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Estimating the Effect of Controlled Drainage on Soil Salinity and Irrigation Efficiency in the Harran Plain using SaltMod

İdris BAHÇECİ[1,*], Recep ÇAKIR[2], A. Suat NACAR[3], Pınar BAHÇECİ[4]

[1]Harran University, Faculty of Agriculture, Agricultural Structure and Irrigation Dept., 63 040 Şanlıurfa - TURKEY

[2]ATATÜRK Soil and Water Resources Research Institute, Kırklareli - TURKEY

[3]Soil and Water Resources Research Institute, Şanlıurfa - TURKEY

[4]Çukurova University, Faculty of Agriculture, Agricultural Structure and Irrigation Dept., Adana - TURKEY

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Abstract: Soil salinity and water logging, as well as water scarcity, are the most common problems limiting irrigated agriculture crop production in southeast Turkey. Thus, this study was conducted in order to predict the effect of drainage control factors on irrigation efficiency, irrigation sufficiency, root zone salinity, and drain discharge using SaltMod simulation. Investigations were conducted in the Harran Plain, also known as the Fertile Crescent or Upper Mesopotamia. High crop evapotranspiration rates and deep water table levels have led to visible increases in irrigation water requirements in the region. Therefore, the level of the water table appears to be a factor of great importance to sustainable crop production. Root zone salinity will increase to 3.0 dS m^{-1} at the end of a 10-year period if the drainage control factor (Frd) increases to above 0.75; however, the drain discharge rate was estimated to decrease from 1.350 m to 0.050 m for the summer season and to increase to 0.026 m in the winter season. In contrast, total drainage is predicted to decrease while irrigation efficiency is forecasted to increase during the summer season.

Key Words: Controlled drainage, SaltMod, Discharge rate, Root zone salinity

Harran Ovasında Kontrollü Drenajın Toprak Tuzluluğu ve Sulama Randımanı Üzerine Etkisinin, SaltMod Kullanılarak Tahmin Edilmesi

Özet: Türkiye'nin Güneydoğu Anadolu Bölgesinde toprak tuzluluğu ve su altında kalma yanında, su eksikliği bitkisel üretimi sınırlandıran yaygın sorunlardır. Onun için, bu çalışma değişik drenaj kontrol faktörlerinin kök bölgesi tuzluluğuna, drenaj suyu miktarına, sulama etkinliğine ve sulama yeterliliğine etkilerini belirlemek amacıyla SaltMod bilgisayar programı kullanılarak yapılmıştır. Araştırmalar, "Verimli Hilal" veya "Yukarı Mezopotamya" olarak ta bilinen Harran Ovasında yürütülmüştür. Bölgede yüksek bitki su tüketimleri ve derin taban suyu düzeyleri, sulama suyu ihtiyacını önemli düzeylerde artırmaktadır. Bu nedenle su tablası düzeyi sürdürülebilir bir bitkisel üretim için büyük öneme sahiptir. Çalışma sonuçları, drenaj kontrol faktörü 0.75 olduğunda kök bölgesi tuzluluğunun 3.0 dS m^{-1} ye artacağını, drenaj suyu miktarının ise yaz döneminde 0.135 m den 0.050 m'ye azalacağını, kış döneminde 0.010 m'den 0.026 m'ye yükseleceğini göstermiştir. Diğer taraftan sulama randımanı artarken toplam drenaj suyunun azalacağı tahmin edilmiştir.

Anahtar Sözcükler: Kontrollü drenaj, SaltMod, Boşaltım hızı, Kök bölgesi tuzluluğu

Introduction

An irrigation and land development project, one of the largest irrigated agriculture projects in the world, has been constructed in southeast Turkey. Approximately 1.7 million ha of land is expected to be under irrigation in the near future (DSİ, 2001).

One of the largest subprojects of this project is the Harran Plain irrigation system, located near the city of Şanlıurfa. In general, cotton and wheat are cropped on 140,000-150,000 ha and is irrigated mainly using surface irrigation methods. Recently, corn production has increased to become the secondary crop. Water required

* Correspondence to: bahceci@harran.edu.tr

for irrigation is mainly supplied from the Atatürk Dam Lake by 2 tunnels. Ground water and drainage water are expected to account for 25% and 7% of irrigation, respectively.

