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Characterization of Semivegetated Salt-Affected Soils by Means of Field Remote Sensing

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Many recent attempts to map soils and related ecological phenomena are concerned with spatial patterns. There is a large diversity of approaches to determine 1) the actual parameters to be measured, 2) the most informative categories to be formed based on them, and depending on both of the above, 3) the sampling locations and 4) the resolution of the map. This paper reports a field remote sensing project to meet the requirements of a detailed botanical and soils survey to understand salinity status of the Hortobágy region in east Hungary. The problem of association-level recognition of land cover is addressed in terms of quantitative description and ground resolution. It is concluded that the most characteristic six to seven vegetation association types are well identifiable based on their TM spectra using discriminant analysis/nonhierarchical clustering with half-meter ground resolution.

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1. INTRODUCTION

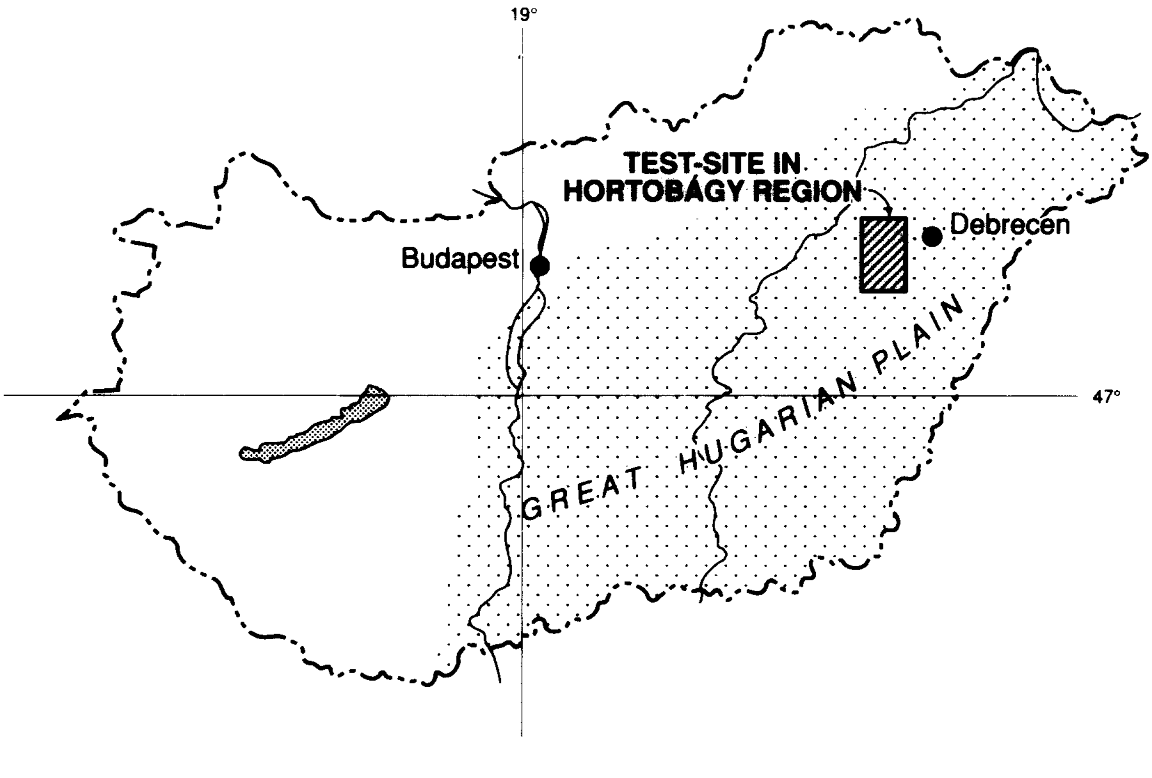
In most parts of the world *salinity* is one of the principal causes of *soil degradation*, with a consequent reduction in biomass production. According to some estimates, salt-affected soils cover as much as 7% of the global land area (Szabolcs, 1979). These soils lie primarily in arid and semiarid regions, but there are also important salt-affected areas in subhumid and coastal zones. Some of the most unfavorable properties of these soils include high salt content, poor structure, limited microbial activity, low percolation rates, low fertility, and other characteristics, which restrict plant growth and human settlement. In many areas of the world, the use of otherwise potentially arable land for agriculture, forestry, and pasture is severely limited because of the salt content of the soils and/or the high ionic concentration of irrigation water. Since the capacity of soils to support plant growth in turn is the product of the interactions of organic and inorganic materials and energy cycles under specific environmental conditions, the practice of sustainable biomass production is impossible without understanding these processes that can lead to adequate technical management.

In Hungary, salinization and alkalization have some specific and/or unique features. There are many types of salt-affected soils because of the evolution of the Carpathian Basin, which has hydrologically closed characteristics rather than arid or semiarid conditions. The source of sodium salts is mainly subsurface water and the dominant forms of salt accumulation are Na_2CO_3 and $NaHCO_3$. The main limiting factor to the productivity of salt-affected soils is closely related to water management, which manifests itself in extremes of excess water (ponds) or drought. These conditions result from a combination of factors, including high clay content, predominance of swelling clays, poor structural conditions, and high sodium saturation on the cation exchange complex. A significant part of the salt-affected soils in Hungary have natural vegetation cover and occur in National Parks with protected ecosystems. However, salt-affected soils under cultivation comprise 10% of the agricultural land of the country. Therefore, the possibility for the characterization of salt-affected soils and processes related to them is of special scientific interest.

