

## Soil variability as reflected by the factors of salt accumulation

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One of the primary goals of current soil science is the regulation of soil processes with defined purpose, direction and extent. The prerequisite of regulation is to possess a fuller and reliable record of the spatial (horizontal and vertical) and temporal variability and dynamism of the soil properties, and to know the mechanisms and the opportunities of influencing the processes.

### Introduction

In recent years, several investigations have been carried out in many countries for the more detailed, more accurate and more exact characterization of the spatial and temporal variability of soils in order to quantify, three-dimensionally display, model and predict soil properties, using the new opportunities offered by the modern technological developments. A very good summary of this is provided by the special issue of the journal *Geoderma* “Developments in Quantitative Soil Resource Assessment” (COLLINS et al., 2000), in which more than ten papers reported such new scientific findings, based on the following basic questions of the concepts:

- Is soil variability random? (WEBSTER, 2000);
- Are soil properties predictable, is it possible to predict their changes with simulation models? (GOOVAERTS, 2000; LAGACHERIE & VOLTZ, 2000; ODEH & MCBRATNEY, 2000; BOURENNANE et al., 2000)

The affirmative response to the second question infers the pedological application of the new techniques. From the geostatistical methods (GROENIGEN, 2000; BOURENNANE et al., 2000), through the use of DTM and GIS technology (LAGACHERIE & VOLTZ, 2000; MENDONCA SANTOS et al., 2000; DOBOS et al., 2000) and various remote sensing methods (ODEH & MCBRATNEY, 2000; DOBOS et al., 2000; CHAPLOT et al., 2000, MCBRATNEY et al., 2000), the revolutionary development in this area continues to hold.

The particularly high spatial and temporal variability, heterogeneity, relative rapid-changing mosaicism of salt-affected soils, and areas has been known for a

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long time. Therefore, for the exact and quantitative characterization of the status of soil salinization and for the prediction of salt accumulation and sodification processes – enabling their timely prevention – numerical simulation is extensively used (VÁRALLYAY, 1968; SZABOLCS *et al.*, 1969a,b, 1976; SIMUNEK & SUAREZ, 1994; WAGENET & HUTSON, 1987; ABDEL-DAYEM & SKAGGS, 1990; OOSTERBAAN & ABU SENNA, 1990; VANDERBORGH *et al.*, 1997; RHOADES *et al.*, 1989b; KARUCZKA, 1999; BAKACSI & KUTI, 1998).

### **Objectives of the present research**

The presented investigation was designed to assess the controlling factors of the salinization processes in a selected salt-affected study area. By analysing these factors it was intended to obtain information suitable for the numerical analysis of the salt accumulation processes, by sub-dividing the study area into characteristic, best separable subareas.

An explicit characterization of the ongoing salt accumulation is possible only with a finite number of simulation runs. In order to decide – rationally – how many simulations are necessary or sufficient, it is necessary to answer the following two questions:

– How many subareas must the area be divided into? (The answer to this question determines the number of soil profiles/pits to be opened for analysis.)

– How is the delineation of subareas done and on which concept is it based on?

According to the preliminary survey carried out for the detailed soil characterization of the study area, the four soil profiles were very similar in their soil chemical properties, particle size distribution and soil water retention curves. Extremely low hydraulic conductivity (K value) was observed in the most saline soil profile. Among the most important salt accumulation factors, in the study area elevation, soil salinity, as well as the depth and salinity of the groundwater table showed the greatest variability. Therefore, detailed studies were primarily focused on those factors.

### **Materials and methods**

In the first phase of the study data collection and analysis were carried out in the field, which was followed by the computer processing of collected information.

The study was performed north of Karcag (Nagykunság area of Hungary) on a 2.5 square km rectangular territory of the “May 1” Co-operative Farm. The test plots were irrigated for years and as a consequence of irrigation the groundwater table level rose from time to time, this way causing secondary salt accumulation in the deeper layers of the soil (TÓTH & BLASKÓ, 1998).

