

Application of Soil-Vegetation Correlation to Optimal Resolution Mapping of Solonetzic Rangeland

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An optimal resolution surveying technique was developed and tested in the solonetzic grassland of Hortobágy, Hungary. Indication of soil properties by vegetation is utilized to create a sampling design by applying a satellite image of the pilot area and to estimate soil properties on the basis of the statistical correlation between vegetation and soil data. The spatial sampling scheme was designed in accordance with the local heterogeneity of the satellite image. In order to study the predictability of the vegetation categories in terms of soil chemical properties, discriminant analysis was used with pH, electrical conductivity, and sodium activity at three depths, used as grouping variables. Based on the taxonomy of vegetation types, about two-thirds of the cases can be classified and correlated with the soil chemical properties.

Keywords catena, discriminant analysis, quadtree, sampling, satellite image

The majority of salt-affected soils, including the solonetztes, are located in climatic zones that permit cropping and pasturing. The use of these lands and the inventory of natural resources require thorough soil surveys. During a soil survey, it is of vital importance to take into consideration the vegetation of the salt-affected areas because this vegetation indicates the differences of the natural conditions between distinct locations (Tóth & Rajkai, 1994).

The present study is part of a major project aiming to develop and test a technique for the optimal mapping of the vegetation and soil of salt-affected landscapes covered by vegetation. The other objective of this study is to demonstrate the applicability of the relation between vegetation and soil properties in surveying solonetzic rangelands. The indication of the soil properties by vegetation is used in the mapping of the soil properties (Kertész & Tóth, 1994).

The aim of mapping is to optimize the quality of the map within the cost constraints. The term "quality" expresses the success of decisions based on the map. In this study, two constraints were considered: the number of sampling points and laboratory analyses.

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The optimization of a survey requires the use of as much previous knowledge of the sample site and results of analyses as possible. The following should be considered:

- spatial-temporal pattern of surveyed properties
- statistical relation between the spatial-temporal patterns
- significance of measurable variables in the determination of surveyed properties
- ancillary data sources, such as maps and remotely sensed data
- cost of sampling, analyses, and ancillary data.

Since during the dry season the soil moisture status changes in the sample site, in the present survey the temporal variation of the soil properties has been ignored, and we use analysis data of samples collected in one field campaign. The spatial pattern of the sample site was considered in the sampling design, applying a satellite image of the site. The examination of the statistically valid relation between vegetation and soil is one of the major goals of the present study. Based on previous studies (Rajkai et al., 1988; Tóth & Rajkai, 1994), a limited set of studied variables was selected that is informative about the ecological limitations posed by the soils and that requires relatively inexpensive analyses.

Materials and Methods

Natural Conditions of the Study Area

Hortobágy National Park, where the study was carried out, has been dedicated to protect the largest area of solonetzic grassland of central Europe, the preservation of the nesting area of more than 200 bird species and the conservation of ancient animal husbandry and land use. It is situated between 47°45' and 47°25' N and 20°55' and 21°20' E.

The area is very flat; the mean elevation above sea level is between 88 and 92 m in most of the area. The highest points are ancient burying places built by nomadic peoples in the previous millennia, the maximal elevation being 105 m. The average air temperature is -4.5°C in January and 21.5°C in July. The long-term mean annual precipitation is 540 mm. During summer the climate is semiarid to semihumid.

As a part of the Great Hungarian Plain, the formation of the region of Hortobágy was dominated by the effect of rivers. The regulation and control of the river flows and of the drainage of the area in the last 15 decades have caused drastic changes in the environment: the territory dried out and the area, which was influenced by periodic floods and the fluctuation of saline groundwater, now appears as salt-affected landscape. The highest patches (which were never flooded) are covered by chernozem soils, and hydromorphic soils are found on the lower areas (Tóth & Kertész, 1993).

Due to the extreme physical and chemical conditions for plant growth, the vegetation of solonetz soils reflects the soil conditions exceptionally well. Based on the vegetation, it is not only possible to predict the fertility of the plots but also to predict the soil type in most cases. Cross-classification systems to match the soil types with the plant associations were elaborated, such as the system of Bodrozközy (1965) (Figure 1). Some data of the typical plant associations are shown in Table 1.