During the past several decades scientists in numerous countries have made significant improvements in the capability to characterize, describe, and classify salt-affected soils (Szabolcs, 1981; Bresler et al., 1982). Diagnostic systems have been developed from field and laboratory studies to identify and distinguish soils (U.S. Salinity Laboratory Staff, 1954; Szabolcs et al., 1966; Kovda et al., 1973) and ecosystems (Bodrogközy, 1965). Recently Szilágyi and Baumgardner (1991) reported the use of high resolution laboratory spectral measurements to identify salinity status of soils. Spatial extension of local characteristics has also received considerable attention (Webster et al., 1989; Csillag and Kertész, 1989). Especially these two latter technical achievements are of specific interest here that provide entirely new possibilities for *detailed quantitative regional survey*: field remote sensing and geostatistics.

This paper is the first report on our comparative studies on the characterization of salt-affected soils developed under different conditions. In Section 2 we describe in some detail the Hortobágy region, one of our Hungarian test sites, with natural environmental conditions generalized. Special attention is paid to characteristic variables, diag-

Figure 1. Sketch map of the Carpathian Basin, the Great Hungarian Plain, and the test site.



nostic conditions of plants and soils, as well as to sampling strategy. Then, the possibilities of spectral characterization of salt-affected soils are briefly discussed. In Section 4 our classification results are summarized based on spectral and botanical sampling and statistical analysis. It is concluded that salt-affected soil conditions under natural vegetation is well recognizable in good coincidence with botanical classification of associations.

2. ENVIRONMENTAL CONDITIONS OF THE HORTOBÁGY REGION

Geological and Geomorphological Conditions

The origin of the Great Hungarian Plain (Fig. 1) is closely related to the Alpine orogenesis that led to the formation of the Carpathian Basin around the end of the Miocene (Stegena et al., 1975). In the Pliocene the basin, the Sarmathian (Pannonian) Sea, was reduced to a lake without any outlet. By the end of the Tertiary, this Pannonian Sea and the lakes derived from it were filled up, their sediments becoming covered with those of subsequently formed lakes and rivers, the thickness of the latter layers amounting to several hundred meters in some places. During the Quaternary, the glaciers of the Carpathians did not extend into the Plain; this latter was, however, strongly influenced by the glacial era.

The characteristic soil-forming loess material of the Plain is a product of that period. Water, too, is a decisive factor in the formation of parent material. The kind of loess that was formed under its influence is denoted as lowland loess or infusion loess. During the glacial epoch and in subsequent times the Plain became filled up with river sediments, a process which continues. The Great Hungarian Plain, formed at the end of the Tertiary and in the Quaternary, is rather homogeneous. Its height above the sea level varies from 85 m to 120 m. It is divided into smaller basins occupied by continuous areas of alkali soils. Their height above the sea-level varies in different parts as follows: Danube Valley 95–97 m, Hortobágy 90 m, Nagykunság 88 m, and, along the lower regions of the Tisza River, 80–82 m.

Meterological Conditions

The Great Hungarian Plain is the hottest and dryest region of the Carpathian Basin which is otherwise characterized by temperate climate. In the central region, where our study sites are located, data describing annual averages and dynamism is summarized in Table 1.

Hydrological Conditions

The Great Hungarian Plain is a basin filled up 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 that the different types of salt-affected soils in the Hungarian soil classification system are closely related to distinct groundwater table depths. There are regional differences in the composition and concen-

Table 1. Yearly Dynamism of Some Climatic Parameters in the Central Region of the Great Hungarian Plain

	Monthly Summary												
Parameter	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*Year*
Precipitation (mm)	30	30	28	41	51	71	53	50	34	33	46	46	527
Potential evaporation (pan evaporat., mm)	12	19	40	78	112	136	156	144	106	58	25	14	900
Drought index (p. evap./prec.)	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 temperature (°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

tration of groundwater that resulted in the wide variety of salt affected soils.

Soil Conditions

According to the general 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 which, together with the intrazonal alluvial soils, form a chain of these soil types. According to the difference in parent material, the salt-affected soils of Hungary may be divided into two categories: 1) calcareous sodic alkali soils and 2) noncalcareous alkali soils. The latter, the subject of our studies, is characterized by high clay-content and unfavorable hydrophysical properties, high ESP (exchangeable sodium percentage) and high pH in the columnar B horizon and, as a rule, low salt content. The unfavorable 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, for example, the unequal distribution of the precipitation, the high aridity index, and the high fluctuating saline groundwater, call for a complex approach for improvement.

Groundwater

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

Ecological/Botanical Site Characteristics

Our studies were carried out in Hortobágy, one of the most peculiar European scenes of nature. The almost treeless and flat area (ca. 2300 km^2) is covered by extensive rangelands, marshes, abandoned water courses, fishponds, reeds, meadows, and some woody patches.

The area was filled up in the Pleistocene by ca. 100–200 m thick river sediments and on this sediment approximately 4–5 m of loess or "meadow clay" were deposited. The latter accumulated in the more or less closed lateral courses of the river Tisza. Both materials have fine particles. Hortobágy earlier, in historical times, was regularly inundated by the river Tisza, and had marshy and open forest vegetation with grassland between them. The formation of szik soil (typically solonetz) began probably in the hazelnut period of the Pleistocene era by the concentration of sodium salts transported to the surface layers by groundwater. The area was first deforested and then regulated by building dams and canals, but together with drying the area of the particular salt-affected ("szik") soils extended considerably.

