The aftereffect of land-reclamation norms of municipal sewage residue and their combinations with zeolite on the yield and quality of crops

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Abstract. The influence of land-reclamation norms of municipal sewage residue and their combinations with zeolite-containing agronomical ore on the yield and quality of crops was shown. It was found that a complex aftereffect of municipal sewage residue and zeolite-containing agronomical ore increased the yield of common oats Konkur in 2018 by 0.76-1.22 t/ha or by 27.5-44.2%, of digestible protein content by 0.84-1.20 %, harvesting of digestible protein by 37.2-59.8%. The yield of peas Jackpot in the conditions of 2019 increased by 0.61-1.14 t/ha, or by 26.6-49.8%, protein content in pea grain – by 1.2-2.7%, the yield of winter wheat Moskovskaya 56 in 2020 – by 0.68-1.62 t/ha, or by 14.4-34.4%, the content gluten in winter wheat grain – by 1.8-4.7%.

1. Introduction
The middle Volga region is the largest grain-producing region in the Russian Federation. At the same time, the yield of grain crops over the past decades has remained at a low level. In most cases, grain is characterized by low quality, which, in addition to the complex of soil and climatic conditions, largely depends on the agricultural technology of growing grain crops [1].

One of the promising methods for increasing the yield and quality of agricultural products against the background of constantly increasing prices for mineral fertilizers is the use of non-traditional sources of plant nutrients. The latter is a constantly renewable source of organic matter and elements of mineral nutrition - municipal sewage residue, which is not inferior to manure in terms of agrochemical value but also surpasses it [2–4]. In this regard, municipal sewage residue may be used as a fertilizer for agricultural crops. Application of municipal sewage residue in the form of an organomineral fertilizer is an ecologically safe method of their disposal. Thus, the application of municipal sewage residue as a fertilizer allows solving not only agronomic and environmental, but also resource problems [5-8].

According to numerous studies, the effectiveness of the influence of municipal sewage residue on soil fertility, crop yields and the quality of crop production increases when the residue is used in a complex with chemical ameliorant [9, 10].

2. Materials and methods
The aim of the study was to study the aftereffect of the land-reclamation norms of municipal sewage
residue of Penza city and their combinations with zeolite-containing agronomical ore on the yield of common oats, peas, winter wheat and the quality of crop production.

To achieve this goal, in 2014 a field experiment was laid in the first agrosoil region of the Penza region on a meadow-chernozem, leached, low-humus, medium-thick, medium loamy soil according to the following scheme. 1. Without MSR (municipal sewage residue) and zeolite-containing agronomical ore (control). 2. Zeolite-containing agronomical ore. 3. MSR 100 t/ha. 4. MSR 120 t/ha. 5. MSR 140 t/ha. 6. MSR 160 t/ha. 7. MSR 180 t/ha. 8. MSR 100 t/ha + zeolite-containing agronomical ore. 9. MSR 120 t/ha + zeolite-containing agronomical ore. 10. MSR 140 t/ha + zeolite-containing agronomical ore. 11. MSR 160 t/ha + zeolite-containing agronomical ore. 12. MSR 180 t/ha + zeolite-containing agronomical ore.

The experiment was repeated three times, the variants in the experiment were placed by the method of randomized repetitions, and the accounting area of one plot was 4 m². The municipal sewage residue of Penza city was used in the experiment, which is characterized by the following indicators pHsol value - 6.0 units, hydrolytic acidity – 2.4 mg-eq/100 g of precipitation, total exchangeable bases - 31.6 mg-eq/100 g precipitation. Nutrients content: nitrogen - 291, phosphorus - 116 and potassium - 120 mg / 100 g of precipitation; organic matter carbon - 21.2%. The content of heavy metals in the municipal sewage residue of Penza city was characterized by the following data in mg / kg of dry matter in residue: cadmium - 6.98, nickel - 89.45, lead - 46.14, zinc - 389.73, copper - 168.42, manganese - 174.36. The concentration of heavy metals in the dry matter of the municipal sewage residue of Penza city was significantly lower than the maximum permissible concentration. A zeolite-containing agronomical ore from the Lunino deposit with a clinoptilolite content of 41% was used as a chemical ameliorant in the experiment. The municipal sewage residue and zeolite-containing agronomical ore were put into the fallow field for the main tillage in 2014. The ameliorant rate was calculated according to the content of clinoptilolite in the agronomical ore and was equal to 24.4 t/ha. Common oats (Konkur variety), peas (Jackpot variety), Moskovskaya winter wheat 56 were cultivated during the experiment.

