Controlling and simulating the use of salt removing species

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Abstract - The aims of this study were to control and to simulate and to simulate the salt removal by crops irrigated with saline water and salt and water balances, under saline conditions. As an additional objective, the concept of crop rotation as a method to reduce soil salinity by alternating salt removing crops with salt sensitive crops was tested. Experimental work and the SWAP model (Soil Water Atmosphere Plant) were used to reach these objectives. The experimental work and the tests were conducted in the Negev desert of Israel, Faro / Algarve / Portugal and Izmir / Turkey. Soil profiles of salinity and water content were simulated using SWAP and compared them with observed data. In addition, it was compared measured and calculated transpiration from field experiment with several salinity treatments (electrical conductivity ranged from 1.2 up to 10 dS/m). The complete seasonal water and salt balances were analyzed. The comparative test under the local climatic and soil initial conditions showed that in the simulated and the observed results, fresh water treatment benefited from the higher water quality and used water more efficiently than the other treatments.

Keywords - Water and salt balance; SWAP simulation model; clean techniques, environment.

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1. INTRODUCTION

WATER scarcity and high salinity of both soil and irrigation water are major limiting factors for agro-productivity in arid zones [1]. In some cases, it may be possible to gain from some advantages or arid climate. Among these advantages is the large amount of solar energy and the hot climate observed during the cold season, in other parts of the world. Soil salination is one of the major threats to the environment [2] and is especially problematic where human interventions have disturbed natural ecosystems [3]. Anthropogenic activities have increased soil salinity by changing the natural balance of the water cycle [4], by allowing excess recharging of saline groundwater and salt accumulation through its concentration **Erro! A origem da referência não foi encontrada.**.

Conventional techniques to mitigate soil salinity can be characterized by four generations: 1) Problem of root zone salination by soil leaching, where contamination can be observed [6] 2) Use of subsurface trickle irrigation - economy of water, and therefore less additional salts; however the problem of groundwater contamination due to natural rain or artificial leaching can remain [7]; 3) Enhanced fertilization increases tolerance to salinity and sensitivity also increases [8, 9], but the contamination will be increased by other hazardous chemicals such as nitrates [10]; 4) Use of salt tolerant species - this technique will be very useful to the plants, but it does not solve the problem of soil or groundwater contamination [11]. When using saline water in the Mediterranean areas, the only way to control the salination process and to maintain the sustainability of landscape and agricultural fields is to combat the salination problems by environmentally safe and clean techniques, as follows: 1) Use of salt (ions) removing species [12]; 2) Use of drought tolerant crops, because less water is applied and, therefore, less will be infiltrated [13]; 3) reduction of salt application by deficit irrigation [14], and 4) application of minimal levels of water to obtain a good visual appearance GVA [15]..

The best way to select salt removing species is to assess native naturally grown halophytic species since the salt tolerance of a plant relates to its resistance and ability to grow under conditions of high winds, salt spray, alkaline soils and infertile sandy soils. Moreover, it was shown that halophytes contribute not only to desalinate the soil, but also to fertilize it, by: (1) mineralization of organic matter returned by halophytes, (2) improvement of litter by organic matter carried away by water and wind and keeping it in the tufts, (3) the heightening of soil in the tufts maintained most drainage, therefore a better ventilation which is a favorable condition to increase the availability of nutrients [16]. These salt removal species can be integrated into crop rotation programmes, as well as to remove soil salts in the salt-affected soils. In order to evaluate the wild plants ability to remove salts from the soil, several species from the Mediterranean coastal flora ([17]., living in saline environments have been studied. These species, generally halophytes, are recognizable plants wich survive high concentrations of electrolytes in their environment [18]; These environments are vnormally dominated by Na and Cl. Under these conditions the upper limit for survival is normally in excee of 300 mol m^{-3} [19]. Two exotic leaf vegetable crops - *Tetragonia tetragonoides* and *Portulaca oleracea*, living at a wild status were studied as salt removal species. They showed also that they have a high interest as horticultural leaf crops. Hence, the only way to control the salination process and to maintain the sustainability of landscape and agricultural fields is to combat the salination problems by environmentally safe and clean techniques. From these techniques, it was selected the use of salt removing species, tolerant to drought [20, 22, 23]. The agricultural characteristics of these two specicies are described, as follows:

Tetragonia tetragonoides (New Zealand spinach Annual grown for its edible leaves like spinach. Successful in autumn, winter and spring in Mediterranean climate. For early crop, sow the seeds in boxes or pots and maintain a temperature of 15-16 ^{o}C. Transplant at 45-60 cm apart in rows 90-100 cm apart. For direct seeding sow in 6 mm deep drills and space the drills 90 cm apart. Soak seed overnight before sowing. Thin the seedlings 45-60 cm apart. Pinch out the flower buds.Known as trouble free. Pick the leaves in bunches for marketing.

