Modeling the effect of salt removing species in crop rotation

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Abstract - The aim of this work was to evaluate SWAP model (Soil Water Atmosphere Plant) ability to account salt removal by crops and for various salinity effects in field crops irrigated with saline water. The test was 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. 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. The salinity threshold value disappeared probably because of high salinity and extreme climatic conditions with a large number of days exceeded 40 ºC. The reasonable agreement that was found between observed and measured results (demonstrated by a very high determination coefficient = 0.8 - 0.9) paved the way to test alternate scenarios of crop rotation and water use efficiency under arid conditions and saline water irrigation.

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Keywords - Water and salt balance; SWAP simulation model; clean techniques
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1. INTRODUCTION

SOIL salination is one of the major threats to the environment and is especially problematic where human interventions have disturbed natural ecosystems [1].

The economic impacts resulting from salination problems are mainly associated with a decrease in the production capacity of land [2]. Yield reduction occur when the salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in a water stress for a significant period of time [3]. The equation relating relative yield (Yr, dimensionless 0-1) and the electrical conductivity of the irrigation water , Ecw, (dSm^{-1}) is:

$$Yr = 1 - b\,(ECw - a) \quad (1)$$

where "a" is the threshold salinity value ($dS\ m^{-1}$) and "b" the crop sensitivity (decrease % / dSm^{-1}) and "ECw ".

Models formulating some physical aspects of the integrated processes of water intake based on transpiration and salinity have been developed by Hanks and co-workers [7, 8], who have described the effect of osmotic potential on plant root extraction.

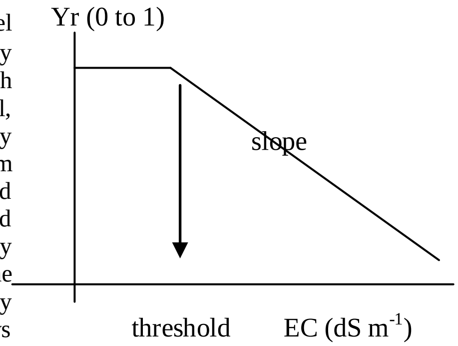

Fig. 1 - Relative yield Yr (1 to 0)

Generalized results from plant yield models with saline water were developed [8, 9]. The simplified diffusion convection equation to obtain production functions, including the effects of water, salinity and nutrition conditions, was solved [10]. All these models describe the plant as a pipeline of water, and, therefore the water uptake and transpiration are synonymous terms such that the yield, which is dependent upon the transpiration rate, is given as a unique function of soil water potential or soil osmotic potential. It was assumed that water uptake depends on matric and water potentials and on a critical root water potential around – 0.3 MPa; the assumption that the major effect of soil salinity is a reduction in water uptake, was consubstantiate [11]. Later on, a model was presented in which the wilting point is a function of the soil salt content [12]: at higher salinity, the water content at wilting point is higher than at low salinity, resulting in an insufficient amount of available water, and, therefore, a reduced yield. This model shows that the movement of salts in the soil is solely dependent on the movement of water in soil; and, it shows also that the effect of salinity is simulated by its effect on the wilting point, thus reducing the soil available water content.

The negative environmental impacts are most often the degradation of land, namely soil salination and groundwater contamination. [13]. In the Mediterranean basin where water use exceeds the natural recharge, reduction of groundwater level and circulation of salts are associated with irreversible salination processes [14]. Moreover, crop irrigation is rarely performed with water that does not contain some salts that, eventually, build-up in the soil. The salts added to the soil by irrigation water salinised the soil and decrease crop productivity what caused the abandonment of horticultural areas with their consequent erosion. To restore those areas for horticulture, removing salts in the only solution. The usual way to remove salt from a salty soil is by leaching down the soil profile but this method has a high risk of underground-aquifer contamination. The danger of aquifer contamination or soil salination is specially high in arid and semiarid climates where the irrigation water is moderate to highly saline and there are very limited water reserves in aquifers.

The main goal of this objective is to prove the economic viability of using phytoremediation to avoid erosion in salt affected agricultural lands.

To reduce the amount of saline water for irrigation has been partially demonstrated by Lettey and co-workers [15] who demonstrated that crop production functions as well as optimal irrigation volumes and scheduling are strongly related to irrigation water quality and that less water is consumed by crops under saline conditions. It is therefore expected that reducing saline water application would contribute to soil remediation. Moreover, it would strongly reduce the leaching fraction which is currently practiced and the consequent ground water contamination. Here we will calculate the yield reduction caused by saline water, the minimum saline water (and minimum salt applied to the soil) necessary for maximum yield and the salt balance in the soil after irrigation with saline water.

