Soil properties and vegetation on saline-sodic soil in the Nature Reserve Mostová

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Abstract

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The objective of this study was soil-oriented and phytosociological characterization of the saline area in the Nature Reserve (NR) Mostová located in the north-western part of the Danube lowland, Slovakia. A soil pit was trenched into the salt pan covered by a degraded community of *Camphorosmetum annuae*. The community occupying the most salinized plots was fairly frequent in the past, today, however, it is very rare in Slovakia. Soil morphology, physical and chemical parameters were analysed for the whole soil profile containing salt pan, and the chemical properties also for humus horizon (SAe) under the saline growth. We have found that the studied soil was compacted and it had unfavourable aggregate composition of SAe horizon. Aggregate disintegration could be due to prevailing Na^+, which moreover caused a strongly alkaline reaction. Capillary raise of water was documented by dynamic of carbonates, percentage of water-soluble salts and colloids, the amount of which increased in topsoil. The results showed 3 times higher content of NaCl, 1.7 times higher electrical conductivity, 1.5 times higher sodium adsorption ratio, 1.3 times higher exchangeable sodium percentage (ESP) and by 0.6 higher pH values in the SAe horizon containing salt pan compared with SAe horizon under the saline growth. The humus content and quality was low. Based on pH values (ranging 10.57–9.91), ESP (58.7–43.0%) and electrical conductivity of solution (7,000–4,200 $\mu S\ cm^{-1}$) we classified the studied soils as Sodic Solonchacks. The obtained results can contribute to better knowledge on ecology of saline soils in Slovakia and the Danube lowland.

Key words

phytosociological characterization, salt pan, pH, ESP, conductivity, humus

Introduction

Alkaline and salt-affected soils are found on more than half of the Earth's arable lands. They dominate most arid and semiarid regions of the world. Most alkaline and saline soils, however, are not used for agriculture. Their native vegetation provides a variety of wild plants, which, along with their native animals, contribute greatly to biological diversity (Brady and Weil, 1999).

Generally, halophyte biotopes belong to the most endangered biotopes in the whole Europe, therefore the European legislative has ranked them to the important biotopes of prime category (Sádovský et al., 2004).

Some of the most unfavourable properties of salt-affected soils include high salt content, poor structure, limited microbial activity, low percolation rates, low fertility and other characteristics, which restrict plant growth and possibilities for human settlement (Tóth et al., 1991).

In Slovakia, the saline soils are located mainly in lowlands of south and east Slovakia and their acreage was around 30,000 ha in year 1958. Extensive melioration of agricultural soils and regulations of watercourses done in years 1970–1980 prevented continuing salinization process and the acreage of saline soils distinctly decreased (Remiš et al., 1981). Nowadays, the acreage of saline soil is only 4,890 ha of agricultural soil (Bielek, 2004).

Quantifying the interrelationship between soil and vegetation in solonetzic grassland is useful for making an inventory of natural resources; and the occurrence of plants can give quantitative information on the soil properties. The vegetation indicates sharp differences in the status of soil in terms of degradation and in the chemistry of the groundwater (Tóth et al., 1994).

Since soil properties considerably influence plant growth and species composition, and correspondingly, plant cover strongly affects soil forming process and soil chemical, physical and biological characteristics, the aim of the work reported here was soil and phytocenological characterization of the saline area in the Nature Reserve (NR) Mostová.

Material and methods

The NR Mostová is located in the north-western part of the Danube lowland (48°09' N; 17°41' E), altitude 116–118 m. The climate is continental, with an average annual temperature of 10.2 °C and annual precipitation of 539 mm (Špánik et al., 2002). Flat relief was formed by alluvial action of Dudváh and Čierna Voda rivers. The parent material consists of clay, carbonate clay, sandstones, rubble sand or gravel, and it is covered with carbonate sediments of the Danube river: loamy sand, loam, sand and gravel. Groundwater level is deeper than 1.5 m, but capillary rise of water in texturally finer soil reaches topsoil (Linkeš, 1963). On chosen locations of Mostová, the third and fourth degree of landscape protection has been legally recognised. The area is proposed to be protected in frame of the Special Areas of Conservation because its inland saline soils and salty grasslands are important biotopes, and because protection of the species of European importance: *Rhodeus sericeus amarus* and *Lutra lutra* (Anonymous) is necessary.

