Monitoring, predicting and quantifying soil salinity, sodicity and alkalinity in Hungary at different scales: Past experiences, current achievements and an outlook with special regard to European Union initiatives

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ABSTRACT

Approximately 13 percent of Hungary is considered to be salt-affected and with this large extent it is unique in Europe. There are large areas of naturally saline and sodic soils, but secondary salinization is also known to occur.

Due to the geological and hydrological conditions, the country demonstrates the most characteristic features of natural continental (not marine) salinization, sodification and alkalinization. Since the most important direct source of soil salinization is the shallow groundwater level below the lowland surface, there is a chance of irrigation-related salinization in two dominant situations: when the abundant use of river waters causes waterlogging and rise of saline groundwater (salinization from below); and when typically saline tubewell-waters are used for irrigation (salinization from above).

The spatial assessment of salt-affected areas began with the systematic mapping of salt-affected areas. There is a series of ten maps describing different aspects (salt-affected soil types, vegetation types, salt-efflorescences) of the salinity-status nationwide from 1897 onward, with the latest survey finished in 2006.

Besides the national scale of 1:500 000, soil salinity is also mapped at the scale of 1:100 000 on the AGROTOPO map sheets and 1:25 000 in the Kreybig Soil Information System (spatial vector data for maps and database for profiles and test boring). In spite of the two systems being digitally available, the information collected at the scale of 1:10 000 is available only for two-thirds of the country and is not digitised.

Very early maps at field scale, later at regional scale showed numerical salinity/sodicity values. At present field scale numerical maps are analysed in order to optimise salinity mapping in space and time.

Systematic monitoring of soil salinization in irrigated areas dates back to 1989 in the irrigation district of Tiszafüred in the county of Jász-Nagykun-Szolnok. A nationwide Soil Information and Monitoring System was initiated from 1991. In this system, from the 1 236 soil profiles, 69 profiles classified as salt-affected are sampled and analysed yearly for the indicators of salinity and alkalinity.

When the large-scale irrigation projects were planned in the second half of the last century, prediction of soil salinization was based on the concept of the critical depth of saline groundwater. As an alternative, a numerical rule-based algorithm was developed for the prediction of the risk of soil salinization in irrigated fields. Numerical process-based modelling with LEACHM and UNSATCHEM simulation programs was tested,

but with limited success so far for Hungarian areas.

Based on environmental correlation, there is a long history of predicting the occurrences of salt-affected areas. A unique physical modelling system using compensation lysimeters are used for testing the effect of saline groundwater at different depths and with drainage management in a dominantly sodic area.

Reclamation, including installation drainage and afforestation of salt-affected soils, has lost its momentum in the country due to a decrease in financial profitability. On the other hand, over the last few years a clear picture has been drawn of how efficient the different reclamation techniques are and how afforestation changes the salt distribution of soils and underlying strata.

Hungarian soil scientists play a leading role in the development of good practice for the management of salt-affected areas in Europe. Based on the initiatives of the Soil Framework Directive of the European Community, salinization is considered as a serious "soil threat" to agriculture. There is a well-developed concept of salinization and a set of common criteria for delineating areas threatened by salinization, are agreed on. A currently running EU-financed research project (ENVASSO) focuses on the assessment methodologies for quantifying soil threats. Another project (RAMSOIL) catalogues and evaluates the available risk assessment methodologies of each EU member country. To facilitate the spatial assessment of soil salinity/sodicity/alkalinity according to the EU-wide legal framework, the EU provides grants for promising research proposals to establish sensor-based digital field soil mapping methodologies. Such projects are based on the rich history of salinity sensing with field devices, such as the *Geophilus Electricus* system for multiple depth assessment of salinity (Lück *et al.*, 2009).

INTRODUCTION

Traditionally the study of salt-affected soils (SAS) is one of the most popular topics among Hungarian soil scientists. The origin, properties and reclamation of these soils were investigated thoroughly during the last two centuries. A full list of the 22 monographs on salt-affected soils is reported by Tóth and Szendrei (2006). The mapping of these soils started in 1897. Mapping at the scale of 1:25 000 was finished by the 1950s and their last assessment, now of the areas covered with native halotolerant vegetation, was carried out in the years 2003–2006 (Bölöni *et al.*, 2003).

Environmental conditions in Hungary

About one third of the soils on the Great Hungarian Plain (46–48.5° N and 19–22.5° E) are affected by salinity/sodicity, mainly by sodification, one third of the territory is covered by potential SAS and one third does not have such soils. Potential SAS are defined as soils, which are not salt-affected at present, but which could become considerably saline or sodic as a consequence of irrigation (Szabolcs, 1974). The territorial segregation of some types of SAS is evident (Figure 1). Soil types Solonchak and Solonchak-Solonetz are concentrated mainly in the Danube-Tisza Interfluve types *Meadow Solonetz* and *Deep Mollic Solonetz* are more typical in the Tisza Plain. In this chapter, the term *Meadow Solonetz Turning into Stepp Formation* (Szabolcs, 1966 and Szabolcs 1989) has been replaced by the term *Deep Mollic Solonetz* for reasons of clarity.

Meteorological conditions

The Great Hungarian Plain is the hottest and driest region of the Carpathian Basin, which is otherwise characterized by temperate climate. In the central region, where SAS are most common, data describing annual averages and dynamism is summarized in Table 1. The area of Hungarian SAS, is located at an elevation of 80–90 m above sea level, under temperate continental climate, with 10 °C mean annual temperature (-2 °C in January to +21 °C in July), 527 mm average annual precipitation (maximum 71 mm in June, minimum 28 mm in March) and 900 mm mean annual pan evaporation.

Table 1. Average meteorological parameters in the middle of the Great Hungarian Plain.

Parameter													Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Rainfall (mm)	30	30	28	41	51	71	53	50	34	33	46	46	**527**
Potential evaporation (mm)	12	19	40	78	112	136	156	144	106	58	25	14	**900**
Drought Index (evap./ precip.)	0.40	0.63	1.43	1.90	2.20	1.92	2.94	2.88	3.12	1.64	0.54	0.30	**1.71**
Actual evaporation (mm) (free soil surface)	11	15	27	63	102	91	76	58	35	21	16	12	**527**
Air temp. (°C)	1.8	0.5	5.2	10.9	16.0	19.7	21.3	20.5	16.4	10.7	5.3	0.6	**10.0**

Hydrological conditions

The Great Hungarian Plain is a basin filled with sediments deposited by rivers and wind. Therefore, the position of surface waters had an important impact on soil formation. These rivers, as typical lowland rivers, affected a vast territory by the periodic floods, creating huge marshlands. According to their origin, sediments deposited from the rivers differ much and the base materials of soil formation reflect these differences.

In the formation of salt-affected soils a decisive role is played by saline groundwater, so the different types of SAS in the Hungarian soil classification system are closely related to distinct water table depths. There are regional and local differences in the composition and concentration of groundwater that resulted in the wide variety of salt-affected soils.

Soil conditions

According to the general Hungarian classification of soils, there are soils of the Atlantic region (Brown Forest soils) in the hilly marginal regions of the plain and there are soils of the steppe region (Chernozems) in the inner plateaus of the plain. Important azonal soils are the salt-affected soils and Meadow soils. These, together with the intrazonal alluvial soils, form a catena. As the parent material between the Danube and $Tisza_{Hungarian}$ (=$Theiß_{German}$ or $Tisa_{Slovakian\&Ukrainian}$) rivers is rich in calcium-carbonate, the Solonchak and Solonchak-Solonetz soils developed on the alluvial sandy soils are classified as Calcareous Sodic soils, whereas the more or less leached Solonetz-like soils that were developing on the more acidic sediments of the Tisza River (loamy and clayey parent material) are frequently referred to as Non-calcareous Sodic soils. The latter is characterized by higher clay-content and unfavourable hydrophysical properties, high ESP (Exchangeable Sodium Percentage) and high pH in the columnar B horizon and, as a rule, low salt content. The unfavourable properties that limit the fertility of these soils are the consequence of the high clay content, high ESP, high pH and the resulting special moisture regime. The climatic conditions, e.g. the unequal distribution of the precipitation, the high aridity index and the high fluctuating saline groundwater call for a complex approach for improvement.

Groundwater conditions

The Great Hungarian Plain consists of a variable layered and textured deep aquifer where the water table varies between 0.5 and 4.0 m below the surface, with an average fluctuation of 0.5–2.0 m. The shallow water table often causes waterlogging on the lower parts of the fields. Surface waterlogging appears also on the low-lying, low permeability plots at the end of winter, after snowmelt and/or during high-precipitation periods. The high salt content of the groundwater and its high $Na^+/(Ca^{2+} + Mg^{2+})$ ratio often result in salinization and alkalinization of the soils.