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 [16]. One of these techniques is the use of salt removing species [17, 18, 19,20]. It is important to know the highest salinity level that a salt removing plant can withstand without yield reduction and still be economically viable and marketable [21]. Therefore, intensive research efforts are carried out to find means to develop agricultural in arid region in spite of its limitations. Many tests of models compared measured and simulated results that were used to predict uptake rates ignoring the distribution of water and salts in the profile. Others, focused on the ability of their model to predict distribution of mass in the profile. The second and the third objectives in our study are therefore somewhat unique since they focused on the simultaneous prediction of both processes below and above ground. One of the research trucks was to grow field crops on saline water [22]. In this study, it was adapted a mathematical crop model suitable for predicting the response of field crops to salinity.. This group of models include a semi-empirical sink term in the Darcy Richards equation to compute water and solute flow in the soil and through the plant to the atmosphere [23]..Its intensity (the rate of salt uptake from the soil) depends upon space, time and soil water status. Various geometries of the sink term were successfully verified under optimal soil water conditions [24, 25], benefiting the fact that in a moist soil root can principally extract salt and water from the upper layer leaving the deeper layers relatively untouched. Other three models adapted to different scenarios (hydroponics, soil, intercropping) have been tested with data of Israel, Spain, Portugal and Turkey [26, 27, 28, 29]. Another common characteristic of these models and their modifications is the introduction of potential demand for evapotranspiration by the atmosphere as an upper limit of water loss upward while partitioning potential evaporation from potential transpiration.

II. MATERIALS AND METHODS

The SWAP (Soil-Water-Plant-Atmosphere) 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. According to Feddes and van Dam [30], SWAP model was developed by Wageningen University jointly with Alterra Green World Research., being various elements used in the model routines, as follows: potential evapotranspiration,, irrigation, crop growth, potential soil evaporation and plant transpiration, actual soil evaporation, actual plant transpiration, soil water flow, drainage, bottom boundary conditions and solute transport. This model simulates deterministic transport of water and solutes, incorporating a semi-analytical sink function and it was already used to successfully simulate the irrigation of grapevines with saline water, indicating acceptable agreements between the simulated and measured results [31].

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

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 [32, 33, 34], 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

$$Q_i = qS_i + qF_i = \quad (2)$$

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

$$MS_i = qS_i \times CS_i \quad (3)$$

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

$$\langle CS_i \rangle = MS_i / Q_i \quad (4)$$

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

$$MS_{j,k} = qS_{j,k} \times CS_{j,k} \quad (5)$$

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

$$\langle CS_{j,k} \rangle = MS_{j,k} / Q_{j,k} \quad (6)$$

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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∘ - emitter; s - saline water (10.98 $dS.m^{-1}$); ns - non saline water (0.89 $dS.m^{-1}$)

Fig. 2.. Double emitter source experiments (DES)

The soil characteristics) in the three locations are summarized in the Table 2. 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 vapor pressure, class A pan evaporation and estimated wind speed throughout the entire growing season

Table 2. Soil characteristics of the salinised plots

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 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 vapor pressure, class A pan evaporation and estimated wind speed throughout the entire growing season

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 3a (1st semester) and 3b (2nd semester).

Table. 3a 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. 3b 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 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

The simulation study followed the measuring period. from day 121 (May 5) until the last measurement, taken at day 310 (October 11) total 190 days. The simulation was made on three virtual crops which differ from each other by their salt uptake parameters. The first crop was salt sensitive – lettuce (*Lactuca sativa*) and did not remove the salts from the soil. The second and the third crops removed 40% of the applied salt.

Initial conditions of soil moisture and salinity were determined in April 13, in each one of the treatments, and additional moisture and salinity profiles were measured following the first irrigation in May 5.

Model results were first compared with actual data in Turkey, Israel and Portugal and then used for the simulation of crop rotation.

Results of comparison between measured and modeled data in all countries are shown in Figs. 7 and 8.

Crop data such as yield, and development stages were measured during the experiment and are summarized in Table 5.

The soil water retention curve and hydraulic conductivity function that were used in the simulations are given in Figs 3 and 4.

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.

