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SYSTEMATIC STUDY OF ARID TERRITORIES

Ecological Intercomponent Relationships in the Natural Solonetzic Soil Complex of the Northern Sarpinskaya Plain (Kalmykia Republic)

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Abstract—Thorough soil–geobotanical studies have been performed on a key plot located in the deserted steppe subzone of the light-chestnut–soil zone within the physicogeographical region of the Northern Sarpinskaya Lowland, Kalmykia, along a 64-m-long profile with coupled analysis of microrelief, vegetation, soils, and remote data (detailed Quickbird image). Geobotanical plots, soil trenches, and holes 1–2 m deep have been established along the profile at 1-m intervals. Analysis of the data has showed a close correlation of soils with plants communities ($r = 0.72$) and loose correlations of these parameters with microrelief ($r = 0.42$ and $r = 0.36$, respectively). Some species—*Falcaria vulgaris*, *Limonium caspium*, *Agropyron desertorum*, *Stipa lessingiana, Artemisia lerchiana*, *Festuca valesiaca*, and *Tanacetum achilleifolium*—are never seen on crust solonetzes; the first four species are also never found on shallow solonetzes, and the first two species are never encountered on solonetzic soils. Other species—*Kochia prostrata*, *Artemisia pauciflora, Anabasis aphylla*, and *Bassia sedoides*—are mainly confined to shallow and crust solonetzes and are rarely found on other soil types. The mowing data are well correlated with the normalized difference vegetation index (NDVI) ($r = 0.77$). The status of vegetation reflected by the NDVI value on the image is clearly determined by edaphic conditions, primarily the soil variety.

Keywords: Russia, Caspian Lowland, solonetzic complexes, microrelief, soils, vegetation, coupled distribution, detailed satellite survey

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INTRODUCTION

Solonetzic complexes in European Russia are mainly confined to the Caspian Lowland and the adjacent Manych Depression, the Yergeni Upland, the southern Volga Upland, and the low Transvolga region (Fig. 1). In administrative terms, solonetzic complexes are concentrated in Kalmykia; Volgograd and Saratov oblasts; and partially in Rostov, Astrakhan, and Orenburg oblasts. The area of solonetzic complexes in European Russia is 41 million hectares, and the area of solonetzes is 9.4 million hectares (Khitrov et al., 2009).

These areas are characterized by microhollow relief with low height differences (less than 50 m), which creates a microcomplexity of soil and plant cover; therefore, strongly contrasting plant communities and soils neighbor on different relief elements. These complexes are referred to as solonetzic complexes because of the presence of solonetzic soils and their typical plants.

Many scientific publications deal with the characterization of solonetzic complexes (Kamenetskaya, 1951; Budina, 1964; Bananova and Gorbachev, 1977; Borlikov, 2001; *Genezis*..., 2008; Novikova et al., 2010). It is believed that a close correlation exists between relief, vegetation status, soil bodies, and soil properties. Therefore, vegetation is frequently used as an indicator of soils. This feature of solonetzic complexes is widely used in cartography, because the plant cover on aerial and satellite images of different scales and resolutions is easy for visual interpretation. However, the recent introduction of automated methods of interpretation puts the focus on the remote sensing parameters, which are easily calculated and clearly correlated with the class and properties of the studied objects. In this context, the search for informative parameters and the analysis and quantification of correlations acquire special importance.

This work solved problems related to the quantification of the strength of relationships between the