Sampling Design

During the planning of the sampling, the following two points were considered.

1. The spatial density of the sampling points should follow the spatial heterogeneity of the study site. As the spatial heterogeneity of the soil cover was not known

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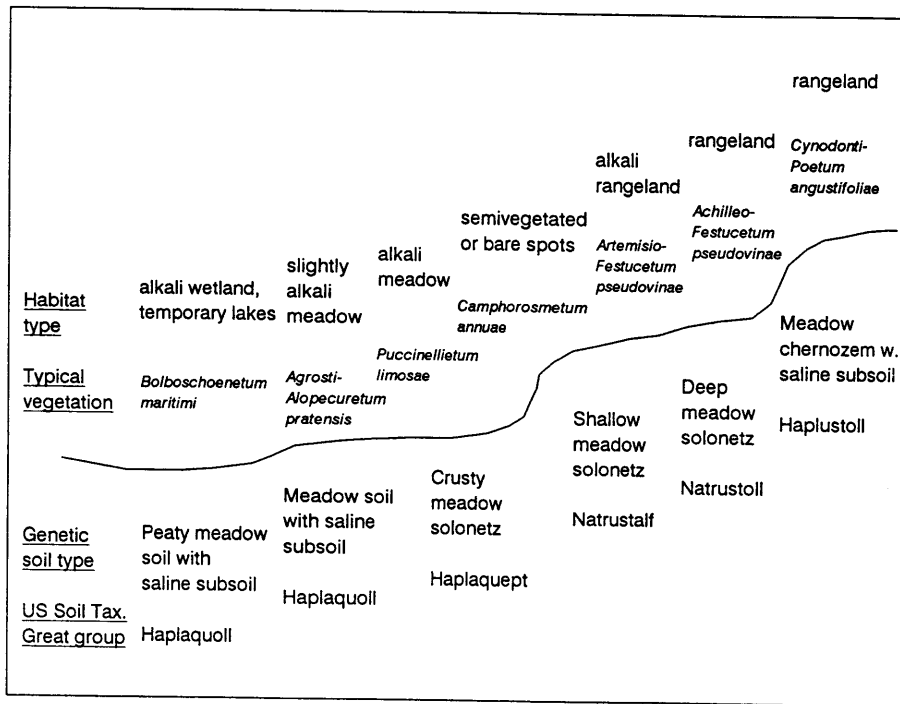


Figure 1. Soils and vegetation in the study region.

- before the survey, it was considered indirectly. It was assumed that the local heterogeneity of the vegetation corresponds to the local heterogeneity of the soil cover. The satellite images of the study site reflected well the vegetation pattern. Thus it was assumed that the heterogeneity of the satellite image corresponded to the heterogeneity of the soil cover as well. It must be noted that a stronger assumption is that there would be global (i.e., valid for the whole image applied) correlation between soil properties and image density values.
- Such soil properties should be mapped that are informative on the limiting ecological conditions of the solonetzic grassland, such as pH, sodium, and total soluble salt concentration, and that at the same time can be measured relatively inexpensively. The botanical recording (i.e., registration of dominant species and type of botanical association) is the most inexpensive sampling method. It should be performed by a botanist versed in plant classification and ecology and qualified to recognize the plant associations. Based on previous results (Tóth & Rajkai, 1994), it was decided to take soil samples only from the upper 30-cm layer. From the samples, only pH, Na^+ activity ($p\text{Na}$), and electrical conductivity (EC) measured in water-saturated soil paste were determined. Exchangeable Na^+ percentage or Na^+ adsorption ratio were not measured, since the latter showed close correlation with the properties measured in saturated paste (Kertész & Tóth, 1994).

For locating the sampling points, a remotely sensed image was used as an ancillary data source. We aimed to make a sampling design where the local density of the sampling points was the function of the local heterogeneity of the satellite image.