The phytosociological relevé was carried out according to the Zürich-Montpellier approach using the adapted Braun-Blanquet's scale (Barkman et al., 1964). The nomenclature of flowering plants follows Marhold and Hindák (1998) and the names of syntaxa are according to Molnár and Borhidi (2003).

A soil pit was trenched in the salt pan of saline meadow. The front of soil pit extended into the part of soil containing salt pan on the top and the pit edges into the saline growth. Soil morphology, physical and chemical parameters were analysed for the whole profile of soil containing salt pan. To compare the chemical properties of saline soil containing salt pan with the soil under vegetation, it was collected also a soil sample from humus horizon under the saline growth (in 0.3 m distance from the salt pan).

The soil samples were analysed for the following properties: soil reaction – potentiometrically in H_2O and 1 mol dm^{-3} KCl; exchangeable base cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) (Sotáková et al., 1988), carbonates – volumetrically (Čurlík et al., 2003), water soluble salts content by gravimetric method (Hanes et al., 1995), electrical conductivity – Conductometer S ATC 3120A (Hanes et al., 1995), chlorides in water solution (Hanes et al., 1995), total soil organic carbon (C_T) – by Tyurin method (Orlov et al., 1981), humus fractionation – by Kononova-Belchikova method (1961); spectral analyses of humus substances (HS) and humic acids (HA) – 6400 Spectrophotometer (Jen Way).

Basic physical and hydrophysical parameters (Hanes et al., 1995) were determined to the depth of 0.8 m. Soil texture was determined by pipette method (Hanes et al., 1995).

Each analyse was done in 3 repeats, and in this paper we report the average values.

Results and discussion

The well-preserved mosaic of saline vegetation was developed in the studied locality by the end of the last century. All area of these saline meadows was grazed – which insured conservation of the vegetation cover (Svobodová and Řehořek, 1992). Later, the site was abandoned and negative processes of secondary succession started (biomass accumulation, draining, ploughing etc.). A moment ago, the sub-saline vegetation of *Festucion pseudovinae* predominated and a few small plots of salt pans still survived. Our soil pit was trenched in the salt pan plot occupied by a markedly degraded association of *Camphorosmetum annuae*. The vanishing community merged into vegetation of the alliance *Puccinellion limosae*. This stage is documented by the phytosociological relevé:

Mostová Nature Reserve, sampled area 4 m^2, elevation 2°, exposition: west; E_1: 20%, E_0: 0%, 12. 5. 2005.

Puccinelia distans 2a, *Artemisia santonicum* subsp. *patens* 1, *Camphorosma annua* 1, *Cerastium dubium* 1, *Atriplex tatarica* +, *Cynodon dactylon* +, *Tripolium pannonicum* +.

Soil physical properties are listed in Table 1. Since soil forming substrate of the studied locality are alluvial sediments of the Dudváh river, the values of particle density (ρ_s) changed irregularly across the profile. Higher values of particle density in upper parts of the profile were probably caused by mineral composition of the soil forming substrate. Since the critical values of bulk density (ρ_d) and porosity (P) – reported by Zaujec et al. (2002) were exceeded over the whole soil profile, we can conclude that the studied soil was compacted.

The porosity or total pore space, however, does not give any indication of pore size distribution. The optimal pore distribution is: 1/3 macropores – for aeration and 2/3 meso and micropores – for water retention and accumulation (Bedrna et al., 1989). Our results showed that the percentage of meso and micropores exceeded 2/3 of the total porosity (Table 1). The soil moisture (θ) was either sufficient or excessive, and over the whole profile, sufficient amount of utilizable water (W_V) was found.

The low percentage of waterproof aggregates (63.2%) manifested an unfavourable aggregate composition of SAe horizon (Table 2). The main reason for soil structure disintegration was probably the high amount of monovalent cations – mainly Na^+, the percentage of which from the sum of base cations in SAe horizon was even 73.3% (Table 5).

Remiš et al. (1981) stated that adsorption of Na^+ on soil colloids cause the susceptibility of colloids to swelling in wet conditions. It results to disintegration of structure aggregates. During wet state, the saline sodic soils are sticky and gleic, poor aerated and cold, in profile prevail reductive processes decreasing and limiting the activity of soil organisms. In extreme cases Na^+ ions have toxic influence on plant roots. High amount of Na^+ limits water absorption and its transport in plants. Tóth et al. (1991) reported that the Carpatian Basin has hydrologically closed characteristics rather than arid or semiarid conditions. The source of sodium salts is mainly in subsurface water and the dominant forms of salt accumulation are Na_2CO_3 and $NaHCO_3$.

