Review of research on salt-affected soils in the Debrecen agricultural high educational institutions, with special focus on the mapping of Hortobágy

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Summary

The history of the research of Debrecen scholars on salt-affected soils of Hortobágy and the region is very rich and diverse.

Focusing on mapping, the following stages can be distinguished, indicating the completeness of the maps and the purpose of the performed work

- First, quantitative maps (Arany, 1926) for the utilization of the lands at 1:75,000 (*Figure 1*).
- Second, quantitative map (Kreybig, 1943) for the utilization of the lands at 1:25,000.
- Third, category map (Kreybig et al., 1935) testing the suitability of the classification system at 1:75,000.
- Fourth, partial category map (Szabolcs, 1954), showing the reasons of unsuccessful management at 1:10,000.
- Fifth, partial quantitative map (Csillag et al., 1996), showing the utility of digital sampling at 1:25,000.
- Sixth, partial quantitative map (Tamás and Lénárt, 2006), showing the capacity of multispectral remote imagery at 1:100.
- Seventh, partial quantitative map (Douaik et al., 2006), showing the usefulness of geostatistical mapping at 1:10,000.
- Eight, national quantitative maps (Pásztor et al., 2016), showing the applicability of geostatistics for administrative purposes at 1:10,000.
- Ninth, partial quantitative/category map (authors, 2019), finding the optimal methods at 1:10,000.

Keywords: salt-affected soils, solonetz, sodic soils, mapping, soil type

Introduction on soil mapping

The history of soil mapping (see Várallyay, 1989 on earlier developments in Hungary), with particular emphasis on salt-affected, soils is a history of competition between two paradigms, one of quantitative appraisal of soil properties, mainly salinity and the other, of categorical delineation of patches of similar pedons. In short, mapping categories, such as soil types, orders, etc are abstract terms, which are difficult to elucidate in a few words for the uninitiated. Although quantitative maps deliver directly understandable message for the users, such maps are suited only for a limited number of soils, among which salt-affected soils are the most prominent, since their main features: salinity, sodicity and alkalinity are all easily quantifiable characteristics (Arany, 1956). During the history of soil science first categorical maps were compiled, but salt-affected soils were the first being spatially represented by quantitative maps. Later, due to technological advances, categorical maps lost ground, but still thrive parallel to quantitative maps.

History of the study of salt-affected soils in Debrecen

The history of research and management of salt-affected soils was well documented during the history of high agricultural education in Debrecen, partly covered by the review of Blaskó (2012). Research on salt-affected soils in Hungary was always active, but after the Versailles peace treaty, following the First World War it became more concentrated on the remaining national territories, since large areas of the old country, among the newly defined borders were salt-affected. Such research lasted until the nineteen-eighties and then slowed down to the current pace.

During the last 63 years in the Debrecen agricultural academy/ college/university and the closely collaborating institutions (Debrecen University of Sciences, Hortobágy National Park, Soil Reclamation Station, etc.), several professors of the Soil science and other departments of the agricultural institution graduated as chemists in the Debrecen University of Sciences (under several names) and technical collaboration was easy to organize.

Often the professors and docents of the agricultural academy/ college/university carried out precious research. The main activity of Sándor Arany, one of the leading scientists of salt-affected soil research was multifold ranging from mapping to laboratory analysis and reclamation (e. g. Arany, 1926, 1934; Arany and Babarczy, 1937).

Scientific debate was frequent in those days and two cases deserve special attention. Professor Ferenc Szelényi installed a field reclamation experiment in Hortobágy with multiple deep plowing of sodic soils under standing water (Szelényi, 1956, 1957), thereby intending the washing away of salts, but his research received rather critical reviews (Károly Páter and others). Another special event for the domestic specialists of salt-affected soils of those times (and that time there were many!) was the paper of the invited Austrian soil scientist (zoologist), Herbert Franz on the formation of the solonetz soils of Hortobágy (Franz, 1964), using the concept of Székyné et al. (1959) among others. Two hotshots of the Hungarian school, Katalin Darab, (1967) and György Várallyay (1967), analyzed his ideas very critically.