Table 1
Characterization of some plant associations of the study site

| | Cynp | AchF | ArtF | AgrA | Bolb |
|---|-------|-------|-------|-------|-------|
| Total plant cover (%) | 100 | 96 | 90 | 97 | 100 |
| No. of species with constancy >2 | 27 | 12 | 8 | 13 | 5 |
| Species with constancy of 5 | | | | | |
| <i>Achillea collina</i> L. | + | + | | | |
| <i>Agropyron repens</i> P. B. | + | | | | |
| <i>Agrostis stolonifera</i> L. | | | | + | |
| <i>Alopecurus pratensis</i> L. | | | | + | |
| <i>Artemisia santonicum</i> L. | | | + | | |
| <i>Bolboschoenus maritimus</i> (L.) Palla | | | | | + |
| <i>Euphorbia cyparissias</i> L. | + | | | | |
| <i>Festuca pseudovina</i> Hackel ap Wiesb. | | + | + | | |
| <i>Festuca rupicola</i> Heuff. | + | | | | |
| <i>Galium verum</i> L. | + | | | | |
| <i>Koeleria cristata</i> (L.) Pers. em. Borb. | + | | | | |
| <i>Poa angustifolia</i> L. | + | | | | |
| <i>Poa bulbosa</i> L. | + | | | | |
| Soil properties in 0–10 cm | | | | | |
| EC (S m ⁻¹) in saturated paste | 0.037 | 0.051 | 0.148 | 0.004 | 0.088 |
| SAR | 4.8 | 6.1 | 14.2 | 9.6 | 11.5 |
| pH in 1:2.5 H ₂ O | 5.89 | 6.12 | 7.50 | 6.50 | 7.75 |

Plant associations are CynP, *Cynodonti-Poëtum angustifoliae* (Rapaics, 1926) Soó (1957); AchF, *Achilleo-Festucetum pseudovinae* (Magyar, 1928) Soó (1945); ArtF, *Artemisio-Festucetum pseudovinae* (Rapaics, 1927) Soó (1933); AgrA, *Agrosti-Alopecuretum pratensis* Soó (1933) 1947; Bolb, *Bolboschoenetum maritimi continentale* Soó (1927) 1957.

Data were quoted from Varga (1984) and from this study. SAR, the sodium adsorption ratio, was calculated according to Kertész and Tóth (1994).

To achieve this task, first, a map of the satellite image was compiled. The method applied is described in detail by Kertész et al. (1994). The map consisted of a predefined number of patches, and in each patch a potential sampling point was allocated. Within a patch of the map, the value belonging to the pixels (the gray tone of the pixel) is equal to the average of the values of the corresponding pixels of the image (values of panchromatic density). In other words, the patches of the map indicate the mean density of the corresponding fragments in the image. Due to the fact that the pixels of the map correspond to the pixels of the satellite image, the difference between the map and the image, i.e., the measure of loss of detail during the mapping, can be easily calculated by comparing the corresponding pixel values.

The map was compiled by an iterative procedure. The satellite image applied was square shaped with side lengths an integer power of 2 expressed by pixels. At the beginning the map consisted of one homogeneous patch, which was divided into four parts in the first step. In the second step, from among the four squares the one that contributed the most to the difference between the map (not more than four patches) and the remotely sensed image was selected for division. In this way, we had a map consisting of three larger squares (each corresponding to one-fourth of the area of the image) and four smaller squares (each covering one-sixteenth of the image). In the third step, once again the square

contributing the most to the difference was selected and divided into four parts. The procedure was repeated until the predetermined number of patches was reached. The difference between the map and the image can be expressed with the following formula. Graphs are called patch maps. They were drawn on computers (Samal, 1994).

The difference between the map and the image is a measure of the divergence of the map from the image. In the case of a perfect map, the difference is zero (Csiszár, 1975).

and

where p and q are the number of pixels in the map and the image, respectively, $f(i)$ is the frequency of the value i in the map, and $g(i)$ is the frequency of the value i in the image. The difference between the map and the image is a measure of the loss of detail during the mapping. The conditions were met when the difference is zero.

D

and

where $\text{map}(Q)$ is the value of the pixel i of the map, Q is the number of pixels in the map, and i is the number of pixels in the image. The measure of loss of detail during the mapping is such distributions.

where image'_i is the value of the pixel i of the image, i is the number of pixels in the image, and image is the value of the pixel i of the image. The panchromatic image was taken in July 1990 and converted to a grayscale. Each pixel represents an area of 100 m².

contributing the most to the difference between the remotely sensed image and the map was selected and divided into four parts. These successive divisions were continued until the predetermined number of patches was reached. The pattern of the resultant map can be expressed with a graph that represents the divisions of the squares. These types of graphs are called "quadtree" and are utilized extensively for the storage of maps in computers (Samet, 1990).

