New Approaches in Salinity/Sodicity Mapping in Hungary

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Introduction

Due to various forms of secondary salinization the area covered by salt affected soils increases, so does the significance of the new techniques developed for its mapping. Where there is a need for extended development of irrigation due to population pressure secondary or human induced salinization increases with increasing acreage of irrigated land (TANJI, 1990). Sustainable irrigation, – i. e. maintaining or increasing yield level without degradation of soil due to waterlogging and increased salinity of the root zone – requires maps directly indicating the possibilities, limitations and treatments necessary for the proper management of the soil.

In developed countries due to the very intensive land use in the past and present only small islands of salt affected ecosystems of closely natural status have been left out of cultivation. Those areas are usually the less productive ones for agriculture, with large salt affected croplands among them, where intensive agricultural production is the least profitable. However, they have become refugees of elements of the formerly diverse biome, therefore they should be protected. In those areas the motivation of soil survey is to achieve a scientific basis for protecting the present status (NAVAS & MACHIN, 1996) rather than increasing fertility.

Specific Features of Mapping Salt Affected Soils

Decisions on land use and land management require reliable maps. We consider maps as spatial predictors which foretell the users what they should expect to find at a certain location. The quality of a map depends on the degree of help it can give to users in their decision-making. In case of soil maps of salt affected landscapes a very detailed and reliable soil type map can be less effective considering its use than one or two cartograms of the most important soil variables, such as topsoil pH or electrical conductivity (EC). Furthermore, mapping needs a compromise between quality of the resultant map and cost of mapping. Selection of informative and easily measurable variables is a key issue of effective mapping.

The physical, chemical and biological variables of salt affected soils as well as the vegetation (which indicates the soil conditions and modifies soil formation) are all closely interrelated due to the extreme chemical composition of the soils, the coupled moisture and salt dynamism in the profiles, as well as moisture, soil and salt redistribution on the surface by means of water runoff. These relationships can be studied well by multivariate statistical techniques (Figure 1). Even if the theoretical physico-chemical relations between the variables were rather complex, they are so strong that simple linear statistical methods (such as principal component analysis, multiple regression analysis or discriminant analysis) are suitable for describing the relations and predicting some of the variables knowing some others (LESCH et al., 1995a,b). In statistical terms, the degree of freedom of such a system is much less than the number of the important variables. This is the conceptual basis of the selection of easily measurable or observable variables for mapping.

Preconditioning factor	Main variables	Consequential variables
Relief	**Salinity⇔Sodicity⇔Alkalinity (pH)**	*Surface discoloration*
Hydrology	↓	*Mechanical properties*
Other soil forming factors	**Electrical conductivity**	Hydrophysical properties
		Extent of plant cover/biomass
		Species composition/abundance

Figure 1

Schematic representation of the relationship of some factors that facilitate the mapping of salt affected soils. **Bold character = main variable to map**, Underlined character = observable by remote sensing. *Italic* character = *covariable*

Electrical conductivity proved to be an almost equivalent substitute for soil salinity. It can be measured easily in laboratory, in the field with portable field probes and with airplanes, providing instantaneous EC values (RHOADES, 1991).

Natural vegetation indicates soil conditions by definition, i. e. reflects the pattern of soil fertility. In general terms, the spatio-temporal pattern of coexisting populations of living organisms indicates their environment, and this pattern can be rather complex. In case of the vegetation of salt affected areas, the indication is very simple due to the harsh abiotic conditions. On a complex of salt affected soils markedly different habitats can be found because of the great differences in the thickness of humic horizon, salt concentration of the root zone, duration of waterlogging, runoff and erosion (TÓTH & RAJKAI, 1994; TÓTH et al., 1994, 1995, 1996). These factors affect the performance of plant species mainly through the temporal pattern of moisture accessibility for plants. Different plant species are adapted to different conditions, and their occurrence, as well as the overall canopy cover and vertical structure of the grass and herb vegetation sufficiently indicate the pattern of the soil variables, or even their critical values (TÓTH et al., 1997.) In the case of croplands, the pattern of crop performance indicates the critical salt concentrations of the topsoil and the duration of waterlogging.

