FACTORS AFFECTING SOIL SALINIZATION IN A SODIC GRASSLAND

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Abstract

During seven years the spatial and temporal changes of a plot in the most characteristic sodic (solonetzic) landscape of Hortobágy, Hungary were studied with repeated observations of soil EC_a and groundwater depth and composition.

The soil EC showed large fluctuation in subsequent years. There were large changes in the average salinity, but EC also changed in a spatially variable manner.

Groundwater depth was closely related to the precipitation and could be predicted precisely based on 10-day sums of precipitation.

Based on the ratio of bromide to chloride ions in the three profiles studied, the Haplic Solonetz (HS) lying in the deepest area showed free mixture of precipitation and groundwater. The Salic Solonetz (SS) lying in intermediate elevational position, and Mollic Solonetz (MS) from the higher lying zone showed strong evaporation.

The stable isotope composition helped to interpret the importance of regional groundwater flow in the salinization of the soils. Largest evaporation and infiltration of precipitation could be found at the HS profile, but at the SS and MS profiles evaporation was the dominant process. Smallest infiltration of precipitation was inferred at the SS profile.

Based on the data a conceptual model of soil salinization has been compiled based on the contrastive water regime of warm, dry and rainy periods. Most important factors in this model are elevation, plant cover of surface, surface soil temperature and soil hydraulic conductivity, and the seasonally changing direction of groundwater movement.

Key words: solonetz, conceptual model, shallow groundwater, stable isotopes

Introduction

The salt concentration of soils is not constant, but a dynamic parameter (Arany, 1956, Szabolcs, 1971, Várallyay, 1966, 1989). Since the presence of soluble salts is the most characteristic feature of the salt-affected soils, its role in the spatial distribution, utilization, reclamation of salt-affected soils has been treated with hundreds of papers worldwide and in Hungary also (recently Blaskó, 1999, Szendrei, 1999, Szabó et al. 1998, Karuczka, 1999) and this topic remains in the focus of interest.

We selected the most characteristic native sodic grassland of Hungary in the Hortobágy National Park to characterize the spatial and temporal aspects of soil salinization. The studied area has already been described in several papers, regarding geology (Tóth and Kuti, 1999a,b), soil properties (Tóth and Jozefaciuk, 2002), vegetation (Tóth et al., 1991, Tóth and Rajkai, 1994, Tóth and Kertész, 1993), groundwater conditions (Kuti et al., 2002), spatial variation (Tóth and Kuti, 2002, Douaik et al., 2005). Our objective in this work was to combine the concepts of regional groundwater flow and elevational catena to explain the zonation of saline habitats in the grassland. For this objective repeated observation on groundwater and surface soil EC were used. We relied heavily on the zonation of the plant associations as indicators of soil salinity/sodicity conditions and sampling units, as is typical in geobotany (Chapman, 1960, Alvarez et al., 2001). A previous version of this paper was presented earlier by Tóth et al. (2002)

Materials and Methods

Repeated observations

There were four groundwater observation wells observed at ten-day intervals for groundwater depth and monthly for groundwater quality. The elevation of the wells was the following: #1: 90, #2: 89.32, #3: 88.8, #4:88.68 m.

The soil bulk electrical conductivity (EC_a) was measured with a 4-month frequency at 420 points, arranged systematically in a 25 x 25 m grid. The equipment used for the measurements was a four-electrode probe (Rhoades and Miyamoto, 1990). At 20 points soil samples were collected from 10 cm increments to the depth of 40 cm. Duplicate sample collection was made between the endpoints of the probe, but the samples were bulked for each depth increment. In the laboratory $EC_{2.5}$ was determined in 1:2.5 soil:water suspension.

At three selected profiles (MS, SS, HS) a morphologic description and horizon-wise sampling for laboratory analysis was carried out. Also a series of 15 repeated samplings down to the ground-water was made. The level and composition of the groundwater were also characterized.