Later György Filep (Filep, 1999ab, 2001; Filep and Wafi, 1992, 1993; Filep and Rédly, 1992), an eminent researcher and professor was working on the details of chemistry of salt-affected soils.

During the nineteen-seventies "complex amelioration", that is drainage of salt-affected fields prone to waterlogging, combined with reclamation was the most typical costly investment in the affected areas, recruiting researchers from several university departments, such as Gusztáv Sziki (1961). Grazing studies were always evident in the grassland (e. g. Milkovich and Bánszky, 1962). József Fekete (1968) studied the salt and water cycle of related slightly salt-affected soils. Lajos Ábrahám (1957) worked on the effect water bodies on the salt-affected soils among other topics.

The foundation of the Hortobágy National Park provided new opportunity for the study of the vegetation and soils of salt-affected grasslands, and in this work the researchers of Debrecen University of Sciences had greater role, Júlia Varga (1984, 1986) carried out botanical studies, Lajos Varga (1960) and András Szabó (1996) studied microfauna in the national park.

In recent years Lajos Blaskó, János Tamás and co-workers carried out important research on salt-affected soils (Blaskó et al., 2003, 2006ab; Tamás et al., 2014). These are closely related to the long research activity of the Karcag Research Institute, which is not covered by this short review. We must also skip the long recent activity of the Research Station of Afforestation of Salt-affected lands at Püspökladány (e. g. Leszták and Szabolcs, 1959; Jassó, 1962; Tóth, 1972) due to lack of available space in this journal.

The fellow scientists and alumni in other faculties of the now united Debrecen University continue research in the Hortobágy on geomorphology, vegetation, erosion, tumuli, such as Albert Tóth and Csaba Tóth, Tibor Novák (Tóth 1988, 1997, 2001; Kovács and Tóth, 1988; Novák et al., 2016), but also the Gödöllő based Attila Barczi (Joó et al., 2003) attract students in large numbers. Pál Sümegi with his interest in the reconstruction of ancient landscapes also contributed to soil knowledge in the region (Bede et al., 2015). Albert Tóth directs a summer camp in the Hortobágy for students with a soil research section (e.g. Tóth, 1996 among many volumes) every year already for 44 years.

History of the mapping of soils in Hortobágy

Regarding the mapping of such soils a special condition for that was, that the City of Debrecen was the historic owner of large parts of the