Portulaca oleracea (Purslane) rows wild all through the Mediterranean basin. Varieties with large leaves are cultivated commercially for its succulent stem and leaves. Best growing period is early spring toautumn. No germination at low temperatures. Flowers lower the leaves quality under hot, dry or long day conditions. Seeds are sown at 1-2 cm depth as rows 20 cm apart. Germination occurs 15 days later. No major pest or disease problems. Weeds are removed once or twice manually. Harvest is by pulling out whole plants with roots or by cutting from the ground level, 60-70 days after sowing. In Portugal and Turkey, marketed with roots as 0.5-1.0 kg bundles. Some of the plants may be left after harvest to collect seeds. Seeds mature in July-August In this study the SWAP model was used to simulate salt removal by crops irrigated with saline water, which incorporates water uptake term with the Darcy Richards equation to compute water and solute flow in the soil and through the plant to the atmosphere [24]. In order to use it for analyses under saline conditions, we employed it with local initial and boundary conditions and compared the simulated results with observed data. To account for the dynamic processes of water and salts in the soil, plant and atmosphere continuum was assumed as the uniform sink function and SWAP model may mimic real-life process [25]. We therefore present here existing macroscopic approach [26] and incorporating root extraction as a sink in the flow equations.

II. MATERIALS AND METHODS

The model was tested using data from several experimental sites, as follows: 1) Ramat Negev, Experimental Station, Negev desert, Israel; b) Faro, Algarve; Portugal; 3) Izmir, Turkey. Average weather parameters for the experimental sites in Israel, Portugal, and Spain are given in Table 1.

Table 1. Description of the weather parameters

Climatic data	Israel	Portugal	Turkey
Annual rain (mm)	200	500	637
Maximum temp.^{o}C	35	28.5	34
Min. Temp ^{o}C	5.4	8.0	4.5
Rel. hum (summer)	31	50	33.3
Rel.hum. (% winter)	54	70	50
Annual pan eva.(m)	2.3	1.3	3.3
Altitude (m)	200	38	10
Longitude (^{o})	34^{o} 41E	7^{o} 58'W	27^{o}13 E
Latitude (^{o}N)	31^{o}05 N	37^{o}02'N"	38^{o}27 N

Three salinity levels were tested experimentally. The electrical conductivities of the irrigation water were 1.2, 2.7 and 4.2 dS/m. Water was applied by trickle irrigation to satisfy crop ET requirements in the three saline treatments. Monthly averages of pan evaporation and the crop factors that were used are summarized in Tables 2a (1st semester) and 2b (2nd semester).

Table. 2a Average 1st semester monthly irrig. parameters used during the growing season.

		Month					
	units	1	2	3	4	5	6
Pan Eo	mmd^{-1}		2.8	4.2	7.1	9.0	9.5
Pan coeff.	No.	0	0	0	0.5	0.6	0.7
Irrigat.	mm d^{-1}	0	0	0	4	5	6

Table. 2b Average 2nd semester monthly irrig. parameters used during the growing season.

		Month					
	units	7	8	9	10	11	12
Pan Eo	mmd^{-1}	9.9	8.7	6.4	5.2	3.1	2.0
Pan coeff	No.	0.7	0.7	0.6	0.5	0	0
Irrigation	mmd^{-1}	7	6	4	2.4	0	0

The response of the various crop varieties in the above countries was analyzed by SWAP model using measured variations in global radiation, minimum and maximum temperature, atmospheric vapour pressure, class A pan evaporation and estimated wind speed throughout the entire growing season .

The selected salt sensitive crop to be introduced in crop rotation was lettuce (Lactuca sativa). Double emitter source DES [26,27, 28], were several salinity gradient, in order to obtain the several saline treatments used in the experimental work in Israel and Portugal. Trickle irrigation and double emitter source DES was used for water application, allowing a gradient of a trickle irrigation applied salt (NaCl).. All the emitters were self compensating emitters. One salt trickle line and its emitters was connected to a tank of NaCl solution. These two trickle lines were coupled together with a fresh water trickle line to form a double-joint. The emitters of the three laterals have different and varying discharges to obtain various mixings between the two lines while maintaining constant application rates for each dripping point. The space between trickle points along the lateral and between sets of three lines was 1m. However the varying discharges of the emitters provokes varying salt concentrations of each dripping point along the lateral, and the darkness represents increasing salinity (Fig. 2). Layout of the double emitter source DES design. S, F lines represent the salt, and fresh water trickle lines, respectively. The discharge of each trickle point Q_i, at the ith location of each dripping point (where i = 1 to n), is constant and given by

$$Q_i = qS_i + qF_i = \qquad (1)$$

where qS_i, and qF_i are the discharges of the emitter of each single line, respecively, the salt line and the fresh water line, at the ith location of the trickle point.The masses of each solute MS_i (NaCl) applied at each ith location of the dripping point is

$$MS_i = qS_i \times CS_i \qquad (2)$$

where CS_i is the NaCl weighted concentrations, at the dripping point i , which are obtained as

$$\langle CS_i \rangle = MS_i / Q_i \qquad (3)$$

The emitters of the two laterals had different and varying discharges to obtain various mixing between the two lines while maintaining constant application rates for each dripping point. One trickle fertilizer line and its emitters was connected to a tank of fertilizer solution which was coupled to the double joint lateral in order to form a triple joint lateral. The self compensating emitters of each trickle fertilizer line had constant discharges, but the trickle fertilizer lines had different discharges, according to the different fertilizer amounts of the fertilizer treatments. The space between trickle points along the lateral and between sets of two lines was 1m. However the varying discharges of the emitters provokes varying salt concentrations of each trickling point along the laterals. The discharge of each dripping point Q_i, at the same ith location of each dripping point (where i = l.