The difference between the remotely sensed image and the map was measured with f divergence, a nonparametric measure, which can be calculated by the comparison made in the case of each element (in this work, for each pixel) of the discrete distributions (Csiszár, 1975). The formula of the f divergence is

$$D_f(p/q) = \sum_{i=1}^M p_i f(p_i/q_i)$$

and

$$\sum_{i=1}^M p_i = \sum_{i=1}^M q_i = 1 \quad p_i \neq 0 \quad q_i \neq 0$$

where p and q are discrete distributions of M elements, f is a fixed convex function, and $f(1) = 0$. The f divergence was selected because it has no limitation on the type of distribution and requires neither homogeneity nor stationarity, as it was assumed that those conditions were not met in the case of the satellite image of the sample site. The selected measure is

$$D[\text{image}/\text{map}(Q)] = \sum_{i=1}^M \text{image}_i / \text{SUM} \log [\text{image}_i / \text{map}(Q)_i]$$

and

$$\text{SUM} = \sum_{i=1}^M \text{image}_i = \sum_{i=1}^M \text{map}_i$$

where $\text{map}(Q)$ is the map described by the quadtree Q , image_i is the value (density) of pixel i of the image, $\text{map}(Q)_i$ is the value of pixel i of the map with Q quadtree, and M is number of pixels.

The measure used by the authors is a modified version of the Kullback divergence for such distributions, which do not sum to 1:

$$D(\text{image}/\text{map}) = D_{\text{Kullback}}(\text{image}'/\text{map}')$$

where $\text{image}'_i = \text{image}_i / \text{SUM}$ and $\text{map}'_i = \text{map}_i / \text{SUM}$. The measure shows how much information has been lost during mapping.

The panchromatic SPOT satellite image applied for the sampling design was taken in July 1990 and contained 512×512 pixels of 10×10 m nominal size (Figure 2), which represent an area of approximately 5×5 km. Based on the image, a map of 256 patches

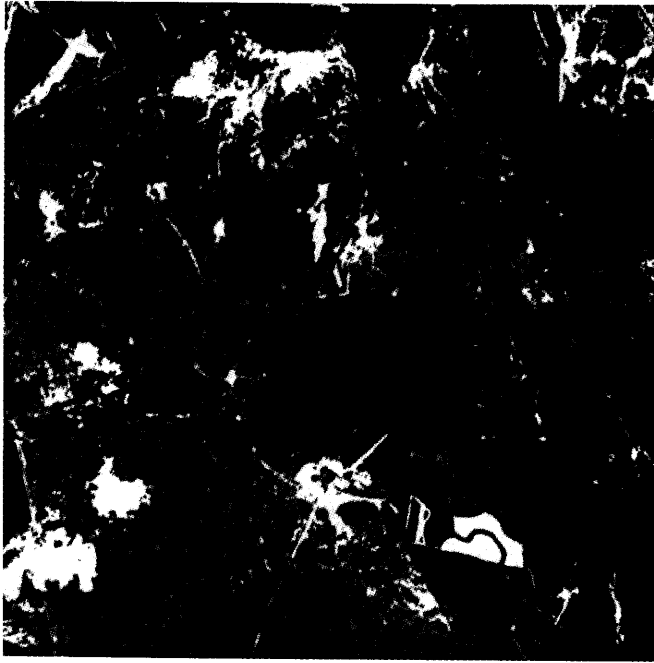


Figure 2. The SPOT (®SPOTIMAGE) panchromatic image used. The image consists of 512×512 pixels and represents an area of 5120×5120 m.

was made. The sampling points were allocated in the centers of the patches (Figure 3). Csillag et al. (1992) studied the sampling performance of such designs using spatially structured noise added to smaller parts of the same satellite image that had been applied in the present study. According to the results, the reconstruction of the spatial pattern of an area is more precise if it is based on sampling done with this algorithm than if it is sampled randomly or regularly.