Both poor water management and leakage from irrigation canals have caused a the water table to rise on approximately 35,000 ha of land. Records of the organization responsible for water management showed that about 50%-60% of the south Harran Plain that is irrigated has a shallow water table regime (DSİ, 2004).

Due to the high percentage of cotton presently grown on the plain, along with inefficient surface irrigation methods, problems associated with water scarcity and drainage have became critical to sustaining agricultural production in the region. Drainage water and low quality well water have been widely used for irrigation due to water shortages during the cotton irrigation season on the Harran Plain (DSİ, 2004).

Ayars et al. (2006) reported that irrigated agriculture will continue to play a significant role in meeting the world's food supply and for it to remain sustainable, drainage must also be provided. There are at present no generally accepted design criteria for controlled or managed drainage systems, in either humid or arid areas. Thus, there is an urgent need to develop new design criteria and management methods for controlled drainage systems to meet the challenges of sustainable irrigated agriculture with minimal environmental impact.

Christen and Ayars (2001) stated that the design of drainage systems for irrigated agriculture should support efficient water management, irrigation water savings, and reduced salt discharge.

The contribution of ground water to meeting the water requirements of different crops has been studied under various soil and climatic conditions in different regions of the world (Benz et al., 1978; Benz et al., 1982; Benz et al., 1987; Meyer et al., 1996; Ayars et al., 1999).

Zhonghua et al. (2006) showed that for rice in China (the major water use crop), controlled drainage could reduce subsurface discharge through field ditches up to 94%. For wheat and corn, the benefit of controlled drainage is negligible, since the major drainage discharge is directly through the main ditch system and the Yellow River Channel.

Several studies that reported the positive impact of adopting controlled drainage in arid and semi-arid regions by reducing drainage discharge and saving irrigation water (Khalil et al., 2004). Doering et al. (1982) determined that uncontrolled drainage systems were over-draining land and recommended a shallow water table concept for drainage design as a means to reduce drainage flow, and proposed a shallow drainage installation concept to increase crop water use from shallow ground water in semi arid areas with good quality ground water.

A number of reports related to drainage system solutions and designs have been recently published (Ayars, 1996, Christen and Ayars, 2001; Christen and Skehan, 2001; Soppe and Ayars, 2003).

Abbott et al. (2002) indicated that significant beneficiaries of controlled drainage were the farmer (in terms of increased yields) and the wider community (in terms of water saving). Evans et al. (1996) reported that many farmers in North Carolina's lower coastal plain are considering the installation of a dual-purpose system of underground tubing that can be used both for subsurface drainage and sub-irrigation. In a similar manner, Manguerra and Garcia (1997) proposed a series of alternating drainage and no-drainage cycles.

Fausey (2004) compared the use of free drainage, controlled drainage, and sub-irrigation water management practices in an Ohio lakebed. Controlled drainage resulted in a reduction of water and nitrate released offsite, and a reduction in the concentration of nitrate in vadose zone water, as compared to uncontrolled drainage.

The objectives of the present study were to predict the effect of different drainage control factors on root zone salinity, drainage discharge rate, water table depth, and irrigation efficiency and sufficiency in the Harran Plain, using the SaltMod simulation model.

Materials and Methods

Research Area

The research was conducted in the Harran Plain, located in southeastern Turkey, near the city of Şanlıurfa (Figure 1). The plain lies mainly between 520 m and 345 m above sea level and has a flat topography.

Figure 1. Location of the Harran Plain and experimental area.

There are 2 different aquifers under the Harran Plain. The first, which lays deeper within the calcareous stones (confined), is not affected by irrigation; however, the shallow aquifer (unconfined) is significantly affected by irrigation practices. The water source of the Eocene calcareous aquifer is from higher altitudes and this aquifer is a confined aquifer. Recent sinkholes lay on Miocene series and are on top of an unconfined aquifer. Pliocene-clay and Miocene-clay calcareous rocks limit the flow of water and cause water to collect in Pleistocene sediments of sand and gravel, and Pliocene and Miocene calcareous rocks are impermeable. Well depth ranges from 15 to 150 m and the water flows from north to south.

Climate in the region is classified as semi-arid; the weather is hot and dry in the summer, and cold and rainy during the winter. The long-term mean maximum air temperature is 31.3 °C for July, while the long-term mean minimum temperature measured in January is 4.9 °C. Long-term total annual rainfall and the seasonal evaporation rate are 365 mm and 1849 mm, respectively. Almost no rain falls during the summer season (GDRS, 2003).