Salt affected soils can be mapped by the use of remotely sensed images because either of the presence of natural vegetation, or the stunted growth of crops, or the specific coloration of the soil surface. The statistical relations between the soil variables and reflection of the electromagnetic waves from either the vegetation or the soil surface are rarely strong enough to use remotely sensed images directly for predicting soil variables (TÓTH et al., 1991; TÓTH & PÁSZTOR, 1996), but they can generally be applied to adjust the sampling scheme (WEBSTER et al., 1989; TÓTH & KERTÉSZ, 1996).

A novel method of taking the pattern of mapped variables into consideration for adjusting sampling schemes has been elaborated (KERTÉSZ et al., 1995; CSILLAG et al., 1996). The area to be mapped is partitioned according to local heterogeneity and the density of sampling points can follow the partition and therefore the local heterogeneity. This way the „exciting" parts of the area will be overrepresented while the „boring" parts will be underrepresented. Thus the variation represented by each sampling point will be more equal than in case of random or regular sampling scheme, i. e. the sample can carry the maximum variation. The heterogeneity of the variable to be mapped cannot be seen prior to sampling, but remotely sensed images are applied to estimate the pattern of heterogeneity (KERTÉSZ & TÓTH, 1994; TÓTH & KERTÉSZ, 1996).

Salt affected soils appear to be mosaic-like to different degrees, and in the evaluation of heterogeneity advanced statistical techniques must be used. The application of geostatistics is not satisfying when the covariance structure of the soil variables changes from location to location. CSILLAG & KABOS (1997) have recently elaborated a novel method to describe those patterns by means of wavelet decomposition. Their method is data intensive, so remotely sensed images are required to estimate the local covariance structures. The result of the analysis can be applied in the local estimation of the variables to be mapped by means of conditional simulation. The application of this approach to map the salinity pattern of an arable land is in progress.

In the above treatise of mapping salt affected soils we considered the patterns of soil features as static patterns. However, those patterns vary in time, because water is the main transporting agent of salts in soils, so changes in salinity and in the related soil properties follow the changes in water content. At profile level the changes can be described and modelled, but their consequences at the level of pattern, i. e. the spatio-temporal pattern, cannot be studied without repeated mapping of salt affected areas in a time period of at least a year. The vegetation integrates the temporal effects, but the vegetation itself changes in time, and furthermore, without measuring important soil variables in a longer time period, one cannot determine what is indicated by the vegetation.

Example of Mapping Salinity Risk Based on Existing Maps at 1:500,000 Scale

On the basis of Hungarian agrogeological and soil maps in 1:500,000 scale we created a data system for describing the agrogeological conditions of the occurrence of salt affected soils in the Great Hungarian Plain. As a synthesis of the five map layers studied (map of salt affected soils (SZABOLCS, 1974); groundwater level above sea level; groundwater depth below surface; soluble salt concentration of the groundwater; chemical composition of groundwater) we evaluated the typical situations in which soil salinization and sodification occur. Following the statistical testing of the maps for the closeness of the association between individual agrogeological conditions and salt affected soil types, the coincidence of the combination of the two major agrogeological factors of the occurrence of salt-affected soils (groundwater level above sea level and total soluble salt concentration of groundwater) with salt affected soils was displayed (Figure 2).

The coincidence is not complete, as shown by Table 1. Although the overall 66% precision of the prediction could be accepted to be promising, it is obvious that the agrogeological conditions suit salt affected soils relatively well, but an area larger than that of the salt affected soils would be predicted to be salt affected by these conditions. Therefore this approach must be improved by setting other restricting conditions.

