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GENESIS
AND GEOGRAPHY OF SOILS

Soil Salinization of the Baer Mounds in the Volga River Delta

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Abstract—The Baer Mounds are elongated hills arranged in parallel rows stretched from the east to the west in the Astrakhan steppe. The distance between the mounds varies from 200 to 1500 m (300 m on the average). The width of the mounds is about 250 m and their length is from 450 m to 4.5–5 km long (sometimes, up to 15–20 km). The height of the mounds varies from 7 to 10 m and increases in the southward direction. The mounds are composed of clayey sand; loamy sand; light loam; and, sometimes, loam. Their top (1–3 m) parts consist of clayey sand and loamy sand with thin interlayers of loam, clay, and argillite pebbles. The upper horizons of the brown semidesert soils are not saline. Soluble salts are leached off from them into deeper horizons. On the slopes, the deep soil horizons are saline, and salts are transported from the deep soil layers into the upper layers. This can be explained by the regular flooding of the foots of the mounds with floodwater and the capillary rise of water. Alternation of salinization and desalinization processes is responsible for the nonuniform distribution of salts in the soil profiles and along the soil catena.

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INTRODUCTION

The Baer Mounds are specific landforms found in the western part of the Caspian Lowland. They were first described by Karl von Baer in 1856. The mounds create a specific landscape characterized by a sharp transition from zonal brown desert soils on the mounds to saline soils and meadow solonchaks in the intermound depressions [10]. The plant cover is sensitive to the salinity and physical properties of the soils [7]. The Baer Mounds are of regular elongated shape resembling long loaves. They are arranged in parallel rows stretched from the east to the west. The distance between the rows varies from 200 to 1500 m (300 m on the average). Their width usually does not exceed 250 m, and their length varies from 450 m to 4.5–5 km and, sometimes, up to 20 km. The height of the mounds does not exceed 7–10 m and increases in the southward direction [1].

The mounds are composed of clayey sand; loamy sand; light loam; and, sometimes, loam. Their upper (1–3 m) parts consist of clayey and loamy sand with thin interlayers of loam, clay, and argillite pebbles [1]. The uppermost layers usually consist of clayey and silty sands, and the sand content in the eastern part of the territory occupied by the mounds is generally higher than that in the western part.

This paper is devoted to the soil cover of the Baer Mounds and to the specificity of the soil salinization in this area. The origin of the deep saline horizon in brown semidesert soils developed on the mounds is open to argument. Published data [4] show that the groundwater table under the mounds is very deep (8–13 m); at the foots of the mounds, it is found at a depth of 3–4 m and more. Such deep groundwater should not exert a direct effect on the water and salt regimes of the sandy soils [6]. The soil salinization at some depth is usually considered as a residual salinization inherited from the previous stages of the soil development. However, the flooding regime of the surrounding area may cause the capillary rise of salts in the mounds and enhance the soil salinization in the deep horizons [2]. It is a challenge to distinguish between the salts inherited from the soil-forming material and appearing in the soils under the impact of saline groundwater. However, it is important to solve this problem in order to understand the genesis of soil associations in the Volga River delta.

OBJECTS AND METHODS

We studied the Bol'shoi Barfon Mound and the adjacent territory in Volodarsk district of Astrakhan oblast. Two soil catenas (A and B) crossing the mound in perpendicular directions were surveyed. Profile A had a length of 1100 m, and profile B had a length of 330 m. The control full-profile soil pit was set on the top of the mound; 45 small pits (down to a depth of 60 cm) were described and sampled along the catenas. The distances between the sampling points was about 30 m. Geobotanic descriptions of the plots around the sampling points were also made.

The salt content and composition of the soluble soils were determined in water extracts, the trilonometric method was used to determine the concentrations of Ca^{2+} and Mg^{2+}, flame photometry was used for K^+ and Na^+, the argentometric method was for used for Cl^-, and

Analytical data on water extracts from the heavy loamy brown semidesert soils and solonchaks