The formation of the salt-affected soils of Hungary

At the beginning of the Miocene geological Era (23 to 5.3 million years before present) between the ancient Carpathian and Dinaric Mountains a vast gulf of the *Tethys* ancient sea flowed in to create the *Parathethys*. This sea gulf later became detached from the Tethys to form the *Sarmathian* or *Pannonic* Sea by the end of the Pliocene Era (5.3 million to 1.8 million years before present), which has been filled up with several hundred metres of thick alluvial sediment. During the Pleistocene Era (1.8 million to 11 550 years before present) this process continued and loess formation also took place on the previously deposited alluvial sand. In some areas the sand was blown into dunes.

On the parent materials formed during the Pleistocene Era the influence of shallow fluctuating, saline-sodic groundwaters, as well as the permanent or temporary waterlogging created the conditions of SAS formation. The sodium ions, being considered as the most important factors, either dissolved from the Tertiary Era (65 million to 1.8 million years before present) deposits into the groundwater (supported by data of Mádlné *et al.*, 2005) or concentrated during consecutive drying and wetting of infiltrated water (as argued by Bakacsi and Kuti, 1998), Szöőr *et al.* (1991) have shown that salinization has been present in the Great Hungarian Plain at least 30 000 years before. Among the anions in the groundwater and soil solutions there were plenty of bicarbonates, carbonates and other ions associated with alkaline hydrolysis and these caused almost irreversible sodium exchange processes.

CLASSIFICATION OF HUNGARIAN SALT-AFFECTED SOILS

In the late US classification of SAS the term *white alkali soil* stood for Solonchak soils and *black alkali* for Solonetz soils. The modern Hungarian soil classification is based on these categories as well. Also the categories like saline, sodic and saline-sodic as suggested by Richards (1954) and de Sigmond (1938) are still in use. In agronomical practice the limit for a soil to be called SAS is 0.1 percent soluble salt content, as suggested by de Sigmond (1938) and Richards (1954).

The current classification system of Hungarian SAS meets two requirements: 1) it fits the general principles of genetic soil classification, first developed in Russia (described in Gerasimov, 1960) and later further developed in Europe (Kubiena, 1953) and USA (Marbut, 1927; Soil Survey Staff, 1951) up to the middle of the twentieth century and 2) it keeps the traditional categories of Hungarian SAS.

The Hungarian SAS, belonging to the Halomorphic soils type of the national soil classification system (Szabolcs, 1966) are divided into five soil types: Solonchak soils, Solonchak-Solonetz soils, Meadow Solonetz soils, Deep Mollic Solonetz, Secondary Salt-affected soils. The following sections describe the current official classification of the main types of salt-affected soils of Hungary (Szabolcs, 1966 and Guidelines, 1989). The area of the soil types was calculated from the Agrotopographical Map Database (AGROTOPO) database, (Várallyay *et al.*, 1985). The map of salt-affected soils is shown in Figure 1.

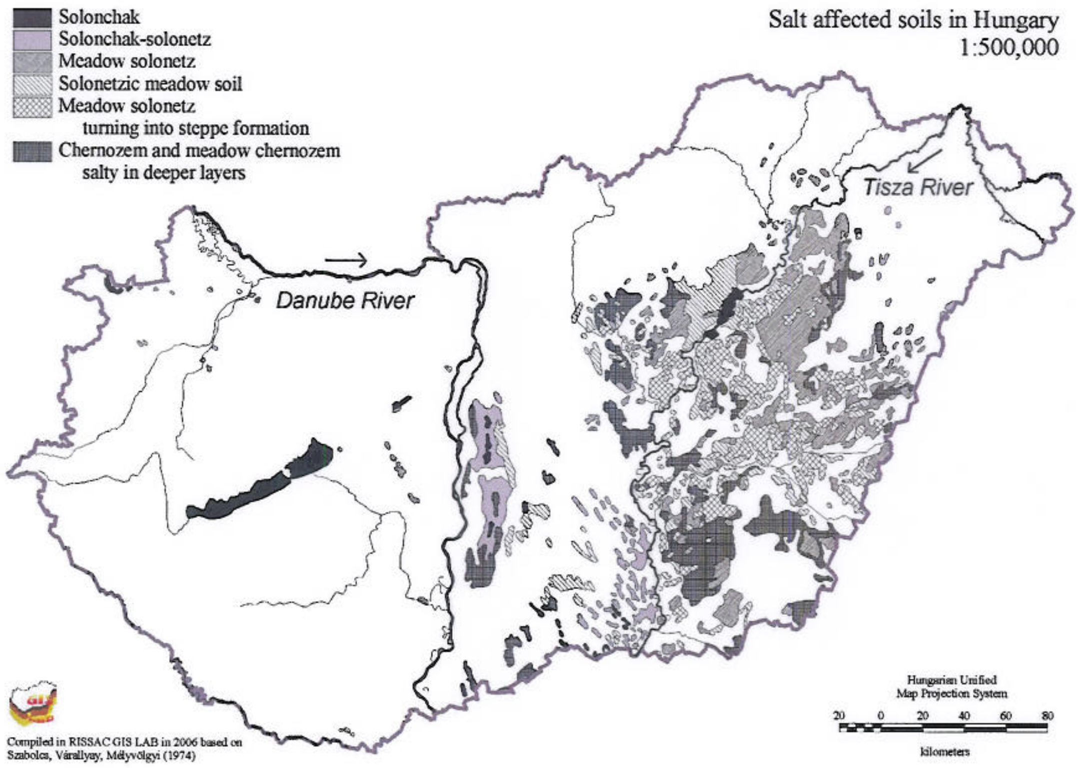


Figure 1. Map of Hungarian salt-affected soils (Szabolcs, 1974).

Solonchak soils (total area 47 km²)

These soils are *per definitio* the saline soils, which are mainly located in low-lying areas, typically shorelines of saline/sodic lakes, in the region between the Danube and Tisza Rivers, but also occur in patches east of the Tisza River. These soils are characterized with 60–80 cm deep water table and an average total soluble salt content of 0.3–0.5 percent at the surface. Dominant salts are sodium carbonate, bicarbonate, sulphate and chloride. There is calcium-carbonate in the whole profile. It is difficult to distinguish horizons in the profile of this soil. These soils are not cropped, but sustain native halophyte vegetation which is grazed.

Solonchak-Solonetz soils (total area 659 km²)

These saline-sodic soils are also located mostly between the Danube and Tisza Rivers, but above deeper groundwater level, ca at 1m. In the profile a weakly developed columnar/prismatic natric (=Solonetzic) B horizon can be distinguished. There is calcium carbonate in the whole profile. These soils sustain native halophyte vegetation which is grazed.

Meadow Solonetz soils (total area 2 749 km²)

The typical Solonetz soils of Hungary are the typical sodic soils on the Great Hungarian Plain, mostly east of the Tisza River, but also west of the Danube River. These soils are characterized by large exchangeable sodium percent and not high salt content. This latter can be low enough in the A horizon to permit cultivation on these soils. Otherwise these soils sustain native halophyte vegetation which is grazed. The fertility of the soil is proportional to the thickness of slightly saline A horizon. In the characteristic columnar/prismatic natric B_1 horizon, where the maximum of the sodium adsorption can be encountered, the value of exchangeable sodium percent (ESP) is 20–25 percent. The maximum of salt accumulation can be found in the B_2 horizon, where the soil structure is prismatic or *nutty* (=large subangular blocky). Calcium-carbonate is generally absent from the A and B_1 horizons. The depth to the water table is between 150 and 350 cm.

Deep Mollic Solonetz soils (total area 2 122 km²)

When the water table is lower (3–4 m below the soil surface) the leaching reduces the soluble salt and calcium carbonate content of the upper horizons of these sodic soils. The term *Turning into steppe formation*, originally used for this soil type by Szabolcs (1966) denotes soil forming processes similar to those of the steppe (Chernozem) soils. These soils are typically ploughed.

Secondary salt-affected soils (not distinguished on the AGROTOPO database as polygons)

This soil type comprises all soils, which were originally not salt-affected, but due to human influence became salt-affected.

Besides the mentioned SAS there are other SAS types which belong not to the main type of Halomorphic soils, but to other main soil types, such as Solonetzic Meadow soils with total area of 2 419 km² and Chernozem soils with saline/sodic subsoil with total area of 4 185 km². These soils are typically ploughed.

