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EFFECTS AND CONSEQUENCES OF SEWAGE SLUDGE FROM URBAN WASTEWATER AND THEIR COMBINATIONS WITH ZEOLITE ON SOIL FERTILITY AND PRODUCTIVITY OF GRAIN CROPS

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Abstract

The intensive development of agricultural production in the forest-steppe regions requires solving the problem of preserving the soils and their effective fertility. In this regard, the development and implementation of technological methods for preventing soil degradation in agricultural areas using local cheaper raw materials and agronomic ores (fertilizing ores) are the urgent areas of modern agronomic science. The purpose of the research was to study the effects and consequences of sewage sludge from urban waste waters and their combinations with zeolite on soil fertility and productivity of grain crops. It was found that the reclamation rates of urban wastewater sludge in combination with zeolite-containing agronomic ores increased the humus content in the arable layer of the soil by 0.23-0.36%, provided transformation soils from unsatisfactory structural state into a class with good soil and reduced the bulk soil density of the arable layer by 0.12-0.21 g/cm^3 The urban sewage sludge (160 and 180 t/ha) and the urban sewage sludge (140-180 t/ha) in combination with zeolite increased the productivity of grain crops by 57.8-70.0%.

Key words*: zeolite, humus, structure, density, acidity.*

INTRODUCTION

Intensive use of arable land with a low level of application of organic and mineral fertilizers has led to the development of physical, chemical, biological degradation of soils and reduced productivity of crops.

Among degradation processes the most widespread are dehumification, destructuring, acidification, re-compaction and soil slitization (Arefyev et al., 2017).

Improvement and stabilization of soil fertility is impossible without the development and implementation of methods of biological and chemical land reclamation.

At present, there is significant foreign experience in using local raw materials and agronomic ores to prevent soil degradation and increase crop productivity (Alvarenga et al., 2019; Mitri et al., 2019; Melece and Shena, 2019).

In Russian agriculture the use of local raw materials and agronomic ores is limited. In this regard, there is a need for scientific justification, development and implementation of technological methods for biological and chemical land reclamation of soils of the forest-steppe Volga region based on them (Proskoryakova, 2005; Korolev, 2007).

MATERIALS AND METHODS

To achieve this goal in the first agricultural soil allotment in the Penza region, field experience was laid down according to the following scheme: 1. Without Urban Sewage Sludge (USS) and zeolite (control); 2. Zeolite 10 t/ha; 3. USS 100 t/ha; 4. USS 120 t/ha; 5. USS 140 t/ha; 6. USS 160 t/ha; 7. USS 180 t/ha; 8. USS 100 t/ha + zeolite 10 t/ha; 9. USS 120 t/ha + zeolite 10 t/ha; 10. USS 140 t/ha + zeolite 10 t/ha; 11. USS 160 t/ha + zeolite 10 t/ha; 12. USS 180 t/ha + zeolite 10 t/ha.

The experiment was conducted three times, the variants in the experiment were placed by the method of randomized repetitions, the accounting area of the first allotment was 4 m^2. The studies were carried out in arable crop rotation. The soil of the experimental allotment is represented by meadow-chernozem leached low humus medium thick medium loamy soil. The humus content in the arable layer was 5.09-5.12%, alkaline hydrolyzable nitrogen - 119.9-120.6 mg/kg of soil, mobile phosphorus -

101.7-102.1 mg/kg of soil, mobile potassium - 151.8 -152.1 mg/kg of soil.

In the experiment the sewage sludge from the city of Penza (Russia) was used. It was mechanically treated and dehydrated (after four-years storage on the silt site), and could be characterized by the following indicators: pH (KCl) - 6 units and hydrolytic acidity - 2.4 meq/100 g of the urban sewage sludge, and with content of the nutrients: nitrogen - 291.0, phosphorus - 116 and potassium - 120 meq/ 100 g of the urban sewage sludge; carbon organic matter - 21.2%.