Table 1

Areal coincidence of salt affected soils and specific agrogeological conditions, as shown in Figure 2

	Groundwater level above sea level < 105 m and total soluble salt concentration of groundwater > 1 g/l		
	No	Yes	Column sum
Not salt affected soil	20,812 km²	11,931 km²	32,743 km²
Salt affected soil	3,453 km²	9,467 km²	12,920 km²
Row sum	24,265 km²	21,398 km²	45,663 km²

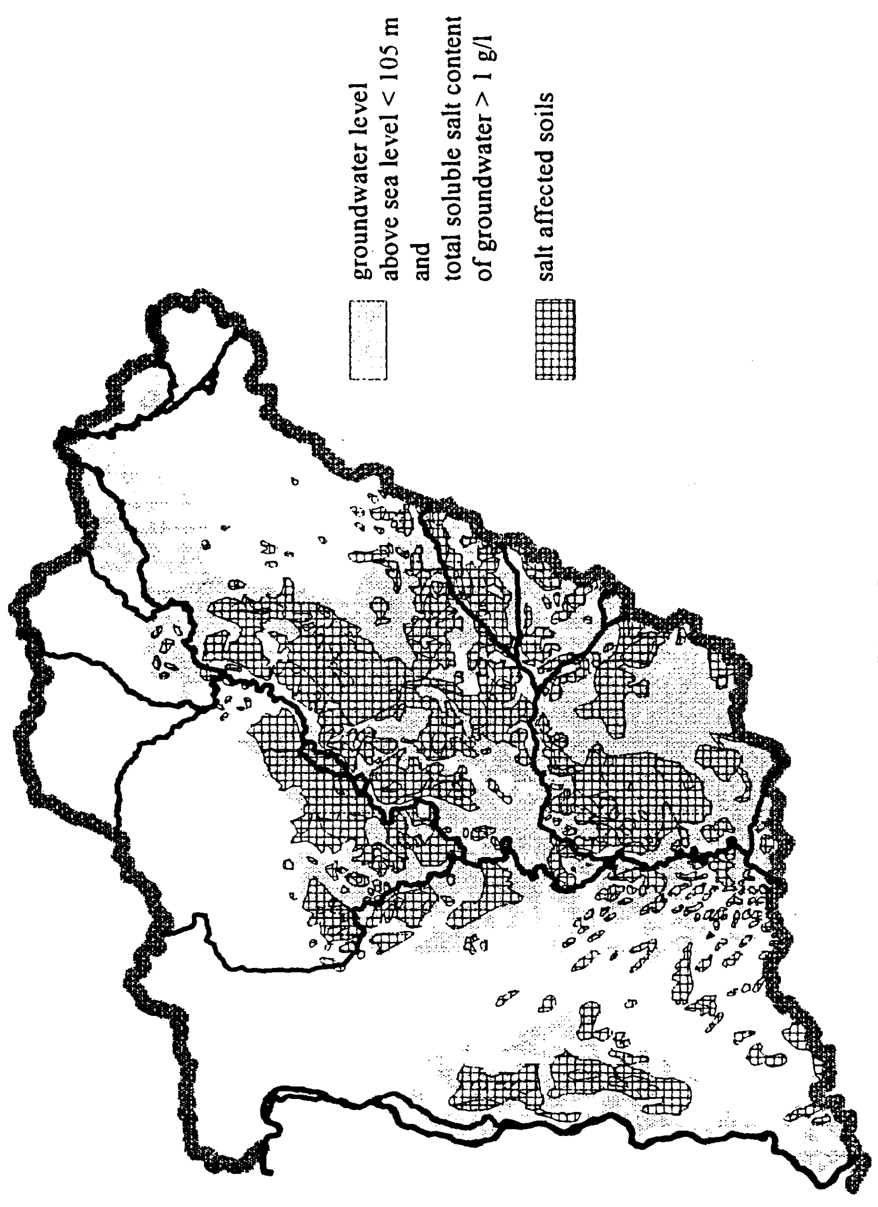

Figure 2
Coincidence of agrogeological conditions with soil salinity

Example of Mapping Temporal Changes in EC at 1:1,000 scale

In an 800 x 300 m site of natural sodic grassland in the Hortobágy National Park, Hungary, soil bulk electrical conductivity (EC) was repeatedly measured at 420 points using a „four-electrode probe". Soil samples were collected at 20 points for calibrating the instrument readings. By the calibration equation the bulk soil EC was recalculated into our standard EC of 1:2.5 soil:water suspension for the 0-40 cm soil depth. Interpolated EC maps were compiled from the 420 estimated EC values for five consecutive dates at 3-month intervals.