During the field work the distance of designated sampling points of the transects (about 300 meters from each other) was measured by counting steps. The UTM (Universal Transverse Mercator) coordinates of the sampling points were determined by hand-held satellite positioning device (Garmin eTrex GPS – Global Posi-

tioning System) with  $\pm 15$ -meter accuracy. UTM coordinates were used because the US-manufactured GPS did not provide the EOV (Unified National Projection System) coordinates used on Hungarian 1:10 000 scale topographic map sheets.

The height of sampling points was estimated with linear interpolation of the contour lines read on 1:10 000 scale topographic maps. To do this, first the UTM coordinates of the sampling points had to be converted into EOV coordinates. To do this, 5 distinct and identifiable reference points were used, at which UTM coordinates were determined.

In the field Electrical Conductivity meter (SCT Martek 12) was used in three replicates to determine the 0–40 cm soil layer's electrical conductivity (EC<sub>a\_0-40</sub> cm), and the average of three measurements was recorded. Soil and subsoil layers were sampled with Edelman auger down to the groundwater table level. Samples were collected from every 50 cm and their electrical conductivity was determined on the spot as follows: soil samples were collected in 6.2 ml spoon and 12.5 ml of distilled water was added. The 1:2 soil:water suspension was worked smooth with fingers in a plastic bag, and the conductivity of the suspension was measured (EC<sub>0-10</sub> cm, etc). The groundwater table level was recorded after reaching its depth. After 15 minutes the water table level rising closer to the surface was re-recorded. The groundwater table was sampled and its electrical conductivity (EC<sub>watertable</sub>) was measured. The electrical conductivity of the water table sample was measured with pocket conductimeter (Horiba). Although it is impossible to calculate the soil salt content exactly from the conductivity of the soil paste or moist soil (or soil suspension), (RHOADES et al., 1989a,b; FILEP, 1999), the EC variation in time and/or depth is proportional to the changes in salinity. Therefore, the quickly obtained field-measured EC values were considered suitable for assessing the relationships sought.

The preliminary data analysis showed a nearly normal distribution and no data transformations were needed for further analysis.

The relationships between the variables were evaluated by drawing graphs and by calculating Pearson correlation coefficients and regression equations.

Cluster analysis was applied to define the number of possible distinct groups that could be differentiated from the database of sampling points. As four groups were well separable, in the next step the "Quick Cluster" algorithm of the SPSS statistical software (ANDERBERG, 1973) was used to allocate the sampling points into four relatively homogeneous groups.

## Results and discussion

The database structure of the on-site field measurements, observations and measurements are summarized in Table 1. The full dataset is available in Table 1 in TÓTH and VÁRALLYAY (2001).

A variety of crops were observed in the study rectangle. A significant part of the sampling points fell into the 9 waterlogged spots that were the consequence of the rainy spring of 2000. The maximum height difference of the sampling points was

*Table 1*  
Results of on-site observations, measurements and analyses and basic statistical parameters of some characteristic sampling points in the salt-affected study area (Karcag, Hungary)

Sampling point and vegetation		x EOV m	y EOV m	ECa_ 0-40 cm	WT depth, cm	WT depth after 15', cm	EC_WT
1	Patch of standing water in wheat	785591	221114	0.39	138	130	2.40
2	Wheat stubble	785586	220840	0.55	160	147	4.10
4	Patch of standing water in wheat	785233	220851	0.44	160	–	–
73	Irrigated alfalfa	785548	219634	0.34	244	234	2.30
74	Irrigated alfalfa	785231	219624	0.28	193	188	1.50
75	Irrigated alfalfa	785233	219924	0.28	174	141	4.40
Case number				67	67	58	59
Minimum (Min)				0.22	75	24	1
Maximum (Max)				1.23	300	268	11.30
Mean				0.468	208	173	3.892
Standard deviation (SD)				0.176	50.6	48.8	2.127

