducing the final emergence percentage and increasing the time to emergence. Extensibility and not metabolite supply is the main limiting factor for seedling growth under both stresses. Salinity stress has different effects from water stress on seedlings. Shoot growth was more sensitive to water stress and root growth was more sensitive to salt stress. ESP and gypsum did not significantly affect the seed emergence and seedling growth. Growth rate and final emergence cannot be compared directly to diferentiate berwee growth stages with respect to tolerance. Growth rate is a continuous variable of the performance of the surviving seedlings, whereas the final emergence percentage is a binary attribute, whose value depends largely on the non-surviving seedlings.

Figures Legends

Figure 1. The effect of soil water content on the cumulative emergence of four chickpea cultivars.

Figure 2. Tolerance of the final emergence percentage (top) and seedling elongation rate (bottom) of four chickpea cultivars, to reduced soil water content.

Figure 3. The effects of soil salinity and water content on the cumulative emergence of chickpea (cv. Bulgarian).

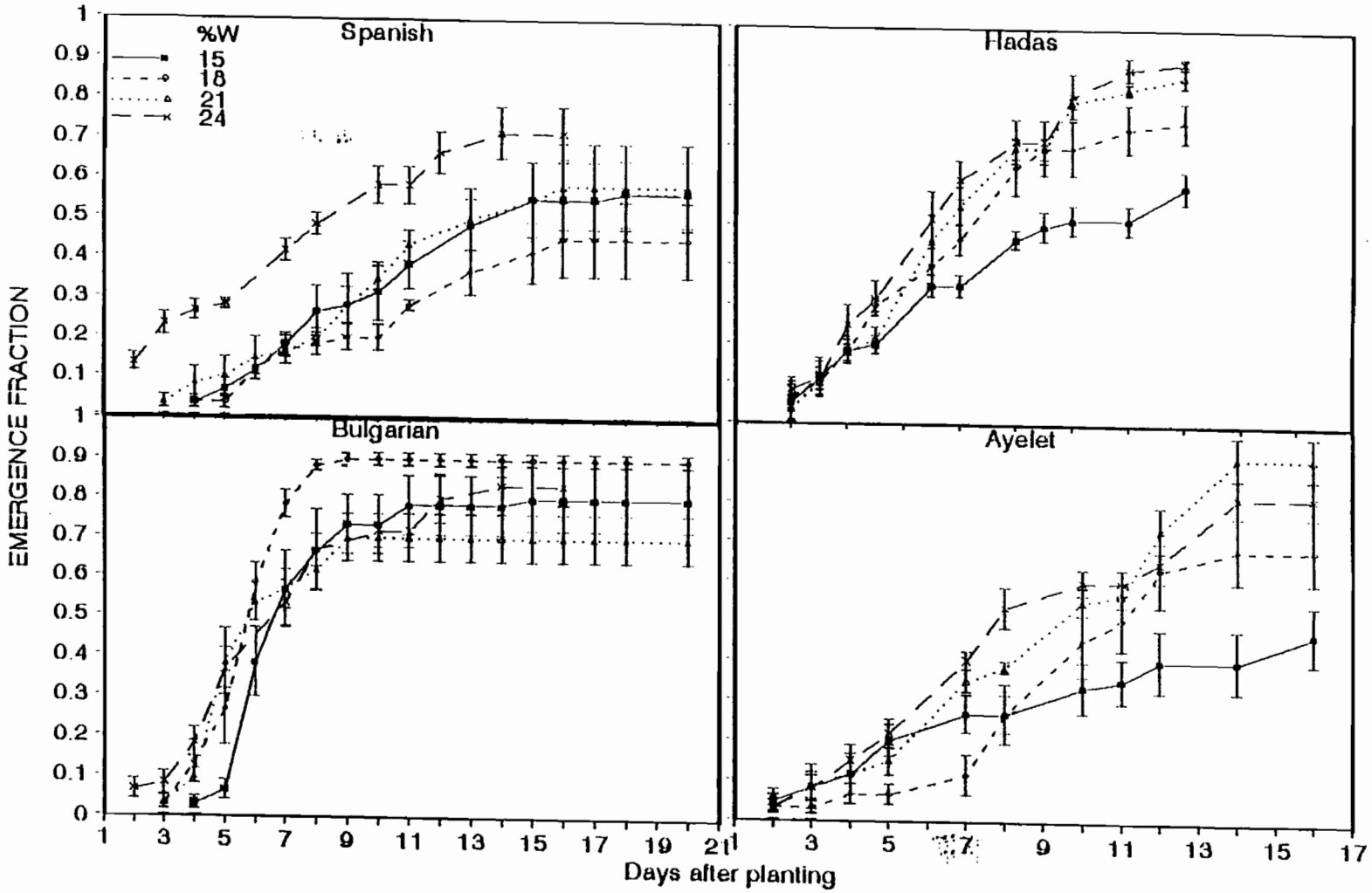
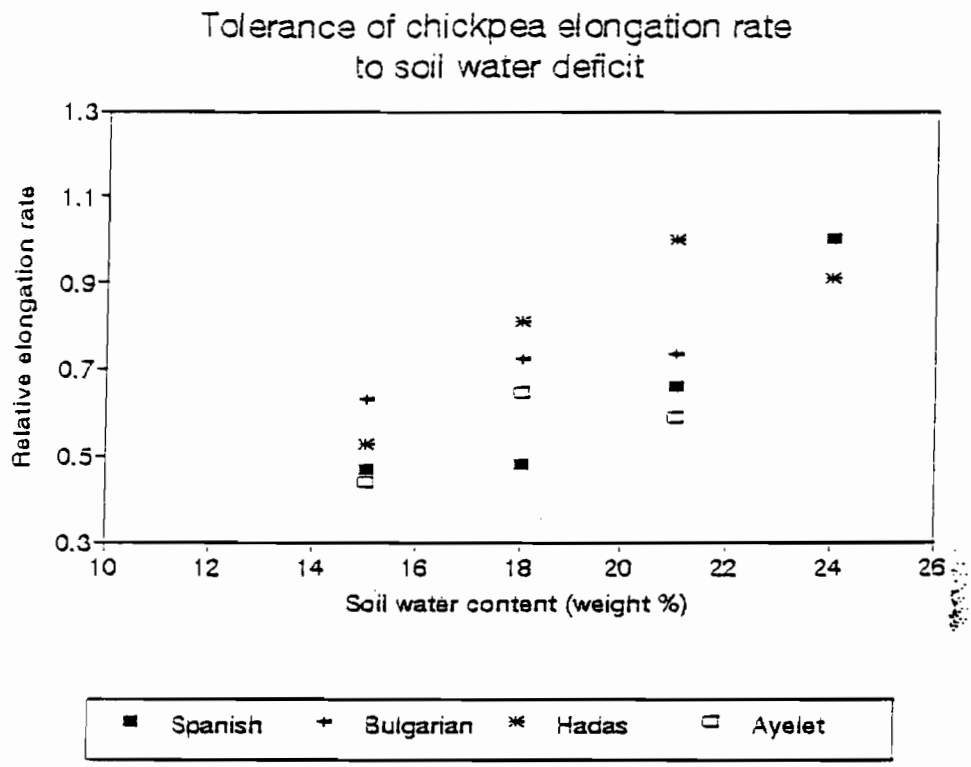


Figure 1. The effect of soil water content on the cumulative emergence of four chickpea cultivars.



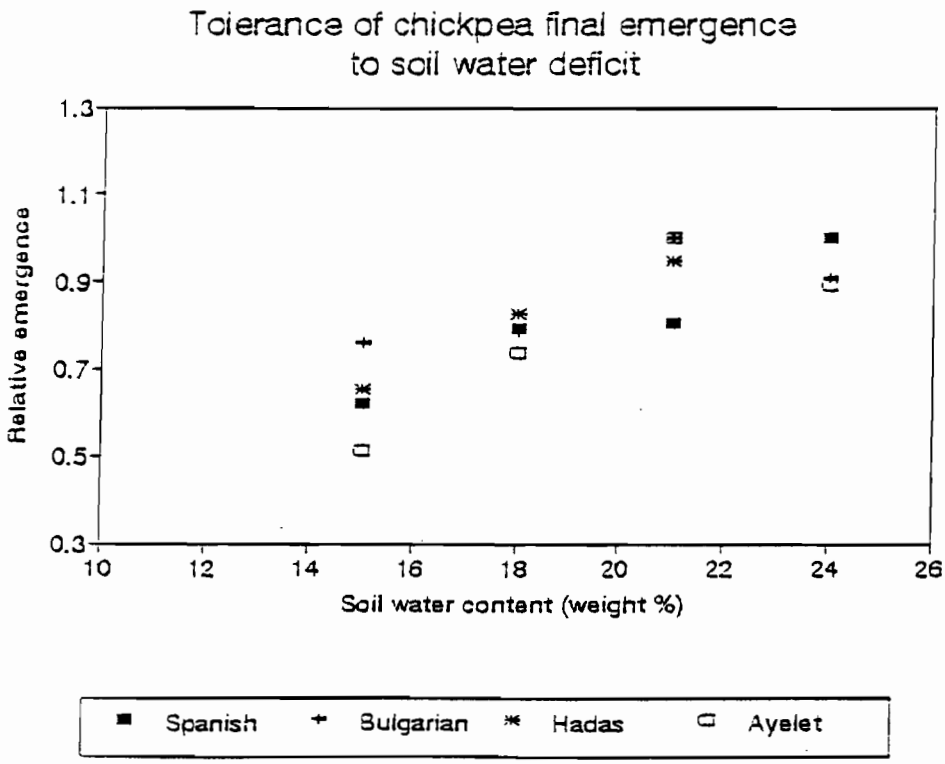


Figure 2. Tolerance of the final emergence percentage (top) and seedling elongation rate (bottom) of four chickpea cultivars, to reduced soil water content.

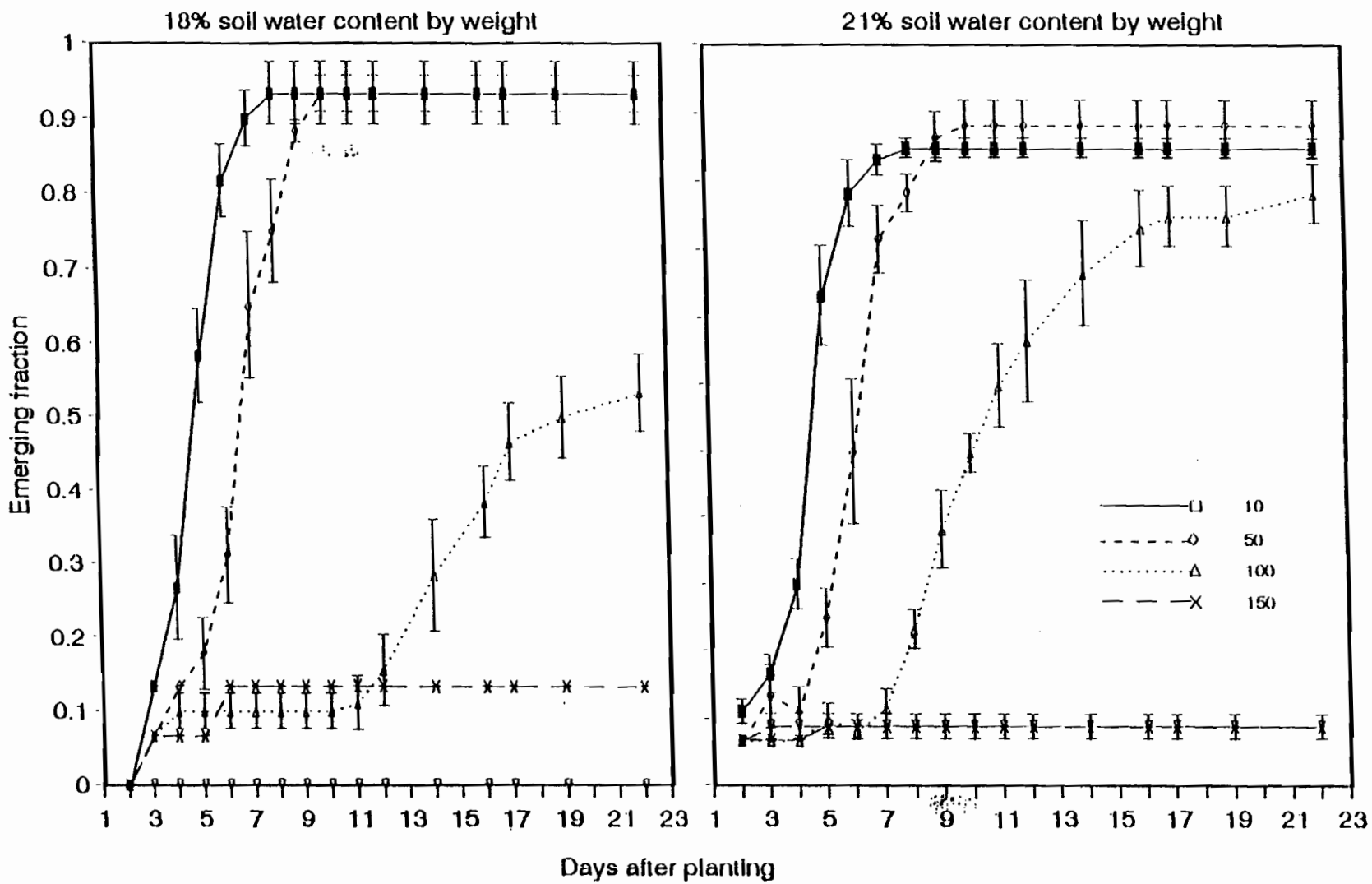


Figure 3. The effects of soil salinity and water content on the cumulative emergence of chickpea (cv. Bulgarian).

Chapter 2. Chickpea (cv. Hadas) response to planting date, and salinity and water stresses.

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Abstract

A field study, with 22 treatments, in the north-west Israeli Negev investigated the effects of four salinity and water stress variables on chickpea. The variables were: residual soil salinity from previous years, water salinity, length of non-irrigated period and planting date. All tested variables affected growth and yield. Initial soil salinity higher than 2.8 dS m^{-1} reduced yield mainly by reducing seed number. Increased water stress resulting from a longer period of no irrigation mainly reduced the seed number. Higher water salinity reduced yield mainly by reducing seed size. Seed growth show interaction between seed number and the strength of the source, i.e., the shoot. Water stress reduced shoot size and enhanced senescence more than salt stress. The seed size was found to interact with seed number, and shoot size and vitality. Stored soil water could not satisfy the crop water requirement for a long time, since the plants did not extract much water from a greater depth than 0.6 m.

Irrigation should stimulate initial shoot growth and avoid water stress during the early part of the reproductive growth stage. Irrigation water with electrical conductivity (EC_i) below 3 dS m^{-1} can elevate water stress, but water with EC_i of 5.5 or higher should be avoided.

Introduction.

Many irrigated areas in arid and semi-arid zones, specifically deserts, face the choci between saline irrigation and water shortage. The use of saline water is to be recommended if it can increase yield in comparison with no irrigation, or if its substitution for fresh water would have economic advantages such as releasing fresh water for more sensitive crops or reducing water cost. Testing the crop response to salinity during the first season of saline irrigation of nonsaline soil will not reveal the full salinity damage potential. The soil has a large buffer capacity and the salt input during one irrigation season will not salinize the root zone to the salinity level typical of a field irrigated for many years with saline water (Rhoades et al. 1989). There are carryover effects from year to year as soluble salts in the soil solution and as exchangeable sodium

in the exchange complex. The carryover effects are influenced by leaching and by natural amelioration or the application of amendments during leaching. Carry over of soluble salts will increase the osmotic or toxic effect of the soluble salts. Carry over of exchangeable sodium will increase the indirect effects of deterioration of the soil physical conditions; it has the maximum effect when the soil salinity is low, during winter after rain leaching. Using only a saline sodic water resource for a given field will eventually aggravate the carryover effects, while seasons of irrigation with fresh water will leach the soluble salts and reduce sodicity by exchange with natural calcium in the soil thus reducing the carryover effects (Meiri and Plaut 1985, Meiri 1990, Rhoades et al. 1989). It was hypothesized that under limited winter leaching the carryover salinity would increase the damage to crops irrigated with either fresh or saline water. Chickpeas are an important protein source, planted in late winter and suitable for warm and dry regions under irrigation. Like most pulses, chickpeas as are salt sensitive (Maas 1990) and success in irrigating them with saline water depends on the quantitative effects of water and salt stresses on the plant growth and yield. Chickpeas are planted before the end of the rainy season and benefit from rains and stored soil water. Therefore, delay of the first irrigation, thereby maximizing the use of the residual soil water, may reduce the salinity effect. The overall treatment effect depends on the seasonal integrated stresses and the synchronization of the differential stresses levels with the tolerance of the crop during ontogenesis (Meiri 1990). Whole plant growth and yield response to overall seasonal water and salt stresses may interact strongly with the temporal changes in the stress levels. Data on the effects of the stresses on individual seeds and pods may explain these interactions. This report provides data only on the whole plant response, and interpretation of the results assumes certain effects on the individual pod and seed that integrate into the overall plant response. Validation of the interpretation needs determination of the individual pod and seed data.

Materials and Methods.

A field study in kibbutz Nahal-Oz investigated the response of chickpeas (cv. Hadas) to the following variables: history of the soil salinity, planting date, water quality, and the delay of the 1st irrigation during the spring of 1994. Hadas is a high-quality cultivar; it is also tolerant to ascochyta, a common disease in the late time of planting needed in this irrigation study. The treatments differ in the length of the delay in irrigation following

the last rain, but used the same daily irrigation during irrigated periods. Therefore, the length of the delay in irrigation determined the seasonal water quantity and the length of the water deficit period. Differences between plots in the history of water quality resulted in differences in preplanting sail salinity. The use of two water qualities influenced the soil salinity during the irrigation period. Kibbutz Nahal-Oz is located in the north-west of the Israeli Negev. The soil is loess with moisture-holding capacity of 22.5 and 10 % by weight at field capacity (FC) and wilting point (WP) respectively; its cation exchange capacity (CEC) is about 17.5 Cmol kg^{-1}. The field had 88 plots of three beds, 1.92 m wide and 10 m long, divided into 22 treatments in four randomized blocks (Figure 1b). The treatment numbers and the levels of the experimental variables in each treatment are presented in table 1b. Irrigation was through 2.3 l h^{-1} drippers spaced at 1 m along drip laterals placed along the center of each bed . Planting on day of the year (DOY) 37 or 61 was in two rows, spaced 0.96 m apart in each bed, using 10 seeds per m row. The seeds were inoculated and no fertilizers were applied. The seasonal rainfall was 206, 243 and 311 mm respectively to the 1st and 2nd planting dates and for the full winter. Plants from the 37 DOY planting served to test the two experimental variables: history of the soil salinity and water quality. Plants from the 61 DOY planting served to test, in addition to the above two variables, the effects of different levels of seasonal irrigation obtained by delay of the first irrigation.

