

IMPLICATION OF GROUNDWATER FLUCTUATION ON THE SEASONAL SALT DYNAMIC IN THE HARRAN PLAIN, SOUTH-EASTERN TURKEY[†]

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ABSTRACT

Inefficient farm-level water management aggravates groundwater fluctuation and salt accumulation particularly in arid and semi-arid irrigated agriculture. Inappropriate water management practices in the Harran Plain are a good example. A study was carried out to investigate the effect of groundwater fluctuation on the seasonal salt dynamic in four widespread soil series in the Harran Plain with different natural drainage, south-eastern Turkey. Four profiles were excavated and soil samples were collected seasonally up to 100 cm depth with 10 cm intervals. Similarly, irrigation and groundwater samples were collected from the fields where soil sampling was carried out. Significant seasonal variations in the salt dynamic were observed with the fluctuation levels of the groundwater. Total salt content at 1 m soil depth remained constant during the year, however salt fluctuation throughout the root zone in the growing season exceeded the threshold values of corn, wheat and cotton, commonly grown crops in the region, of 1.7, 6.0 and 7.7 dS m⁻¹, respectively. However, soils with less water fluctuation showed lower salt accumulation in the root zone from May to October. Results also confirmed that soils can be non-saline, but groundwater salinity, which may not be point specific, requires special attention. Copyright © 2009 John Wiley & Sons, Ltd.

KEY WORDS: salt movement; irrigated soils; salinity monitoring; salinization; groundwater fluctuation

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RÉSUMÉ

Une gestion de l'eau inefficace en agriculture irriguée aggrave les fluctuations de nappe et l'accumulation de sel dans les zones arides et semi-arides. Les pratiques inappropriées de gestion des eaux dans la plaine de Harran sont un bon exemple. Une étude a été réalisée pour étudier l'effet de la fluctuation des eaux souterraines sur la dynamique saisonnière du sel dans quatre types de sols fréquents avec différents drainages naturels dans la plaine de Harran au sud-est de la Turquie. Quatre profils ont été creusés et des échantillons de sol recueillis à chaque saison jusqu'à 100 cm de profondeur à intervalle de 10 cm. De même, des échantillons d'eau d'irrigation et d'eau souterraine ont été recueillis dans les champs où l'échantillonnage des sols a été réalisé. D'importantes variations saisonnières dans la dynamique de sel ont été observées avec la fluctuation des niveaux des eaux souterraines. La teneur globale en sel dans le sol à 1 m de profondeur est restée constante au cours de l'année, toutefois la fluctuation du sel dans la zone racinaire pendant la période de végétation a dépassé les seuils pour le maïs, le blé et le coton, les

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[†]Effet des fluctuations des eaux souterraines sur la dynamique saisonnière du sel dans la plaine Harran, sud-est de la Turquie.

valeurs admises dans la région étant de 1.7, 6.0 et 7.7 dS m⁻¹ respectivement. Toutefois, les sols avec moins de fluctuations d'eau ont montré moins d'accumulation de sel dans la zone racinaire de mai à octobre. Les résultats ont également confirmé que les sols peuvent être non-salés, mais que la salinité des eaux souterraines non localisée nécessite une attention particulière. Copyright © 2009 John Wiley & Sons, Ltd.

MOTS CLÉS: mouvement de sel; sols irrigués; suivi de la salinité salinisation; fluctuation des eaux souterraines

INTRODUCTION

Although irrigation is inevitable to meet the food and fibre demands of the growing population, there are associated environmental concerns such as salinization of land and groundwater, particularly under arid and semi-arid conditions (Patel *et al.*, 2002; Feng *et al.*, 2003). This necessitates the re-evaluation of agricultural practices under irrigation (Qadir *et al.*, 2007).

Inefficient irrigation aggravates the risk of salt-induced land degradation and water quality deterioration, which are major threats to sustainable crop production in irrigated agriculture (Metternicht, 2001; Rogers, 2002). While excess application of water in the absence of a drainage system may cause the water table to rise to a damaging level, it can also cause an increase in soil salinity (Mondal *et al.*, 2001). Management of drainage water by irrigation is a necessity to maintain soil salinity, through leaching, at acceptable levels for crop growth (Qadir and Oster, 2004). Estimates suggest that at least 20% of the global irrigated area already falls under different types of salt-affected soils (Ghassemi *et al.*, 1995).

Poor irrigation and management of drainage practices and water losses through high evapotranspiration, especially during the summer period, low precipitation rates and high capillary rise of saline groundwater are the main causes of secondary salinization. As the water table rises, salts dissolved in the groundwater reach the soil surface and accumulate there through capillary movement (Northey *et al.*, 2006). This is influenced by climate, soil and crop types, irrigation water quality and management practices, depth to water table, and groundwater salinity. In saline soils, crop growth is hampered by salt accumulation in the root zone when salt concentration exceeds the tolerance limits of the crop (Karim *et al.*, 1990).