The topography of the study site is flat and is covered by soils of alluvial origin. Soil texture of the experimental area is clayey, with more than 50%-60% clay and about 25% lime content. Soil reaction (pH) values are in the range of 7.1-8.0.

Soil and water samples were analyzed in the laboratory of The Soil and Water Resources Research Institute in Şanlıurfa. Physical and chemical analyses of soil and water were performed at the laboratory of Köy Hizmetleri Konya Araştırma Enstitüsü (Village Affairs and Rural Service Institute), according to the methods described by Richards (1954).

The salinity of secondary and main drainage canal water is reported to vary in the range of 0.4-0.81 (Berakatoğlu and Bahçeci, 2005). While the average salinity of water used in the study area was 0.470 dS m^{-1}, the average salinity of water discharged from lateral drains reached 19.4 dS m^{-1} (Table 1).

Properties of SaltMod

In order to estimate the effect of controlled drainage on soil salinity and irrigation efficiency, the SaltMod simulation model was used. SaltMod is a computer-based model for simulating the salinity of soil and drainage waters, water table depth, and drain discharge in irrigated agricultural lands under different hydrological and geo-hydrological conditions, varying water management options, and several crop rotation schedules.

The model was developed to make long-term predictions of the impact of water management programs (including drainage) on the level of the water table, and on the salt content of the soil, ground water, and drainage effluent. It can also assess the impact of re-

Table 1. Some chemical properties of the irrigation waters from the test area.

Water resource	pH	EC dS m^{-1}	Cations meq l^{-1}			Total	Anions meq l^{-1}			Total
			Na	Ca	Mg		HCO_3	Cl	*SO_4	
Euphrates water	7.6	0.350	1.8	0.05	1.8	3.65	1.15	1.24	1.16	3.65
Irrigation water	7.98	0.470	2.0	0.1	2.05	4.13	1.48	1.54	1.11	4.13
Drainage water	7.35	19.4	151.0	0.1	46.1	197.2	61.4	63.2	72.5	197.2

*Calculated.

used drainage water. It includes area frequency distributions of salinity. SaltMod can also simulate farmers' agricultural and water-management responses to changes in water table depth and soil salinity, which, in turn, can influence the salt and water balance (Oosterbaan, 1998).

In order to use SaltMod some factors should be determined first. Determination of the data required could be done by entering different values for leaching efficiency (F_{lr}), and natural drainage (G_n) into SaltMod until values that match the actual measured soil salinity and water table depths are obtained.

Some of the data used as input parameters in SaltMod were estimated or determined with in situ, laboratory, and correlation methods, while the others were calculated by the model (Table 2).

Experimental Setup

Plastic drain pipes were installed to an average depth of 1.50 m. The length and space between the laterals were 250 and 60 m, respectively. Three laterals were connected to a manhole (Figure 2). Trench width, and lateral and collector slopes were 0.36 m, and 0.0005-0.0010 and 0.0025-0.2, respectively. The diameter of the laterals and the collector were 100 and 160 mm.

The irrigation water entering the plot area during the irrigation season was measured using a Parshall flume installed at one of the inlet points. In order to determine drain discharge rates, flow measurements were made using an electronic water level meter mounted on a flume at the end of the collector connected to the open drainage

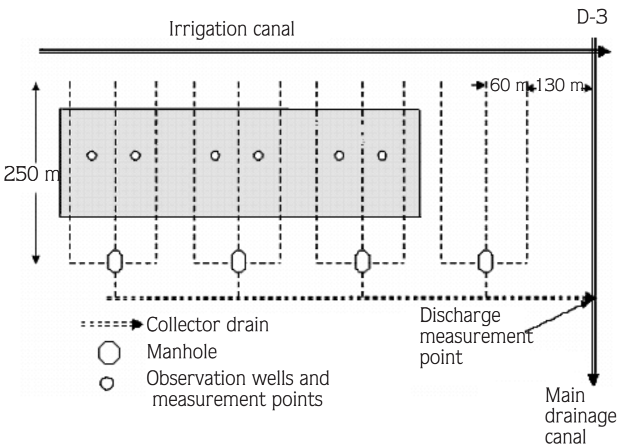

Figure 2. Layout of the experiment.

Table 2. Summary of input parameters required by SaltMod.