The fresh water of the region has an electrical conductivity (EC_i) of 1.0 dS m^{-1}. The saline water was prepared by injection of concentrated NaCl solution (200 g l^{-1}) into the fresh water in controlled proportions. Proportionality was obtained by controlling the number of strokes of a hydraulic fertilizer pump (Amiad) for a flow of 100 l of fresh water. The first irrigation, on 110 DOY, was given 73 or 48 days after planting (DAP) to plants from the 1st and 2nd planting dates, respectively. Irrigations with 5.5 dS m^{-1} water from 110 DOY caused severe damage to plants and from 124 DOY the water salinity was reduced to 3.0 dS m^{-1}. The 1st irrigation in each treatment was of 40 mm to the total area, or 38.4 l per dripper; it resulted in overlapping of the wetting circles along the laterals and wet about half the area. Additional irrigations were given once a week as the equivalent of 0.5 of the evaporation (E) from a class A pan, calculated for the whole area. The last irrigation, equivalent to 30 mm, was given on 160 DOY only to treatments 1, 2, 6, 7, 12, 13, 15, 16 and 17 that were still green with growing shoots, and which by

subjective judgment, could still benefit from irrigation. Other treatment were at a senescence level that could not benefit from irrigation.

Before planting, the soil was sampled, to determine salinity, in 0.3-m layers to 1.2-m depth, in the centers of the beds, the long-term location of the drip lines, in treatments 1, 2, 3, 4, 12, 13, 14, 15, 17 and 18, which represent different salinity history. After harvest, salinity was determined in all treatments at a distance of 0.2 m from the lateral and 0.28 m from an emitter outlet. Soil water content was determined in 0.3-m layers to a 1.2-m depth, in the same position as the final soil salinity sampling, in two replications of the treatments that were sampled for salinity before planting.

Table 1b. The treatments and experimental variables in a chickpea irrigation study in Nahal-Oz in 1994.

Treat.	History		1994 treatments				
	1986-91 Water quality	1992-3 Salt load Kg/ Acre	Planting DOY	1st Irrigation DOY	Seasonal Irrigation mm	Water Quality	Salt load Kg/ Acre
1	Fresh	4910	61	110	198	Fresh	1120
2	Fresh	8010	61	124	156	Fresh	890
3	Fresh	11090	61	139	64	Fresh	360
4	Fresh	7460	61	none	0	——	0
5	Fresh	11070	61	139	85	Fresh	480
6	Fresh	10510	61	110	198	Fresh	1120
7	Fresh	17210	61	110	198	Fresh	1120
8	Fresh	4810	37	110	168	Fresh	960
9	Fresh	4850	37	110	168	Fresh	960
10	Fresh	17320	37	110	168	Fresh	960
11	Fresh	11220	37	none	0	——	0
12	Saline	17320	61	110	198	Saline	4440
13	Saline	8010	61	110	198	Saline	4440
14	Saline	11050	61	139	85	Saline	1690
15	Saline	4980	61	110	198	Fresh	1120
16	Saline	4850	61	124	156	Saline	3140
17	Saline	10680	61	117	177	Saline	3790
18	Saline	4350	61	146	64	Saline	1300
19	Saline	11110	37	110	168	Fresh	840
20	Saline	11540	37	110	168	Saline	3620
21	Saline	7960	37	110	168	Fresh	840
22	Saline	17410	37	110	168	Saline	3620

Final seed yield, on 180 DOY, was harvest mechanically from two 8-m-long rows per plot, or an area of 7.7 m^2. A subsumple of 1 kg per plot was sorted by size and the weight of 1000 seeds was determined.

Plants were sampled on DOY 143 and 166 from 1-m row in treatments 1, 3, 12 and 18. The number of plants and the total fresh and dry weight of shoots, and the number and

fresh and dry weight of pods and seeds from the 1-m row were determined and calculated per plant. The pods of one plant per plot were coded according to position on the plant, and the sizes of individual pods where determined. The data measured were: envelope weight and seed number and weight. These data are presented in Chapter 3 of this report.

Results and discussion.

Irrigation - Seasonal irrigation was 0 or 177 mm in the early planting treatments and ranged from 0 to 198 mm in the late planting treatments, based on area, or 0–412 l per emitter. Additional irrigation, on DOY 160, was given to treatments from the 2nd planting date which had received first irrigation before DOY 125. They included treatments with fresh (1, 2, 6, 7, 15) or saline (12, 13, 16, 17) water and histories of low (1 and 15), medium (2, 6, 7, 13, 16, 17) and high (12) residual salinity. Other treatments senesced earlier and their last irrigation was on DOY 152. Senescence was mainly the result of plant age and water stress at an early growth stage. Plants from the DOY 37 planting that received the wettest regime with fresh or saline water senesced before 160 DOY while plants from the DOY 61 planting with similar wetting regime were vigorous. From the DOY 61 planting, only treatments that were not irrigated before DOY 125 belonged to the senesced treatments group. Senescence time was less affected by water salinity or soil salinity.

Initial soil salinity profiles in the centers of the 1.92-m beds, in the lateral positions but with no reference to previous emitter locations, are presented as bar diagrams for all the sampled treatments (figure 2b) and as line diagram for selected saline and non-saline soil history during 1986-91 and different salt loads during 1992-93 (figure 3b). Both figures show only small effects of the 1986-91 salinity and large effects of the water salinity during the 1993 irrigation season on the pre-planting soil salinity profiles. This was the result of complete leaching of the 1.2-m profiles, in the centers of the beds, by the irrigation and rain water during the 1991 and 1992 seasons and insufficient leaching during the dry winter of 1993. The correlation coefficients of the 1994 initial soil salinities (EC_e, Cl_e and Na_e) to the salt loads in the irrigation water during the 1993 season (Table 2b) increased with the depth of the profile for all parameters, and the correlations slopes increased with depth for Cl and was maximal at 0-0.6 m depth for Na. These changes in the regression parameters reflect the faster leaching of Cl. The

correlations from the 10 measured treatments served in estimating the initial soil salinity in all treatments (Table 3b).

Final soil salinity was determined at a distance of 0.2 m from the bed center and 0.28 m from the emitter position. The mean salinity for the various depths was lower than the preplanting salinity in most cases (Table 3b). The reduction in salinity was larger for the deeper profiles and the more saline treatments. This reduction in salinity indicates leaching of the profile at this distance from the emitter by the irrigation water. Figure 4b presents the EC_e and Na_e profiles at harvest for treatments of continuous use of fresh (treatment 1) or saline (treatment 12) water since 1986, and for treatments that were irrigated with saline water from 1986 to 1991, with fresh water during 1992 and 1993, andfresh (treatment 15) or saline (treatment 18) water during 1994.

Table 2b. Parameters of the linear correlations between the pre-planting, spring 1994, soil salinity parameters and the salt load in the 1993 potato irrigation water (profiles in the centers of the 1.92-m beds)

Profile Depth m	Salinity Parameter	Intercept	Slope	r^2
0 - 0.3	EC_e	0.55 dS m^{-1}	0.00206 dS m^{-1}/g m^{-2}	0.80
	Cl_e	2.36 mM l^{-1}	0.00566 mM l^{-1}/g m^{-2}	0.44
	Na_e	1.30 mM l^{-1}	0.01065 mM l^{-1}/g m^{-2}	0.83
0 - 0.6	EC_e	1.20 dS m^{-1}	0.00219 dS m^{-1}/g m^{-2}	0.72
	Cl_e	5.04 mM l^{-1}	0.01107 mM l^{-1}/g m^{-2}	0.54
	Na_e	2.96 mM l^{-1}	0.01357 mM l^{-1}/g m^{-2}	0.84
0 - 0.9	EC_e	1.04 dS m^{-1}	0.00206 dS m^{-1}/g m^{-2}	0.77
	Cl_e	3.37 mM l^{-1}	0.01211 mM l^{-1}/g m^{-2}	0.70
	Na_e	2.21 mM l^{-1}	0.01319 mM l^{-1}/g m^{-2}	0.84
0 - 1.2	EC_e	0.97 dS m^{-1}	0.00183 dS m^{-1}/g m^{-2}	0.78
	Cl_e	2.18 mM l^{-1}	0.01178 mM l^{-1}/g m^{-2}	0.76
	Na_e	2.94 mM l^{-1}	0.01077 mM l^{-1}/g m^{-2}	0.83

The decreasing order of salinity and Na content in the profiles of the four treatments were: 12>18>15>1 in the top layer for both EC_e and Na_e , 12>18=15=1 for EC_e in the 0.6-1.2 m layer and 12>18=15>1 for Na_e in the 0.3-1.2 m layer. The top layer salinity responded rapidly to the irrigation or rain water salinity, whereas the Na_e level is influenced by the CEC and exchangeable Na content in the soil and changes more slowly. Therefore, the Na_e level shows residual effects of the water quality before 1991: two or three seasons of fresh water did not reduce the Na_e to its level in the fresh water plot. EC_e in treatment 12 that was irrigated with 198 mm showed the effects of

percolation of the irrigation water through the entire depth whereas in treatment 18 that was irrigated with 130 mm, the percolation was to 0.6 m.

Table 3b. Measured and estimated pre-planting soil salinity (EC_e dS m^{-1}) profiles in the different treatments.

Treat.	0-0.3 m Profile			0-0.6 m Profile			0-0.9 m Profile		
	Initial Meas[a]	Initial Est[a]	Final Meas[a]	Initial Meas[a]	Initial Est[a]	Final Meas[a]	Initial Meas[a]	Initial Est[a]	Final Meas[a]
1	1.51	1.55	1.69	2.07	2.28	1.51	1.80	2.05	1.45
2	2.02	2.19	2.20	2.97	2.96	1.77	2.55	2.69	1.72
3	2.43	2.83	2.64	3.17	3.63	1.96	2.96	3.32	1.91
4	1.61	2.08	1.36	2.25	2.84	1.53	2.13	2.58	1.59
5		2.83	1.87		3.63	1.73		3.32	1.68
6		2.71	1.88		3.51	1.68		3.21	1.63
7		4.09	2.36		4.98	1.97		4.59	1.91
8		1.54	2.75		2.26	2.11		2.03	1.76
9		1.54	1.77		2.27	1.64		2.04	1.54
10		4.11	3.48		5.00	2.71		4.61	2.64
11		2.85	2.31		3.66	2.35		3.35	2.42
12	4.11	4.11	3.63	4.75	5.00	3.05	4.47	4.61	2.85
13	2.94	2.20	2.36	3.63	2.96	2.21	3.24	2.69	2.06
14	2.53	2.82	3.54	3.41	3.63	2.70	3.08	3.32	2.36
15	1.68	1.57	1.88	2.14	2.29	1.72	1.91	2.06	1.65
16		1.54	2.95		2.27	2.39		2.04	2.12
17	3.37	2.74	3.73	4.72	3.54	2.68	4.20	3.24	2.35
18	1.34	1.44	3.01	2.19	2.16	2.46	2.17	1.94	2.18
19		2.83	2.14		3.64	1.97		3.33	1.95
20		2.92	2.88		3.73	2.46		3.42	2.39
21		2.18	2.14		2.95	2.07		2.68	2.03
22		4.13	4.09		5.02	3.17		4.63	2.81

[a] Est=estimated, Meas=measured.

Soil water content before irrigation, in selected treatments from the 2nd planting date (Figures 5b and 6b) showed very little seasonal change at depths greater than 0.6 m. Even in treatment 4 that was not irrigated and in which the soil had low salinity, the soil water content at 0.9-1.2 m depth was stable: maximal water content at 0.9-1.2 m depth was 26% by volume and minimal water contents at 0.0-0.3 m depth was 11% by volume. The field capacity (FC) and wilting point (WP) for this soil are 30 and 14% by volume, respectively. The large amount of water near the emitter increased the measured seasonal water content over the entire profiles with each water quality. Plots with saline water had higher soil water contents than those with fresh water under similar watering. This would be the expected result of reduced evapotranspiration. The increase in soil water content at 0.9-1.2 m, with the increase in watering level indicates percolation of the irrigation water to this depth and perhaps also below this depth. The percolation under the center of water application should be deeper than under the remote measuring point.

Final yield - Data of the final yields and their components - pod envelope and seed - are presented in Table 4b for early planted treatments and in table 5b for late planted treatments. Final yields were influenced by all tested variables: they were lower at the early planting, for higher soil and water salinities and for extension of the dry period preceding the 1st irrigation, which also implies reduced seasonal watering. The reduced yield was the result of reduction in both seed number and size, but the different stresses had different effects on these yield components. The differences could not be the result of timing of the water and salt stresses, as they were imposed at the same time, but are specific effects of the salt or water stresses.

Table 4b. Effect of soil and water salinity and irrigation quantity on the components of the final yield of early-planted chickpeas.

Treatment				Yield	Seed W	Seed No	Seed distribution by size (%)						Relative to treat. 1 (in table 5b)		
No	a	b	Irr[c]	gm^{-2}	g/1000	no. m^{-2}	16	18	20	22	24	W	RY	W	N
8	F;L	F	169	316	397.8	125.8	1	3	60	34	2	20.7	.80	.87	.92
9	F;L	F	169	328	425.7	139.6	1	2	54	40	3	20.8	.89	.93	.96
10	F;H	F	169	239	366.0	87.3	5	7	78	10	0	19.9	.56	.80	.70
11	F;M		0	51	310.6	15.8	14	17	64	5	0	19.2	.10	.68	.15
19	S;M	F	169	311	387.2	120.5	2	19	47	30	1	20.2	.77	.85	.91
20	S;M	S	169	347	318.6	110.5	11	12	64	12	1	19.6	.71	.70	1.01
21	S;L	F	169	298	402.8	120.1	2	4	67	26	2	20.4	.77	.88	.87
22	S;H	S	169	208	308.3	64.2	18	15	62	5	0	19.0	.41	.68	.79

WMW=weighted mean weight, RY=relative yield, RSW and RSN=relative seed weight or number

[a] Soil salinity history. 1st letter for water quality during 1986-91 season 2nd for residual salinity from 1993 (low-L, medium=M, high=H).

[b] Water quality F=fresh, S=saline

[c] Seasonal irrigation in mm/total area.

Both water and salt stresses reduced seed number, but seed size was affected more by salinity than by water shortage. In all early planted treatments irrigation started early and totaled 169 mm, except for treatment 11 that was not irrigated. The late planting treatments included a wide range of irrigation quantities (0-198mm) and 1st irrigation delay time.

For each planting date maximal yields were obtained in soils with low residual salinity and with short post-winter delay of irrigation and larger quantities of fresh water (treatments 8 and 9 from the early planting and 1 and 15 from the late planting).

In the early-planted treatments soil history influenced the yield slightly. This can be seen in the lower yield in treatment 21 than in treatments 8 and 9 which had similar initial salinity and water treatment. In each salt history group higher initial salinity coused yield reduction (compare treatment 10 with treatments8 and 9 or treatment 22 with treatment 20). Saline water reduced the yield only slightly beyond the reduction due to initial soil salinity (compare treatment 20 with treatment 19 or treatment 22 with treatment 10). Water stress had the largest effect on the yield (treatment 11). Yield was affected more by seed number than by seed weight. Even in treatment 11 where yield decreased by 90%, seed weight decreased by only 32%. Irrigation with saline water and higher initial soil salinity reduced the seed weight (compare treatment 20 with 19, 10 with 8 and 9, 19 with 21). The different effects of the water and salt stresses on seed number and size are clearest in figure 7b where treatments are grouped according to irrigation water quality and plotted against initial soil salinity. Initial soil salinity higher than 2.8 dS m^{-1} reduced seed number. Increase of initial soil salinity also slightly reduced the seed size. Water salinity had little effect on seed number but reduced seed size. Treatment 11, with no irrigation, produced a very small number of seeds but the decrease in size of these seeds was no greater than that with saline water.

In the late planting (table 5b) yield decreased mainly as a result of water stress. Also for this planting date, salinity had a larger effect on seed size than on seed number. The relative effects of water and salt stresses become clear when treatments that can be grouped according to initial soil salinity and irrigation water salinity are plotted against total seasonal irrigation depth (Figure 8b). With all water levels, seed number was lower for medium initial soil salinity and saline irrigation. High initial salinity and irrigation with 198 mm saline water did not reduce seed number. Seed size was smaller when initial soil salinity increased. Saline irrigation farther decreased seed size under medium or high initial soil salinity. Watering level had only a small effect on seed size also for this planting date.

Since water stress had a large effect on yield, we tend to explain the lower yield of the early-planted treatments by greater water stress during the transient period before the first irrigation. Plants from the early planting were larger and consumed more stored water before the first irrigation and during the first irrigation intervals. During this period the plants are most sensitive to stress. The plants suffered water stress when we expected the supply from stored soil water to be sufficient. The minimal water content in the soil before DOY 110 was higher than 20% and only decreased to 17 or 15 % in the

0-0.3 m depth and was not lower than 22 % in the 0.3-0.6 m depth between 110 and 124 DOY. The reason for this reduced consumption of stored soil water is not clear and needs special investigation.

Table 5b. Effect of soil and water salinity and irrigation quantity on the components of the final yield of late planted chickpeas.

Treatment				Yield	Seed W	Seed No	Seed distribution by size (%)						Relative to treat. 1 (in table 5b)		
No	SSH[a]	WQ[b]	Irr[c]	gm^{-2}	g/1000	nm^{-2}	16	18	20	22	24	WMW	RY	RSW	RSN
1	F;L	F	198	156.7	456.6	343	0	1	32	60	7	21.5	1.00	1.00	1.00
2	F;L	F	148	87.1	382.3	228	3	5	69	21	1	20.1	.56	.84	.66
3	F;M	F	64	33.6	348.0	97	8	13	70	9	0	19.6	.21	.76	.28
4	F;L		0	49.3	382.3	150	2	6	72	18	1	20.1	.31	.84	.44
5	F;M	F	85	44.2	350.8	126	11	15	66	9	0	19.5	.28	.77	.37
6	F;M	F	198	106.7	373.7	286	2	5	74	19	0	20.2	.68	.82	.83
7	F;H	F	198	90.9	361.5	251	4	8	76	11	0	19.9	.58	.79	.73
12	S;H	S	198	92.6	339.6	273	5	10	79	5	0	19.7	.59	.74	.80
13	S;L	S	198	96.8	411.1	235	4	8	74	13	1	20.0	.62	.90	.69
14	S;M	S	85	28.4	316.1	90	14	17	63	5	0	19.2	.18	.69	.26
15	S;L	F	198	153.4	432.2	355	0	1	50	45	3	21.0	.98	.95	1.03
16	S;L	S	157	94.7	396.6	239	2	4	67	26	2	20.4	.60	.87	.70
17	S;M	S	177	46.2	300.4	154	17	17	60	5	0	19.0	.29	.66	.45
18	S;L	S	64	53.7	373.5	144	2	7	72	19	0	20.2	.34	.82	.42

[a] Soil salinity history. 1st letter for water quality during 1986-91 season 2nd for residual salinity from 1993.