Stable isotope and tritium analysis

Water samples were analysed for stable oxygen and hydrogen isotopic compositions in the Laboratory for Geochemical Research of the Hungarian Academy of Sciences. The oxygen and hydrogen isotopic compositions were determined using the standard techniques detailed by Epstein & Mayeda (1953) and Coleman et al. (1982), on a Finnigan MAT delta S mass spectrometer. Results are expressed using the conventional delta (δ) notation, $\delta = (R_{sample} - R_{standard})/R_{standard} * 1000$ [‰], where R_{sample} and $R_{standard}$ are the ratios of heavy and light isotopes. Uncertainty is ±0.1‰ for oxygen and ±1‰ for hydrogen. The tritium measurements were made in the Water resources Resources Research Centre Plc. by the standard scintillation counting, uncertainty is ±10% relative.

Spatio-temporal analysis

We had 2 data sets:

- calibration data: soil bulk electrical conductivity (EC_a) measured using an insertion-probe sensor, along with the soil salinity determined in laboratory ($EC_{2.5}$). This was available for 15 to 20 locations;
- data to calibrate : EC_a at more than 400 locations (the calibration data is a subset of these locations), also we had the x-y coordinates and the vegetation cover.

The 2 data sets are available for 17 time instants (November 1994 to December 2000). We established the stochastic calibration equation relating $EC_{2.5}$ to EC_a using a multiple linear regression model. Then we determined $EC_{2.5}$ for the locations of the 'data to calibrate' set. Next, we interpolated the calculated $EC_{2.5}$, using ordinary kriging, to produce a soil salinity map for the whole area of study. At the last step, we tested if there was a temporal change in the soil salinity levels using mixed linear analysis of variance and conditional regression models. We had two tests:

- the first to determine if the salinity pattern had changed in a spatially variable manner, which is called dynamic spatial variation (the change in soil salinity level differs from location to location and is not proportional)
- the second to determine if the average salinity level across the whole field had changed with time

Results and Discussion

Description of the "Nyírőlapos" study site

Three profiles of a solonetzic toposequence: Mollic Solonetz, MS, Salic Solonetz, SS, and Haplic Solonetz, HS were studied. The position in the toposequence is closely related to the vegetation: tallgrass grassland (**Achilleo-Festucetum pseudovinae** plant association) at the top (MS), shortgrass (**Artemisio-Festucetum pseudovinae** plant association) in between (SS) and meadow (**Agrosti-Alopecuretum pratensis** plant association) in the bottom (HS) (Bodrogközy, 1965). The profiles represent a complex heterogeneous solonetzic landscape in which a difference of a few decimeters of elevation results in radically different pattern of salt accumulation. The SS profile is the most sodic and saline of the three. Based on field observations and measurements of saturated hydraulic conductivity and surface temperature values of these profiles during seven-year period, the following processes seem to have the most dominant effect on salt accumulation:

Processes

Profile	W	R	I/L	Cr	Ha
MS	-	-	+++	+	+++
SS	+	++	+	+++	+
HS	+++	-	++	++	++

The letters denote: MS Mollic Solonetz, SS Salic Solonetz, HS Haplic Solonetz, W- Waterlogging, R- Runoff, I/L- Infiltration/Leaching, Cr- Capillary rise, Ha- Humus accumulation. The minus sign stands for negligible effect and the plus for positive.

Basic properties of the studied profiles are presented in Tables 1 and 2. The contrasting physicochemical properties of the three Solonetz profiles are evaluated in Tóth and Jozefaciuk (2002).

Table 1. Location and general characteristics of three studied solonetzic soils from Hortobágy, Hungary

Soil	Latitude N	Longitude E	Elevation	Assoc	D_g*	EC_g*	EC*	SAR*	pH*
MS	47°33. 777’	21°18. 258’	89.35 m	Achi	1.0	3.6	2.2	30	7.7
SS	47°33. 821’	21°18. 269’	89.09 m	Arte	0.9	6.0	6.7	85	7.9
HS	47°33. 780’	21°18. 170’	88.84 m	AgAl	0.7	18.0	3.8	39	7.6

Abbreviations MS Mollic Solonetz, SS Salic Solonetz, HS Haplic Solonetz, Assoc is plant association, (Achi=Achilleo-Festucetum pseudovinae, Arte=Artemisio-Festucetum pseudovinae, AgAl=Agrosti-Alopecuretum pratensis), D_g [m] groundwater depth, EC_g [mS cm^{-1}] electrical conductivity of the groundwater, EC electrical conductivity, SAR sodium adsorption ratio and pH of soil saturation extracts from 0-10 and 50-60 cm layers, *average values measured monthly in Jun-Sept 1999.

