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IMPACT OF POLLUTANTS IN THE SOIL OF THE AGROLANDSCAPE OF THE RECULTIVATED LANDFILL ON CROPS

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After recultivation of municipal solid waste (MSW) landfills using sewage sludge, such landfills should become environmentally sustainable and productive agricultural landscapes. Sewage sludge significantly impacts the productivity of the newly created agricultural landscape and the quality of agricultural products when creating the arable layer of the recultivated MSW landfill. The research aims to study and analyze the influence of heavy metals and arsenic in the soil of the recultivated landfill on the yield and quality of agricultural products.

Perennial grasses on the reclaimed landfill are forced to adapt to adverse environmental conditions, which leads to a loss of plant resistance. The research was required due to the presence of heavy metals and other pollutants in the soil, which negatively impact agricultural products and their quality and are also associated with a wide range of physiological and biochemical changes in plants.

The results of the chemical analysis of Triticosecale, Bromus inermis Leyss, and Festulolium showed low levels of mercury, cadmium, lead, arsenic, copper, and zinc, as well as their suitability for feed. Physico-chemical analysis showed that the most significant amount of crude protein (27.5 g/kg) from the studied samples is contained in Bromus inermis Leyss, crude fiber – in Triticosecale (Option 3) (35.04 g/kg), crude ash – in Festulolium (Option 3) (11.7 g/kg).

Keywords: *polygon; agrolandscape; Triticosecale; Festuloliuma; Bromus inermis Leyss; microbiological studies; parasitological studies; heavy metals; arsenic*

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ВЛИЯНИЕ ПОЛЛЮТАНТОВ В ПОЧВОГРУНТЕ АГРОЛАНДШАФТА РЕКУЛЬТИВИРУЕМОГО ПОЛИГОНА НА СЕЛЬСКОХОЗЯЙСТВЕННЫЕ КУЛЬТУРЫ

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После рекультивации полигонов твердых коммунальных отходов (ТКО) с использованием осадка сточных вод, такие полигоны должны стать экологически устойчивыми продуктивными сельскохозяйственными ландшафтами. На продуктивность вновь созданного сельскохозяйственного ландшафта и качество сельскохозяйственной продукции существенное влияние оказывает осадок сточных вод при создании пахотного слоя рекультивированного полигона ТКО. Целью исследования является изучение и анализ влияния тяжелых металлов и мышьяка в почвогрунте рекультивируемого полигона на урожайность и качество сельскохозяйственной продукции.

Многолетние травы на рекультивированном полигоне вынуждены адаптироваться к неблагоприятным условиям окружающей среды, что приводит к потере устойчивости растений. Проведение исследований потребовалось в связи с наличием в почвогрунте тяжелых металлов и других загрязняющих веществ, которые оказывают негативное влияние на сельскохозяйственную продукцию и её качество, а также связаны с широким спектром физиологических и биохимических изменений в растениях.

Результаты химического анализа Triticosecale, Bromus inermis Leyss и Festulolium показали низкие содержания ртути, кадмия, свинца, мышьяка, меди и цинка, а также их пригодность для корма. Физико-химический анализ показал, что наиболее значительное количество сырого белка (27.5 г/кг) из исследуемых образцов содержится в Bromus inermis Leyss, сырой клетчатки – в Triticosecale (Вариант 3) (35.04 г/кг), сырой золы – в Festulolium (Вариант 3) (11.7 г/кг).

Ключевые слова: *полигон; агроландшафт; Triticosecale; Festuloliuma; Bromus inermis Leyss; микробиологические исследования; паразитологические исследования; тяжелые металлы; мышьяк*

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Introduction

The amount of waste is growing all over the world every year. *T*he amount of waste generated in Russia over the past decade has increased annually from 3,735 million tons to 6,221 million tons, i.e., by 66.5%. For 7 years, the volume of removed municipal solid waste [MSW] increased by 39 million m^3, i.e., by 16.6% [4]. Overloaded landfills are subject to closure with subsequent recultivation and the creation of agricultural landscapes[11]. Soil is used for the recultivation of polygons. The use of sewage sludge as the soil will increase soil fertility and simultaneously involve secondary resources in the economic cycle.