In Hungary the total area of salt-affected soils, based on the AGROTOPO database (printed on the map sheets by the Kartográfiai Vállalat in 1983), is

12 181 km^2. With this area the overall area of SAS covers 13 percent of the national territory. The map provided by the Hungarian Central Statistical Office (2006) is almost the same as published by Stefanovits (1963), based on his map of the soils of Hungary at the scale of 1:200 000. Although there are differences in the areas of the distinct SAS types between the two sources, the total areas of 11 087 km^2 (Stefanovits, 1963) and 12 181 km^2 (AGROTOPO) are close.

THE UTILIZATION OF SALT-AFFECTED SOILS IN HUNGARY

Though the improvement (reclamation or amelioration) of these soils is scientifically well founded, it is a rather costly operation. This is the reason why large tracts of these soils are kept as grazeland or hayfield, land for afforestation, paddy field or fishpond. Most of the Hungarian National Parks have salt-affected grasslands, hayfields, marshes, reedlands, lakes and these provide habitat for protected animals (mainly birds), plants and attract lots of tourists. Many of the protected animals barely find a place for feeding and breeding on other soil types, since most of those are cropped or otherwise intensively utilized. In total, 88 percent of the surface of the country has no natural vegetation cover (cropland, tree plantations with exotic species, orchards, vineyards, settlements, roads, etc).

Among the crops that may be grown economically on these soils the most important is winter wheat. It covers more than half of the area of SAS. Other important crops are winter barley, sunflower, Sudan grass, vetch, rice and sometimes maize, sugarbeet and pea.

INFORMATION AVAILABLE ON THE SPATIAL EXTENT OF SALT-AFFECTED SOILS

There is an outstanding record of collecting soil information in Hungary. The historical past is summarized in several publications (Ballenegger and Finály, 1963). Just like in other countries in the early period of soil mapping, before the First World War there were two tendencies: special mapping of selected, usually small areas and preparation of very small-scale maps, based on scarce observations and continental-scale conceptual models. In Hungary the first Hungarian soil (that time called agrogeologic) map was compiled in 1861 (Szabó, 1861) for the area of two counties at the scale of 1: 576 000. Few years later the soil map of Tokaj-Hegyalja intended to improve the production of the famous Tokaj wine in the region (Szabó, 1866). A major achievement was the first complete soil map of Hungary prepared by Timkó in 1914. During the period 1935–1951 the Kreybig soil mapping was completed and displayed on maps at 1:25 000. From the 1960s the 1:10 000 scale mapping of the agricultural lands was performed. From 1989 no systematic large-scale soil mapping is carried out.

AGROTOPO map database

It was the 1:100 000 scale AGROTOPO soil spatial database, which became available first digitally. This database, which was developed in the 1990s, integrates the dominantly small-scale soil related data into digital format and is organized into spatial soil information systems (AGROTOPO: Várallyay, 1989; HunSOTER: Várallyay *et al.*, 1994; MERA: Pásztor *et al.*, 1998). Information in the AGROTOPO is provided for nine properties, such as soil types, soil parent material, soil texture, clay-mineral composition, soil water regime category, soil reaction and carbonate status, soil organic matter stock, depth of *solum*, soil bonitation (soil quality assessment) value. There are altogether 3 312 polygons for the total area of 93 000 km^2 of the country. As background to the soil polygons there is a general topographic sheet with land use categories, elevation contour lines, settlements, waterways, roads, etc.

The 1:25 000 Kreybig Digital Soil Information System

The national soil mapping project initiated and led by L. Kreybig was unique, being a national survey based on both field and laboratory soil analyses and at the same time serving practical purposes (Kreybig, 1937). Due to the Second World War it was carried out between 1935 and 1951 in several stages. In the fifties, when the mapping was successfully completed, Hungary was among the first countries in the world to have such detailed soil information for the whole country. These maps still represent a valuable treasure of soil information. The soil and land use conditions were shown jointly on the maps. Altogether three characteristics were attributed to soil mapping units and displayed on each mapsheet. First feature distinguished was land use, both ploughland and grassland was not distinguished. Second was the chemical reaction shown by colours and third feature was the physical soil properties of the soil root zone. Some further soil properties were determined and measured in soil profiles. A very remarkable feature of the map series is that it distinguishes three different categories of SAS by colour codes:

- *Reddish purple colour*: SAS suitable for cropping.
- *Light purple colour*: SAS potentially suitable for cropping; can be reclaimed with $CaCO_3$.
- *Dark purple colour*: SAS not suitable for cropping; cannot be reclaimed with $CaCO_3$.

The GIS adaptation of soil information originating from the soil maps displayed on 1:25 000 scale is still under construction (Pásztor *et al.*, 2006). There is much more utilizable information originating from this survey than it was processed earlier and published on the map series and in reports and what is provided by simply archiving them digitally. The surplus information should be exploited by the new technologies provided by GIS and DS M (digital soil mapping) and provide the basis of improved management of the soils.

Genetic soil maps of 1:10 000 scale

In the early sixties a mapping technology was elaborated by the Hungarian soil scientists, soil surveyors and soil-mapping specialists for the large-scale soil survey to satisfy the practical needs of soil information of large farming units (state and cooperative farms), which characterized the Hungarian agriculture between 1950 and 1990. Such maps were prepared for about one-third of the area of Hungary, representing two thirds of the cropland (ca 35 000 km^2). The mapping reports consist of four main parts: (i) genetic soil map, indicating soil taxonomy units and the parent material; (ii) thematic soil maps on the most important physical and chemical soil properties; (iii) thematic maps, indicating recommendations for rational land use, cropping pattern, amelioration, 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; results of field observations or measurements and data of laboratory analyses (Szabolcs, 1966). These maps were widely and successfully used in Hungary and became an easily applicable scientific basis of intensive, large-scale agricultural production, in spite of the fact that generally these maps were not published in printed form and are available only as manuscripts at the given farming units or at the Plant and Soil Conservation Stations. The large-scale soil-mapping programme was restarted in 1986 within the framework of the National Land Evaluation Programme (Guidelines, 1989). The aim of this Programme was to valuate the agricultural land based on soil survey at the scale of 1:10 000, but was also left uncompleted. These huge archives provide appropriate raw material for recent digitally based applications. Spatial soil information systems based on these data could be efficiently used in numerous fields.

Szabolcs (1966) described the methodology to be used in the detailed mapping of soils. For example, in the case of SAS this method at the scale of 1:10 000 can be illustrated best with the set of individual map sheets which might make up a complete soil mapping document:

- Soil map
  - soil type and subtype (c. 100 categories for the country)
  - parent material (56 categories for the country)
  - textural class of plough-layer (9 categories for the country).
- Humus cartogram
  - thickness of humic layer (6 categories for the country)
  - organic matter content (5 categories for the country)
- Soil reaction and $CaCO_3$ content cartogram
  - pH of plough-layer (7 categories)
  - depth of appearance of $CaCO_3$ (6 categories for the country)
  - $CaCO_3$ content in the depth of appearance (5 categories for the country)
  - hydrolitic acidity value (according to Kappen) of plough-layer (5 categories for the country)
  - amount of secondary $CaCO_3$ (4 categories).
- Groundwater cartogram
  - average groundwater level (5 categories for the country)
  - salt concentration of groundwater (6 categories for the country)
  - Na percentage of groundwater (8 categories for the country).
- Salt-affected properties cartogram
  - depth of appearance of salt-affected layer (6 categories for the country)
  - pH in the depth of appearance of salt-affected layer (3 categories for the country)
  - total soluble salt content and exchangeable sodium (exNa) percentage in the depth of appearance of salt-affected layer (8 categories for the country)
  - depth of most salt-affected layer (6 categories for the country)
  - pH in the depth of most salt-affected layer (3 categories for the country)
  - total soluble salt content and exNa percentage in the depth of most salt-affected layer (8 categories for the country)

The complete documentation of field soil maps contains field records of profile descriptions, results of laboratory analyses and evaluations. The smallest polygon distinguished on large-scale maps of 1:10 000 is 1 ha.

THE RECLAMATION OF SALT-AFFECTED SOILS IN HUNGARY

Chemical reclamation

Based on the properties (pH, $CaCO_3$ content) of the sodic soils there is a classification of the Hungarian SAS for deciding the adequate chemical amendment. This categorization of soils according to their necessity for reclaiming material resembles somewhat that of Richards (1954).

For the non-calcareous acid/neutral sodic soils the suggested amendment can be limestone powder or "digo earth". This latter is excavated subsoil material from such spots where deeper layers contain at least 5 percent calcium-carbonate, small amount of soluble salts and not much sodium.

