Changes in Soil Salinity and Alkalinity During Two Years of Irrigation with Saline Groundwater in the Semihumid Carpathian Basin

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Abstract

The effects of irrigation over a two-year period with shallow groundwater were evaluated for two typical areas of the Great Hungarian Plain. The site at Kunmadaras has light-textured soil, and the site at Karcag has heavy-textured soil. No adverse effects of irrigation with groundwater were evident at the Kunmadaras site with light-textured soil. An increase in subsoil alkalinity but not soil salinity was found at the Karcag site with heavy-textured soil.

1. Introduction

In the drought-sensitive areas of Greater Cumania (Nagykunság in local nomenclature), which are located in the center of the Great Hungarian Plain and characterized by a water table depth of less than 10 m, several high-water-demand crops are grown. In order to secure high yields, growers adapt to the weather conditions and do not consider the unfavorable quality of groundwater obtained from unauthorized bored wells. The consequences of such negligence are salt accumulation and the deterioration of the topsoil structure, which are costly to correct.

Throughout the Great Hungarian Plain, over-irrigation, even with good-quality water, can result in the rise of the water table and consequent soil salt accumulation (Szabolcs, 1989). During the last decades, considerable attention has been focused on the risks of using groundwater with unfavorable properties (e.g., high salinity, sodicity and alkalinity) for irrigation, considering the adverse effects of soil salt accumulation (Tanji, 1990). On the other hand, it is well known that if reclamation materials are applied, calcium will replace the sodium deposited by the groundwater at the exchange sites of soil colloids (Sumner and Naidu, 1998). Consequently, the hydraulic conductivity of the soils can be improved for ensuring deep leaching of salts by precipitation after the growing season.

The objective of this research was to investigate the effects of irrigation with shallow groundwater for two representative areas of the Great Hungarian Plain. Two cases were studied: treatment with preventive application of reclamation materials and control treatment.

2. Materials and Methods

Two production fields were set up for irrigation with groundwater: one sweet corn field at Karcag (N47° 17' 25.81", E20° 53' 17.24" 89 m asl) and a green pepper field at Kunmadaras (N47° 26' 34.60", E20° 48' 54.15", 89 m asl). There were two blocks of Irrigated and Non-irrigated plots, each consisting of three 7x12 m plots at Karcag. In each block there was a plot Not reclaimed, a Gypsum-treated and a Lime-treated plot sampled. There were two blocks of Light-textured and Less-light-textured plots, each consisting of two 14x35 m plots at Kunmadaras. In

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each block there was a plot Not reclaimed, and a Gypsum-treated plot.

On eight occasions between May 21, 2002 and Aug 27, 2003, soil was sampled from each field at 10-cm intervals to a depth of 120 cm. The sampled soil depths were divided into two layers: "topsoil" between 0 and 40 cm, and "subsoil" between 40 and 120 cm. This distinction was made because we aimed to investigate the effects of irrigation on the topsoil, as well as the effects of the water table on the subsoil.

There were important differences between the two sites, as shown in Table 1.

Soil salinity is far less than the threshold value of 4 dS m^{-1} (Richards, 1954). In the analyses carried out in this study, soil salinity is characterized by electrical conductivity measured in a 1:2.5 soil:water suspension. The electrical conductivity measured for this suspension is denoted as $EC_{2.5}$ [dS m^{-1}].

The quality of groundwater used for irrigation differed greatly between the two sites. The groundwater at Karcag had an EC of 2.5 dS m^{-1}, was dominated by sulfates and had low sodicity. The salt concentration of the groundwater at Kunmadaras was even lower than this.

The depth of the water table fluctuated between 3.3 and 4.5 m at Karcag, and was deeper at Kunmadaras.

The soil characteristics of the two sites had distinct depth profiles. At Karcag, increasing trends for $EC_{2.5}$ and nitrate were observed because of the presence of the water table. On the other hand, at the Kunmadaras site, no such tendency in these parameters was observed.

In order to prevent the unfavorable effects of the groundwater, gypsum was applied, with the dose neutralizing the sodifying effect of groundwater. Furthermore, lime was added at Karcag as a traditional reclamation material.

At Kunmadaras, the following types of irrigated fields were compared: 1) gypsum-treated light-textured soil, 2) untreated light-textured soil, 3) gypsum-treated less light-textured soil and 4) untreated less light -textured.

At Karcag, the more saline and shallower water table presented a larger risk of salinization and therefore the following types of control fields were also examined: 1) non-irrigated and not reclaimed, 2) non-irrigated and gypsum-treated, 3) non-irrigated and lime-treated, 4) irrigated and not reclaimed, 5) irrigated and gypsum-treated, and 6) irrigated and lime-treated.

During the experimental period, precipitation was less than average (568 mm) for the region: 440 mm in 2002 and 381 mm in 2003; consequently, irrigation was necessary in order to obtain crops in good yield.

The changes of the chemical properties after the implementation of each treatment were analyzed by one-way ANOVA or the Student's t-test. The data on the soil layers were combined for the statistical analyses.