The masses of each solute $MS_{j,k}$ (NaCl) applied at each jth dripping point, located the at kth different double joint lateral is

$$MS_{j,k} = qS_{j,k} \times CS_{j,k} \qquad (4)$$

where $CS_{j,k}$ is the NaCl weighted concentrations, at each jth dripping point located at the kth double joint lateral , which are obtained as

$$\langle CS_{j,k} \rangle = MS_{j,k} / Q_{j,k} \qquad (5)$$

This layout is connected to a tank of salt solution which was coupled to the single fresh watert lateral in order to form the double joint lateral).

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                0      2      4      6      8      10
Q (L.h-1)   s   o------o------o------o------o------o
           ns   o------o------o------o------o------o
                10     8      6      4      2      0
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o - emitter; s - saline water (10.98 dS.m^{-1}); ns - non saline water (0.89 dS.m^{-1})

Fig. 1.. Double emitter source experiments (DES)

The selected high capacity salt removing species, tolerant to drought were *Tetragonia tetragonoides* (common name: New Zealand spinach) and *Portulaca oleracea* (common name: Purslane). .

The soil characteristics in the three locations are summarized in Table 2. In Israel the soil was loess (sandy loam, typic haploxeralf). Three salinity levels were tested experimentally.

The electrical conductivities of the irrigation water were 1.2, 2.7 and 4.2 dS/m respectively. Water was applied by trickle irrigation to satisfy crop ET requirements in the three saline treatments. Monthly averages of pan evaporation and the crop factors that were used are summarized in Table 3 .

Table 3. Soil properties for the three soil sites

Soil properties	Israel	Portugal	Turkey
Sand (%)	55	86.1	66,9
Silt (%)	30	8.4	22,7
Clay (%)	15	5.5	10,4
Texture	Silty loam	Loamy sand	Loamy sand
PH	7.0	7.3	6.98
Wilting point (%)	10.8	6.2	9
Field capacity (%)	22.5	14.1	19.3
Pore volume (%)	44.2	36.4	41.3
Hydraulic conduc. Ks (mm/h)	13.8	66.9	25.4
Bulk density g/cm^3	1.53	1.68	1.55
ECe (min-max)	0.92-34.4	1-10	3.2-7.2

The soil water retention curve and hydraulic conductivity function that were used in the simulations are given in Figs 1 and 2.

These soil water data were obtained from the experiments carried out in the Ramat Negev Experimental Station, located 35 km south-west of Beer Sheva, Israel.

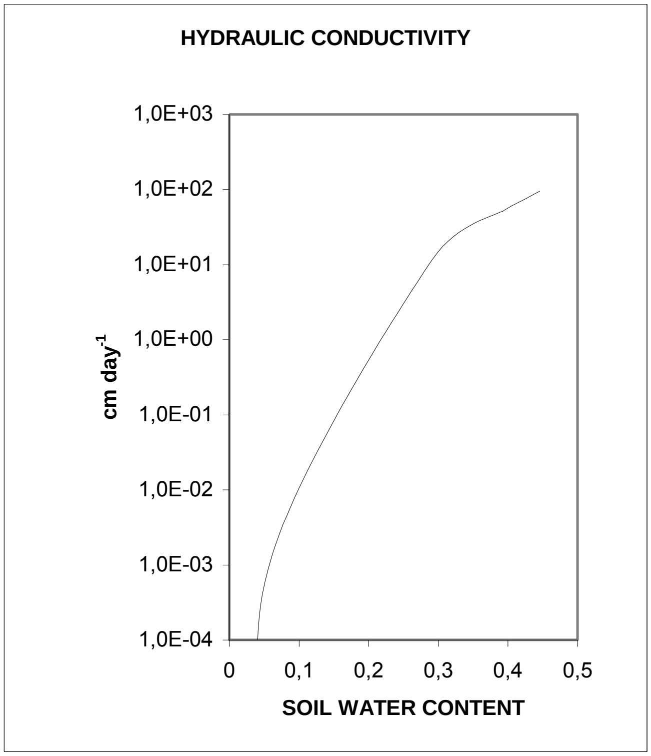

Fig. 2 Hydraulic conductivity function used in the simulation

An example of the measured profiles and their associated initial conditions used for the simulations of the most saline is given in Fig. 3