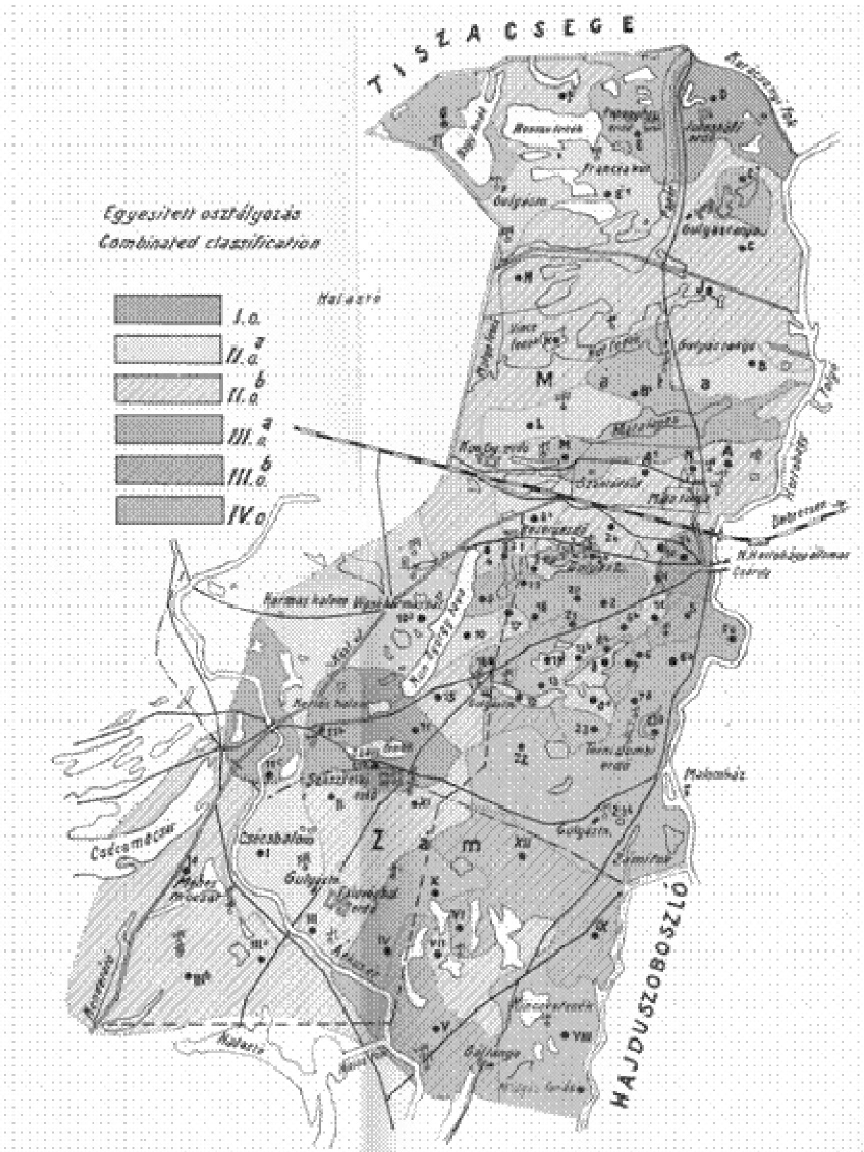
Hortobágy Puszta, a mainly treeless mosaic of salt-affected dry grasslands, sparse croplands, meadows and marhes. When the first method of medium-scale mapping (1:75,000) of salt-affected soils was developed, Pál Magyar, a forester, sharing the concepts of the botanists Raymund Rapaics (1927) and Rezső Soó (1934), worked together with the chemist Sándor Arany. On large part of Hortobágy P. Magyar (1928) compiled a vegetation map, whereas S. Arany (1926) a soil map. P. Magyar later established the Research Station of Afforestation of Salt-affected lands on 1 October 1924. The soil salinity and alkalinity classes distinguished by them were defined by *Table 1*, showing the classification of Alexis De Sigmond (1927). It was based on the properties of soil samples taken from 0–30 cm and 30–120 cm depths (*Table 1*). De Sigmond defined his scheme as a "practical botanical classification". This is a typical artificial classification system based on the ranges of total salt concentration and soda (Na_2CO_3), being dominant components of the Hungarian sodic soils, which are so much widespread in Hortobágy. This quantitative soil classification system was, and is still actively used by botanists and foresters. Since the appearance of this classification in Hungary, the lower threshold of a soil, qualified as "true salt-affected soil" is 0.1% salt content. The threshold value for a saline soil, Solonchak, in the genetic classification is 0.25% salt content in the topsoil. The system shows similarities to the practical classification of salt-affected soils of Hayward and Wadleigh (1949).

Table 1. *Classification of salt-affected soils by De Sigmond (1927)*

A) Based on one characteristic only		
Class	Salt % (salt)	Soda % (soda)
Class I	<0.1	0. –0.05
Class II	0.1–0.25	0.05–0.1
Class III	0.25–0.5	0.1–0.2
Class IV	>0.5	>0.2
B) Based on the combination of the two Classes of Class_salt and Class_soda		
I = Isalt/Isoda		
IIa= IIsalt/Isoda or Isalt/IIsoda,		
IIb=IIsalt/IIsoda or IIIsalt/Isoda		
IIIa=IIIsalt/IIIsoda or IIsalt/IIIsoda,		
IIIb=IIIsalt/IIIsoda or IVsalt/IIsoda		
IVa=IVsalt/IIIsoda or IIIsalt/IVsoda,		
IVb=IVsalt/IVsoda		

The patches delineated by the two researches showed great coincidence and represented one of the first quantitative soil maps, directly showing the salt or soda concentration of the soil (see Table 7 in Tóth and Várallyay, 2002). On the other hand the vegetation map remained category map.