Table 2. Laboratory characteristics of profiles

Soil and horizon		CO_3^{2-} %	OM %	CEC	EB	ESP %	pH	EC	SAR	BD	Ks	Silt %	Clay %
MS	A	0.25	4.22	25.0	15.5	3.04	8.15	0.89	4.5	1.19	81.7	67.1	15.7
	B	0.38	2.06	17.4	20.7	83	8.68	0.75	98.1	1.42	0.014	54.4	43.8
	BC	20	0.93	18.5	13.0	82.8	9.07	6	106.8	1.55	0.023	60.2	42.9
	C	32.3	0.53	10.9	10.9	93.5	9.18	5.4	96.2	1.64	0.012	65.6	33.4
SS	A	0.17	1.56	15.2	8.7	74.9	8.53	10.3	125.6	1.46	0.028	80.1	28.8
	B	0.59	0.88	20.7	21.1	92.9	9.05	9.3	222.6	1.56	0.144	54.4	42.1
	BC	25.2	0.54	13.0	16.9	95.8	9.31	11	271.2	1.66	0.161	59.0	36.1
	C	16.8	0.27	10.9	11.7	81.8	9.25	5.8	160.2	1.64	0.119	63.3	27.2
HS	A	0.08	4.08	10.9	16.1	10	7.8	0.75	13.8	1.18	8.80	79.7	14.2
	B	0.08	1.38	21.7	17.4	60.9	8.26	6.7	76.6	1.62	0.006	54.5	42.7
	BC	0.5	0.66	17.4	18.6	64.4	8.2	8.7	81.3	1.61	0.010	53.4	36.1
	C	19.3	0.37	12.0	10.9	72.5	8.18	10.5	79.3	1.62	0.143	60.6	26.7

Abbreviations: CO_3^{2-} carbonates content, OM organic matter content, CEC and EB (exchangeable bases) cMol kg^{-1}, ESP exchangeable sodium percentage, SAR sodium adsorption ratio, BD bulk density, Ks saturated hydraulic conductivity cm/day EC electrical conductivity mS cm^{-1}; EC, pH and SAR were determined in the saturation extract

Spatio-temporal changes of soil EC

We compared temporal change for September 1995, 1998 and 1999 to 1997.

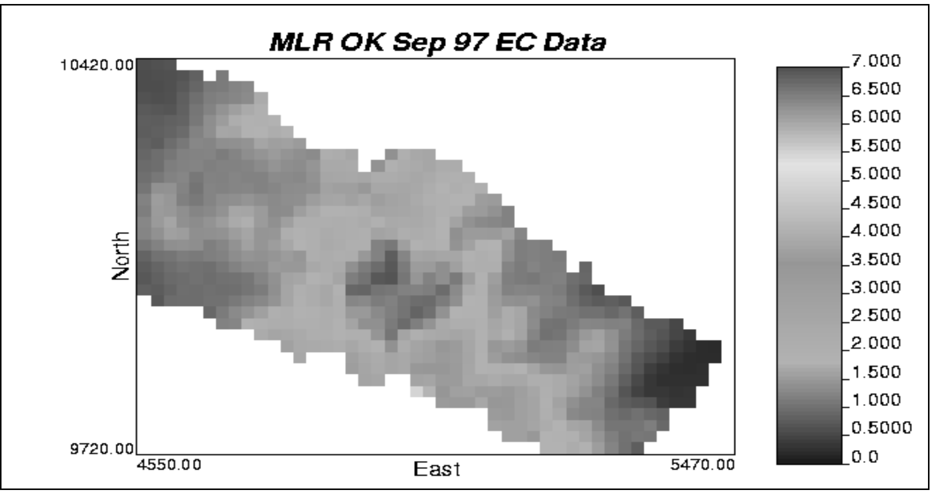
We found that there was a strong evidence of a significant dynamic spatial variation between the reference time (September 1997) and the other times. Also we found that the mean soil salinity level across the entire field had changed significantly with time.