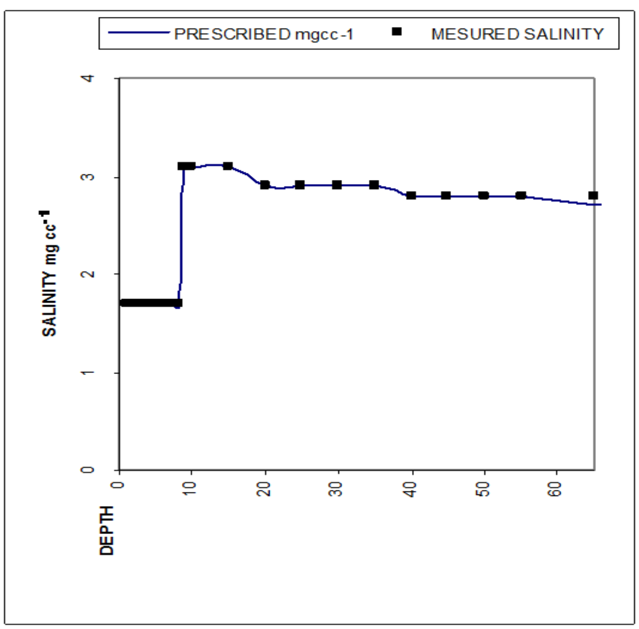

Fig. 3 - Measured and prescribed initial conditions of salinity.

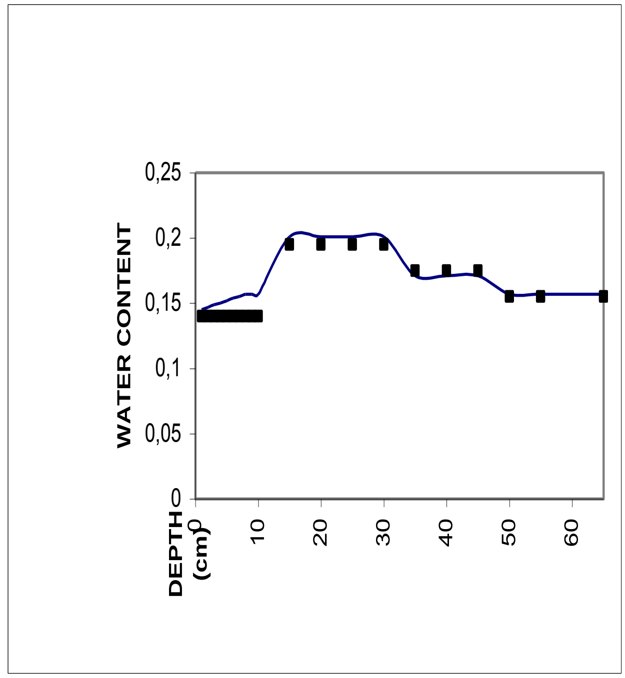

Fig. 4 - Measured and prescribed initial conditions of salinity.

Fig. 4 - pH of the drainage water - lettuce (were grown in the pots of *T. tetragonioides* and *P. oleracea*). Means ± S.E., $n = 4$. Bars with different letters are significantly different at $P < 0.05$

The relationship between the salinity treatments and the resulting soil salinity is displayed in this figure by the difference between the three profiles. From Fig. 5 it can be seen that on the top of the profiles EC values were higher (2, 4 and 6 dS/m) than the EC of the applied water (1.2, 2.7 and 4.2 respectively) due to evaporation from the surface.. The soil water distribution along the profiles also agreed, reasonably well, with observed data. In Fig.6. three water content profiles are shown together with an average measured profile

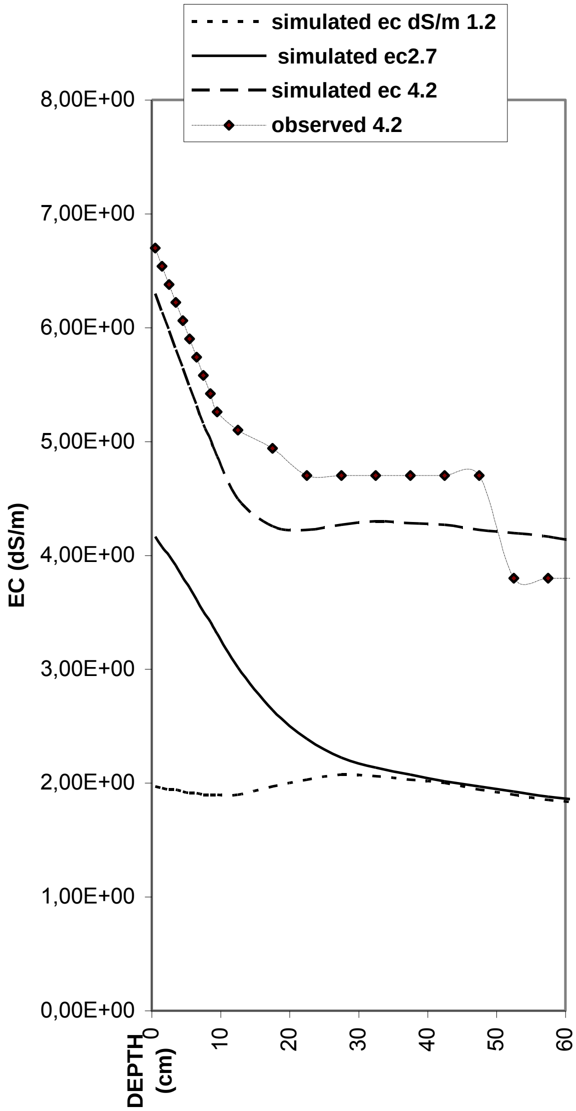

Fig. 5 - Simulated salinity profiles and a measured profile of the saline treatment

