Impact of space and rocket activity on soil cover in central Kazakhstan

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Abstract. The results of environmental monitoring and integrated assessment of the stability of brown, mostly solonchaks to chemical pollution and mechanical stresses at the fall places of the first stage of "Proton" launch vehicle (LV) in the Yu-2 zone (Central Kazakhstan) are provided. With the help of GIS technologies, zoning maps of the investigated territory have been created based on the criteria of soil cover resistance to the impact of space and rocket activity (SRA).

Introduction

The areas of the territory of the Republic of Kazakhstan are currently occupied by the impact areas of separating parts of space launch vehicles (SLV SP IA). These fields, which are located in sparsely populated regions of the country, have been actively exploited by the Baikonur Cosmodrome as a crash site of depleted parts of missile that dispose the Spacecraft into orbit around Earth and geostationary orbit. The complete or partial destruction of the SLV SP (first and second stages, heat shield, and etc.) during the fall and its impact on the ground is often accompanied by mechanical disturbance of the soil and vegetation fire, pollution of the environment with debris and remnants of toxic propellant components that have not burnt in dense layers of atmosphere [1]. Thus, unsymmetric dimethylhydrazine (UDMN) being used in the «Proton» LV as a rocket fuel acts as a base and an active reducing agent by its chemical properties, it is easily oxidized by various oxidants and reacts with compounds that contain a carbonyl group. UDMN belongs to the group of carcinogenic and mutagenic substances of the first class of the risk of human exposure. Therefore, monitoring surveys of the state of the soil cover in SLV SP IA is a very topical issue [2-5].

During the period of intensive exploitation by the Baikonur Cosmodrome (1989-2010), 27 falls of the first stages of the «Proton» LV were registered in the territory of the Yu-2 zone with an area of 0.1 million hectares. On the fields of Kazakhstan's territory, subject to long-term exposure to the SRA as a SLV SP IA, the soil takes the main share of the technogenic load in the form of mechanical and pyrogenic deformation of soil horizons,

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disturbance of balanced development of soil biocenosis [6-7]. Taking into account the risk of negative consequences for the environment, the implementation of the SRA in the Yu-2 zone remains a potential factor of external technical impact on the ecosystem, despite that 7 years have passed since the last fall of the first stage of the «Proton» LV. This aspect provides the basis for monitoring of the natural ecosystem in the Yu-2 zone with subsequent assessment of its environmental sustainability.

For the studies regularly carried out in the Kazakhstani SLV SP IA, the criteria of environmental sustainability are used, which reflect factors that can disturb the equilibrium state of natural ecosystems as abiotic (weather and climate conditions, terrain topography, morphogenetic and physicochemical properties of land cover, etc.) and anthropogenic (SRA, household activities, grazing on pastures, and etc.). The key subject of environmental assessment are biocenosis, since environmental sustainability can be explained only on the basis of biotic compensation of all fluctuations and directed abiogenic changes [8].

Materials and Methods

The Yu-2 zone is located in the semi-desert landscape zone (Central Kazakhstan), where the processes of self-cleaning of ecosystem from chemical contamination by the rocket fuel components (RFC) are largely conditioned by sharply continental climate with increased thermal resources and a low amount of atmospheric precipitation, and frequent thunderstorms, which leads to an accelerated oxidation by the products of technogenesis and their rainout (up to 11-14 days with a thunderstorm in June). Aerogenic transport of pollutant transformation products in the Yu-2 zone becomes possible with wind strengthening, especially accompanied by dust storms and snow blizzards (8-20 days with snowstorms per year). The maximum daily air temperature amplitudes are observed in the warm period of the year with a clear sky (16.1°C); minimum - in the winter with a cloudy sky (5.3°C). The average duration of the frost-free period is 110-160 days, the period of stable snow cover is 105-160 days, the annual precipitation is about 200 mm. Rainfall prevails over snow. The greatest amount of precipitation falls in the warm period (80-120 mm), in the cold period - 70-75 mm. In the territory of the Yu-2 zone, north-eastern and northern winds predominate at a speed of 4.0-4.5 m / s (at an average annual rate).

There can be observed the benefits of the processes of physicochemical and biological decomposition and migration of UDMN in the descending stream of soil moisture or with meltwater in the land cover of the Yu-2 zone (brown soils, solontzic) with low humus content and alkaline reaction of the pH range. The time frame for these processes is limited due to the aridity of the spring-summer period.