3. Results and discussion

According to the research results, under the conditions of 2018, the yield of common oats of the Konkur variety on the variant without the use of municipal sewage residue and zeolite-containing agronomical ore was 2.76 t/ha. Zeolite-containing agronomical ore, against the background of its one-sided aftereffect, statistically increased the yield of oats by 0.39 t/ha, or 14.1%. The oat yield against the background of the one-sided aftereffect of the zeolite-containing agronomical ore was 3.15 t/ha (Table 1).

The one-sided aftereffect of municipal sewage residue depending on their rate statistically increased the grain yield of oats by 0.36 (MSR 100 t/ha) – 0.75 t/ha (MSR 180 t/ha) or by 13.0– 27.2%. The oat yield against the background of their aftereffect varied in the range from 3.12 (MSR 100 t/ha) to 3.51 t/ha (MSR 180 t/ha).

Among the variants with the aftereffect of municipal sewage residue in combination with zeolite-containing agronomical ore, the oat yield varied in the range from 3.52 (MSR 100 t/ha + zeolite-containing agro-ore) to 3.98 t/ha (MSR 180 t/ha + zeolite-containing agro-ore).

The increase in relation to the control variant was significant and amounted to 0.76-1.22 t/ha, or 27.5-44.2%.

The analysis of the research results showed that the zeolite-containing agro-ore, municipal sewage residue and their complex aftereffect had a positive effect on the content of digestible protein in oat grain.

In the control variant, the content of digestible protein in oat grain was equal to 11.12%. The one-sided aftereffect of the zeolite-containing agro-ore significantly increased the digestible protein content by 0.44%. Against the background of the one-sided aftereffect of municipal sewage residue depending on their rate, the content of digestible protein in oat grain increased in relation to the control variant by 0.39 (MSR 100 t/ha) - 0.79 t/ha (MSR 180 t/ha). The content of digestible protein in the case of one-sided aftereffect of municipal sewage residue varied from 11.51 to 11.91%.
Table 1. Yield of common oats (Konkur variety)

| Variant | Yield, t/ha | Deviation from control t/ha | %  |
|---------|-------------|-----------------------------|----|
| 1. Without MSR and zeolite-containing agro-ore (control) | 2.76 | – | – |
| 2. Zeolite-containing agro-ore | 3.15 | 0.39 | 14.1 |
| 3. MSR 100 t/ha | 3.12 | 0.36 | 13.0 |
| 4. MSR 120 t/ha | 3.30 | 0.54 | 19.6 |
| 5. MSR 140 t/ha | 3.37 | 0.61 | 22.1 |
| 6. MSR 160 t/ha | 3.51 | 0.75 | 27.2 |
| 7. MSR 180 t/ha | 3.51 | 0.75 | 27.2 |
| 8. MSR 100 t/ha + zeolite-containing agro-ore | 3.52 | 0.76 | 27.5 |
| 9. MSR 120 t/ha + zeolite-containing agro-ore | 3.68 | 0.92 | 33.3 |
| 10. MSR 140 t/ha + zeolite-containing agro-ore | 3.83 | 1.07 | 38.8 |
| 11. MSR 160 t/ha + zeolite-containing agro-ore | 3.96 | 1.20 | 43.5 |
| 12. MSR 180 t/ha + zeolite-containing agro-ore | 3.98 | 1.22 | 44.2 |

The maximum content of digestible protein was recorded in variants with the aftereffect of municipal sewage residue in combination with zeolite-containing agro-ore. The content of digestible protein against the background of their aftereffect varied in the range from 11.96 to 12.32%, exceeding the control by 0.84 (MSR 100 t/ha + zeolite-containing agro ore) - 1.20% (MSR 180 t/ha + zeolite-containing agro ore).

The one-sided aftereffect of the zeolite-containing agro-ore increased the harvesting of digestible protein by 59.5 kg/ha, or 19.4%. Against the background of the one-sided aftereffect of municipal sewage residue, the harvesting of digestible protein depending on the residue rate varied from 359.1 to 418.0 kg/ha, exceeding the control by 52.2-111.1 kg/ha, or 17.0 -36.2%.