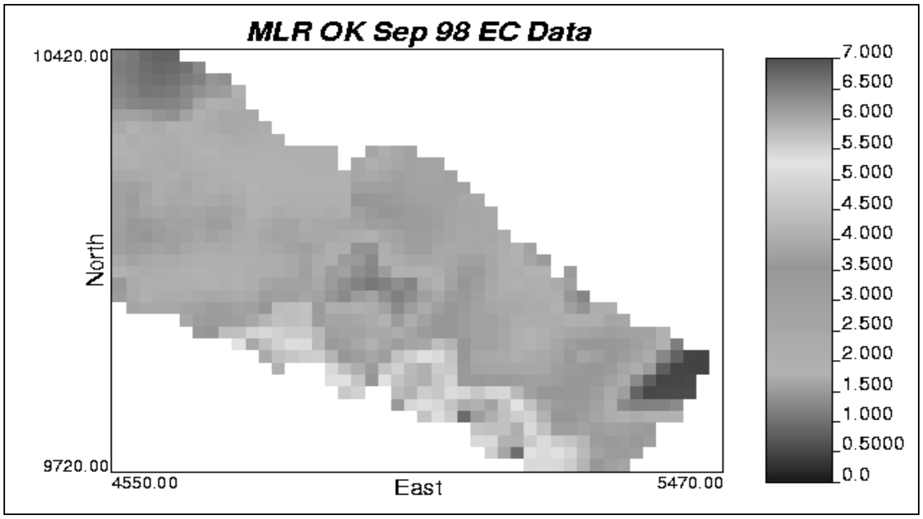
The overall salinity level increased by 36% between September 1995 and 1997, and increased by 110%, and 32% between September 1997, and 1998 and 1999 respectively.

As we found a significant dynamic spatial variation, we needed to compute a new multivariate linear regression model and to ordinarily krige the result, in order to map soil salinity for a new time instant (we used September 1998).

Comparing the two maps (see Fig1), we noted that the soil salinity level increased in the whole area of study, except the most eastern and the northwestern parts of the field. That points to the effect of inhomogeneity inside the area and leads to further study.

Fig 1. Map of EC2.5 measured on September 1997 (upper map), and September 1998 (lower map), prepared with Ordinary Kriging.





Temporal changes in the groundwater level

Since groundwater level is a decisive factor in the salinity of soils we tried to predict it with the sum of precipitation of the previous 10-day long intervals (decades). As an example the best fitting equation for Well #2 was the following:

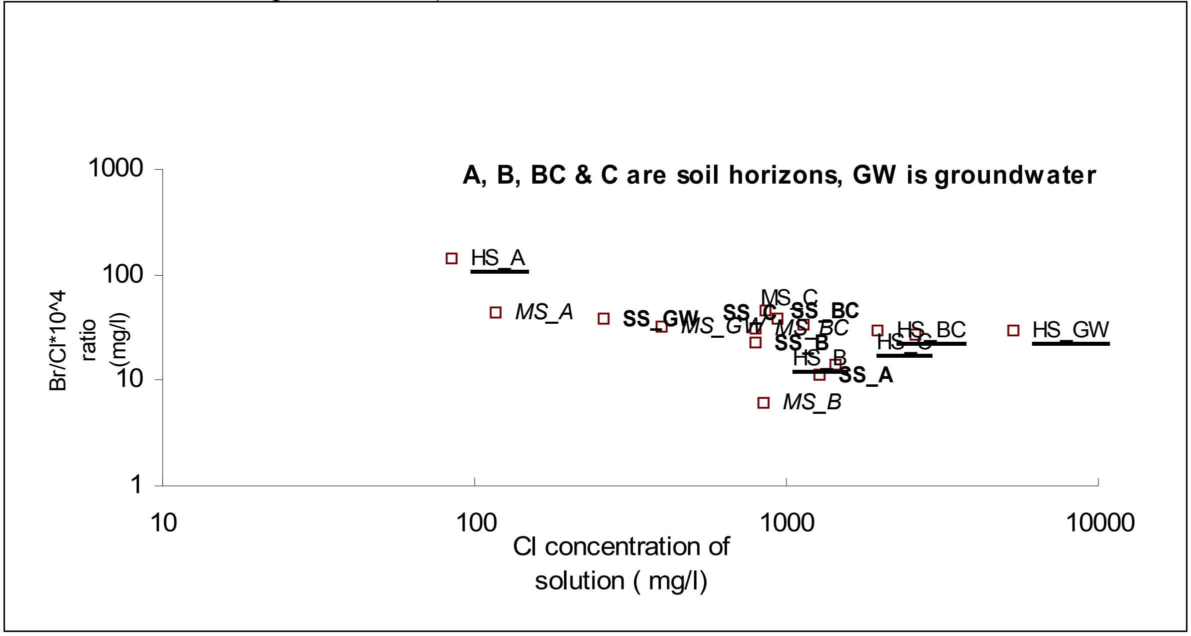
Equilibrated groundwater-level =0,73 * precipitation-of-actual-decade + 0,23 * precipitation-one-decade-before –0,022 * precipitation-two-decades-before+0,040 * precipitation-three-decades-before –0,023 * precipitation-four-decades-before