Figure 1. *Map of the area of Hortobágy which was owned by the city of Debrecen showing the combined salinity/soda content (see Table 1B) according to the categories defined by De Sigmond (1927) as published by Arany (1926)*



The second large mapping in the area, the national soil mapping project initiated and led by Lajos Kreybig was unique for being a national survey based on field and laboratory soil analyses and at the same time serving practical purposes (Kreybig, 1937). It was carried out between

1935 and 1951 in several stages. These maps still represent a valuable treasure of soil information. The soil and land use conditions were presented together on the map sheets. Chemical (soil calcareousness/ alkalinity/acidity on a continuous grade) and physical soil properties (texture classes) of the soil root zone were identified inside croplands and grasslands/meadows, but not in forests. This map series did not introduce mapping categories and used quantitative classes of soil chemical and physical characteristics, being a typical quantitative map serving clearly practical purposes.

By that time Alexis De Sigmond, the greatest person of the Hungarian salt-affected researches, compiled a new theoretically based universal soil classification system, covering also the salt-affected soils and this system was put on map in the Hortobágy, creating the only map of his unique soil classification (Kreybig et al., 1935). The types of his soil map, together with the current equivalent categories are shown in *Table 2*.

Table 2. *Salt-affected soil types in the "Soil order 12. Sodium soils" of De Sigmond (1938)*

Main types	Interpretive name based on the Russian names
1: Saline soils	Solonchak
2: Saline alkali soils	Solonchak-Solonetz
3: Leached alkali soils	Solonetz
4: Degraded alkali soils	Solod
5: Regraded alkali soils	Soil salinized again

After the Second World War the new paradigm was the "genetical soil mapping" based on the Russian school, following the Dokuchaev principles. A system was elaborated by Hungarian soil scientists, soil surveyors and soil-mapping specialists for large-scale soil survey, to satisfy the practical needs of soil information for large farming units (state and co-operative farms), which characterized the Hungarian agriculture between 1950 and 1990. Such maps were prepared for about one-thirds of the area of Hungary (about 35,000 km^2). The system consists of four main parts: (i) genetic soil map, indicating categorical genetic soil taxonomy (type, subtype) units and parent material; (ii) thematic soil maps of the most important physical and chemical soil properties; (iii) thematic maps, indicating recommendations for rational land use, cropping pattern, soil improvement, tillage practice and fertilization; (iv) explanatory booklets, including a short review on the physiographical conditions; description of soils, recommendations for their rational utilization, field description of soil profiles and results of field observations or measurements and data of laboratory analyses (Sarkadi et al., 1964; Szabolcs, 1966). One of the first such published maps showed a part of Hortobágy by István Szabolcs (1954), an alumnus of the Debrecen University, who later became world class scientist of salt-affected soils. The mapping followed a failed irrigation project of the grasslands and showed the high sodicity of the areas. The mapping categories of Hortobágy were discussed by Szabolcs and Máté (1955).

During the last decade of the last century the novel methods of satellite remote sensing, geographical information system, geostatistics, spatial sampling and digital image processing provided new opportunities as foreseen already by Várallyay (1989) in his review. A team of researchers from the Budapest Soil Institute of the Hungarian Academy of Sciences (under several names) performed several sampling and mapping experiments in Hortobágy with the participation of several authors of this report. First the correlation between relief, soil and vegetation was analysed under the leadership of Kálmán Rajkai (Rajkai et al., 1986; Oertli and Rajkai, 1988ab; Tóth and Rajkai, 1994; Tóth and Kertész, 2002), then a medium-scaled map of vegetation and soil properties was compiled based on a sophisticated sampling design, derived from a satellite image (Csillag et al., 1996; Tóth and Kertész, 1996).

The modern techniques of multispectral mapping were applied by the Debrecen Agricultural University staff. János Tamás and Csaba Lénárt, (2006) and Pechmann et al. (2003) tested multispectral mapping northeast from the contiguous Hortobágy area.

Another approach was carried out in the eastern part of Hortobágy, where several papers focussed on soil variability (Tóth and Kuti, 1999ab; Tóth et al., 2001; Tóth and Jozefaciuk, 2002). Douaik et al. (2007) analysed the spatio-temporal variability of surface soil salinity at 400 points, measured 19 times with instrumental technique for the assessment of topsoil salinity.