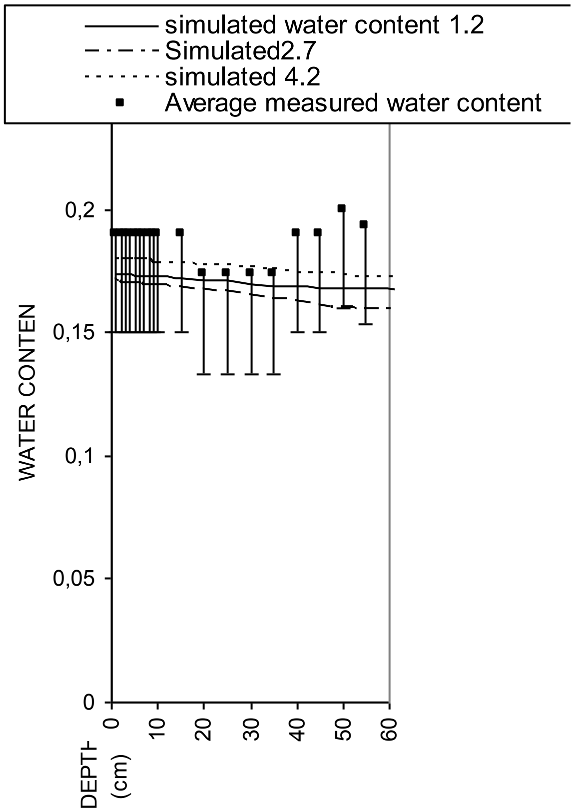

Fig. 6 Simulated soil water profile and average measured water content.

The common crop water used or all treatments parameters are summarized in Table 4.

Table 4 Common crop water used parameters for all treatments

No water use at higher pressure head due to anaerobicity (cm)	-15
Potential below optimum water extraction starts for top layer (cm)	-30
Potential below optimum water extraction starts for top layer(cm)	-30
Water potential below water extraction starts to reduce. High ET	-1000
Water potential below water extraction starts to reduce. Low ET	-1500
No water extraction(cm)	-5000
Salinity level at which salt stress starts. (dS/m)	2
Decline rate of relative crop production (%/dS/m)	3
Relative root density on soil surface (z=0)	1
Relative root density at maximal relative rooting depth (z=1)	1

III: RESULTS

In order to know the relative yield of lettuce, as a function of salinity and its water use efficiency WUE in function of yield [31], the determination of its production function was done, according to the data obtained in the field experiments. Tables 5 shows the relative yield of lettuce as a function of salinity

Table 5. Relative yield as a function of salinity for Lettuce

Crop	Slope (%/dSm^{-1})	Threshold (dS/m)	Cef. Det. R^2
Lettuce (Israel)	-7.5	1.5	0.99
Lettuce (Port.)	-8.5	1.9	0.87

Table 6 shows the salt applied (App.), the salt absorbed (Abs.) in t ha^{-1} and % of salt absorbed, by lettuce crop..

Table 6. Salt applied (App.), salt absorbed (Abs.) in t ha^{-1} and % of salt absorbed, in lettuce

App.	Abs.	%abs.
1.4	0.45	31.12
4.2	0.25	6.04
6.3	0.13	2.12
7.8	0.29	3.76

The lettuce absorbed more salt al higher than at lower soil salt concentration, however there were no proportionality between the salt absorbed and the salt applied, and salt in the soil increased with salt applied (Table 5). The percentage of salt absorbed by the crops was, in general, only 3 to 5 % of the salt applied

Table 7 shows the water use efficiency (WUE) of lettuce in function of dry matter.

Table.7 Water use efficiency average in function of dry matter and of marketable yield - Lettuce water use, fresh yield (FY) and dry yield (DY) in kg/plant, and water use efficiency. WUE in kg FY/L and in kg FY/mm) under varying salinities

EC dS m^{-1}	WUE L/plant	FY kg/plant	DY kg/plant	WUE kg FY/L	WUE kg FY/mm
1.0	2.235	0.103	0.0210	0.0462	0.0108
1.5	3.255	0.300	0.0357	0.0921	0.0198
3.0	2.955	0.237	0.0302	0.0802	0.0192
4.5	2.740	0.244	0.0304	0.0889	0.0203

In order to know the real potential of the high potential salt removing species *Tetragonia tetragonioides* and *Portulaca Oleracia*, it was analysed their performance, respectively, in Portugal (growth and NaCl concentration) and in Turkey (Na concentration). Table 8 and Figs.5 and 6 show these results.

