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On the State of the Soil Microflora in the Areas Separating from Launch Vehicle in Central Kazakhstan

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Abstract: The results of the comparative analysis of physical, chemical and biological characteristics of the soil cover at the sites of the first stage of the proton launch vehicle (LV) fall in the Yu-2 zone (Central Kazakhstan) are presented. Conclusions are made about the increased sensitivity of the microflora of brown, mostly solonetzic soils to mechanical and chemical loads during the fall of the separating parts of space rockets. Lack of moisture, increased carbonate content and density of saline in the upper horizons complicate the restoration of the disturbed fertile soil layer even 10 years after the impact of rocket and space activities (SRA).

Key words: Rocket and space activity, Central Kazakhstan, solonetzic soils, microflora, stability, chemical pollution.

1. Introduction

Areas separating from parts of rockets (SLV SP IA), located in sparsely populated Kazakhstani regions are zones of ecological risk in the result of years of exposure to rocket and space activities (SRA) [1]. Mechanical deformation of the soil layers and chemical pollution of the soil cover of heptyl (a rocket fuel—unsymmetrical dimethyl hydrazine, UDMH, is a substance of class 1 toxic hazard), as a rule, leads to disruption of the balanced development of soil ecological communities on the dropping of the exhaust parts design LV [2]. Low content of nitrogen-containing contaminants (UDMN) and products of its chemical transformation) can stimulate microbiological processes in saline soils in arid conditions of Central Kazakhstan. High concentrations of contaminants cause the death of microorganisms [3]. The risk of negative impact of SRA on human, animal and plant life activity provides the basis for monitoring studies of the sites of SLV SP falls with the subsequent assessment of soil ecological stability according to the criteria of their chemical, physical (mechanical) and biological transformation [4, 5].

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2. Materials and Methods

2.1 Study Area

In 2017, SLV SP IA with an area of 0.1 million hectares (zone Yu-2 in Central Kazakhstan) was studied, where in the period 1989-2010, 27 drops of the first stages of the "Proton" LV occurred during launches from the Baikonur cosmodrome. The samples of brown, mostly solonetzic soils (layer 0-25 cm) from the places of the first stage of "Proton" LV fall (map-scheme of soils and photos in Figs. 1 and 2) were studied. In 2000-2007 the soil was discovered in UDMH. In June 2017, the man-made disruption of the soil structure (funnel depth 0.5-4.0 m, diameter of 1.5-7.0 m), planar and linear erosion (micro-gullies with a depth of 10-25 cm) was identified.

In the semi-desert landscape of Central Kazakhstan, accumulation of UDMH occurs on the sorption-biogeochemical barrier of humus horizons and sorption geochemical barrier of the illuvial soil horizons (water-resistant clay and loam in the upper soil layers). Oxidation of UDMH and migration of its

Fig. 1a Baikonur Cosmodrome.