The maximum harvesting of digestible protein was obtained against the background of a complex aftereffect of municipal sewage residue with zeolite-containing agro ore. The harvesting of digestible protein from their combined aftereffect varied from 421.0 to 490.3 kg/ha, exceeding the control by 114.1-183.4 kg/ha, or 37.2-59.8%.

In 2019, the yield of peas in the control variant was 2.29 t/ha. Against the background of the aftereffect of the zeolite-containing agro-ore, the yield of peas made up 2.67 t/ha. The increase in relation to the control variant was significant and amounted to 0.38 t/ha, or 16.6% (Table 2). The yield of peas on these variants of the experiment varied in the range from 2.69 to 3.09 t/ha.

The highest effect on the impact on the yield of peas was the aftereffect of the land-reclamation norms of municipal sewage residue in combination with zeolite-containing agro-ore. The yield of peas on these variants varied from 2.90 (MSR 100 t/ha + zeolite-containing agro ore) to 3.43 t/ha (MSR 180 t/ha + zeolite-containing agro ore), statistically exceeding the control by 0.61-1.14 t/ha, or 26.6-49.8%.

The protein content in the grain of peas in the variant without the application of municipal sewage residue and zeolite-containing agro-ore made up 20.5%. Against the background of a one-sided aftereffect of zeolite-containing agro-ore and municipal sewage residue with a rate of 100 t/ha, a tendency to an increase in the protein content in pea grain was observed (20.8-21.4%).

The one-sided aftereffect of municipal sewage residue with rates from 120 to 180 t/ha statistically increased the protein content in pea grain by 1.2 (MSR 120 t/ha) - 2.3% (MSR 180 t/ha). The protein content against the background of their aftereffect varied in the range from 21.7 to 22.8%.

Against the background of the aftereffect of municipal sewage residue in combination with zeolite-containing agro-ore, the protein content in pea grain varied from 21.7 (MSR 100 t/ha + zeolite-containing agro ore) to 23.2% (MSR 180 t/ha + zeolite-containing agro ore), statistically exceeding...
control by 1.2-2.7%.

Table 2. Yield of peas (Jackpot variety)

| Variant | Yield, t/ha | Deviation from control t/ha | % |
|---------|-------------|-----------------------------|---|
| 1. Without MSR and zeolite-containing agro-ore (control) | 2.29 | – | – |
| 2. Zeolite-containing agro-ore | 2.67 | 0.38 | 16.6 |
| 3. MSR 100 t/ha | 2.69 | 0.40 | 17.5 |
| 4. MSR 120 t/ha | 2.71 | 0.42 | 18.3 |
| 5. MSR 140 t/ha | 2.85 | 0.56 | 24.5 |
| 6. MSR 160 t/ha | 3.08 | 0.79 | 34.5 |
| 7. MSR 180 t/ha | 3.09 | 0.80 | 34.9 |
| 8. MSR 100 t/ha + zeolite-containing agro-ore | 2.90 | 0.61 | 26.6 |
| 9. MSR 120 t/ha + zeolite-containing agro-ore | 3.08 | 0.79 | 34.5 |
| 10. MSR 140 t/ha + zeolite-containing agro-ore | 3.10 | 0.81 | 35.4 |
| 11. MSR 160 t/ha + zeolite-containing agro-ore | 3.41 | 1.12 | 48.9 |
| 12. MSR 180 t/ha + zeolite-containing agro-ore | 3.43 | 1.14 | 49.8 |

least significant difference (LSD) p = 0.05

As the research results show, the yield of winter wheat in 2020 was 4.71 t/ha (Table 3) on the variant without the municipal sewage residue and zeolite-containing agro-ore,