The non-calcareous/slightly alkaline sodic soils are reclaimed with limestone and gypsum added combined. The ratio of limestone powder to gypsum depends on the alkalinity of the soil. The higher the pH the more is the gypsum requirement. If the "digo earth" contains gypsum, it can be used also for this kind of SAS.

The calcareous-soda containing sodic soils can be reclaimed with gypsum, lignite powder or other acidic material.

Other aspects of this classification originally presented by Prettenhoffer (1969) are shown by Szabolcs (1989).

There is a strict regulation for the protection of soils. In the Section VI of *Law LV. of 1994 On the Protection of Cultivated Soils* it is specifically written "Paragraph No. 3 on salt-affected or potentially salt-affected soils:

- only such water management and such quality of irrigation water may be used that does not cause secondary salinization;
- soil reclamation on salt-affected soils must be performed based on an expert report."

There are existing National Standards for carrying out the reclamation of SAS. The sampling is described by *MSZ-08 0202-77 (Field sampling)*. There is at least one sample for each 5 ha, but if a soil type map (1:10 000) is available, one profile for each 12 ha must be opened and sampled.

MI-08 0166-80 (General features of soil reclamation) describes the how to decide on the kind of reclamation material which must be applied. For acid and neutral salt-affected soils the criteria are the following: in the 0–30 cm layer pH_H_2O value is pH 5–7; Total Soluble Salt Content is less than 0.2 percent; Saturation Percent is greater than 36; Na_{mobile} is greater than 1 me/100 g soil.

These soils are noncalcaric in the surface 0–50 cm layer. If the area is prone to waterlogging first surface drainage is necessary. It must be prevented with (sub)surface drainage that the groundwater gets closer than 200 cm to the surface. The reclamation material for these soils is $CaCO_3$.

For slightly alkaline and alkaline salt-affected soils the criteria are the following: in the surface 0–50 cm layer pH_H_2O values are greater than pH 7, Total Soluble Salt Content is greater than 0.2 percent, Saturation Percent (SP) is greater than 36, Na_{mobile} is greater than 1 me/100 g soil. These soils are saline, alkaline and sodic. The chemical reclamation must be preceded by drainage. The reclamation material for these soils is $CaSO_4$.

MSZ-08 0228/2-80 (Dosage of reclamation material) is the standard for the determination of the dosage of the reclamation material.

For liming, the dosage is the same as for acid soils, plus 50 percent:

$y_1 \times factor_{-SP} \times 1.5=$ tonnes ha^{-1} reclamation material expressed in $CaCO_3$

where y_1 is hydrolitic acidity value, according to Kappen), $factor_{-SP}$ is texture factor and the values are as follows:

Texture factor	SP
0.35	36
0.9	50–60
1.2	>72

Example: if SP=48 and y_1=10, the liming requirement is:

$0.7 \times 10 \times 1.5 = 10.5$ tonnes ha^{-1} $CaCO_3$.

For the determination of gypsum requirement, the following calculation is performed:

The exchange of 1 me/100 g soil Na in a soil layer of 20 cm thickness, 2.5 tonnes ha^{-1} $CaSO_4 \times 2H_2O$ requires:

$(Na_{existing} - Na_{tolerable}) \times 2.5$ tonnes ha^{-1} gypsum.

Example: if the soil has 10 me/100 mobile (exchangeable plus soluble) Na and the tolerable is 4 me:

$(10-4) \times 2.5 = 15$ tonnes ha^{-1} $CaSO_4$ is required.

There is an alternative method for determining the gypsum requirement – MSZ08-0204-80 (determination of the dosage of reclamation material with sedimentation). According to this standard a series of the suspensions of reclamation material mixed with soil is examined after 2, 6 and 24 hours for clearness and the pH of the suspension.

The criteria of the evaluation are the following: There is a clear suspension and the increase of pH with a value of 1 in the case of liming. In the case of gypsum the decrease of pH to the value 8 is required.

The effect of the chemical amendments on croplands is about 10–20 percent yield increase. In the case of Solonetz soils the chemical reclamation of the underlying natric B horizon can provide another 20 percent yield increase (Blaskó, 2005.)

Leaching

There were several studies for leaching of SAS. Only in very special situations was leaching successful. The most severe problem was that the destruction of the original Natric B horizon resulted in a plastic soil (when wet) or stone hard (when dry) surface not suitable for a seedbed (Arany, 1956). Evidently since the saline groundwater is shallow only together with efficient drainage can the leaching be operative.

Deep loosening of SAS

Deep loosening of heavy clay sodic soils can provide some 10 percent yield increase. Care must be taken to the selection of the crop, since these show different reaction to loosening.

Subsurface drainage

There is full agreement on the principle that chemical reclamation *per se* may not be capable of complete improvement of SAS. The unfavourable physical properties of SAS are leading to the waterlogging of these soils, therefore it is necessary to control the moisture regime of the soils. There were a few trials for the subsurface drainage of the heavy clay sodic soils and the combination of chemical reclamation with subsurface drainage and deep loosening (locally called *complex amelioration* of SAS) proved to be a successful, but very costly way of the improvement of SAS. There are two major effects of moisture regulation considered to be important on heavy clay sodic soils:

- Since there is an increase in the water infiltration capacity, more water is infiltrating into the soil and there is a smaller chance of waterlogging. There is an increase in the field capacity, temperature and air-filled porosity of these soils. This way the leaching of the salts is facilitated.
- The above measures provide longer periods for the field works and wider range of crops to be grown on these soils. Crops that can be grown on the reclaimed sodic soils include alfalfa, sorghum, rape (canola). Alfalfa is considered to be very important, since its root system favours the biological improvement of the deeper layers. The yield can reach 150–200 percent compared to the non reclaimed control plots. But in many cases it is the reclamation which provides the basis for field crop growing on a previously not cropped grazeland.

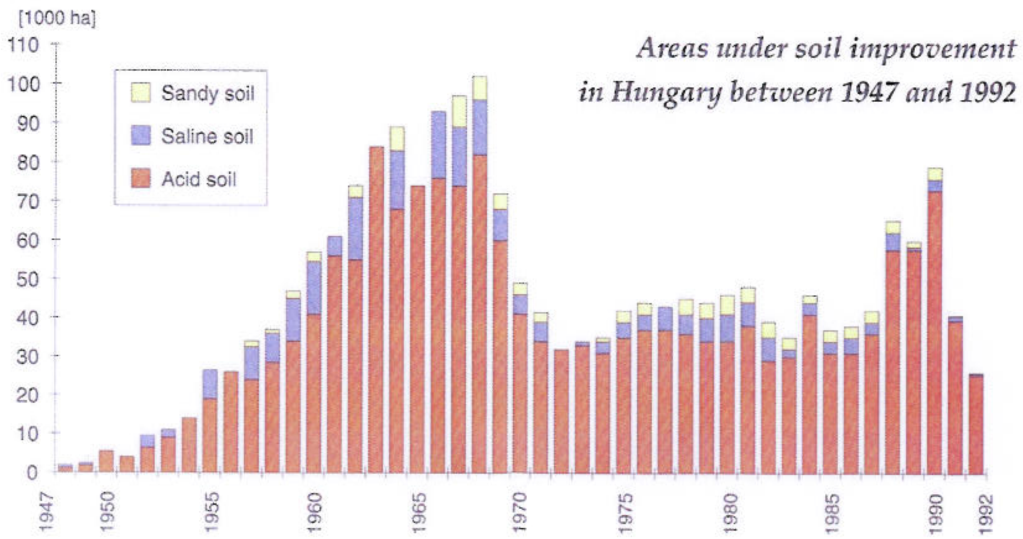


Figure 2. Areas reclaimed yearly between 1947 and 1992 in Hungary (as published by the Center for Plant and Soil Conservation).

There are several other options for the improvement of SAS. In Hungary the sand cover of saline sodic soils was used extensively (Arany, 1956).

Figures 2 and 3 show the extent of soil reclamation in Hungary. As a reference, data on the reclamation of acid soil is also shown. It is important for assessing the magnitude of the efforts, since acid soils are widespread. There was a big boom in the reclamation of soils after the Second World War until 1968. There followed a decline and a levelling-off the 1970s. After a small rise at the end of the 1970s when SAS reclamation was accompanied by drainage (complex amelioration) soil reclamation declined sinificantly at the end of the 1980s when the political regime changed.