In the conditions of a recultivated landfill, perennial grasses are forced to adapt to unfavorable environmental conditions, which leads to a decrease in plant resistance. The need for research arose due to the complex of physiological and biochemical changes in plants because of the heavy metals and other pollutants in the soil, which negatively affect the yield and quality of agricultural products.

Once MSW landfills are reclaimed with sewage sludge [SS], they should represent environmentally sustainable productive agricultural landscapes. The use of SS in the creation of the arable layer will have a significant impact on the productivity of the newly created agricultural landscape and the quality of agricultural products.

Materials and methods

The aim of the study is to study and analyze the effect of heavy metals and arsenic in the soil of the recultivated landfill on the yield and quality of agricultural products.

The research object is a newly created agricultural landscape on the reclaimed SMW landfill. The SMW landfill is situated in the northwestern part of Barnaul. Its reclaiming and agricultural landscape creating were completed in August 2019. The technical stage of reclamation was carried out according to the instructions of the Ministry of Construction, Housing, and Utilities (Minstroy).

The SMW landfill was reclaimed to restore the state of the environment and restructure the territory into a state suitable for economic exploitation [21]. The landfill was reclaimed in two stages: biological and technical. The technical stage included the following steps: (1) development of technological and construction measures; (2) development of solutions and structures for the installation of protective screens in the grounds and on the surface of the landfill; (3)

collection and utilization of biogas; and (4) collection and treatment of leachate and surface wastewater [24].

The biological stage of reclamation included agrotechnical and phytomeliorative measures aimed to restore disturbed lands. The biological stage followed the engineering-technical stage of reclamation.

The final stage of technical reclamation of the SMW landfill consisted of applying a reclamation layer. The thickness of the reclamation layer is 65 cm. The thickness of the potentially fertile layer is 50 cm, which corresponds to the necessary operating conditions for machines and mechanisms for laying soil over loam. The thickness of the filling layer of economically fertile soil is 15 cm. It is determined according to the sanitary and hygienic norms of reclamation [20].

For the biological stage of reclamation and further research, we used the instruction of Minstroy of Russia and the method of B.A. Dospekhov. Chemical analysis of soil and crops was carried out according to generally accepted methods. The data were processed with the use of statistical methods.

Results

For reclaiming the SMW landfill site in Barnaul and creating an agricultural landscape, we used soil or sewage sludge of urban complex treatment facilities as soil. The field experience of SS using was laid at the reclamation stage in the following options:

- Soil (606 t/ha);
- Sewage sludge + soil (303 t/ha + 303 t/ha);
- Sewage sludge (606 t/ha), control [2].

The technical stage was carried out according to the instructions approved by the Minstroy of Russia. The climate of the SMW site is continental [26]. Fig. 1 shows the weather conditions of the SMW site during the growing season.

Average temperatures during the growing season ranged from 11.8 °C in May to 19.9° C in July.

The total amount of precipitation during the growing season in 2020 was 47 mm more compared to 2021. The maximum amount of precipitation during the growing season was in July 2021.

The soil and sewage sludge used in the field tests were taken from Barnaul Vodokanal LLC. The characteristics of the experimental soil are as follows: chernozem, ordinary, thin, and medium loamy.

Sewage sludge for the experiment was taken in the dewatering areas (sludge sites) of complex treatment facilities in Barnaul, with established storage periods of more than five years. The SS characteristics are as follows: It is a homogeneous loose mass with a mass fraction of moisture not more than 60% and organic matter not less than 32.8%.