3. Results

Effects of irrigation on soil salt content and pH

At both sites, a positive correlation was found between the soil salt content and the nitrate content, because the same mechanism affects the translocation of salts and nitrate. Owing to the acidifying effect of the applied fertilizer, the nitrate content exhibited a negative correlation with pH. Since salt accumulation is characteristic of drier soils, a negative correlation was found between the soil salt content and moisture content.

The differences in the soil salt content reflect the distinct soil textures and water table depths, and pH was found to correlate with salt content (Table 2). The contradiction between the $EC_{2.5}$ values in Table 2 and the EC_e values in Table 1 can be attributed to the distinct textures of the soils: the average saturation percentages

Table 1. Mean characteristics of surface samples taken at depth of 0-1 m from irrigated fields before the experiment

Site	Clay %	Sand %	EC_e (dS m^{-1})
Kunmadaras, light-textured	10	26.5	0.78
Kunmadaras, less light-textured	13	24	0.89
Karcag	47	15	0.50

Note: EC_e denotes electrical conductivity of saturation extract.

Table 2. Mean $EC_{2.5}$ and pH values of soil layer (0-120 cm in depth) during the study period

Site	N	$EC_{2.5}$			pH		
		Avg	Min	Max	Avg	Min	Max
Kunmadaras[#]	384	0.14	0.03	0.98	6.74	5.83	7.65
Karcag	528	0.20	0.08	0.65	7.30	5.71	8.55

Notes: N is the number of samples, $EC_{2.5}$ is the electrical conductivity of a 1:2.5 suspension (dS m^{-1}), Avg is the mean, Min is the minimum, Max is the maximum. [#]Samples from the area of a former dung heap were excluded.

(0-100 cm) of the Karcag samples were 61 ml/100 g and 26.4 ml/100 g of the Kunmadaras samples. The $EC_{2.5}$ values shown in Table 2 correspond to soil with a saturation percentage of 250 ml/100 g for both sites. At Karcag, increasing salt content was correlated with increasing pH. Due to the differences in the composition of the soil solutions, opposite relationships were observed for the two sites. In the Karcag groundwater samples, the bicarbonate:chloride:sulfate equivalent ratio was 58:19:23, but in the Kunmadaras soil samples, this ratio was more balanced, namely, 39:32:29. Owing to the dominance of bicarbonate, pH tended to increase with increasing salinity at Karcag.

Kunmadaras site with light-textured soil

Through paired comparisons, the $EC_{2.5}$ and pH values were evaluated between the initial (before irrigation) and subsequent (irrigated) sampling dates (data not shown).

During the two growing seasons, there was no significant difference in salinity or alkalinity values between the fields with light-textured and less light-textured soils in the studied layers.

In the gypsum-treated topsoil, pH was not significantly lower, but this cannot be considered to be an effect of gypsum, since the reaction of gypsum does not notably affect the pH of the soil (Table 3.).

In the case of fields with light-textured soil (Table 4), the application of gypsum was accompanied by a decrease in pH for both the topsoil and subsoil. We attribute this result to the dissolution of gypsum and the leaching of salts, which then led to slight salt accumulation in the subsoil.

In the subsoil of fields with less light-textured soil

Table 3. Comparison of gypsum-treated and untreated fields at the Kunmadaras site by Student's t-test

Treatment/depth	0-40 cm		50-120 cm	
	$EC_{2.5}$ (dS m^{-1})	pH	$EC_{2.5}$ (dS m^{-1})	pH
Number of samples	128		256	
Untreated	0.21a	6.62a	0.10a	6.80a
Gypsum-treated	0.21a	6.56a	0.11a	6.83a

Note: Means within the same column followed by the same letter are not significantly different at $p<0.05$.

Table 4. Comparison of gypsum-treated and untreated fields with light-textured soil at the Kunmadaras site by Student's t-test

Treatment/depth	0-40 cm		50-120 cm	
	$EC_{2.5}$ (dS m^{-1})	pH	$EC_{2.5}$ (dS m^{-1})	pH
Number of samples	64		128	
Light-textured, untreated	0.23a	6.67a	0.08a	6.86a
Light-textured, gypsum-treated	0.21a	6.38b	0.12b	6.73b

Note: Means within the same column followed by the same letter are not significantly different at $p<0.05$.

treated with gypsum, lower salinity and higher pH were observed (Table 5) because of the spatial variability of the field and not because of the treatment.

Karcag site with heavy-textured soil

For the Karcag site, the $EC_{2.5}$ and pH values of the irrigated and non-irrigated fields were compared. Neither overall salinization nor alkalization in the topsoil was evident (Table 6). On the other hand, leaching of salts occurred in both layers (significant in subsoil). Irrigated soils had significantly higher pH.

In the lime-treated fields, the soluble salt content was lower in both the topsoil and the subsoil. As shown in Table 7, the pH in both soil layers was lower in the reclaimed fields.