There is an overall tendency in the Great Hungarian Plain that on higher locations there are chernozems, lower meadow-chernozems, while in

Table 2. The Occurrence of the Main Types of Surface Elements, Groundwater Levels, Plant Associations, and Soil Types in the Studied Area (after Varga et al., 1982)

Surface Element	*Erosion Form*	*Association*	*Soil type*
Loess Plateau	No	Cynodonti–Poetum augustifoliae[a]	Meadow chernozem
Grassy lower place	Slight	Achilleo-Festucetum pseudovinae	(Steppizing) meadow solonetz
Wormwoody rangeland	Torn grasscover	Artemisio-Festucetum pseudovinae	Meadow solonetz
Bare spot on lower part	No A horizon	Camphorosmetum annuae	Decapitated meadow solonetz
Bare spot on lower temporary water course	1–2 cm of A	Puccinellietum limosae	Solonchaky decapitated solonetz

[a]Note: in places not severely affected by pasturing the original Salvio-Festucetum sulcatae (loess rangeland) remained.

Figure 2. Characteristic picture of the salt-affected soils in the Hortobágy region, Great Hungarian Plain ("Szikes puszta").

deeper lying sites "szik" soils can be found (Fig. 2). These, together with meadow soils and different alluvial and meadow alluvial soils, form a catena (Marosi and Szilárd, 1968). There is another catena, however, on the salt affected soils ranging from the chernozem of the higher surfaces to the salt-affected meadow soils and marshes as illustrated in Table 2 and Figure 3.

As can be seen now, the determinant factors are the status of both vegetation and soil degradation (surface erosion and pasturing) and also the depth to the groundwater. At the shore lines of former river beds, which may be partly filled, the wall of the bed is continuously eroded away by water resulting from snow meltings and/or heavy spring showers. On higher sites animal or vehicle tracks can initiate the erosion of the material of the A horizon. When the nonsaline A horizon is partly or completely eroded, the conditions change dramatically for plants. Now the roots have to live in a thinner and thinner surface horizon until it is completely eroded. Then the plants can live only on the compact, hard, saline prismatic, or columnar B horizon. These changes are the reasons for having such spatially heterogenous, variable vegetation on these surface formations. Depending on whether there are temporary water flows or not, vegetation is different, because the rare (e.g., 2–3) slow flowing water periods a year can provide sufficient water for a good grassy vegetation. In the depressional spots there is bare soil surface with scarce plant coverage. Disregarding vegetation types of the depressions, marshy areas and following the scheme of Bodrogközy (1965), basically there are four groups of the associations (see also Table 3): 1) Beckmannion = salt-affected meadow with Agrostis alba; 2) Puccinellion limosae = associations of bare salt affected spots; 3) Festucion pseudovinae = salt affected rangeland; and 4) Festucion sulcatae = slightly salt affected rangeland.

3. FIELD SAMPLING

The primary objectives of field sampling were 1) to identify properties to be measured and 2) to