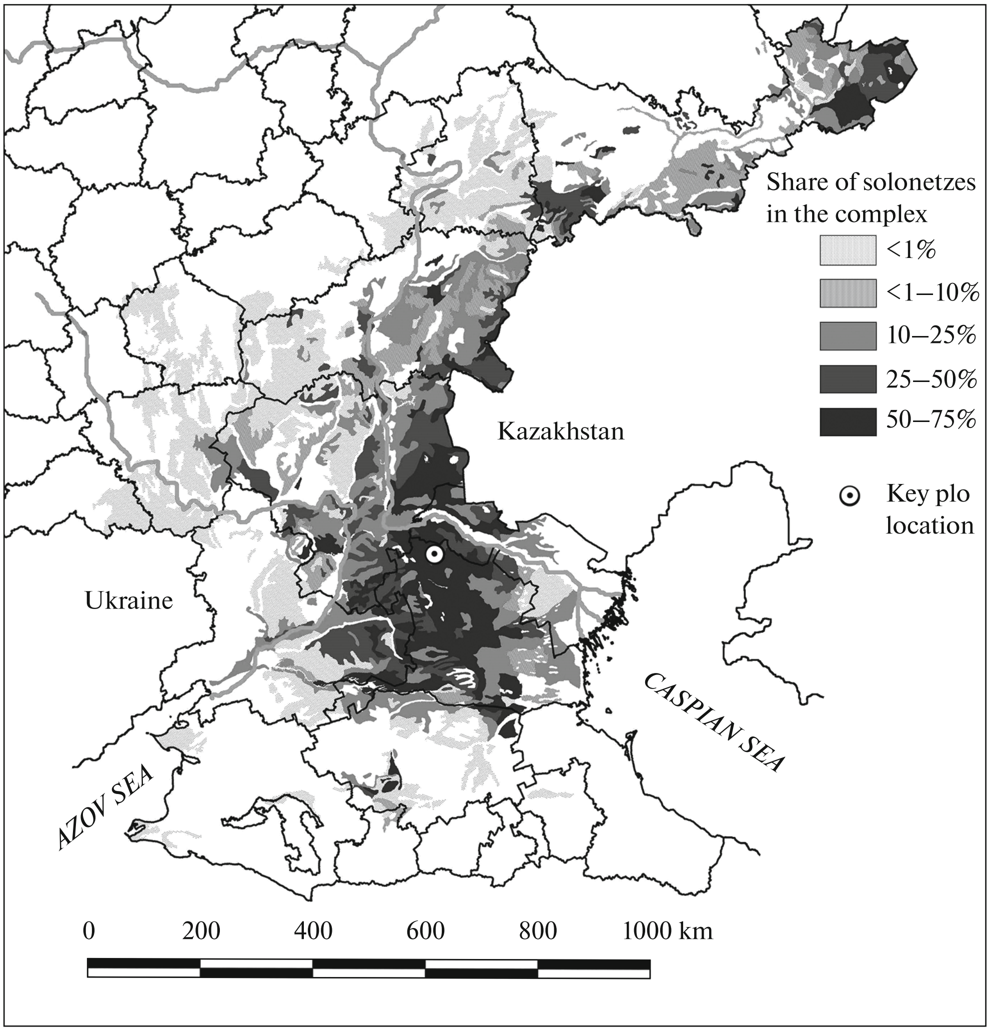


Fig. 1. Distribution of solonetzes in European Russia (Khitrov et al., 2003).

solonetzic complex components and their properties (relief; soils; vegetation; and such parameters as total projective cover, plant height, and aboveground biomass), soil types and dominant plant species with their confinement to different microrelief elements, and solonetzic complex components and their parameters with the values of normalized difference vegetation index (NDVI).

MATERIALS AND METHODS

Region of study. An experimental plot to study solonetzic complexes was established on the Volga right bank, within the physicogeographical region of Northern Sarpinskaya Lowland (Doskach, 1979), near the settlement of Iki-Manlan (48.0° N, 45.5° E), 8 m BES (Baltic Elevation System). In administrative terms, the plot is located in the Malye Derbety district of Kalmykia, near the boundary with the Astrakhan oblast (Fig. 1). In this area, the share of solonetzes in the complex is 25–50% or higher (Khitrov et al., 2003).

According to the classification of solonetzic complexes developed by Fridland (Buyanovskii et al., 1956) and modified by Budina (1964), the studied area is a stepped meadow-steppe complex with leveled microrelief. The 6-m-deep holes established in the spring of 2011 (on April 25) did not reach the groundwater table, and the capillary fringe was also not reached, according to the water content in the soil. This suggests that the depth of groundwater on the studied plot exceeds 9 m and that groundwater is neither used by plants nor involved in pedogenesis.

Materials and methods. Test materials were collected during the 2010 and 201 field works. An instrumental level line was run from the center of a rounded hollow (microdepression) to the center of another hollow in spring of 2010 (Fig. 2), and a profile of 1 m in width and 64 m in length was dug along it. Geobotanical descriptions and mowings for the determination of aboveground phytomass (living biomass, waste, litter) were made along the profile at 1-m intervals (on

1 × 1 m plots); a trench was made near each geobotanical plot to determine the type and subtype of the soil and the content of water to a depth of 1 m. Observations were repeated in spring and fall of 2011.

The level line made it possible to characterize the relief, to relate all measurement results for plants and soils along the profile with each other and with the relief, and to quantify the relationships between the solonetzic complex components and their characteristics by the paired correlation method with Excel software (CORREL statistical function). The obtained correlation coefficients were qualitatively assessed by the approach developed by Dmitriev (1995): $r > 0.85$ (the variability of parameters is mutually related by 75% and more) corresponds to a very close correlation; $r = 0.85–0.70$ (mutually related variation 75–50%) corresponds to a close correlation; $r < 0.7$ (mutually related variation <50%) corresponds to a weak correlation.

On the relief plot (Fig. 2) the mark of the deepest point (64) was taken as zero on the axis of height marks (y); thus, all of the height marks have relative height values.

In the study of the distribution of soil varieties and plant communities, the occurrence frequency of each soil and plant community along the profile was estimated from the parameter calculated as the percentage of plots with these elements in the total number of plots along the profile (64); the confinement of soils and vegetation to different microrelief elements was also estimated from the parameter calculated as the percentage of their findings on a given relief element in the total number of plots with these elements along the profile.

The aboveground phytomass is a good indicator of solonetzic complex components in the work with remote sensing data. In this work, the reserves of aboveground phytomass on different microrelief elements were assessed, and their changes in different seasons of 2010 and 2011 were analyzed.

The suitability of a plant species as an indicator of soil type was determined from such parameters as (1) the presence of the species in the area, which was estimated from its occurrence frequency along the profile; (2) validity, which was estimated from the strength of relationship between the species and different soil types; and (3) phytocenotic significance. The representation ratio was estimated as the percentage of the plots with the given species in the total number of plots along the profile (64); the strength of relationship was determined as the percentage of coupled soil–species findings in the total number of plots with the given soil type. The phytocenotic significance of a species was estimated in the field on each plot where it was found on the Drude scale, and the values were then converted to scores (sol, 2; sp, 3; cop, 4).

Land data were compared to spectral parameters and calculated NDVI values from a detailed Quickbird image (resolution 2.4 m, survey date August 21, 2007) by analysis of variance. The main goal of the study was to assess the effect of the spatial structure of soil and plant cover on remote parameters in order to use available archive space information that was not synchronous with the land survey.

The Latin names of plants are given according to Cherepanov (1995).