[b] Water quality F=fresh, S=saline

[c] Seasonal irrigation in mm/total area.

The effects of treatments on mean seed size reflects changes in seed size distribution, which was affected by all experimental variables (Tables 4b and 5b). The effect is clear for groups of treatments according to planting date, water salinity and initial soil salinity (Figure 9b). Most seeds in all groups belong to size 20. However, the early-planted treatments had larger fractions of small seeds. Among salinity treatments the increase in initial soil salinity and the use of saline water increased the fractions of small seeds. With no irrigation there was a larger fraction of small seeds than in saline irrigated treatment in the early planting and a larger fraction of large seeds in the late planting.

Conclusions.

At this stage we can conclude that, for chickpea, we should aim at rapid shoot development and avoidance of water stress during the early to mid-growth season. Initial soil salinity should be below 2.8 dS m^{-1} to avoid reduction in seed number and perhaps

lower to avoid reduction in seed size. The plants could not effectively use stored soil water from a greater depth than 0.3 m early in the season or from the 0.6-0.9 m depth over the entire season, even when planted in low-salt soil and with no irrigation at all. Thus, watering should start early, perhaps with small water quantities. Shorter irrigation intervals and smaller spaces between emitters may reduce deep percolation for chickpeas of similar shoot size. The question of supplementing the fresh water with late saline irrigation was not investigated. It is evident that water having EC of 3.0 dS m^{-1} or lower but not of 5.5 dS m^{-1} or higher should replace water stress. Study is needed of the effects of water with salinity in the range 3.0-5.5 dS m^{-1}, and of the effects of late water and salt stresses.

Figures legends.

Figure 1b. The layout of the experimental field. Upper and lower numbers in a plot are the treatment and plot number respectively.

Figure 2b. The effect of saline and non-saline irrigation seasons (S and NS on the X scale) during the 1986-1991 and of salt input (g m^{-2}) with the irrigation water during the 1992 and 1993 seasons (labels) on the preplanting salt content of the soil.

Figure 3b. The effects of saline and non-saline irrigation seasons (S and NS in the legends) during the 1986-1991 and of salt input (g m^{-2}) with the irrigation water during the 1992 and 1993 seasons (numbers in the legends) on the preplanting soil salinity profiles.

Figure 4b. Final profiles of electrical conductivity (EC_e) and soluble sodium (Na_e) in the saturated paste extract of treatments that differ in the long-term history of salinity, watering levels and water quality (see Table 1 for details).

Figure 5b. Seasonal soil water content in plots that were irrigated with fresh water during the 1986-91 seasons, differed in the residual soil salinity from 1993 season (LRS, MRS and HRS in the subtitles indicate low, medium and high residual salinities) and were irrigated with different levels of fresh water during 1994 (FW and mm in the subtitle). (arrows indicate beginning and termination of the irrigation season).

Figure 6b. Seasonal soil water content in plots that were irrigated with saline water during the 1986-91 seasons, differed in the residual salinity from 1993 season (LRS, MRS and HRS in the subtitles indicate low, medium and high residual salinities) and were irrigated with different levels of fresh or saline water during 1994 (FW or SW and mm in the subtitle). (arrows indicate beginning and termination of the irrigation season).

Figure 7b. Influence of initial soil salinity (x scale) and water salinity (FW=low, SW=high) and no irrigation (NW) on the yield components in early planting treatments.

Figure 8b. Influence of the initial soil salinity (LS, MS and HS = low, medium and high) and water quality (FW and SW = fresh and saline) on the response of yield components to seasonal water quantity (x scale) of late-planting treatments.

Figure 9b. Influence of water quality (FW and SW = fresh and saline), initial soil salinity (EC_i) and no irrigation (NW) on the size distribution of the seeds.

Aknowledgement. For the wonderful care of the field by Eyal Ofir from Kibutz Nahal-Oz and plant analysis by Mrs. Shuali Margot.

12 -- 1	13 -- 5	6 -- 9	11 -- 13	8 -- 17	2 -- 21	17 -- 25	17 -- 29	20 -- 33	22 -- 37	15 -- 41
16 -- 2	3 -- 6	15 -- 10	11 -- 14	8 -- 18	5 -- 22	12 -- 26	7 -- 30	19 -- 34	21 -- 38	6 -- 42
3 -- 3	2 -- 7	16 -- 11	10 -- 15	9 -- 19	1 -- 23	13 -- 27	5 -- 31	20 -- 35	22 -- 39	14 -- 43
4 -- 4	18 -- 8	7 -- 12	10 -- 16	9 -- 20	4 -- 24	18 -- 28	14 -- 32	19 -- 36	21 -- 40	1 -- 44
14 -- 45	13 -- 49	5 -- 53	22 -- 57	9 -- 61	2 -- 65	12 -- 69	16 -- 73	20 -- 79	10 -- 81	16 -- 85
1 -- 46	18 -- 50	14 -- 54	22 -- 58	8 -- 62	5 -- 66	17 -- 70	15 -- 74	19 -- 80	11 -- 82	3 -- 86
6 -- 47	3 -- 51	17 -- 55	21 -- 59	9 -- 63	4 -- 67	13 -- 11	6 -- 75	19 -- 81	10 -- 83	12 -- 87
15 -- 48	2 -- 52	7 -- 56	21 -- 60	8 -- 64	1 -- 68	18 -- 72	7 -- 76	20 -- 82	11 -- 84	4 -- 88

Figure 1b. The layout of the experimental field. Upper and lower numbers in a plot are the treatment and plot number respectively.

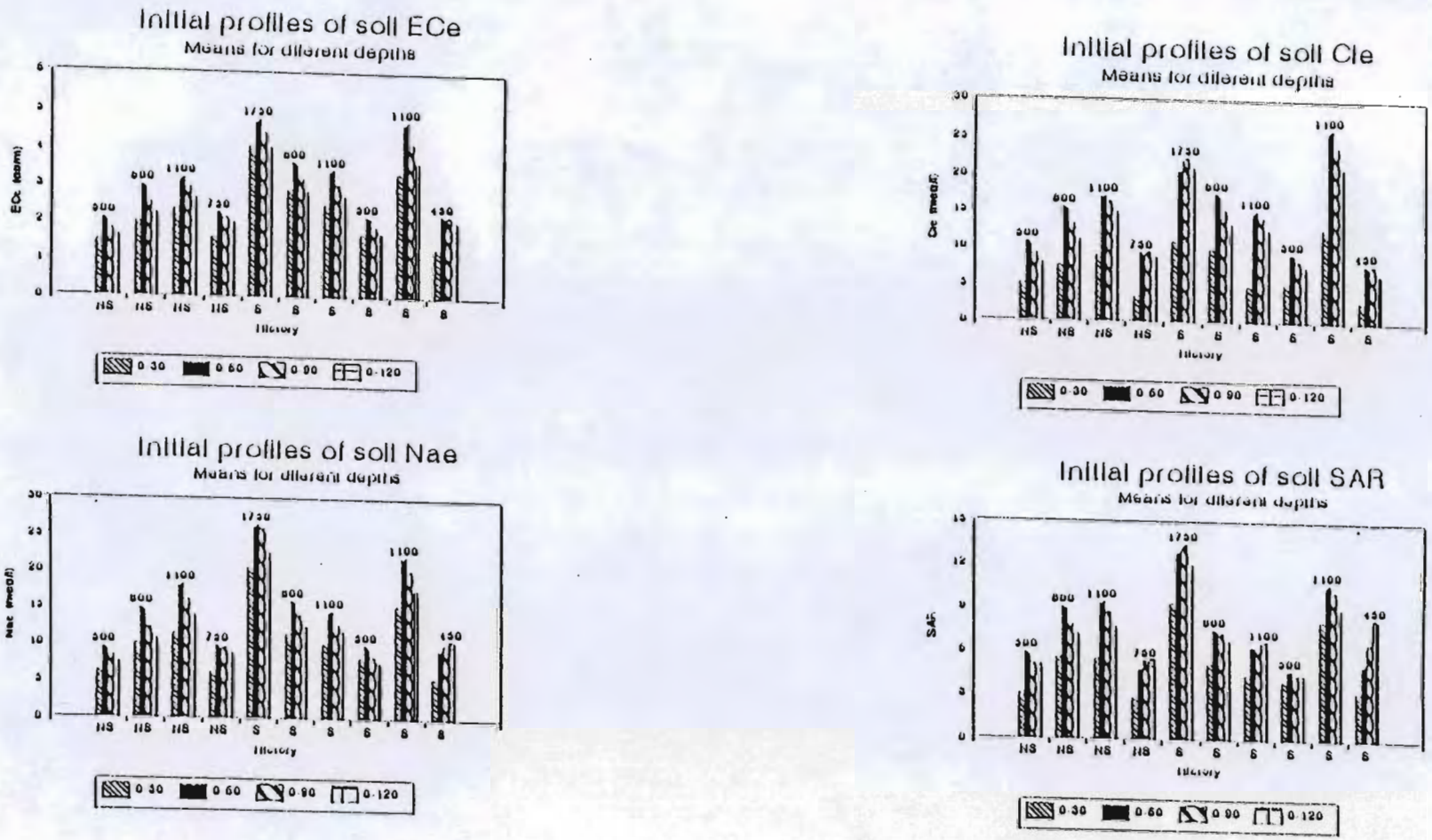


Figure 2b. The effect of saline and non-saline irrigation seasons (S and NS on the X scale) during the 1986-1991 and of salt input (g m^{-2}) with the irrigation water during the 1992 and 1993 seasons (labels) on the preplanting salt content of the soil.

Initial soil
Salinity profiles

Nahal-Oz 1994

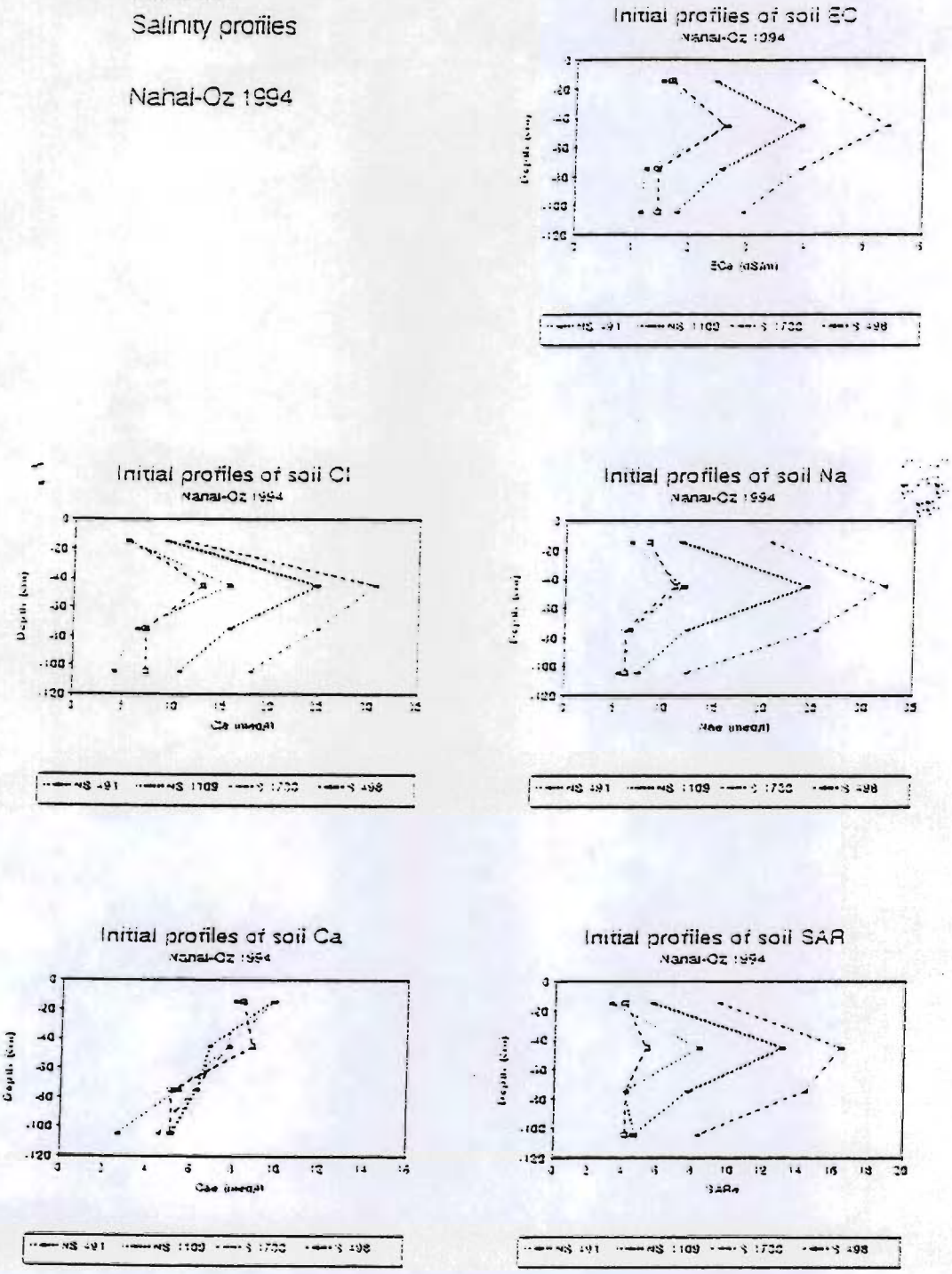
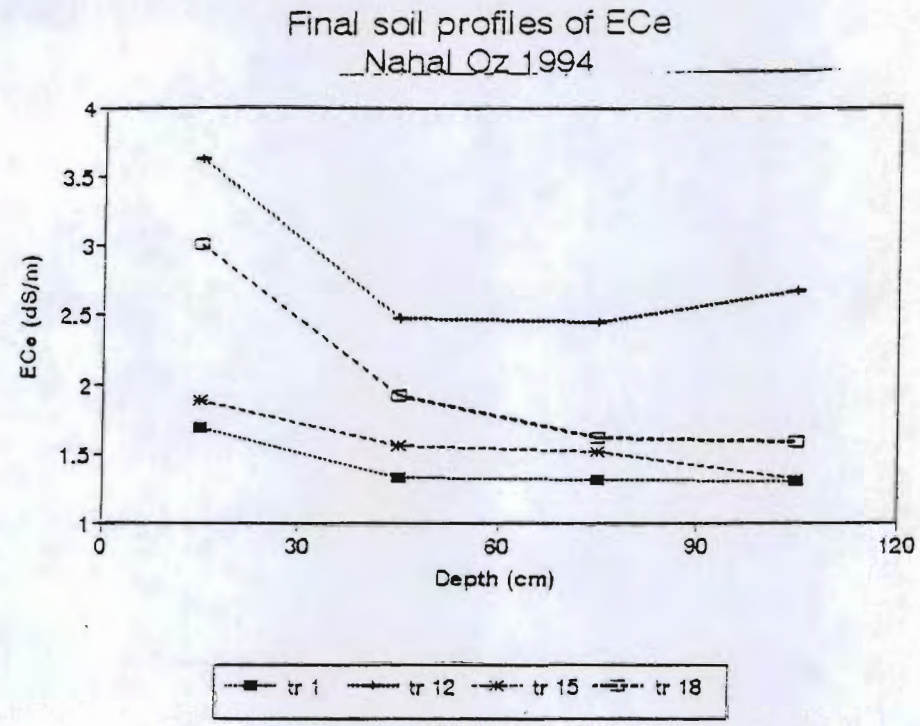


Figure 3b. The effects of saline and non-saline irrigation seasons (S and NS in the legends) during the 1986-1991 and of salt input (g m^{-2}) with the irrigation water during the 1992 and 1993 seasons (numbers in the legends) on the preplanting soil salinity profiles.



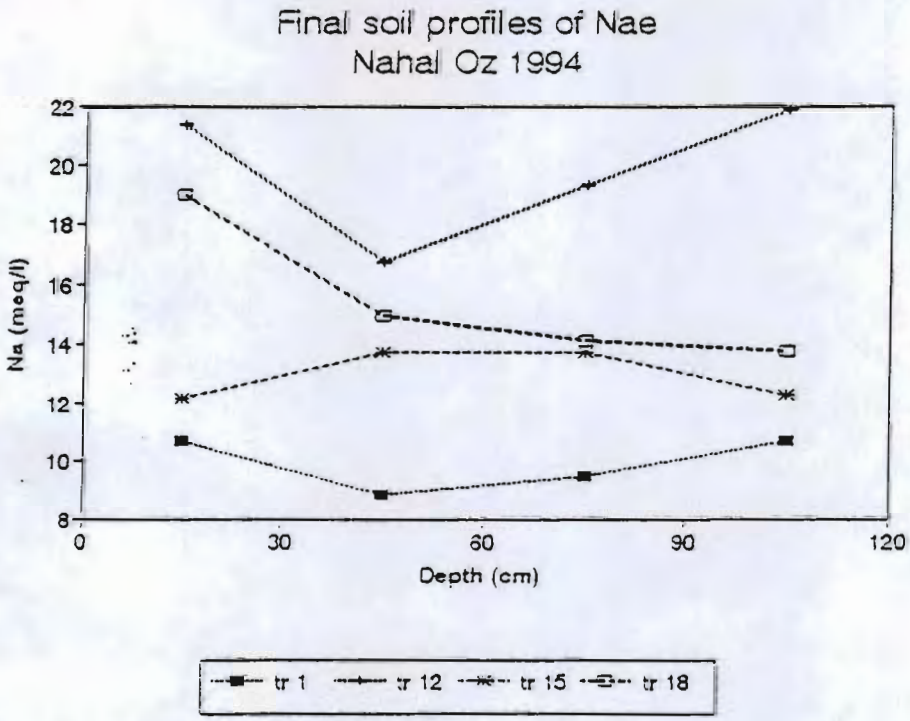


Figure 4b. Final profiles of electrical conductivity (EC_e) and soluble sodium (Na_e) in the saturated paste extract of treatments that differ in the long-term history of salinity, watering levels and water quality (see Table 1 for details).