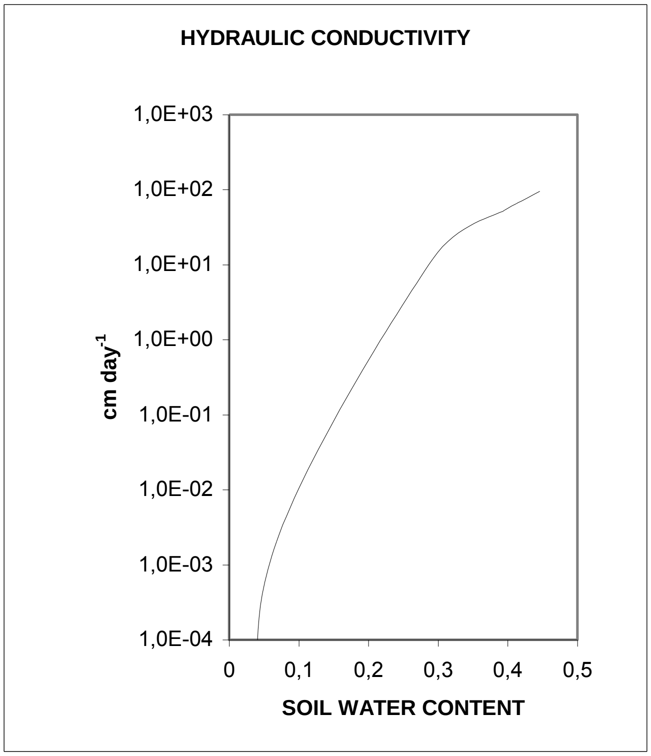

Fig. 3 Hydraulic conductivity function used in the simulation

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

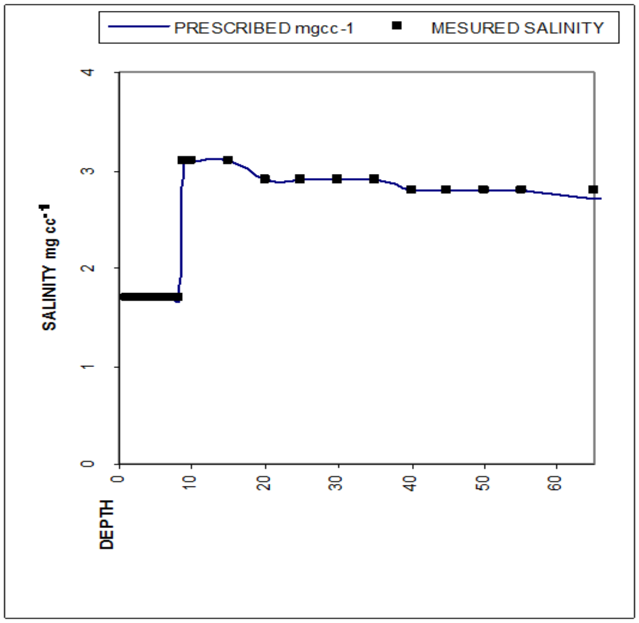

Fig. 4 - Measured and prescribed initial conditions of salinity.

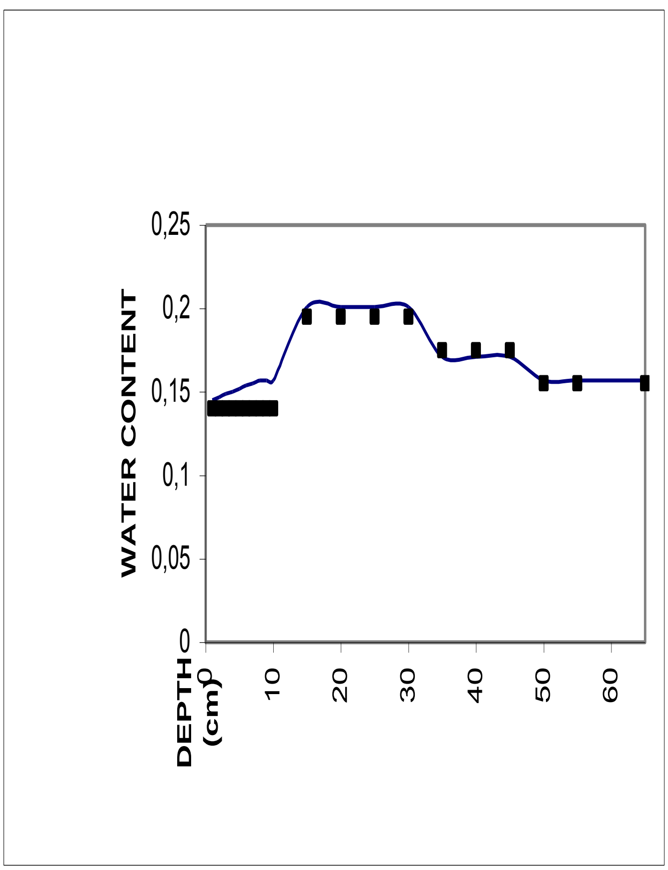

Fig. 5 - Measured and prescribed initial conditions of salinity.