Table 2
Multitemporal regression equations between field and laboratory EC values, and their determination coefficient

Date	Equation	Determination coefficient (R^2)
November 1994	$\ln EC_{lab}0.208*\ln EC_{field}-0.912$	0.357
March 1995	$\ln EC_{lab}0.133*\ln EC_{field}-0.154$	0.227
June 1995	$\ln EC_{lab}0394*\ln EC_{field}-2.280$	0.767
September 1995	$\ln EC_{lab}0.346*\ln EC_{field}-1.831$	0.862
December 1995	$\ln EC_{lab}0.396*\ln EC_{field}-2.361$	0.887

Note: EC_{lab} is the average EC of 1:2.5 soil:water suspension for the 0-40 cm depth (mS/cm), EC_{field} is the EC measured in field by the bulk EC meter (mS/cm)

The suitability of the soil bulk EC meter was shown by the regression equations of the 5 studied dates (Table 2). As the equations of the first two dates (November 1994 and March 1995) were not significant statistically, other variables, such as elevation, were included, which increased the significance to an acceptable level for producing the maps shown in Figure 3. As compared to the reported use of four electrode probes in irrigated fields, in natural grasslands due consideration must be given to the inclusion of other covariates for the estimation of standard EC values.

There were great temporal changes in the measured soil parameters. At the 0-40 cm depth during a year, the average EC_{lab} varied between 1.3 and 2.3 mS/cm, soil moisture between 14 and 30% and pH between 8.2 and 8.4. At each 5 studied time stage the overall pattern of salinity remained similar and the differences between different parts of the study area were clearly perceivable (Figure 3). Considering Nov 1994 as an extreme low EC date and Mar 1995 as an extreme high EC date the 3 following dates show a remarkably similar pattern and magnitude of EC, and show that there is a characteristic EC value for the observation points. The areal maximum of EC was found at intermediate elevations, and both at higher and lower elevations EC was smaller (see elevation inlet on Figure 3).