Geodesy Applied

The predetermined sampling points were located in the field by geodetic procedures. The basic point of the field geodesy system was an ancient tumulus of 4-m height, and the basic orientation was determined by a church tower that was visible from the tumulus. The measurements were carried out by using a theodolite with an infrared distance meter with a 900-m range. Based on repeated determinations, the accumulated error of the field geodesy (from the base point to the furthest points) was estimated to be no greater than 3 m. The adjustment error between the local geodetic system and the remotely sensed image was not detectable; thus it must be smaller than 10 m, the pixel size.

Field Recordings and Laboratory Analyses

The field sampling was performed in June and early July 1992. At the sampling points, soil samples were taken in 10-cm-depth increments from the surface to 30 cm. Plant species were recorded in 25×25 cm squares. Small sampling units were used in order to minimize the chance of meeting borders of vegetation patches in the often extremely

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Figure 3. Positions
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heterogeneous vegetation. The categorization of the vegetation types was based on the taxonomy of plant associations but also included weedy types.

Water-saturated paste was prepared from the soil samples and left to equilibrate overnight. Next-day electrical conductivity was measured with conductivity cells, pH with glass electrodes, and sodium ion activity with ion selective electrodes, this latter expressed as pNa , i.e., the negative logarithm of the concentration (mol L^{-1}).

Discriminant analysis was used to study how much the field categorization of vegetation can be reproduced based on the linear combinations of the soil data. The results were expressed in terms of the ratio of matching of the two categories.

Results and Discussion

Performance of the Algorithm for the Allocation of Sampling Points

Studies have been done on how the planned sampling density can satisfy the requirements of the traditional mapping and geostatistical evaluation (Burgess et al., 1981). The variogram of the panchromatic density of the remotely sensed image was calculated, i.e., the estimation of the variance of the difference of pairs of values as the function of distance (Webster, 1985). During the calculation, not all data were used, only the data of 256 randomly selected points.

The range of the fitted spherical variogram was 619 m (Figure 4). This shows that points located at an average distance of 619 m from each other can be considered to be spatially independent. The sample of the 256 points represents a 320-m average distance between the points, and this is suitable for map compilation. Although the requirement of

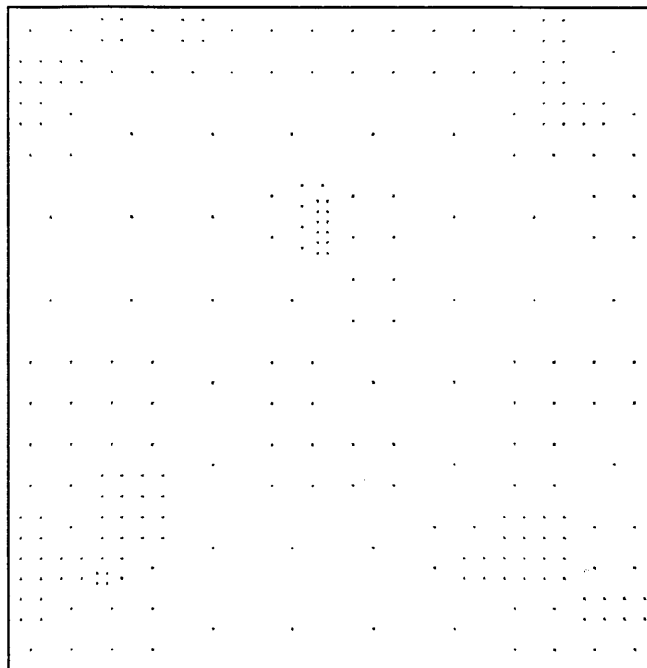


Figure 3. Positions of 256 sampling points. The minimum distance is 80 m, the maximum is 640 m.