Salt-induced land degradation is a major impediment to optimal utilization of land resources in many arid and semi-arid countries, including Turkey. Economically irrigable land potential in Turkey is about 8.5 million ha, of which 4.9 million ha are now irrigated. The government of Turkey aims to expand the area under irrigated agriculture. Therefore, the South-eastern Anatolian Project, commonly known as GAP, has been established to irrigate 1.7 million ha of land, which is about 20% of the total irrigable land of Turkey. Soils are exposed to salinization and this is especially a very distinct problem in the GAP region (Kendirli *et al.*, 2005), resulting in considerable yield losses (Çullu, 2003). The GAP is a large-scale, multi-sector development project in south-eastern Turkey. The Atatürk Dam constructed on the Euphrates River is one of the largest in the world, providing good-quality irrigation water, including the Harran Plain, which is the largest for irrigated agriculture within the GAP project.

The water budget for the Harran Plain as reported by the Turkish State of Water Works for the year 2000 reveals that water entering the plain for irrigation is about 1208 million m³ and precipitation contributes about 104 million m³. The losses of water from the plain occur in two ways: (1) evapotranspiration accounting for about 996 million m³, (2) discharge as runoff and drainage resulting in 193 million m³. The annual rate of water storage in the plain is about 121 million m³. The stored water stays in the system and causes the increase in groundwater level, especially from the south to the middle north of the plain (Özgür *et al.*, 2001). Currently, about 15% of the plain is salt-affected and 30% of it has a shallow water table with the potential to develop salinity-related problems (Çullu *et al.*, 2002).

The objective of this study was to estimate the effects of groundwater fluctuation on seasonal salt dynamics in selected irrigated and non-irrigated areas of the Harran Plain. Information will assist researchers and farm advisors in choosing appropriate crops as well as soil and irrigation management practices in areas where salt-induced land degradation and water quality deterioration are on the rise.

MATERIALS AND METHODS

Study area and site characterization

The study site occurs in the largest and first irrigated area of the south-eastern region of Turkey (between $38^{\circ} 47'$ – $39^{\circ} 15'$ E and $36^{\circ} 40'$ – $37^{\circ} 21'$ N) and located in the Harran Plain, which covers about 152 000 ha irrigable land. The location of the sampling sites is given in Figure 1.

The study area has the major climatic features of the eastern Mediterranean with a strong continental influence. The mean average temperature is 18.8°C and annual rainfall is about 300 mm with evaporation reaching as high as 2023 mm. The highest evaporation is generally in the month of July and the lowest in February. Rainfall is irregular and mostly falls in winter. The area receives almost no rainfall between June and September (Figure 2).

The soil moisture regime is xeric and temperature regime is mesic (Soil Survey Staff, 1999). However, the moisture regime of the southern part of the study area is close to aridic. The soils of the area studied have high pH and are moderately to highly calcareous. The cation exchange capacity (CEC) is high and organic matter content low. The particle-size distribution reveals that soils are heavy clayey in texture down to 100 cm depth (Table I).

Four sites were selected for the study: (1) Akcakale (S1) soil formed on lowland clayey deposits, (2) Gurgelen soil (S2) developed from the mudflow materials transported during the Pleistocene climatic fluctuations with small-scale fluvial materials, (3) Cepkenli soil (S3) located in the middle of the plain, (4) Ekinyazi soil (S4) derived from marls and sandy marls of lacustrine deposits in the south-eastern part of the plain. These four soils represent the major soil series of the Harran Plain. In general, the soils of the plain are classified as Entisols, Vertisols,



Figure 1. Location of the Harran Plain in Turkey and study area consisting of four sites (soil series): S₁ (Akcakale), S₂ (Gurgelen), S₃ (Cepkenli), and S₄ (Ekinyazi)

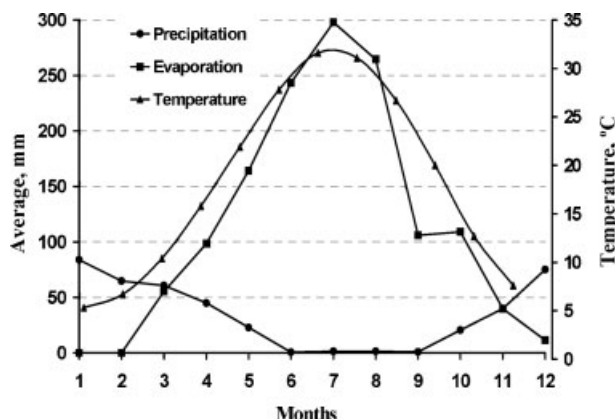


Figure 2. Distribution of monthly average rainfall, temperature, and evaporation values in the study area (based on 30-year average)

Inceptisols, and Aridisols according to Soil Taxonomy (Soil Survey Staff, 1999) and Leptosols, Vertisols, Cambisols, and Calcisols in World Resource Base (International Society of Soil Science (ISSS), International Soil Reference and Information Centre (ISRIC), Food and Agriculture Organization of the United Nations (FAO), 1998) classification systems.