RESULTS AND DISCUSSION

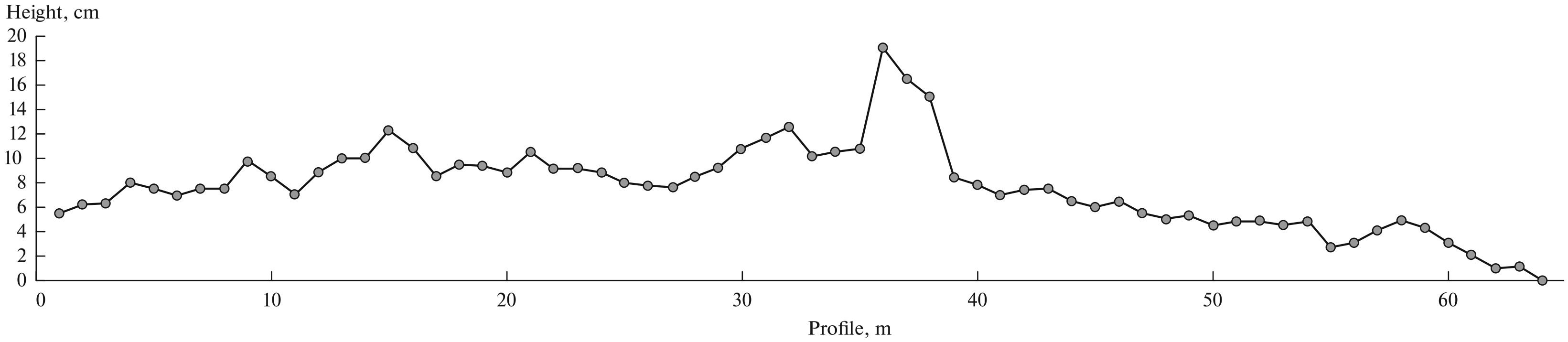
Microrelief. It can be seen in Fig. 2 that the range of height marks along the profile is 19 cm, and the surface of the considered profile rises from the beginning to the 14th meter and then descends to the end of the profile. The difference in height of neighboring points (spaced 1 m apart) varies from 2 to 8.8 cm along the entire profile. Hereafter, these microrelief elements are termed as elevations and lows, and the segments between them are called slopes.

The highest point of the profile (19 cm, on the 36th meter) is located almost in the midlength and is formed by soil spilling from a gopher hole. The difference between this elevation (points 35–38) and the adjacent areas is 8.8 cm. The lowest points are 14.5 and 19 cm lower in microhollows at the beginning (points 1–3) and at the end (points 60–64) of the profile, respectively, than the highest points.

Soils. Along the profile, the following soil varieties were seen (Fig. 2): meadow-chestnut soils (Cm), nonsolonetzic light-chestnut soils (Cl), solonetzic light-chestnut soils (Cls), crust solonetzes (S0, abovesolonetzic horizon, 0–5 cm), shallow solonetzes (S1, 5–10 cm), middle solonetzes (S2, 10–15 cm), and deep solonetzes (S3, >15 cm). Solonetzic light-chestnut soils, shallow solonetzes, and nonsolonetzic light-chestnut soils are the most widely distributed (Table 1). Chestnut soils (including solonetzic varieties) mainly are in the first half of the profile, to 35 m (Fig. 2); solonetzes alone occur in the segment of 36–51 m and again give place to solonetzic chestnut soils beginning from the 55th meter. The solonetzes of the Sarpin Plain are mainly characterized by chloride and sulfate–chloride salinity (Novikova et al., 2010). Gypsum is almost absent.

Analysis of soil coupling with microrelief elements (Table 1) shows that each soil can be met on almost every relief element. The exceptions are as follows: meadow-chestnut soils (Cm), which are not found on slopes and mainly confined to lows; deep solonetzes (S3) , which are extremely rare and occur only in lows; and middle solonetzes (S2), which are also rare but occur mainly on elevations. Khitrov (2005) observed an analogous situation for the solonetzic complex of the Dzhanybek Station.

Vegetation. In botanical–geographical terms, the considered region is located in the deserted steppe subzone (Lavrenko, 2000; Safronova, 2002), and wormwood–grass complexes are the main type of veg-



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	1		2	1		2	4			3	4					
I	4	3	3	2	2	2										
II	3	3	3		3	2	2	2	3	2	3	3	3	3	2	3
III			2			2	3	2	2		2	2	2	2	3	2
IV	2	2	3	3	2				3		2	3		3	2	2
V		2														
VI																
VII																
VIII		2			2	2			2	2	2	2	2	2	2	
B	1				2				3							6

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
A		2		4	2							4	3	7		
I		2	2		2	2	2	2	2	3	3					
II	2	3	3	2	2	3	3	2	2	3	3	2	2			
III	2	2	2	2	2	2	2	2	2	2	2	2				
IV			3	2	2	3	3	3	2		2					
V																
VI																
VII							2			2			2	2	2	2
VIII	2	2	3		2	2	2	2			2	2	2	2	2	2
B		5		3												6

	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
A	6					5										
I																
II																
III																
IV							2	2	2	2	2	2	2	2	2	2
V				3	3	4	4	3	3	3	3	3	2	2	2	2
VI	3	3	3	3	3	2		2	2	2	2		2	2	2	2
VII	2		2													
VIII	2	2	2		2		2	2	2	2	2	2	2	2	2	2
B		7					6									