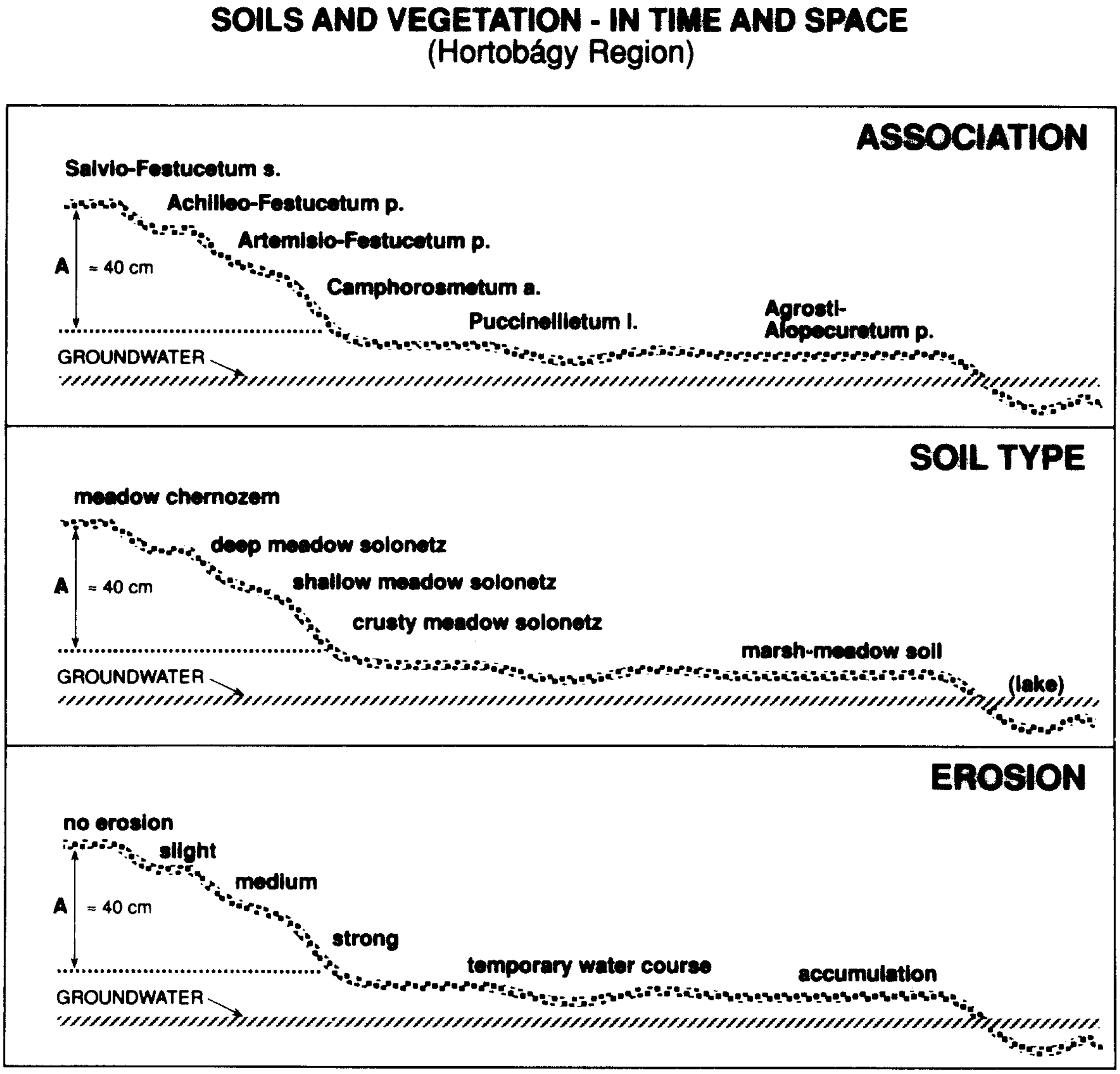


Figure 3. An illustrative summary of the environmental conditions of the study area (see Table 2 and text for details).

determine the most informative categories to characterize our test sites as well as extended regions. Therefore, large amounts of botanical and soil data were collected to set up a kind of standard of "szikes puszta" (salt-affected steppe), a reference in further investigations, spatial extension, and regional mapping.

Two additional technical problems had to be solved during sampling design: 1) sampling locations and 2) spatial resolution. Based on intensive previous botanical studies and reports of spatial heterogeneity (Rajkai et al., 1989a), 50 cm × 50 cm quadrat sampling was carried out along 10–50-m-long transects. Nested sampling design was applied, that is, where sampling locations are clustered by their distances in order to equally cover large and small lags. These values are the result of detailed analysis of variance of vegetation and soil parameters like pH, ESP, salt content, and their geostatistical evaluation, along with large scale aerial survey of vegetation cover as related to 10–200 cm quadrat sampling botanical pilot studies (Rajkai et al., 1989b; Kertész, 1990).

Coenological Data

In order to set up the above-described "standard" characteristics in quantitative terms, very broad groups of environmental attributes have to be taken into consideration. These are summarized in Table 4. With four associations of the toposequence (Fig. 3) in the focus of our interest, the "szikes puszta"

Table 3. Correlation of the Main Types of Vegetation and Genetic Soil Types in the Northern Hortobágy (According to Bodrogközy, 1965.)

Vegetation (Federation, Association)	*Soil Type (Subtype, Variant)*
Beckmannion erucaeformis	Solonetzized meadow soil
Puccinellion limosae	Meadow solonetz
Puccinellietum limosae	Slightly solonchakized crusty meadow solonetz
Characteristic species: Puccinellia limosa, Nostoc commune, Myosurus minimus etc.	
Camphorosmetum annuae	Highly solochakized crusty meadow solonetz
Characteristic species: Camphorosma annua, Matricaria chamomilla	
Festucion pseudovinae	Steppizing meadow solonetz
Artemisio-Festucetum pseudovineae	Moderately leached crustily steppizing meadow solonetz
Characteristic species: Festuca pseudovina, Artemisia santonicum ssp. patens, Gypsophila muralis	
Achilleo-Festucetum pseudovinae	Moderately steppizing meadow solonetz
Characteristic species: Festuca pseudovina, Achillea setacea, Trifolium angulatum	
Festucion sulcatae	Meadow chernozem of higher salinity in greater depth

Table 4. Environmental Attributes of the Salt-Affected Steppe ("Szikes Puszta") (Based Partly on Bodrogközy, 1965)

Major Associations Attributes	*Achilleo Festucetum (A-F)*	*Artemisio Festucetum (ArF)*	*Camphorosmetum (C)*	*Puccinellietum (P)*
Typical phyytogeographic area	Euro-Asian		Pontusian-Pannonic	Pannonic
Typical life form	Hemicryptophyte		Therophyte	Hemicryptophyte
Preference for				
Temperature	Slightly cryotolerant		Thermophile	
Wetness	Dry habitat with temp. waterlogging	Slightly moist habitat	Dry habitat	Indifferent
Soil reaction	Acidic	Slightly acidic	Alkaline	Slightly alkaline
Salt concentration	Halotolerant		Halophile	
Soil Nitrogen	Slightly fertilized		Unfertilized	Slightly fertilized
Total plant coverage (%)	96	90	57	43
No. of species with constancy[a] > 2	15	9	3	5
Species with constancy of 5				
Artemisia maritima	+			
Champhorosma annua			+	+
Festuca pseudovina	+	+		
Kochia prostrata		+		
Poa bulbosa sp. vivipara		+		
Puccinellia limosa				+
Scorzonera cana	+			
Thickness of A horizon	30–50	7–15	0	0–10
Exchangable Na (%) (ESP)	25	41	86	58
pH	7.6	8.6	8.9	9.3
Total salt (%)	0.01	0.12	0.29	0.11
Texture of surface	Loam	Loam	Clay-loam	Clay

[a]Note: Constancy is an integer between 0 (0%) and 5 (100%) showing the relative occurrence of one plant species in a series of survey.

can be characterized as follows. The *Achilleo-Festucetum pseudovinae* is situated in an intermediate position between the higher lying (non-salt-affected) loess-steppe vegetation and the saline spots. The *Artemisio-Festucetum pseudovinae* is the characteristic association of the microerosion plateaus. On the bare spots *Camphorosmetum annuae* is thriving and on the areas with temporary water standing *Puccinellietum limosae* association is found.