Soil pit	Horizon	Depth, cm	pH	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-/SO_4^{2-}
				mmol/100 g of soil							
Brown semidesert heavy loamy soils											
A-00-03	A_{sod}	0–7	7.32	0.10	0.09	0.05	0.22	0.10	0.24	0.02	3.60
	B1	7–22	7.26	0.05	0.03	2.75	6.10	0.75	0.16	0.01	0.02
	Bs	22–57	6.99	0.05	0.14	2.66	4.40	2.00	1.15	0.02	0.10
	B2	57–87	7.23	0.07	0.95	2.04	1.60	1.92	3.47	0.02	0.92
	B3	87–110	6.99	0.06	2.74	2.12	1.60	2.50	7.16	0.02	2.58
A-01-03	A_{sod}	0–4	6.80	0.54	0.36	0.16	0.16	0.08	0.90	0.04	4.48
	B1	4–22	8.11	1.10	0.71	0.08	0.14	0.06	1.57	0.01	17.40
	Bs	22–52	7.01	0.26	10.60	19.44	13.26	3.67	14.23	0.05	1.10
	B2	52–6	7.26	0.34	10.03	15.92	9.03	3.28	13.61	0.07	1.26
A-02-03	A_{sod}	0–3	7.60	0.84	5.27	0.64	0.40	0.20	5.94	0.08	16.48
	Bs	3–19	7.62	0.52	12.20	3.52	1.04	0.70	14.76	0.03	6.92
	B1	19–29	7.04	0.37	13.20	8.50	5.01	3.45	14.64	0.05	2.78
	Bs2	29–41	7.09	0.30	13.43	15.30	9.22	4.56	14.50	0.06	1.84
	B2	41–60	7.35	0.38	19.81	13.20	6.31	5.37	21.05	0.07	3.00
Solonchak soils											
B-01-03	A_{sod}	0–4	7.26	0.40	1.37	1.84	1.68	0.24	0.96	1.01	1.52
	II	4–22	7.03	0.40	1.15	2.96	7.51	3.38	2.05	0.99	0.80
	III	22–52	7.03	0.38	13.99	10.10	6.51	1.89	8.94	0.79	2.82
	IV	52–60	7.65	0.36	13.32	10.19	4.41	2.39	18.01	0.95	2.64
B-03-03	A‰	0–10	7.27	0.52	0.48	0.76	2.67	1.58	0.91	0.13	1.28
	II	10–27	7.15	0.44	2.91	12.20	4.85	6.66	2.85	0.07	0.48
	III	27–42	7.29	0.62	1.50	2.84	6.18	1.02	8.94	0.05	1.08
	IV	42–65	7.35	0.38	11.90	9.00	3.61	3.70	12.55	0.08	2.68
B-05-03	A_{sod}	0–8	6.88	0.44	6.15	1.08	1.32	7.69	5.72	0.18	11.56
	II	8–14	7.22	0.48	10.00	5.20	2.32	6.41	9.47	0.19	3.90
	III	14–24	7.07	0.40	18.40	11.00	3.73	9.85	18.43	0.18	3.40
	IV	24–43	7.16	0.38	14.88	9.90	2.91	n.d.	14.92	0.18	3.04
	V	43–62	7.02	0.36	18.65	17.40	3.50	n.d.	23.99	0.18	2.18
A-07-03	IA	0–8	6.67	0.54	3.31	2.6	5.31	3.24	2.6	0.30	0.94
	II	8–18	6.71	0.43	4.96	4.7	14.02	6.89	4.7	0.09	0.52
	III	18–38	7.08	0.53	4.38	5.05	7.81	4.86	5.05	0.04	0.70
	IV	38–57	7.12	0.55	4.18	4.28	9.51	5.57	4.28	0.12	0.56
	V	57–65	6.58	0.40	0.56	0.55	1.6	0.57	0.55	0.11	0.58
A-08-03	As	2–6	6.71	0.80	0.76	0.68	3.53	1.09	0.68	0.12	0.38
	B1	6–13	6.92	0.64	0.51	0.57	1.33	0.71	0.57	0.05	0.62
	A_{buried}	13–22	6.79	0.56	0.8	1.26	5.00	2.57	1.26	0.04	0.22
	Bg	22–29	7.15	0.53	0.65	1.31	4.9	2.67	1.31	0.03	0.16
	B2	29–42	7.42	0.54	0.6	1.22	4.61	2.38	1.22	0.03	0.16
	B3	42–60	7.35	0.56	0.72	1.79	8.25	3.87	1.79	0.03	0.16

the gravimetric method was used for SO_4^{2-} [3]. The data on the soil salinity obtained by us were comparable with the earlier results [4].