Sampling point	EC						Elevation, m	Cluster
	0-10 cm	50-60 cm	100-110 cm	150-160 cm	200-210 cm	250-260 cm		
1	0.19	0.19	0.25	0.31			86.5	2
2	0.15	0.27	0.18	0.50			87	2
4	0.16	0.25	0.33	0.40			86	2
73	0.20	0.24	0.24	0.52	0.73	0.50	87.4	4
74	0.14	0.22	0.43	0.38			87.2	3
75	0.31	0.43	1.24	1.08			86.6	2
Case no.	67	67	66	62	34	7	67	
Min	0.12	0.13	0.18	0.24	0.31	0.50	85.6	
Max	0.83	1.44	2.30	1.97	1.59	2.10	88	
Mean	0.315	0.377	0.595	0.753	0.838	1.144	86.95	
SD	0.145	0.248	0.393	0.403	0.364	0.583	0.557	

*Remarks:* EC = electrical conductivity,  $\text{mS}\cdot\text{cm}^{-1}$ ; WT = groundwater table. Information on all sampling points was published in Table 1 in TÓTH and VÁRALLYAY (2001)

2.4 m, which is considered to be high for the Nagykunság region – taking into account the small size of the study area.

The mean groundwater table depth was about 2 m below the surface and there were great differences between the minimum (75 cm) and maximum (300 cm) values. The water table level in the drilled holes rose by an average of 35 cm after 15

minutes, which is not unusual in this area, where the groundwater table is under pressure/confined.

The mean electrical conductivity of groundwater table samples was high (about  $4 \text{ mS}\cdot\text{cm}^{-1}$ ) and varied between  $1\text{--}11 \text{ mS}\cdot\text{cm}^{-1}$ . The maximum salt accumulation was found in the deeper soil layers, and the average salinity of soil layers gradually increased downwards from the soil surface (Table 1).

### Correlation studies

Table 2 shows the correlation coefficients between the bulk soil electrical conductivity (ECa<sub>0–40 cm</sub>) and the measured electrical conductivity values of the soil suspensions collected from different soil layers.

Table 2

Correlation between the bulk electrical conductivity (ECa) of the soil (determined instrumentally on-site in the field) and the electrical conductivity measured in soil suspensions of samples collected from various soil layers

Variable pairs	Pearson's correlation coefficient	Case number
ECa versus EC <sub>0–10 cm</sub>	0.430**	67
ECa versus EC <sub>50–60 cm</sub>	0.389**	67
ECa versus EC <sub>0–60 cm</sub>	0.475**	67

Remark: \*\*Correlation significant at 0.05 level.

The correlation coefficient values between laboratory measured and bulk electrical conductivity values did not approach the values determined earlier with the same instrument (TÓTH et al., 1997, 1998). The reason for the less close correlation was the low soil moisture content during the field work (17–21 July, 2000). The soil moisture content was lower than field capacity; therefore the correlation between soil salinity and ECa<sub>0–40 cm</sub> had a component of considerable random fluctuations.

A close correlation was found between the groundwater table observation depth and the elevation above sea level: the higher the sampling point lay, the deeper was the observed water table depth.

The electrical conductivity (EC) of the groundwater table showed a close relationship with the EC of the soil layers above it (Fig. 1). Fig. 1 shows only those cases where the 0–250 cm soil profile was sampled continuously with 50 cm increments. As this depth was reached only at seven sampling points, only these cases are shown in the figure.

The correlation coefficients shown in Fig. 1 belong to 59 pairs of observation in the topsoil, and to 6 observations in the case of maximum depth. It was concluded that the salinity of the groundwater has a significant effect on the layers near the water table. Increasing groundwater salinity is associated with increasing salinity of the subsoil. This effect is weaker in the layers further upward from the water table.