Poor water management practices have caused water tables to rise in an approximately 50 000 ha area of the plain (State Hydraulic Works, 2004). As the basin is closed, discharge of the drainage water is currently the biggest problem in the Harran Plain (Bahçeci *et al.*, 2008).

METHODOLOGY

Soil samples were collected at 10 cm intervals to a depth of 100 cm. Samples were collected in February, May, August, and November of 2000. Water table levels were also measured at 3-month intervals from February to November by using a water-level recorder. Similarly, water samples from irrigation and groundwater were collected at the same sites, near the soil profile. Determinations of pH, electrical conductivity (EC), soluble cations and anions were made for each water sample using the standard methods as described by the US Salinity Laboratory Staff (Richards, 1954).

As an index of sodicity, sodium adsorption ratios (SAR) were calculated using Equation (1):

$$\text{SAR} = C_{\text{Na}} / [(C_{\text{Ca}} + C_{\text{Mg}}) / 2]^{1/2} \quad (1)$$

where C represents the concentrations in $\text{mmol}_c \text{ l}^{-1}$ of the ions. The electrical conductivity of the soils (EC_e) and soluble cations and anions were determined from the saturated soil paste extract. The CEC was determined with ammonium acetate (Richards, 1954). Other determinations consisted of soil texture (Bouyoucus, 1951), contents of organic matter (Nelson and Sommers, 1982), and CaCO_3 (Allison and Moode, 1965). Soil texture, organic matter content, and CEC were determined only once on samples taken in February, as these characteristics were not expected to change to a significant extent over a short period.

The exchangeable sodium percentage (ESP) was calculated from Equation (2) using the exchangeable Na^+ (E_{Na}) and cation exchange capacity (CEC), both expressed as $\text{cmol}_c \text{ kg}^{-1}$ of the soil:

$$\text{ESP} = 100 (E_{\text{Na}}) / \text{CEC} \quad (2)$$

A treatment effects model was used to investigate the seasons and soil series on the salt dynamic of the plain using soil electrical conductivity. The first treatment comprises the four regular seasons, i.e. winter, spring, summer, and autumn (February, May, August, and November), while the soil series comprises two treatments: non-irrigated