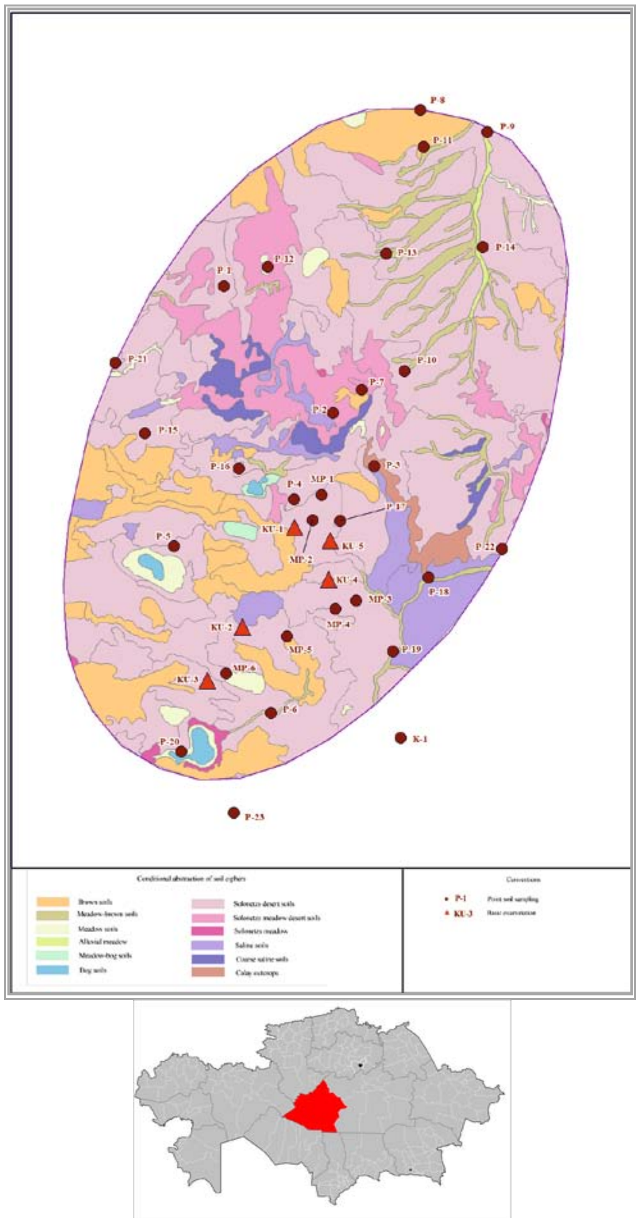

Fig. 1b Central Kazakhstan Karaganda region and soil map of the Yu-2 zone.

transformation products with surface and soil runoff occurs in soils with oxidative alkaline and slightly alkaline conditions [6, 7].

In June 2017, the water-physical properties of 17 samples from soil profiles in 3 sections were studied in the area of Yu-2 (Central Kazakhstan), within the framework of environmental monitoring of SLV SP IA (two on the ground of falling SLV SP, one at the control point with relatively clean soil). Determination of pH of medium was conducted by the method of salt extraction of TIN (GOST 26483-8523-85).

2.2 Materials and Methods

In 10 samples of surface soil layer 0-25 cm, the total microbial number (TMN) of ammonification (colony forming units, CFU) was determined by the seeding of soil samples in the diagnostic nutrient medium—meat-peptone agar (MPA) and starch-ammonia