1. Duration of season (month)	
Season 1 (March to September)	7
Season 2 (October to February)	5
2. Soil properties	
Fraction of irrigation or rain water stored in the root zone	0.75
Total porosity of the root zone (calculated)	0.60
Total porosity of the transition zone (calculated)	0.45
Total porosity of the aquifer (assumed*)	0.40
Drainable porosity of the root zone (determined in area)	0.06
Drainable porosity of the transition zone (determined in area)	0.04
Drainable porosity of the aquifer (assumed)	0.20
Leaching efficiency of the root zone (calibrated)	0.70
Leaching efficiency of the transition zone (assumed)	0.80
Leaching efficiency of the aquifer (assumed)	1.00
3. Water balance components	
Irrigation in season 1 (m)	0.80
Irrigation in season 2 (m)	0.00
Rainfall in season 1 (m)	0.110
Rainfall in season 2 (m)	0.255
Potential evapotranspiration in season 1 (m)	0.950
Outgoing groundwater flow through the aquifer in both seasons (calibrated) (m)	0.160
4. Drainage criteria and system parameters	
Root zone thickness (m)	1.0
Depth of subsurface drains (m)	1.50
Drain spacing (m)	60
Thickness of the transition zone between the root zone and aquifer (m)	10
Thickness of aquifer (assumed) (m)	30
Ratio of drain discharge and height of the water table above the drain (m d^{-1} m^{-1})	0.008
Rate of drain discharge and squared height of the water table above the drain (m d^{-1} m^{-2})	0.000
Natural drainage computed by SaltMod (m)	0.155
5. Initial and boundary conditions	
Depth of the water table at the beginning of season 1 (m)	1.65
Initial salt concentration of soil moisture in the root zone at field sat. (dS m^{-1})	9.03
Initial salt concentration of the soil moisture in the transition zone (dS m^{-1})	8.40
Average salt concentration of incoming irrigation water (dS m^{-1})	0.47

*Assumptions were correlated with texture and structure of soil.

canal. Measurements were automatically made with a Parshall flume every 30 min, as described by Grant and Dawson (1997).

In addition, the following measurements and water table level observations were made during the experiment: (i) quantity of irrigation water and drain discharge rate, (ii) water table level and changes in the water table level everyday during crop growth, at 6 points, (iii) average seasonal soil salinity in the plant root zone during spring and fall, at 6 points.

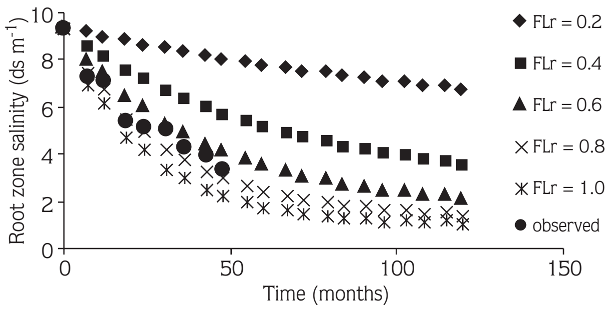

Figure 3. Calibration of root zone salinity and leaching efficiency in the test area.

Results

Calibration of the SaltMod

Some factors could not be measured, notably the leaching efficiency of the root zone (F_{lr}) and transition zone (F_{lx}), and the natural drainage (G_n) of groundwater through the aquifer (there was no upward rise of groundwater from the aquifer into the upper soil layers). All these factors should be determined prior to applying the SaltMod model. This can be done by trials with SaltMod using different values of root zone and transition zone leaching efficiency, and the natural drainage, choosing those values that produce soil salinities and water table depths that correspond with the values actually measured (Oosterbaan, 1998, 2000).

Determination of Leaching Efficiency

Leaching efficiency of the root (F_{lr}) or transition zone (F_{lx}) is defined as the ratio of the salt concentration of the water percolating from the root or transition zone to the average concentration of the soil water at saturation. A range of arbitrary values were given for the leaching efficiency of the root zone (F_{lr}) and transition zone (F_{lx}); the corresponding root zone salinity results of the program were compared with the values actually measured. The arbitrary F_{lr} values were taken as 0.2, 0.4, 0.6, 0.8, and 1.0, salinity levels of the root zone were obtained, and the data are shown in Figure 3. F_{lr} = 0.7 was the best matching value to the observed values and was used in all calculations (Bahçeci and Nacar, 2007).