In June 2017, monitoring environmental studies were carried out at 34 locations of the SLV SP IA in the Yu-2 zone and at a control point on the contiguous territory (map in Figure 1), with selection of 240 soil samples for quantitative chemical analysis (QCA) for content of rocket fuel components (RFC), including usymmetric dimethylhydrazine (UDMN) and the product of its chemical transformation, nitrosodimethylamine (NDMA). The following QCA methods are used: determination of UDMN by ion chromatography with amperometric detection (MVI No. 41-01; KZ.07.00.01779-2013); determination of NDMA by reversed-phase liquid chromatography with spectrophotometric detection (MVI No. 103-08 KZ.07.00.03190-2015); determination of nitrate ions by ionometry (GOST 26951-86). Soil profiles were described according to standard soil survey methods [9]. From each soil horizon, representative samples were collected. Bulk soil samples were air dried, gently crushed and passed through a 2-mm sieve and analysis undertaken using fine earth. Soil texture was analysed using the pipette method following dispersion after 3-h shaking with 0.1 M $\text{Na}_4\text{P}_2\text{O}_7$ [10-11]. Total carbonates were determined by gas-volumetric

method. Soil pH was measured potentiometrically in 1:2.5 w/v suspension (soil:1M KCl and soil:H₂O), using a Metrohm 691 with a glass electrode AC 9101. Total N was determined by Kjeldhal's method. The analysis of organic carbon was performed using the Walkley–Black Wet Oxidation method and organic matter was calculated from Corg (i.e. Corg x 1.724). Total potassium was determined according to Radov et al [14]. P₂O₅tot was carried out following the Russian Handbook on the Chemical Analysis of Soils [15].

Results and discussion

Analysis of the dynamics of RFC pollution in soils at the fall places of the first stage of "Proton" LV in the Yu-2 zone

For 5 years of observations (during the period of 2002-2007) in brown solonetz of KU-2 (the place of fall from 30.12.1998), concentration of UDMN has decreased more than 20 times - from 13.83 mg/kg (multiplicity of maximum threshold limit value of UDMN is 138 TLV = 0.1 mg/kg) to 0.65 mg/kg (6.5 TLVs). In brown soils of MP-5 (the place of fall from 04.04.1991), the content of UDMN has decreased by 4.5 times - from 0.55 mg/kg (5.5 TLVs) to 0.12 mg/kg (1.2 TLVs). In brown solonchic soils of KU-3 (place of fall from 05.09.2000), UDMN was detected only in 2002, in an amount of 110.4 mg/kg (1,104 TLVs).

Fig.1 - Map-scheme of zoning according to the criteria of chemical contamination of soils in the Yu-2 zone in June 2017

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Place of fall from 30.12.1998), UDMN concentration has decreased more than 20 times - from 13.83 mg/kg (multiplicity of maximum threshold limit value of UDMN is 138 TLV=0.1 mg/kg) to 0.65 mg/kg (6.5 TLVs). In brown soils of MP-5 (the place of fall from 04.04.1991), the content of UDMN has decreased by 4.5 times - from 0.55 mg/kg (5.5 TLVs) to 0.12 mg/kg (1.2 TLVs). In brown solonetzic soils of KU-3 (place of fall from 05.09.2000), UDMN was detected only in 2002, in an amount of 110.4 mg/kg (1,104 TLVs).

In the years of further observations in the Yu-2 zone (2011, 2017), the UDMN was no longer detected in the soils of the fall places of SLV SP. So, in 2017, UDMN and NDMA were not found in all 240 soil samples under study within the sensitivity range of applied

QCA techniques (<0.05 mg/kg of UDMN, <0.05 mg/kg of NDMA).

In the period of 2007-2017 years, at the fall places of «Proton» LV in the Yu-2 zone the 11-fold increase in nitrate ion concentrations in brown solonetz KU-2 (1.3-14.6 TLV nitrate ions = 130 mg/kg) and 2-fold in brown solonetzic soils KU-3 (1.5-3.3 TLVs) was observed. On the contrary, in the brown soils of MP-5, the amount of nitrate ion decreased by 12.8 times - from 2.9 TLVs in 2007 to 0.2 TLV in 2017.