In recent years Szabó et al. (1999) and Pásztor et al. (2016) created country-wide maps of several characteristics, most importantly of soil salinity and sodicity. The reason for this map series is that inside the European Union a new delineation of Areas with Natural Constraints was performed based on a set of unified biophysical criteria. Farmers will receive financial compensation when their land is affected by such constraint, salinity and sodicity. The method for delineating such areas is strict (Terres et al., 2016) and has such threshold values for each criterion which were never used before. Therefore new maps of salinity and sodicity, with one hectare accuracy, were compiled with digital techniques for this purpose, evidently covering our area of interest.

Authors of this report are currently working on a project that intends to find the best mapping technique of salt-affected soils, thereby combining the best experience of the above predecessor researchers. The project will be carried out inside the Hortobágy grasslands/meadows as the most typical salt-affected area of the country. The concepts and approaches used by the above researchers will be tested. Again the category and quantitative maps will be compared. During the research five alternative survey strategies (A-E) are tested.

Survey Strategy A, traditional profile-based survey as performed by Szabolcs (1954), complemented with proxy survey. In this survey profile locations will be allocated based on *digital terrain model (DTM) (a) and vegetation map (β) weighted by spatial extension*, then 2nd (already collected) profile data will be *extended by Electromagnetic induction transects* covering each rastercell, 3rd spatial interpolation will be used to predict each variable in the all rastercells.

Survey Strategy B is survey based on biomass. In this survey 1st with the combination of *biomass map* (estimated by an indicator such as Normalized Difference Vegetation Index [ε]) by DTM (α) 4–6 large sampling strata will be distinguished for selecting the profile locations, and 2nd based on (already collected) profile data spatial interpolation (with the proxies of biomass and DTM) will be used to predict each variable in all rastercells.

Survey Strategy C is based on theoretical salinization model. 1st using national *watertable level and salinity maps* (γ) *combined by DTM* ((α) salinization maps will be prepared, 2nd from which 4–6 large sampling strata will be distinguished for selecting the profile locations and 3rd spatial interpolation (with the two proxies) will be used to predict each variable in the all rastercells.

Two Land use-specific survey strategies (D and E) will be realized depending on the typical land uses.

Survey Strategy D will be followed in arable lands *via calculation of salinity index*. 1st *0–10 cm soil sampling*, 2nd *multicopter hyperspectral survey* (δ) *of bare surface*, 3rd *spectral and chemical (Electrical Conductivity as proxy of salinity, Sodium Adsorption Ratio, pH*) analysis of surface samples, 4th *calculation of salinity index*, 5th *matching of field and laboratory spectra, 6th calculation of salinity index for the field hyperspectral values*, 7th selection of profile locations based on extremes and spatial distribution of salinity index values, 8th direct surface salinity prediction based on salinity index, 9th interpolation of profile data to predict each variable in all rastercells.

Survey Strategy E is developed for salt meadows and steppes and is *based on the distribution of vegetation categories*. 1st based on the combination of 3–4 strata of DTM (α) and 3–4 strata of vegetation category map (β) 4–6 survey strata will be selected to assign the profile locations, 2nd spatial interpolation using DTM and vegetation classes will be used to predict each variable in all rastercells.

The preliminary results show promising results. *Figure 2* shows the result of applying the salinity index (mentioned in Survey Strategy D) in a sodic pan (Szappanszék). The UAV-based image capturing system consists of a Cubert UHD-185 hyperspectral snapshot camera (http://cubert-gmbh.com/uhd-185-firefly/), a Compulab Fitlet mini PC (http://www.fit-pc.com) and a CarbonCore octocopter UAV. The Cubert camera simultaneously records 125 bands in a spectral range of 450–950 nm with a sampling interval of 4 nm. *Figure 3* shows the clear border of very saline patch indicated by red colour.

As a proxy of clay content a novel method of using gamma dosimetry was applied in an experimental transect covering 70 m transition from an interdune valley to the sand dune using InSpector™ 1000 dosimeter. Fig 3 proves the possibility of using a simple device to infer on the clayiness of surface soil. The method can be useful to interpolate clayiness in Survey Strategy A.

The initial testing exercises show promising results and the project participants look forward to a new wave of modern mapping activity to satisfy the data need of farmers, domestic and EU administrators, scientist as well. This is the motivation for our team.