Table I. Some physical and chemical properties of the soils studied

Soils	Depth (cm)	pH (Paste Extract)	ECe (dS m ⁻¹)	ESP	Particle size distribution (%)			CEC (cmol _c kg l ⁻¹)	Organic matter (%)	CaCO ₃ (%)
					Sand	Silt	Clay			
S1 Non- irrigated soil	0–10	7.65	9.3	21.9	9.9	25.2	64.9	33.8	0.94	16.6
	10–20	7.73	12.6	27.2	12.0	25.2	62.8	35.0	0.90	19.9
	20–30	7.50	20.9	25.3	12.0	25.2	62.8	37.8	0.92	17.9
	30–40	7.38	17.4	26.7	7.8	25.2	67.0	37.0	0.78	18.4
	40–50	7.66	14.3	27.4	7.8	27.3	64.9	36.7	0.66	18.5
	50–60	7.74	13.9	32.9	9.9	27.3	62.8	36.5	0.64	19.8
	60–70	7.84	12.5	32.7	9.9	27.3	62.8	36.3	0.70	19.5
	70–80	7.83	13.7	36.7	7.8	25.2	67.0	34.5	0.58	20.2
	80–90	8.02	12.5	37.9	7.8	33.6	58.6	34.2	0.54	18.0
S2 Irrigated soil	90–100	8.03	13.9	29.0	7.8	31.5	60.7	31.7	0.50	22.0
	0–10	8.15	2.3	7.4	7.8	21.0	71.2	28.6	1.38	22.4
	10–20	8.04	2.1	7.4	12.0	21.0	67.0	29.4	1.44	24.2
	20–30	8.14	3.8	9.3	14.0	14.7	71.2	30.4	1.20	25.5
	30–40	7.79	4.0	15.1	7.8	25.2	67.0	30.2	0.84	26.1
	40–50	7.72	6.2	18.6	7.8	27.3	64.9	30.0	0.78	25.9
	50–60	7.76	7.5	19.3	7.8	25.2	67.0	31.7	0.78	26.1
	60–70	8.10	8.3	23.8	12.0	23.1	63.0	29.1	0.72	25.1
	70–80	7.85	8.0	27.8	16.2	21.0	62.8	28.7	0.70	23.8
S3 Irrigated soil	80–90	7.75	9.8	29.0	18.3	16.8	64.9	28.6	0.64	25.0
	90–100	7.80	6.2	27.3	18.3	16.8	64.9	30.5	0.66	25.0
	0–10	8.05	1.2	2.9	18.3	18.9	62.8	31.5	1.34	25.0
	10–20	8.41	1.0	5.2	16.2	21.0	62.8	31.5	1.30	24.0
	20–30	8.09	1.6	7.0	18.3	16.8	64.9	31.5	0.98	23.6
	30–40	7.91	2.8	8.6	18.3	14.7	67.0	31.5	0.76	25.1
	40–50	7.91	4.3	6.9	20.4	14.7	64.9	31.1	0.72	26.9
	50–60	7.78	3.0	6.5	18.3	16.8	64.9	31.1	0.70	26.6
	60–70	7.52	2.0	6.8	16.2	18.9	64.9	31.1	0.66	27.0
S4 Irrigated soil	70–80	7.75	1.8	5.0	14.1	18.9	67.0	29.2	0.64	32.0
	80–90	7.37	2.1	5.6	7.8	25.2	67.0	31.0	0.58	27.6
	90–100	7.54	2.0	14.7	14.1	23.1	62.8	28.0	0.50	30.5
	0–10	8.22	5.3	11.2	18.3	21.0	60.7	27.1	1.06	27.3
	10–20	8.29	5.4	7.9	18.3	18.9	62.8	27.0	1.34	25.2
	20–30	8.21	6.4	6.5	20.4	23.1	56.5	27.4	1.12	23.5
	30–40	8.16	7.6	3.5	20.4	18.9	60.7	28.0	0.90	26.2
	40–50	7.74	6.1	17.9	22.5	10.5	67.0	25.4	0.76	30.7
	50–60	8.01	5.5	12.3	20.4	12.6	67.0	27.2	0.86	30.4
	60–70	7.99	3.9	11.0	20.4	14.7	64.9	20.4	1.12	30.1
	70–80	7.94	3.0	6.7	20.4	12.6	67.0	28.0	0.72	26.3
	80–90	7.89	2.7	6.0	20.4	12.6	67.0	27.6	0.72	33.6
	90–100	7.96	2.2	5.9	16.2	18.9	64.9	28.0	0.74	34.6

S1 = Akcakale soil, S2 = Gurgelen soil, S3 = Cepkenli soil, S4 = Ekinyazi soil; soil samples were collected in February 2000.

(Akcakale) and irrigated soils (Gurgelen, Ekinyazi, and Cepkenli). The treatment effect model can be expressed as

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijk} \quad (3)$$

$$i = 1, 2, 3, \dots, a \quad b = 1, 2, 3, \dots, b \quad k = 1, 2, 3, \dots, r$$

where μ is the grand mean, α_i is the effect of the i th level of season, β_j is the effect of the j th level of soil series, and $(\alpha\beta)_{ij}$ is the interaction effect between the i th level of season and the j th level of soil series. Ten samples at each site

in each season at different soil layers were taken to represent replications. We expect that sums of the treatment effects are likely to be equal to zero (Equation 4). That is

$$\sum_{i=1}^a \alpha_i = 0, \quad \sum_{j=1}^b \beta_j = 0, \quad \sum_{i=1}^a (\alpha\beta)_{ij} = \sum_{j=1}^b (\alpha\beta)_{ij} = 0, \quad (4)$$

RESULTS AND DISCUSSION

Groundwater fluctuation and quality

Since the start of irrigation in 1995 from Atatürk Dam, cotton (*Gossypium hirsutum* L.) was chosen as a main crop, due to its high income potential. Considering the general perception that the greater the amount of water used for irrigation the greater production will be, farmers used excess water with furrow irrigation methods. Irrigation in the area has caused a high water table and fluctuations of the groundwater and its quality, with salinity levels reaching as high as 30 dS m^{-1} over the growing season (Table II).