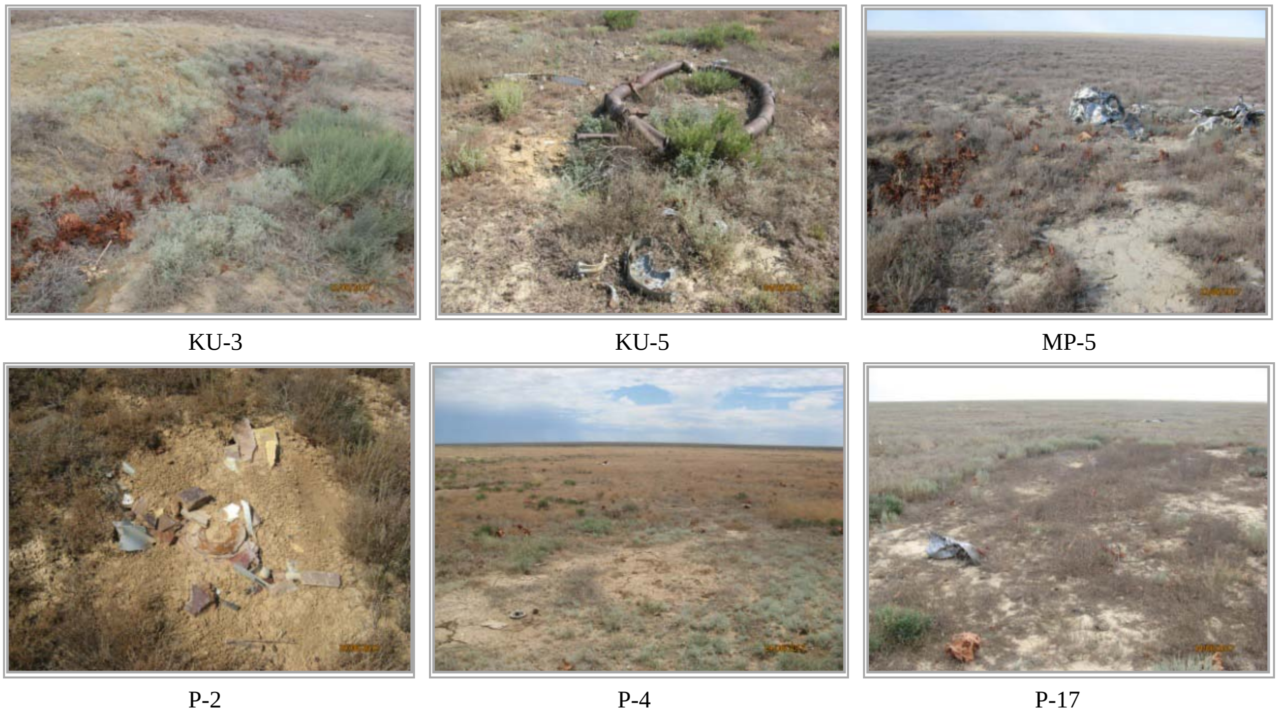

Fig. 2 Places of falling of the first stage of "Proton" LV in the area of Yu-2 in June 2017.

agar (SAA) [8]. For isolation of actinomycetes we used nutrient medium 2 GAUZE [9], microscopic fungi-nutrient medium Capek. For spore-forming bacteria was carried out after the preliminary heating of the soil sample [10]. Analysis of the direction of the processes of biological transformation of organic matter in the soil is performed using the estimated coefficient of mineralization-immobilization of nitrogen [11]. The intensity of soil respiration (mg $CO^2/m^2/h$) is determined by taking into account the quantitative changes in carbon dioxide in the soil atmosphere [12]. Characteristics of phytotoxicity of soil samples were obtained on the basis of radish test culture *Raphanus sativus* L. var. Sativus [13]. The degree of soil toxicity is determined by the difference in the number of sprouted seeds (% of the total number of seeds) and the length (cm) of sprouts and roots in the experiment and control. If seed growth deteriorates by 20-30%, the soil is considered toxic [14].

3. Results and Discussion

3.1 Analysis of Chemical Properties of Saline Soil Samples Taken in "Proton" LV in the Yu-2 Zone

At the two sites of the first stage of "Proton" LV with historical soil contamination of UDMH (2000-2007) in June 2017, soil sections were made—in small brown solonetzic (KU-2) and in brown saline sandy loam soils (KU-3). For comparison, an incision was made in the control of brown saline alkali soil solonetzic light loamy soils (K-1) (soil schematic map in Fig. 1, Table 1).

By type of salinization sulfate-chloride on 32-72 cm in soil profile, amount of salt 0.77%, the degree of salinization is average, deeper in the layer 77-99 cm 0.985% the type of salinization sulfate degree of salinization is strong. Horizons KU-3 (from 05/09/2000) the weighted average value of the dense residue in the layer 55-90 cm 0.21%. Salinity type is mainly sulphatic and less sulphate of soda, the degree

Table 1 Water extraction of soil (in %/m, EQ, on absolutely dry soil).