In 2017, in the Yu-2 zone nitrate ion was detected in all studied 240 soil samples, an average of 98.8 mg/kg (Table 1). The excess of the TLV of the nitrate ion in the soil was found mainly in the epicenters of the old fall places of SLV SP from 1980 to 2000 years (center and south of Yu-2). In the topsoil of 0-25 cm 3.3-33.7 TLVs were detected, in the underlying layer of 25-50 cm several times less - 1.2-7.5 TLVs. At separate points on desert solonetz, elevated concentrations of nitrate ion were also found at depths in the 75-100 cm layer (1.1-3.9 TLVs).

Table 1 - Nitrate ions in the soils of the Yu-2 zone in June 2017

Name of the trial plot	Limits of nitrate content, mg/kg		
	Threshold limit value of nitrates in soil =130		
	min	max	mean
Locations of a local survey of places where the LV «Proton» first steps fell			
MP-1, LV start-up date unknown	11,9	15,2	13,6
MP-2, LV start-up date unknown	980,7 (7,5 TLVs)	4 376,2 (33,7 TLVs)	2 678,4 (20,6 TLVs)
MP-3 LV start-up date approximately in 1985-87.	1,08	1,48	1,3
MP-4, LV start-up date 31.05.1989.	897,9 (6,9 TLVs)	1 257,07 (9,7 TLVs)	1 077,5(8,3 TLVs)
MP-5, LV start-up date 04.04.1991.	13,5	29,8	21,6
MP-6, LV start-up date 01.07.2000.	427,2 (3,3 TLVs)	894,1 (6,9 TLVs)	660,7(5,1 TLVs)
Mean by MP	1,08	4376,2 (33,7 TLVs)	472,2 (5,7 TLVs)
Sites of local study of places with detection in the soil of RFC in 2000-2011			
KU-1, LV start-up date approximately in 1995.	0,31	164,0 (1,3 TLV)	50,3
KU-2, LV start-up date 30.12.1998.	1,27	1 891,3 (14,6 TLVs)	107,2
KU-3, date of start-up of the LV 05.09.2000.	1,8	431,8	43,97
KU-4, LV start-up date approximately at the end in 1980.	1,6	570,9 (4,4 TLVs)	87,02
KU-5 LV start-up date unknown	0,45	1 284,7 (9,9 TLVs)	75,1
Mean by KU	0,31	1 891,3 (14,6 TLVs)	72,7
Mean by P (area survey sites)	1,5	171,3 (1,3 TLVs)	36,9
Control point K-1	11,99	12,34	12,2
Mean in the Yu-2 and contiguous territory	0,31	4 376,2 (33,7 TLVs)	98,8

Analysis of physical, chemical and morphological properties

Brown solonetz, meadow-brown solonetz, meadow and brown solonetz, and solonchak typical, meadow and sodic (soil map-scheme is illustrated in Fig. 1) prevail in the SLV SP fall places of the central and south part of Yu-2 zone. In June 2017, signs of disturbance in

the soil structure as well as of planar and linear erosion of soils (nano- and micro-r-ills with a depth of 10-25 cm, recesses, funnels with a depth of 0.5-4.0 m diameter of 1.5-7.0 m) were discovered in the SLV SP fall places (photo in Fig. 2).

Fig. 2 - The places of falling of the Proton LV first stage in the zone Yu-2 in June 2017.

Tables 2-4 show the main morphological, chemical and physical properties of the soil profiles in the perspective of three insections made in 2017 at the two fall places of the first stage of «Proton» LV in the Yu-2 zone and at control point with conditionally clean soil (Fig. 3):

- 1 KU-2 at the place of SLV SP falling in 30.12.1998;
- 2 KU-3 at the place of SLV SP falling in 05.09.2000;
- 3 K-1 at the control point on the adjacent territory.

Fig.3 - Soil insections in June 2017 in the Yu-2 zone

According to the results of surveys conducted in 2017 it was determined that the soil profiles at the KU-2 crash sites (small brown solonetzic), KU-3 (brown saline alkali sabulous soils) and at the K-1 control point (brown saline alkali soil solonetzic light loamy soils) are characterized by a small capacity of humus horizons (about 12 cm) (Table 2). In the upper horizon A, the color varies from pale-gray, brownish-gray to light-brownish, and in the lower horizon C to yellowish-brownish. The topsoil horizons (A) are soft; B, C - dense, BC - condensed.