Table 3. Yield of winter wheat (Moskovskaya 56 variety)

| Variant | Yield, t/ha | Deviation from control t/ha | % |
|---------|-------------|-----------------------------|---|
| 1. Without MSR and zeolite-containing agro-ore (control) | 4.71 | – | – |
| 2. Zeolite-containing agro-ore | 5.04 | 0.33 | 7.0 |
| 3. MSR 100 t/ha | 5.05 | 0.34 | 7.2 |
| 4. MSR 120 t/ha | 5.31 | 0.60 | 12.7 |
| 5. MSR 140 t/ha | 5.49 | 0.78 | 16.5 |
| 6. MSR 160 t/ha | 5.90 | 1.19 | 25.3 |
| 7. MSR 180 t/ha | 5.97 | 1.26 | 26.8 |
| 8. MSR 100 t/ha + zeolite-containing agro-ore | 5.39 | 0.68 | 14.4 |
| 9. MSR 120 t/ha + zeolite-containing agro-ore | 5.64 | 0.93 | 19.7 |
| 10. MSR 140 t/ha + zeolite-containing agro-ore | 5.87 | 1.16 | 24.6 |
| 11. MSR 160 t/ha + zeolite-containing agro-ore | 6.28 | 1.57 | 33.3 |
| 12. MSR 180 t/ha + zeolite-containing agro-ore | 6.33 | 1.62 | 34.4 |

least significant difference (LSD) p = 0.05

Zeolite-containing agro-ore against the background of its one-sided aftereffect statistically increased the yield of winter wheat by 0.33 t/ha, or 7.0%.

Against the background of a one-sided aftereffect of the municipal sewage residue the yield of winter wheat varied from 5.05 (MSR 100 t/ha) to 5.97 t/ha (MSR 180 t/ha). The deviation from the control variant was statistical and amounted to 0.34-1.26 t/ha, or 7.2-26.8%.

The aftereffect of municipal sewage residue in combination with zeolite-containing agro-ore statistically increased the yield of winter wheat by 0.68 (MSR 100 t/ha + zeolite-containing agro ore) – 1.62 t/ha (MSR 180 t/ha + zeolite-containing agro ore), or by 14.4-34.4%.

The gluten content in the grain of winter wheat in the control variant was 22.4%. A statistical increase in the gluten content against the background of a one-sided aftereffect of municipal sewage residue was
observed in variants with an aftereffect of residue rates 120-180 t/ha. The gluten content in the grain against the background of their aftereffect varied from 23.6 to 26.0%, exceeding the control by 1.4-3.6%.

The aftereffect of municipal sewage residue in combination with zeolite-containing agro-ore significantly increased the gluten content in winter wheat grain by 1.8-4.7%. The gluten content against the background of their aftereffect varied in the range from 24.2 to 27.1%.

4. Conclusion

Proceeding from the above, the most significant impact on the yield of common oats (Konkur variety), the yield of peas (Jackpot variety), winter wheat (Moskovskaya 56 variety), the harvesting of the digestible protein, the content of protein and gluten had a complex aftereffect of municipal sewage residue in combination with zeolite-containing agronomical ore. The aftereffect of municipal sewage residue in combination with zeolite-containing agronomical ore increased the yield of oats by 27.5-44.2%, the content of digestible protein – by 0.84-1.20%, the harvest of digestible protein – by 37.2-59.8%, the yield of peas – by 26.6-49.8%, protein content in pea grain – by 1.2-2.7%, winter wheat yield – by 14.4-34.4%, gluten content in winter wheat grain – by 1.8-4.7%.

References
[1] Kulikova A Kh and Nikiforova S A 2011 Bulletin of Ulyanovsk State Agricultural Academy 4(16) 26-32
[2] Prokopova L V and Zhitin Yu I 2013 Bulletin of Voronezh GAU 1(36) 35-39
[3] Klimova N V and Pochinova T V 2009 Agricultural Science 1 13-16
[4] Berezhnaya N P and Berezhnaya V P 2013 Proc. of the III Int. Sci. and Environmental Conf. of Kuban State Agrarian University pp 303-306
[5] Kulikova A Kh and Zakharov N G 2015 Bulletin of Ulyanovsk State Agricultural Academy 2(30) 6-13
[6] Petrova O A 2013 Ecological Bulletin of Russia 9 40-43
[7] Argunov N G, Abramov Ya K, Solomatina N A, Veselov V M, Zalevsky V M and Merzlaya G E 2012 Bulletin of FGOU VPO MGAU 2 83-86
[8] Khabarova T V, Levin V I and Pravkina S D 2014 Problems of Agrochemistry and Ecology 2 24-28
[9] Arefiev A N and Kuzin E N 2018 Sursky Bulletin 1(1) 3-6
[10] Arefiev A N, Kuzin E N, Efremova E N and Kalmykova E V 2015 Bulletin of the Nizhnevolzhsky agro-university complex: Science and higher professional education 2(38) 80-84