In our research the chemical composition of the urban sewage sludge was determined in laboratory conditions by the following methods: pH (KCl) extraction - according to the method for determination of exchangeable acidity (State Standard 26484-85); hydrolytic acidity - according to the Determination of hydrolytic acidity by Kappen method modified by CINAO (State Standard 26212-91); gross nitrogen - according to the Determination of mobile compounds of phosphorus and potassium by Chiricov method modified by CINAO (State Standard 26204-91), the organic matter content - according to the Methods for determination of organic matter (State Standard 26213-91).

In the experiment, zeolite (zeolite-containing agronomic ore) was used as a chemical ameliorant. The clinoptilolite content in the zeolite-containing agronomic ore was 41%. The rate of chemical ameliorant was calculated by the content of clinoptilolite in it.

Urban sewage sludge and chemical reclamation was introduced into the steam field according to the experimental scheme in 2014 for the main tillage.

RESULTS AND DISCUSSIONS

This research has established that the one-sided effect and consequences of reclamation norms for sewage sludge from urban wastewater and their effect and consequences in combination with zeolite-containing agronomic ore had a positive effect on the humus content in the arable layer of meadow-chernozem soils (Table 1).

Table 1. Humus content in the arable layer of meadow-chernozem soils, %

Variant	Pure vapour 2014	Winter wheat		Corn		Spring wheat		Oat		Pea	
		2015	± from 2014	2016	± from 2014	2017	± from 2014	2018	± from 2014	2019	± from 2014
1. Without USS and zeolite (control)	5.12	5.10	-0.02	5.08	-0.04	5.09	-0.03	5.10	-0.02	5.09	-0.03
2. Zeolite 10 t/ha	5.10	5.12	0.2	5.12	0.02	5.13	0.03	5.15	0.05	5.14	0.04
3. USS 100 t/ha	5.09	5.23	0.14	5.26	0.17	5.29	0.20	5.28	0.19	5.24	0.15
4. USS 120 t/ha	5.10	5.26	0.16	5.31	0.21	5.35	0.25	5.35	0.25	5.32	0.22
5. USS 140 t/ha	5.11	5.30	0.19	5.35	0.24	5.38	0.27	5.37	0.26	5.35	0.24
6. USS 160 t/ha	5.10	5.34	0.24	5.39	0.29	5.44	0.34	5.42	0.32	5.39	0.29
7. USS 180 t/ha	5.10	5.37	0.27	5.44	0.34	5.46	0.36	5.45	0.35	5.42	0.32
8. USS 100 t/ha + zeolite 10 t/ha	5.10	5.25	0.15	5.30	0.20	5.34	0.24	5.35	0.25	5.33	0.23
9. USS 120 t/ha + zeolite 10 t/ha	5.10	5.27	0.17	5.34	0.24	5.38	0.28	5.40	0.30	5.37	0.27
10. USS 140 t/ha + zeolite 10 t/ha	5.10	5.32	0.22	5.38	0.28	5.42	0.32	5.42	0.32	5.40	0.30
11. USS 160 t/ha + zeolite 10 t/ha	5.09	5.35	0.26	5.40	0.31	5.45	0.36	5.46	0.37	5.43	0.34
12. USS 180 t/ha + zeolite 10 t/ha	5.09	5.39	0.30	5.45	0.36	5.48	0.39	5.47	0.38	5.45	0.36
Least significant difference (LSD) p = 0.05		0.11		0.12		0.14		0.13		0.12	

Before introducing the sewage sludge from urban wastewater and zeolite, the humus content in the arable layer of meadow-chernozem soils was 5.09-5.12%.

The unilateral action and consequences of a zeolite-containing agronomic ore had an insignificant effect on the accumulation of humus in the arable layer. The humus content in this experiment varied over the years of research in the range from 5.12 to 5.15%, exceeding the initial values by 0.02-0.05%.