Table 2 - Main morpho-descriptive characteristics of the insections surveyed

M (Hori zon)	Depth (cm)	aBo und ary	Color (dry)	bStru cture	cTexture	dConsist ence (dry)	eEfferv escence	fRoot s
KU-2. The place where the LV «Proton» first steps fell in 30.12.1998 Solonetz brown small								
A	0-9	C	10YR5/2	SG , f&m, 1	C	SO	2	1, f

B1	9-21	C	10YR7/1	SG& SG f&m, 1	CL	SH	3	1, f
B2	21-32	U	10YR6/3	abk& SbC, f&m, 2	CL	H	3	1, f
BC	32-77	G	2.5Y 7/3	SG& abk, f&m, 2	L	VH	3	1, vf
C1	77-99	C	2.5Y 7/4	SG& abk, f&m, 2	SL	H	3	0
C2	99- 196	U	2.5Y 7/6	MA	SL	H	3	0
KU-3. The place where the LV «Proton» first steps fell in 05.09.2000 Brown solonetsous sandy loam soils								
A	0-12	C	10YR6/3	SG& abk, f&m, 1	SCL	SO	2	1, f
B	12-32	C	10YR6/6	CO& SbC, f&m, 1	L	H	2	1, f
BC	32-55	C	10YR6/2	abk& SbC, f&m, 1	SL	VH	3	1, f
C1	55-90	G	2.5Y 6/6	SG& abk, f&m, 2	SL	H	3	1, vf
C2	90- 185	U	2.5Y 6/6	MA, f&m, 2	L	H	3	0
K-1. Control point with conditionally clean soil at contiguous territory Brown solonetzic-solonchakous light loamy soils								
A	0-14	C	10YR6/2	SG& abk, f&m, 1	SC	SO	2	1, f
B1	14-28	C	10YR5/3	abk&	CL	H	2	1, f

				SbC, f&m, 1				
B2	28-44	U	10YR6/4	abk& SbC, f&m, 1	SCL	H	3	1, vf
BC	44-89	G	2.5Y 6/4	SG& abk, f&m, 2	SCL	VH	3	1, vf
C1	89- 115	G	2.5Y 6/2	MA	SCL	H	3	0
C2	115- 163	U	2.5Y 6/2	MA	SCL	VH	3	1, f

aBoundary: C=clear; G=gradual; U=unknown.

bStructure: MA=massiv; sbk=subangular blocky; abk=angular blocky; f=fine; m=medium; 1=moderate, 2=strong.

cTexture: L=loam; SL=sandy loam, SC – sandy clay loam, CL – clay loam, SCL - sandy clay loam.

eConsistence: SO=soft; H=hard; VH=very hard.

fEffervescence: 1=slightly; 2= strongly; 3= violently

gRoots: 0=absent; 1=few; f=fine

The mechanical composition of the soil profiles is mainly sandy and sandy loam, clay, clay loam and sandy clay, sandy clay loam. The structures of the soil profiles are not homogeneous. In the fall places of KU-2 and KU-3, in the lower soil horizons (B₂, BC, C₁, C₂), there is an increased carbonate content (roughly boils from 10% hydrochloric acid) (Table 2).

In soil sections at the fall places (KU-2 and KU-3), the humus content in horizons A and B exceeds the control level (K-1), respectively, by 1.25 and 3.95 times (Table 3). Nutrients in the studied soils are less of control one. It is noted that humus content in illuvial horizons B is higher than in upper horizons A. At the fall place of the KU-2 in brown solonetzic, the amount of humus (0.79%) corresponds to the control parameters in brown saline alkali soils of K-1. This might serve as a sign of the restoration of the fertile soil layer, 20 years after the «Proton» LV first stage falling in 30.12.1998. At the fall place of the KU-3 in brown solonetzic soils, the humus content (0.20-0.28% in horizons A and B) are less of control one (K-1), which might be a sign of preservation of the disturbance of soil structure after 17 years after the «Proton» LV first stage falling in 05.09.2000.

Table 3 - Chemical properties of soils

H or iz on	Depth	Cla y	p H	Ca CO ₃ , %	N tot.	P ₂ O ₅ tot.	K ₂ O tot.	humu s	C a _c xc	M g _c xc	N a _c xc	K _e xc	Na fro m the abs orpt ion cap acit y,%
	(cm)	(g kg- 1)	H ₂ O	(g kg- 1)	(%)				(cmol+kg ⁻¹)				

