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IMPACTS OF ARIDIFICATION ON SOILS AND VEGETATION IN A SAND REGION OF HUNGARY

ABSTRACT: KERTÉSZ A., PAPP S., SÁNTHA A., HUSZÁR T. & LÓCZY D., *Impact of aridification on soils and vegetation in a sand region of Hungary.* (IT ISSN 0391-9838, 1998).

Sand areas are regarded most sensitive to changes in water budget brought about by the aridification of climate. In the paper the sand region of the Kishunság National Park is studied for the sensitivity of soil and vegetation cover to drought. The quickest response to climate changes is expected to be manifested in the hydrological regime, followed by alterations in the composition of vegetation cover, inducing, with some time lag, modified soil processes. The list of the non-arborous flora of the test area was analysed using a range of ecological indices partly developed by Hungarian ecologists. Soil profiles were studied to find traces of a modified water regime and element migration induced by aridification.

The high shares of submediterranean and other xerophilous or drought-tolerant species show that vegetation has already adapted to dry conditions, which has been a concomitant of regional climate. There are two ways of soil formation in the sand region: on dune summits humification to the effect of pioneer associations and in inter-dune hollows the accumulation of fine deposits and soil moisture content are the principal controlling factors. Reduced infiltration and capillary rise endanger exsting water regimes. A positive impact of aridification is local dealkalinisation of sodic soils.

KEY WORDS: Aridification, Sand areas, Hungary.

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Le aree ricche di sabbia sono ritenute molto sensibili ai cambiamenti nei bilanci idrici indotti da un mutamento climatico in senso arido. È stata studiata la regione sabbiosa del Parco Nazionale del Kiskunság nei riguardi della sensibilità del suolo e della copertura vegetale alla siccità. La più immediata risposta al cambiamento climatico è data dall'alterazione nel regime idrologico, seguita da quella nella composizione della copertura vegetale, che inducono, dopo un certo tempo, modificazioni nei suoli. La flora non arborea è stata analizzata mediante uno spettro di indici, parzialmente studiato dagli ecologi ungheresi; i profili dei suoli sono stati studiati per trovare tracce di una modificazione del regime idrologico e di una migrazione degli elementi indotta dall'aridificazione. L'elevata percentuale delle specie submediterranee e xerofile mostrano che la vegetazione si è quasi adattata alle condizioni aride. Per la formazione dei suoli si è visto che i principali fattori di controllo dei suoli sono l'umidificazione delle creste delle dune che favorisce l'instaurarsi di specie pioniere e l'accumulo di sedimento fine nelle depressioni intradunari. Una ridotta infiltrazione e una maggiore capillarità compromettono i regimi idrici. Un positivo impatto dell'aridificazione è la locale dealcalinizzazione dei suoli sodici.

TERMINI CHIAVE: Aridificazione, Aree sabbiose, Ungheria.

INTRODUCTION

In Hungary the meteorological records of the last decades point to an increase of drought hazard and a rearrangement in the monthly distribution of precipitation. On this basis a gradual aridification of climate is assumed with a range of impacts on physical conditions (Kertész & *alii*, 1977).

The sand region of the Kiskunság, a Pleistocene alluvial fan the Paleo-Danube, is one of the areas with the highest radiation balance and lowest annual precipitation in Hungary. Potential evaporation amounts to 870-900 mm, while

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annual precipitations between 530 and 570 mm have been recorded at the meteorological stations. The aridity index (Budyko, 1977) ranges from 1.2 to 1.38. Over 39 per cent of the area blown sand soils are characteristic with less than 40 per cent soil moisture content in the summer. In additon to a significant reduction in the rainfall of the growing season (long-term average ca 330 mm, sinking groundwater levels began to foreshadow environmental changes as early as the last years of the 1970s (Szalai & Lóczy, 1995). This trend is equally reflected in groundwater observation wells and in the shrinkage of water surfaces of alkali ponds primarily fed from rainwater and free groundwater.