Determination of the Natural Subsurface Drainage

In SaltMod, natural subsurface drainage ($Gn = G_0 - G_i$) is defined as the quantity of horizontally outgoing ground water (G_0, m^3 season per m^2 total area) minus the quantity of horizontally incoming ground water (G_i) in season. This value was determined by setting the natural drainage values (G_i) at zero, arbitrarily changing the outgoing ground water values, and finding the corresponding values for water table depth (D_w) and drain discharge (G_d). Since the 1st season (7 months) was longer than the second season (5 months), the arbitrary G_{01} and G_{02} values, i.e. the G_o values for the 1st and 2nd season respectively, are in pairs: (0.00, 0.00) and (0.04, 0.03), (0.07, 0.05) and (0.09, 0.07), and (012, 0.09) and (0.14, 0.11). As inflow G_i values were taken to be equal to zero, G_0 values for both seasons together gave G_n values (Table 3).

Results from the simulation showed that when the annual natural drainage was set at 0.0 m for both seasons, drain discharge (G_d) was 0.190 and 0.067 m for the first and second seasons, respectively. These discharge values are much higher than those observed in the test area. When the natural drainage was accepted as

Table 3. Simulated values of annual natural drainage (G_n m/year), seasonal average depth (D_w, m), and quantity of drainage water (G_d, m/season) for the 2nd year.

Gn Annual	1st Season (summer)		2nd Season (winter)	
	Dw	Gd	Dw	Gd
0.00	1.29	0.190	1.34	0.067
0.07	1.31	0.150	1.37	0.037
0.12	1.33	0.121	1.39	0.017
0.16	1.34	0.097	1.44	0.0
0.21	1.37	0.047	1.87	0.0
0.25	1.39	0.017	2.09	0.0
Observed values	1.40	0.099	1.60	0

0.25 m (0.14, 0.11), the simulated discharges (G_d) of 0.017 and 0.0 m for the first and second seasons, respectively, were much lower than those observed. Drain discharge (G_d) was simulated by the model as 0.099 and 0.002 m when the annual natural drainage was assumed to be 0.16 m. The simulated values were close to the discharge values measured during the summer and winter seasons.

Drainage Control Factor and Water Table Depth

The water table depth was in the range of 1.5-2.0 m at the beginning of the irrigation season (1st or 2nd week of April), and rose almost to the soil surface during the period of June-August due to inappropriate irrigation management and over irrigation of cotton in the test area. Due to over irrigation during the irrigation season, part of the water diverted for irrigation flowed directly to the drainage canal and diluted the drainage water in the canals, decreasing the salinity of the water. There was also a water shortage in the pilot area during the irrigation season; thus, drainage canal waters were routinely used to supplement the irrigation process.

The model was run for the various combinations of F_{rd} and QH1 values. The simulation model was run for drainage control factor (F_{rd}) values of 0.00 0.25, 0.50, 0.75, and 1.0. Drainage reaction factors (QH1) were calculated as 0.008, 0.006, 0.004, 0.002, and 0.0 for these F_{rd} values. The outputs simulated are summarized in Tables 4 and 5.

When the drainage control factor was increased from 0.00 to 0.25, 0.50, 0.75, and 1.0, water table depth was simulated to be 1.42, 1.36, 1.20, 1.02, and 0.86 m for the summer, and 1.49, 1.49, 1.47, 1.41, and 0.96 m for the winter season at the 10th year.

When the drainage control factor was 0.75, water table depth was simulated to be 1.02 m for the summer and 1.41 for the winter season at the 10th year.

Field Irrigation Efficiency and Sufficiency

Field irrigation efficiency (F_f) is known as the ratio of the quantity of irrigation water evaporated to the quantity of irrigation water applied. On the other hand, field irrigation sufficiency (Js) is defined as the rate of actual over potential evapotranspiration.

When the water table fell below the level of the drains within a short time, without controlled drainage conditions, irrigation efficiency and sufficiency were negatively affected; the crops could not use water due to fast, deep percolation.

Table 4. Estimates of drain depth (D_d, m), soil salinity (C_r4, dS m^{-1}), seasonal average depth of the water table (D_w, m), amount of drainage water (G_d, m per season), irrigation efficiency (F_fA), and irrigation sufficiency (J_sA) for the 10th year.