The soluble salt content in the subsoil of the non-irrigated fields treated with lime was significantly lower (Table 8). In the same layer, pH was lower in the chemically reclaimed fields. No significant difference was found between the mean pH values of the gypsum-treated and lime-treated fields.

The results presented in Table 9 show that in the topsoil of the irrigated fields, the mean $EC_{2.5}$ and pH values did not significantly differ between the gypsum-treated and untreated fields, but fields treated with lime showed significantly lower values. In the subsoil, the pH values of the lime-treated and gypsum-treated fields differed significantly. Specifically, the measured pH was lower in the gypsum-treated fields.

Table 5. Comparison of gypsum-treated and untreated fields with less light-textured soil at the Kunmadaras site by Student's t-test

Treatment/depth	0-40 cm		50-120 cm	
	$EC_{2.5}$ (dS m^{-1})	pH	$EC_{2.5}$ (dS m^{-1})	pH
Number of samples	64		128	
Less light-textured, untreated	0.18a	6.57a	0.13a	6.75a
Less light-textured, gypsum-treated	0.20a	6.73b	0.10b	6.93b

Note: Means within the same column followed by the same letter are not significantly different at $p<0.05$.

Table 6. Comparison of irrigated and non-irrigated fields at the Karcag site by Student's t-test

Treatment/depth	0-40 cm		50-120 cm	
	$EC_{2.5}$ (dS m^{-1})	pH	$EC_{2.5}$ (dS m^{-1})	pH
Number of samples	104		208	
Non-irrigated	0.22a	6.36a	0.21a	7.55a
Irrigated	0.18a	6.42a	0.19b	7.75b

Note: Means within the same column followed by the same letter are not significantly different at $p<0.05$.

Table 7. Comparison of chemical reclamation treatments at the Karcag site by one-way ANOVA

Treatment/depth	0-40 cm		50-120 cm	
	$EC_{2.5}$ (dS m^{-1})	pH	$EC_{2.5}$ (dS m^{-1})	pH
Number of samples	104		208	
Not Reclaimed	0.20a	6.48a	0.21a	7.78ac
Gypsum-treated	0.25ab	6.36a	0.20ab	7.52bc
Lime-treated	0.15ac	6.31a	0.18b	7.62c

Note: Means within the same column followed by the same letter are not significantly different at $p=<0.05$ pairwise.

Table 8. Comparison of non-irrigated reclamation treatments at the Karcag site by one-way ANOVA

Treatment/depth	0-40 cm		50-120 cm	
	$EC_{2.5}$ (dS m^{-1})	pH	$EC_{2.5}$ (dS m^{-1})	pH
Number of samples	52		104	
Non-irrigated, not reclaimed	0.22a	6.45a	0.24a	7.87a
Non-irrigated, gypsum-treated	0.25a	6.24a	0.23a	7.46b
Non-irrigated, lime-treated	0.19a	6.36a	0.17b	7.24b

Note: Means within the same column followed by the same letter are not significantly different at $p<0.05$ pairwise.

Table 9. Comparison of chemical reclamation treatments for irrigated fields at the Karcag site by one-way ANOVA

Treatment/depth	0-40 cm		50-120 cm	
	$EC_{2.5}$ (dS m^{-1})	pH	$EC_{2.5}$ (dS m^{-1})	pH
Number of samples	52		104	
Irrigated, not reclaimed	0.18a	6.52a	0.19a	7.69a
Irrigated, gypsum-treated	0.24a	6.47a	0.18a	7.58ab
Irrigated, lime-treated	0.10b	6.27a	0.19a	8.00ac

Note: Means within the same column followed by the same letter are not significantly different at $p<0.05$ pairwise.

Conclusions

At the Kunmadaras site, irrigation was not found to lead to an increase in soil salinity. During the two growing periods, no significant difference was observed in the chemical properties of the fields with different textures. For the fields with light-textured soil at the Kunmadaras site, no clear risk of irrigation with saline groundwater was detected.

At the Karcag site during two growing periods, irrigation with salinizing and sodifying groundwater resulted in decreased salinity but higher pH in the subsoil, which could affect the hydraulic properties of the soil according to Suarez et al. (1984). The Karcag subsoil was slightly alkaline, and pH was lower in the reclaimed fields. The salinity and alkalinity of the lime-treated topsoil was lower than that of the gypsum-treated topsoil; this higher efficacy of lime compared to gypsum is in good agreement with the traditional local reclamation of slightly acidic topsoils with calcium carbonate in Greater Cumania (Prettenhoffer, 1969).

In lowland areas with a shallow saline and sodic water table, the use of groundwater for irrigation is proposed from time to time. Therefore, further studies must be carried out, because the results of a two-year-long study are insufficient for drawing far-reaching conclusions. The results of the present study are consistent with those obtained in previous works. It is critical to raise awareness among growers that careless and unsystematic irrigation with groundwater can cause severe damage in several situations. On the other hand, in other circumstances, irrigation with groundwater can increase the yield of crops without evidence of adverse short-term effects.

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