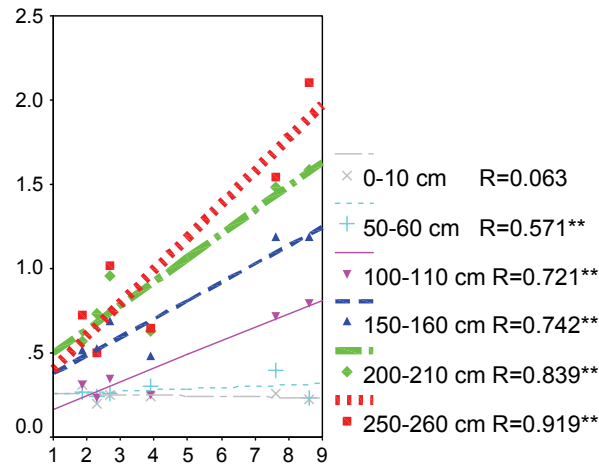


Fig. 1

Correlation between the electrical conductivity (EC,  $\text{mS}\cdot\text{cm}^{-1}$ ) of the water table and of the soil layers situated above the water table at various depths. Horizontal axis: Water table EC. Vertical axis: Soil layer EC

In the soil layer 2 m above the water table there is no correlation between the EC values. In this case 2 m is the “critical groundwater table depth”.

#### Regression analysis

Bivariate linear stepwise regression equations were calculated to study the affecting factors of root zone salinity. The statistically significant affecting factors selected by the algorithm were the groundwater table depth and the electrical conductivity of the water table:

$$\text{EC}_{50-60 \text{ cm}} = 0.418 + 0.07514 \times \text{EC}_{\text{watertable}} - 0.00184 \times \text{Watertable depth after 15'}$$

$$R^2 = 0.467$$

Thus, the shallower the water table below the surface and the greater its electrical conductivity is, the greater the electrical conductivity of the root zone is as well. The relevant data are presented in Fig 1. This result is consistent with earlier findings of SIGMOND (1923), ARANY (1956), KOVDA and SZABOLCS (1979), SZABOLCS (1979), SZABOLCS and co-workers (1969a,b) and VÁRALLYAY (1974), and the conclusions drawn by TÓTH and KUTI (1999a,b) in a Hortobágy area.

#### Cluster analysis

Table 3 shows the calculated cluster centres. According to the ANOVA analysis, the four groups significantly differ in their groundwater table depth, elevation, and EC measured in the 50–60 cm layer.

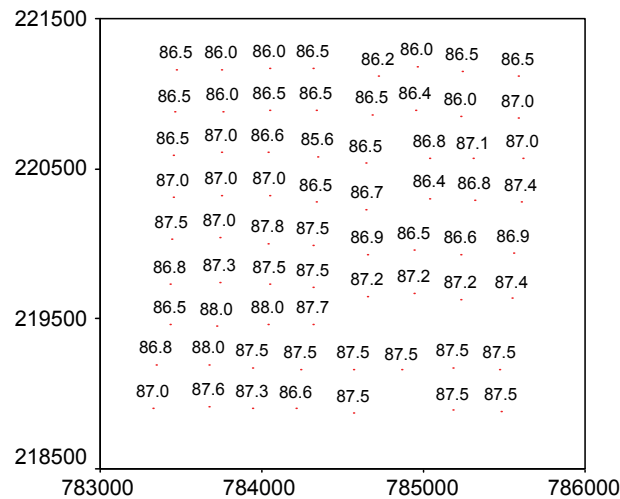
*Table 3*  
Group means for the cluster centroids separated by means of cluster analysis

Parameters	Groups			
	1	2	3	4
ECa_0-40 (mS·cm <sup>-1</sup> )	0.53	0.46	0.45	0.49
Water table depth (cm)	97.33	155.00	202.00	264.36
Water table depth after 15' (cm)	38.00	131.82	171.59	224.65
EC_water table (mS·cm <sup>-1</sup> )	2.90	4.68	3.57	4.08
EC_0-10 (mS·cm <sup>-1</sup> )	0.37	0.26	0.34	0.32
EC_50-60 (mS·cm <sup>-1</sup> )	0.53	0.47	0.37	0.30
EC_100-110 (mS·cm <sup>-1</sup> )	0.82	0.75	0.55	0.53
Elevation (m)	87.20	86.59	86.80	87.31

From Group 1 to Group 4 an increase can be observed in the groundwater table depth and a decrease in the EC measured in the 50–60 cm layer. From Group 2 to Group 4 the elevation increases.