The variables in the equation were standardized in order to select the best predicting algorithm based on the comparison of model residuals. The correlation coefficient of the shown multiple linear regression equation was 0.992, and it shows that the amount of precipitation is very closely related to the groundwater level. The importance of precipitation is less and less with increasing time lag.

The Cl^-/Br^- ratio of soil solutions and groundwaters

For the study of the mixing of precipitation, soil solution and groundwaters in the three profiles, the ratio of Cl^- and Br^- was determined (Fig 2). According to Flury and Papritz (1993), Vinogradov (1959) and Whittemore (1988), the ratio of the two anions is suitable for following some changes of the soil solutions, since both anions behave as “conservative” components, that is dissolve well and enters very sparingly chemical reactions and adsorption. Bromide concentration shows a close correlation with the soil organic matter content, therefore in the saturation extracts collected from the surface "A" horizons of the Mollic (MS) and Haplic Solonetzes (HS) large Br$^-$ concentration was found. If the soil solutions and the groundwater freely mix then the points of one profile are situated on a line. It was found in the case of the lowest lying Haplic Solonetz. Here it seems proven that the precipitation has a direct role in the salt composition of the profile, and the effect of evaporation and leaching can be seen simultaneously. In the case of the Salic Solonetz (SS) the Cl$^-$ concentration of groundwater is smaller than in the saturation extracts of the soil horizons, therefore compared to the groundwater there is an increase in chloride concentration in the soil solutions during evaporation. In the saturation extract of "A" horizon of Mollic Solonetz the chloride concentration is small, but in the deeper horizons it is greater than in the groundwater, in these depths the same processes go on as in the Salic Solonetz profile.

Fig 2. The ratio of bromide to chloride in the saturation extracts of soil genetical horizons and groundwater samples of the three profiles (MS=Mollic Solonetz, SS=Salic Solonetz and HS=Haplic Solonetz)