Drainage control factors	Drainage reaction factors	1st season (summer)				
$F_{rd}1$	QH1	C_r4	G_d	D_w	F_fA	J_sA
0.00	0.008	2.17	0.135	1.42	0.75	0.57
0.25	0.006	2.17	0.131	1.36	0.75	0.72
0.50	0.004	2.17	0.125	1.20	0.75	0.72
0.75	0.002	3.00	0.050	1.02	0.82	0.79
1.00	0.00	4.65	0.00	0.86	0.89	0.86
		2nd season (winter)				
0	0.008	2.01	0.010	1.49	0	1.0
0.25	0.006	2.01	0.013	1.49	0	1.0
0.50	0.004	2.01	0.020	1.47	0	1.0
0.75	0.002	2.78	0.026	1.41	0	1.0
1.00	0.00	4.36	0.00	0.96	0	1.0

Table 5. Cumulative frequency distribution of root zone salinity for varying drainage control (reduction) factors for EC_{iw} = 0.470 dS m^{-1} (10^{th} year).

Salinity frequency	$F_{rd}1$ = 0.0, $F_{rd}2$ = 0 QH1 = 0.008		$F_{rd}1$ = 0.25, $F_{rd}2$ = 0 QH1 = 0.006		$F_{rd}1$ = 0.50, $F_{rd}2$ = 0 QH1 = 0.004		$F_{rd}1$ = 0.75, $F_{rd}2$ = 0 QH1 = 0.002		$F_{rd}1$ = 0.10, $F_{rd}2$ = 0 QH1 = 0.002	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	season 1	season 2
Cr4 80%	2.64	2.44	2.64	2.44	2.64	2.44	3.65	3.38	5.65	5.30
Cr4 60%	2.19	2.03	2.19	2.03	2.19	2.03	3.03	2.80	4.69	4.40
Cr440%	1.87	1.73	1.87	1.73	1.87	1.73	2.59	2.40	4.01	5.76
Cr420%	1.57	1.45	1.57	1.45	1.57	1.45	2.17	2.00	3.35	3.14

The model predicted 0.75 and 0.57 irrigation efficiency and irrigation sufficiency, respectively, when the drainage control factor was zero for the summer and winter. The values were predicted to increase to 0.82 and 0.79 by increasing the drainage control factor to 0.75 (Table 4). Further increasing of the drainage control factor provided water saving and increased salinity in the root zone. Similar conclusions were previously reported by other authors. As can be seen, irrigation efficiency and sufficiency increased at the rate of 11% and 38.5%, respectively, when the drainage control factor was 0.75.

Drain Discharge Rates and Root Zone Salinity

The effects of different drainage control factors (F_{rd}) on drain discharge rate were also simulated. The quantity of drainage water decreased in response to increasing the drainage control factor during the summer season (Table 4).

The amount of drainage water decreased from 0.135 to 0.050 m when the drainage control factor increased from 0 to 0.75 during the summer season, but it increased from 0.010 to 0.026 m during the winter season; however, the total amount of drainage water decreased and salinity increased from 2.17 to 3.00 dS m^{-1} in the root zone.

Root zone salinity was not influenced by increasing the drainage control factor to 0.50 during the summer or to 0.75 during the winter.

On the other hand, root zone salinity was not influenced when the drainage control factor was increased to 0.50, but the simulated data also showed that increasing the drainage control factor to above 0.75 leads to significant increases in root zone salinity. Thus, after a period of 10 years, under conditions of drainage control factors of 0.75 and 1.0, root zone salinity in 80% of the entire irrigated area was predicted to increase up to 3.65 and 3.38 dS m^{-1} and 5.65 and 5.30 dS m^{-1} during the first and second seasons respectively. In a similar manner, the salinity of 60% of the total study area is expected to be in the range of 3.03-2.80 dS m^{-1} and 4.69-4.40 dS m^{-1}, respectively, during the summer and winter seasons of the 10^{th} year (Table 5 and Figure 4).

Irrigation Water Salinity and Drainage Control Factors

When both the water salinity and drainage control factor increased, root zone salinity increased significantly. With the same drainage control factor and water salinity of 0.5, 1.0, and 1.5 dS m^{-1}, root zone salinity increased from about 2.0 to 8.0 dS m^{-1} in the 10^{th} year (Figure 5). Therefore, when irrigation water has high salinity, it should be used very carefully in controlled drainage conditions.