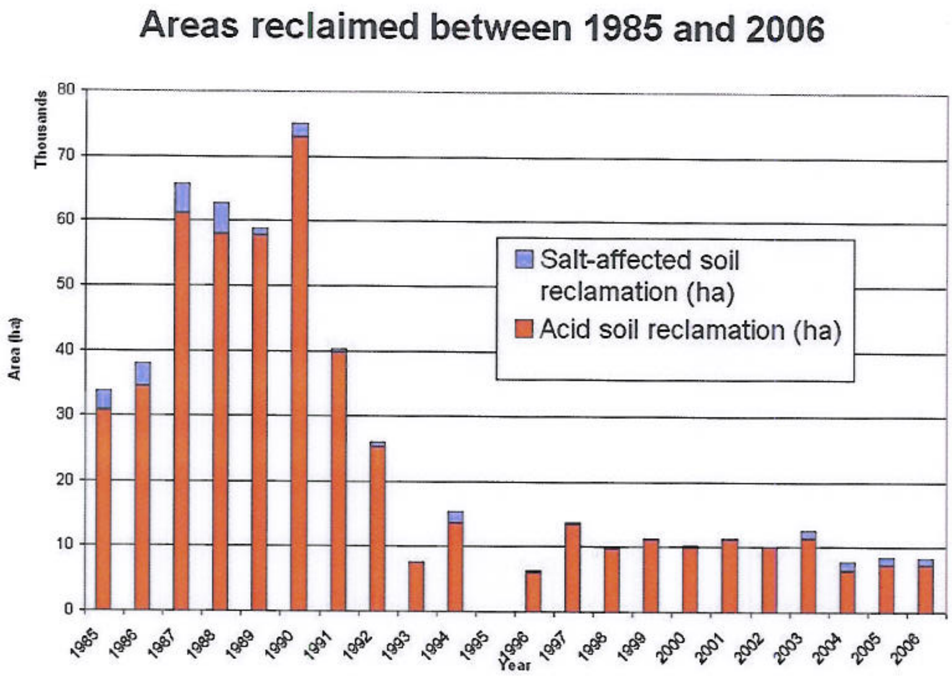


Figure 3. Areas reclaimed yearly between 1947 and 1992 in Hungary (based on the data of Institute of Agricultural Economy).

Table 2 shows the kind of reclaiming materials which are used in these years. The most important materials are lime, gypsum and by-products.

Table 2. Types and areas of reclamation material applied on the salt-affected soils (SAS) of Hungary for the years 2000–2006 (based on the data of Institute of Agricultural Economy).

Type of reclaiming material	2000	2001	2002	2003	2004	2005	2006
Ground gypsum (ha)	-	40	20	25	-	40	27
Gypsum with lignite (ha)	-	-	-	-	-	-	-
Industry gypsum containing waste (ha)	-	-	-	60	-	50	11
Ground limestone (ha)	1	50	-	-	106	-	209
Sugar factory lime (ha)	243	-	-	343	281	368	775
Industrial waste with $CaCO_3$ content (ha)	-	-	-	156	-	-	-
Other (ha)	22	-	-	558	932	621	55
Total SAS reclamation (ha)	266	90	20	1142	1318	1079	1077
Total reclaiming material (10^3 tonnes)	1897	633	230	13880	29733	6311	4 025

Afforestation of salt-affected soils

On the wet, slightly saline sodic soils of Hungary there are native oak forests growing (Molnár and Borhidi, 2003). Although the first mention of the afforestation of Hungarian SAS dates back to 1764, the large-scale afforestation of slightly saline and sodic soils started after the establishment of the Experimental Station on the Afforestation of Salt-affected Soils at Püspökladány in 1924 (Tóth *et al.*, 1972). The best tree species on theses soils are oak, ashtree, poplar, elm, tamarix. The effect of the afforestation has been studied by several authors (Lesztāk, 1961). In general there is a beneficial effect on the topsoil characteristics compared to the native grassland, but there is an increasing salt accumulation under the surface (Nosetto *et al.*, 2006).

Prediction of salinization

A calculation method, based on the salt balance and the effect of shallow water table, was proposed by Szabolcs *et al.* (1969) and Darab *et al.* (1994), which aimed at giving suggestions for decisions regarding irrigation, such as whether drainage is required, or irrigation water quality is suitable regarding the risk of secondary salinization. Moreover the method facilitates the calculation of possible combinations of soil salt concentration versus irrigation water amount and indicates which is the critical depth of groundwater for the given irrigation situation.

The method is focussing on the prediction of the soil salt content after irrigation according to the equation

$$b = a + x + z + d$$

where b is the soil salt content after irrigation, a is the same before irrigation, x is the quantity of salts added by the irrigation water, z is the quantity of salts transported by capillary flow from the groundwater and the capillary saturated soil layers to the unsaturated zone of the soil and d is the salt balance of non-irrigated soils.

There are several computer models, which contain subroutines for the calculation of salinization and changes of groundwater in soils as a consequence of irrigation, such as LEACHMS (Wagenet and Hutson, 1987), DRAINMOD, Abdel-Dayem and Skaggs, 1990, SALTMOD (Oosterbaan and Abu Senna, 1990). A two-dimensional transport model, UNSATCHEM was presented by Simunek and Suarez, 1994, which is accounting for the CO_2 concentration in the unsaturated zone (Simunek and Suarez, 1993 and Suarez and Simunek, 1993). In addition to predicting solute movement, this model simulates equilibrium and transient chemical processes, covering ion exchange dissolution, precipitation and related processes. LEACHM and UNSATCHEM were tested on Hungarian SAS (Tóth and Kuti, 2002).

In a field-size drainage/reclamation experiment on a heavy sodic soil at Karcag (Nyíri and Fehér, 1981) during 23 years the original salt content of the soil profile decreased to c. 60 percent in chemically reclaimed plots and to ca 20 percent in plots provided with subsurface drainage (Blaskó, 2005).

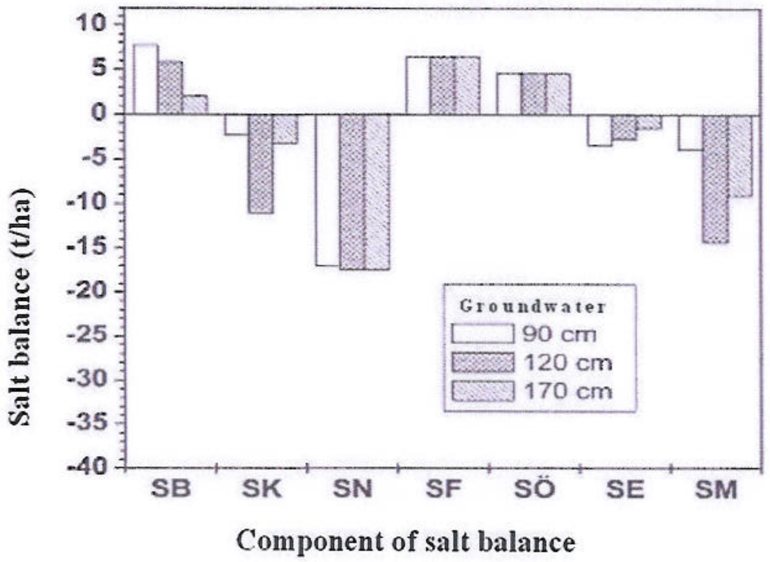


Figure 4. Average components of salt balance between the years 1984–1996 in Meadow Solonetz soil lysimeters vessels as published by Karuczka, 1999 (based on Blaskó, 2005). Salt balance components shown are the following: SB input with groundwater, SK output with groundwater, SN output by plants, SF input by mineral fertilizers, SÖ input with irrigation water, SE output with surface run-off water, SM summary balance.

In order to model the effect of management options to control groundwater level at different depths, a lysimeters station was set up at Karcag. A unique physical modelling system, compensation lysimeters are used for testing the effect of saline groundwater with different depths and drainage management in the dominantly sodic area (Karuczka, 1999). The lysimeters are filled with 2 m deep soil columns and the groundwater level is stabilized with compensation system using locally typical water composition. During 13 years of running the components of soil salt balance were quantified as shown in Figure 4. Evidently there was a correlation between the depth of groundwater level and summary salt balance. In Hungary deeper groundwater level will promote greater natural salt leaching. In the total balance the amount of salt originating form groundwater, fertilizer or irrigation waters is similar. The amount of summary salt balance, which was negative, was comparable to the amount of salts removed by the crops.

An interesting observation of Karuczka, 1999 was the dependence of salt balance from the yearly precipitation surplus. Since Hungary is found in the subhumid-temperate climatic zone there are big changes from year to year. Characteristically in dry years there is salt accumulation and in wet years there is leaching. The extent of these changes depends on the groundwater depth (Figure 5).