Soil reaction was strongly alkaline over the whole profile studied (Table 4). Such extreme values of pH are very unfavourable for vegetation. The highest value of soil reaction was determined in topsoil where it was found also the highest amount of monovalent base cations – mainly Na^+ and K^+ (Table 5). Hanes (2001) stated that alkaline soil reaction occurs in soils saturated with Na^+ after leaching of water soluble salts. This leads to alkaline hydrolyse and then to Na_2CO_3

Table 1. Physical and hydrophysical properties of Sodic Solonchack profile

Depth	ρ_s	ρ_d	P	Θ	V_{AM}	Pk	Ps	Pn	W_V	Θv
[m]		[t m^{-3}]					[% vol.]			
0.0–0.1	2.84	1.72	39.4	24.0	15.5	29.7	2.3	7.5	13.7	10.3
0.1–0.2	2.75	1.76	36.5	29.5	6.5	31.4	1.8	3.3	20.9	8.7
0.2–0.3	2.88	1.70	41.0	29.2	11.8	31.7	1.4	7.9	21.8	7.5
0.3–0.4	2.77	1.63	41.1	32.5	9.2	34.9	1.0	5.3	27.7	4.3
0.4–0.5	2.71	1.61	40.6	32.3	8.3	34.1	1.9	4.6	25.5	6.8
0.5–0.6	2.66	1.63	38.7	31.3	7.5	34.0	1.6	3.1	25.1	6.2
0.6–0.7	2.77	1.68	39.4	30.6	4.4	33.5	1.7	4.8	27.6	2.9
0.7–0.8	2.76	1.68	39.1	27.6	11.5	30.4	1.8	6.9	22.1	5.5

ρ_s – particle density; ρ_d – bulk density dray; P – porosity; Θ – water content; V_{AM} – soil aeration; Pk – capillary pores; Ps – semi-capillary pores; Pn – non-capillary pores; Θv – wilting point; Wv – utilizable water

Table 2. Aggregate composition of SAe horizon containing salt pan

Percentage of fractions after dry sieve [%]						
>7.0 mm	7.0–5.0 mm	5.0–3.0 mm	3.0–1.0 mm	1.0–0.5 mm	0.5–0.25 mm	<0.25 mm
4.02	9.74	24.76	31.24	15.08	6.36	8.80
Percentage of waterproof aggregates [%]						
>5.0 mm	5.0–3.0 mm	3.0–2.0 mm	2.0–1.0 mm	1.0–0.5 mm	0.5–0.25 mm	<0.25 mm
22.04	6.36	7.56	9.28	9.60	8.40	36.76

formation.

Compared to the SAe horizon containing salt pan, the pH values under vegetation were lower by 0.6. We suppose that higher contents of soil organic matter in SAe horizon under saline vegetation could contribute to decrease in the pH values (Table 4, 6). It is in accordance with Tóth et al. (1994) who refer that the vegetation on solonetzic grassland was the densest at the most acid spots.

Capillary raise of water was documented by dynamics of carbonates, percentage of water soluble salts, colloids and particles with diameter 0.01–0.001 mm, the amount of which increased in the upper parts of soil profile (Table 3, 4).

Our results showed a three times higher content of NaCl in the SAe horizon containing salt pan compared to the SAe horizon under the saline growth (Table 4). The electrical conductivity of soil leach confirmed less favourable conditions for plants growth in soil containing salt pan, since the conductivity of leachate from the SAe horizon was 1.7 times higher compared to SAe horizon under the saline growth.

ESP (exchangeable sodium percentage) and SAR (sodium adsorption ratio) values were calculated from the determined content of base ions. Our results suggest that Na^+ was the dominant cation over the whole soil profile (Table 5). The highest content and percentage of Na^+ from the sum of base cations and therefore also the highest values of ESP and SAR were found in the (Bnt)SCc horizon. The 1.5 times higher values of SAR and 1.3 times higher values of ESP in the SAe horizon with the salt pan points out a worse cation composition compared with the SAe horizon under the saline growth.

On the base of ESP values being higher than 20% over the whole profile, the values of soil reaction higher than 8.5 and values of solution electrical conductivity higher than 4,000 μS cm^{-1}, we can classify the studied soil as a Sodic Solonchack (WRB, 1994).