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

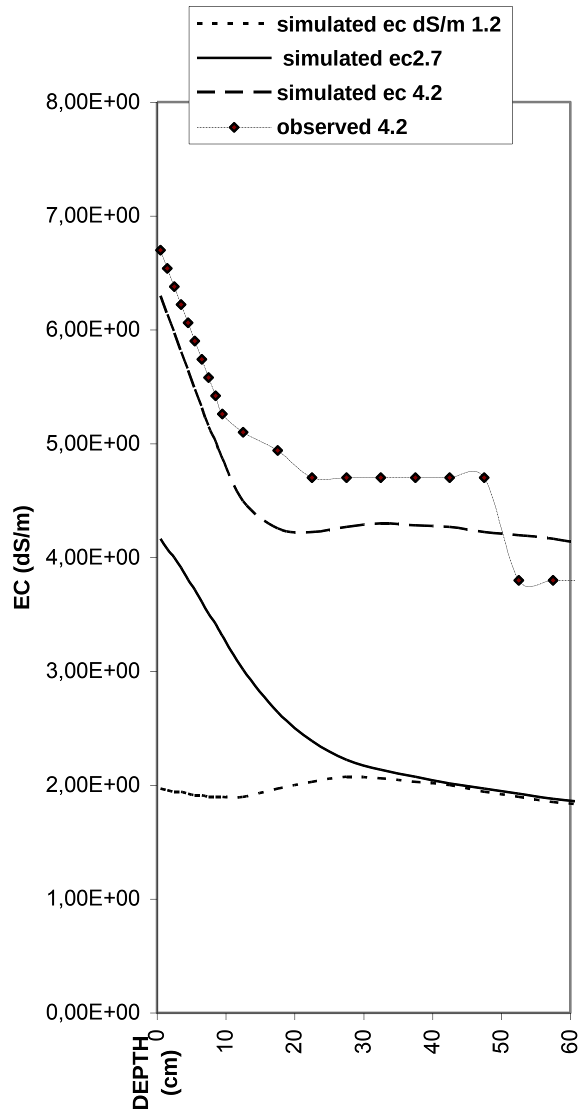

Fig. 6 - Simulated salinity profiles and a measured profile of the saline treatment

Table 5 - Crop input parameters*

Measuring day	Develop. stage	LAI, 1.2dS/m	LAI 2.7 dS/m	LAI 4.2 dS/m	Crop factor
121	0	0.5	0.5	0.5	0.5
124	0.042	0.9	0.9	0.5	0.6
133	0.137	1.2	0.9	0.9	0.65
142	0.231	2.4	1.5	1	0.7
154	0.357	3.8	3.2	1.4	0.7
160	0.421	5.2	3.3	2	0.75
172	0.547	4.4	3.6	3.1	0.75
201	0.853	4.1	3.2	3	0.65
217	1.021	3.5	2.6	2.9	0.65
243	1.295	2.7	2.3	2.3	0.6
265	1.526	2.4	1.7	1.6	0.55
279	1.673	2.4	1.7	1.4	0.5
310	2	1.5	0.8	0.5	0.5
*Green leaf area index of lettuce for each treatment=LAI					

The common crop water used or all treatments parameters are summarized in Table 6.

Table 6 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

Sink parameters for water were calibrated according to SWAP routine against measured transpiration and using Penman-Monteith equation. Free discharge at the bottom of the 2 meter soil profile was employed . Measured values of transpiration (cm) and dry matter production compared to simulated values. The indicator of model confirmation was based on subjective judgment of the comparison between observed and simulated actual transpiration.

III: RESULTS

3.1 Comparison of measured and simulated results :

Model results were first compared with actual data in Turkey, Israel and Portugal and then used for the simulation of crop rotation.

Simulated salinity profiles differed from the observed profiles of the various treatments. However, linear regression test (Fig 1) indicated that EC of the measured data was systematically higher than the simulated EC by 1.2 dS/m.

Results of comparison between measured and modeled data in all countries are shown in Figs. 7, 8 and 9.

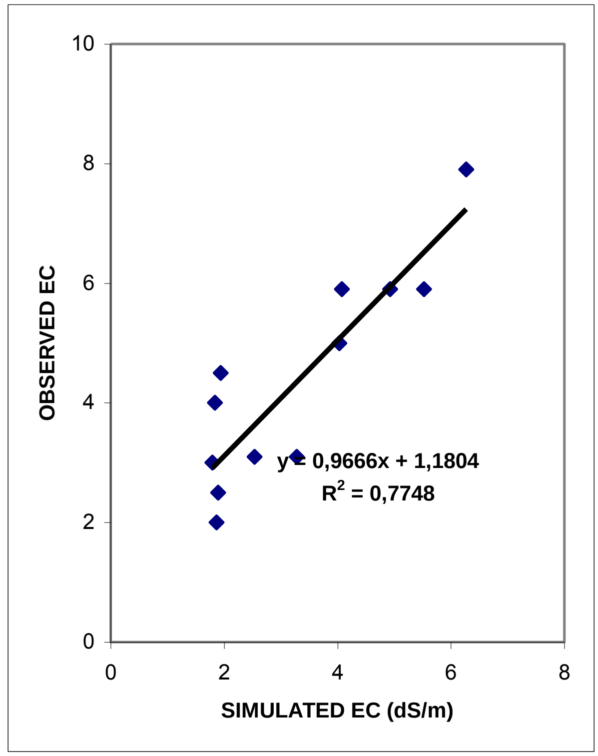

Fig. 7 - Correlation between observed and simulated results.