KU-2. The place where the LV «Proton» first steps fell in 30.12.1998 Solonetz brown small													
A	0-12	14.0	9.1	0.0	0.06	0.10	16.3	0.35	4.00	2.25	0.26	0.61	2.88
B	12-32	35.7	9.0	0.0	0.08	0.92	18.4	0.79	12.7	6.50	0.35	0.13	10.9
B C	32-55	31.2	8.1	0.1	0.04	0.17	20.1	0.45	12.5	5.50	0.40	0.09	2.72
C ₁	55-90	34.9	8.0	0.8	0.02	0.01	22.0	0.11	10.5	4.8	0.43	0.05	-
C ₂	90-185	36.1	8.4	0.8	-	-	-	-	-	-	-	-	-
KU-3. The place where the LV «Proton» first steps fell in 05.09.2000 Brown solonetsous sandy loam soils													
A	0-14	8.41	7.5	0.0	0.08	0.34	18.2	0.28	6.00	3.00	0.27	0.26	5.89
B ₁	14-28	38.8	8.3	0.0	0.09	0.21	20.3	0.20	20.0	7.00	3.16	0.05	11.9
B ₂	28-44	35.2	7.9	0.8	0.07	0.24	21.4	0.24	18.0	7.00	0.86	0.14	5.33
B C	44-89	22.4	7.9	0.8	0.05	0.21	22.6	0.13	15.8	6.80	0.82	0.12	-
C ₁	89-115	0.41	7.9	0.6	-	-	-	-	-	-	-	-	-
C ₂	115-163	7.66	7.8	0.8	-	-	-	-	-	-	-	-	-
K-1. Control point with conditionally clean soil at contiguous territory. Brown solonetzic-solonchakous light loamy soils													
A	0-9	14.8	9.1	0.66	0.07	0.10	17.2	0.35	4.00	2.25	0.26	0.61	9.20
B ₁	9-21	43.3	8.5	0.66	0.09	0.92	19.1	0.79	12.7	6.50	0.35	0.13	14.5
B ₂	21-32	33.7	7.9	0.66	0.09 0	0.10	21.0	0.45	12.5	5.50	0.40	0.09	2.58
B C	32-77	32.1	7.9	0.66	0.06	0.11	23.0	0.33	12.0	4.8	0.37	0.08	-
C ₁	77-99	24.5	8.1	1.33	-	-	-	-	-	-	-	-	-
C ₂	99-196	30.0	7.5	0.50	-	-	-	-	-	-	-	-	-

Increased solontzicity was observed in the soil horizons A and B at the fall places in comparison with the control level. The absorption capacity of sodium in the soils of KU-2 and KU-3 is lower than in the control level - 2.88-10.9% (KU-2), 5.89-11.9% (KU-3), 9.2- 14.5% (K-1).

A strong alkaline pH range was detected in horizons A and B of brown solonetz at the fall place of the KU-2 (9.0-9.1) and in control brown saline alkali soil of K-1 (8.5-9.1). In the remaining horizons of KU-2 and K-1, as well as in brown solonetzic soils, an alkaline pH-medium (7.5-8.4) was established at the fall place of the KU-3. Thus, the processes of transformation of technogenic pollution in the Yu-2 soils are provided by an alkaline and strongly alkaline pH range.

The topsoil horizon A in the sections studied is characterized by a low content of silty fractions (8.4-14.8%) (Table 3). This gives grounds for the conclusion regarding the light mechanical

composition of the surface layers of the soil and their reduced sorption capacity. At the same time, UDMN, settling on soil colloids, can migrate deep into the profile, or on its surface, due to soil erosion by water flows and wind [16-17].

In brown solonchak soils in the fall place of the KU-3, there can be observed a very loose composition of horizon A (bulk density 0.80 g/cm³, porosity 70%) that is similar to the control K-1 (Table 4). In the horizon B, at the fall place of KU-3, an insignificant compaction to loose was revealed (bulk density 1.13 g / cm³, porosity 59%), while in the control it was very loose. In the lower horizons of KU-3, the soil structure becomes denser, bulk of density from 1.10-1.13 g / cm³, porosity 55-58% (BC-C₁ horizons) to 1.39 g / cm³ a bulk of density, 48% porosity (80- 100 cm in the horizon C₂).