Horizon	Depth (cm)	Amount of salts, %	Amount		HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	Ka^+
КU-2: The place where the LV "Proton" first steps fell in 30/12/1998 Solonetz brown small											
A	0-9	0.025	0.11	0.29	0.007	0.00	0.009	0.002	0.000	0.001	0.006
					0.11	0.00	0.18	0.10	0.00	0.04	0.15
B_1	9-21	0.062	0.33	0.91	0.015	0.003	0.028	0.006	0.005	0.004	0.001
					0.25	0.08	0.58	0.30	0.41	0.17	0.03
B_2	21-32	0.055	0.52	0.73	0.027	0.003	0.010	0.008	0.001	0.005	0.001
					0.44	0.08	0.21	0.40	0.08	0.22	0.03
BC	32-77	0.766	0.28	11.4	0.017	0.000	0.21	0.40	0.08	0.22	0.03
					0.28	0.00	0.534	0.180	0.024	0.008	0.003
C_1	77-99	0.985	0.33	14.52	0.015	0.003	0.681	0.260	0.012	0.010	0.004
					0.25	0.08	14.19	13.00	0.99	0.43	0.10
C_2	99-196	0.991	0.33	14.6	0.015	0.003	0.68	0.27	0.006	0.011	0.003
					0.25	0.08	14.2	13.5	0.49	0.48	0.08
КУ-3: The place where the LV "Proton" first steps fell in 05/09/2000 Brown alkaline sandy loam soils											
A	0-12	0.027	0.08	0.37	0.05	0.00	0.014	0.004	0.001	0.001	0.002
					0.08	0.00	0.29	0.20	0.08	0.04	0.05
B	12-32	0.076	0.75	0.96	0.041	0.003	0.010	0.002	0.000	0.019	0.001
					0.67	0.08	0.21	0.10	0.00	0.83	0.03
BC	32-55	0.079	0.59	1.07	0.034	0.001	0.023	0.002	0.004	0.014	0.001
					0.56	0.03	0.48	0.10	0.33	0.61	0.03
C1	55-90	0.207	0.31	2.97	0.017	0.001	0.128	0.046	0.002	0.010	0.003
					0.38	0.03	2.66	2.30	0.16	0.43	0.08
C2	90-185	0.526	0.25	7.73	0.015	0.000	0.359	0.126	0.010	0.01	0.005
					0.25	0.00	7.48	6.30	0.82	0.48	0.13
К-1: Control point with conditionally clean soil at contiguous territory. Brown solonetzic-solonchakous light loamy soils											
A	0-14	0.050	0.39	0.63	0.022	0.001	0.012	0.002	0.001	0.008	0.004
					0.36	0.03	0.24	0.10	0.08	0.35	0.10
B1	14-28	0.116	1.19	1.45	0.068	0.03	0.012	0.004	0.000	0.028	0.001
					1.11	0.003	0.26	0.20	0.00	1.22	0.03
B2	28-44	0.083	0.47	1.18	0.027	0.001	0.034	0.008	0.006	0.006	0.001
					0.44	0.03	0.71	0.40	0.49	0.26	0.03
BC	44-89	0.953	0.53	14.13	0.017	0.009	0.653	0.240	0.018	0.013	0.003
					0.28	0.25	13.60	12.00	1.48	0.57	0.08
C1	89-115	0.418	0.25	6.09	0.015	0.000	0.280	0.110	0.002	0.008	0.003
					0.25	0.00	5.84	5.50	0.16	0.35	0.08
C2	115-163	0.069	0.36	0.93	0.022	0.000	0.027	0.010	0.001	0.007	0.002
					0.36	0.00	0.57	0.50	0.08	0.30	0.05

of salinity is weak, 90-185 layer 55-90 cm of 0.53%, the degree of salinity of medium. Horizons KU-1: By type of salinization sulfate salinity on 44-89 cm in soil profile, amount of salt 0.99%, the degree of salinity is strong, deeper than 89-115 cm 0.418% salinity type sulfate salinity degree is average (Table 1).

The Solonets are soils that have in the humus horizon such an amount of exchangeable sodium (in the practical absence of easily soluble salts), which causes their specific properties such as alkaline reaction, the formation of soda, high solubility of organic matter, high dispersion of soil fine-grained, soil viscosity and swelling in the wet state, strong compaction and hardness during drying. Solonets have low water permeability and weak physiological availability of moisture [15].

Thus, in the area of Yu-2, granulometric composition of chestnut and solonets soils clay and loam. These soils have poor water permeability so the roots of plant develop poorly and humus accumulates in small quantities, it is assumed increased absorption capacity (accumulation) of liquid propellant (heptyl) in soil horizons, against the background of weak physiological availability of moisture. At the same time, the increased exchange capacity in the saline horizon forms the ability of the soils of the Yu-3 zone to transform the LRF, due to the high content of silt particles and exchange sodium in the Solonets. Determination of the diffusion nature of mass transfer of UDMH with simultaneous processes of its destruction, depends on the type of soil and the degree of its moisture.