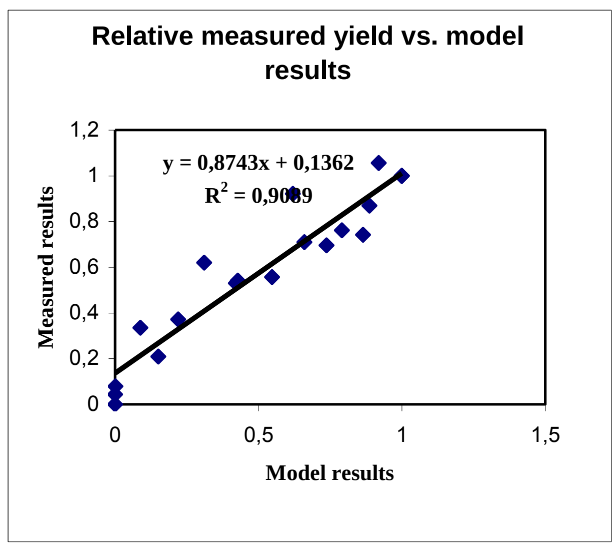

Fig 8 Comparison between measured and modeled yields of the crops tested in Turkey, Portugal and Israel.

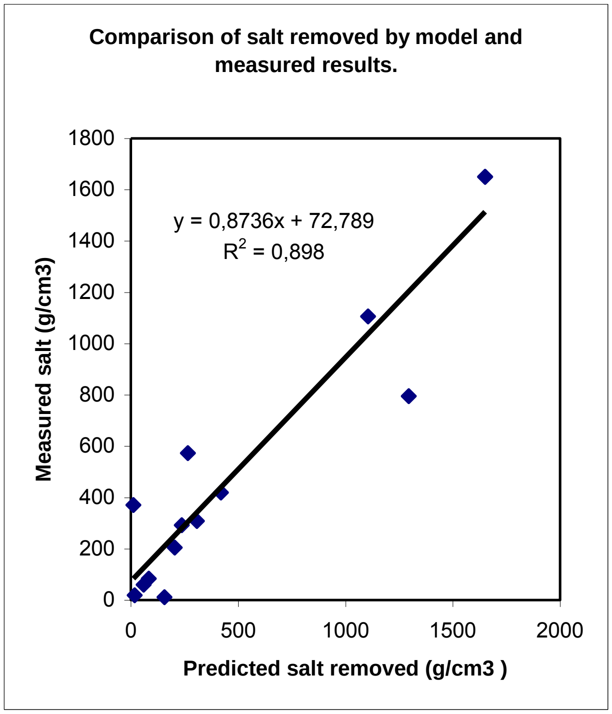

Fig 9. Accumulated salt in the soil for several crops in Portugal Israel and Turkey.

In addition a one unit slope and correlation coefficient r^2 = 0.77 was obtained between observed and model EC (Fig. 7). Thus, after correction for this difference, the simulated profile described, reliably, the actual profile. In Fig.8 (24 hours after irrigation) the similarity between the simulated 4.2dS/m and the observed values seems acceptable.
Fig 9 indicated a reasonable agreement between predicted and measured salt removed from the soil for several crops in Israel, Portugal and Turkey (R^2 = 0.9).
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. 10 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. 11. three water content profiles are shown together with an average measured profile

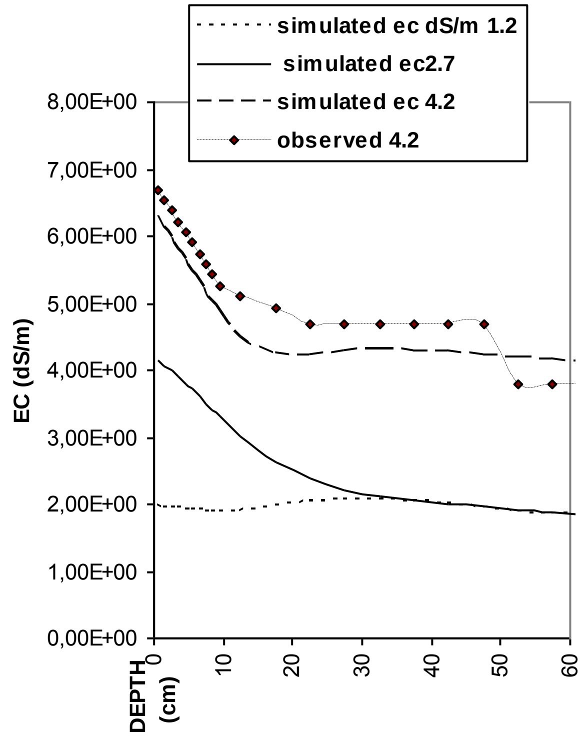

Fig. 10 - Simulated salinity profiles and a measured profile of the saline treatment