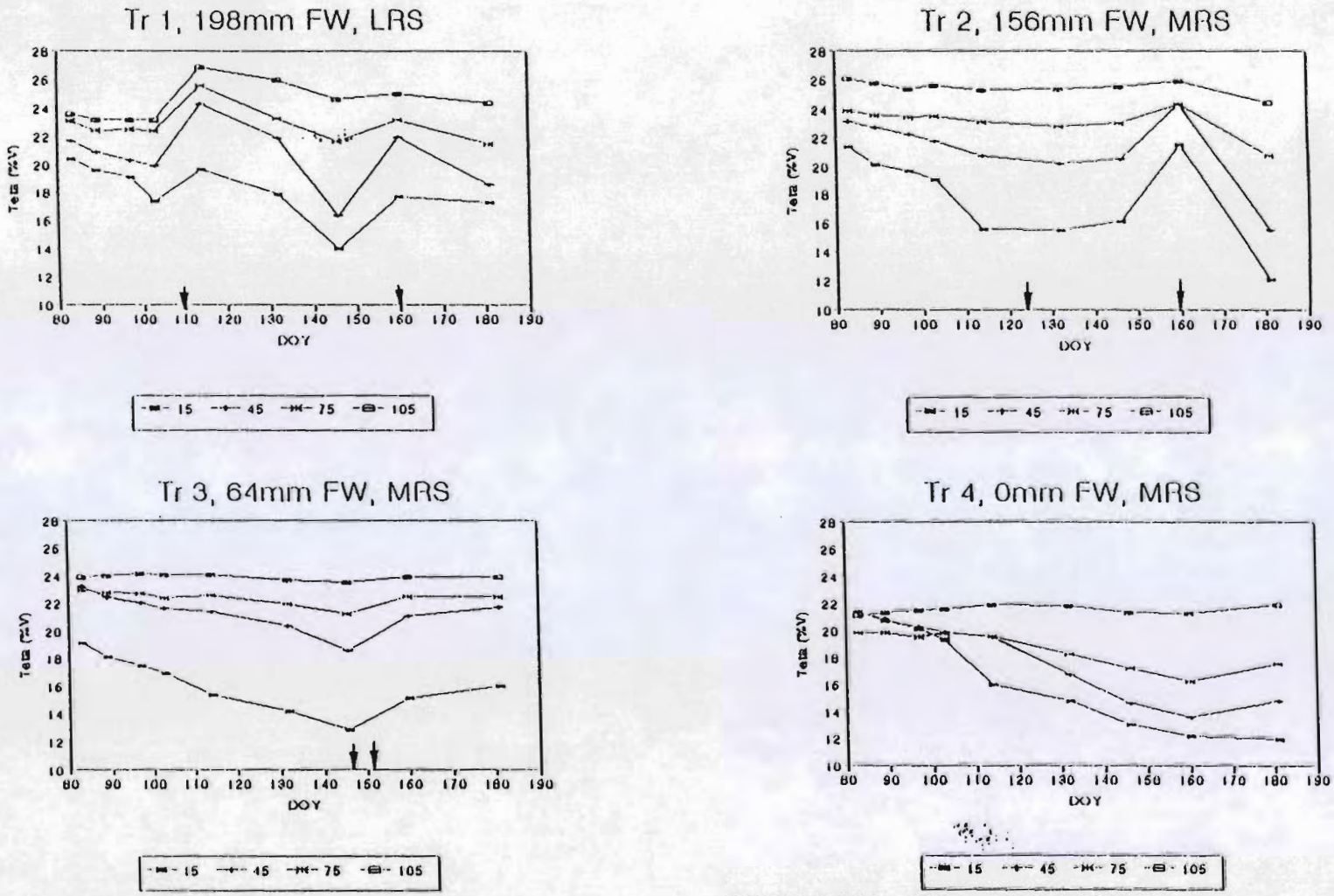


Figure 5b. Seasonal soil water content in plots that were irrigated with fresh water during the 1986-91 seasons, differed in the residual soil salinity from 1993 season (LRS, MRS and HRS in the subtitles indicate low, medium and high residual salinities) and were irrigated with different levels of fresh water during 1994 (FW and mm in the subtitle). (arrows indicate beginning and termination of the irrigation season).

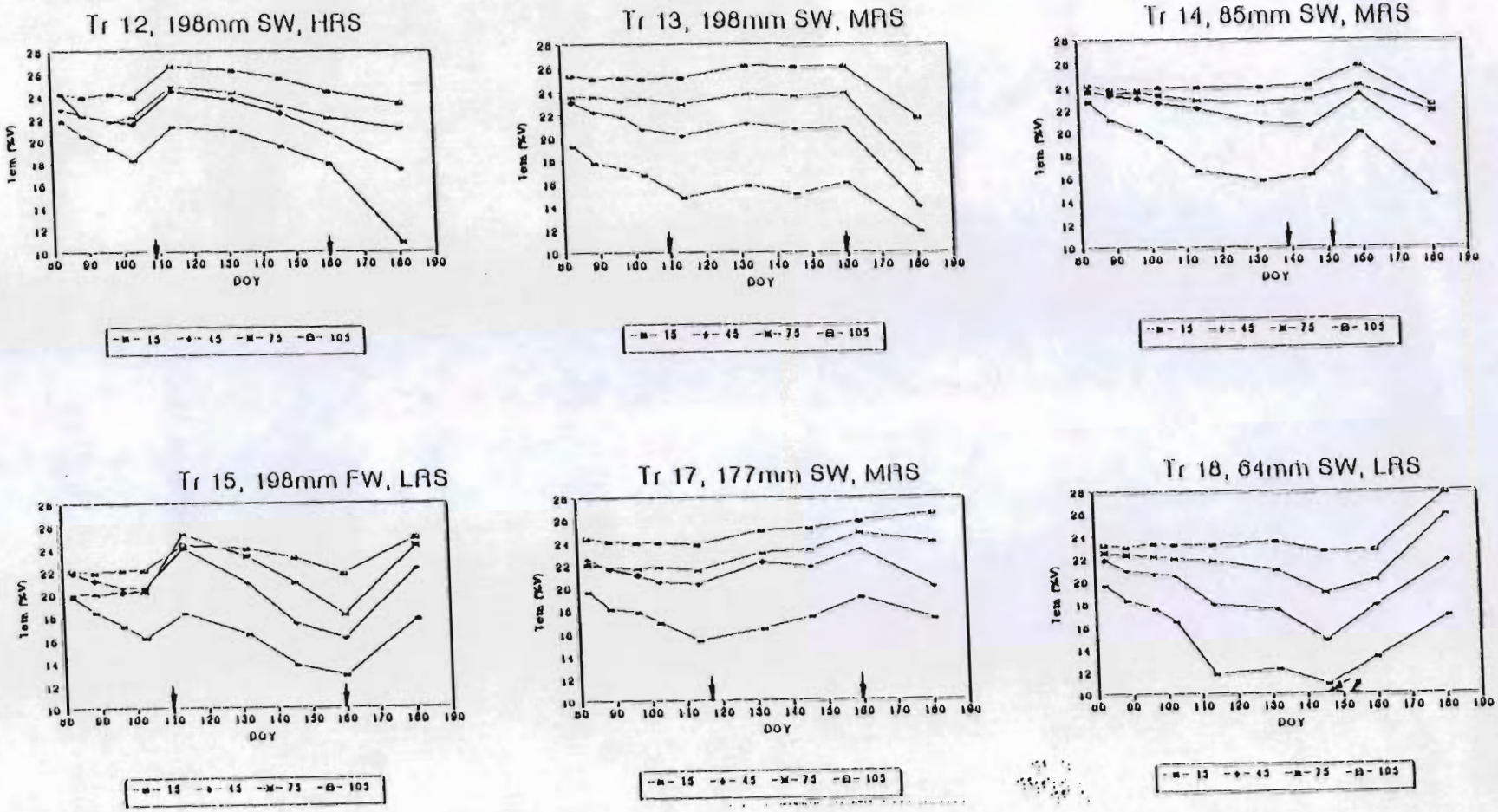
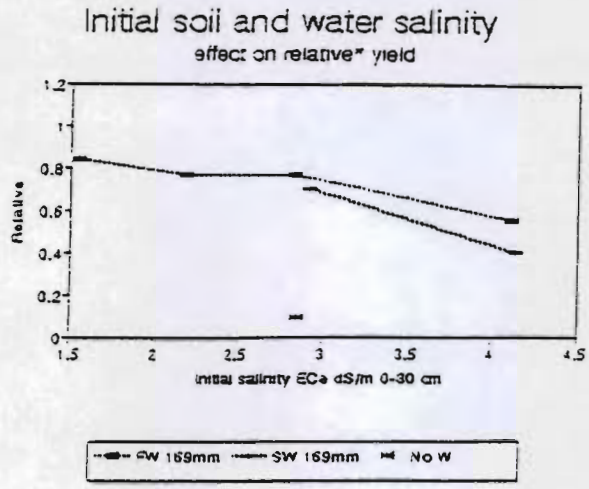
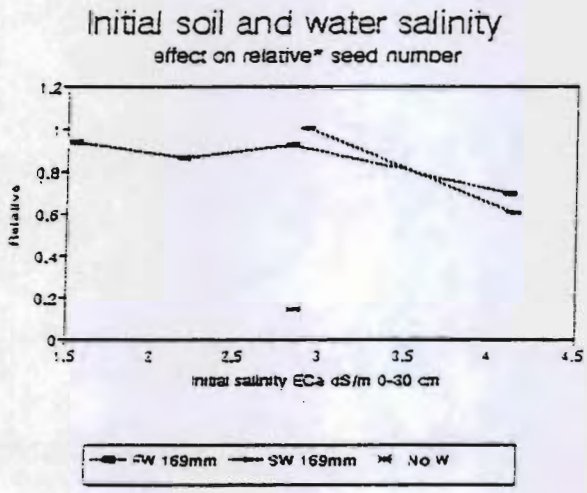


Figure 6b. Seasonal soil water content in plots that were irrigated with saline water during the 1986-91 seasons, differed in the residual salinity from 1993 season (LRS, MRS and HRS in the subtitles indicate low, medium and high residual salinities) and were irrigated with different levels of fresh or saline water during 1994 (FW or SW and mm in the subtitle). (arrows indicate beginning and termination of the irrigation season)





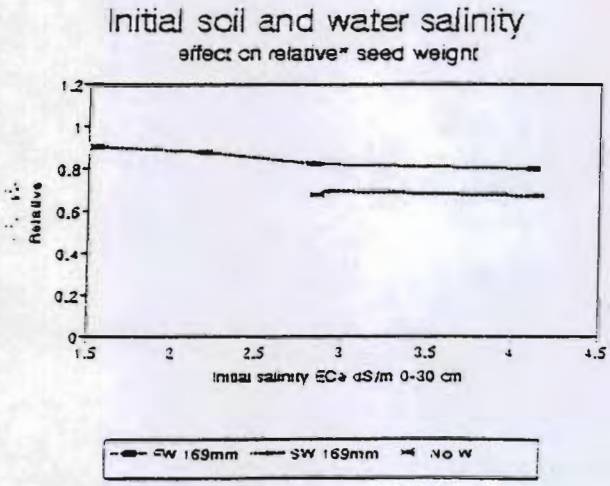


Figure 7b. Influence of initial soil salinity (x scale) and water salinity (FW=low, SW=high) and no irrigation (NW) on the yield components in early planting treatments.

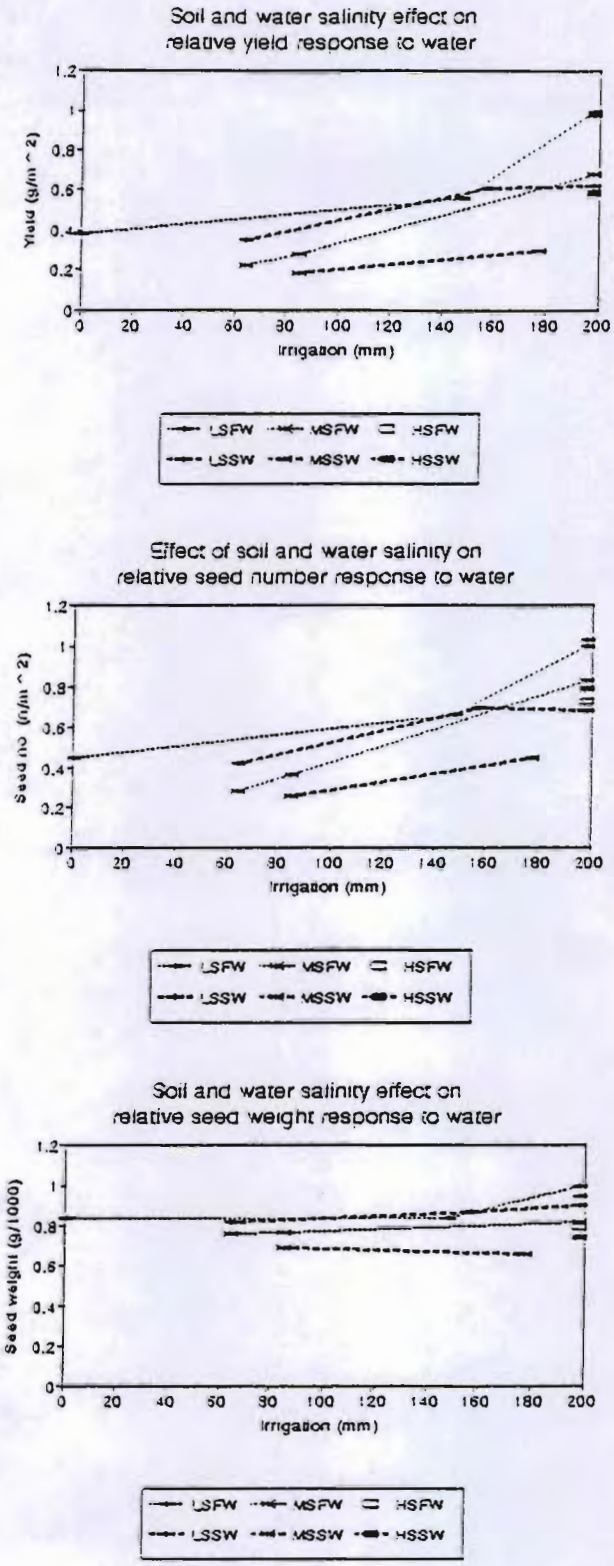
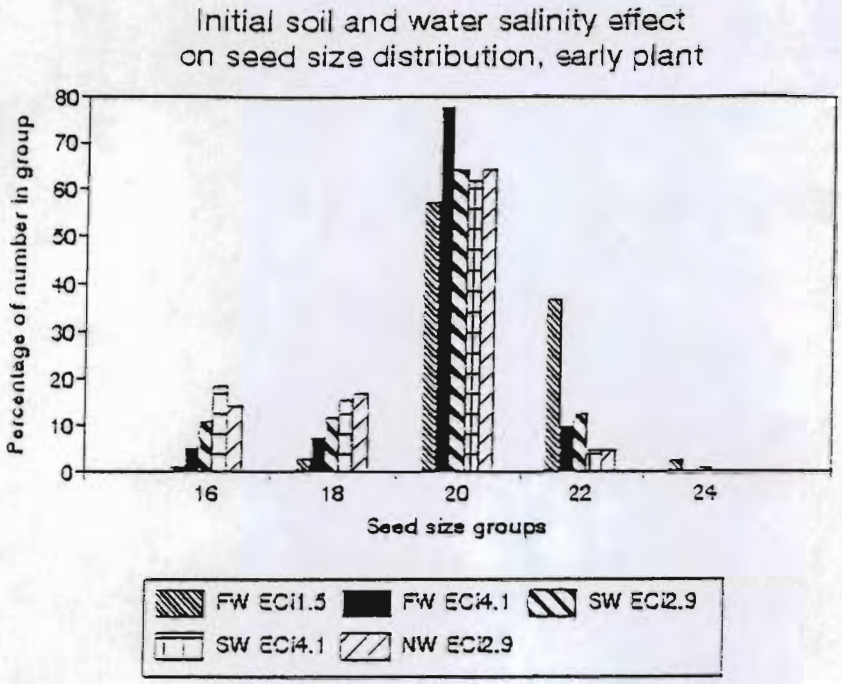


Figure 8b. Influence of the initial soil salinity (LS, MS and HS = low, medium and high) and water quality (FW and SW = fresh and saline) on the response of yield components to seasonal water quantity (x scale) of late-planting treatments.



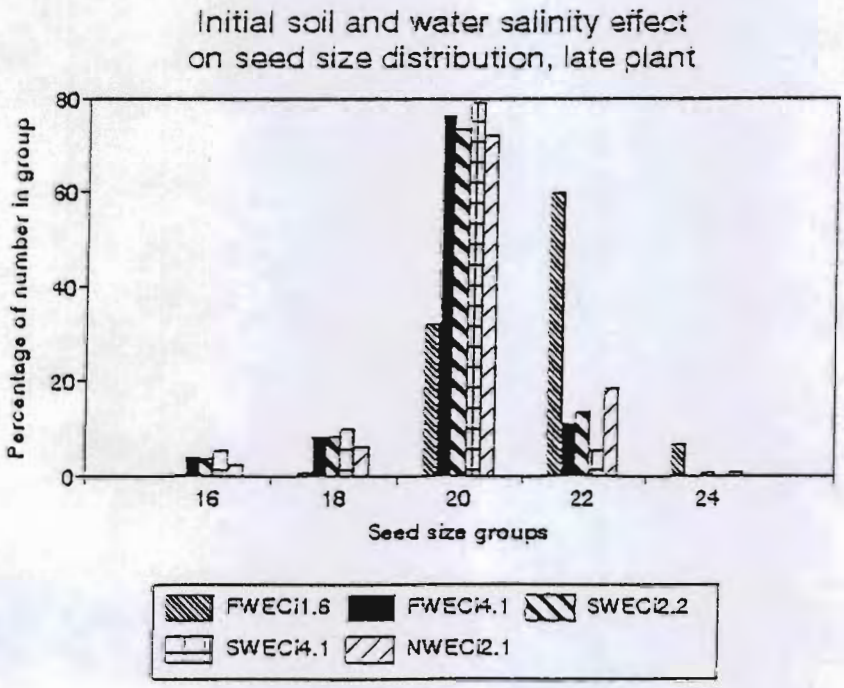


Figure 9b. Influence of water quality (FW and SW = fresh and saline), initial soil salinity (EC_i) and no irrigation (NW) on the size distribution of the seeds.

Chapter 3. Effects of water and salt stress timing on growth of whole plants and individual pods of chickpea.

A. Meiri[1] and Shuali Margot[1].

Abstract.