	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
A				4			2	1			2					
I							2	2	2	2	3	3	3	3	3	3
II						2	3	4	3	3	2	2	2	2	2	2
III				2	2	2	2				2	2	2	2	2	2
IV	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
V	2	2														
VI	2	2	3													
VII																
VIII	2	2	2	2	2	2	3	2	2	2						
B					5		4		2							

A Plant communities

1* *Stipa lessingiana* + *Festuca valesiaca* +*Artemisia lerchiana*
2 *Stipa lessing.* + *Festuca vales.* + *Tanacetum achilleifolium*
3 *Festuca vales.* + *Artemisia lerch.* + *Tanacetum achilleifolium*
4 *Artemisia lerch.* + *Tanacetum achill.* + *Artemisia pauciflora*
5 *Kochia prostrata* + *Artemisia pauciflora*
6 *Artemisia pauciflora*
7 *Anabasis aphylla-Poa bulbosa*

Plant species

I *Stipa capillata*
II *Festuca valesiaca*
III *Tanacetum achilleifolium*
IV *Artemisia lerhiana*
V *Kochia prostrata*
VI *Artemisia pauciflora*
VII *Anabasis aphylla*
VIII *Poa bulbosa*

Figures 2, 3, 4 denote scores
*Data are presented in the horizontal line

B Soils

1* (Cm) meadow-chestnut soil
2 (C1) light-chestnut soil
3 (C1s) solonetzic light-chestnut soil
4 (S3) deep solonetz
5 (S2) middle solonetz
6 (S1) shallow solonetz
7 (S0) crust solonetz

Fig. 2. Microrelief and data on vegetation and soils along the profile.

Table 1. Distribution of soils along the profile: coupling with microrelief elements and representation ratios

Soil	Coupling with microrelief element, %*			Number of findings (plots)	Representation ratio** along the profile, %
	tops	slopes	lows		
Cm	25	0	75	4	6
C1	17	58	25	12	19
C1s	21	58	21	19	30
S3	0	0	100	2	3
S2	75	0	25	4	6
S1	34	33	33	18	28
S0	20	60	20	5	8

* Percentage of plots with soil on the given microrelief element in the total number of plots with this soil along the profile; **percentage of plots with the given soil in the total number of plots along the profile (64).

etation. Plants found along the profile were classified into seven communities: (1) needle grass-Volga fescu-white sagebrush (*Stipa lessingiana-Festuca valesiaca-Artemisia lerchiana*), (2) needle grass-Volga fescue-milfoilleaf tansy (*Stipa lessingiana-Festuca valesiaca-Tanacetum achilleifolium*), (3) Volga fescue-white sagebrush-milfoilleaf tansy (*Festuca valesiaca-Artemisia lerchiana-Tanacetum achilleifolium*), (4) white sagebrush-milfoilleaf tansy-levant wormseed (*Artemisia lerchiana-Tanacetum achilleifolium-Artemisia pauciflora*), (5) levant wormseed-prostrate summercypress (*Artemisia pauciflora-Kochia prostrata*), (6) levant wormseed (*Artemisia pauciflora*), (7) anabasis-bulbous bluegrass (*Anabasis aphylla-Poa bulbosa*). An idea of the distribution of plant communities along the profile is given in Fig. 2 (row A).

It can be seen (Table 2) that each community, as well as each soil, can be found on any microrelief element. The exceptions are three communities: the *Festuca valesiaca-Artemisia lerchiana-Tanacetum achilleifolium* community is met only on slopes; the *Artemisia pauciflora-Kochia prostrata* community is not encountered on elevations and is mainly distributed on slopes; the *Anabasis aphylla-Poa bulbosa* community is not found in lows. Analogous features of coupling between plant communities and relief elements are also typical for other areas with solonetzic complexes. An exception is the *Artemisia pauciflora* community, which is generally confined to microelevations on the territory of the Dzhanybek Station of the Institute of Forest, Russian Academy of Sciences (Volga left bank, Northern Caspian Lowland) (Vyshivkin, 2010).

On the recorded 1-m-long plots along the profile, the main community parameters were measured and assessed: total projective cover of vegetaiton, projective abundance of each species on the Drude scale; number of species; height of plants; weights of air-dry living (green) phytomass, waste, and litter; and total phytomass.

The total projective cover on the plots and along the entire profile is low; its mean value is 25%. The maximum values (on five of 64 plots) reach 60–75%; the minimum values (from 10 to 20%) are noted on more than half of the plots (39 plots, or 61%).

The number of species on 1-m-long plots varies in a narrow range, from oneight to 8. The mean value is four species. Three plant species are present on almost one-third of the plots (20). Six species are found on ten plots, and the maximum number of species (eight) is seen on two plots with meadow-chestnut soils in the deepest hollows at both ends of the profile.

Plant height was measured in 2011, because the grass stand was still not grazed out. The grass stand is lower than 10 cm on half of the plots and 20–50 cm on the other half. It is noticeable that the maximum stand height is in the deepest hollows, and the minimum (almost zero) height is on crust solonetz.

Phytomass. The mean value of living aboveground phytomass is 12.6 dt/ha; the minimum and maximum values differ from the mean value by almost ten times and make up 0.5 and 124 dt/ha, respectively. The mean weight of waste and litter is 4.9 dt/ha, the range being almost equal to that for living phytomass (minimum ~0.6 dt/ha, maximum ~29.5 dt/ha).