The sewage sludge from urban wastewater with their unilateral action and consequences, increased the humus content in the arable layer in winter wheat crops by 0.14 (USS 100 t/ha) - 0.27% (USS 180 t/ha), in corn crops - by 0.17-0.34%, in crops of spring wheat - by 0.20-0.36%, in crops of oats - by 0.19-0.35% and in crops of peas - by 0.15-0.32%

The humus content in the arable layer against the one-sided effect and consequences of the urban sewage sludge varied from 5.23 to 5.46%, depending on the sludge rate, according to years of research.

Against the one-sided effect and consequences of the urban sewage sludge in combination with zeolite-containing agronomic ore, the humus content in the arable layer slightly exceeded its content in similar variants using urban sewage sludge without zeolite and varied in 2015 in the range from 5.25 (USS 100 t/ha + zeolite 10 t/ha) up to 5.39% (USS 180 t/ha + zeolite 10 t/ha), in 2016 - from 5.30 to 5.45%, in 2017 - from 5.34 to 5.48%, in 2018 - from 5.35 to 5.47%, in 2019 - from 5.33 to 5.45%, exceeding the initial values by 0.15-0.39%.

In the arable layer of meadow-chernozem soils without spreading urban sewage sludge and zeolite-containing agronomic ore, within the years of the current research the soil acidity varied from 5.33 to 5.38 units pH (Arefiev A.N. et al., 2019). Zeolite-containing agronomic ore against the one-sided effect and consequences reduced the value of metabolic acidity in the arable layer by 0.63-0.94 pH units. After pea harvesting in 2019, the pH (KCl) value in this experiment was 6.27 units (Table 2).

Table 2. Soil acidity of the arable horizon of meadow-chernozem soils, pH (KCl)

Variant	Pure vapour 2014	Winter wheat		Corn		Spring wheat		Oat		Pea	
		2015	± from 2014	2016	± from 2014	2017	± from 2014	2018	± from 2014	2019	± from 2014
1. Without USS and zeolite (control)	5.38	5.37	-0.01	5.35	-0.03	5.36	-0.02	5.35	-0.03	5.33	-0.05
2. Zeolite 10 t/ha	5.37	6.00	0.63	6.22	0.85	6.31	0.94	6.29	0.92	6.27	0.90
3. USS 100 t/ha	5.38	5.65	0.27	5.69	0.31	5.71	0.33	5.69	0.31	5.67	0.29
4. USS 120 t/ha	5.38	5.71	0.33	5.75	0.37	5.78	0.40	5.77	0.39	5.74	0.36
5. USS 140 t/ha	5.38	5.76	0.38	5.81	0.43	5.87	0.49	5.86	0.48	5.84	0.46
6. USS 160 t/ha	5.37	5.,83	0.46	5.87	0.50	5.90	0.53	5.90	0.53	5.87	0.50
7. USS 180 t/ha	5.36	5.89	0.53	5.94	0.58	5.96	0.60	5.94	0.58	5.92	0.56
8. USS 100 t/ha + zeolite 10 t/ha	5.36	6.28	0.92	6.53	1.17	6.60	1.24	6.62	1.26	6.58	1.22
9. USS 120 t/ha + zeolite 10 t/ha	5.35	6.34	0.99	6.58	1.23	6.65	1.30	6.68	1.33	6.64	1.29
10. USS 140 t/ha + zeolite 10 t/ha	5.36	6.40	1.04	6.64	1.28	6.75	1.39	6.77	1.41	6.72	1.36
11. USS 160 t/ha + zeolite 10 t/ha	5.36	6.46	1.10	6.72	1.36	6.80	1.44	6.82	1.46	6.78	1.42
12. USS 180 t/ha + zeolite 10 t/ha	5.37	6.53	1.16	6.82	1.45	6.87	1.50	6.88	1.51	6.84	1.47
Least significant difference (LSD) p = 0.05		0.16		0.18		0.17		0.19		0.17	

The action and effect of urban sewage sludge reduced the value of soil acidity, depending on the sludge dose, by 0.27-0.60 pH units. The pH (KCl) value before pea harvesting in 2019 varied as the sediment rate increased from 5.67 to 5.92 units.