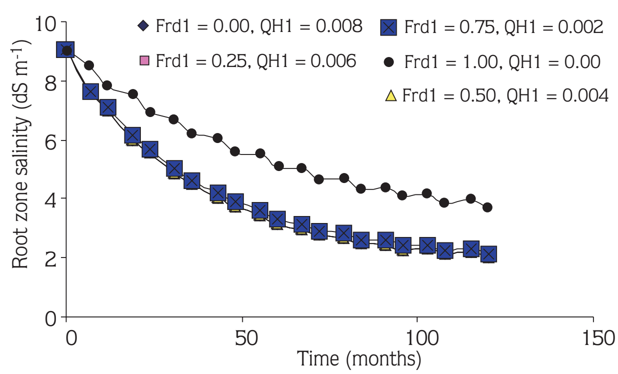

Figure 4. Effects of varying drainage control factors (F_{rd}) on root zone salinity (EC_e) for EC_{iw} = 0.470 dS m^{-1}.

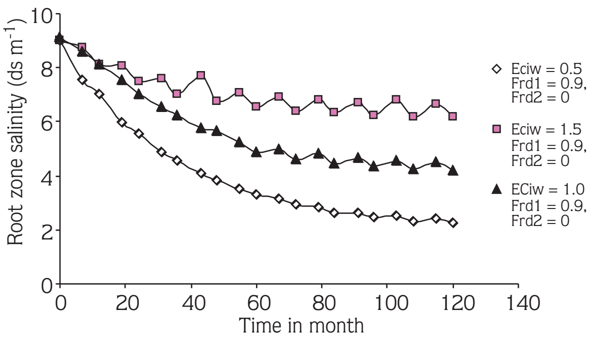

Figure 5. Effects of varying irrigation water salinities (EC_{iw}) on the root zone salinity (EC_e) in the controlled drainage conditions.

Discussion

SaltMod is a very useful tool for predicting root zone soil salinity and the amount of drainage water from land equipped with subsurface drainage systems. The model successfully predicts water table depth and drain discharge rates across agricultural areas using various water management practices (Oosterbaan, 2000; Srinivasulu et al., 2004; Bahçeci et al., 2006; Bahçeci and Nacar, 2007).

Results of our simulation demonstrated that root zone salinity was not influenced by drainage control factors less than 0.50, though increasing the drainage control factor above 0.75 led to significant increases in root zone salinity. No crop-damaging consequences are expected due to increasing the drainage control factor to 0.50 under the conditions of the Harran Plain.

Pratharpar and Qureshi (1998) observed that irrigation requirements can be reduced to 80% of the total crop ET without reducing crop yield or increasing soil salinization in areas where shallow water tables exist. Our SaltMod simulations showed that controlled drainage will increase irrigation efficiency and sufficiency in the Harran Plain by 11% and 38.5%, respectively. Crops can be grown with salty ground water as irrigation water in arid areas. Kruse et al. (1985) stated that maize grown in the presence of saline ground water (6.0 dS m^{-1}) obtained approximately 55% of its water requirement when the water table depth was about 0.6 m below the soil surface.

Safwat and Ritzema (1990) determined the seasonal average depth of 0.8 m is also sufficient for good crop production. By employing the 0.8-m depth as a drainage criterion, one can avoid the design of an excessively extensive drainage system. Rao et al. (1990) revealed that the time-averaged depth of the water table during the critical season need not be more than 0.8 m below the soil surface to allow for adequate reclamation of saline soils.

Disposal of drainage water is one of the biggest problems in the experimental area since the Harran Plain does not have a sufficient drainage outlet. At present, there is no solution to the problem of collecting drainage waters from the plain, but in the near future it will have to be stored in a reservoir. For that reason, the amount of drainage disposal and its quality is a problem of great importance. When the drainage control factor increased to 0.50, the drainage water decreased from 0.135 m to 0.125 m during the irrigation season, without any increase in root zone salinity. When the drainage control factor increased to 0.75, the drainage water decreased from 0.135 m to 0.050 m during the irrigation season, but the salinity increased from 2.17 to 3.00 dS m^{-1} in the root zone.

Considering water and soil management in the study area for the next decade, the results of the simulation indicate: (i) no significant changes in the root zone salinity should be expected if the drainage control factor applied is lower than 0.75; (ii) a significant increase in root zone soil salinity will occur if the drainage control factor increases above 0.75; (iii) high salinity due to an increased drainage control factor will damage most crops grown in the study area, except for crops with high salt tolerance, such as cotton and barley; (iv) a more significant increase in root zone salinity should be expected if both the drainage control factor and water salinity are increased.

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