RESULTS

The soil on the top of the studied mound is classified as a saline heavy loamy brown semidesert soil developing under desert-steppe vegetation [7]. The dominant species are *Camphorosma monspeliaca* and *Anabasis salsa*. The plant community belongs to the Artemisietea lerchianae class (Artemisietum lerchianae association). It includes the following species: *Camphorosma monspeliaca* L. (a chamaephyte), *Eremopyrum orientale* (L.) Jaub & Spach (a therophyte), *Eremopyrum triticeum* (Gaertn.) Nevski (a therophyte), *Aeluropus pungens* (Bieb.) C. Koch (a chamaephyte), *Meniocus linifolius* (Steph.) DC (a therophyte), *Salsola australis* R. Br. (a therophyte), *Anabasis aphylla* L. (a chamaephyte), *Anabasis salsa* (C.A. Mey.) Benth. ex Volkens (a chamaephyte), and *Ceratocarpus arenarius* L. (a therophyte). The plant cover is very sparse, and the soil surface is mostly bare. The surface horizons of the soil are not affected by floods. The soil water supply is only due to seldom summer and autumn rains and the snowmelt in the early spring.

Soluble salts are absent in the surface horizons; salts are crystallized below 20–50 cm. This is the depth of salt leaching by atmospheric precipitation.

The morphological features of the brown semidesert soil were studied in pit A-00-03.

A_{sod}, 0–7 cm. Dry, finely aggregated, loose, silty horizon with a thin discontinuous surface crust; clear boundary; the transition is seen from changes in the soil structure and moisture content.

B1, 7–22 cm. Slightly dry, light brown, compact; dissected by fissures into columns 5×15 cm in size; the lower boundary corresponds to the appearance of salt concentrations.

Bs, 22–57 cm. Light brown, with some darkening in the lower part due the higher moisture content; compact; contains abundant concentrations of soluble salts and gypsum.

B2, 57–87 cm. Moist, brown, relatively loose; salt concentrations gradually disappear.

B3, 87–110 cm. Somewhat heavier in texture; clearly layered.

The surface humus (A_{sod}) horizon is dry, poorly aggregated (sometimes, structureless), and discontinuous. The horizontal layering and vertical fissuring are typical of this horizon. It is the zone of maximum concentration of roots. It can be classified as a light-humus horizon; its color is light gray or brown-gray. The humus content is low (no more than 0.47%). Thin vegetation does not supply the soil with a sufficient amount of organic matter. Specific climatic factors and predominant aerobic processes favor complete mineralization of plant remains. In the course of mineralization processes, considerable amounts of ash elements are accumulated; among them, the portion of alkali metals, including sodium, is considerable.

Sodium, sulfate, and chlorine ions predominate in the composition of soluble salts (table). The content of SO_4^{2-} in the soil profile is nonuniform: 0.025 mmol/100 g of soil in the layer of 0–7 cm (pit A-00-03) and 0.32 mmol/100 g of soil in the layer of 0–3 cm (pit A-02-03). The content of sulfate ions increases down the soil profile. The increased content of sodium ions is explained by their mobility and their participation in exchange reactions of the soil adsorption complex. The sodium content in the soil varies from 0.24 to 20.74 mmol/100 g of soil. The sulfate–chloride and chloride types of salinization predominate, which is typical of the soils of desert and semidesert zones.

At the foot of the mound, meadow hydromorphic solonchaks predominate (catena B). These soils do not compose large areas; they alternate with other soils. They have a heavy texture and clear layering of the alluvial genesis.

Solonchaks are covered by halophytic desert-steppe vegetation with a predominance of *Aeluropus pungens* (Bieb.) C. Koch.

Pit B-01-03 at the foot of the eastern slope of the Bol'shoi Barfon Mound characterizes a typical meadow solonchak.

Layer I (A), 0–9 cm. Dark gray, dry, loose, silty; with separate small aggregates; the boundary is clearly distinguished by the appearance of salt concentrations and changes in the soil color.

Layer II, 9–27 cm. Light brown, slightly dry, with numerous salt concentrations; the boundary is clear by color.

Layer III, 27–36 cm. Dark brown, with chocolate tint; the number of salt concentrations is smaller; there are gleyed mottles 3–5 cm in size; the boundary is clear by the soil color and moisture content.

Layer IV, 36–60 cm. Somewhat lighter in color and more strongly moistened.

The analyses of water extracts from this soil attest to the high degree of salinization. The dry residue (after water evaporation) is from 3.2 to 3.7%. The total alkalinity is not high (0.0150–0.02%, or 0.4 mmol/100 g of soil) and is mainly related to alkali bicarbonates. The soil salinization is of the chloride–sulfate type. Chlorides and sulfates are uniformly distributed in the soil profile. The amount of water-soluble calcium and magnesium is similar. Their content in the top horizons is 1.3–2.0 mmol/100 g of soil and slightly increases down the soil profile.