Thus, in the area of Yu-2 physical, the chemical composition of the brown semi-desert soil is a small amount of humus. pH is neutral or weak alkaline. Granulometric composition of the soil clay and loam, a significant capacity of absorption of rocket fuel (heptyl) is assumed. Brown semi-desert soils contribute to oxidation and migration of liquid rocket fue, and Solonets can accumulate liquid rocket fuel (LRF) in the upper soil horizons and further ensure the migration of pollution.

3.2 Analysis of Microbiological Indicators of Soils in the Area of Yu-2

In June 2017, the soil cover SLV SP (brown soils, brown saline sandy loam, small brown Solonets, meadow and desert Solonets, clays) is characterized by a low capacity of humus horizons (about 12 cm), and, accordingly, a small number of soil microbes and bacteria. Nevertheless, in some samples the signs of active life activity of soil microorganisms performing the functions of biological transformation of chemical pollution, synthesis of organic matter and restoration of soil structure disturbed by falling fragments of the first stage of LV “Proton” were noted (Table 2).

The largest zones of Yu-2 indicators are detected in the sample of brown soils of MP-5 (the place of the fall SLV SP of 04/04/1991) where the respiration rate of soils (510 mg $CO^2/m^{-2}/h^{-1}$) total number of germs grown on organic and mineral forms of nitrogen is 50 million CFU/g (TBC in MPA) and 91 million CFU/g (TBC on KAA), the number of spore forming bacteria—150 thousand CFU/g Minimum microbiological parameters (salt desert P-17, КУ5) in the tens and even hundreds of times lower than the maximum values (brown soils of MP-5). Compared with the control of K-1 (brown saline-saline light loamy soils) , the number of soil microorganisms at the sites of the fall of SLV SP is underestimated—in 67% of cases of ohms per MPA and the number of spore bacteria; in 44%—actinomycetes; in 22%—microscopic fungi.

In 2017 (as compared to 2011), the number of soil microorganisms decreased in the area of Yu-2 at the sites of SLV SP fall (Table 3). In 86% of the considered cases (in 6 out of 7 samples) the total number of microorganisms consuming organic forms of nitrogen (omch per MPA) decreased by tens, hundreds and thousands of times, and the number of microorganisms on mineral forms of nitrogen (omch per CAA)—by 1.2-65 times. The number of actinomycetes increased in brown ku-2 Solonets (from 0.4 to 4.6 million CFU/g) and in brown soils MP-5 (from 0.1 to 1.0 million CFU/g). An increase in the number of spore-forming bacteria in 5 samples out of 7 examined, with the exception of desert saline P-4 and K-1 control soil, was noted.

Marked increase in the rate of mineralization of nitrogen. In 2017 (compared to 2011), the coefficient of mineralization (the ratio of SLV SP to KAA/MPA) increased by several orders of magnitude—in the brown shale ku-2 (from 0.02 to 21.4), hundreds of times—in the brown shale sandy soils KU-3 (from 0.1

Table 2 The multiplicity of the number of microorganisms in the upper soil layer compared to the control soil K-1 in 2017.

Code samples, date of the fall of the SLV SP, soil type	Omch on MPA, CFU/g	Omch on KAA, CFU/g	Actinomycetes; CFU/g	Microscopic fungi CFU/g	Spore bacteria, CFU/g
MP-5, LV start-up date 04.04.1991 brown soil	8.9	13.8	5.6	1.7	5.4
KU-3, LV start-up date 05.09.2000 brown alkaline sandy loam soil	0.2	13.0	0.7	6.0	2.4
KU-2 , LV start-up date 30.12.1998 salt brown small	0.4	6.8	25.6	16.7	0.4
P-2, LV start-up date 05.12.2010 salt meadow	0.2	3.6	2.9	1.0	1.1
KU-5, LV start-up date unknown, salt desert	0.2	1.7	0.3	0.2	0.1
P-4, LV start-up date 31.05.1989 salt desert	7.7	3.6	6.7	0.3	0.2
P-17, LV start-up date unknown salt desert	0.05	0.03	0.06	1.7	0
P-21, LV start-up date unknown salt desert	0.4	1.7	0.3	4.3	0.3
P-3, roughly LV start-up date 1985-1987 clays	1.07	8.5	2.8	10.0	0.3

Table 3 Comparative analysis of microbiological indicators and phytotoxicity of soils in the area of Yu-2 according to 2011 and 2017.