Group 1 includes only 3 extreme sampling points, which are characterized by extremely shallow water table, and consequently soil salinity is the highest in this group.

Fig. 2 presents the elevation above sea level at the sampling points. As Fig. 2 shows, elevation varies in a uniform manner, except around the lowest point, where a waterlogged plot (probably a former riverbed) occurred.



*Fig. 2*

Elevation above sea level at the sampling points. Horizontal axis: EOTR x coordinate.  
Vertical axis: EOTR y coordinate. EOTR = Uniform National Mapping System

Fig. 3 clearly shows that the groups classified by cluster analysis form contiguous patches. When the result of the clustering is represented by two dimensions (not considered during clustering) clearly distinguished patches are perceivable. The extent of salt accumulation was predicted by numerical simulation for these patches in the framework of an international project (TÓTH et al., 2000).

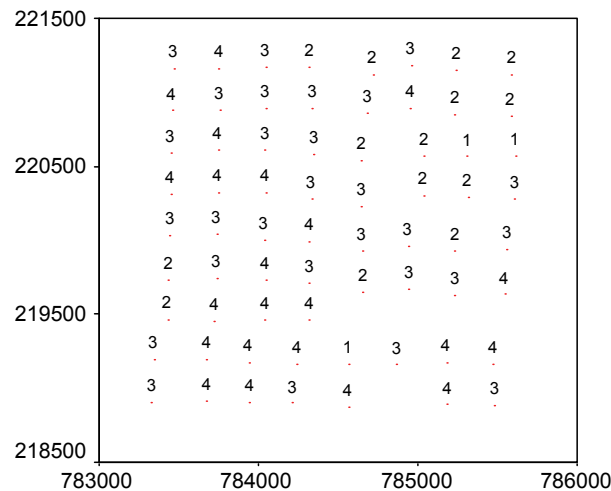


Fig. 3

Spatial distribution of the groups (clusters) distinguished on the sampling area.  
 Horizontal axis: EOTR x coordinate. Vertical axis: EOTR y coordinate.  
 EOTR = Uniform National Mapping System

### Summary

Soil salt accumulation factors were characterized and analysed on the basis of on-site examinations at 67 points of a 2.5×2.5 km area in the Nagykunság region of Hungary. The aim of the study was to distinguish homogeneous patches, which differed from each other and on which the numerical simulation of salt accumulation could be tested.

It was confirmed that the higher the soil surface lay, the greater was the depth of the groundwater table below the area. The salt content of the soil layers above the groundwater table was directly proportional to the salt content (electrical conductivity) of the groundwater.

Using the “Quick Cluster” algorithm four groups could be distinguished in the multidimensional space of the variables. The most important variables in distinguishing the groups from the point of view of salt accumulation were the depth of the groundwater table, the elevation above sea level and the salt content of the 50–60 cm layer. The groups were quite distinct on the area map and were used to predict salt accumulation by means of numerical simulation.