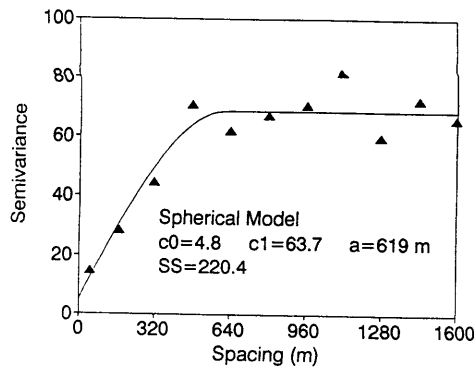


Figure 4. Semivariogram of the panchromatic density of the SPOT image. C0 = nugget, C1 = sill, a = range of the semivariogram, SS = sum of squares of the fitted semivariogram model.

the spatial stationarity condition is not assumed to be met in the image and the points are not allocated in a regular or random arrangement, the variogram indicates that the selection of the number of sampling points was adequate.

On the other hand, the semivariogram of the electrical conductivity of the 0- to 10-cm layer (Figure 5) showed a relatively low nugget/sill ratio (0.27) and a range similar to that of the panchromatic density calculated from random points (589 m). The other measured properties showed similar ranges (471–702) and low nugget ratios (0.2–0.47) as well. The similarity of the semivariogram parameters suggests that the spatial patterns of the vegetation (reflected by the image) and the soil properties are correlated. Nevertheless, the spatial distribution of the soil properties is “smoother” than that of the vegetation. This is why they resulted in semivariograms of low nugget/sill ratio in spite of the uneven sampling arrangement.

Separation of the Vegetation Categories on the Basis of Soil Properties

The soil chemical data were used to examine whether the vegetation categories distinguished in the field match the grouping that is based on the similarities of the soil properties. This task is the opposite to that solved during the routine mapping of solonchic soils, but it is convenient for the quantification of the power of the soil-vegetation relationship and for deciding which are the easily predictable vegetation categories. This task

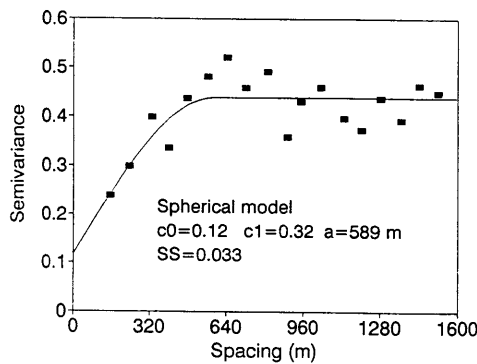


Figure 5. Semivariogram of the electrical conductivity measured in saturated paste of 0–10 cm.

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Vegetation

Loess steppe
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Artemisia-Festuca
Agrostis-Alopecurus
Humid
F

Loess steppe
Achillea-Festuca
Artemisia-Festuca
Agrostis-Alopecurus
Humid
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Loess steppe
Achillea-Festuca
Artemisia-Festuca
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SP, saturation permeability (mol L⁻¹) of...
*Significance of...
**Significance of...

also favors the compilation of a hierarchical system of vegetative associations based on the similarity of soil properties.

In studies carried out in smaller areas, comprising three to four associations (Rajkai et al., 1988; Tóth et al., 1991a), it became evident that, based on soil properties, the points can be classified relatively precisely by clustering and discriminant analysis. When there were four categories, the discriminant analysis based on the soil properties of 0–5 and 10–15 cm depths classified the categories with a precision of approximately 80%. This result was not worse than that received by the linear combination of the cover of plant species and was very similar to the precision received during a repeated field classification 1 year later.

In the study area, about 60 vegetation categories were distinguished in the field and were grouped hierarchically in three steps, finally yielding one system with five and another with three vegetation categories (Table 2). The categories were named after the characteristic plant associations (see Table 1 and Figure 2). As Tables 3 and 4 show, the system of three categories was received by uniting the loess steppe with *Achillea-Festuca* and the *Agrostis-Alopecurus* with humid vegetation categories. The precision of the classification was expressed by the classification matrix of discriminant analysis, which was created by comparing the original field categorization of observations to the classification provided by the discriminant scores. In Table 3, out of 14 total loess steppe cases observed during sampling, the discriminant function classified six (43%) into this category