The measured values of phytomass in different seasons and years significantly vary among the relief elements (Fig. 3). It can be seen that the values of phytomass on different microrelief elements are relatively close, except deeper hollows with meadow-chestnut and light-chestnut soils, where the growth conditions are better than on other relief elements. There, the reserves of phytomass are about double those on the other microrelief elements of the solonetzic complex. It should be taken into consideration that the measured phytomass reserves depend on not only natural factors but also grazing. The high values of aboveground phytomass in hollows can also be attributed

Table 2. Distribution of plant communities along the profile: coupling with microrelief elements and representation ratios

Plant community	Coupling with microrelief element*, %			Number of findings (plots)	Representation ratio** along the profile, %
	tops	slopes	lows		
Stipa lessingiana—Festuca valesiaca—Artemisia lerchiana	29	29	42	7	11
Stipa lessingiana—Festuca valesiaca—Tanacetum achilleifolium	22	39	39	18	28
Festuca valesiaca—Artemisia lerchiana—Tanacetum achilleifolium	0	100	0	2	3
Artemisia lerchiana—Tanacetum achilleifolium—Artemisia pauciflora	33	40	27	15	23
Artemisia pauciflora—Kochia prostrata	36	36	28	14	22
Artemisia pauciflora	0	60	40	5	8
Anabasis aphylla—Poa bulbosa	33	67	0	3	5

* Percentage of findings of the plant community on the microrelief element in the total number of plots with this community along the profile; **percentage of plots with this plant community in the total number of plots along the profile (64).

to the growth of *Stipa lessingiana* alone, which is a poorly eaten species.

Consideration of relationships between the solonetzic complex components and their parameters (Table 3). As noted above, the strength of relationships was determined by the paired correlation method without separation among the relief eleemnts. Plant communities and soils are arranged in lists in the order of increasing solonetzicity of soils and plant resistance to this factor.

It can be seen in Table 3 that the correlation of microrelief with other components of solonetzic complex (soils, plant communities) is low, and its correlation with plant community parameters is low (no higher than 0.59) and negative. This is easily explainable: when the relative height of microrelief elements increases, the total projective cover, the height of plants, the number of species, and the weight of waste and litter decrease.

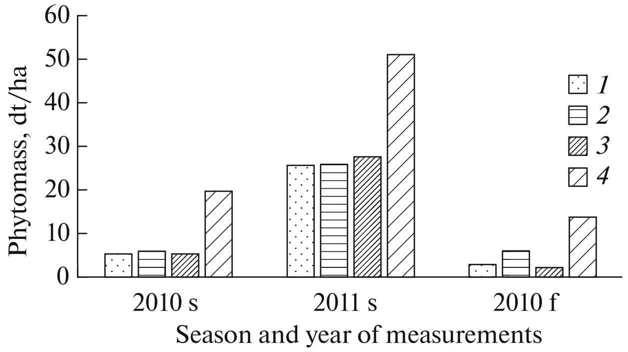


Fig. 3. Phytomass on different microrelief elements in spring and fall: (*1*) elevations; (*2*) slopes; (*3*) lows; (*4*) hollows; sampling time: (s) spring; (f) fall.

Soils and plant communities are most closely correlated ($r = 0.72$). According to the estimation practice (Dmitriev, 1995), this correlation can be estimated closely, because the coefficient of correlation corresponds to 75–50% of mutually related variation of soils and plant communities. This can be also related to the fact that the classification of communities was made with consideration for soil variety and microrelief element, but the communities on 1-m-long plots along the profile were identified by their species composition, regardeless of soils. A close correlation ($r = -0.71$) is also revealed for soils and total projective cover of vegetation. The negative coefficient value is related to the numbering of soils in the soil series from meadow-chestnut soil to crust solonetz. It is obvious that the projective cover of vegetation decreases with an increasing number of soils in this series. An analogous situation is also observed for the correlation of soils with plant height, waste, litter, and total phytomass. Waste and litter are accumulated in large amounts in deeper lows with meadow-chestnut and chestnut soils, while they are almost absent on solonetzes. The absence of a correlation between the soils and the number of plant species can be related to the disturbance of vegetation by grazing and the presence of species with wide ecology, including bulbous bluegrass (*Poa bulbosa*), cheat grass (*Anisanta tectorum*), and so

Table 3. Correlations between the solonetzic complex components

	Components and their parameters								
	components and parameters	soils	communities	TPC	number of species	height	living phytomass	waste and litter	total weight
Components and their parameters	Relief	0.42	0.32	−0.30	−0.59	−0.09	0.05	−0.51	−0.51
	Soils		0.72	−0.71	−0.09	−0.57	0.27	−0.57	−0.55
	Communities			−0.59	−0.65	0.13	0.16	−0.42	−0.41
	TPC (total projective cover on the plot)				−0.09	0.55	0.41	0.71	0.66
	Number of species					0.33	0.04	0.29	0.31
	Height						−0.13	0.29	0.27
	Living aboveground phytomass							−0.25	−0.09
	Waste and litter								0.99
	Total weight								

on, the distribution of which depends on grazing. The presence of ruderal species decreases the parameters of correlation between species richness and soils.

Analysis of the intercomponent relationships in the natural solonetzic complex shows that the relationship of microrelief with soils and plants communities is absent in the landscape region of Northern Sarpin Lowland and that plant communities are closely related to soils.