Code soil samples	Seed germination, %	Omch on MPA, million.KOE/г	Omch on KAA million, CFU/g	Mineralization coefficient— nitrogen immobilization The ratio of omch to KAA/MPA	Actinobacteria million, CFU/g	Spore bacteria, thousand. CFU/g	Microscopic fungi, CFU/g	The relationship of the number of fungi/spore bacteria	Breathing intensity mg $CO_2/m^{-2}/h^{-1}$
MP-5, LV start-up date 04.04.1991 brown soil	60 100	55 50	160 91	2.9 1.8	0.1 1.0	1.4 150.0	50.0 5.0	35.7 0.03	450 510
KU-3, LV start-up date 05.09.2000 brown alkaline sandy loam soil	80 20	350 1.1	25 86	0.1 78.2	0.5 0.1	0.2 66.0	0 18.0	0 0.3	440 310
KU-2 , LV start-up date 30.12.1998 salt brown small	80 0	3300 2.1	54 45	0.02 21.4	0.4 4.6	0.3 12.0	0 50.0	0 4.2	400 210
P-2, LV start-up date 05.12.2010 salt meadow	40 0	180 1.0	200 24	1.1 24.0	0.5 0.5	3.6 31.0	0 3.1	0 0.1	410 210
P-4, LV start-up date 31.05.1989 salt desert	80 20	14 43	170 24	12.1 0.6	2.8 1.2	28.0 5.0	10.0 1.0	0.4 0.2	450 420
P-3, roughly LV start-up date 1985-87 clays	20 0	100 6.0	510 56	5.1 9.3	7.0 0.5	0.7 9.0	1.0 30.0	1.4 3.3	420 210
K-1, brown alkaline and saline soils	80 0	270 5.6	430 6.6	1.6 1.2	0.3 0.2	100.0 28.0	53.0 3.0	0.5 0.1	420 210

Note: in the numerator (2011), the denominator (indicators, 2017).

to 78.2), dozens of times—in the saline meadow P-2 (from 1.1 to 24.0), and less than 2 times—in the clays P-3 (from 5.1 to 9.3).

The fertile properties of saline soils of the Yu-2 zone were deteriorated. In 2011, the percentage of convergence of plants from soil samples from the sites of SLV SP fall was 40-80%, with the exception of p-3 clays. In 2017, 9 soil samples were found to be phytotoxic (convergence 0-20%). The only specimen in the brown soil of the MP-5 has provided 100% of radish sprouts.

Thus, the signs of the depressed state of soil microflora were established 10-20 years after the fall of the SLV SP. A possible cause of the anomalies detected in 2017 (reduced microbiological parameters, phytotoxicity of brown saline soils and Solonets) may be technogenic changes in the morphological and physico-chemical properties of saline soils-the presence of saline clay, low humus content and high content of carbonates.

4. Conclusions

Thus, the natural conditions of the Yu-2 zone (salinity of soils and oppression of soil microflora) provide resistance to chemical pollution of liquid rocket fuel (LRF) (potential for chemical reactions of LRF with carbonate layers of soils), and low potential of soil microflora to biological processing of chemical pollution of LRF. Microbiological restoration of technogenically disturbed fertile soil layer in the area of Yu-2 is extremely difficult in conditions of increased soil salinity, in the presence of saline clay and high content of carbonates. In 2017, reduced microbiological parameters were found in the soils at the sites of the fall. Phytotoxicity of all studied samples of brown saline soils and Solonets of brown, meadow, desert was found. Soil microorganisms are sensitive to soil contamination of ndmg, changes in their numerical and qualitative composition can serve as an indicator of anthropogenic disturbances of soil structure in the fall of the first stage of LV “Proton” in the area of Yu-2.

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