It is generally agreed that fluctuation in groundwater and capillary movement of saline water to the soil surface contribute to salt accumulation in the soil profile (Khang *et al.*, 2001; Northey *et al.*, 2006). The groundwater in the soil profile from the Akcakale site fluctuated between 180 and 88 cm, with different levels of salts changing from 7.0 to 29.6 dS m^{-1} during the study period. While the EC was 29.6 dS m^{-1} at 110 cm soil depth in February, it decreased to 7.6 and 7.0 dS m^{-1} at 88 and 180 cm depths in May and November, respectively. Water samples collected in May and November at the Akcakale site have a lower EC than the other months, as there is lateral water flow from the excessively irrigated adjacent lands. Because of the cotton cultivation on about 80% of the irrigated area in the plain, farmers apply intensive and excessive irrigation water between May and August resulting in a rise of groundwater levels. There is no irrigation between November and February.

When the poor-quality groundwater (high in salt and sodium levels) was deeper than 2 m, its effects on salt accumulation in the soil were not significant. However, in case of groundwater shallower than 2 m, its effects were significant, depending on the soil type, amount of irrigation water, rainfall, groundwater salt content, and level of evaporation. As can be seen in Figure 3 (A, B), fluctuation of saline groundwater (between 1 and 2 m) was observed with time. The salt accumulation and fluctuation are also given in Figure 4.

The groundwater analyses indicated that the Akcakale and Cepkenli sites which are located in a lower position on the plain, had higher concentrations of Na^+ , Ca^{2+} , Mg^{2+} , and SO_4^{2-} than in the other two locations (Table II). A high level of electrolytes in the groundwater supports the idea that salt concentration fluctuates in the soils. Fluctuations in the water table within 1–2 m and capillary movement of saline water to the soil surface have contributed to salt accumulation at different soil depths. Increasing levels of the water table and salt content of shallow groundwater also have environmental implications for non-saline and non-irrigated areas, because they may become saline over time.

Despite the high seasonal groundwater fluctuation in the plain, the natural drainage of the sites studied (irrigated and non-irrigated soils) using the USDA classes (Soil Survey Division Staff, 1993) was described as moderately well (S3, S4) and somewhat poorly drained (S1, S2), and annual natural drainage in the plain was found to be 0.155 m yr^{-1} (Bahceci *et al.*, 2008). Soils S1 and S2 have less sand and carbonate content, whereas soils S3 and S4 contain more carbonate and sand. These play a major role in natural drainage and permeability and consequently in salt balance and speed of the water flow (Table I). Despite the fact that soil S3 is moderately well drained, however as it occurs in a local depression, it has high saline groundwater, even in May (Table II). This supports the view that while a soil could be non-saline, because of its position in the landscape, it could receive saline groundwater from surrounding slightly higher elevations. These findings suggest that salinity is not point specific but somehow associated with the entire soils in of the plain. Soils that are non-saline but with high groundwater require closer attention, as they may become saline in the near future.

Table II. Temporal variations in groundwater characteristics of the four selected soils studied

Soil series and groundwater sampling time	Sampling months	Water table depth (cm)	pH	EC _w (dS m ⁻¹)	Soluble cations and anions (mmol _c l ⁻¹)							SAR	Water class ^a
					Na ⁺	K ⁺	Ca ²⁺ +Mg ²⁺	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻		
S1 (Soil groundwater sampling time in the non-irrigated Akcakale soils)	February	110	7.32	29.6	296	0.13	189	0.80	2.80	145	336	30.5	C ₄ S ₄
	May	88	7.47	7.6	69	0.26	38	0.80	1.70	36	68	15.7	C ₄ S ₂
	August	120	7.27	29.4	294	0.13	166	8.80	0.50	151	300	32.2	C ₄ S ₄
	November	180	7.85	7.0	64	0.21	42	5.20	2.30	28	2	14.0	C ₄ S ₂
S2 (Soil groundwater sampling time in the irrigated Gurgelen soil)	February	180	7.48	7.3	50	0.17	47	0.80	1.20	39	56	10.3	C ₄ S ₂
	May	150	7.22	7.5	38	0.20	64	0.60	2.40	34	66	6.70	C ₄ S ₁
	August	153	8.10	6.9	47	0.22	58	1.80	2.50	25	76	8.70	C ₄ S ₁
	November	190	7.43	6.9	45	0.15	61	2.60	3.60	28	2	8.20	C ₄ S ₁
S3 (Soil groundwater sampling time in the irrigated Cepkenli soil)	February	185	7.61	26.9	301	0.21	150	3.60	5.00	73	369	34.7	C ₄ S ₄
	May	145	7.97	30.1	337	0.19	176	1.40	3.90	84	424	36.0	C ₄ S ₄
	August	135	7.93	7.4	51	0.18	41	0.84	1.32	40	56	11.2	C ₄ S ₂
	November	195	7.58	6.1	54	0.47	32	3.00	4.40	12	2	13.6	C ₄ S ₂
S4 (Soil groundwater sampling time in the irrigated Ekinyazi soil)	February	150	7.78	0.9	3	0.24	10	2.20	2.00	2	8	1.40	C ₃ S ₁
	May	120	7.65	0.5	2	0.08	4	1.20	1.70	2	2	1.70	C ₂ S ₁
	August	100	7.70	5.9	43	0.1	52	5.6	3.6	10	76	8.3	C ₄ S ₁
	November	125	7.12	3.0	10	0.5	32	6.0	1.2	7	1	2.5	C ₄ S ₁

S1 = Akcakale, S2 = Gurgelen, S3 = Cepkenli, S4 = Ekinyazi.