There is a close relation between the (genetic) soil type and the plant association dwelling on it. As erosion develops, the relief changes the thickness of horizon A, thus changing the surface properties of soils as well. As a consequence of the different extent of horizon A removal, the conditions for water supply differ much in the different stages of the erosion. For the four types of plant associations the most important species, the ecological characteristics and soil parameters are summarised in Table 4 (species, ecology, soils). There is an overall tendency of decreasing plant diversity and coverage when moving down the slope, though *Puccinellietum 1.* is expected to have generally higher coverage than *Champhorosmetum a.* The ratio of the coverage of the four different types of vegetation in a given area is rather variable, from 1:9:1:3 to 10:2:1:5, etc.

Based on the relative abundancy of the most dominant species in each association the ecological requirements of the associations were expressed based on the weighted ecological requirements of the individual species (Table 4). Comparing the relative requirements for temperature, there is a sharp difference between the high lying associations and the thermophile low lying semivegetated ones. The *Camphorosmetum a.* differs much from the *Puccinellietum 1.* with respect to the requirements for dry/wet soil. As discussed above, the plants of *Puccinellietum* require much water. The *Camphorosmetum annuae* is characterized with very moderate N requirement, but the associations of closed grassland require much higher N. There is a tendency of stronger and stronger halophile character with decreasing N and decreasing height. There is one outstanding association among the associations studied with respect to life forms: The *Camphorosmatum a.*, occurring in the spots of most adverse circumstances are overwhelmingly annual ones.

The idealized scheme must not be thought to be universal not even on the Hungarian alkali soils. When the salt concentration and/or salt composition of the soil is different, there might be other associations involved. However, for the sake of this study, we consider this description as a "standard," and all other sites will be characterized by their deviations. The toposequence presented here can be both a scheme for erosion from *Salvio-Festucetum s.* or *Cynodonti-Poetum a.* to *Camphorosmetum a.* and a scheme for accumulation from *Puccinellietum 1.* through *Artemisio-*

Table 5. Sample Botanical Data of 10-m Transects (with Association Classification, Dry and Total Coverage, and Proportion of Individual Species)

Hortobágy, 26 Apr. 1989, #PL2-transect	1	2	3	4	5	6	7	9	10
Association[a]	Ar	Ar	P-Ar	Ac	Ar	Ar	Ar	Ar	P-Ar
% Total	87	75	82	100	100	85	83	93	97
% Dried	35	20	5	15	10	4	2	2	1
[Cover by species]									
Festuca p.	51	30	3	24	32	19	13	10	3
Artemisia m.	0	0	5	1	0	5	6	7	7
Nostoc. c.	33	36	67	0	0	56	58	69	67
Juncus sp.	1	1	0	0	0	0	2	2	8
Polygonum a.	0	2	7	0	0	1	4	4	0
Agropyron r.	0	0	0	8	7	0	0	0	0
Moss	0	0	0	64	61	4	0	0	0
Trifolium sp.	0	0	0	2	0	0	0	0	0
Camphorosma a.	2	6	0	0	0	0	0	1	6
Puccinellia l.	0	0	0	0	0	0	0	0	6
⋮									

[a]Associations: Ar = Artemisio-Festucetum pseudovinae, P = Puccinellietum limosae, Ac = Achilleo-Festucetum pseudovinae (transient zones are marked with hyphens, e.g., P-Ar = transition between P and Ar).

Festucetum p. to *Achilleo-Festucetum p.* In the end of the succession line stands a forest association of the salt-affected steppes. But since the dry matter of the grass associations cannot accumulate, there is at present no perspective for further succession. The erosion processes are accelerated by thrashing and grazing. As a consequence of the disturbance, species diversity is decreasing.

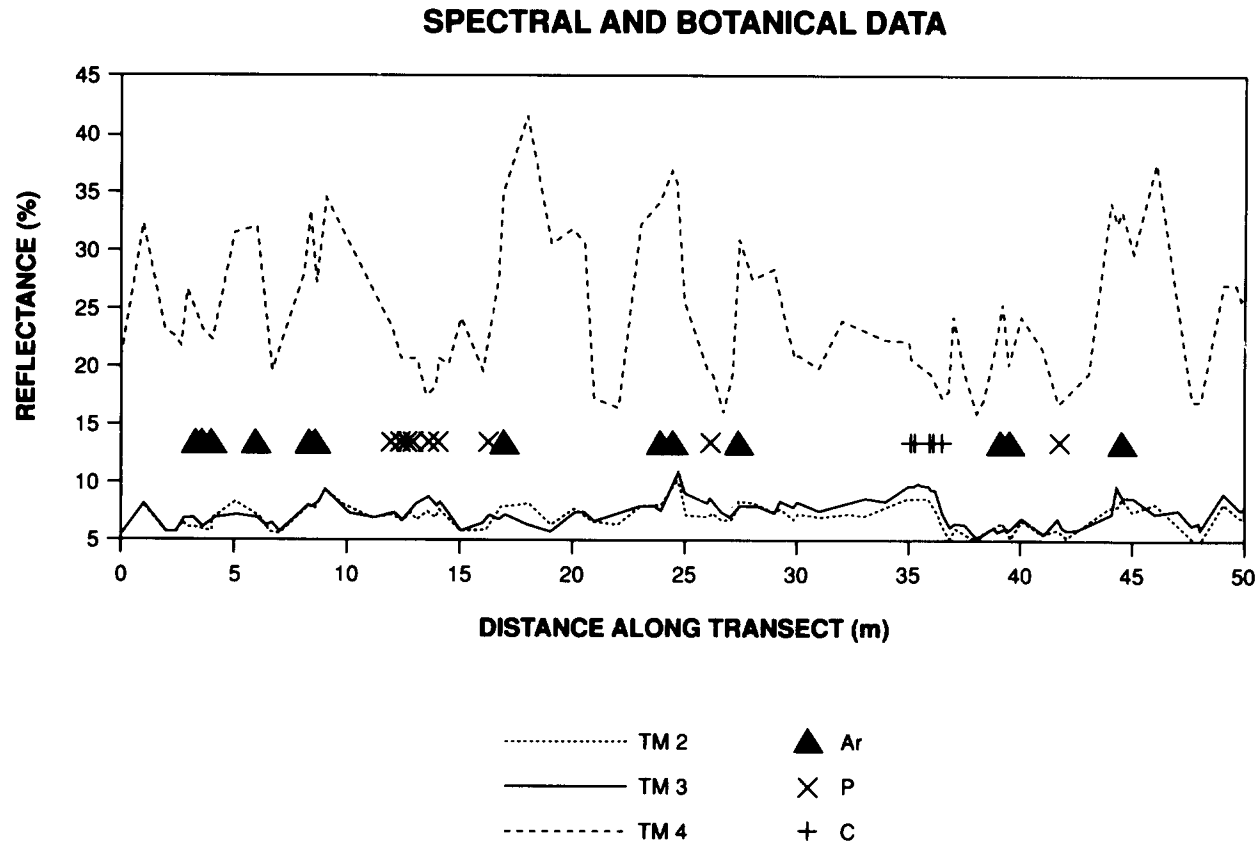
The sampling sites were selected on the basis of representativity, that is, these sites are to represent variations of the parameters that are described above and are subject of subsequent analysis. There were more than 50 locations selected for field sampling, where measurements were completed along transects (Table 5, for example).