Second in Hungary, in 1975 a national park was established in the region of Kiskunság, in order to preserve endangered ecosystems in seminatural blown sand, floodplain and alkali puszta environments with their typical flora and fauna, to maintain traditional animal husbandry of ancient Hungarian breeds and the typical life-styles on scattered farmsteads. The area of the Kiskunság National Park is composed of nine isolated units of various character (fig. 1) and that raises special problems in nature conservation. The heterogenity of these «islands» is primarily due to different geological, geomorphological, hydrological and pedological properties (Tóth, 1985, 1996). The prevailing landforms of this blown-sand area are rows of dunes. Another typical feature is a mosaic of alkali flats, resulting from high groundwater table and the extremely high salt contents of groundwater. Adjusted to the ecological conditions created by the above influences, a biota of particular composition and dynamics is also characteristic. In spite of all this variation there are common characteristics for the entire National Park, which allow general conclusions:

– The extreme water budget of sand areas bring about vegetation types of special composition and in unstable balance with their environment. This means that vegetation reacts very sensitively to changes in the ecological conditions of sand areas (climatic or man-induced changes) through altered species compositions and individual numbers.

– Changes in groundwater table in alkali flats or in the amounts of water stored in alkali ponds are immediately reflected in the altered dynamics of water-soluble salt migration and accumulation. Thus, along with vegetaton also influenced by them but showing a lag in reaction time, salt dynamics are among the most sensistive indicators of environmental change.

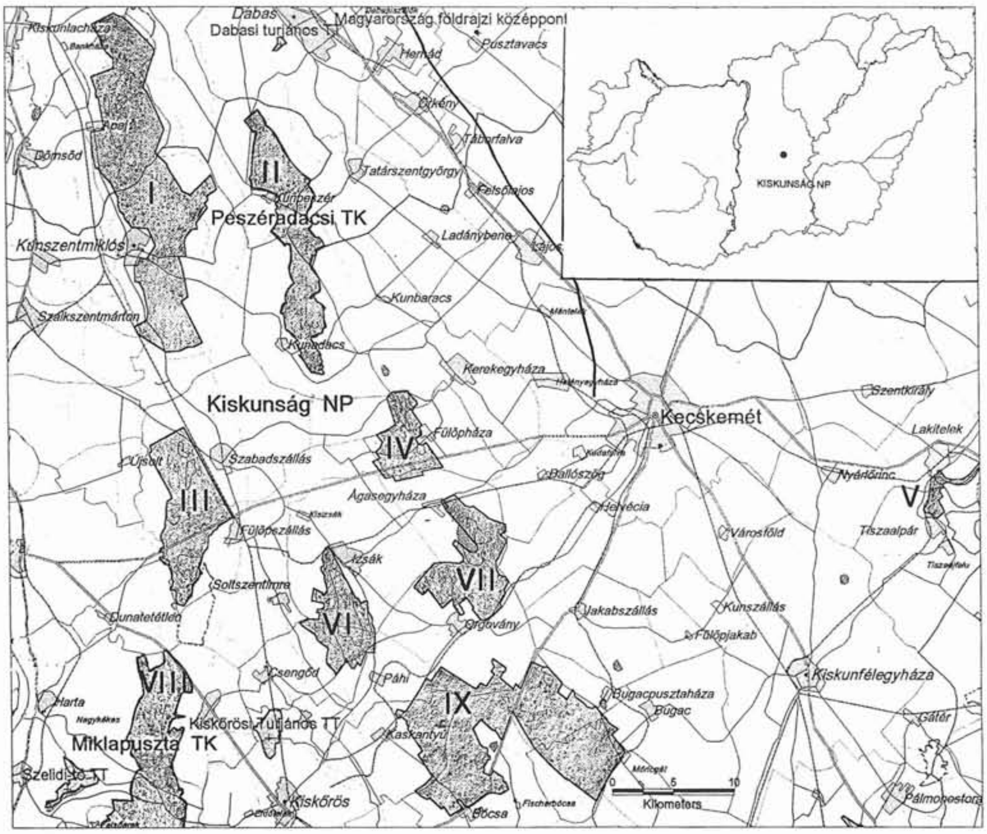

FIG. 1 - Protected areas in the Kiskunság National Park, Central Hungary. - I-IX = units of Kiskunság National Park; TK = protected landscapes (integrated in the National Park); TT = nature reserves.