For practial purposes, the relationships between the most dominant plant species, soils, and relief are the most frequently used in indication studies. In our case, species permanently present along the profile (in different years and seasons), the abundance of which on the Drude scale is sol (2) and more, were selected (Fig. 2). The strength of a relationship was determined by analysis of the coupled findings of plant species and soil variety on the same 1-m-long plot. It was found (Table 4) that some plant species (*Falcaria vulgaris, Limonium caspium, Bassia sedoides*) have a narrow ecological range: they grow on a single soil variety. Thus, *Bassia sedoides* can be used as an indicator, because it grows on crust solonetzes alone and is found on all their plots (100%) with an abundance of 3 (sp), although its representation ratio along the profile is insignificant. *Falcaria vulgaris* and *Limonium caspium* cannot be indicators, because of their low connection with the soil type on which they are found (25%).

Artemisia pauciflora is found on crust and shallow solonetzes and is highly coupled to both soils; however, it has a higher phytocenotic significance (sp) on crust solonetzes. This can serve as an additional parameter, which should be considered when this species is used for indication purposes.

Some species (*Stipa lessingiana, Festuca valesiaca, Artemisia lerchiana, Tanacetum achilleifolium*) have a wide distribution and wide ecological range (Table 4): they occur on a number of soils and can have high coupling with some of them (up to 100%). However, they cannot be used as reliable indicators of a soil with which they completely coincide in distribution, becaue they also occur on other soil types.

As can be seen, no reliable indicators of any soils were revealed among plant species, except *Bassia sedoides*, which can be considered a reliable indicator of crust colonetzes. It is found that a number of species—*Falcaria vulgaris*, *Limonium caspium*, *Agropyron desertorum, Stipa lessingiana*, *Artemisia lerchiana*, *Festuca valesiaca, Tanacetum achilleifolium*—are never encountered on crust solonetzes; the first four species are also never found on shallow solonetzes, and the first two species are never met on solonetzic soils. Other species—*Kochia prostrata*, *Artemisia pauciflora*, *Anabasis aphylla*, and *Bassia sedoides*—are mainly confined to shallow and crust solonetzes and are rarely seen on other soil types.

Comparison of land and remote data. Mowing data are well correlated with the NDVI values, regardless of the asynchronous land and remote data, which reflects the stability of the spatial structure of plant cover (Fig. 4). The correlation is close ($r = 0.77$). High NDVI values (0.11–0.14) are noted on both ends of the profile. Mowings gave 400–1200 g/m^2 in spring and 100–400 g/m^2 in fall. The background values were 100–400 g/m^2 in spring and 0–100 g/m^2 in fall, which

Table 4. Correlations between dominant plant species and soils along the profile, %

Species	Soil							Species representation ratio along the profile, %	Phytocenotic significance of species, score
	Cm	C1	C1s	S3	S2	S1	S0		
Falcaria vulgaris	25/3							1.6	3.0
Agropyron desertorum	25/2	33/2		50/2				8.2	2.0
Stipa lessingiana	75/3	67/2.3	47/2.3	50/2	20/2			36.1	2.4
Festuca valesiaca	50/3	75/2–4	100/3	100/2.3	60/2.3	11/2.3		59.0	2.6
Artemisia lerchiana	75/3	58/3	65/2.3	100/3	60/2.3	83/2		68.9	2.5
Tanacetum achilleifolium	25/2	42/2.3	82/2	100/2	100/2	11/2.3		49.2	2.1
Limonium caspium		25/2						4.9	2.0
Poa bulbosa	25/2	42/2	76/2	100/2.3	80/2	94/2	83/2	77.0	2.0
Anisantha tectorum		8/2	24/2.3			6/2	33/2	13.1	2.3
Kochia prostrata	25/2					78/2–4	33/3	26.2	2.7
Artemisia pauciflora						72/2	100/3	27.9	2.4
Anabasis aphylla			18/2			6/2	100/2	13.1	2.0
Bassia sedoides							100/2	6.6	2.0

The percentage of findings of plant species on soil type in the total number of plots with this type and the phytocenotic significance of the species in scores on different plots with this soil (2, sol; 3, sp; 4, cop1) are given above and below the line, respectively; values equal to or higher than 60%, which can be used in indication studies, are highlighted.

corresponded to the background NDVI values of 0.09–0.11 (August).

The status of vegetation reflected by the NDVI value on the image is clearly determined by edaphic conditions, primarily soil variety (Fig. 5). The increased NDVI values (0.12–0.14) correspond to meadow-chestnut soils; the background values (0.09–0.11) correspond to solonetzes and solonetzic soils; intermediate values (0.095–0.125) are typical for nonsolonetzic light-chestnut soils. It should be noted that light-chestnut soils are characterized by a relatively wide range of NDVI values as compared to other soil variet-