^aWater classes are based on Richards (1954).

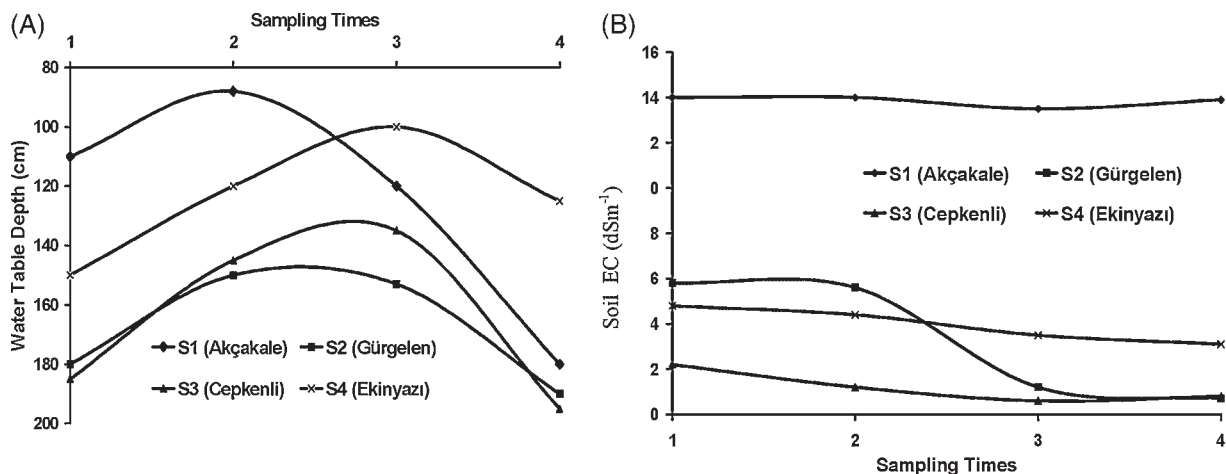


Figure 3. Relationships between water table fluctuation vs sampling times (A) and average soil electrical conductivity (ECe) for each site (at 1 m depth) at different sampling times (B). The sampling times 1, 2, 3 and 4 represent February, May, August and November, respectively