The content of sodium ions in the top horizons varies from 0.96 to 5.72 mmol/100 g of soil; it sharply increases up to 12.55–23.99 mmol/100 g of soil in the lower horizons. The distribution of chlorine ions in the soil profile is similar to that of sodium ions. The high contents of these ions are due to their presence in the rising groundwater and fixation in the heavy-textured horizons upon the groundwater lowering. In catena A, the transition from the hydromorphic solonchak to the salt-affected peat gley soil is through the solonchak with buried horizons. The peat gley soil is characterized by the gleyed mineral horizons, the peat accumulation on the soil surface, the high water content (80–90%), and the low bulk density (<1 g/cm^3). It is replaced by the strongly saline gley soddy-meadow soil with sandy interlayers in the upper 10 cm and sandy material of the deep horizons. The layered morphology of the soils affects the soil water regime; it increases the duration of the soil waterlogging after the spring floods. It also affects the development of vegetation. The total projective cover of vegetation on the plots with peat gley soils reaches 65%, and the average height of the herbs is 80 cm. An azonal species *Typha latifolia* L. predominates in the plant community. In general, the plant species of the studied plot with peat gley soils are typical of the moist and nonsaline soils of the Volga River delta.

Soil pits A-07 and A-08 characterize solonchaks with buried horizons on the southern footslope of the Bol'shoi Barfon mound.

IA, 0–5 cm. Aggraded (deposited by water) black clayey horizon.

II, 5–18 cm. Dark gray tinted brown, with salt effervescences.

III, 18–38 cm. Black, with numerous salt concentrations of the pseudomycelium form.

IV, 38–57 cm. Brown, with well-pronounced mottles of salt effervescences.

V, 57–65 cm. Brown, horizon with separate salt concentrations.

Data on the soil water extracts show that the total alkalinity is not high (0.05–1.10 mmol/100 g) throughout the soil profile and is mainly related to alkali bicarbonates. Sulfates predominate in the composition of the soluble salts, and the amount of chlorides is considerably smaller. The highest amount of Cl^- (about 5 mol/100 g) in these soils (pit A-07) is registered in the layer of 5–18 cm. Down the soil profile, its content decreases to 0.5 mmol/100 g. The content of sulfate ions in the saline soil horizons rises up to 19 mmol/100 g and decreases considerably in the deep horizons (down to 2 mmol/100 g).

DISCUSSION

In general, the upper horizons of brown semidesert soils are nonsaline or slightly saline with a predominance of sulfate salts. In the deeper horizons of these soils and in the solonchaks at the footslopes of the Baer Mounds, the salinization is of the sulfate–chloride type, and the content of chlorine ions exceeds the content of sulfate ions by more than four times. This fact has already been noted by researchers [6]. An increase in the content of chlorine ions in comparison with the content of sulfate ions attests to the migration of salts in the soil profile. A rise in the Cl^-/SO_4^{2-} ratio points to the direction of the migration [8]. In the soils described in pits A-00, A-08, and A-07, salts are leached off from the upper two horizons. In the soil of pit B-05, salts are removed from the uppermost 8-cm-thick layer; no features attesting to the migration of salts in the deeper horizons have been found. In the soils of pits B-07, B-09, and B-03, salts migrate to the topsoil. This may be explained by the effect of floodwater creating a capillary fringe in the soil at the foot of the mound and, thus, causing the rise of solutions to the soil surface. Our data support this hypothesis. In the deep soil layers, the salt content is considerably higher than in the topsoil. At the same time, the Cl^-/SO_4^{2-} ratio increases toward the upper horizons, which points to the ascending salt movement. Salts may migrate only with capillary water forming in the deep part of the mound during the floods. Atmospheric precipitation leaches off salts from a thin surface horizon leading to a well-pronounced differentiation of salts in the profile of brown soils. In the solonchak (pit B-01), the salt accumulation is more intensive. Considerable amounts of salts are accumulated in the topsoil, and the content of chlorides exceeds the content of sulfates by 8–17 times. The layered stratigraphy of the mounds may decelerate the capillary rise of water with dissolved salts to the upper horizons; on the tops of the mounds, the latter remain slightly saline or nonsaline [5]. In general, the degree of soil salinization within the studied semidesert catenas increases from the top to the foot of the mound.

CONCLUSIONS

(1) The upper horizons of brown semidesert soils on the Baer Mounds are nonsaline; soluble salts are leached off from them into deeper horizons.

(2) On the slopes of the Bol'shoi Barfon mound, the deep soil horizons are saline and the ascending migration of salts is registered.

(3) It can be supposed that the ascending migration of salts is related to temporary capillary water appearing within the mound bodies during the floods.

(4) A combination of desalinization and salinization processes is responsible for the nonuniform distribution of salts in the soil profiles and along the soil catenas.

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