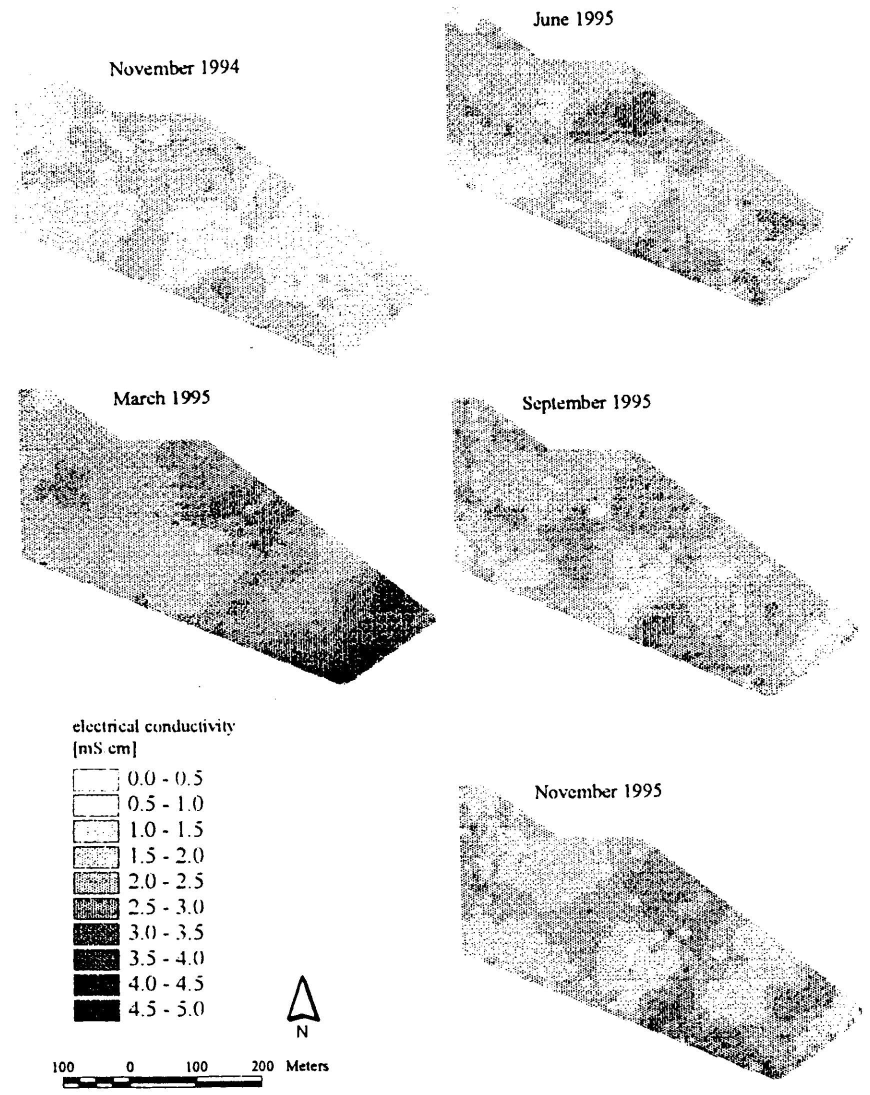

Figure 3
Dynamism of EC in the „Nyírőlápos" test site (Hortobágy National Park, Hungary) at five studied dates

Example of Mapping Within-Plot Gypsum Requirement at 1:5,000 Scale

Inside a heterogeneous sodic arable plot the determination and placement of required gypsum was optimized by applying two novel approaches: a) the direct use of aerial photo for the placement of gypsum, and b) utilization of simple assessment methods for gypsum requirement. The basic hypothesis of the close relationship between gypsum requirement and aerial photo pixel intensity (or brightness) was supported by the sampling (Figure 4A). Though the overall determination coefficient is not higher than 0.4, the analysis of variance showed highly significant differences in gypsum requirement between intensity classes. The testing of schemes for the sampling and placement of gypsum inside the plot are presented in Figure 5.

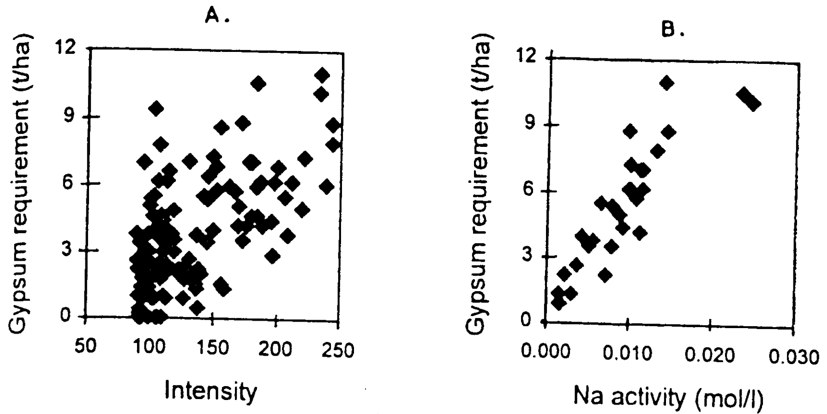

Figure 4
Scatterplot of pixel intensity of aerial photo and gypsum requirement (A) and scatterplot of gypsum requirement and sodium ion activity measured in water saturated paste (B)

As an alternate of complicated laboratory methods for the determination of gypsum requirement, we tested some simple techniques, which could be used even in the field. As Figure 4B shows, sodium ion activity measured in saturated paste with selective electrodes can be used directly for the prediction.