A field study compared the effects of three levels of initial soil salinity, two levels of water salinity, and two periods without irrigation on chickpea. The non-determinate plant produced new vegetative and reproductive organs under drastically changing conditions, and the aim was to determine the effect of stress timing on the growth and function of each vegetative and reproductive organ according to its growth or development stage. Intermediate measurements of plant shoot size and of total weights and numbers of pods or seeds provided the measures of overall treatment effects on all organs. Monitoring of individual nodes, leaves, pods and seeds can also provide the distribution of the organs measured values. The present study shows a practical way to monitor all developing fruit by measuring representative fruits that differ in their development stage. The effect on other fruit can then be estimated by means of the relation between response and development stage. The number of fruit in each development stage can be deduced from fruit envelope and seed weight and dry matter content, determined by destructive testing of samples. There might be a need to normalize the relation between development stage and weight, to the season, the pod position on the plant indicates the time when it developed. Consideration of the time when each fruit grew and its response to water and salt stress should provide a guide to the control of temporal stresses, optimized in terms of the mean yield parameters and their variances. Water stress had a large effect on pod number and a small effect on pod size. Resumption of irrigation after prolonged water stress could not initiate the development of many new pods nor instil the shoot vitality needed to support the growth of large pods on the early-stressed plants. Salinity stress reduced pod size and had little effect on pod number; it was milder in its effects than the water stress, and saline wet treatment allowed balanced vegetative and reproductive growth over a long time.

Introduction.

The final yield of chickpea represent the integrated result of several variable stages of growth and development, and also the integrated responses to temporal stresses of various durations and magnitudes. The tolerance of many crops changes during ontogenesis (Maas 1990, Meiri and Plaut 1985). The non-deterministic chickpeas have long periods of simultaneous production and growth of new vegetative and reproductive organs. Stress at

different periods may interact with the plant development stage, and with the distribution of the development stages of the growing pods. The stress timing and level can modify the relations of vegetative to reproductive growth, and may also exert different influence on pods at different development stages and modify the size distribution of the seed population. Intermittent whole plant sampling provides information on the effects of the temporal stresses on the whole plant vegetative and reproductive growth. Relating individual pod data to pod age and development scales provides the effects of stress on individual pods. Comparing these data will indicate whether the differences in yield tolerance to temporal stresses reflect changes at the level of the individual organ or the whole plant. Whole-plant changes could be in sink-source relations, plant stress level, etc. We assumed that in the growing pod, the weight correlates with the development stage. So that relating stress effects to pod weight is equivalent to relating them to the pod development stage.

Materials and methods.

A field study with 22 treatments compared the effect of planting date, soil and water salinity, and water stress on chickpeas (Chapter 2). Four treatments (1, 3, 12 and 18) from the DOY (day of year) 61 planting, with large differences in their salt and water regimes, were used to monitor the effects of stresses on growth and yield components. The experimental variables in these treatments are presented in Table 1c. The field experiment details are described in Chapter 2. Plants along 1 m row, in each plot were sampled on DOY 147 and 161. These plants were divided into shoots and pods, and the weights of shoots and pods, and the numbers of pods and seeds and the weights of envelopes and seeds were determined. One plant in each plot was used for determination of the fresh and dry weights of the components of each pod. The pods were coded according to their position on the plant (Figure 1c), defined in terms of the three sorting levels: 1st branching, 2nd branching, and position on these branches with code numbers increasing towards the plant apex. Then, for each pod, the number of seeds and the fresh and dry weight of envelope and seed were determined. Ranking the data by pod weight served to relate pod groups response to stress to their development stages. It was assumed that in each treatment all pods and seeds of a given chronological and development age have the same size.

Table 1c. The experimental variables in treatments in which plant and yield growth were followed, in a chickpea irrigation study.

ment.	History		1994 treatments					
	1986-91 Water quality	1992-3 Salt load kg/ acre	1st Irrigation DOY	Seasonal Irrigation mm	Water Quality	Salt load kg/ acre	Soil salinity EC_e dS m^{-1} (0- 0.9 m) initial	final
1	Fresh	4910	110	198	Fresh	1120	1.79	1.55
3	Fresh	11090	139	64	Fresh	360	2.85	2.17
12	Saline	17320	110	198	Saline	4440	4.44	3.18
18	Saline	4350	139	64	Saline	1300	1.90	2.55

Results and discussion.

Soil salinity data for all four treatments are presented in Table 1c. The final salinities were lower in treatments 1, 3 and 12, and higher in treatment 18, than the initial salinities. In treatments 1 and 12 there was deep percolation of the irrigation water below the 0.9-m depth. In treatments 3 and 18 there was displacement of the water from upper to lower layers. Soil water content data are presented in Figures 4b and 5b in Chapter 2 of this report. The treatments had low (1 and 18 LS), medium (3 MS) and high (12 HS) initial soil salinity. They were irrigated with fresh (1 and 3 FW) and saline (12 and 18 SW) water, in wet (1 and 12 wet) or dry (3 and 18) regimes.

Table 2c summarizes the means and STD values of the yield components of the whole plants on the two sampling days. The data from the intermediate harvests on DOY 143 and 166 provided information on whole plants shoot and yield development (Table 2c) in four treatments from the DOY 61 planting that differ in soil and water salinity and in watering. The DOY 143 data show a larger stand in the non-saline wet treatment than in all other treatment. The DOY 161 data show no differences in stand among all four treatments. The two data sets indicate that the initial soil salinity had only small or no effect on the final stand. Both salinity and water stresses reduced shoot and pod growth. The 1st harvest was 3 days before the first irrigation in the dry treatments, 3 and 18, and 33 days after the first irrigation in the wet treatments, 1 and 12. The 2nd harvest was 14 days after the last irrigation in the dry treatments, 3 and 18, and 6 days after the last irrigation in the wet treatments, 1 and 12 (Table 1c). Treatment 1, with the lowest stress levels for both factors had the largest shoot yields in the 1st harvest and the largest pod yields in the 1st and 2nd harvests. Salinity reduced shoot growth less than water stress

before the 1st sampling. In the 2nd harvest, the shoot of the wet saline treatment (12) was slightly larger than the shoot of the wet non-saline treatment (1). Among the dry treatments, treatment 3, with the higher residual salinity, produced smaller plants with less pods than treatment 18, with the lower residual salinity, in both samplings. The difference was larger in the 1st harvest, when the response was to the residual soil salinity. As irrigation started the faster growth rate with fresh (3) than with saline (18) water reduced the difference. The smaller shoots of the dry treatments also senesced earlier, as judged by their high dry weight percentage in the 2nd harvest, which indicates that time- and size-integrated shoot activity was reduced more than shoot size.

Salinity and water stress reduced yield by reducing the rate of new pod and seed production and the final size of pod and seed. In all treatments, the number of pods, but not the mean pod weights, had linear correlation with shoot size (Figure 2c). In the 1st harvest the average seed or pod weight was much larger in the dry than in the wet treatments and larger in the non-saline than in the saline treatments. In the 2nd harvest, the non-saline wet treatment produced largest pods and seeds and the saline wet treatment the smallest pods and seeds. Among the saline irrigated treatments the dry treatment (18) had larger pods and seeds than the wet treatment (12) and among the non-saline treatments the wet treatment (1) produced larger pods and seeds than the dry one (3). The non-deterministic chickpea produces new shoot and pods as long as the shoot is green and vigorous, and the average pod and seed weight can not show the large variability resolting from differences in development stages or final sizes. With maturation the relative numbers of pods and seeds that are at their final size increase, and make large contribution to the average weight, while the contribution of growing pods and seeds decrease. Among the four treatments, 18 which developed to the 1st harvest under non-saline water stress that changed to saline irrigation, produced more pods than treatment 3, that was exposed to both salt and water stresses at the beginning. The saline irrigation of treatment 18 did not allow many of the pods to develope a large final weight. Treatment 3 producedhad small pods despite the irrigation with fresh water, probably, because of the small shoot, that could not supply the metabolites needed by larger pods. Non-saline soil and early fresh water irrigation in treatment 1 resulted in maximal pod number with large weight, as it imposed to smallest salt stress and low water stress during pod production and growth, and had sufficient shoot vitality. Treatment 12, that was exposed to wet saline conditions produced a large number of small pods. The interaction of pod number and mean seed size is apparent in the two dry treatments, where small numbers of new pods caused large mean

seed weights, and in the saline wet treatment where a large number of new pods resulted in a small mean seed weight. Final weights of 1000 seeds in these treatments were in the decending order: LS,FW wet > LS,SW dry > MS,FW dry = HS,SW wet.

Initial soil salinity and a long period without irrigation exerted dominant effects on the numbers of pods and seeds on both sampling days. Irrigation from DOY 110 increased the numbers of pods and seeds in comparison with irrigation from DOY 139. The smallest numbers of pods and seeds were found with medium initial salinity and 1st fresh water irrigation on DOY 139. High initial salinity and saline irrigation from DOY 110 resulted in large numbers of late developing pods and seeds.

The pod envelope growth precedes that of the seed. Therefore, most of the increase in yield between DOY 147 and 161 was the result of the increase in mean seed weight. Treatments that were first irrigated only on DOY 139 had more mature pods, as indicated by the dry weight percentage of envelopes and seeds on DOY 147 and 161, and the dry matter fraction in seed on DOY 161. High initial soil salinity followed by saline irrigation from DOY 110 resulted in the slowest and most prolonged growth and production, with the largest increases in pod number, with low dry matter content in envelope and seed and with low dry matter fraction in the seed. The order in which growth and production of new pods stopped was: 1st, long water stress with low or medium initial salinity and late irrigation with fresh or saline water (treatments 3 and 8); 2nd, low initial soil salinity and early irrigation with fresh water (treatment 1); 3rd, high initial soil salinity and irrigation with saline water (treatment 12).

Data for whole plants (Table 2c, Figure 2c) for non-deterministic plant like chickpea, which produce new pods continuously, cannot discriminate among the effects of temporal stress on pods at different development stage or between the effect on final pod size and that on rate of pod production. Ranking the pods by weight, with a 1st approximation that age and development stage are correlated with weight, provides a basis for comparing the various yield component data. Such a comparison was made for the yield component parameters: weight, number and dry weight percentage (Figures 3c to 10c).

Pod growth parameters for pods grouped by 0.04-g weight increments (x scale) were compared to show the treatment effects on pod of different development stages. Maximal pod dry weight was 0.48 g on DOY 147 and 0.92 g on DOY 161. Pods of less than 0.24 and 0.44 g weight on DOY 141 and 161, respectively, had only one seed per pod. Larger pods could have one or two seeds per pod (Figure 3c). Medium or high initial salinity resulted in smaller pods with two seeds. Pod growth starts with growth of the envelope,

which is followed by the growth of the seed. The fast initial growth of the envelope slowed rapidly and nearly stopped with attainment of the final envelope weight of 0.14 g on both days. The corresponding pod weights were 0.4 g on DOY 147 and 0.5 g on DOY 161

Table 2c Effect of salt (history, last season and current water) and water (current) stresses on intermediate growth parameters (means and SE in brackets) of plants from the 2nd planting (DOY 61).

Treatment				Stand	Shoot DW	Shoot	Pods	Pod DW	Pods	Seed DW	Harvest index
No.	SSH[a]	WQ[b]	Irr[c]	plants m^{-1}	g $plant^{-1}$	% DW	No. $plant^{-1}$	g pod^{-1}	% DW	g 1000^{-1}	
					1st harvest - DOY 143						
1	F;L	F	198	17.5	7.1	22.0	17.9	0.17	0.21	99.3	0.30
				(2.7)	(0.4)	(0.8)	(2.5)	(0.01)	(0.01)	(13.6)	(0.03)
3	F;M	F	64	14.3	2.6	23.6	5.0	0.20	0.24	133.7	0.30
				(2.2)	(0.6)	(1.8)	(2.3)	(0.01)	(0.01)	(17.2)	(0.06)
12	S;H	S	198	13.3	5.6	18.6	8.6	0.10	0.19	51.5	0.16
				(1.9)	(1.5)	(1.7)	(3.0)	(0.04)	(0.02)	(24.6)	(0.09)
18	S;L	S	64	14.3	4.0	22.8	10.1	0.24	0.24	130.0	0.37
				(1.5)	(1.0)	(4.6)	(2.9)	(0.01)	(0.00)	(8.3)	(0.03)
					2nd harvest - DOY 166						
1	F;L	F	198	13.0	8.3	43.4	22.1	0.52	0.74	423.5	0.59
				(1.6)	(1.0)	(7.4)	(2.3)	(0.03)	(0.06)	(16.6)	(0.03)
3	F;M	F	64	13.0	4.4	68.9	8.2	0.40	0.83	305.9	0.44
				(1.9)	(0.5)	(6.0)	(2.3)	(0.04)	(0.03)	(8.3)	(0.06)
12	S;H	S	198	13.8	9.1	44.5	25.3	0.36	0.56	276.2	0.49
				(2.7)	(2.1)	(6.3)	(7.1)	(0.02)	(0.06)	(10.4)	(0.03)
18	S;L	S	64	12.0	5.6	76.9	14.7	0.46	0.85	336.6	0.55
				(3.0)	(1.5)	(7.5)	(4.6)	(0.02)	(0.01)	(12.3)	(0.03)

[a] Soil salinity history:1st letter for water quality during 1986-91 season, 2nd1st letter for residual salinity from 1993.

[b] Water quality: F=fresh, S=saline

[c] Seasonal irrigation in mm/total area.

(Figure 4c). What indicate that the envelope growth stoped before the pod reach the weight of 0.4 g. The weight of seeds per pod, mainly single seeds with a few double, showed a linear increase over the entire range of pod size for both DOY 141 and 167 (Figure 5c). The result of the different growth patterns for envelope and seed is an increase in the fraction of the seed weight with pod growth (Figure 6c). There were only small differences among treatments in the relations between envelope or seed weight and the pod weight (Figures 4c and 5c). The exception was treatment 3 with medium initial salinity and late irrigation with fresh water, which produce smaller envelopes and larger seeds than all other treatments, for pods that weighed more than 0.1 g. The water contents

in envelopes (Figure 7c) and seeds (Figure 8c) decreased with increasing pod weight and were higher on DOY 161 than on DOY 147 for pods of similar size. The difference in dry matter content of envelope or seed were larger between DOY 161 and 147 than between pods of different sizes on each day. Small seeds on DOY 161 had larger dry matter content than large seeds on DOY 147. These observations indicate that reduced pod water content was more strongly related to whole plant conditions than to pod age. Treatment 12, with the largest salt load in soil and water, and smallest water stress show delayed dryout, whereas all other treatments showed similar water contents for a given pod size on each day (Figures 7c and 8c). The similar relations of pod envelope weight and seed weight to whole pod weight in the different treatments indicate that the effects of the treatments on final pod size did not involve changes in the growth of individual pod components.

The pod distribution according to size showed large treatment effects (Figures 9 to 11c). Figure 9c show the absolute numbers of pods of the various sizes and Figures 10c and 11c show the relative pod weight or number in each size group. The DOY 147 data show that many of the pods in the dry treatments (3 and 18) were large and many in the wet treatments (1 and 12) were small. The DOY 161 data show the largest number of large pods in the non-saline wet treatment and the largest number of small pods in the saline wet treatment. The dry treatments produced pods as long as the water stress allowed; later, the water stress reduced the production of new pods more than it affected the growth of old pods. The reduced competition of new pods for metabolites allowed rapid growth of the pods which had been formed early, before DOY 147. An additional period of water stress reduced the final size of those seeds with the fastest initial growth. Increase in initial soil salinity resulted in a larger fraction of smaller pods. This salinity effect showed up in both the dry (3 and 18) and the wet (1 and 12) treatments. In treatment 12, saline irrigation also contributed to the larger fraction of small seeds.

The individual pod data for DOY 161 accentuate the differences among treatments in pod distribution by size and the differences between water and salt stresses. Maximal pod dry weight on DOY 161 was 0.92 g in the low-salt wet treatment and 0.68 g in the high-salt wet treatment; in the two treatments with large water stress it was 0.76 g. Relative pod size and weight distributions within each treatment afford better comparisons, among treatments with different numbers and weights of pods, than absolute values (Figures 10c and 11c). The use of relative pod weight and pod number distributions did not change the differences between the saline and non-saline wet treatments. Between the dry treatments,

the medium initial soil salinity and late fresh water irrigation produced smaller pods than the low initial salinity and late saline irrigation. The large pods in each treatment had two seeds (Figure 3c). Plants produced more pods with two seeds under high salt and low water stress. Seeds were larger on DOY 161 than on DOY 147, and this increase was the result of additional growth of old pods, or faster growth during the late part of the season. In discussion of the treatment effects, pod weight was used as a substitute for a time scale. This substitution needs normalization if the treatments differ in final pod size. The position on the plant is another parameter that can substitute for time, since, in chickpea there is a sequence of initiation of new branches and set of new pods.

We assumed that two orders of branching occur early in the season and that setting of new pods along the branches take longer. Therefore, we grouped all the pods of similar position on both 1st and 2nd order branches into the same time group and compared these groups (Table 3c).

Table 3c. Effect of water and salt stress on the weight of pods on different positions on 1st and 2nd order branches.

Treat ment no.	Water and salt treatment	Pod weight (g)							
		Pod position on branches of 1st or 2nd order							
		1	2	3	4	5	6	7	8
					DOY	147			
1	LS, FW, wet	0.219	0.172	0.121	0.128	0.124	0.097	0.045	
3	MS, FW, dry	0.259	0.185	0.156	0.026				
12	HS, SW, wet	0.141	0.152	0.156	0.128	0.085	0.089	0.054	0.030
18	LS, SW, dry	0.270	0.218	0.241	0.190	0.119			
					DOY	161			
1	LS, FW, wet	0.549	0.532	0.527	0.485	0.441	0.378	0.510	
3	MS, FW, dry	0.485	0.390	0.524	0.401	0.438	0.317		
12	HS, SW, wet	0.415	0.373	0.321	0.302	0.350	0.193		
18	LS, SW, dry	0.445	0.429	0.434	0.438	0.441			

On DOY 147, the pod weight decreased with increasing pod serial number in all treatments. On DOY 161 pod size decreased with increasing pod serial number only in the high-salt wet treatment. The decrease was clear when the pods were young and had low water content. Pods that stopped growing did not show a clear position effect. There was farther increase in basal pods and faster growth of new pods between DOY 147 and DOY 161 (Table 3c) than earlier, what may be the result of growth rate reasponse to season conditions. In the dry treatments large fraction of the pods developed early and their weights were largest on DOY 147. Growth under water stress did not allow the growth of the seeds to large size at DOY 161. Low salinity and low water stress resulted in large

numbers of large pods and high salt and low water stress resulted in large numbers of small pods.