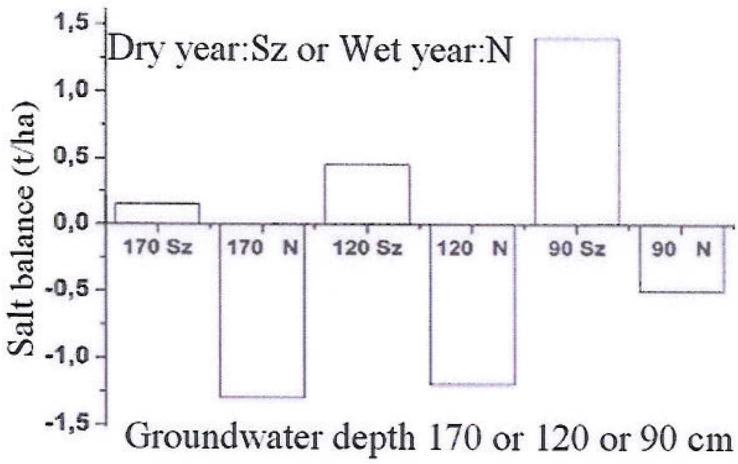


Figure 5. Average salt balance in the dry year of 1989 and the wet year of 1991 in lysimeter vessels with groundwater stabilized at different depths.

Monitoring of salinization

The follow-up of possible salinization is important for the prevention of major damages to the soil, groundwater or the environment. The following ways of monitoring and detecting of salinization are suggested by Hillel (1990):

- use of observation wells to check the rise of groundwater level,
- continuous check of the salt content of soil, subsoil and groundwater,
- observations of the germination, development, growth and yield of crops.

The instrumental monitoring and the spatial interpolation of salinity is very much facilitated by the recent advances in spatial statistics, electronics and computer techniques. One of the reasons for this advancement is that soil salinization is rather well defined electrochemically and that the standard method of expressing levels of salinization is also based on the relatively easily measurable electrical conductivity. Moreover, where salinization is important, such as irrigated fields, levelling is often required and often there is not much heterogeneity of other soil properties. Consequently those instruments whose detected signal is influenced by a combination of factors can be used with success in irrigated lands, because other affecting properties (water content, textural differences) are controlled or rarely influential. One other reason for the large number of studies of salinization in advanced mapping studies is that salinity has clearly defined limits (Richards, 1954) for the ranges of salt tolerance. Therefore the isoline maps of soil salinity have concrete significance for crop growers and ecologists.

The suitability of salinity surveys for spatial analysis was shown by several geostatisticians, a contemporary mapping technique which is based on the theory of regionalized variables. Kriging and co-kriging are often used for interpolation of salinity levels. Cokriging uses easily available auxiliary variables, which show strong correlation with salinity and since soil salt content shows strong correlation with several ecological factors, cokriging is a useful method in natural or seminatural areas for predicting salinization and sodification (Tóth *et al.*, 1994).

Based on the mentioned correlations also multivariate linear predictions, such as regression techniques and trend surface analysis can be used in irrigated (Lesch *et al.*, 1995) and also in semi-natural areas (Tóth and Rajkai, 1994, Tóth and Kertész, 1996).

Douaik *et al.* (2004, 2005, 2006, 2007) has compared a range of possible techniques for detecting spatial and temporal changes of soil salt concentration inside a sodic grassland.

Several rapid measurement techniques are available for the field assessment of salinity level. Most of these are based on the measurement of electrical conductivity, such as direct current techniques and electromagnetic induction techniques for measuring bulk soil electrical conductivity (Hoffman *et al.*, 1990). Tóth *et al.* (2006) and Ristolainen *et al.* (2006) have reported the comparative advantages of a range of field sensors for assessing salinity in Hungarian soils.

Remote sensing is a very suitable technique for the detection of salinization in irrigated soils, because irrigation techniques try to homogenize the conditions (smooth relief, homogeneous plant density, fertilization, irrigation water distribution etc.) inside a plot. Therefore, if one limiting factor has great effect, its consequences are relatively easy to follow. Levels of soil salinity can be inferred from the state of the crop stand or from the changes in the surface reflectance of bare soils. Due to the spatial resolution, or the minimal size of the pixels of the sensors (10-30-80m), satellite remote sensing is a technique for the regional detection of salinization problems rather than for within-field application.

Application of remote sensing for detecting distinct grades of salinity and alkalinity at the field scale in grasslands was reported by Tóth *et al.* (1991). Accompanying these studies a laboratory study was carried out to distinguish grades of salinity based on high-resolution spectra (Csillag *et al.*, 1993; Pásztor and Csillag, 1995). An innovative use of aerial photos and Geographical Information Systems for the optimisation of gypsuming in a sodic soil was discussed by Tóth *et al.* (1998). On a smaller scale, Tóth *et al.* (1991) distinguished different grades of sodicity with Landsat and SPOT satellite remote sensing using 1:25 000 and 1:10 000 maps.

Salinization caused by irrigation in Hungary

The history of irrigation in this country is short. For centuries it was connected to the rice cultivation, which was introduced in state owned lands in southern Hungary. The large scale irrigation of agricultural lands began about 60 years before in the alluvial plain of Tisza river. Large part of the area of this plain was previously periodically affected by floods and was not used for cropping. Irrigation became a necessity with the spread of intensive crop production and now it is considered to be a supplementary treatment to assure stable high yields. In the lowlands where irrigation is feasible there are several factors that limit the large-scale use of irrigation, such as shallow, often saline groundwater level, occurrence of salt-affected soils, etc.

During the construction of large irrigation systems of the areas along the river Tisza, the necessity to prevent seepage of irrigation waters was not considered seriously. Major sources of such seeping waters were the excessively applied irrigation waters themselves, the water in the irrigation canals, reservoirs and drainage canals. The canals were not lined with waterproof materials. Groundwater level rise occurred in almost all irrigation districts. The average rise was 29 cm per year, but reached 220 cm per year in one case (Ubell, 1955). The height of the rise showed positive correlation with the clay content of the soils.

Before the implementation of Tisza II Irrigation System a detailed study was carried out on the possible effects of the realized water reservoir on salinization and waterlogging. There were two scales, at 1:100 000 and 1:25 000 of preparing prognostic maps of salinization (Szabolcs, 1989). The base maps were maps of soil type, texture, soil salinity maps as well as groundwater depth and composition maps. Critical depth of groundwater and maps of preconditions for irrigation were the maps prepared for decision makers.

The Hungarian national territory installed for irrigation is ca 300 000 ha, which is ca 6 percent of the cultivated area. Earlier there were state incentives for installing irrigation, such as non-refundable loans of investment and reduced interest rates. Yet no more than 50 percent of this territory is used for irrigation due to high water and energy prices. At present the structure of irrigation establishments is changing, due to the overall reconstruction of national economy, mainly privatisation and dissolution of the large cooperative and state farms and water control structures.

In the last decades, as a consequence of the lasting shortage of precipitation in the Carpathian Basin, increased use of groundwater etc., sinking of water table was characteristic. The only areas showing rising groundwater level are the intensively irrigated areas and territories affected by irrigation canals.

In Hungary, most of the irrigation water stocks are of relatively good quality river waters. River/canal waters with salinity less than 0.5 g l^{-1} are generally suggested for irrigation. Waters with salinity up to 0.8–1 g l^{-1} are considered to be permissible only in areas with sandy subsoil where groundwater is deep. In Table 3 the water quality characteristics of the main irrigation canals in the Hungarian Plain are summarised. Most of the canal systems are unlined earthen canals and these canals often cross areas of salt-affected soils. Besides there are several, so called "double function" canal reaches, which are used alternately both for drainage and irrigation.

Table 3. Water quality of some irrigation canals (based on Tóth and Blaskó, 1998).