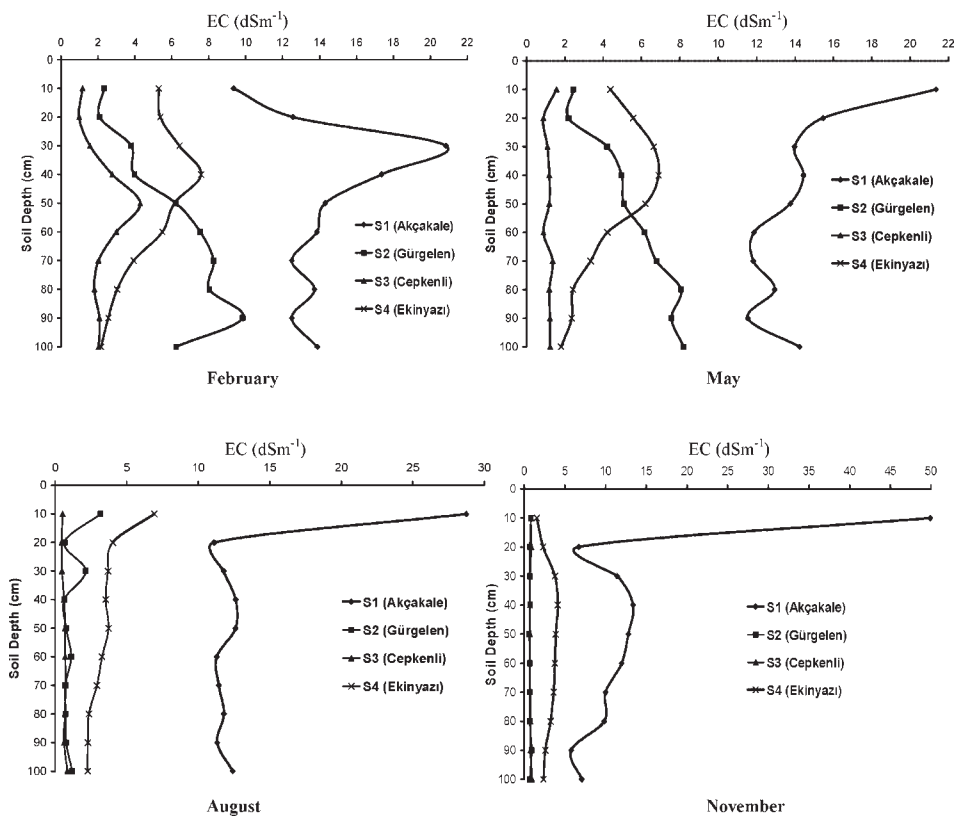


Figure 4. Temporal variations in soil salinity (EC) at different depths

Contribution of irrigation water

Another important parameter affecting the salt dynamic in the plain is the quality and quantity of the water used for irrigation. There are two major types of irrigation water available in the study area: (1) pumped drainage water from the main drainage canal with EC of $1\text{--}3\text{ dS m}^{-1}$, which is used in a limited area; and (2) good-quality irrigation water with EC of 0.38 dS m^{-1} from the Atatürk Dam (Table III).

Table III. Quality parameters of the waters used in irrigation

Water sources	pH	EC _w (dS m ⁻¹)	Soluble cations and anions (mmol _c l ⁻¹)							SAR	Water class
			Na ⁺	K ⁺	Ca ²⁺ +Mg ²⁺	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻		
Irrigation water	8.36	0.38	0.78	0.07	2.15	2.40	1.30	1.80	1.50	0.75	C ₂ S ₁
Main drainage canal water	8.30	0.99	4.04	0.09	4.50	2.00	2.00	2.24	2.39	2.69	C ₃ S ₁

Because of the topographic characteristics of the study area, water accumulates on the lower slope position of the plain (Akcaale soil) where high evaporation and low rainfall increase salt concentration in the shallow groundwater. Where the irrigation waters (good and poor quality) have been applied extensively, excess water leached the salts down and at the same time caused increased levels of saline groundwater. This has been an indirect effect on good-quality irrigation waters causing fluctuation of groundwater and salt movement at depth. Non-irrigated soil located on the lower slope of the plain has also been affected by the irrigations on the upper slope. This resulted in much shallower and saline groundwater in the area.

Seasonal salt dynamic in the soils

The soils in the study area are deep with high clay and lime content (Table I). Smectite is the dominant clay mineral in most soils of the Harran Plain followed by palygorskite, kaolinite, and illite (Aydemir, 2001; Çakmaklı, 2008). Palygorskite contributes to a higher permeability in clayey soils of the study area. High permeability of soils in the study area, dry climate and high evaporation result in rapid movement of salts in the profile between June and November. Since the soils in the area studied are clayey and contain a large amount of fine pores, in the dry season unsaturated flow is expected to decrease with decreasing matric potential (decreasing thickness of the water film). The soils studied are saturated with Ca²⁺ which keeps the interlayer pore spaces at a minimum and inter-particle pore spaces at a maximum state. Consequently, under our soil conditions capillary movement and salt transport would be more rapid, both under saturated and unsaturated conditions, than in usual clay soil with less Ca²⁺ saturation at their exchange site.

Aydemir (2001) reported that dominant expandable clay minerals such as smectite might also cause sodification of soils with Na⁺ saturation, following irrigation in the plain. It is interesting to note that high concentrations of Ca²⁺ and SO₄²⁻ and low concentrations of CO₃²⁻ and HCO₃⁻ in groundwater and the soil prevented the Akcaale soil becoming sodic. The non-irrigated Akcaale soil showed saline-sodic characteristics with a pedogenic gypsic horizon, found within 100 cm depth. A large amount of evaporation from the soil surface may cause gypsum precipitation from supersaturated soil solution in a shorter time (Owliaie *et al.*, 2006). Characteristics such as high soluble Ca²⁺ in the soil also give an advantage in the amelioration of Akcaale soils as a source of Ca²⁺ that can replace the excess Na⁺ present at the exchange site of silicate clays.

There were contrasting behaviours of the irrigated and non-irrigated soil series to the seasonal salt dynamics. The irrigated soils showed a decreasing trend in salt accumulation (at 1 m depth) from the beginning of the irrigation season in May until November. However, the non-irrigated Akcaale soil showed an increasing trend in salt accumulation from February to November (Figure 4).