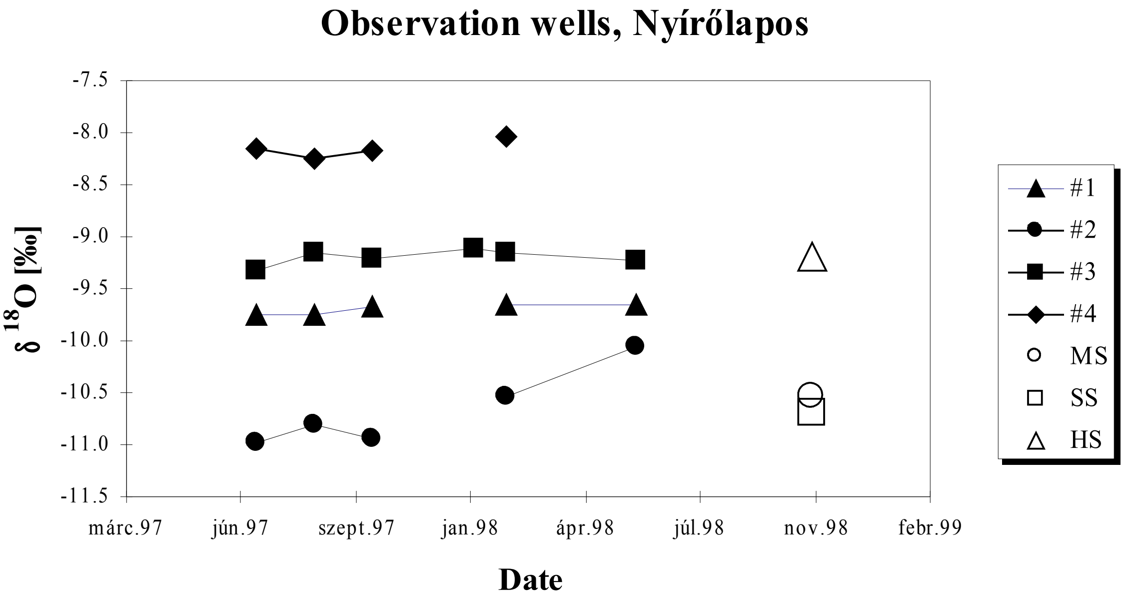


Interpretation of isotope data

The study area (Nyírőlapos) lies on a discharge area of a regional flow system, where old groundwater (infiltrated in the Ice Age) is flowing upward. The $\delta^{18}O$ value of this old groundwater is between -11.5‰ and -11.8‰ vs. VSMOW in the depth range of 30-60 meters. The radiocarbon age of groundwater in Balmazújváros (few kms away from the study area) is 13-15 ka. This ascending groundwater mixes with the infiltrating precipitation fallen to the area nowadays. Hence the $\delta^{18}O$ value of the infiltrating modern groundwater is -9.3 ±0.4‰ (Deák et al. 1996), this mixing process can be traced by measuring the $\delta^{18}O$ values.

The $\delta^{18}O$ values of all the seven observation wells are less negative than that of the ascending deep groundwater (Fig. 3), indicating that some infiltrating precipitation mixes to the upcoming groundwater in every well, but mixing ratio differs a lot well-by-well. The $\delta^{18}O$ values are rather constant in time (Fig. 3) with the exception of Well#2, where the $\delta^{18}O$ value changed about 1 ‰ in the studied period. The constancy of the $\delta^{18}O$ values indicated that the mixing ratio and the rate of evaporation at an observation well are the same in time, while the mixing ratio differ a lot in the different wells, which are spatially close to each other (cca. 250m).

Fig 3. Stable oxygen isotope compositions of the shallowest groundwater taken from the observation wells in the Nyírőlapos (Hortobágy) area during the years 1997-1998, Hungary.



The Well#4 has the least negative $\delta^{18}O$ value, which is more positive than that of the infiltrating water, clearly showing that evaporation has an effect on the isotopic composition of the groundwater. The δD-$\delta^{18}O$ relationship in the case of three observation wells (points are on the right side of the meteoric water line on Fig. 4) suggests that evaporation takes place at every part of the studied area.

Fig 4. The δD vs. $\delta^{18}O$ values of three observation wells in the Nyírőlapos (Hortobágy, Hungary) area in the year 1998.