Spectral Reflectance Data

Spectral data collection was adjusted to the diagnostic findings of preliminary botanical analysis. For measurements of the reflectance factor an EXOTECH-100 multiband radiometer was used with TM filters [TM1 (450–520 nm), TM2 (520–600 nm), TM3 (630–690 nm), TM4 (760–900 nm)] and a painted barium–sulfate panel was used for calibration (Robinson and Biehl, 1979). At some sites a Barnes eight-band portable spectrometer was also used to cover the whole TM spectrum. In order to collect information from surfaces comparable to botanical samples, the equipment was man-mounted at a height of about 120 cm with 15° field of view. Since collection of spectral data is much less cumbersome that that of botanical ones, spectral measurements were made at not only locations of botanical sampling, but at equidistant 1-m increments along the transect (Fig. 4).

Spectral reflectance was hypothetized to reflect variations of vegetation cover. There is quite a long history in remote sensing of using vegetation as an indicator of environmental conditions (Carnegie et al., 1983; Hardisky et al., 1983). In our case, however, the study focused on a complex phenomenon (i.e., salt-affected soils) at a high

Figure 4. Sample spectral and botanical data along 50 m transect. (there are 105 points all together, of which at 60 sites both data were collected. Three major associations are represented on the figure: Artemisio-Festucetum, Puccinellietum limosa, and Camphorosmetum annuae; their symbols are not scaled on the vertical axis just to guide the eye.)



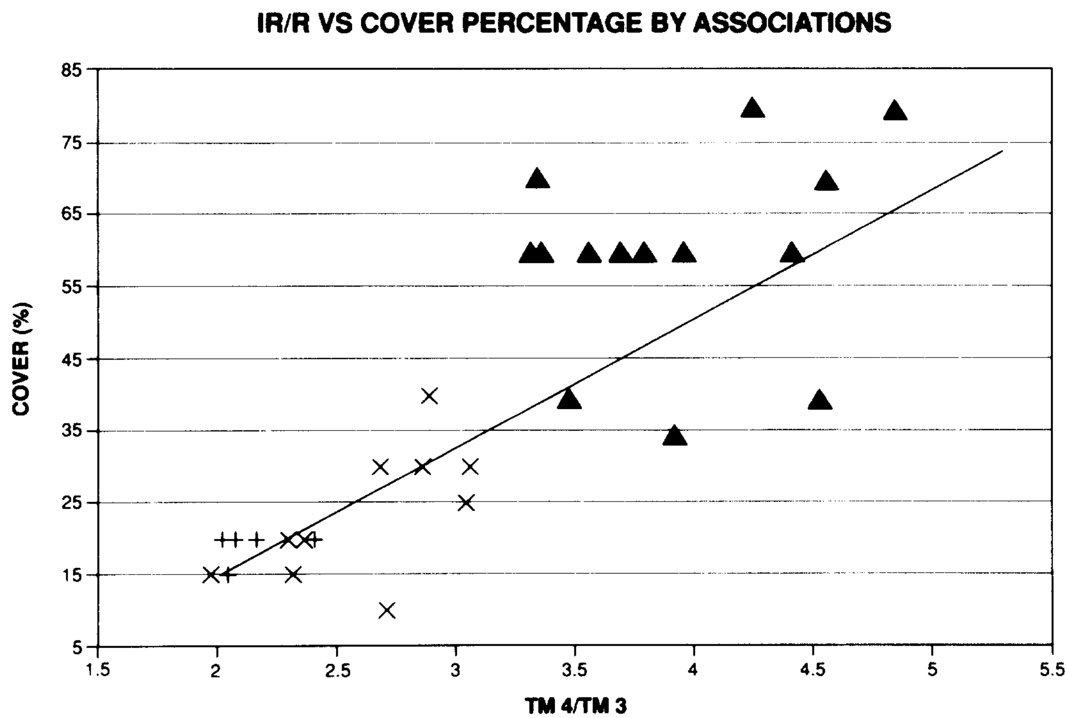
spatial resolution. It is important to emphasize that there is no direct way to derive/deduce regional information from satellite remote sensing data without understanding and formalizing coherent "mixing" rules (Girard, 1982; Jasinksy and Eagleson, 1989; Mark and Csillag, 1989). Calibrated reflectance data were first qualitatively evaluated along transects against botanical (association level) data (Fig. 4). There is no obvious relationship between the occurrence of certain associations, or species, and widely used attributes, like estimated green cover or the infrared/red ratio. Analyzing field data in quantitative terms, however, reveals that quite a good relationship can be found between the occurrence of some given associations, cover percentage, and the infrared/red ratio (Fig. 5).