Table 8 – *Tetragonia tetragonioides* - NaCl content (values expressed in mole/100 g of plant dry weight)

NaCl concentration of irrigation solution (mol/l)	Electrical Conductivity of irrigation water (dS/m)	mole/100 g of plant dry weight
0	0.9	0.062 ±0.29
0.025	3.6	0,145± 0.20
0.050	6	0.167± 0.34
0.075	8.5	0.165 ±0.27
0.1	10.8	0.189 ±0.16

It may be seen in Table 6 that *Tetragonia tetragonioides* shows a high ability to extract salts from the soil and this extraction is greater when the salt soil concentration increases. On the other hand, Fig. 5 shows a clear effect of salinity on growth of *Tetragonia tetragonioides*, observed by the reduction of the main stem length when increases the salinity

The gaz exchange properties of Tetragonia tetragonioides, observed in Turkey are given in Table 9.

Table 9. Gas exchange properties of *Tetragonia tetragonioides* leaves

Salinity dS m^{-1}	Photosynthesis (µmol.m^{-2}s^{-1})		Transpiration (mmol.m^{-2}s^{-1})		WUE g/L		Leaf area index (LAI)	
	Feb 15	March 7	Feb 15	March 7	Feb 15	Marc h 7	Feb 15	Mar. 7
0.65	53.2	41.7	21.8	25.9	2.44	1.61	0.98	3.89
3.5	55.9	49.1	21.1	24.3	2.65	2.02	1.12	4.01
5.0	49.3	38.4	25.5	33.5	1.93	1.14	0.87	3.65
6.5	57.2	43.4	19.3	31.0	2.96	1.40	1.13	3.34

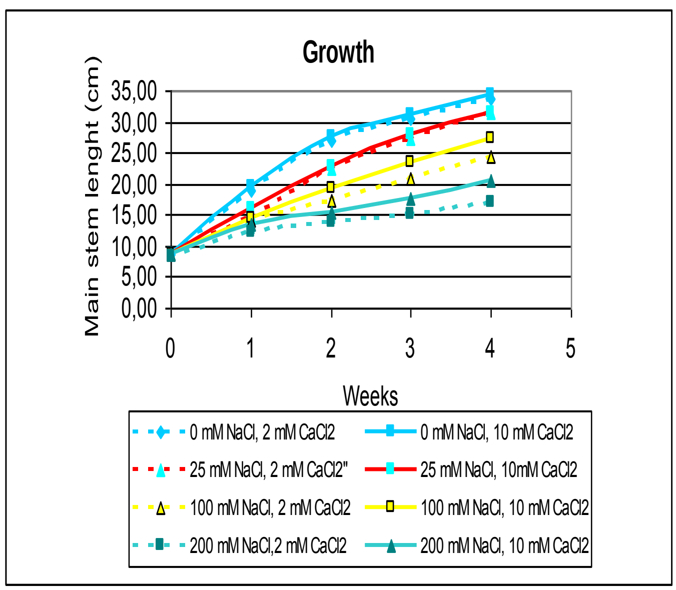

Fig. 5 – Effect of salinity on the stem growth of *Tetragonia tetragonioides*.

In Turkey, results related to *Tetragonia tetragonoides* have revealed that the fresh weights consistently decline from 302 g/plant to 121 g/plant as affected by enhanced salinity from 0.65 up to 3.5 dS / m.. [31]. On the other hand, the Na concentration of plants increased from 1.8% to 2.4% in accordance with increased salinity levels from 0.65 up to 3.5 dS / m. The harvested yield per liter consumed water was 6.7 g/L in control pots and declined to 2.9 g/L at 6.5 dS / m treatments.

The analysis of Portulaca oleraceae showed in Turkey that Na uptake per plant was similar at 0.65 and 3.5 dS/m salinity levels [32}. The uptake rate was reduced at 6.5 dS/m salinity due to restricted plant growth. The Na concentration in the dry matter increased through the vegetation period (Fig. 6). The maximum Na concentration was found at the highest salinity level. The production function (g/l) of Portulaca oleraceae was higher at 3.5 dS/m compared to 0.65 or 6.5 dS/m salinity levels. Results have shown that edible fresh weight decrease from 16.3 g/plant to 7.3 g/plant as the salinity levels increase from 0.65 to 6.5 dS/m. Total Na uptake per plant was high in the control (0.65 dS/m) and 3.5 dS/m treatments. Owing to the restricted plant growth and consecutive fresh weight reduction, Na uptake was less in the 6.5 dS/m application. In this regard, Na concentrations (%) in the shoots increased by saline water applications compared to the control. Similarly, Cl concentrations also increased with increased salination compared to that of control treatment. However, Cl uptake by purslane tended to decline like Na uptake. The harvestable yield per liter water consumed was the highest in S1 treatment, followed by S0 and S2 .