THE PHYSICAL ENVIRONMENT

Detailed geological-hydrogeological, pedological and botanical-zoological investigations have revealed the main features of the physical environment. The findings were published in voluminous monographs (Hung. Ac. Sc., 1980; Tóth, 1985; Szujkó-Lacza & Kováts, 1993).

Among the partial areas of the National Park, Fülöpháza sand dune area (19.92 km^2; IV in fig. 1), which is still characterised by shifting sand locally, while elsewhere sand is fixed by open grassland on sand soils (*Festuca vaginata, Stipa borystenica* with sporadic junipers) and by plantations, seemed to be an optimal test area to study vegetation change, since here the most widespread environmental types occur next to each other.

The major types are sand areas of the alluvial fan built by the Paleo-Danube and flat-floored hollows of various size.

This is the only region in Central Europe with locally shifting sand, while in interdune hollows and on wind-sheltered dune slopes advanced stages of sand grasslands succesison and in habitats with the most favourable endowments patches of arborous associations (Szodfridt, 1991) also occur (naturally disregarding planted forests). Dunes offer various microhabitats: summits and southern slopes exposed to strong radiation, of extreme microclimate, with open sand grasslands and humic sand soils of shallow profile, liable to drying out quickly; more equable, cooler and moister northern slopes and western and eastern slopes of transitional character.

Flat-floored hollows of various size, one often associated with alkali ponds (Molnár & Murvai, 1976; Várallyay, 1967). Some decades ago hundreds of alkali ponds could be surveyed. As a consequence of dropping groundwater table (induced by climate and human intervention), however, more than half of them are dry now. Thus on floors soil dynamics change entirely and new conditions for plant growth are created. As microhabitats, hollows are characterised by favourable moisture conditions, equable microclimate, closed grass (occasionally tree) vegetation and soils of deeper profile (occasionally of multiple horizon).

MICROCLIMATE MEASUREMENTS

In order to provide a precise description of local ecological conditions, in October, 1955, 24-hour microclimate measurements were made at five sites representing different microhabitats (fig. 2). At the stations temperature was mesaured at 100 cm and 20 cm above the soil surface, on the soil surface and in the soil, 15 cm below the surface. Evaporation was recorded at 100 cm and 20 cm height and wind hourly at 100 cm.

The range of temperature was found greatest on the ground surface or at 20 cm height, but exposure and vegetation cover caused remarkable variation. An exception was a closed depression with uninterrupted grassland, where the accumulation of cold air reduced temperature range. Minimum temperature range occurred in the soil and maximum values, as expected, on the summit with incomplete vegetation cover and on the almost barren southern slope. The amount of evaporated water was largest at 100 cm height and also depended upon temperature and wind conditions. Wind conditions indicate a wind channel effect among dunes.

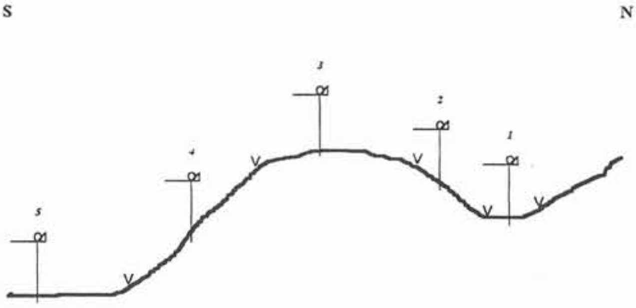

FIG. 2 - The microhabitats studied near Fülöpháza (by PAPP S.) 1) interdune hollow of higher elevation; 2) northern dune slope; 3) dune summit level; 4) southern dune slope; 5) larger interdune hollow of lower elevation; v) boundary of microhabitats.