Conclusions.

Water stress had a large effect on pod number and a small effect on pod size. Resuming irrigation after prolonged water stress could not initiate development of new pods nor could it instil the shoot vitality needed to produce large pods. Salinity stress reduced pod size and had little effect on pod number. The salt stress was milder in its effects than the water stress, and the saline wet treatment allowed balanced vegetative and reproductive growth over a long period. Stress timing had a strong effect on seed and pod distribution by size that does not show in the whole plant data.

Figures legends.

Figure 1c. Scheme of the codes for chickpea branches (br.) and pods.

Figure 2c. Influence of soil and water salinity and water stress on the relation between pod number (top) and mean pod or seed weight (bottom), and shoot size on DOY 147 (1st harvest) and DOY 161 (2nd HARVEST) in four treatments.

Figure 3c. Influence of soil and water salinity and water stress on the relations between the number of seeds per pod and the size of the pod on DOY 147 (top) and DOY 161 (bottom) (LS, MS and HS are low, medium and high initial salinity; FW and SW are fresh and saline water; wet and dry indicate 1st irrigation on DOY 110 or 139, respectively).

Figure 4c. Influence of soil and water salinity and water stress on the relations between the weights of the envelope and whole pod of chickpea on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).

Figure 5c. Influence of soil and water salinity and water stress on the relations between the weights of the seed or seeds and whole pod of chickpea on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).

Figure 6c. Influence of soil and water salinity and water stress on the relations between the fraction of dry matter in seed and whole pod of chickpea on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).

Figure 7c. Influence of soil and water salinity and water stress on the dry matter content in seeds in chickpea pods of different sizes on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).

Figure 8c. Influence of soil and water salinity and water stress on the dry matter content in the envelopes of chickpea pods of different sizes on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).

Figure 9c. Influence of soil and water salinity and water stress on the numerical distribution of chickpea pods of different weights on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).

Figure 10c. Influence of soil and water salinity and water stress on the relative numerical distribution of chickpea pods of different weights, on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).

Figure 11c. Influence of soil and water salinity and water stress on the relative weight distribution of chickpea pods of different size on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).

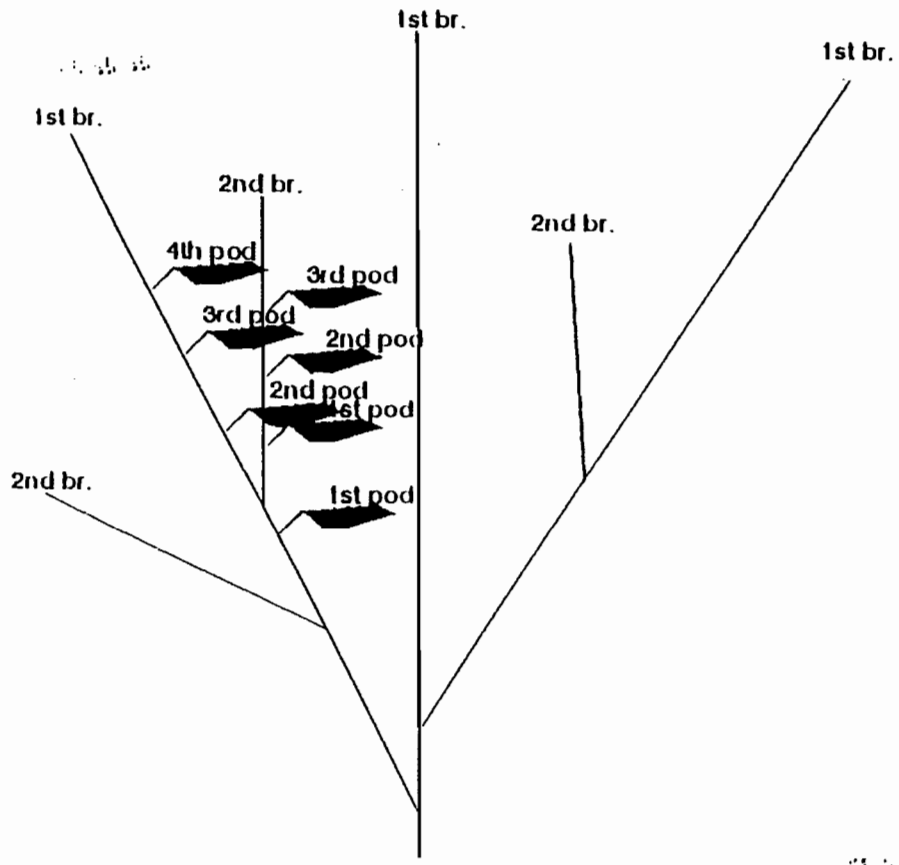
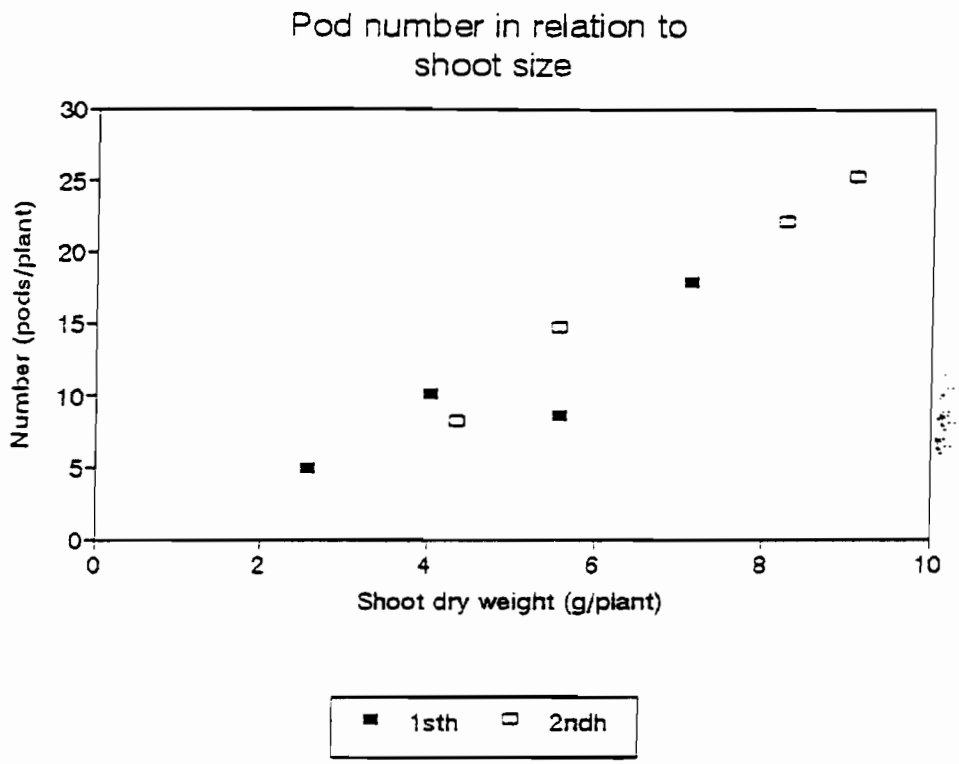


Figure 1c. Scheme of the codes for chickpea branches (br.) and pods.



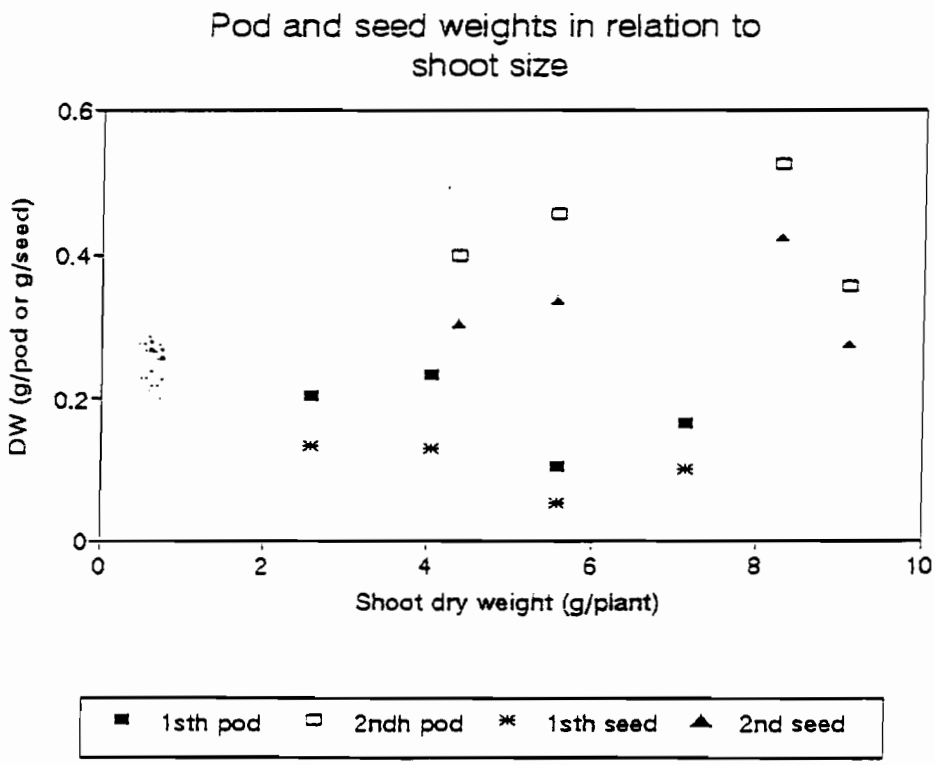
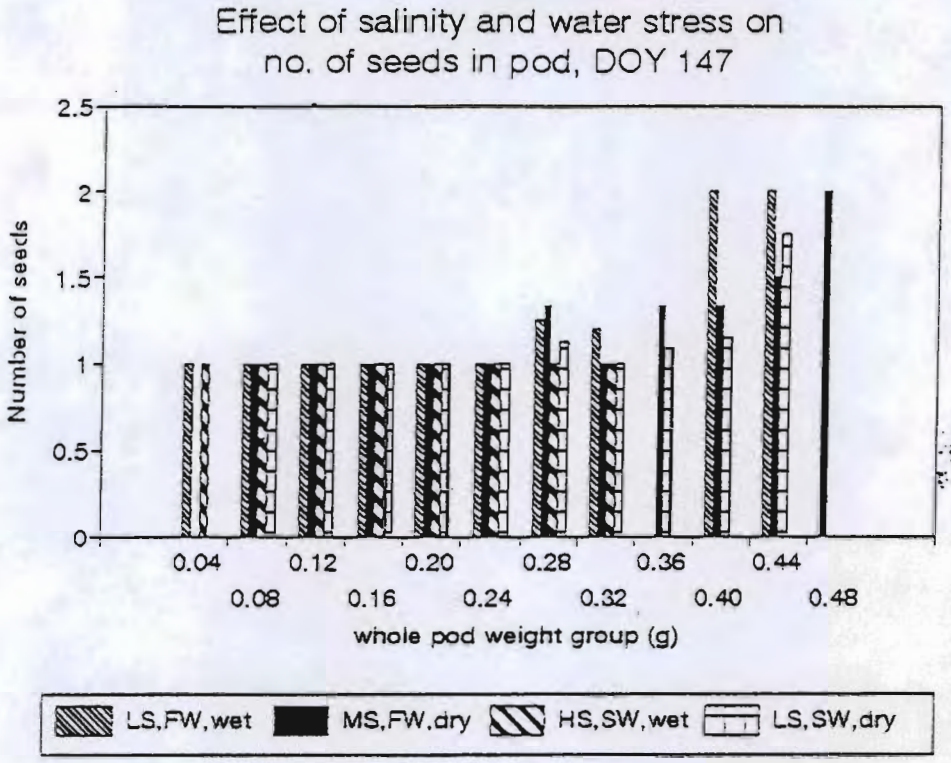


Figure 2c. Influence of soil and water salinity and water stress on the relation between pod number (top) and mean pod or seed weight (bottom), and shoot size on DOY 147 (1st harvest) and DOY 161 (2nd HARVEST) in four treatments.



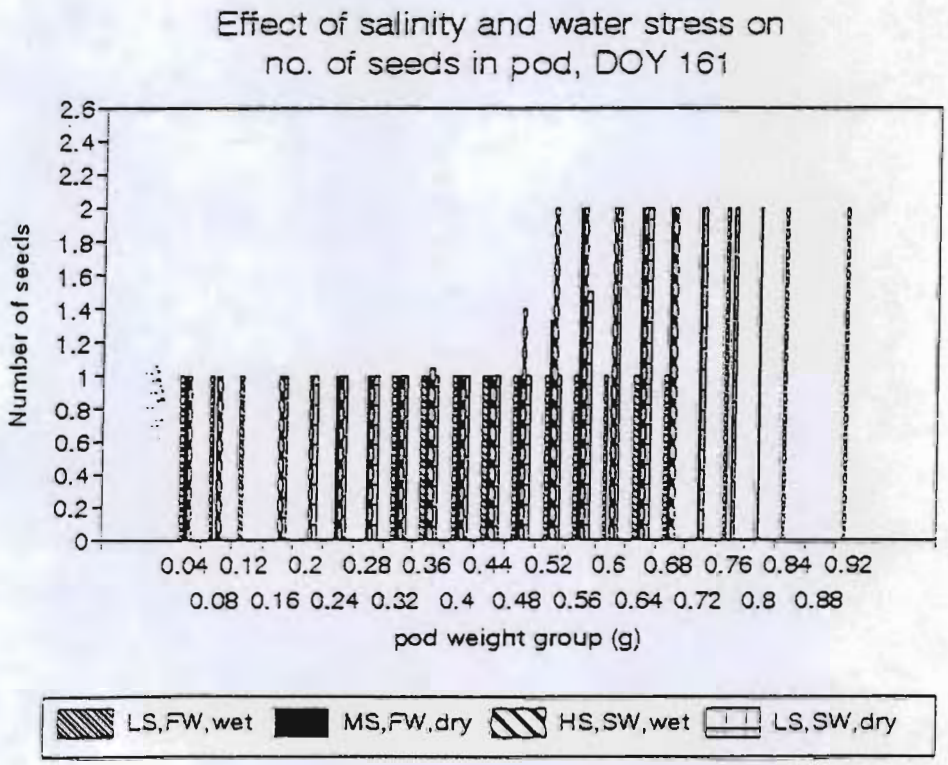
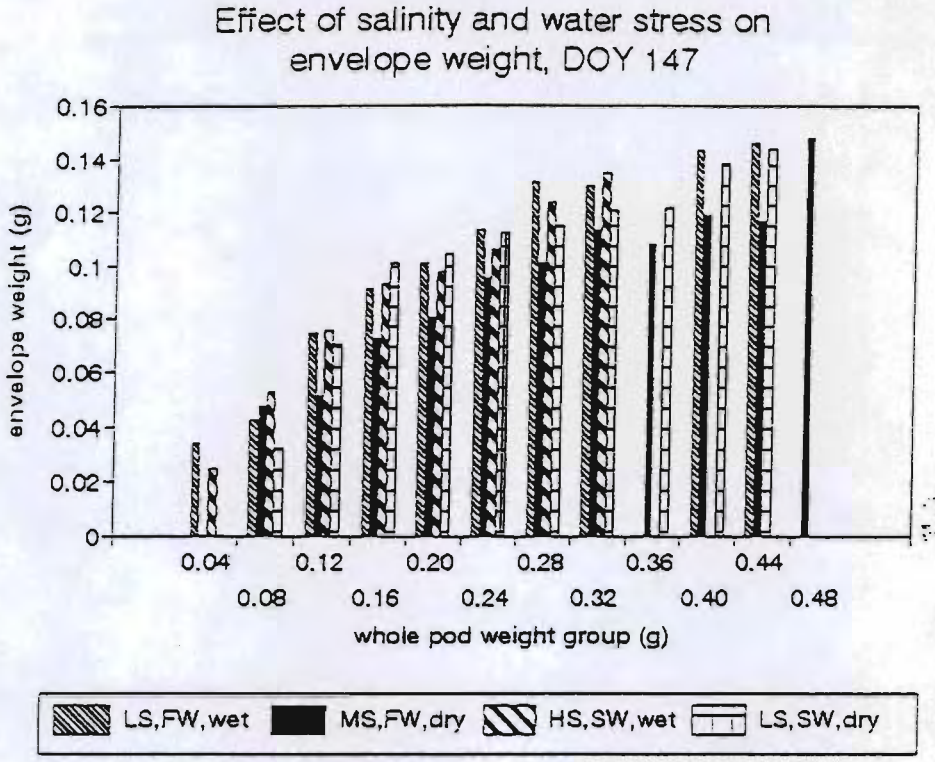


Figure 3c. Infiuence of soil and water salinity and water stress on the relations between the number of seeds per pod and the size of the pod on DOY 147 (top) and DOY 161 (bottom) (LS, MS and HS are low, medium and high initial salinity; FW and SW are fresh and saline water; wet and dry indicate 1st irrigation on DOY 110 or 139, respectively).