4. STATISTICAL ANALYSIS AND DISCUSSION

The focal point of "classical" statistical analysis as applied to remotely sensed data is to detect coincidence of spectral and botanical data. In terms of salt-affected soils there is evidence that different salinity status can be recognized by a limited number of spectral bands on bare soil samples (Szilágyi and Baumgardner, 1991). In our case we had to rely on indirect identification. Beyond this obvious issue to be addressed, we are concerned with not only relating spectral and botanical classes, but characterizing a rather complex terrain as well. Therefore, even the number of classes to be used is in question. Below we present our strategy and some illustrative examples.

If one applies clustering on coincident spectral data, there is no *a priori* rule to define the optimum number of spectral classes. Furthermore, there is no direct way to compare the goodness of two classifications with different numbers of resulting classes, because of the different number of the discriminant model parameters. A generalized measure of information, namely the Akaike information criterion (AIC) is proposed here to provide a solution (Akaike, 1973). The definition of AIC is AIC = $-2 \times \ln(\text{maximum likelihood}) + 2 \times$ (number of parameters). The smaller the AIC, the better the classification provided by the discriminant functions. Its estimate can be computed by AIC = $n \times \ln(R) + 2p$, where n is the number of observations, p is the number of estimated param-

Figure 5. Scattergram of infrared/red ratio and cover percentage. (The regression line was computed based on 105 points, while only points representing the three major associations were marked.)



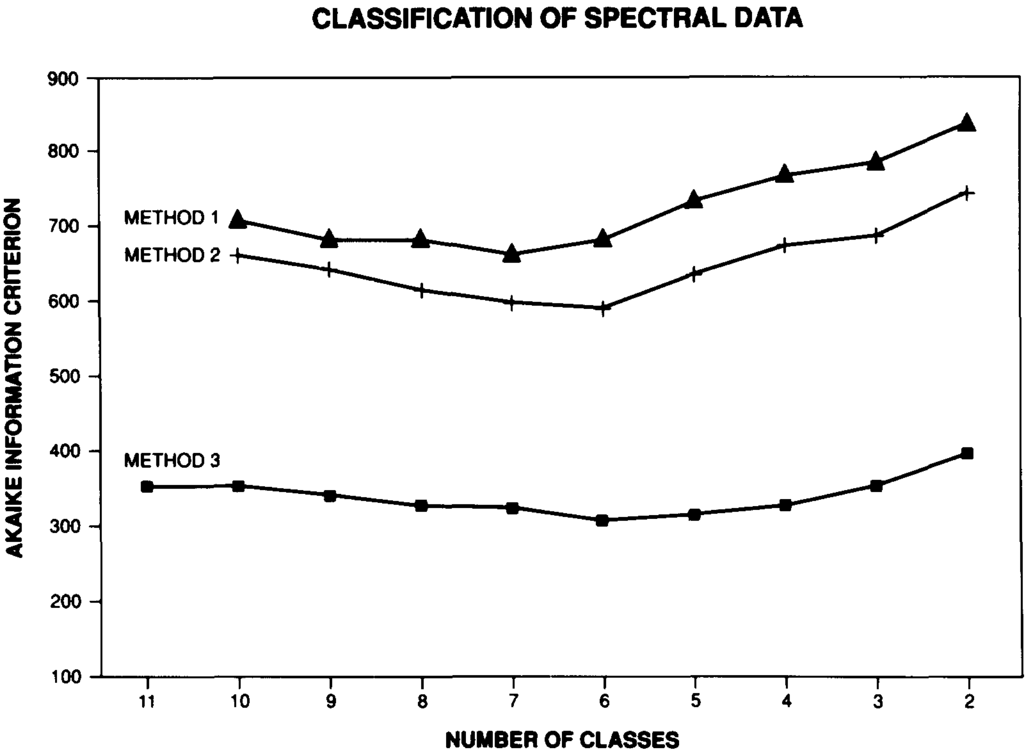


Figure 6. Evaluation of classification results of spectral data measured along 50 transect (60 points). Note for the legend: 1) TM1-4 bands, automatic initialization with 10 classes; 2) TM1-7 bands, automatic initialization with 10 classes; 3) TM1-7 bands, botanical initialization with 11 classes.

eters, and *R* is the residual sum of squares of deviation from the fitted model. Thus we have a statistically relevant criterion for selecting the optimum number of classes besides using, for example, contingency tables and distance measures (like mean or minimum separation) between the resulting classes.

Let us take a sample of 60 points (of a 50-m-long transect) as an example. There were 11 botanical classes determined in the field, but some of them cannot be linked to a unique association. Consequently, it is questionable in statistical terms what number of classes should be used. Nonhierarchical clustering (Anderberg, 1973) was applied

Table 6. Contingency Table of Original Botanical Classification (Vertical Axis) against Six Spectral Classes of Nonhierarchical Clustering, Selected Based on Akaike Criterion[a]

			Output Classes						
Input Classes			*1*	*2*	*3*	*4*	*5*	*6*	*Sum*
Achilleo-Festucetum	(Ar)	1	5						5
Puccinellietum	(P)	2		4					4
Camphorosmetum	(C)	3			11				11
Meadow grass	(G)	4				3			3
	(A-P)	5					9		9
	(P^c)	6	1					4	5
Tall meadow grass	(H)	7				2			2
	(A-C)	8					1	8	9
	(C^P)	9		7					7
	(G-A)	10				2			2
	(G-P)	11				3			3
Sum			6	11	11	10	10	12	60

[a]Note: superscripts indicate massive presence.