EVALUATION OF VEGETATION COVER

A rather confined test area with five homogeneous microhabitats has been selected in the rolling sand region, where all of the microforms (dune summits, slopes of various exposure, interdune hollows etc.) and every succession stage typical of the region are represented (fig. 3). In order to reconstruct the seasonal changes of plant associations in the various stages of succession, cenological surveys were performed. For each microhabitat two test squares of 5 m times 5 m size were delimited (altogether ten).

The prevailing vegetation type consists of grass associations typical of the calcareous sand of the Danube-Tisza Interfluve. Arborous vegetation is of subordinate importance: smaller white poplar (*Populus alba*) and common juniper (*Juniperus communis*) groves are only colouring elements in the landscape. Locally *Robinia pseudoacacia, Ailanthus altissima* and *Asclepias syriaca* also occur, indicating local disturbance.

From the information collected during a field survey, the list of plants was first analysed for thermal conditions (T value) (Ellenberg, 1973; Zólyomi & Précsényi, 1964; Zólyomi & *alii*, 1967).

The percentage distribution of water budget (W) values (fig. 4) spectacularly prove the arid character of the study area and typical of water demands of plants in all the

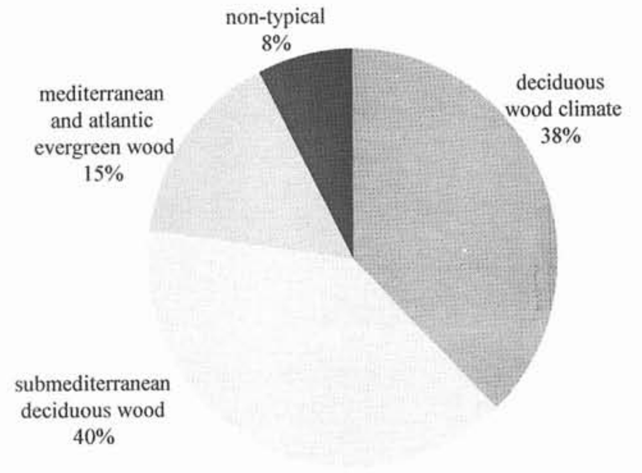

FIG. 3a - Distribution of flora by thermal index values (T) in the Fülöpháza study area (by A. Sántha).

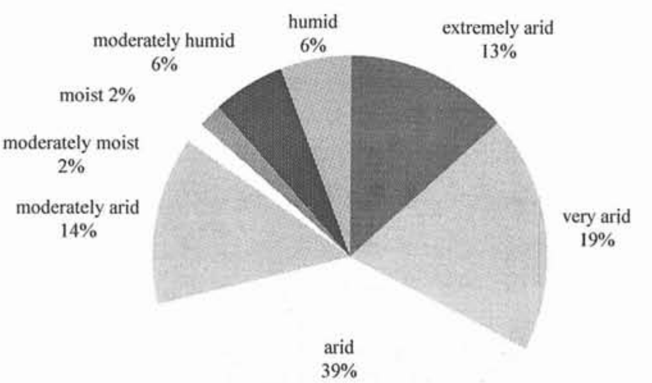

FIG. 3b - Distribution of flora by water index values (W) (by A. Sántha).

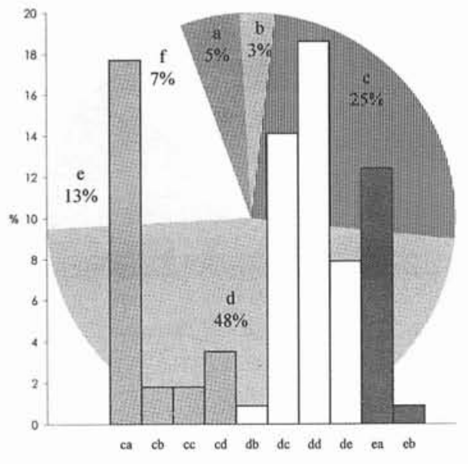

FIG. 3c - Main groups of flora by nature conservation value a) adventive group, b) cosmopolitans, c) European group, d) continental group, e) mediterranean group, f) endemic (Pannonian) group, ca) Eurasian, cb) European, cc) Central European, cd) Circumpolar, da) continental, db) Pontian, dc) Pontian-Mediterranean, dd) Pontian-Pannonian, de) Turanian, ea) Submediterranean, eb) Balkanic (by A. Sántha).