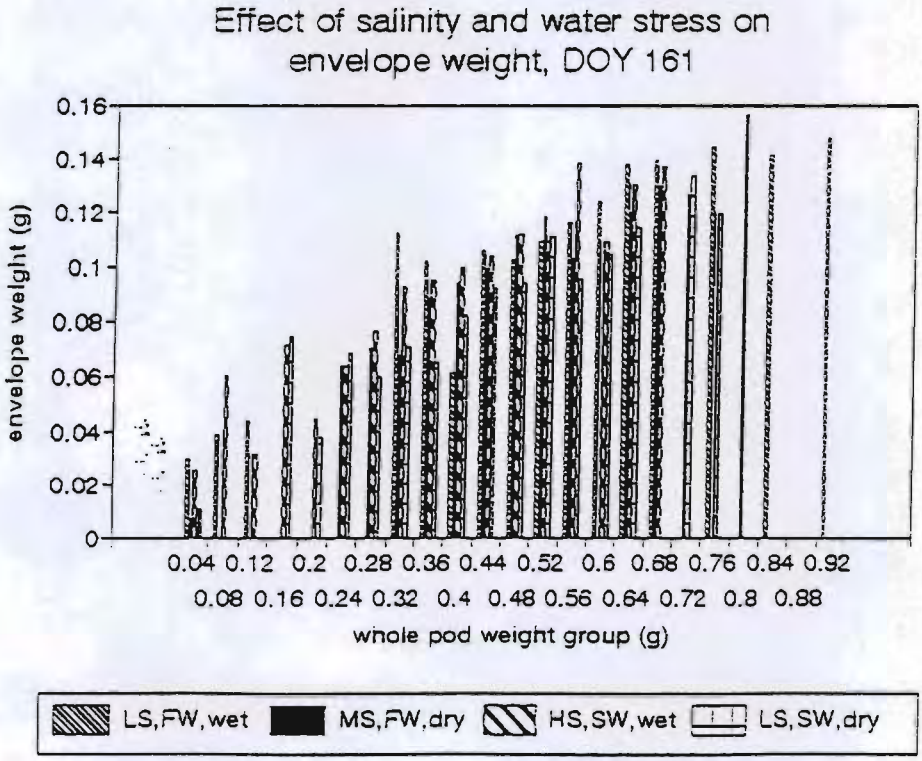
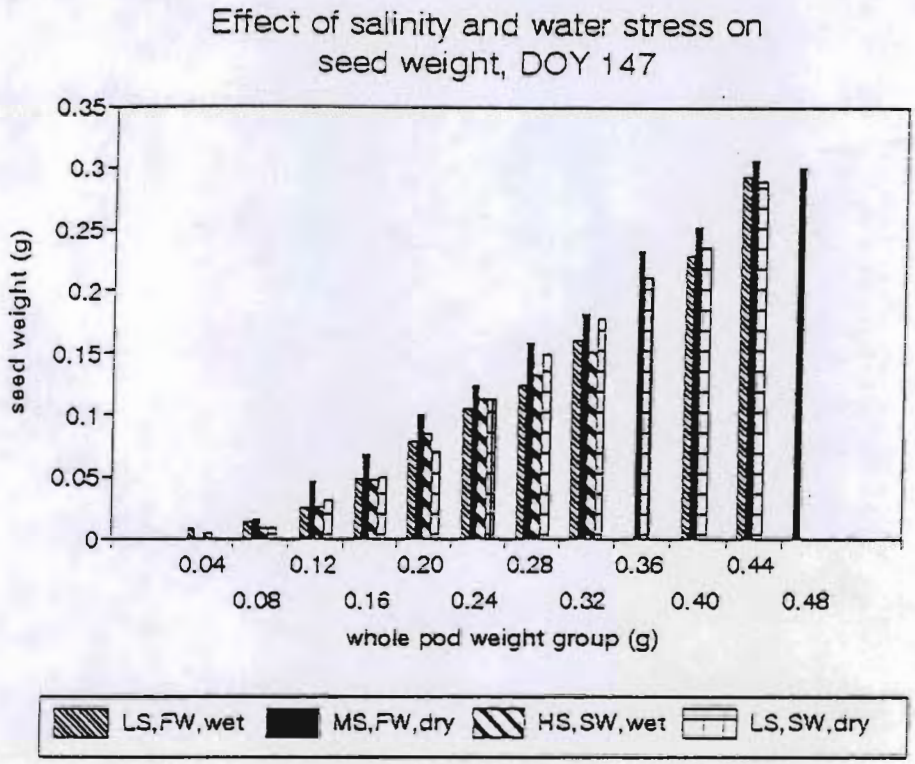


Figure 4c. Influence of soil and water salinity and water stress on the relations between the weights of the envelope and whole pod of chickpea on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).



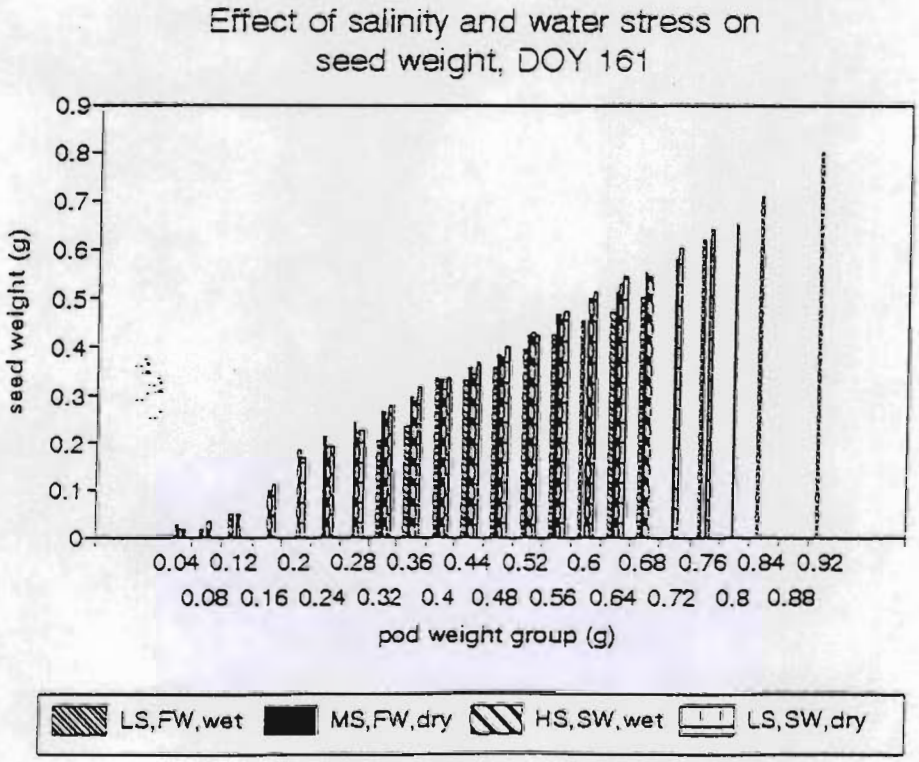
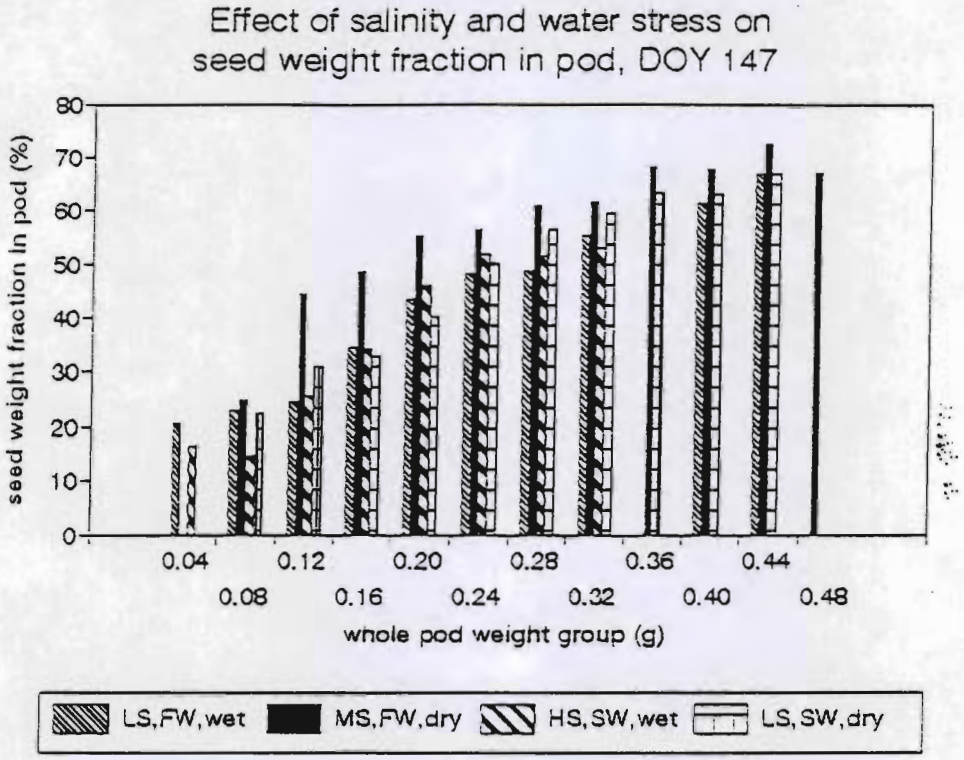


Figure 5c. Influence of soil and water salinity and water stress on the relations between the weights of the seed or seeds and whole pod of chickpea on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).



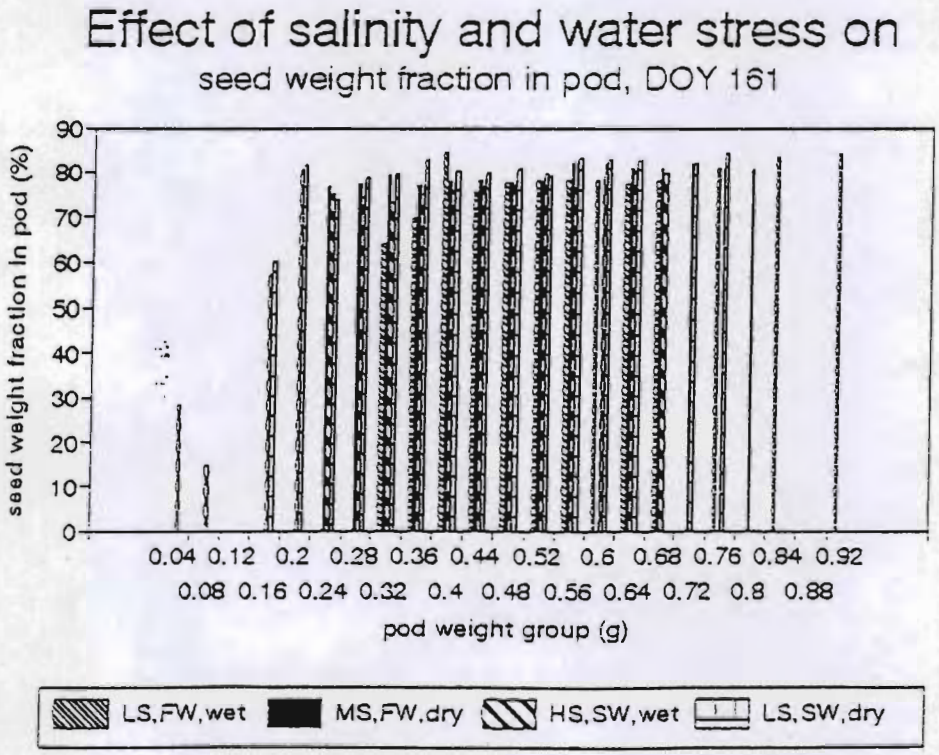
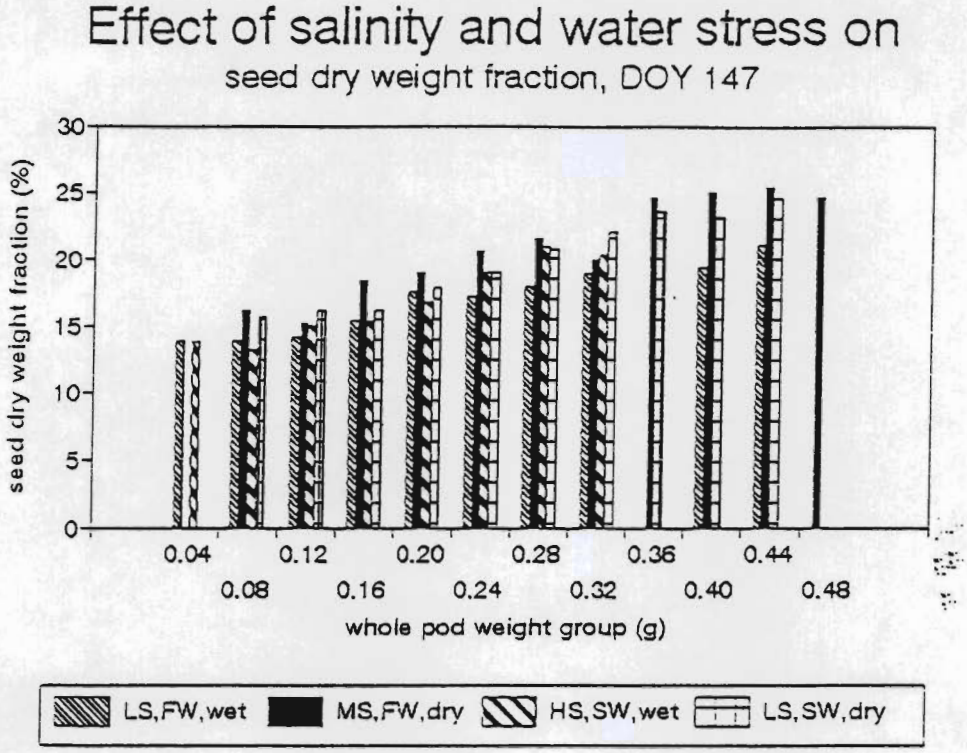


Figure 6c. Influence of soil and water salinity and water stress on the relations between the fraction of dry matter in seed and whole pod of chickpea on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).



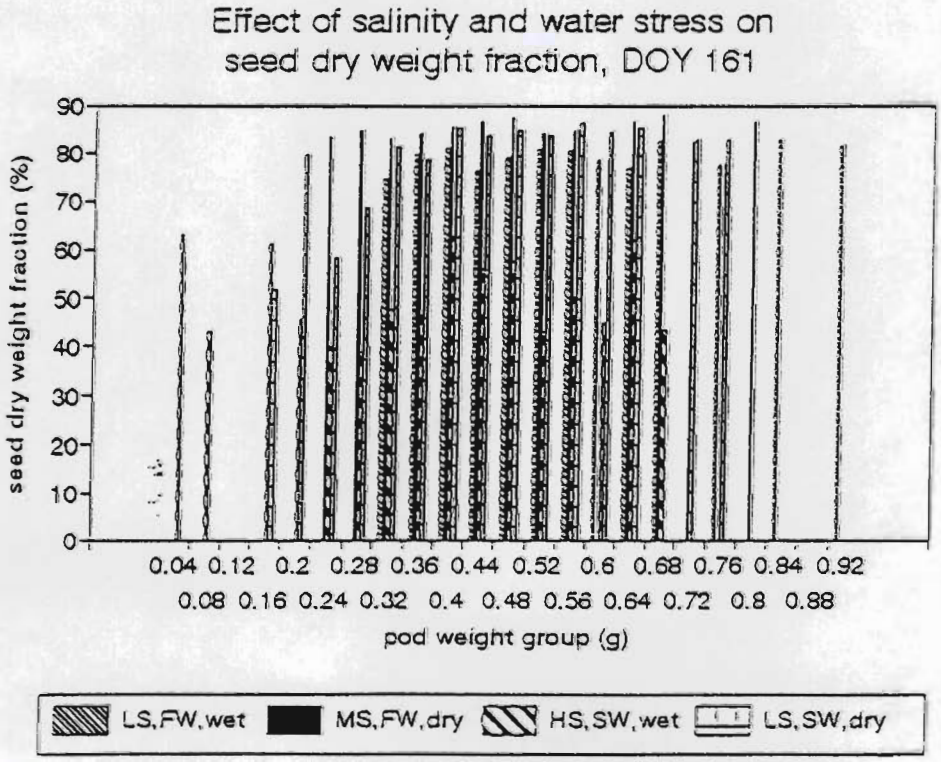
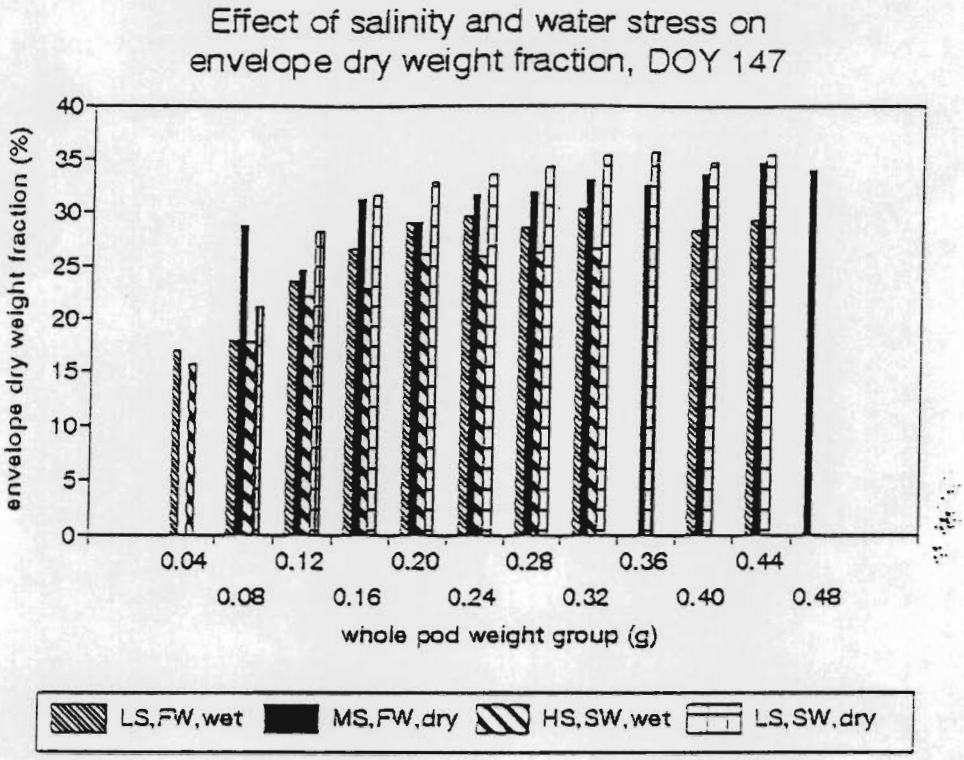


Figure 7c. Influence of soil and water salinity and water stress on the dry matter content in seeds in chickpea pods of different sizes on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).