Generally, the content and quality of humus in saline and sodic soils is low (Hanes, 1997, Remiš et al., 1981). Our results showed that the content of humus in the whole profile under the salt pan was very low, but in the SAe horizon under the saline growth it was evidently higher – because the plant residues and root exudates permanently enriched this horizon with organic compounds (Table 6). The quality of humus in the SAe horizons was very low (amount of humic acids – HA was lower than fulvic acids – FA), but in the deeper parts of profile it increased. Higher humus quality in deeper parts of profile was confirmed by the degree of humification (percentage HA of humus) which also increased in depth.

Since salt-affected soils and mainly saline vegetation, microbial and animal species are very rare in Slo-

Table 3. Textural composition of Sodic Solonchack

Horizon	Depth	Texture	Textural fractions [%]					
			>0.25	0.25–0.05	0.05–0.01	0.01–0.001	<0.001	<0.01
	[m]		mm	mm	mm	mm	mm	mm
SAe	0.0–0.08	ssh	0.1	5.4	10.0	69.5	15.1	84.5
(Bnt)SCc	0.08–0.5	ssh	0.2	19.8	51.2	19.4	9.5	28.9
(Bnt)SCc	0.5–1.1	sp	0.3	49.7	35.9	10.8	3.3	14.1
CGo(S)c	1.1–2.0	sp	5.7	50.7	31.5	9.8	2.3	12.1

ssh – silt loam; sp – sandy loam

Table 4. Values of pH, content of chlorides, NaCl, conductivity and mineralization of water

Horizon	Depth	pH H_2O	pH KCl	Cl^-	NaCl	CO_3^{2-} HCO_3^-	Water soluble salts	Electrical conductivity
	[m]			[%]				[μS cm^{-1}]
Profile with salt pan on the top								
SAe	0.00–0.08	10.57	9.58	0.11	0.17	30	0.45	7,000
(Bnt)SCc	0.08–0.50	10.46	9.47	0.15	0.25	26	0.46	7,350
(Bnt)SCc	0.50–1.10	10.21	8.99	0.11	0.18	11	0.29	4,750
CGo(S)c	1.10–2.00	10.02	8.88	0.08	0.13	14	0.26	3,850
SAe horizon under halophyte plants								
SAe	0.0–0.1	9.91	9.02	0.03	0.06	28	0.33	4,200

Table 5. Base cations, and their percentage of sum of base cations, SAR and ESP

Horizon	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Σ	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SAR	ESP
	[mmol (p^+) kg^{-1}]					[% of sum of cations]				[%]	
SAe	30.0	12.5	233.2	42.5	318.2	9.4	3.9	73.3	13.4	50.6	55.4
(Bnt)SCc	35.0	–	226.3	16.1	277.4	12.6	0.0	81.6	5.8	54.1	57.3
(Bnt)SCc	32.5	7.5	253.7	7.3	301.0	10.8	2.5	84.3	2.4	56.7	58.7
CGo(S)c	55.0	63.6	150.8	5.1	274.7	20.0	23.2	54.9	1.9	19.6	30.8
SAe horizon under halophyte plants											
SAe	35.0	16.3	164.6	51.3	267.1	13.1	6.1	61.6	19.2	32.5	43.0

Σ – sum of base cations ($Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}$); SAR – sodium adsorption ratio; ESP – exchangeable sodium percentage

Table 6. Organic carbon content and humus

Horizon	Humus	C_T	C_{HS}	C_{HA}	C_{FA}	C_{HA}/C_{FA}	C_{HA}	$Q_{HS}^{4/6}$	$Q_{HA}^{4/6}$
	[g kg^{-1}]						[% of C_T]		
Profile with salt pan on the top									
SAe	4.22	2.45	1.00	0.42	0.58	0.73	17.1	4.82	3.45
(Bnt)SCc	2.95	1.71	0.98	0.53	0.45	1.02	31.0	3.25	2.21
(Bnt)SCc	2.74	1.59	1.04	0.49	0.56	0.88	30.8	3.60	2.13
CGo(S)c	2.29	1.33	1.00	0.71	0.29	2.46	53.4	3.20	2.00
SAe horizon under halophyte plants									
SAe	30.55	17.72	2.89	1.22	1.66	0.74	6.9	7.50	4.00

Humus = C_T * 1.724; C_T – total content of organic carbon; C_{HS} – carbon of humus substances; C_{HA} – carbon of humic acids; C_{FA} – carbon of fulvic acids; C_{HA}/C_{FA} – humic acids to fulvic acids ratio; $Q_{HS}^{4/6}$ – absorbance ratio of humus substances; $Q_{HA}^{4/6}$ – absorbance ratio of humic acids

vakia, additional research and mapping is necessary.