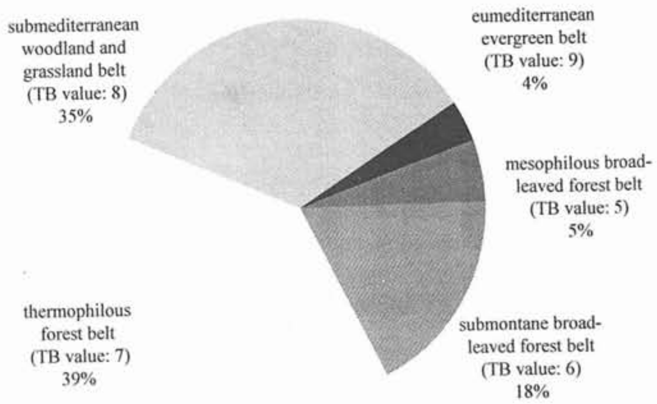

FIG. 3d - Distribution of flora by relative heat demand demonstrated by the thermal climate of vegetation zones (TB values) (by A. Sántha).

sand regions of the Carpathian basin. More than 80 per cent of all surveyed species indicate an arid habitat. The proportion of species pointing to wetter-than average habitats (11.6 per cent) corresponds to that of interdune hollows.

Evaluating the natural character of the study area, an index of nature conservation value was applied (Simon, 1988; fig. 5). Based on late summer-autumn aspect, the species found in the area are mostly indicative of natural conditions (66.7 per cent), the ratio of species showing disturbace or degradation (33.3 per cent), however, is also high.

The distribution of floral elements shows that in the study area species of the continental group predominate. Mediterranean and Pannonian (endemic) species are relatively abundant, but the shares of adventives and cosmopolitans are negligible. If the Pontian-Mediterranean elements are classed with the continental group, the Mediterranean character is even more pronounced.

TABLE 1 - Distribution of floral elements by nature conservation value in the study area (per cent)

a		*adventive group*	4.4	
b		*cosmopolitans*		2.7
c		*European group*	24.8	
	ca	Eurasian		17.7
	cb	European		1.8
	cc	Central European		1.8
	cd	Circumpolar		3.5
d		*continental group*	47.7	
	da	continental		6.2
	db	Pontian		0.9
	dc	Pontian-Mediterranean		14.1
	dd	Pontian-Pannonian		18.6
	de	Turanian		7.9
e		*Mediterranean group*	13.3	
	ea	Submediterranean		12.4
	eb	Balkanic		0.9
f		*Endemic (Pannonian) group*	7.1	

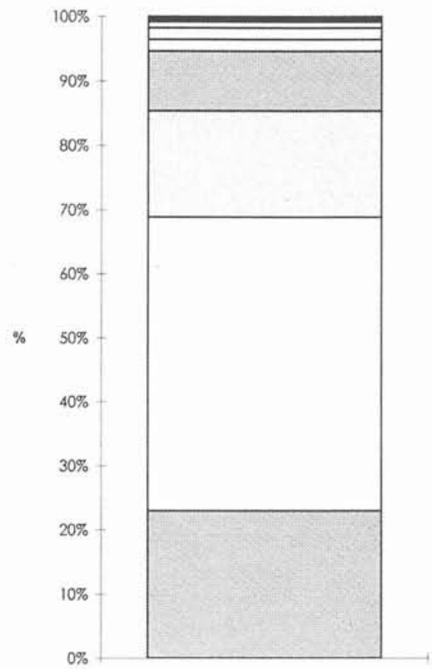

FIG. 4 - Distribution of flora by water budget (WB values). 1) Plats of wet soils tolerating short waterlogging (WB value: 8); 2) Plants of wet soils not drying out and well aerated (WB value: 7); 3) Plants of moist soils (WB value: 6); 4) Plants on semihumid habitats, under intermediate conditions (WB value: 5); 5) Plants on semiarid habitats (WB value: 4); 6) Xero-tolerants, but eventually occuring on moist soils (WB value: 3); 7) Xero-indicators on habitats with a long dry period (WB value: 2); 8) Plants of extremely dry habitats of bare rocks (WB value: 1) (by A. Sántha).