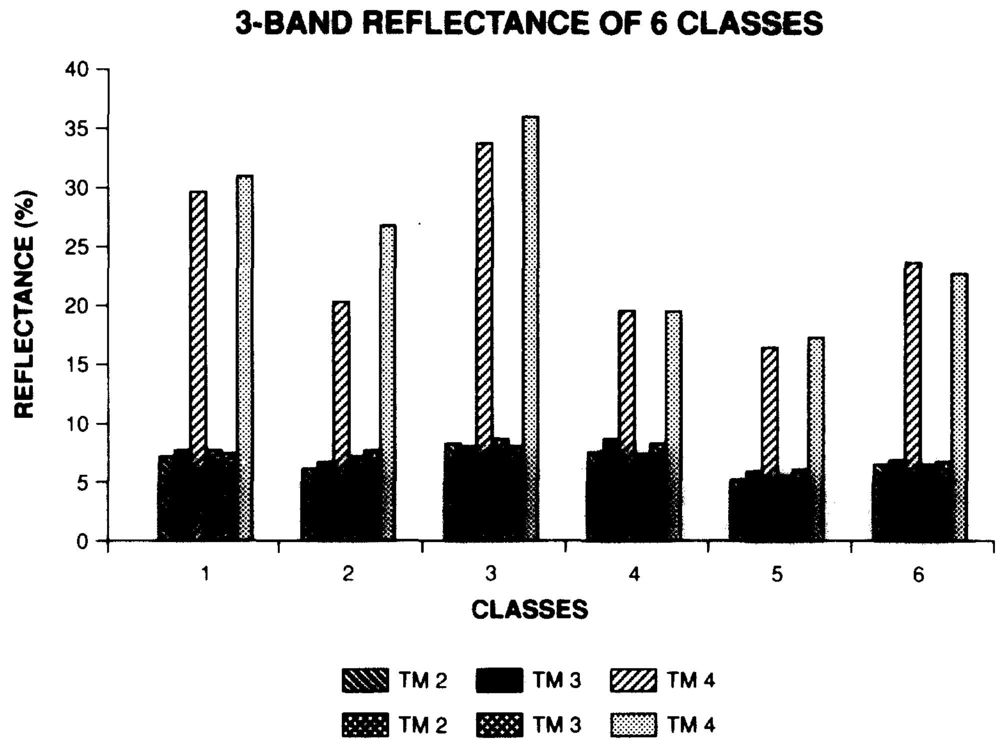
Table 7. Contingency Table of Spectral Classes of Nonhierarchical Clustering Obtained by Botanical Initialization (Horizontal Axis) against Result Obtained by Automatic Initialization (Vertical Axis)

	Output Classes						
Input Classes	*1*	*2*	*3*	*4*	*5*	*6*	*Sum*
1	6						6
2					9		9
3				10			10
4			11		1		12
5		11					11
6						12	12
Sum	6	11	11	10	10	12	60

with optional initialization, using Mahalanobis distance as the feature space metric and with various initial number of classes to search for the minimum value of the AIC (Fig. 6). The classification was based either on the categories defined by botanists (botanical initialization) or only by defining the number of classes to be separated (automatic initialization). Quite consistently, regardless of the initial number of classes and/or the kind of initialization, the minimum was reached at six to seven classes in all of our cases. The analysis of the classification (Table 6) led to further encouraging conclusions, because the contingency table shows that the clustering procedure exhibits class consistency. In other words, this refers to the extent and nature of the hierarchical relationship between the predefined (botanical) classes (Jardine and Sibson, 1977).

The next step of statistical analysis was to test the stability of these classes. That can be performed by examining the contingency table, or distribution of samples along classes obtained by

Figure 7. Three-band mean reflectance of six classes selected based on the Akaike criterion. (Left triplets: class means obtained with botanical initialization. Right triplets: class means obtained with automatic initialization. See also Table 7 and text for more details.)



botanical initialization against automatic initialization (Table 7). Since all elements, with the exception of one, are in the main diagonal, the assignment of samples to six classes can be regarded as being consistent. The final step of statistical analysis in this phase is to test these results beyond "training" data. Taking training data of 60 points of one particular transect against 210 points, rather high degree of stability can be found in the distribution of classes (Fig. 7): Class centers, as defined by means of TM bands, do not shift considerably when taking additional data points into the analysis. Conclusively, the six classes cover the area in space *and* are not only representative, but characterize the measurement space as well.

5. CONCLUDING REMARKS

This paper reports the first phase of our research on the characterization of salt-affected grasslands in Hungary. Based on a complex inventory of environmental attributes, field sampling was designed to collect information sufficient for detailed quantitative regional mapping. Soil, botanical, and spectral reflectance data were measured at approximately 50 representative sites with 50 cm × 50 cm ground resolution along short transects of 10–50 m. In order to map the status of environmental conditions or related processes stable categories were established, primarily based on vegetation associations. Detailed comparative statistical analysis of botanical and spectral data revealed that there is a firm relationship between spectral characteristics of surface cover and their association-level classification. The next phase of this research is envisioned to deal with spatial characteristics of the region and the individual classes. Understanding scenes at various spatial resolutions based on field remote sensing studies can contribute to the improvement of ecological monitoring by means of high resolution satellite remote sensing.

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