Despite the complex effect and consequences of urban wastewater and zeolite, the pH (KCl) value at the end of the research varied from 6.58 to 6.84 units, exceeding the initial values by 1.22-1.47 units.

As shown by the data presented in Table 3, the structural state of the arable layer in the meadow-chernozem soils before laying the experience was characterized as unsatisfactory. The content of water-resistant aggregates in the arable layer before the introduction of urban sewage sludge and zeolite was 38.3-38.9%.

Under grain crops without introducing the urban sewage sludge and zeolite, there was a tendency to decrease the content of water-resistant aggregates in the arable layer of meadow-chernozem soils (Table 4). After harvesting peas in 2019 the content of water-resistant aggregates in the arable layer in this embodiment was 37.7%, which was 1.2% lower than the initial one.

Table 3. The content of water-resistant aggregates in the arable horizon of meadow-chernozem soils, %

Variant	Pure vapour 2014	Winter wheat		Corn		Spring wheat		Oat		Pea	
		2015	± from 2014	2016	± from 2014	2017	± from 2014	2018	± from 2014	2019	± from 2014
1. Without USS and zeolite (control)	38.9	38.5	-0.4	37.4	-1.5	37.7	-1.2	38.0	-0.9	37.7	-1.2
2. Zeolite 10 t/ha	38.5	40.6	2.1	41.5	3.0	42.1	3.6	43.2	4.7	43.1	4.6
3. USS 100 t/ha	38.6	46.2	7.6	47.3	8.7	48.4	9.8	48.5	9.9	47.9	9.3
4. USS 120 t/ha	38.4	48.0	9.6	49.3	10.9	50.5	12.1	50.7	12.3	50.4	12.0
5. USS 140 t/ha	38.5	50.0	11.5	51.3	12.8	52.8	14.3	53.4	14.9	53.1	14.6
6. USS 160 t/ha	38.8	51.9	13.1	53.3	14.5	55.2	16.4	56.0	17.2	55.8	17.0
7. USS 180 t/ha	38.7	54.0	15.3	55.6	16.9	57.2	18.5	57.8	19.1	57.7	19.0
8. USS 100 t/ha + zeolite 10 t/ha	38.3	48.9	10.6	50.4	12.1	52.3	14.0	53.1	14.8	52.5	14.2
9. USS 120 t/ha + zeolite 10 t/ha	38.6	51.0	12.4	53.1	14.5	55.2	16.6	56.0	17.4	55.6	17.0
10. USS 140 t/ha + zeolite 10 t/ha	38.4	53.1	14.7	55.1	16.7	57.4	19.0	58.1	19.1	58.0	19.0
11. USS 160 t/ha + zeolite 10 t/ha	38.6	55.0	16.4	57.5	18.9	59.7	21.1	60.8	22.2	60.8	22.2
12. USS 180 t/ha + zeolite 10 t/ha	38.5	57.2	18.7	59.8	21.3	61.5	23.0	62.0	23.5	61.6	23.1
Least significant difference (LSD) p = 0.05		1.9		2.4		2.8		2.6		2.5	