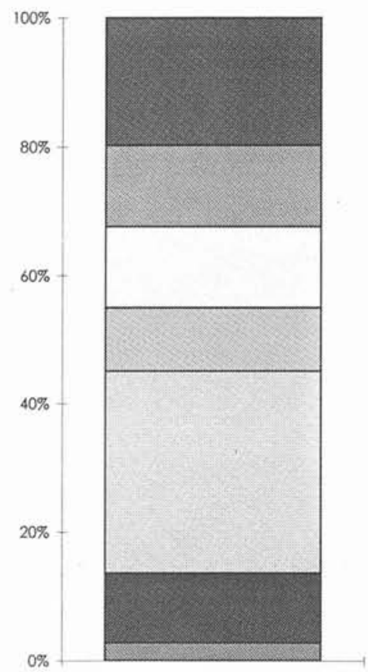

FIG. 5 - Distribution of flora by continentality (CB values). 1) subcontinental species, main area in Siberia and Eastern Europe (CB value: 9); 2) continental species only reaching the eastern part of Central Europe (CB value: 8); 3) continental-subcontinental species, main area in Eastern Europe (CB value: 7); 4) subcontinental species, main area in eastern Central Europe (CB value: 6); 5) intermediate types with slight suboceanic-subcontinental character (CB value: 5); 6) suboceanic species, mainly in Central Europe but expanding eastwards (CB value: 4); 7) oceanic-suboceanic species, area in whole of Central Europe (CB value: 3) (by A. Sántha).

In another approach, another group of ecological indices (Borhidi, 1995) was used for describing relative heat demand interpreted by the thermal climate of vegeation zones (TB values, scale: 1-9, tab. 1; fig. 6); relative groundwater and soil moisture (scale: 1-12, fig. 7) and continentality, i.e. the tolerance of species to climate extremities (scale: 1-9, fig. 8).

The high ratio of TB 8 category in the distribution by thermal balance reflects a pronounced mediterranean character, while WB values unambiguously show a dry character: the ratios of WB 1, WB 2 and WB 3 category species together amount to 80 per cent. The relatively most frequent WB 2 category indicates an intensive Mediterranean influence. Although the CB categories point to a continental character in the region, transitional nature is indicated by the high ratio of species in the CB 5 category.

From the investigation of vegetation in the test squares in the Fülöpháza sand dune region it is claimed that in this area (and in the broader environment) the typical continentality is accompanied by a remarkable (sub)mediterranean character. A possible explanation to this phenomenon could be aridification induced by global warming.

SOIL DYNAMICS

The calcareous sand of the Danube forms dunes in a rolling landscape of realtively high relief. Today, however, deflation is only active over some tens of square metres of the area. The shift of wind-blown sand was stopped by the expansion of vegetation. The decompositon of organic matter produced humus in sufficient amounts to make the individual quartz grains more coherent, sometimes in only some centimetres thickness, and stabilise sand movement. This is the origin of humic sand (tab. 2), a characteristic soil type of dune summit levels in the Danube-Tisza Interfluve (including the Kiskunság National Park). Some summits are still covered by blown sand or blown sand veneer.

A more complicated soil formation produced soils in the depressions, interdune hollows and flats (tab. 3). Locally, a hydromorphic (or often alkali) influence was also present, since groundwater table was closer to the surface. Frequently, multi-layered soils (humous horizons buried under blown are sand) are also found. Disgregarding salt-affected horizons, on the whole, hollows have more favourable ecological conditions and give rise to the development of a more closed vegetation richer in species.