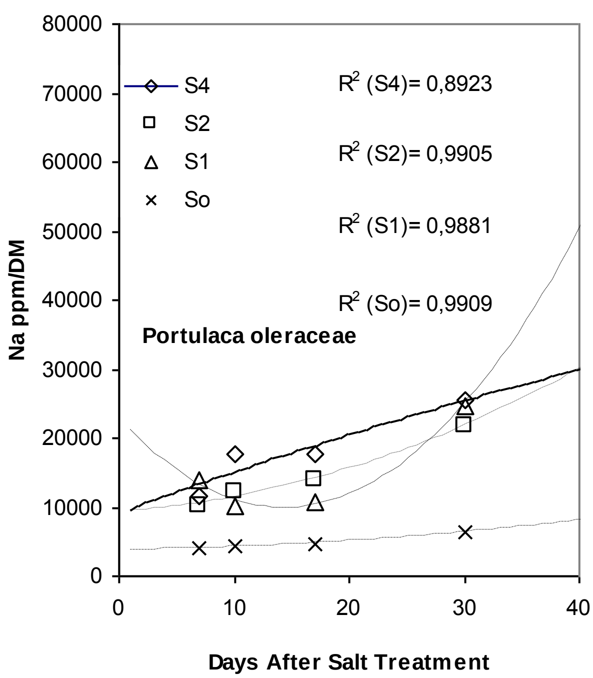

Fig. 6 – Na concentration in *Portulaca oleracea* during the vegetation period (S0 = 0.65; S1 = 2.0 ;S2 = 3.5; S3 = 5.0; S4 = 6.5 dS m^{-1}).

Table 10 shows the water use efficiency (WUE) of *Portulaca oleracea* as a function of salinity (g/L), in Turkey.

Table.10 Water use efficiency WUE in function of salt levels

Treatment	Salinity levels (dS m^{-1})	K / Na	WUE g/L
S0	0.65	3.00	8.88
S2	3.5	1.99	8.72
S3	5.0	1.67	8.21
S4	6.5	1.05	7.99

Table 10 shows that K was significantly was decreasing with increase of salinity (Na). On the other hand WUE WUE decreased slightly from 8.88 to 7.93 g L^{-1}, with the increase of salinity.

An example of salt removal under crop rotation is shown in Tables 11a, b, c and d, which constitutes the output in the simulation model.

Table 11a describes a theoretical situation in which no salt is applied and no salt is removed. As expected, throughout the three crop cycles only water storage was changed in this case. Transpiration was about 115 cm and irrigation was 92 cm. The remaining came from initial water storage.

Table 11a. Salt and water balance under three crops rotations.

Water 0 salt application 0; salt uptake by plants:
Period : 5/05/1997 until 15/11/1997
Depth soil profile : 200.00 cm

	Water storage	Solute storage
Final :	13.27 cm	0.0000E+00 mg/cm^2
Initial :	51.10 cm	0.0000E+00 mg/cm^2
	============	================
Change	-37.84 cm	0.0000E+00 mg/cm^2

Water balance components (cm)

In		Out	
=======================		======	
Rain :	0.00	Interception	0.00
Irrigation :	92.86	Runoff	0.00
Bottom flux	-1.59	Transpiration	114.84
		Soil evaporation :	14.27
		Crack flux :	0.00
		Drainage :	0.00
=======================		======	
Sum	91.27	Sum :	129.10

Solute balance components (mg/cm^2)

In		Out	
=======================		========	
Rain :	0.0000E+00	Decomposition :	0.0000E+00
Irrigation :	0.0000E+00	Root uptake :	0.0000E+00
Bottom flux :	0.0000E+00	racks :	0.0000E+00
		Drainage :	0.0000E+00
================ ============		=============	
Sum :	0.0000E+00	Sum	0.0000E+00

Table 11b presents water balance. In this simulation salt accumulation in the soil profile was large. There was no drainage below the root zone (depth of 2 m) or through the cracks as can be deduced from the zero sum out. Under these conditions it is expected to gain from salt removing plants.

Table 11b. Salt and water balance under three crops rotations. Two cycles Irrigated with saline water (total 19.5 ton/ha.). One cycle irrigated with fresh water. No uptake by plans
Period : 5. May until 15. November
Depth soil profile : 200.00 cm

	Water storage	Solute storage
Final :	17.88 cm	0.1953E+03 mg/cm^2
Initial :	51.10 cm	0.0000E+00 mg/cm^2
Change	-33.22 cm	0.1953E+03 mg/cm^2

Water balance components (cm)

In		Out	
Rain :	0.00	Interception :	0.00
Irrigation :	97.67	Runoff :	0.00
Bottom flux	-1.59	Transpiration :	114.91
		Soil evaporation :	14.38
		Crack flux :	0.00
		Drainage :	0.00
Sum :	96.08	Sum :	129.30

Solute balance components (mg/cm^2)

In		Out	
Rain :	0.0000E+00	Decomposition :	0.0000E+00
Irrigation :	0.1953E+03	Root uptake :	0.0000E+00
Bottom flux :	0.0000E+00	racks	0.0000E+00
		Drainage	0.0000E+00
Sum :	0.1953E+03	Sum :	0.0000E+00

Table 11c. shows that when all irrigations were given with saline water more salt was applied to the field compare to a single irrigation that was
analyzed in Table 11b. However, one cycle of uptake by salt removing plants (*Tetragonia tetragonioides*, *Portulaca oleracea*, *Cynara Carbunculus* and Barley) reduced the cumulative amount of salt in the profile from about 23 ton/ha to about 4 ton/ha. This indicated the importance of salt removing plants to maintain clean soil profile compare to the impact of drainage with the given amount of water application.