Table 4. Bulk density of the arable layer of meadow-chernozem soils, g/cm^3

Variant	Winter wheat		Corn		Spring wheat		Oat		Pea	
	2015	*	2016	*	2017	*	2018	*	2019	*
1. Without USS and zeolite (control)	1.33	–	1.35	–	1.34	–	1.35	–	1.37	–
2. Zeolite 10 t/ha	1.29	0,04	1.31	0.04	1.29	0.05	1.30	0.05	1.33	0.04
3. USS 100 t/ha	1.26	0.07	1.27	0.08	1.26	0.08	1.27	0.07	1.30	0.07
4. USS 120 t/ha	1.24	0.09	1.26	0.09	1.24	0.10	1.25	0.10	1.29	0.08
5. USS 140 t/ha	1.22	0.11	1.23	0.12	1.21	0.13	1.23	0.12	1.27	0.10
6. USS 160 t/ha	1.21	0.12	1.21	0.14	1.19	0.15	1.20	0.15	1.24	0.13
7. USS 180 t/ha	1.19	0.14	1.20	0.15	1.18	0.16	1.20	0.15	1.23	0.14
8. USS 100 t/ha + zeolite 10 t/ha	1.23	0.10	1.23	0.12	1.20	0.14	1.22	0.13	1.25	0.12
9. USS 120 t/ha + zeolite 10 t/ha	1.22	0.11	1.21	0.14	1.19	0.15	1.20	0.15	1.24	0.13
10. USS 140 t/ha + zeolite 10 t/ha	1.19	0.14	1.19	0.16	1.17	0.17	1.19	0.16	1.22	0.15
11. USS 160 t/ha + zeolite 10 t/ha	1.16	0.17	1.17	0.18	1.14	0.20	1.17	0.18	1.19	0.18
12. USS 180 t/ha + zeolite 10 t/ha	1,14	0.19	1.16	0.19	1.13	0.21	1.15	0.20	1.18	0.19
Least significant difference (LSD) p = 0.05		0.03		0.02		0.04		0.04		0.03

*Deviation from control

Zeolite-containing agronomic ore increased the content of water-resistant aggregates by 4.6%. The number of water-resistant aggregates in this variant upon completion of research (2019)

was 43.1%, and the structural state of the arable layer was assessed as satisfactory.
The urban sewage sludge with rates from 100 to 140 t/ha, as well as the unilateral action of zeolite-containing agronomic ore, provided a satisfactory structural state of the arable layer. The content of water-resistant aggregates in the arable layer against the one-sided consequences of urban sewage sludge varied in 2019 from 47.9 to 53.1%, exceeding the initial values by 9.3-14.6%.
A satisfactory structural state of the arable layer was also noted after introduction of 100 t/ha of urban sewage sludge in combination with zeolite-containing agronomic ore. The number of water-resistant aggregates in the arable layer in this embodiment exceeded the initial value by 14.2% and increased to 52.5%.
A good structural condition in the arable layer was ensured by the introduction of the urban sewage sludge with dose of 160-180 t/ha and the introduction of the urban sewage sludge with dose of 120 to 180 t/ha in combination with zeolite-containing agronomic ore. The number of water-resistant units at the same time exceeded the initial value by 17.0-23.1% and amounted to 55.6-61.6% after pea harvesting in 2019.
In the arable layer of meadow-chernozem soils without urban sewage sludge and zeolite-containing agronomic ore, the bulk density after winter wheat harvesting was 1.33 g/cm^3, after corn harvesting - 1.35 g/cm^3, after spring wheat harvesting - 1.34 g/cm^3, after oats harvesting - 1.35 g/cm^3, after peas harvesting - 1.37 g/cm^3. The drift from the optimal density according to the gradation of A.G. Bondarev was 0.03-0.07 g/cm^3 (Korchagin et al., 2011). The action and aftereffect of zeolite-containing agro-ore significantly reduced the bulk density in the arable layer by 0.04-0.05 g/cm^3.
In case of unilateral action and aftereffect of urban wastewater sludge, the bulk density in the arable layer after winter wheat harvesting was 1.19-1.26 g/cm^3, after corn harvesting - 1.20-1.27 g/cm^3, after spring wheat harvesting - 1.18-1.26 g/cm^3, after oats harvesting - 1.20-1.27 g/cm^3, after peas harvesting - 1.23-1.30 g/cm^3. Deviations from the control option were significant and varied from 0.07 to 0.14 g/cm^3 in 2015, from 0.08 to 0.15 g/cm^3 in 2016, from 0.08 to 0.16 g/cm^3 in 2017, in 2018 - from 0.07 to 0.15 g/cm^3, and in 2019 - from 0.07 to 0.14 g/cm^3.
The most significant decrease in the equilibrium density in the arable layer was observed against the background of the action and aftereffect of urban wastewater precipitation in combination with zeolite. The value of the equilibrium density against the background of their combined action and aftereffect significantly decreased in relation to the control in 2015 by 0.10-0.19 g/cm^3, in 2016 - by 0.12-0.19 g/cm^3, in 2017 - by 0.14-0.21 g/cm^3, in 2018 - by 0.13-0.20 g/cm^3, and in 2019 - by 0.12-0.19 g/cm^3.
An analysis of the total crop productivity by the method of conversion the crop into grain units made it possible to express the quantitative side of the resulting production (Arefyev et al., 2019). Studies conducted in the period from 2014 to 2019 showed the high efficiency of unilateral action and aftereffect of the urban wastewater sludge, as well as in combination with zeolite in the cultivation of grain crops.
Without the use of urban wastewater sludge and zeolite-containing agronomic ore, the total productivity of grain crops increased to 14.49 t/ha in standard units (s.u.). Despite the one-sided effect and consequences of a zeolite-containing agronomic ore, the total crop productivity was 16.23 t/ha s.u., exceeding the control by 1.74 t/ha s.u. or 12.0% (Table 5).