Canal	Jászság Main Canal				Nagykunság Main Canal			
Sampling date	Summer 1989 (April - August)							
	May 2	Jun 12	Jul 3	Aug 3	Apr 17	May 29	Jul 24	Aug 21
pH	7.8	7.4	7.7	7.6	8.0	8.2	7.9	7.5
EC (dS m^{-1})	0.27	0.37	0.36	0.36	0.62	0.44	0.37	0.34
SAR	0.58	0.69	0.69	0.78	1.84	1.02	0.70	0.80
Canal	Millér Main Canal				Hortobágy-Berettyó Main Canal			
Sampling date	Summer 1989 (May - August)							
	May 10	June 7	July 5	Aug 2	May 22	Jun 19	Jul 17	Aug 14
pH	8.3	7.2	7.9	7.5	7.4	7.8	7.6	7.9
EC (dS m^{-1})	0.84	0.39	0.45	0.43	0.86	0.93	0.55	0.59
SAR	4.05	0.57	1.11	0.93	3.00	3.19	2.11	2.42

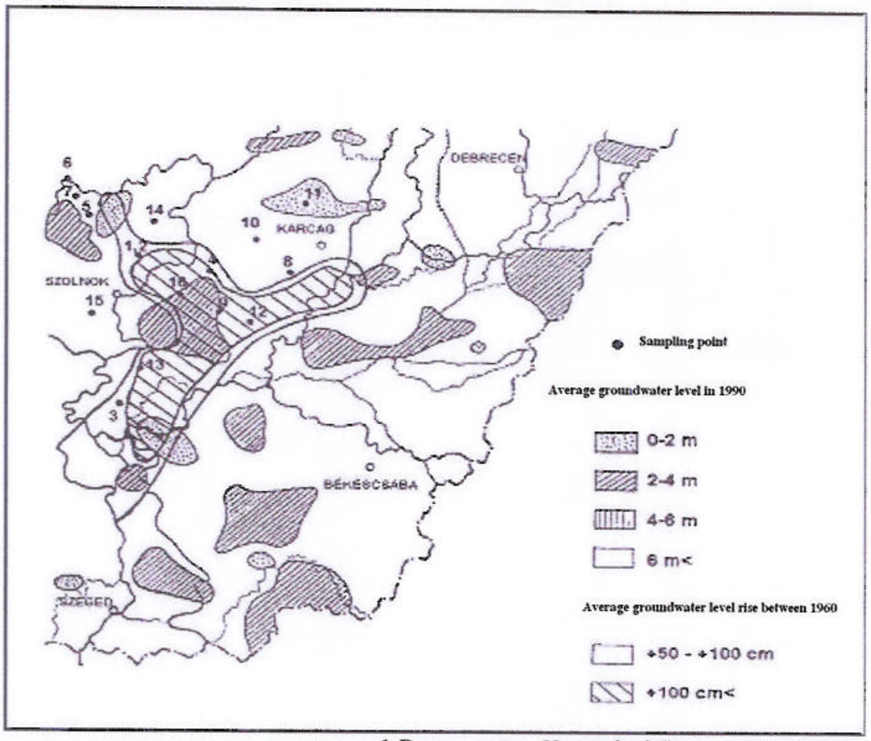
In the subsequent sections we present data on secondary salinization due to the salt concentration of irrigation waters and on the effect of the rising groundwater.

The possibility of the contamination of transported water by salts in the unlined canals, from the salt-affected soils and groundwater which the canals cross have been studied in two cases. According to our preliminary results the salt contamination of the irrigation water originating from the soil, which it is crossing, is not as great as had been expected, even in case of double function canal, where the irrigation water was mixed with the drainage water of the rice fields.

The danger of secondary salinization is much more expressed in case of the use of groundwater for irrigation. This situation is mostly typical for small-scale private vegetable fields. The quality of the groundwater in the Hungarian Plain is extremely heterogeneous and in most of the cases it is not favourable for irrigation. A field study of Tóth and Blaskó (2004) showed that soil clayiness, groundwater depth and composition strongly affect the process of salt accumulation in the situation when soils are irrigated with shallow groundwater.

For monitoring and controlling secondary salinization processes – until now only on large irrigated fields – a monitoring system is operated by the Research Institute of the Debrecen University, which has detailed information on the soil and the hydrological conditions of the irrigated areas of Jász-Nagykun-Szolnok county in the middle part of the Hungarian Plain (Figure 6). This county is one of the driest and warmest areas in Hungary, having the largest irrigated area, which can only conditionally be irrigated because of salinity hazard. Here we quote some observations reported by Tóth and Blaskó (1998).

The monitoring system was developed in 1989. Soil samples were taken (2 samples/100 ha) on the area of 4 255 ha (8 percent of the whole irrigated area in the country) at geodetically defined points. The allocation of sampling points permits the repetitive sampling during the investigation from the same place in order to follow the changes of the soil characteristics.



Sites with increasing soil salinity 1.Besenyszög , Kossuth; 2.Besenyszög Palotás; 3. Cserkeszőlő; 4. Fegyvernek;5. Jászalsószentgyörgy ; 6. Jászberény; 7. Alattyán; 8. Kisújszállás Tisza II.; 9. Kuncsorba; 10. Kunhegyes;11. Kunmadaras;12. Mesterszállás; 13. Tiszaföldvár; 14. Tiszasüly ; 15. Tószeg; 16. Törökszentmiklós; 17. Túrkeve

Figure 6. Monitoring points and groundwater levels on irrigated areas of Jász-Nagykun-Szolnok county (from Blaskó, 2005).

For the determination of the level and quality of the groundwater we used the data base of the Water Economy Office of this area. The determination of irrigation water quality is made by the Water Economy Office at the main pump stations. The typical range of chemical composition of irrigation waters in the region are EC (dS m^{-1}) 0.2–2.4, Ca (me l^{-1}) 1–7.1, Mg (me l^{-1}) 0.3–5.1, Na (me l^{-1}) 0.3–24.3, K (me l^{-1}) 0–1.7, pH 7–8.5 (Tóth and Blaskó, 1998).

The investigations and data evaluations reported here were carried out from 1989 to 1992 (Tóth and Blaskó, 1998). Soil samples were taken at the end of the vegetation period every year from surface down to 1 m depth at 0.2 m increments.

The field study was set up on four main genetic soil types:

- Chernozem-like Meadow soil (Mollisols)
- Meadow soil (app. Vertisols)
- Meadow soil with saline subsoil
- Solonetzic Meadow soil

The effect of the irrigation on the soil salt content is summarized in Table 4.

Table 4. Some examples of the effect of irrigation on the salt content of soils during 3 years of irrigation (Based on Tóth and Blaskó, 1998). The numbers refer to the location of sampling sites on Figure 6.

Site	Number of samples	Increase in salt content (tonnes ha^{-1})	
		0–40 cm	40–100 cm
8. Kisújszállás	9	1.10	3.34
9. Kuncsorba	38	1.03	3.84
15. Tószeg	5	2.05	5.60
16. Törökszentmiklós	6	1.68	4.48
17. Túrkeve	24	0.99	2.24

The results of the three-year study indicate that among 62 profiles, 29 points have salt accumulation. The salt content increased mainly in the potentially saline soils and in soils saline in deeper layer. Out of 39 profiles, which had originally saline layers in the subsoil, 20 showed that the zone of maximal salt accumulation rose closer to the surface.

In most cases the soils of the region are characterized by an extreme moisture regime, but originally without deep saline layers; and the irrigation in general did not lead to salt accumulation. From 29 profiles related to this soil category only 9 profiles have salt and sodium accumulation, as a consequence of irrigation.

In half of the investigated area the salt concentration increased during the three years, but the pH and the Na_2CO_3 content values only changed slightly. The increase in salt concentration was caused by the increase of the neutral Na and Mg salts.

The positive salt balance, that is salt accumulation in general, was proved in the subsoil (40–100 cm), below the cultivated layer and it means that the phenomenon of secondary salinization and/or alkalisation has already started, but it is not apparent at the surface soil layers yet. The groundwater proved to be the main source of salt accumulation in the study area, because the salt concentration increased in those areas, where the water table rose to 100–180 cm depth under the surface during the investigation period.

Moreover, the rise of the maximum salt accumulation layer (to 40–100 cm) in general was more frequent in those areas where water was supplied with a high pressurized (high intensity) network. The accumulation of the salt was caused by the type of irrigation system (sprinkler) and the effect of the irrigation network (seepage from the irrigation canal) both which resulted in the rise of the groundwater level above the critical depth (see Szabolcs, 1989, p. 223), which causes soil salinization. The highest salt accumulation (10 tonnes ha^{-1}) at 1 m soil depth was in the area of rising groundwater (Figure 6).

According to the analysis of these studies, the secondary salinization caused by unsuitable irrigation water is much more typical for small scale fields and gardens. The secondary salinization caused by rising water table is characteristic for large scale irrigated farms. Considering the coverage of the two types of salinization, the second case (rising groundwater) is more dangerous. But considering the long term interest of the private farmers, the first case (salinity caused by saline irrigation water) is a similarly sensitive issue.