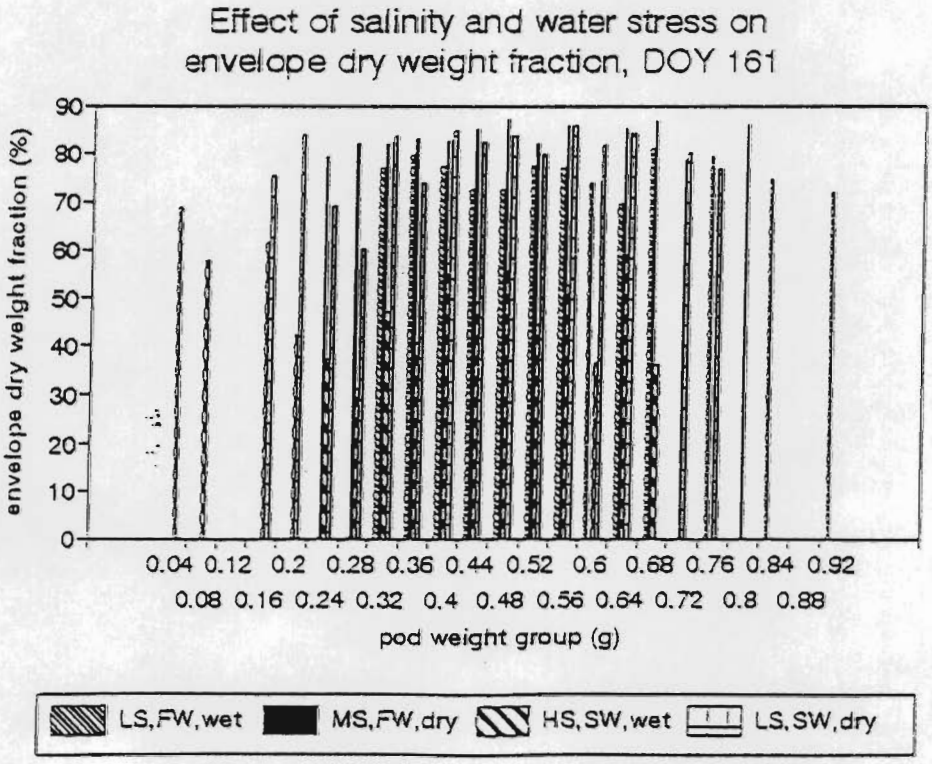
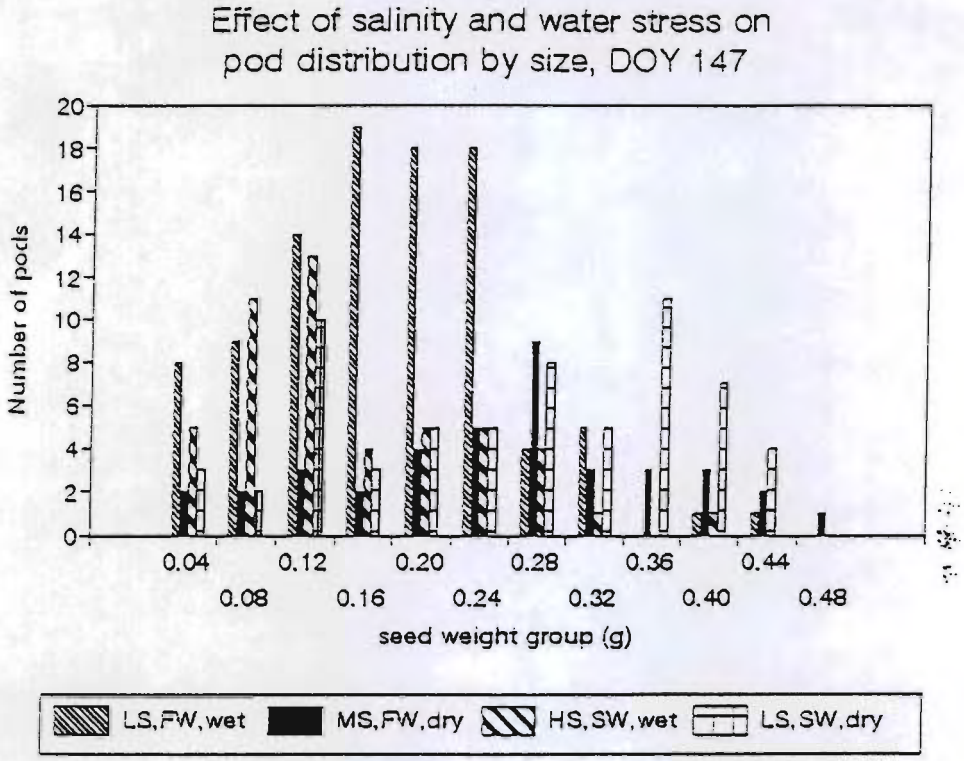


Figure 8c. Influence of soil and water salinity and water stress on the dry matter content in the envelopes of chickpea pods of different sizes on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).



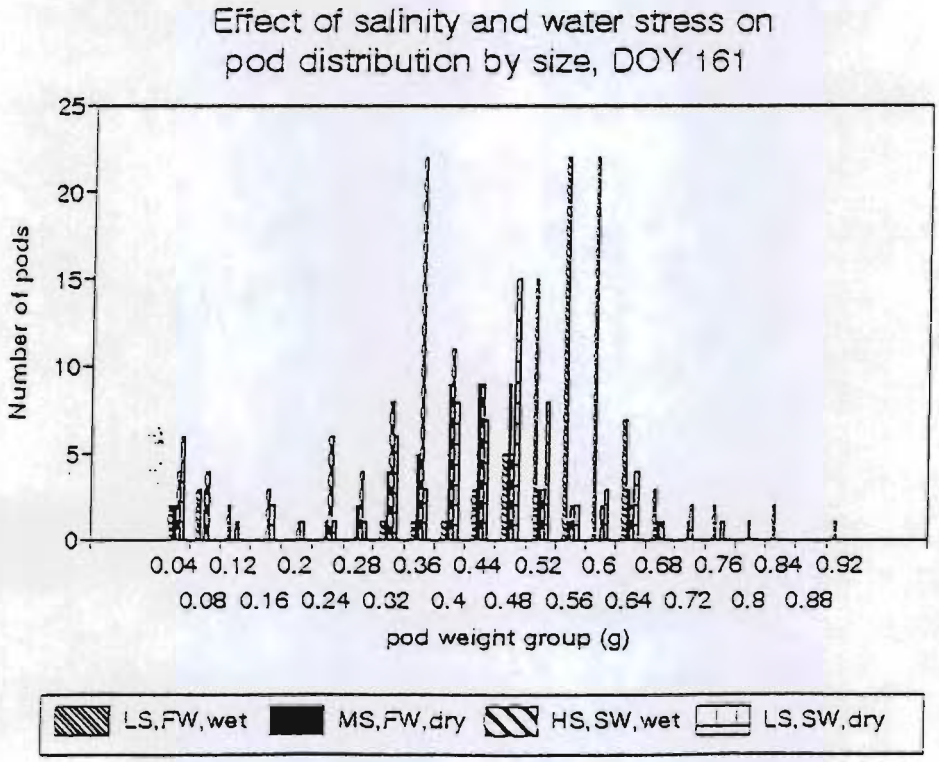
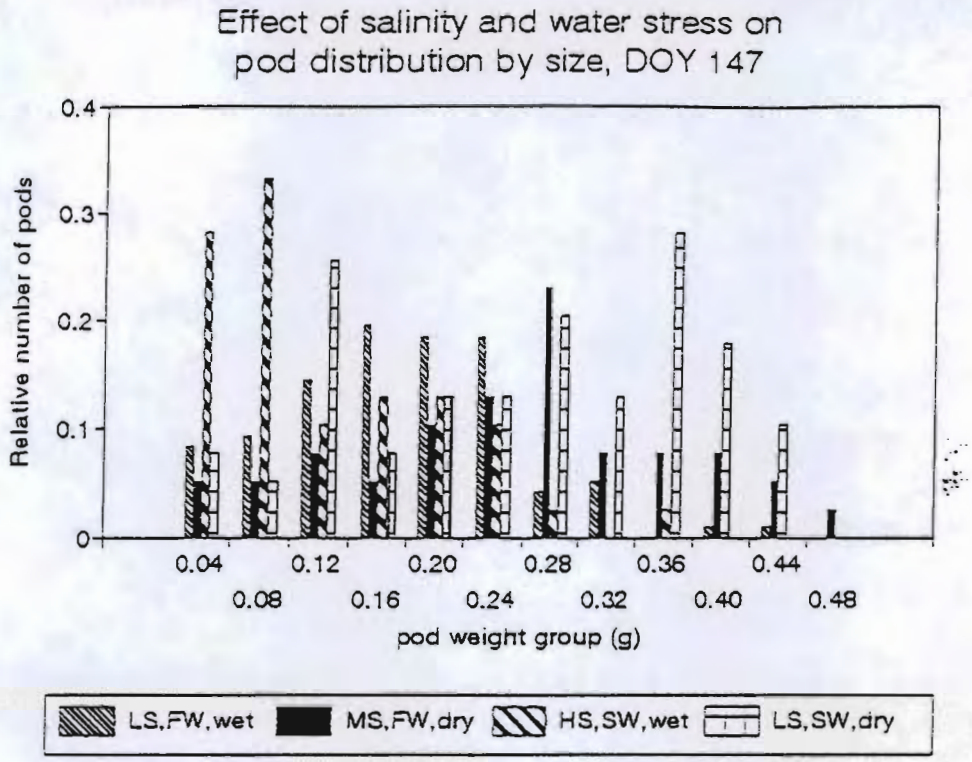


Figure 9c. Influence of soil and water salinity and water stress on the numerical distribution of chickpea pods of different weights on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).



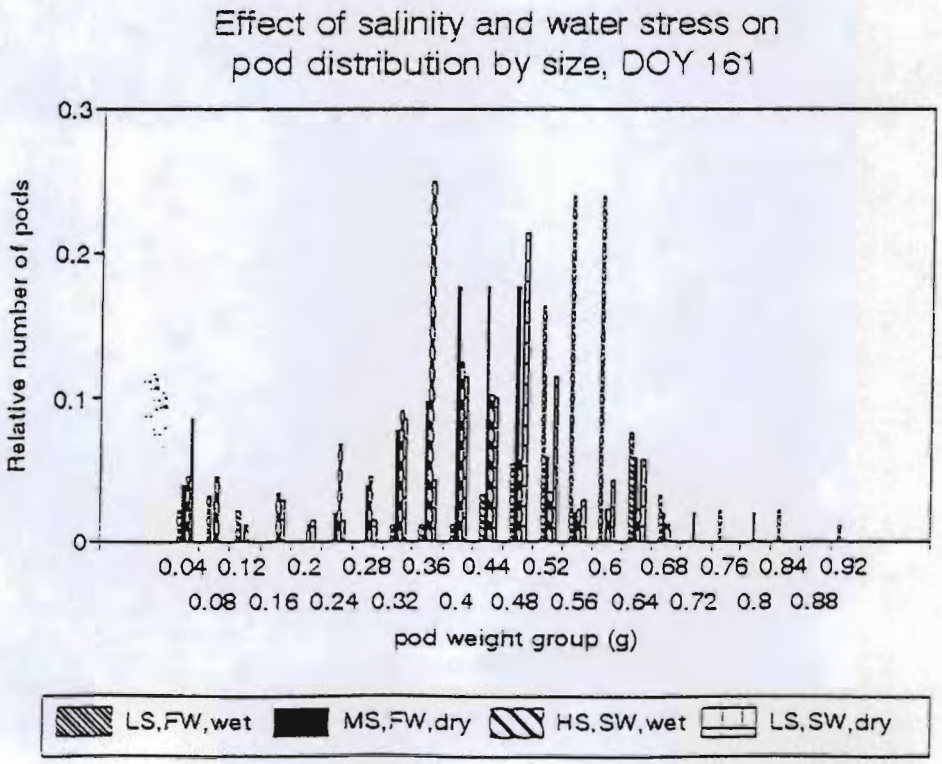
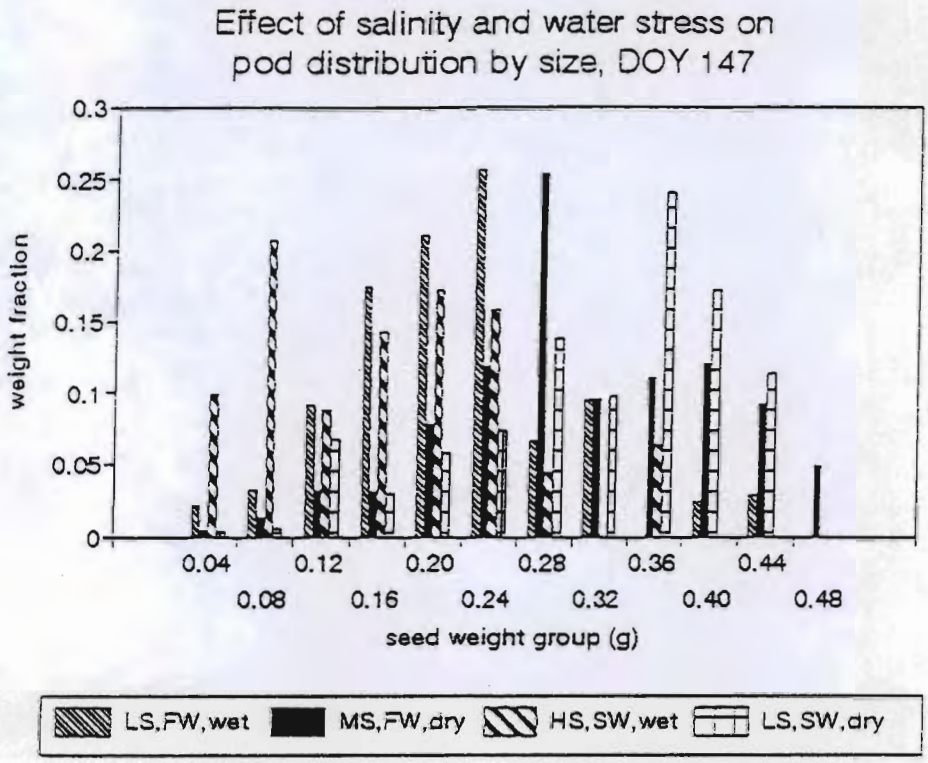


Figure 10c. Influence of soil and water salinity and water stress on the relative numerical distribution of chickpea pods of different weights, on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).



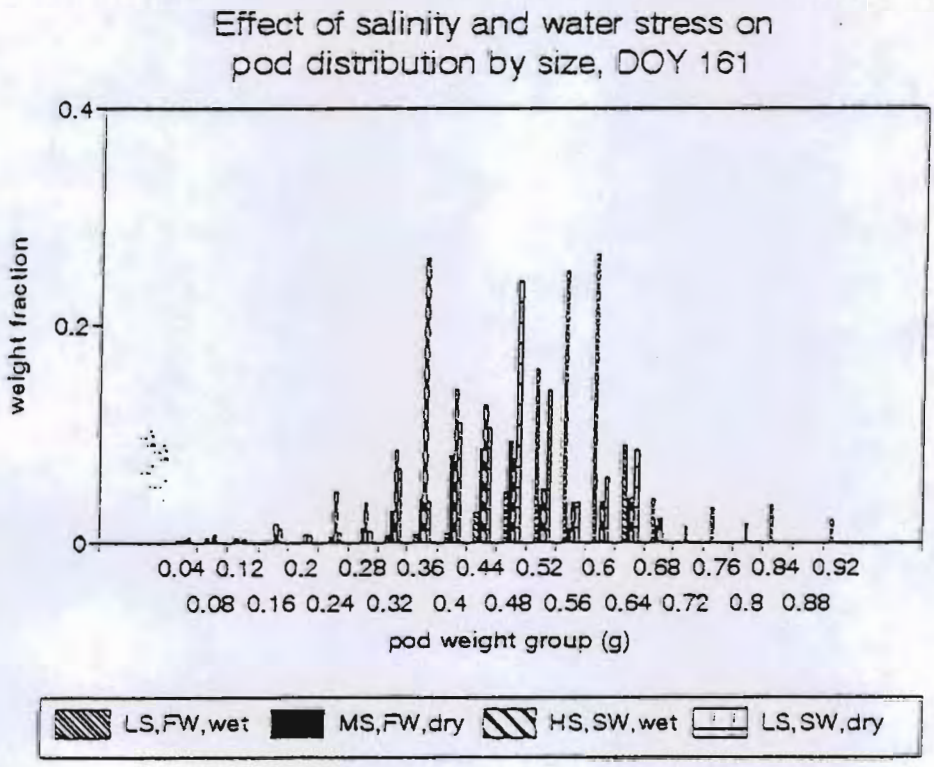


Figure 11c. Influence of soil and water salinity and water stress on the relative weight distribution of chickpea pods of different size on DOY 147 (top) and 161 (bottom) (Legends as in Figure 3c).

General conclusions.

Water and salt stresses interact in reducing final emergence percentage and increasing the time to emergence. Extensibility and not metabolite supply is the main limiting factor for seedling growth under both stresses. Shoot growth was more sensitive to water stress and root growth was more sensitive to salt stress. High ESP did not significantly affect emergence percentage or seedling growth rate. Growth rate, which is a continuous function of the performance of the surviving seedlings cannot be compared with final emergence percentage which is a binary function that depends largely on the non-surviving seedlings.

For chickpea, we should aim at rapid shoot development and avoid water stress during the early- to mid-growth season. Initial soil salinity should be below 2.8 dS m^{-1} to avoid reduction in seed number and perhaps lower to avoid reduction in seed size. The plants could not effectively use stored soil water from depths greater than 0.3 m early in the season and from 0.6-0.9 m depth over the entire season, even when they were planted in low-salt soil and received no irrigation at all. Thus, watering should start early with small water applications. Water stress had a large effect on pod number and a small effect on pod size. Resuming irrigation after long water stress could not initiate the development of many new pods nor instil the shoot vitality needed for production of large pods by the early-stressed plants. Salinity stress reduced pod size but had little effect on pod number. The salt stress was milder than the water stress and saline wet treatment allowed balanced vegetative and reproductive growth over a long period. Stress timing had a strong effect on seed and pod distribution by size which does not show in the whole plant data.

References

Bernstein, L. and Hayward, H.E. (1958) Physiology of salt tolerance. Ann. Rev. Plant Physiol. 9; 25-46.

Elkhatib, E.A., J.L. Hern & T.E. Stanley (1987) A rapid centrifugation method for obtaining soil solution. Soil Sci. Soc. Am. J. 51: 578-583

Frenkel H, Z Gerstel and N Alperovitch 1990. Exchange induced dissolution of gypsum and the reclamation of sodic soils. J. Soil Sci. 40;599-611

Maas, E.V. and G.J. Hoffman (1975) Crop salt tolerance: evaluating of existing data. Proc. Int. Salinity Conf. Texas Tech. Univ. Lubbock. Texas, pp 187-198.

Maas EV 1986. Salt tolerance of plants. Applied Agric. Res. 1;12-25.

Maas EV 1990. Crop salt tolerance. In KK Tanji (ed) Agricultural Salinity Assessment and anagement. ASCE Manuals and Reports on Engineering Practice No. 71. ASCE, New York. pp 263-304.

Meiri A 1990. Management under saline irrigation. In A Kandia (ed) Water, Soil and Crop Management Relating to the Use of Saline Water. FAO, Rome. pp 89-107.

Meiri A and Plaut Z 1985. Crop production and management under saline conditions. Plant and Soil 89;253-271

Rhoades JD, Bingham FT, Letey J, Hoffman GJ, Dedrick AR, Pinter PJ and Replogle JA 1989. Use of saline drainage water for irrigation: Imperial valley study. Agric. Water Manag. 16; 25-36.

Russo, D. (1983) Crop yield-irrigation relationship in a gypsiferous sodic soil. Agron. J. 75;427-434.

U.S.Salinity Lab. Staff(1954) Diagnosis and improvement of saline and alkali soils. U.S. Dep. Agric. Handbook 60.