The EC of Akcaale soil for the upper 20 cm in February was 10.9 dS m^{-1} , but in May, August and November those values were 18.4, 19.9 and 28.3 dS m^{-1} , respectively. The big difference between February and November (17.4 dS m^{-1}) is a result of the high evaporation impact on the capillary movement of the salty groundwater to the

bare soil surface. However, salt accumulation showed an increasing trend within the root depth during the year for non-irrigated Akcakale soil, but total salt accumulation within the 1 m depth did not show significant changes in all the seasons. The salt accumulated at the 1 m depth is moved in different soil depths through irrigation, evaporation, water table depth, and farmer practices. These behaviours of the soils suggest that there is a need for consistent irrigation and groundwater monitoring for salinity in an irrigation scheme in order to develop management practices for optimum crop production.

Factorial analysis

Results for a two factorial treatment effect model are presented in Table IV with a focus on individual factors, since there is an insignificant interaction between seasons on the salt dynamic in the soil.

Overall the F -test statistic signifies the importance of seasonal variations and the soil series ($p < 0.0001$). Most of the variations in electrical conductivity are explained by the variations in both season and soil series ($r^2 = 0.76$).

Pairwise mean comparisons at the levels of each treatment were conducted using least squared means (LSM). The results, reported in Table V, revealed variations in salt dynamics which are statistically significant.

The salt dynamic in the soil was not found to be significant in the same season, implying that variations in soil electrical conductivity among layers are not statistically significant. Significant variations in the salt dynamic were

Table IV. Analysis of variance for soil electrical conductivity in 2×2 factorial arrangements

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	$P > F$
Total	159	3210			
Season	3	235	78	16	<0.0001
Soil series	1	2198	2198	438	<0.0001
Interaction (season $\times$ soil series)	3	11	4	1	0.5568
Error	152	763	5		
R^2			0.76		

Table V. Pairwise comparisons between difference means of levels of each treatment

Source of comparison	Difference between means	95% Confidence limits	
		Lower	Upper
<i>Season comparison</i>			
0–1 (February versus May)	0.43	−0.56	1.42
0–2 (February versus August)	2.27	1.28	3.26***
0–3 (February versus November)	2.90	1.91	3.89 ***
1–0 (May versus February)	−0.43	−1.42	0.56
1–2 (May versus August)	1.83	0.84	2.82***
1–3 (May versus November)	2.46	1.47	3.45***
2–0 (August versus February)	−2.27	−3.26	−1.28***
2–1 (August versus May)	−1.83	−2.82	−0.84***
2–3 (August versus November)	0.63	−0.36	1.62
3–0 (November versus February)	−2.90	−3.89	−1.91***
3–1 (November versus May)	−2.46	−3.45	−1.47***
3–2 (November versus August)	−0.63	−1.62	0.36
<i>Soil series comparison</i>			
0–1 (Non-irrigated versus irrigated)	8.56	7.75	9.37***
1–0 (Irrigated versus non-irrigated)	−8.56	−9.37	−7.75***

***indicates comparisons significant at the 0.05 probability level.

observed between irrigated and non-irrigated soils. The seasonal salt dynamic and accumulation in the studied soils have revealed certain behaviours during different times within a year.

The Turkish government is currently trying to change crop patterns in the plain with the intention of reducing cotton production and increasing the area under alternative plant species. Therefore, our results from this study are expected to provide a reliable database for choosing appropriate plant species for the region.

CONCLUSIONS

The seasonal salt dynamic and accumulation in the soils studied have revealed certain seasonal behaviours within a year. A fluctuation of the saline groundwater has caused accumulation of salts at certain depths of soil profiles. In non-irrigated soil, salts have also greatly accumulated in the topsoil with an increasing trend from February to November. In the irrigated soils, despite high evaporation, salt accumulated at lower depths, as these soils are moderately well drained. Seasonal variations in the salt dynamic were statistically significant. The Cepkenli and Ekinyazi soils with high contents of sand and carbonates have higher natural drainage being classified as moderately well drained, in comparison to Akcakale and Gurgelen which are classified as somewhat poorly drained. While the Cepkenli soil can be considered as non-saline, its groundwater has a high amount of salt, especially in May. Despite its better natural drainage, this soil occurs in a slight depression, and therefore receives saline waters from surrounding areas. These findings suggest that salinity is not point specific but is somehow associated with all the soils in the landscape. Soils that are non-saline but with high groundwater require closer attention, as these soils may become saline in a shorter period of time.

The results are expected to improve soil salinity and to develop irrigation and drainage management practices for optimum and sustainable crop production in the plain. The Turkish government is now trying to change crop patterns in the plain with the intention of reducing cotton to control salinity, as this plant uses high amounts of water. Farmers use excessive water in the hope they can obtain higher production. Yet water resources are limited as more areas are planned to be irrigated in the future. Establishment of the dynamic of salt under irrigation is, therefore, very important for the selection of new crops and appropriate management strategies to improve land and water resources in the plain.

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