Hungarian soil information and monitoring system

The objective of the system is the temporal monitoring of soil conditions in order to provide basis for the legal regulation of the management and protection of soil resources. The sampling period is 1, 3 or 6 years (Várallyay, 2005). The monitoring was started in 1992 and backed in 1994 by parliament. The activity was developed and is being supervised by a committee of scientists from RISSAC and practicing soil specialists.

There are 1 236 points representing the geographical regions of the country as well as different land use types. There are 865 points in agricultural lands, 183 in forests, 189 points such as polluted industrial and urban areas, areas affected by heavy traffic, areas beside military installations and waste storage facilities (40 points).

There are many parameters (see Table 5) checked with different sampling frequency (1–6 years). The list can be considered to be exhaustive for SAS. The basic soil parameters are determined, but there no regular groundwater observations are made. In order to harmonize the available monitoring data with groundwater level and meteorological data Kovács *et al.* (2006) made a comparative analysis. They evaluated the yearly changes between 1992 and 2000 at the 69 SAS profiles of the monitoring system. The conclusion of the work was that there is a large fluctuation of soil salinity from year to year. The tendency of yearly salinity changes (increase, decrease, fluctuation, etc.) showed similarity to the documented groundwater level changes (Figure 7). In the areas where there is a rising groundwater level (coinciding with the irrigated areas) there is increasing salinity in the profiles from year to year. In the region where there is a drop in the groundwater depth the tendency of soil salinity is to decrease.

European perspectives

The recognition of the importance of soil degradation has resulted in the creation of a Thematic Strategy for Soil Protection by the Commission of the European Communities in 2006. This strategy focuses on protecting European soils from a number of soil degradation processes, the so called *soil threats*. These threats are the following: erosion, decline in soil organic matter content, local and diffuse contamination, sealing of soil surface, compaction, decline in biodiversity, salinization, floods and landslides. The Commission concluded that despite existing EU policies, soil degradation still continues. EU member states are expected to adopt a strategy for halt soil degradation processes. The criteria for soil threat risk area identification were summarized by the Soil Information Working Group of the European Soil Bureau Network (Eckelmann *et al.*, 2006) in collaboration with the Joint Research Centre (Ispra, Italy). The criteria for salinization are shown in Table 6. Risk area identification or mapping scales might be national in Tier 1 (typically 1:200 000 to 1:500 000 with an approximate spatial resolution of 1 km^2) and regional in Tier 2 (1:25 000 to 1:100 000). In those cases where there is not enough spatial information is available. In many cases insufficient soil spatial information is available, especially for the more detailed scale. In this situation pedotransfer functions must be used.

Table 5. Required input data collected in the Hungarian Soil Information and Monitoring System for the characterization and risk identification of salinization/sodification (from Várallyay 2005).

Soil characteristics	at start t_0	yearly	3-yearly	6-yearly	Remarks
Morphological description of the soil profile	+				
Particle-size distribution	+				
Texture	+				
Total water storage capacity (WC_T - pF_0)	+				on undisturbed soil cores
Field capacity (FC - pF 2.5)	+				
Wilting percentage (WP – pF 4.2)	+				
Available moisture range (AMR = FC – WP)	+				
Saturated hydraulic conductivity	+				
$CaCO_3$ content: if >5%	+			+	
if 1– 5%	+		+		
if <1%	+	+			
pH (H_2O): if $CaCO_3$ >1%	+		+		
if $CaCO_3$ <1%	+	+			
pH (KCl): if $CaCO_3$ >1%	+		+		
if $CaCO_3$ <1%	+	+			
Total water-soluble salts (in salt-affected soils)	+	+			
1:5 water extract analysis (pH, EC, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+)	+			+	
Phenolphtalein alkalinity	+		+		
Depth of the humus horizon	+			+	profile
Organic matter content	+	+			
CEC (cation exchange capacity)	+			+	
Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+, K^{2+})	+			+	
Depth, fluctuation and chemical composition of the groundwater (pH, EC, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, Ca^{2+}, Mg^{2+}, Na^+, K^+)	+	+			

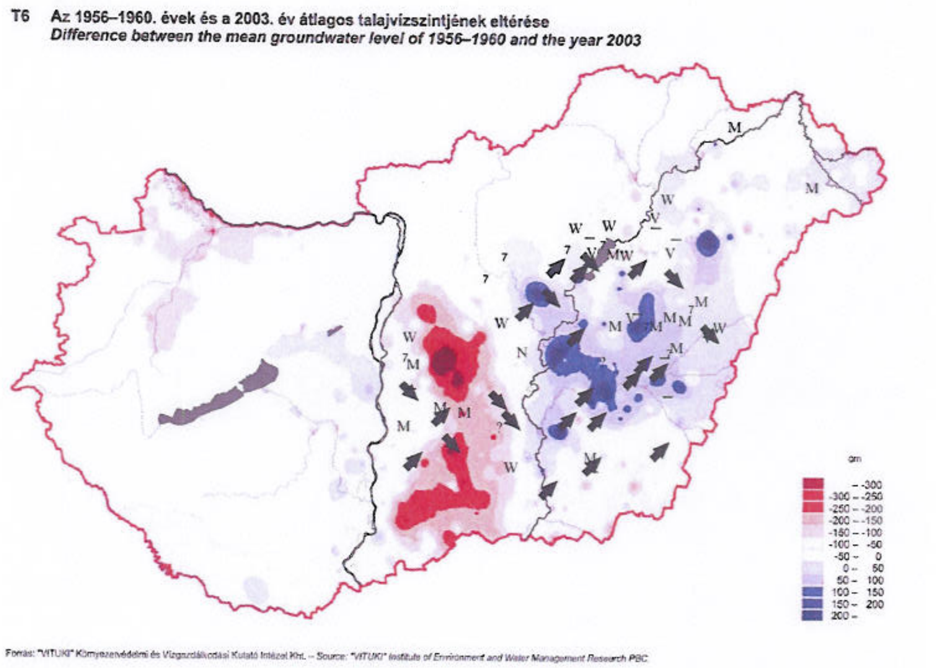


Figure 7. The extent of groundwater drop and rise in Hungary compared to the baseline years of 1956–60 and the trend of soil salinity changes during 1992 and 2000. The "down" arrow indicates decreasing and the "down" arrow indicates increasing yearly soil salinity. Other signs indicate not clear trend of yearly soil salinity changes (based on Kovács et al., 2006).

It is important to note that currently the officially recognized international soil classification in the EU is the latest version of World Reference Base (IUSS Working Group WRB, 2006).

The instrumental background of salinity assessment in Europe is intensively researched and used mainly in precision agriculture (Lück and Eisenreich, 2001; King *et al.*, 2007; Cassel and Zoldoske, 2007).

CONCLUSIONS

The significance of salt-affected soils of Hungary has changed during the centuries. There is vast amount of experience accumulated on its origin, distribution and characteristics. During the last century major questions of the reclamation and rational utilization of the salt-affected soils have been studied. At the moment there are running field researches and a lysimeters study for testing the effect of groundwater control techniques, which are considered to be the fundamental issue, since the groundwater is the direct source of salts. There are two monitoring systems, one specifically on the irrigated areas to monitor salinization and a general national one with 69 salt-affected soil profiles, monitored with yearly frequency. Inside the European Communities, the adoption of the measures to protect the areas from the soil threat salinization will promote the general conditions of crop production in the salt-affected areas.

Table 6. Common criteria for the delineation of areas threatened by soil salinization as defined by the European Union (from Eckelmann *et al.*, 2006).

Common criteria	Data source/type of information	Data quality/resolution	
		Tier 1	Tier 2
Soil typological unit (STU)	European soil database National soil databases	1:1 000 000 1:200 000–1:500 000	1:25 000–1:100 000 (Regional)
Soil texture	Texture class; sand, silt, clay content	Texture class	Particle size distribution, porosity
Soil chemical properties	Salt content, profile distribution, ion composition, pH, cation exchange capacity (CEC), exchangeable sodium rate (ESP)	Not required for Tier 1	National soil profile database, soil inventory/monitoring
Soil hydraulic properties	Infiltration rate, hydraulic conductivity, water retention (pF) curves, (total water storage capacity, field capacity, available moisture content), vertical and horizontal drainage	Not required for Tier 1	National soil profile database, soil inventory/monitoring
Irrigation areas and chemical properties of irrigated water	Irrigated area, irrigation intensity, salt content, sodicity, SAR, alkalinity of irrigation water	National registries	Regional registry
Groundwater information	Depth, salt content, sodicity, alkalinity	European/National Groundwater Database (salt concentration, type of salt, SAR, pH)	Regional database
Climate	Annual rainfall, annual potential evapotranspiration	1 km raster size (modelled from national weather station networks)	Same or higher

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