Table 2
Mean values of the soil properties of the five categories

| Vegetation | Cases | SP | EC | pH | pNa |
|----------------------------|-------|--------|---------|---------|---------|
| 0- to 10-cm samples | | | | | |
| Loess steppe | 14 | 59 | 0.052 | 6.17 | 2.54 |
| <i>Achillea-Festuca</i> | 34 | 55 | 0.049 | 5.98 | 2.28 |
| <i>Artemisia-Festuca</i> | 77 | 54 | 0.152 | 7.10 | 1.57 |
| <i>Agrostis-Alopecurus</i> | 61 | 58 | 0.088 | 6.33 | 1.88 |
| Humid | 20 | 52 | 0.120 | 7.43 | 1.71 |
| <i>F</i> | | 2.49* | 22.00** | 26.56** | 38.10** |
| 10- to 20-cm samples | | | | | |
| Loess steppe | | 55 | 0.080 | 6.91 | 2.26 |
| <i>Achillea-Festuca</i> | | 54 | 0.103 | 6.74 | 1.91 |
| <i>Artemisia-Festuca</i> | | 62 | 0.247 | 7.98 | 1.43 |
| <i>Agrostis-Alopecurus</i> | | 59 | 0.121 | 6.98 | 1.77 |
| Humid | | 60 | 0.151 | 7.93 | 1.61 |
| <i>F</i> | | 2.66* | 24.41** | 25.21** | 19.44** |
| 20- to 30-cm samples | | | | | |
| Loess steppe | | 61 | 0.115 | 7.27 | 2.14 |
| <i>Achillea-Festuca</i> | | 62 | 0.180 | 7.27 | 1.72 |
| <i>Artemisia-Festuca</i> | | 72 | 0.334 | 8.61 | 1.33 |
| <i>Agrostis-Alopecurus</i> | | 66 | 0.153 | 7.51 | 1.69 |
| Humid | | 64 | 0.191 | 8.22 | 1.55 |
| <i>F</i> | | 6.78** | 22.86** | 26.73** | 18.27** |

SP, saturation percentage; EC, electrical conductivity ($S\ m^{-1}$); pNa, negative logarithm of the ion activity ($mol\ L^{-1}$) of Na^+ ; all three cases were measured in saturated paste.

*Significance of *F* is <0.05.

**Significance of *F* is <0.001.

Table 3
The classification matrix of the five categories received with discriminant analysis

| | Actual cases | Predicted category membership | | | | |
|---------------------|--------------|-------------------------------|-----------|-----------|-----------|-----------|
| | | Steppe | AchF | ArtF | AgrA | Humid |
| Loess steppe | 14 | 6 43% | 4 29% | 1 7% | 3 21% | 0 0% |
| Achillea-Festuca | 34 | 6 18% | 21 61% | 4 12% | 1 3% | 2 6% |
| Artemisia-Festuca | 77 | 0 0% | 5 6% | 49 64% | 10 13% | 13 17% |
| Agrostis-Alopecurus | 61 | 5 8% | 2 3% | 8 13% | 37 61% | 9 15% |
| Humid | 20 | 0 0% | 2 10% | 2 10% | 0 0% | 16 80% |

Percent of "grouped" cases correctly classified is 63%. AchF, Achillea-Festuca; ArtF, Artemisia-Festuca; and AgrA, Agrostis-Alopecurus.

and four into Achillea-Festuca, one into Artemisia-Festuca, three into Agrostis-Alopecurus, and none into humid vegetation. Dividing the exact matches of the vegetative categories (located on the left-to-right diagonal) by the number of cases of the original categories (column one), we receive $(6 + 21 + 49 + 37 + 16) / (14 + 34 + 77 + 61 + 20)$, that is 63%.

Table 2 shows the means of electrical conductivity (EC), pH, and sodium activity (*pNa*) in the five-category system. The values of all these properties increase with depth in all vegetative categories. The highest pH, EC, and *pNa* were found under the Artemisia-Festuca vegetative category. The values of the soil properties of the Achillea-Festuca category and the loess steppe were very similar, and only the EC and *pNa* of the 0- to 30-cm layer distinguish them. The soil properties of Agrostis-Alopecurus and Achillea-Festuca vegetative categories are very similar in the 20- to 30-cm depth, but the former has higher average EC and pH in the 0- to 10-cm layer. Comparing the humid vegetation category with the loess steppe and Achillea-Festuca vegetative categories, the humid category had larger EC in the 0- to 10-cm layer than the other two. According to the significance of *F*, except for the saturation percentage of the 0-10 and 10-20 cm layers, it was proved that the means in the vegetation categories are not the same, and the significance level was less than 0.0005.