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### References

- ABDEL-DAYEM, S. & SKAGGS, R. W., 1990. Extension of DRAINMOD for simulating water management in arid regions. In: Symposium on Land Drainage for Salinity Control in Arid and Semi-Arid Regions, Cairo, February 25–March 2. Vol. 2. 201–212.
- ANDERBERG, M. J., 1973. Cluster Analysis for Applications. Academic Press. New York.
- ARANY, S., 1956. Salt-affected Soils and Their Reclamation. (In Hungarian) Mezőgazd. Kiadó. Budapest.
- BAKACSI, ZS. & KUTI, I., 1998. Agrogeological investigation on a salt affected landscape in the Danube Valley, Hungary. *Agrokémia és Talajtan*. **47**. 129–138.
- BOURENNANE, H., KING, D. & COUTURIER, A., 2000. Comparison of kriging with external drift and simple linear regression for predicting soil horizon thickness with different sample densities. In: Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98). (Eds.: COLLINS, M. et al.) *Geoderma*. Special Issue. **97**. (3–4) 255–272.
- CHAPLOT, V., WALTER, C. & CURMI, P., 2000. Improving soil hydromorphy prediction according to DEM resolution and available pedological data. In: Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98). (Eds.: COLLINS, M. et al.) *Geoderma*. Special Issue. **97**. (3–4) 405–422.
- COLLINS, M. et al. (Eds.), 2000. Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98). *Geoderma*. Special Issue. **97**. (3–4) 147–424.
- DOBOS, E. et al., 2000. Use of combined digital elevation model and satellite radiometric data for regional soil mapping. In: Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98). (Eds.: COLLINS, M. et al.) *Geoderma*. Special Issue. **97**. (3–4) 367–392.
- FILEP, GY., 1999. Relationship between the chemical properties of salt-affected soils. (In Hungarian) *Agrokémia és Talajtan*. **43**. 419–430.
- GOOVAERTS, P., 2000. Estimation or simulation of soil properties? An optimization problem with conflicting criteria. In: Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98). (Eds.: COLLINS, M. et al.) *Geoderma*. Special Issue. **97**. (3–4) 165–186.
- GROENIGEN, J. W. VAN, 2000. The influence of variogram parameters on optimal sampling schemes for mapping by kriging. In: Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98). (Eds.: COLLINS, M. et al.) *Geoderma*. Special Issue. **97**. (3–4) 223–236.
- KARUCZKA A., 1999. Effects of weather conditions on the salt balance of a solonetz soil. (In Hungarian) *Agrokémia és Talajtan*. **48**. 459–468.
- KOVDA, V. A. & SZABOLCS, I. (Eds.), 1979. Modelling of Soil Salinization and Alkalinization. *Agrokémia és Talajtan*. **28**. (Suppl.) 1–208.

- LAGACHERIE, P. & VOLTZ, M., 2000. Predicting soil properties over a region using sample information from a mapped reference area and digital elevation data: a conditional probability approach. In: *Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98)*. (Eds.: COLLINS, M. et al.) *Geoderma*. Special Issue. **97**. (3–4). 187–208.
- MCBRATNEY, A. B., BISHOP, T. F. A. & TELIATNIKOV, I. S., 2000. Two soil profile reconstruction techniques. In: *Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98)*. (Eds.: COLLINS, M. et al.) *Geoderma*. Special Issue. **97**. (3–4) 209–222.
- MENDONÇA SANTOS, M. L. et al., 2000. Three-dimensional GIS cartography applied to the study of the spatial variation of soil horizon in a Swiss floodplain. In: *Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98)*. (Eds.: COLLINS, M. et al.) *Geoderma*. Special Issue. **97**. (3–4) 351–366.
- ODEH, I. O. A. & MCBRATNEY, A. B., 2000. Using AVHRR images for spatial prediction of clay content in the lower Namoi Valley of Eastern Australia. In: *Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98)*. (Eds.: COLLINS, M. et al.) *Geoderma*. Special Issue. **97**. (3–4) 209–222.
- OOSTERBAAN, R. J. & ABU SENNA, M., 1990. Drainage and salinity predictions in the Nile delta, using SALTMOD. In: *Symposium on Land Drainage for Salinity Control in Arid and Semi-Arid Regions, Cairo, February 25–March 2*. Vol. 1. 274–286.
- RHOADES, J. D. et al., 1989a. Estimating soil salinity from saturated soil-paste electrical conductivity. *Soil Sci. Soc. Am. J.* **53**. 428–433.
- RHOADES, J. D. et al., 1989b. Determining soil salinity for soil and soil-paste electrical conductivities: sensitivity analysis of models. *Soil Sci. Soc. Am. J.* **53**. 1368–1374.
- SIGMOND E., 1923. *Hungarian Salt Affected Soils and Methods of Their Reclamation*. (In Hungarian) Magyar Tudományos Akadémia. Budapest.
- SIMUNEK, J. & SUAREZ, D. L., 1994. Two-dimensional transport model for variably saturated porous media with major ion chemistry. *Water Resources Research*. **30**. 1115–1133.
- SZABOLCS, I., 1979. *Review of Research on Salt Affected Soils*. Natural Resources Research. XV. UNESCO. Paris.
- SZABOLCS, I., DARAB, K. & VÁRALLYAY, GY., 1969a. Methods of predicting salinization and alkalization processes due to irrigation in the Hungarian Plain. *Agrokémia és Talajtan*. **18**. Suppl. 351–376.
- SZABOLCS, I., DARAB, K. & VÁRALLYAY, GY., 1969b. The Tisza Irrigation Systems and the fertility of the soils in the Hungarian Lowland. II. The “critical depth” of the water table in the area belonging to the Irrigation System of Kisköre. (In Hungarian) *Agrokémia és Talajtan*. **18**. 211–220.
- SZABOLCS, I., VÁRALLYAY, GY. & DARAB, K., 1976. Soil and hydrologic survey for the prognosis and monitoring of salinity and alkalinity. In: *Prognosis of Salinity and Alkalinity (Report of an Expert Consultation, Rome, 3–5 June 1975)*. *Soil Bulletin*. No. 31. 119–129. FAO. Rome.
- TÓTH, T. & BLASKÓ, L., 1998. Secondary salinization caused by irrigation. In: *The Soil As a Strategic Resource: Degradation Processes and Conservation Measures*. (Eds.: RODRIGUEZ, RODRIGUEZ A., JIMÉNEZ MENDOZA, C. C. & TEJEDOR SALGUERO, M. I.) 229–253. Geofoma Ediciones, Logrono.