TABLE 2 - Description of soil profile n° 4

environment: southern dune slope; *slope*: 12 to 17 per cent
vegetation: open sand grassland
depth of profile: 90 cm
depth of humous layer: 20 cm (very slightly humic)
soil type: humic sand with shallow humous horizon
FAO soil type: ochric arenosol

genetic horizon	*depth (cm)*		$CaCO_3$
A	0-20	10YR 5/6 moist, coherent medium grained sand without structure	+++(+)
C	20-(90)	2,5Y 5/5 moist, apparently homogeneous medium-grained sand	++(+)

TABLE 3 - Description of soil profile n° 5

environment: on the floor of the lowest-lying interdune hollow of the study area; flat surface
vegetation:closed, dense grass with sporadic shrubs
depth of profile: 95 cm
depth of humous horizon: 10 cm
genetic soil type: double layered humic sand under hydromorphic influence from two directions
FAO soil type: arenosol with double ochric (slightly gleyic) horizon

genetic horizon	*depth (cm)*		$CaCO_3$
A_{lh1}	0-10	10YR 3/2 crumbling fine sand with poor structure; dense network of shrub and grass roots	++
A_{lh2}	10-20	2,5Y 4/4 loose fine and without structure, with numerous small rust spots.	+++
A_{foss}	20-33	10YR 4/2 buried humous horizon; compact, slightly gleyic fine sand without structure, with rust veins along spots.	+++ (+)
C_1	33-63	pale yellow matrix mostly with gleyic, subordinately with rust spots, iron veins along roots, fine sand without structure	++++
C_2	63-(95)	see above; variegated colour primarily due to rustiness here. Fine sand without structure	++++

TABLE 4 - Basic laboratory analyses of representative soil profiles

depth (cm)	$CaCO_3$ *(%)*	*Humus (%)*	*pH* (H_2O)
Profile 4			
0-20	9.5	0.21	7.3
20-40	13.4	0	7.4
40-60	10.8	0	7.6
60-90	9	0	7.5
Profiles			
0-10	7.7	3.23	7.6
10-20	8.5	0.21	7.6
20-33	12.5	1.55	7.7
33-63	13	0	7.7
63-95	13	0	7.7

The description and laboratory analyses of Profile 4 exemplify soils on just stabilised dunes. The humus content of A horizon in only 0.21 per cent and an overwhelming part of this humus clearly concentrates in the uppermost layer. The humus was produced by an interrupted sand grassland of incomplete (20 to 25 per cent) cover. This is a pioneer association, representing the first stage of vegetation over surfaces of extremely adverse conditions (strongly exposed to radiation, sand substrate of excellent infiltration and poor water retention capacity and containing only traces of mineral colloids [clays] - tab. 5).

In an interdune hollow of lower position (Profile 5) entirely different conditions of soil formation unambiguously controlled by landform are observed. The genetic soil type on the floor of this interdune hollow is double-layered humic sand under hydromorphic influence from two directions. In its formation the accumulation of soil deposit and a hydromorphic influence (indicated by a buried A horizon at 20-33 cm depth and rusty-gleyic sposts and marble fabric in the subsoil) are of primary importance. Interpreting the results of mechanical analysis (tab. 4), the relatively high proportion of clay fraction not easily transported by wind (see tab. 2) suggests that at least part of the deposits

TABLE 5 - Grain size distribution

depth, cm	*grain size classes (mm)*									*Texture*		
	<0.002	0.002-0.005	0.005-0.01	0.01-0.02	0.02-0.05	0.05-0.1	0.1-0.2	0.2-0.5	0.5<	clay	silt	sand
											weight %	
Profile 4												
0-20	0.4	0.2	0.2	0.1	0.3	3.6	38.4	56.2	0.6	0.6	0.6	98.8
20-40	0.3	0.1	0.2	0.1	0.4	3.2	42.4	52.2	1.1	0.4	0.7	98.9
40-60	0.2	0.1	0.2	0.2	0.3	3.3	41.1	54.0	0.6	0.3	0.7	99.0
60-90	0.5	0.1	0.3	0.2	0.8	5.5	45.7	46.3	0.6	0.6	1.3	98.1
Profile 5												
0-10	4.5	0.9	0.2	0.2	1.8	16.4	56.3	19.3	0.4	5.4	2.2	92.4
10-20	1.5	0.6	0.3	0.3	0.5	5.5	52.2	38.2	0.9	2.1	1.1	96.8
20-33	4.6	1.0	0.4	0.5	1.1	20.9	49.1	20.3	1.9	5.6	2.0	92.2
33-63	4.0	0.5	0.3	0.4	1.4	17.4	59.2	16.3	0.5	4.5	2.1	93.4
63-95	0.5	0.3	0.2	0.2	0.4	12.4	64.8	21.0	0.2	0.8	0.8	98.4