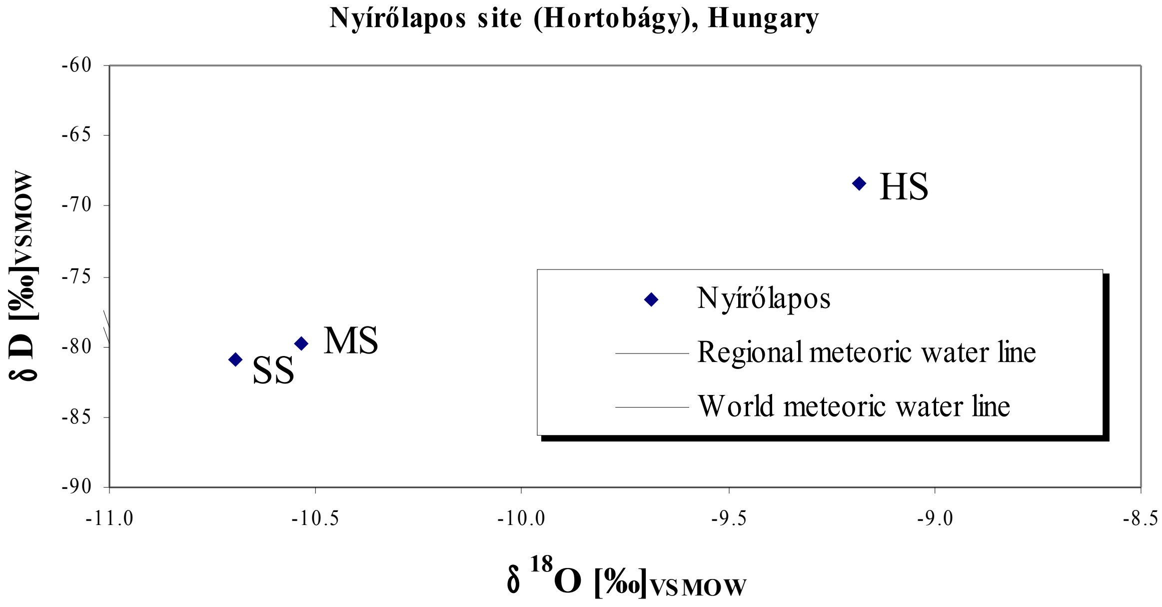


Table 3 Isotope and electrical conductivity data of three observation wells measured in 1998.

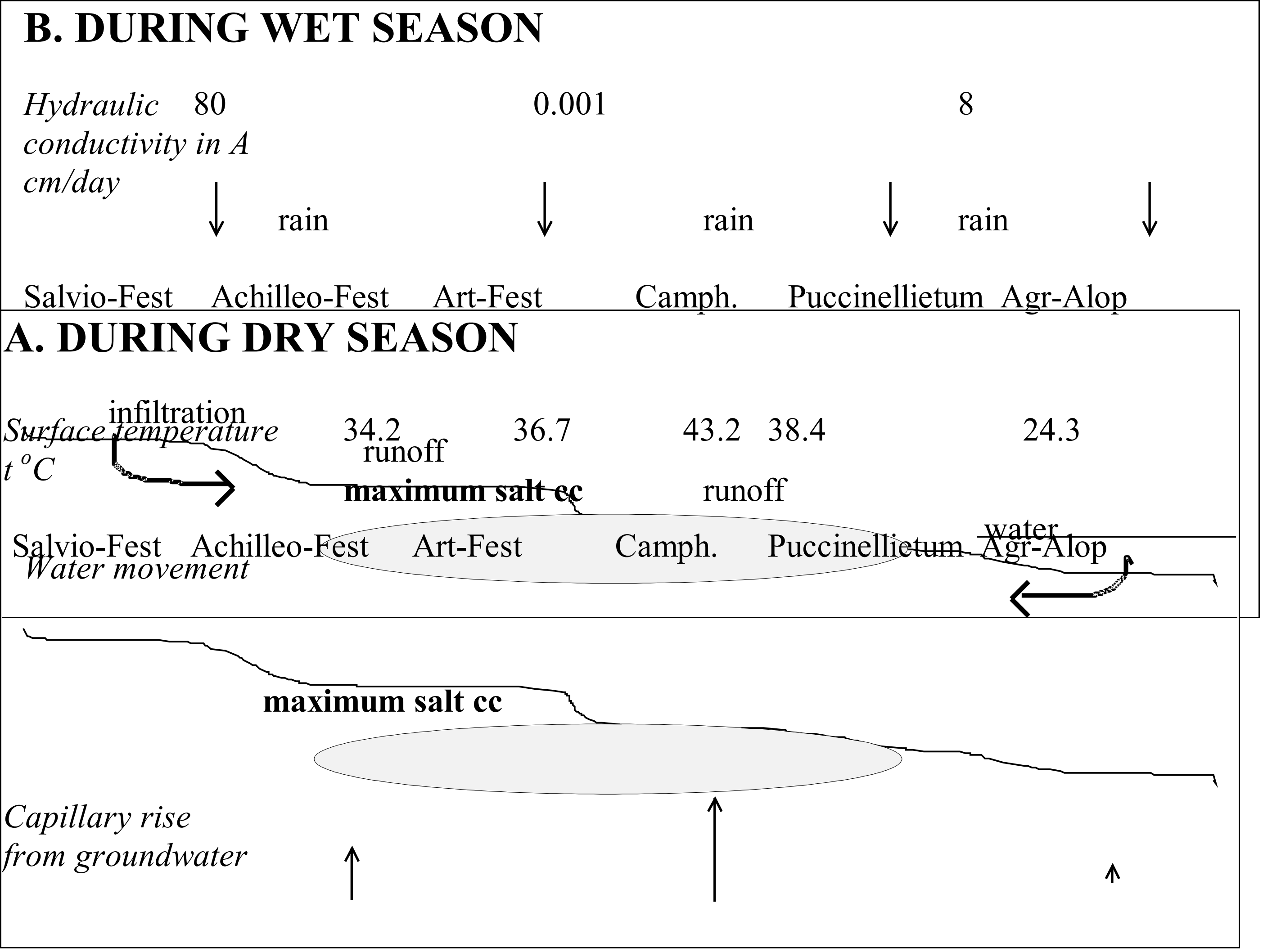
Well no	$\delta^{18}O$ [‰]$_{VSMOW}$	dD [‰]$_{VSMOW}$	Tritium [TU]	Electrical conductivity [mS/cm]
MS	-10.53	-79.69	2.8	3.29
SS	-10.69	-80.91	1.3	1.92
HS	-9.19	-68.43	4.8	12.6