- TÓTH T. & KUTI L., 1999a. Geological factors affecting the salinization of the Nyírólapos sample area (Hortobágy, Hungary). I. General geological characterization, calcite concentration and pH values of subsurface layers. (In Hungarian) *Agrokémia és Talajtan*. **48**. 431–444.
- TÓTH T. & KUTI L., 1999b. Geological factors affecting the salinization of the Nyírólapos sample area (Hortobágy, Hungary). II. Multiple relations and the prediction of surface soil salinity. (In Hungarian) *Agrokémia és Talajtan*. **48**. 445–457.
- TÓTH, T. & VÁRALLYAY, GY., 2001. Variability in the soil of a sample area according to salt accumulation factors. (In Hungarian) *Agrokémia és Talajtan*. **50**. 19–34.
- TÓTH, T., KERTÉSZ, M. & PÁSZTOR, L., 1998. New approaches in salinity-sodicity mapping in Hungary. *Agrokémia és Talajtan*. **47**. 76–85.
- TÓTH, T. et al., 1997. Plant composition of a pasture as a predictor of soil salinity. *Rev. Biol. Trop.* **45**. 1385–1393.
- TÓTH, T. et al., 2000. Prediction of salt concentration with numerical simulation programs. In: 3<sup>rd</sup> International Congress of the European Society for Soil Conservation. Book of Abstracts. P 87.
- VANDERBORGHT, J. et al., 1997. Analysis of solute redistribution in heterogeneous soil: II. Numerical simulation of solute transport. In: *geoENVI – Geostatistics for Environmental Applications*. (Eds.: SOARES, A., GÓMEZ-HERNÁNDEZ, J. & FROIDEVAUX, R.) 283–295. Kluwer Academic Publ. Dordrecht.
- VÁRALLYAY, GY., 1968. Salt accumulation processes in the Hungarian Danube Valley. *Trans. 9<sup>th</sup> International Congress of Soil Science*. Vol. 1. 371–380.
- VÁRALLYAY, GY., 1974. Hydrophysical aspects of salinization from the groundwater. *Agrokémia és Talajtan*. **23**. (Suppl.) 29–44.
- WAGENET, R. J. & HUTSON, J. L., 1987. LEACHM, Leaching estimation and chemistry model: A process based model of water and solute movement, transformations, plant uptake and chemical reactions in the unsaturated zone. *Continuum* Vol. 2. Water Resources Institute, Cornell University, Ithaca, NY.
- WEBSTER, R., 2000. Is soil variation random? In: *Developments in Quantitative Soil Resource Assessment (PEDOMETRICS '98)*. (Eds.: COLLINS, M. et al.) *Geoderma*. Special Issue. **97**. (3–4) 149–164.