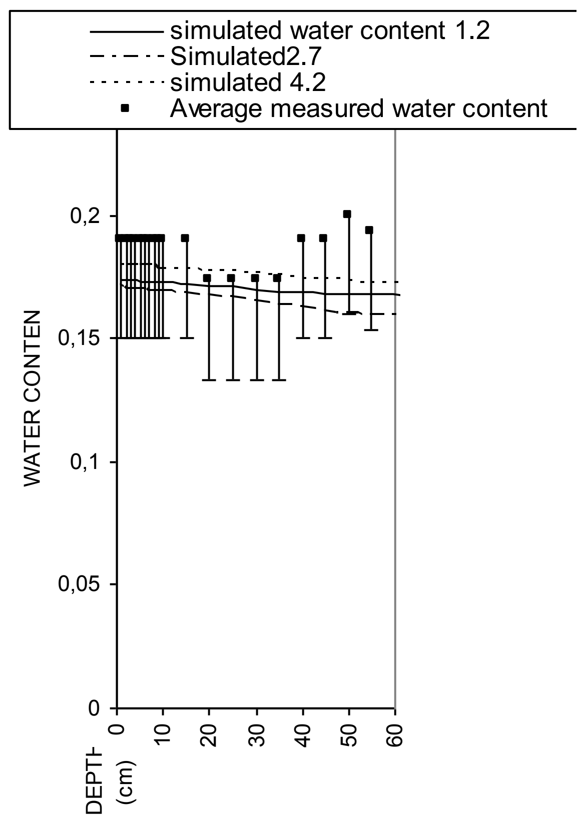

Fig. 11 Simulated soil water profile and average measured water content.

Since water was applied equally according to the transpiration load to all treatments there was no significant differences between the treatments. The measured values from all treatments were averaged and are shown together with their standard deviation. The difference between the various predicted lines resulted from the different initial conditions and it was smaller than the standard deviation of the measured data. Hence they are not considered significant. The uniform distribution of water content within the profile resulted from the soil hydraulic properties especially the high hydraulic conductivity.

The above results indicated reasonable agreement between predicted and measured results and hence the model was considered a suitable tool to study the above scenarios for crop rotations.

The summarised simulated depth of water balance components (cm) generated by various salinity conditions during growing season is shown in Table 7..

Table 7 – 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

3.2 Yield response to crop rotation

In Fig. 12 the yield of first crop was not affected by increased salinity. The second crop started with low relative productivity but recovered with DOY (the day of the year). The third crop improved yield at the beginning of its growth cycle but as salinity increased due to irrigation with saline water the yield reduced.

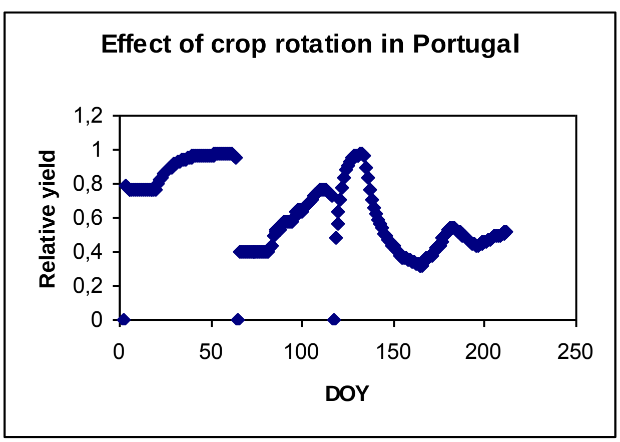

Fig. 12. Crop rotation started with two salt tolerant crops and continued with one sensitive crop – lettuce (*Lactuca sativa*) .

In Fig.13 it was demonstrated a scenario in which the rotation started with a sensitive crops and then salts were removed by two salt removing crops. The yield of the sensitive crop reduced after about one month of saline irrigation. The second crop responded to high salinity by low yield but removed part of the salts while the third crop returned to produce its maximum yield after a short time.

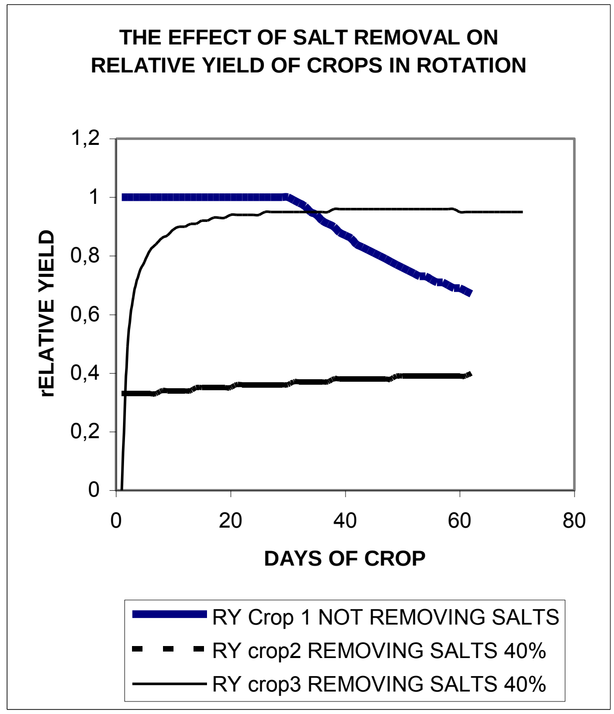

Fig 13. Crop rotation started with a salt sensitive crops and continued with two tolerant crops.