Table 11c. Salt and water balance under three crops rotations.

Three cycles of Irrigations with saline water (total 23.6 ton/ha.) and two cycles of salt uptake by plans
Period : 5/05/1997 until 15/11/1997
Depth soil profile : 200.00 cm

	Water storage	Solute storage
Final :	19.39 cm	0.2336E+03 mg/cm^2
Initial :	51.10 cm	0.4088E+02 mg/cm^2
Change	-31.71 cm	0.1927E+03 mg/cm^2

Water balance components (cm)

In		Out	
Rain :	0.00	Interception :	0.00
Irrigation :	92.88	Runoff :	0.00
Bottom flux	-1.82	Transpiration :	108.28
		Soil evaporation:	14.49
		Crack flux :	0.00
		Drainage	0.00
Sum :	91.06	Sum :	122.77

Solute balance components (mg/cm^2)

In		Out	
Rain :	0.0000E+00	Decomposition :	0.0000E+00
Irrigation :	0.1322E+03	Root uptake :	0.3451E+02
Bottom flux :	-0.1969E+01	Cracks :	0.0000E+00
		Drainage :	0.0000E+00
Sum	0.1302E+03	Sum	0.3451E+02

Table 11d Salt and water balance under three crops rotations.

One cycle of irrigations with saline water (total 13.2 ton/ha.) and one cycle of salt uptake by plants.
Period : 5/05/until 15/11
Depth soil profile : 200.00 cm

	Water storage	Solute storage
Final :	17.19 cm	0.1366E+03 mg/cm^2
Initial :	51.10 cm	0.4088E+02 mg/cm^2
Change	-33.91 cm	0.9569E+02 mg/cm^2

Water balance components (cm)

In		Out	
Rain :	0.00	Interception :	0.00
Irrigation :	92.88	Runoff :	0.00
Bottom flux	-1.82	Transpiration :	110.48
		Soil evaporation :	14.49
		Crack flux :	0.00
		Drainage :	0.00
Sum :	91.06	Sum	124.97

Solute balance components (mg/cm2

In		Out	
Rain :	0.0000E+00	Decomposition :	0.0000E+00
Irrigation :	0.1322E+03	Root uptake :	0.3451E+02
Bottom flux :	0.1969E+01	Cracks :	0.0000E+00
		Drainage :	0.0000E+00
Sum	0.1302E+03	Sum :	0.3451E+02

It may be seen in Table 13 that four cases were simulated: a) High water quality (no salt application) and no crop rotation. b) Medium water quality that added 19.5 t of salt per ha, and cultivation of a low efficient salt removal crop without irrigation. c) Low water quality that added 23.6 t of salt per ha; the crop rotation was for the first year a low efficient salt crop, and the second and the third year a very efficient salt crop. d) Moderately saline water added 13.2 t of salts per ha; the rotation started with two non removing crops (Lettuce, Lactuca sativa) and ended with one very efficient salt removing crop (*Tetragonia tetragonioides)*.

It is noteworthy that in Table 11d we observe how a single salt removing crop removed about 10 ton/ha while in table 7c two cycles of salt removing crops doubled the removed amount and actually removed about 20 ton/ha. Obviously the values are not realistic and they are much larger than the real amounts of salt uptake but they are suggesting that crop rotation may reduce salt accumulation in the field and that two cycles may double the removed amount.

The summarised simulated depth of water balance components (cm) generated by various salinity conditions during growing season is shown in Table 12..

Table 12– Summarized Simulated depth of water balance components (cm) generated by various salinity conditions during growing season.

Salinity treatment	Fresh water 1.2 dS/m	Medium saliniy 2.7 dS/m	Saline water 4.2 dS/m
Initial water storage	33.37	29.82	32.45
Final water storage	15.37	15.17	14.45
Irrigation	94.41	94.41	94.41
Transpiration (out)	60.10	49.76	45.41
Soil evaporation (out)	41.29	47.76	54.10
Bottom flux(in)	-11.21	-11.60	-12.90

Table 13 shows the summarized simulation results of field salt balance under the three cycles of crop routines.

Table 13 – Summarized simulation results of fieltd salt balance under 3 cycles of crop routines

Salt application (t/ha)	% salt uptake cycle 1	% salt uptake cycle 2	% salt uptake cycle 3
(a) 0	0	0	0
(b)19.5	5	5	5
(c) 23.6	5	40	40
(d) 13.2	5	5	40

IV. CONCLUSIONS

Collected data were used as inputs in the SWAP model which proved to be suitable for the simulation of salt removal by crops under saline conditions. For the first time SWAP was used to simulate crop rotation under saline conditions. Even though irrigation was given by trickle irrigation, the sandy soil and the high saturated hydraulic conductivity resulted in an apparent one dimensional flow which was simulated as surface irrigation with uniform root distribution. The study demonstrated the applicability of SWAP model for using detailed data, important for water and salinity management. It also demonstrates the utility of the model to reconstruct past growing events with a good degree of accuracy or to simulate future events with reasonable results.

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