Table 5. The productivity of grain crops, t/ha

Variant	Total grain crops productivity	Deviation from control	
		t/ha s.u.	%
1. Without USS and zeolite (control)	14.49	–	–
2. Zeolite 10 t/ha	16.23	1.74	12.0
3. USS 100 t/ha	19.84	5.35	36.9
4. USS 120 t/ha	20.81	6.32	43.6
5. USS 140 t/ha	21.74	7.25	50.0
6. USS 160 t/ha	22.87	8.38	57.8
7. USS 180 t/ha	23.01	8.52	58.8
8. USS 100 t/ha + zeolite 10 t/ha	21.41	6.92	47.8
9. USS 120 t/ha + zeolite 10 t/ha	22.37	7.88	54.4
10. USS 140 t/ha + zeolite 10 t/ha	23.18	8.69	60.0
11. USS 160 t/ha + zeolite 10 t/ha	24.44	9.95	68.7
12. USS 180 t/ha + zeolite 10 t/ha	24.63	10.14	70.0

The effect and aftereffect of urban wastewater sludge without a zeolite-containing agronomic ore increased the crop productivity, depending on the sludge dose, by 5.35 (USS 100 t/ha) - 8.52 t/ha s.u. (USS 180 t/ha), or by 36.9-58.8%. The complex effect and consequences of the urban sewage sludge with zeolite-containing agronomic ore increased the productivity of grain crops by 6.92-10.14 t/ha s.u. or 47.8-70.0%.

CONCLUSIONS

The unilateral action and consequences of the urban sewage sludge with rates from 100 to 180 t/ha and their action and consequences in combination with zeolite-containing agronomic ore provided the maximum accumulation of humus in the arable layer of meadow-chernozem soils. The humus content during the unilateral action of urban wastewater sludge and in combination with zeolite-containing agronomic ore exceeded the initial value at the end of the research by 0.16 (USS 100 t/ha) - 0.36% (USS 180 t/ha + zeolite 10 t/ha).

The most significant effect on the acidity of the soil was exerted by the complex effect and consequences of urban sewage sludge and zeolite-containing agronomic ore. The pH value at the end of the studies varied from 6.58 to 6.84 units, exceeding the initial values by 1.22-1.47 units.

The action and consequences of the urban sewage sludge with dose of 160 and 180 t/ha and the urban sewage sludge with dose of 120 to 180 t/ha in combination with zeolite-containing agronomic ore ensured the transfer of soils from a class with an unsatisfactory structural state to a class with a good one. The number of water-resistant aggregates at the same time exceeded the initial value by 17.0-23.1% and amounted to 55.6-61.6% after pea harvesting in 2019.

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