Conclusions

- The vegetation of salt pans was degraded in the study site.
- The studied soil was compacted over the whole profile.
- The main reason of soil structure disintegration (only 63.2% of waterproof aggregates) was probably in high amount of monovalent cations – mainly Na^+.
- Since Na^+ was the dominant cation in the whole profile, soil reaction was strongly alkaline.
- Capillary raise of water was documented by dynamics of carbonates, percentage of water soluble salts, colloids and particles with diameter 0.01–0.001 mm, the amount of which increased in the upper parts of soil profile.
- Our results showed 3 times higher content of NaCl, 1.7 times higher electrical conductivity, 1.5 times higher values of SAR, 1.3 times higher values of ESP and by 0.6 higher pH values in the SAe horizon containing salt pan compared to the SAe horizon under saline growth. The content and quality of humus in the studied soils was low. Humus content decreased and humus quality gradually increased with depth.
- On the base of pH, ESP values and electrical conductivity of soil solution, we classified the studied soil as a Sodic Solonchack.
- The results obtained in this study enable us to know better the present state and ecology of saline soils in Slovakia and in the Danube lowland.

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Vlastnosti a vegetácia alkalických slaniskových pôd Prírodnej rezervácie Mostová

Súhrn

Robili sme pôdnu a fytocenologickú charakteristiku salinických pôd v Prírodnej rezervácii Mostová, ktorá sa nachádza v severozápadnej časti Podunajskej nížiny na Slovensku (48°09' SŠ; 17°41' VD), nadmorská výška 116–118 m. Bola vykopaná pôdna sonda na zanikajúcom slanom oku s rudealizovaným porastom *Camphorosmetum annuae*. V minulosti bolo toto spoločenstvo viazané na najviac zasolené pôdy pomerne časté, no v súčasnosti je veľmi vzácne. Morfologické, fyzikálne a chemické vlastnosti boli stanovené pre celý pôdny profil pod slaným okom. Na porovnanie chemických vlastností pôd so slaným okom na povrchu s pôdou pokrytou slanomilnou vegetáciou sme odobrali aj vzorku pôdy z humusového horizontu (SAe) pod porastom slaniska (asi v 0,3 m vzdialenosti od

slaného oka). Zistili sme, že skúmaná pôda bola utlačená, a v celom profile bol dostatok využiteľnej vody. Nízke percento vodoodolných agregátov (63,2 %) bolo dôkazom nepriaznivého agregátového zloženia SAe horizontu. Toto mohlo byť spôsobené prevahou Na^+ katiónov v sorpčnom komplexe, ktoré pravdepodobne zapríčinili aj silne alkalickú reakciu v celom pôdnom profile. Kapilárny zdvih vody bol dokázaný na základe dynamiky karbonátov, obsahu solí, koloidov a častíc s priemerom 0,01–0,001 mm, ktorých obsah bol najvyšší vo vrchnej časti pôdneho profilu. Zistili sme, že SAe horizont slaného oka mal trojnásobne vyšší obsah NaCl, 1,7-násobne vyššiu vodivosť pôdneho roztoku, 1,5-násobne vyššiu hodnotu pomeru adsorpcie sodíka (SAR), 1,3-násobne vyššiu hodnotu percenta výmenného sodíka (ESP), a o 0,6 vyššiu hodnotu pH v porovnaní so SAe horizontom pod slaniskovou vegetáciou. Obsah a kvalita humusu skúmanej pôdy boli nízke. Keďže hodnoty pH v profile boli v rozmedzí 10,57–9,91, hodnoty ESP boli v rozmedzí 58,7–43,0 % a elektrická vodivosť roztoku bola v rozmedzí 7 000–4 200 µS cm^{-1}, klasifikovali sme skúmanú pôdu ako slanisko slancové. Získané výsledky môžu prispieť k lepšiemu poznaniu ekológie slaniskových pôd Slovenska a Podunajskej nížiny.

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