Conclusion

We concluded that with the increase of secondary salinization and of the importance of preserving natural salt affected landscapes the mapping of salt affected soils can satisfy the growing demand for spatial and attribute information at limited expenditure. We emphasize that for the optimization of mapping auxilliary information on spatial and temporal pattern of soil properties should

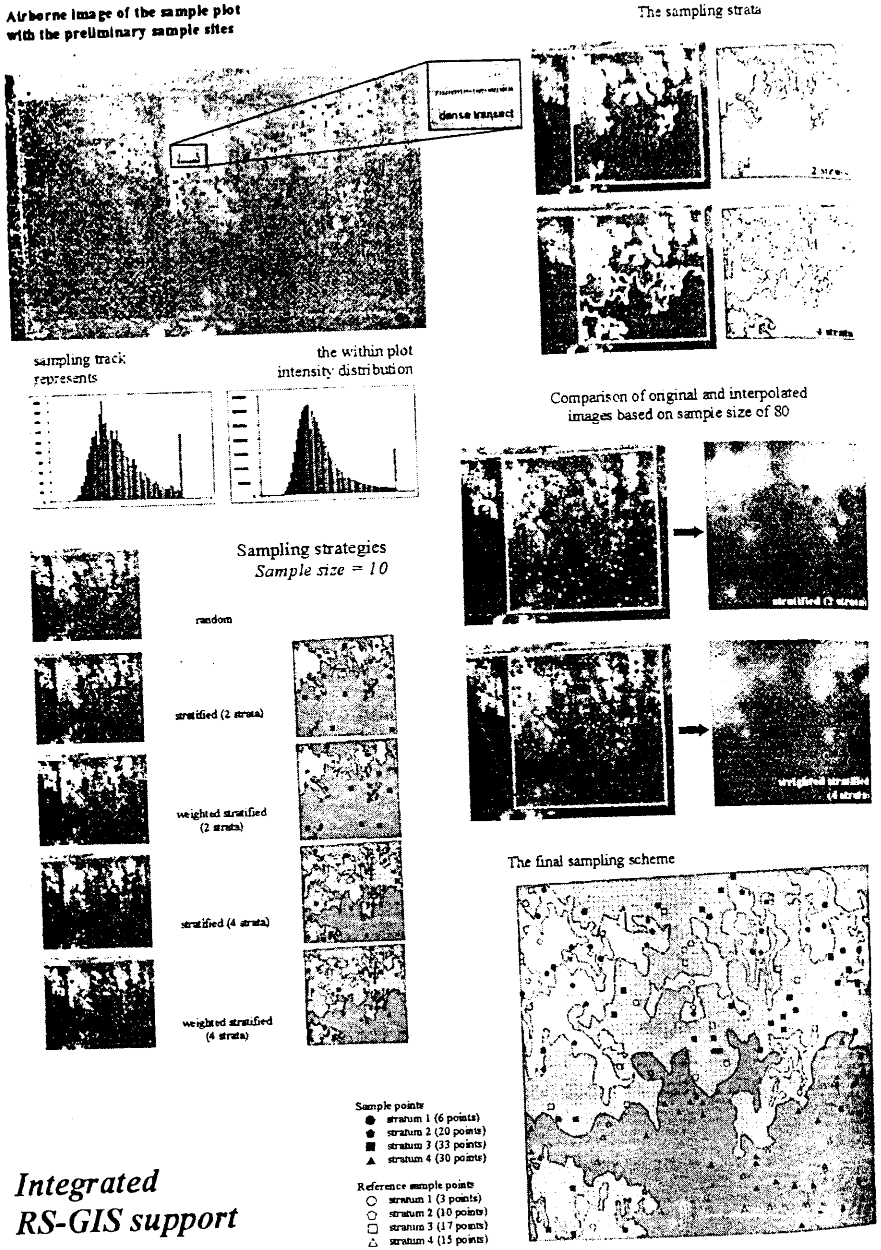

Figure 5
The testing of schemes for sampling and placement of gypsum inside the plot

be taken into consideration, and vegetation maps, remotely sensed images and geographic information system should be applied.

Acknowledgements

Publication and the research was partly financed by the Hungarian National Scientific Research Fund (OTKA) under grant No. T014522 and T023271.

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