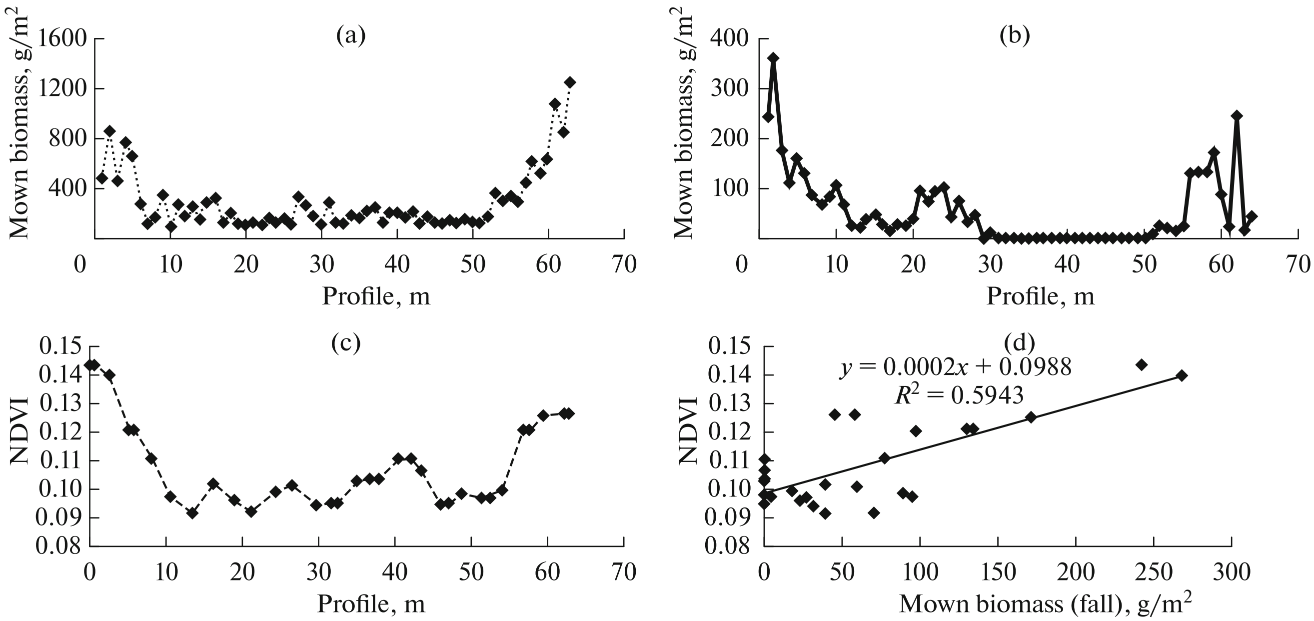


Fig. 4. Data from (a) spring and (b) fall mowings, (c) NDVI values, and (d) their correlation.

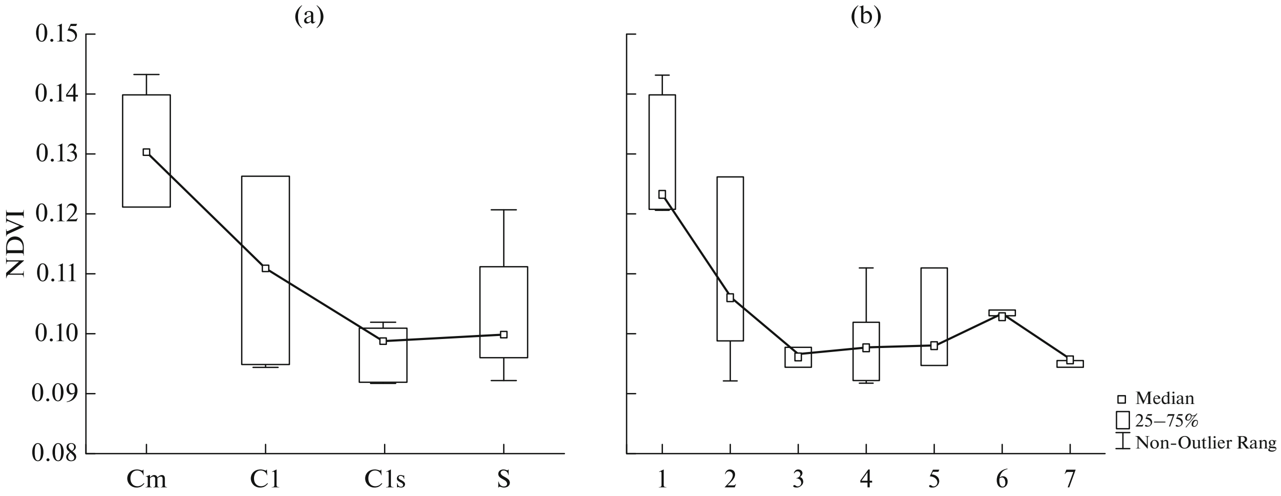


Fig. 5. NDVI variability (median, quartiles, minimum, and maximum) versus (a) soil varieties and (b) plant associations: (Cm) meadow-chestnut soil; (C1) light-chestnut soil; (C1s) solonetzic light-chestnut soil; (S) solonetzes (without subdivision); (1–7) plant associations (see Fig. 2).

ies. Analysis of variance confirmed that the soil factor is significant for the variation of NDVI values ($p = 0.00000$).

CONCLUSIONS

A relatively leveled relief is typical for the landscape region of Northern Sarpin Plain in the Caspian Lowland on a plot with a deep groundwater table (below 9 m). The highest number (85%) of differences between microelevations and microlows is within the range of 3–5 cm. The bottoms of hollows are deeper than these areas by 14–19 cm.

The most common soil varieties in the area include solonetzic light-chestnut soils (C1s), shallow solonetzes (S1), and nonsolonetzic light-chestnut soils (C1); light-chestnut meadow soils (C1m), crust solonetzes (S0), middle solonetzes (S2), and deep solonetzes (S3) are also present. Vegetation consists of communities with the dominance of species typical for solonetzic complexes of the steppe zone (*Stipa lessingiana, Festuca valesiaca, Tanacetum achilleifolium, Artemisia lerchiana, Kochia prostrata, Artemisia pauciflora*).

Soils and plant communities are loosely correlated with relief: the coefficients of correlation are 0.42 and 0.36, respectively. A relatively close correlation with relief is observed for such parameters of plant communities as the species number ($r = -0.59$) and of waste and litter reserves ($r = -0.51$). The negative sign shows that the parameter values tend to decrease with increasing height marks. The closest correlation is revealed between soils and plant communities ($r = 0.72$) and between soils and total projective cover ($r = -0.71$).