The yield of the sensitive crop reduced after about one month of saline water irrigation. The second crop responded to high salinity by low yield but removed part of the salts while the third crop returned to produced its maximum yield after a short time. The first crop was planted on non saline soil but was irrigated with the saline water. As a result, it maintained high relative productivity until about one half of the growing season

The second crop, was a salt removing crop. It, theoretically, removed 40% of the applied salts but responded to the high soil salinity with yield reduction. The third crop which was also a salt removing crop increased the yield gradually until it reached its own potential production.

Table 8 shows the summarized simulation results of field salt balance under three cycles of crop routines. It may be seen in Table 8 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 – 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 and ended with one very efficient salt removing crop (*Tetragonia tetragonioides*).

Table 8 – Summarized simulation results of field 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

In Table 8 we simulated four cases a) High water quality and no crop rotation. b) Medium water quality no crop rotation c) Low water quality. The rotation cycle started with two cycles of very efficient salt removing crops and continued with non-removing crop d) moderately saline water . The rotation started with two non-removing crops and ended with one very efficient salt removing crop. Results of comparison between measured and modeled data in all countries are shown in Figs. 1,2 and 3.

III. CONCLUSIONS

Most collected data were used as inputs in SWAP model which is found to be suitable for crop rotation simulation. For the first time SWAP was used to simulate crop rotation under saline conditions. Thus, bearing in mind Fig. 1 which indicated decline in relative yield together with the water balance calculations it can be concluded that water use efficiency under saline conditions was reduced compared to the non saline irrigation. It is not clear however, whether this conclusion is true for all climatic conditions, crops and soil properties results paved the way to test alternate possible scenarios on crop rotation and water use efficiency under saline conditions.

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REFERENCES

[1] Boonstra J., Bhutta M.N. and Rizvi S.A. 1997. Drainable surplus assessment in irrigated agriculture: field application of the groundwater approach. *Irrigation and Drainage Systems* 11:41-60.

[2] Hamidov, A.; Khaydarova, Khamidov, M.; Neves, M.A.;.& Beltrao, J. 2007. *Apocynum Lancifolium* and *Chenopodium Album*.- potencial species to remediate saline soils. *WSEAS Transactions on Environment and Development* 7(3):123-128.

[3] Ayers, R:S. ; Westcot, D.W. 1985. Water quality to agriculture. FAO Irrig. Drain. Paper. 29. Rome, Italy.

[4] Maas, E.V.; Hoffman, G.J. 1977. Salt crop tolerance – current assessment. *Irrig. Drain. Div., Am. Soc. Civil Eng.* 103:115-134.

[5] Hoffman, G.J.; van Genuchten, M. Th. 1983. Soil properties and efficient use: water management for saline control. In: Taylor, H.M.; Jordan, W.A.; & Sinclair, T.R. (eds.), Limitations to efficient water use (pp. 73-85). ASA, Madison, Wisconsin, USA.

[6] Beltrão, J.; Brito, J.; Neves, M.A.; & Seita, J. 2009. Salt Removal Potential of Turfgrasses in Golf Courses in the Mediterranean Basin. *WSEAS Transactions on Environment and Development* 5(5):394-403.

[7] Nimah, M.N.; Hanks, R.J. 1973. Model forestimating soil water and atmospheric interrelations. *Soil Sci. Soc. Am. Proc.* 37:522-532. Hanks, R.J.; Nimah, M.N. (1988). Integrating soil and plant water measurements. *Irrig. Sci.*: 9:319-328.

[8] Solomon, K.H. 1985. Water salinity production functions. *Trans. ASAE* 28/(6):1975-1980.

[9] Warrick, A.W. 1989. Generalized results from crop yield model with saline waters. *Soil Sci. Soc. Am. J.* 53:1641-1645.

[10] Ben Asher, J. 1988. Combined processes of ions and water uptake: a mathematical model and its implications. *Israel Agrisearch* 335:53-56.

[11] Bresler, E.; Hoffman, G.J. 1986. Irrigation management for soil salinity control: theorie and tests. Soil Sci. Soc. Am. J. 50: 1552-1560.

[12] Beltrão, J.; & Ben Asher, J. 1997. The effect of salinity on corn yield using CERESMaize model. *Irrigation and Drainage Systems* 11:15-28.

[13] Yakirevitch, A.; Malul, A.; Sorek, S.; Shaan, S.; Borisov, V. 1998. Simulation of seawater intrusion into the Khan Yunis area of the Gaza strip coastal aquifer. *Hydrol. J.* 6:549-559.