The ascending groundwater is tritium free, tritium comes with the infiltrating precipitation. The -9.19‰ $\delta^{18}O$ value of the HS observation well points out the highest proportion of infiltrating precipitation vs. ascending groundwater among three wells (Table 3). The tritium content is in very good agreement with this observation, the HS well has the highest amount of tritium. The electrical conductivity (Table 3) also showed a good correlation with isotope data, the well HS has the highest value (12.6 mS/cm).

The conceptual model of soil salt accumulation

Generally largest soil salt concentration is placed in the lowest, depressional zones of the soil catena worldwide. According to our experience in the study site it is not the case. In order to explain this phenomenon we have compiled the conceptual model of soil salt accumulation as shown in Fig 5.

Fig 5. Schematic model of salt accumulation according to the zonation of vegetation ***(Salvio-Festucetum sulcatae, Achilleo-Festucetum pseudovinae, Artemisio-Festucetum pseudovinae, Camphorosmetum annuae, Puccinellietum limosae, Agrosti-***



***Alopecuretum pratensis**) from the highest to the lowest zones. A. During dry season. B. During wet season*

In accordance with the height and cover of the native vegetation in the dry warm periods (Fig. 5. A) the surface of the soil can reach rather large temperature (Kovács and Tóth, 1988). The soil surface in the "tallgrass" (**Achilleo-Festucetum pseudovinae**) stand of Mollic Solonetz can be 10 centigredes, the semivegetated or bare "shortgrass" (**Artemisio-Festucetum pseudovinae**) stand of Salic Solonetz can be 20 centigredes warmer than the soil surface in the "meadow" (**Agrosti-Alopecuretum pratensis**) stand of Haplic Solonetz. As a consequence transpiration decreases, but evaporation increases, and there is larger solution flux from the groundwater towards the surface. The result is larger salt accumulation at the soil surface, coupled with occasional appearance of salt efflorescences.

During wet periods (Fig. 5.B) large infiltration can be expected only in the "tallgrass" and "meadow" stand, since the hydraulic conductivity of the "shortgrass" stand is very small, here the precipitation either runs down or evaporates. In the lowest lying "meadow" stand the precipitation water accumulates from time to time and much of it infiltrates. This infiltration prevents the lateral transport of saline solutions towards the bottom of the depression. Another consequence of the infiltration is a rise in the groundwater-level and a change in the direction of the groundwater level from the lowest areas toward the immediate elevational zones, similarly to that reported by Seelig and Richardson (1994).

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