Table 4 - Physical properties of soils

Horizon	Depth, cm	Soil moisture of, %	Soil bulk density, g / cm ³	Specific gravity, g / cm ³	Porosity, %
KU-3. The place where the LV «Proton» first steps fell in 05.09.2000 Brown solonchak sandy loam soils					
A	0-10	7.17	0.80	2.65	70
B	10-20	8.71	1.13	2.60	58
BC	20-30	6.80	1.13	2.60	58
	30-40	10.2	1.14	2.55	57
C ₁	40-50	1.59	1.14	2.55	58
	50-60	2.13	1.10	2.55	58
C ₂	60-70	1.47	1.10	2.55	55
	70-80	2.66	1.39	2.55	55
	80-90	1.173	1.39	2.55	48
	90-100	1.86	1.39	2.55	48
K-1. Control point with conditionally clean soil at contiguous territory Brown solonchak-solonchakous light loamy soils					
A	0-10	1.04	0.85	2.65	69
B	10-20	1.49	0.97	2.55	57
BC	20-30	1.48	1.08	2.55	59
	30-40	3.69	1.33	2.55	49
C ₁	40-50	3.81	1.17	2.60	54
	50-60	3.95	1.16	2.60	54
C ₂	60-70	4.1	1.16	2.70	54
	70-80	4.56	1.16	2.70	54
	80-90	5.02	1.07	2.70	58
	90-100	5.82	1.07	2.70	58

At the fall place (KU-3), an increased moistening of soil horizons A, B, BC (7.17-10.2%) was determined in comparison with the lower C₁, C₂ (1.47-2.66%), possibly due to natural flow of flood and rainwater. Migrations of technogenic pollution to depths are inhibited by compacted horizons C₁, C₂, with increased carbonate content (Table 2). Thus, in the upper, humid horizons of A, B, BC at the fall place of KU-3, one can assume the advantage of the accumulation processes of UDMN, its chemical transformation in the aquatic environment, and microbiological processing into organic matter.

Analysis of the resistance of ground soils of the Yu-2 zone to mechanical stress from the SLV SP falling

Clay and loamy-clay ground soils, which occupy most of the area under study (77%), including in the SLV SP falling places in the center and in the south of the Yu-2, are classified according to the scale of the rock hardness, as soft and earthy (KK = 1.0-0.6) (the map-scheme is shown in fig. 4). Sandy-loam ground soils in the north and northeast of the Yu-2 are characterized as loose (KK = 0.5). In general, the ground soils, which cover the investigated area of the Yu-2 zone are unstable to mechanical stress during the falling of the first stage of the «Proton» LV fragments.

Fig. 4 - Map-scheme of zoning Yu-2 on the criteria of resistance of ground soils to mechanical stres

Conclusions on the results of monitoring studies of soil cover in the Yu-2 zone in 2017

According to the chemical, physical and water-physical properties of the soil (brown soils, solonetz) it has been determined that soil cover at the places of the «Proton» LV first stage falling in the Yu-2 zone demonstrate is resistanced to chemical pollution of UDMN. Surface chemical pollution migration by wind or water flows is ensured in the Yu-2 by an easy mechanical composition and low sorption capacity of the topsoil layer (horizon A). The processes of biological processing of UDMN are assumed in illuvial horizons B, most saturated with humus and moisture. In the same soil layers (horizon B), the physicochemical transformation of UDMN is most probable, due to the high content of exchangeable sodium, against the background of sufficient soil moisture with an alkaline (up to a strongly alkaline) by pH-range. The further migration of chemical pollution to soil depths is impeded by the compacted soil horizons C (parent rock).

In the Yu-2 zone, the signs of prolonged accumulation of chemical contamination of UDMN at the SLV SP falling places (up to 10 years or more) are noted with heavy mechanical composition (clay, loams) and low humus content for brown solonetz in complex with solonetzic soils.

According to the physical and water-physical properties the Yu-2 zone soils are unstable to mechanical stress during from the SLV SP falling.

The ground soils (clayey, sandy clay, sandy clay loam) on the scale of the rock hardness are characterized as soft, earthy and loose ($KK = 0.5-1.0$). In June 2017, disturbances of the topsoil upper fertile layer and compaction of the lower horizons, flat and linear erosion of soils (gullies, depressions, funnels) were found at the places of the «Proton» LV first stage falling.

The character of the regenerative processes of technologically disturbed soils at the places of the «Proton» LV first stage falling in the Yu-2 zone is ambiguous, taking into account the revealed differences in the general soil parameters, namely, in the mechcomposition, water regime, bulk density and porosity as well as by the content of humus and nutrients.

Thus, in the brown solonetz, the signs of restoration of the fertile soil layer were revealed, 20 years after the first stage of the «Proton» LV falling in 30.12.1998. At the same time, traces of anthropogenic disturbance of the soil structure remain in brown solonetzic soils after 17 years falling of the first stage of the «Proton» LV in 05.09.2000.

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