[14] -Ben Asher, J. 1993. A simplified model of integrated water and solute uptake by salts and selenium accumulating plants. *Soil Sci. Soc. Am. J.*, 58:1012-1016.

[15] Letey, J.; Dinar, A. Knapp, C.K. 1985. Crop water production function model for saline irrigation.waters. *Soil Sci. Soc. Am.* J. 49:1005-1009.

[16] Neves, M.A.; Miguel, M.G.; Marques, C.; Panagopoulos, T.; Beltrão, J. 2008. The combined effects of salts and calcium on growth and mineral accumulation on *Tetragonia tetragonioides*. *WSEAS Transactions on Environment and Development* 4(1):1-5.

[17] Bekmirzaev, G.; Beltrão, J.; Neves, M.A.; Costa, M. 2011. Climatical Changes on the potential capacity of salt removing species.. *NAUN International Journal of Geology* 5(3):79-85.

[18] Kilic¸ C.; Kukul, Y.; Anac¸ D. 2008. Performance of purslane (Portulaca oleracea L.) as a salt removing crop. *Agricultural water management* 95:854–858.

[19] Hamidov, A.; Khaydarova, V.; Sharipova, S.; Costa, C.; & Beltrao, J. 2007 Environmentally useful technique - *Portulaca Oleracea* Golden Purslane as salt removal techniques. . *WSEAS Transactions on Environment and Development* 7(3):117-122.

[20] Neves, M.A.; Miguel, M.G.; Marques, C.; Panagopoulos, T.; Beltrão, J. 2006. Response of *Tetragonia tetragonioides* (Pallas) Kuntze to the combined effects of salts and nitrogen. *WSEAS Transactions on Environment and Development* **2**(4):470-474.

[21] Neves, M.A.; Miguel, M.G.; Marques, C.; Panagopoulos, T.; Beltrão, J. 2008. The combined effects of salts and calcium on growth and mineral accumulation on *Tetragonia tetragonioides*. *WSEAS Transactions on Environment and Development* 4(1):1-5.

[22] Cuartero; J.; Pulido, J. M.; Gómez-Guillaumón, M.L.; & Alvarez, M. 2002. Salt removal potential of barley, alfalfa,

Atriplex patula and *A. prostate. Acta Horiculturae* 573:387-396.

[23] van Dam J.C., Huygen, J., Wesselimg, J.G., Feddes, R.A., Kabat, P., Van Walsum, P.E.V., Groenendijk, P., Van Diepen. C.A. 1997. Theory of SWAP version 2.0 Simulation of water flow, solute transport , and plant growth in the Soil Water Atmosphere Plant environment. Report 71 Dept. of Water resources Wageningen Agricultural university The Netherlands pp 167.

[24] Feddes, R.A.1981.Water uae models for assessing root zone modification. p347-386 in: Arkin, G.F., Taylor, H.M. eds. Modifying the root environment to reduce crop stress. pp 10.

[25] Prasad, R. 1988. A linear root water uptake model *J.Hydrol*. 99:297-306.

[26] Ben Asher, J.; Beltrão, J. Costa, M.; Anaç, S.; Cuartero, J.; & Soria, T. 2002. Modeling the effect of sea water intrusion on ground water salinity in agricultural areas in Israel, Portugal, Spain and Turkey. *Acta Horticulturae* 573:119-128.

[27] Silberbush, M; Ben Asher, J. 2002. Simulation of nutrient uptake by plants from hydroponics as affected by salinity buildaing and transpiration. *Acta Horticulturae* 573:97-106.

[28] Ben Asher, J.; Gordon, J.M.; Gale, J; Kopel, R. 1980. A computational approach for water culture. *Agron. J*. 72:640-645.

[29] Ragab, R. A. 2002. An integrated modelling approach for irrigation water management using saline and non-saline water: The Saltimed model. *Acta Horiculturae* 573: 129-138.

[30] Feddes, R.A.; Van Dam, J. C. 2002. Modeling water flow and solute transport for horticultural and environmental management.. *Acta Horticulturae* 573:107-117.

[31] Ben Asher, J.; van Dam, J.C.; Feddes, R. A. ; Jhorar, R. K. 2006. Irrigation of grapevines. II Mathematical simulation of vine growth and yield...

[32] de Mallach, Y.; Ben Asher, Y; Sagih, M.; Alert, A. 1996. Double emitter source (DES) for irrigation experiments. *Agron. J* 88(6):987-990.

[33] Beltrão, J.; Jesus, S.B.; Sousa, P.B.; Carvalho, I.; Trindade, D.; Rodrigues, M.H.; & Machado, A. 2002.Efficiency of triple emitter source (TES) for irrigation experiments of horticultural crops. Turkey. *Acta Horticulturae* 573: 183-188.

[34] Khaydarova, V. 2006; & Beltrão, J. 2006. Response of Lettuce yield to the combined effects of salts, nitrogen and water. *WSEAS Transactions on Environment and Development* 2(5):512-518.