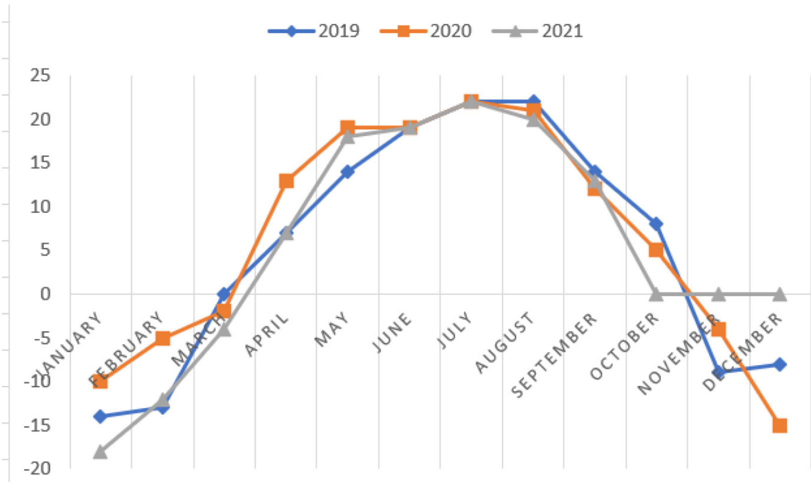

Fig. 1. Air temperature, °C

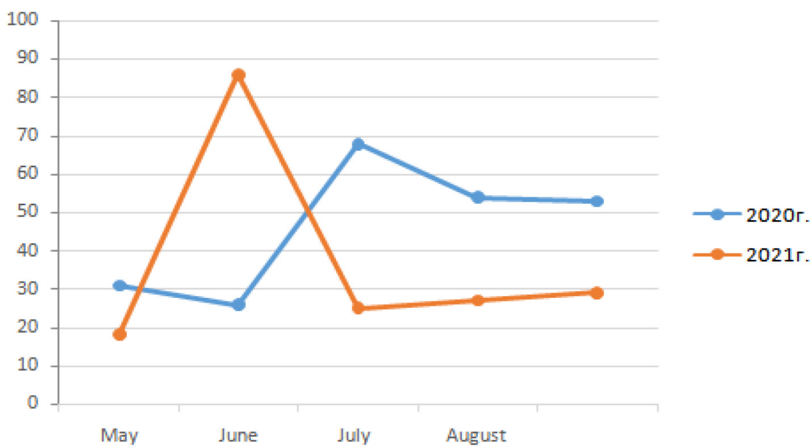

Fig. 2. Amount of precipitation, mm

Table 1 presents the physicochemical indicators of the dirt and soil of the agricultural landscape according to the options for reclamation of the landfill [27].

Table 1.

Physicochemical indicators of agricultural landscape soils according to the options of the reclaimed area of the SMW landfill in Barnaul

Indicator	Option 1 (soil)	Option 2 (SS and soil mixture)	Option 3 (SS)
pH, saline	6.5	5.5	5.7
pH, aqueous	7.8	5.9	5.8
Humus	3.2	7.8	8.7
Nitrate nitrogen, mg/kg	1,6	141.0	380.0
Mobile phosphorus, mg/kg	283.5	1,756.6	1,938.2
Exchangeable potassium, mg/kg	193.1	313.5	291.6
Total nitrogen, %	0.06	0.28	0.23
Total phosphorus, %	0.35	1.85	2.38
Total potassium, %	0.14	0.11	0.98

The reclaimed SMW landfill site has characteristics of the upper soil layer of the agricultural landscape according to the options bordering on a neutral reaction of the medium (pH, aqueous – 5.8 to 7.8), a high content of mobile phosphorus (min 283.5; max 1938 mg/kg), and the content of exchangeable potassium (min 193.1; max 313.5 mg/kg).

Microbiological studies of soil soils of three variants on the index of BHCP, enterococci index, pantogenic bacteria, including salmonella showed the absence of pathogenic microflora. Parasitological studies on viable eggs and larvae of helminths and cysts of pathogenic intestinal protozoa showed their absence.

Determining the effect of using sewage sludge at various rates on crop yield was carried out according to *Triticosecale, Bromus inermis Leyss,* and *Festulolium* (Table 2).

Table 2.

Productivity of Triticosecale, Festulolium, and Bromus inermis Leyss with the introduction of various SS rates during the reclamation of the SMW landfill in 2021

Option	Yield, t/ha		
	Triticosecale (grain)	*Festulolium* (green mass)	*Bromus inermis Leyss* (green mass)
Option 1	3	3.1	6.72
Option 2	8.52	5.1	8.4
Option 3	4.32	14.6	11.3
Least significant difference (LSD), dt/ha	0.42	0.21	0.23

The maximum yield of *Triticosecale* was obtained in Option 2, *Festulolium*, and *Bromus inermis Leyss* – in Option 3. Significant differences in crop yields of the options are confirmed by the analysis of data variance. The difference in the yield of the options is more than 84% .

The quantitative indicators of heavy and toxic elements in crops grown on a newly created agricultural landscape should not exceed the maximum permissible concentration (MPC) established for farm animal feed (Table 3) [27].

Table 3.