found on the hollow floor has been eroded from slopes by water, although, compared to infiltration, runoff is generally of subordinate role in sand areas. From the viewpoint of climatic it should be noted that the role of capillary action has been reduced in soil formation.

The higher proportion of fine fraction, favourable moisture conditions and equable microclimate promoted the development of more closed vegetation richer in species. (In the square on the hollow floor cover is 100 per cent and, naturally, reduces to 75 per cent in the sampling square on the marginal slopes.) Accordingly, a significantly higher humus content is characteristic of both the recent humous horizon (3.23 per cent) and the buried A horizon (1.5 per cent).

CONCLUSIONS

The mosaical landscape pattern of the sand regions on the Danube-Tisza Interfluve has developed partly as a consequence of various landscape-forming factors and partly to the effect of spatially and temporally interacting human activities (grazing, cultivation, dropping groundwater levels induced by drainage measures).

As a primary landscape factor the sand substrate is identified. Its particular properties (relatively large, individual quartz grains, a considerable void ratio, the virtual absence of inorganic colloids and, consequently, large-scale mobility of constituents) allowed the formation of a rolling, minutely dissected, unique, mosaical topography by wind action. The topography controls the mosaic of ecotopes.

According to position or exposure, microclimatic influences produce ecotopes with more-favourable-than-average conditions on the sand surface (northern slopes of equable microclimate, i.e. cooler and moister environments and dry summits and southern slopes exposed to intensive radiation and an extreme range of temperature).

Deeper-lying landform elements (blow-outs, wind furrows, floors of intendune hollows) are in positions closer to ground-water table and its capillary zone and, at the same time, they are localities of accumulation of cooler and moister air. In addition, they are sites attracting surface water and the borne finer sediment. Therefore, microclimate here is more favourable and moisture conditions are significantly better than in their higher-lying environs.

Natural vegetation obviously adjusts to the mentioned regularities and is the best indicator of ecological conditions. The above outlined mosaic of habitats is occupied by plants associations of corresponding ecological demand (species composition and appearance). From the so-called open sand grasslands of low cover percentage in the most adverse habitats to closed grasslands and occasionally even to arborous associations (open or closed *Convallario-Quercetum*) spatial succession form. The originally well-distinguishable plant associations of the rolling sand areas are shifting closer together (eg. the open Junipero-Populetum association of dry dune summits and slopes «wander» into the interdune hollows to «follow» groundwater).

In additon to the continental character of vegetation, an intensive and ever intensifying (sub)mediterranean influence is confirmed from the analysis of ecological indicators. Although, associations are well-adapted to drought conditions, stronger aridity may bring about a impoverishment in the flora of the Kiskunság National Park.

Locally observable interactions between landscape factors control soil formation. In the expansion of grassland over barren dune sufaces, the «microstratification» of sand (i.e. number of intercalations of finer sediments of better water retention, depth of their occurrence, their thickness) is of primary importance, since soil formation proper occurs on already stabilised dunes when overgrown by vegetation. With the gradual desiccation of alkali ponds of various size, the direct contact between groundwater and salt-affected soils is interrupted, the solonchak soil dynamics ceases. Even leaching may ensue and the sodium salts previously accumulated in the soil profile are transported by rainwater (available in sparse but sufficient amount) along cracks into the subsoil or into the groundwater now occuring at lower level (dealkalinisation). Evidence for dealkalinisation is supplied by the spreading of non-halophilous pioneer associations over dry pond floors.

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