No reliable indicators of any soils were revealed among plant species, except *Bassia sedoides*, which can be considered a reliable indicator of crust solonetzes. It is found that a number of species—*Falcaria vulgaris*, *Limonium caspium*, *Agropyron desertorum, Stipa lessingiana, Artemisia lerchiana, Festuca valesiaca, Tanacetum achilleifolium*—are never found on crust solonetzes; the first four species are also never found on shallow solonetzes, and the first two species are never met on solonetzic soils. Other phytogenically significant species—*Kochia prostrata*, *Artemisia pauciflora, Anabasis aphylla*, and *Bassia sedoides*—are mainly confined to shallow and crust solonetzes and are almost not met on other soil types.

Mowing data are well correlated with the NDVI values ($r = 0.77$). The status of vegetation reflected by the NDVI value on the image is clearly determined by edaphic conditions, primarily soil variety.

It should be noted that the revealed features could be extrapolated within the physicogeographical region of Northern Sarpin Lowland, where the studies were performed. Analogous studies are necessary for a similar characterization of other landscape regions.

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REFERENCES

Banonova, V.A. and Gorbachev, S.A., *Rastitel'nyi mir Kalmykii* (Flora of Kalmykia), Elista: Kalmizdat, 1977.

Budina, L.P., Types of solonchak complexes, in *Pochvy kompleksnoi ravniny Severnogo Prikaspiya i ikh meliorativnaya kharakteristika* (Soils of Complex Plain of Northern Caspian Region and Their Meliorative Characteristic), Ivanov, E.N., Ed., Moscow: Nauka, 1964, pp. 196–258.

Borlikov, G.M., Natural zonation of Russian Caspian region and its prospective use, *Ekol.-Geogr. Vestn. Yuga Ross.*, 2001, nos. 3–4, pp. 33–41.

Buyanovskii, M.S., Doskach, A.G., and Fridland, V.M., *Priroda i sel'skoe khozyaistvo Volgo-Ural'skogo mezhdurech'ya* (Nature and Agriculture of the Volga-Ural Interfluve), Moscow: Akad. Nauk SSSR, 1956.

Cherepanov, S.K., *Sosudistye rasteniya Rossii i sopredel'nykh gosudarstv* (Vascular Plants of Russia and Adjacent Countries), St. Petersburg: Mir i Sem'ya-95, 1995.

Dmitriev, E.A., *Matematicheskaya statistika v pochvovedenii* (Mathematical Statistics in Soil Science), Moscow: Mosk. Gos. Univ., 1995.

Doskach, A.G., *Prirodnoe raionirovanie Prikaspiiskoi polupustyni* (Natural Zonation of Caspian Semidesert), Moscow: Nauka, 1979.

Genezis i melioratsiya solontsovykh kompleksov (Genesis and Melioration of Solonchak Soils), Panov, N.P., Ed., Moscow: Rossel'khozakademiya, 2008.

Myasnikov, V.V., Transformation of properties of solonchak soils after rice cultivation in Sarpinskaya Lowland (by example of Bol'shoi Tsryn leman), *Cand. Sci. (Agric.) Dissertation*, Moscow: Dokuchaev Soil Sci. Inst., 1974.

Novikova, A.F., Konyushkova, M.V., Novikova, N.M., Klimanov, A.V., and Vyshivkin, A.A., Soil salinization and vegetation of solonchak complexes of Northern Kalmykia, *Arid. Ekosist.*, 2010, vol. 16, no. 1 (41), pp. 46–56.

Khitrov, N.B., The relationship between the soils of solonetzic complexes in the northern Caspian Lowland and the local microtopography, *Eurasian Soil Sci.*, 2005, vol. 38, no. 3, pp. 237–249.

Khitrov, N.B., Rukhovivh, D.I., Kalinina, N.V., Novikova, A.F., Pankova, E.I., and Chernousenko, G.I., *Elektronnaya versiya karty zasoleniya pochv masshtaba 1 : 2.5 mln.* (Digital Map of Soil Salinization, Scale 1 : 2 500 000), Moscow: Pochv. Inst. im. V.V. Dokuchaeva, 2003.

Khitrov, N.B., Rukhovivh, D.I., Kalinina, N.V., Novikova, A.F., Pankova, E.I., and Chernousenko, G.I., Estimation of the areas of salt-affected soils in the European part of Russia on the basis of a digital map of soil salinization on a scale of 1: 2.5 M, *Eurasian Soil Sci.*, 2009, vol. 42, no. 6, pp. 581–590.

Lavrenko, E.M., Steppes, in *Rastitel'nost' Evropeiskoi chasti SSSR* (Vegetation of European Part of Soviet Union), Leningrad: Nauka, 2000, pp. 203–272.

Safronova, I.N., Phytocenotic diversity of desert steppes of the Black Sea–Kazakhstan subregion of Eurasian steppe area, in *Geobotanicheskoe kartografirovanie 2001–2002* (Geobotanical Cartography 2001–2002), St. Petersburg: Bot. Inst., Ross. Akad. Nauk, 2002, pp. 44–65.

Vyshivkin, A.A., Vegetation shift of solonchak complex of Northern Caspian region caused by climate fluctuations and grazing cessation, *Geogr. Prirod. Resur.*, 2010, no. 1, pp. 78–82.

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