The content of heavy and toxic elements in crops grown on the newly created agricultural landscape

Crop	Option	Mercury, mg/kg	Cadmium, mg/kg	Lead, mg/kg	Arsenic, mg/kg	Copper, mg/kg	Zinc, mg/kg
Triticosecale (grain)	1	0.0096	0.14	1.1	0.035	2.46	28.45
	2	0.0079	0.13	0.96	0.028	2.57	25.75
	3	0.0084	0.15	0.78	0.029	2.82	28.8
Bromus inermis Leyss	1	0.0079	0.123	1.60	0.030	7.65	28.04
	2	0.0089	0.117	1.75	0.041	6.80	29.85
	3	0.0082	0.133	1.35	0.036	8.45	32.37
Festulolium	1	0.0092	0.100	1.90	0.037	3.95	20.00
	2	0.0104	0.125	2.20	0.44	5.72	29.35
	3	0.0098	0.119	1.50	0.035	5.96	30.90
MPC		0.05	0.3	5.0	0.5	30.0	50.0

Table 4.

Nutritional value of crops on the newly created agricultural landscape of the SMW landfill

Crop	Option	Mass fraction of crude protein, g/kg (not less than)	Mass fraction of crude fiber, g/kg (not more than)	Mass fraction of crude ash, g/kg (not more than)
Triticosecale (grain)	1	5.94	33.43	6.8
	2	5.94	32.07	7.0
	3	7.56	35.04	10.08
Bromus inermis Leyss	1	27.00	16.33	10.02
	2	28.94	18.17	10.8
	3	27.00	17.97	10.02
Festulolium	1	18.19	18.63	9.07
	2	25.00	18.20	10.8
	3	25.63	18.77	11.7

Chemical analysis results of *Triticosecale, Bromus inermis Leyss*, and *Festulolium* showed low levels of mercury, cadmium, lead, arsenic, copper, and zinc, as well as feed suitability.

The following results were obtained according to the results of tests of *Bromus inermis Leyss* and *Festulolium* green mass and *Triticosecale* grain in the quantitative ratio of nutrients necessary for optimal health, development, and maximum productivity of animals (Table 4).

The maximum yield was obtained due to SS options used in creating an agricultural landscape of the reclaimed SMW landfill.

Discussion

Many scientists have been engaged in the issues and problems of the landscapes and agricultural lands formation, their design, and the provision of environmentally safe functioning. These include N. A. Solntsev [22], V. A. Nikolaev [16], K. N. Dyakonov [7], I. I. Mamai [12], A. G. Isachenko [8], L. V. Kireicheva [15], N. I. Parfenova [18], B. S. Maslov [13], V. I. Kiryushin [10], A. I. Golovanov, E. S. Kozhanov, Yu. I. Sukharev [5]. Analytical study of Russian and foreign literature testifies the high value of sewage sludge as fertilizer [9; 14; 17; 19; 25; 28; 29]. The objective conclusion was made about the equivalence of sewage sludge and litter manure in agronomic terms. Due to the peculiarities of the chemical composition of sewage sludge, its use as a soil in the formation of agricultural landscapes can cause (1) the accumulation of various pollutants in the soil and (2) an increase in heavy metals in feed crops (I. P. Kanardov, R.P. Vorobyova, L.V. Kireicheva, G. E. Merzlaya, D.P. Gostischev, N.A. Romanenko, etc.) [3;6;23]. The researchers noted that with the abnormal use of sewage sludge as fertilizers, a number of negative processes occur. Among them are (1) soil contamination, (2) contamination of soils and groundwater with heavy metals and other pollutants, (3) salinization and alkalization of the soil, (4) reduction of its biological activity due to the development of pathogenic microflora.

Conclusion

The research results allow us to draw the following conclusions:

- The increased content of heavy and toxic elements in the soil of Option 3 (with the introduction of 606 t/ha of sewage sludge during the formation of the agricultural landscape) did not affect the yield and quality of agricultural products within the standards in the future;
- The absence of enterococci, pathogenic bacteria (including salmonella), viable eggs, helminth larvae, and cysts of pathogenic intestinal protozoa

detected in the soil of agricultural landscapes will not lead to their presence in agricultural products;
- The heavy and toxic elements in crops grown in the newly created agricultural landscape do not exceed the MPC for farm animal feed.

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