The discriminant analysis showed that in the case of the five-category system the match of the observed vegetation categories and those predicted on the basis of soil properties was 63% (Table 3). The most important variable in the prediction was the negative logarithm of sodium ion activity of the 0- to 10-cm layer and the EC of the 0- to 30-cm layer. When the number of categories was reduced to three, the match was 75% (Table 4).

From the classification matrix, it is possible to infer the homogeneity of the vegetation categories in terms of the predictability by the soil data. In the case of the hygromorphic loess steppe and Achillea-Festuca vegetative categories, most of the misclassifications fell into the other category, which indicates that the soil properties of these vegetation types do not differ much. The category of hygromorphic association in the Agrostis-Alopecurus category, was rather heterogeneous. This was manifested at several

levels of groupings when classified.

The classification of vegetation types on the basis of the solonchets (Sigmund 1988) is a simplification of the traditional classification, i.e., the soil properties of the eastern European region. Therefore the

Conclusions

This study shows that the discriminant analysis technique is a useful tool for keeping costs low in the mapping of vegetation types. The sampling of soil properties measured from the samples

The soil properties of the heterogeneous vegetation types are not optimal estimates of the soil properties of the variables used in the

The soil properties of the vegetation categories are not the same, and the estimation of soil properties is promising.

Classification

Achillea-Festuca

Artemisia-Festuca

Agrostis-Alopecurus

Percent of cases correctly classified

levels of grouping because the most detailed categories are rather complex. Therefore when classified with discriminant analysis, these categories are decomposed.

The chemical properties of the salt-affected soils studied can classify substantially the vegetation categories. However, besides these, there are other important factors that affect the solonchic rangeland of Hortobágy, such as the water regime of the soil. Other authors (Szigmond, 1927; Magyar, 1928; Petrova, 1988) have previously written that the classification of the vegetation should consider the gradients of these two ecological conditions, i.e. the salt concentration and moisture supply. This reasoning lead the way to the traditional classification of dry and humid associations of the solonetz soils of central and eastern Europe. Between the members of the two groups of associations (dry and humid) there are overlaps in the water regime and also in the values of the chemical properties. Therefore these properties do not classify the categories precisely.

Conclusions

This study is a part of a major project that aims to develop and test a cartographic technique for salt-affected landscapes covered by vegetation. This technique, besides keeping costs low and degree of spatial detail high, should provide optimal estimation of the mapped variables. One key operation is the sampling. During the planning of the sampling, three points should be considered: (1) the importance of the recorded and measured variables in the determination of the key properties of the survey, (2) the cost of the sampling and analyses, and (3) the spatial pattern of the studied variables.

The sampling points were arranged on the basis of a satellite image, assuming a very heterogeneous vegetation pattern and that a varying sampling density is needed for the optimal estimation of the surveyed variables. We suggest this method for creating a sampling design for surveying such areas where the vegetation indicates well the surveyed variables and the spatial pattern of the vegetation is very heterogeneous.

The linear combination of the soil variables calculated by discriminant analysis correctly classifies the vegetation for two-thirds of the points. This correspondence makes possible the use of vegetation data and remotely sensed images for the estimation of soil properties. Since the sampling and analysis of the soil properties are more expensive than the vegetation survey or remotely sensed data, the use of the latter data in the quantitative estimation of soil properties applying correlation techniques and coregionalization is promising (Tóth et al., 1991b).

Table 4

Classification matrix of the three categories received with discriminant analysis

| | Actual cases | Predicted category membership | | |
|---------------------|--------------|-------------------------------|-----------|-----------|
| | | AchF | ArtF | AgrA |
| Achillea-Festuca | 48 | 37 77% | 5 10% | 6 13% |
| Artemisia-Festuca | 77 | 5 6% | 55 72% | 17 22% |
| Agrostis-Alopecurus | 81 | 8 10% | 11 14% | 62 76% |

Percent of "grouped" cases correctly classified is 75%. AchF, Achillea-Festuca; ArtF, Artemisia-Festuca; and AgrA, Agrostis-Alopecurus.

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