Figure 2. *Map of Salinity Index of a ca 2.5 ha sodic pan as defined by the combination of reflectance values as √(436nm*630nm) of hyperspectral camera carried by UMV, according to the equation of Kumar et al. (2015)*

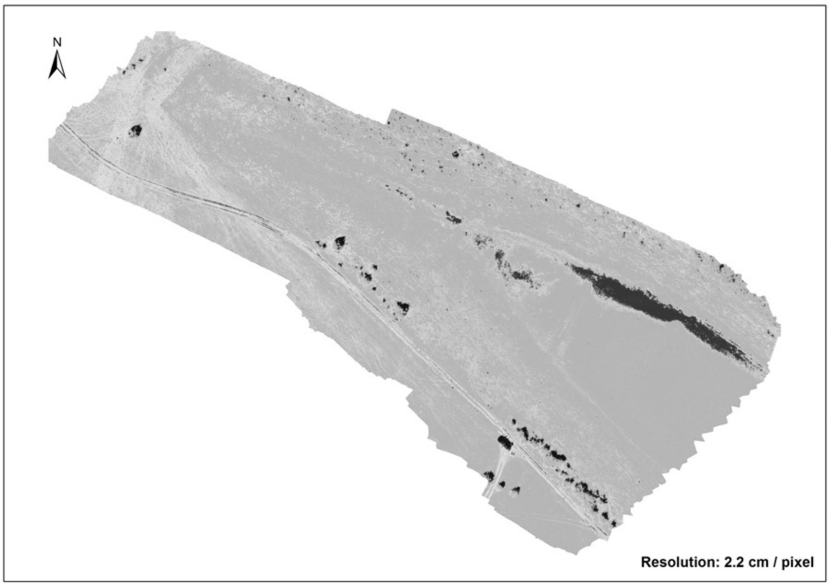
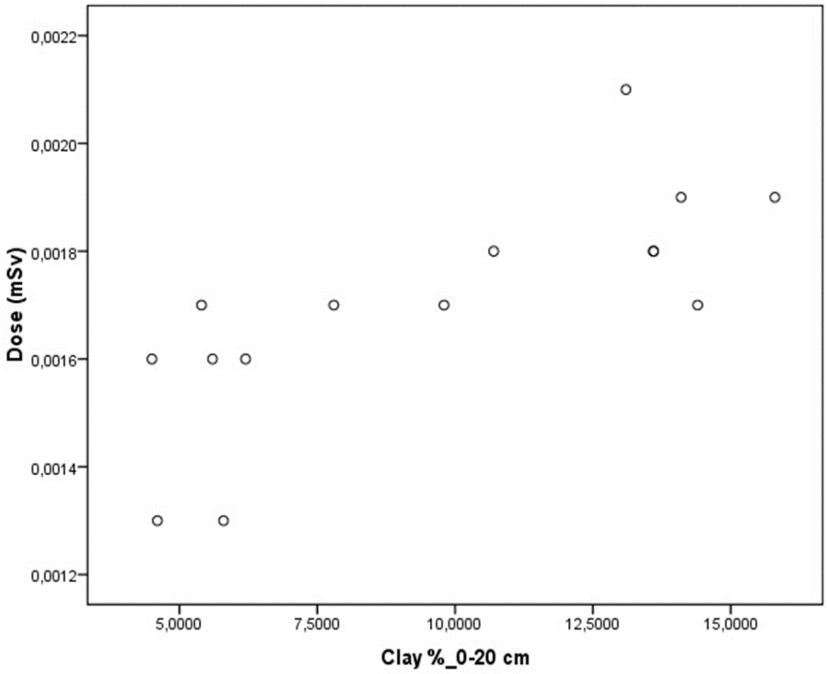


Figure 3. *Scatterplot of in situ surface gamma dose during 3 minutes measurement time (Y axis) versus laboratory determined clay percent of the surface soil layer (X axis) in a sand dune – interdune valley transect.*



Acknowledgment

This short review cannot be full and authors apologize for any shortcomings and mistakes. Authors appreciate the support of the OTKA grant K-124290 for the described research project.

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