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AGRICULTURAL SOIL SCIENCE AND AGROECOLOGY

Agroecological Efficiency of Traditional and New Organic Fertilizers

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Abstract—Municipal waste in the form of sewage sludge and the use of unconventional sources of organic raw materials, in particular, is of great importance as a result of the critical shortage of organic fertilizers, the use of which has not exceeded 15–18% of the demand in Russia in recent years. Research in this direction is relevant due to the poor knowledge of the effects of sewage sludge and products based on them on the soil-plant system. The goal of the study is to establish the comparative agroecological effectiveness of the effect and long–term aftereffect of compost from sewage sludge and dung manure at different application rates when cultivating perennial grasses. The research was carried out in the conditions of the long-term micro-field experiment arranged by the Pryanishnikov Institute of Agrochemistry in Moscow oblast (Barybino village). In the experiment, orchard grass was sown under a cover of spring barley. The design of the experiment considered the following options: (*1*) control without fertilizers, (*2*) compost one at a rate of 10 t/ ha, (*3*) compost one at a rate of 35 t/ha, (*4*) compost two at a rate of 10 t/ha, (*5*) compost two at a rate of 35 t/ha, (*6*) manure at a rate of 10 t/ha, and (*7*) manure at a rate of 35 t/ha on a dry weight basis. Compost is prepared from sewage sludge from the Kur'yanovskaya aeration station; specifically, compost one from sludge from filter presses and compost two from sludge from the drain beds. Compost two was characterized by a higher content of heavy metals, the total amount of which was two times higher than in compost one and ten times higher than in dung manure. All fertilizers were introduced before sowing crops in 2000 and then their aftereffect was tested for 22 years. The rates of all organic fertilizers are given on a dry weight basis. According to the results of the long-term studies, comparison between two types of compost contaminated with heavy metals to different degrees shows that the greatest effect was achieved from compost with a lower pollution level, that is, produced from fresh (nontreated) sludge from filter presses at an increased rate of 35 t/ha on a dry weigh basis, from which gain in the yield was 41% relative to the control. This improvement due to the use of dung manure varied from 28 to 73% depending on the application rate. As for the accumulation of heavy metals in the soil and in the dry matter of perennial grasses, there were no clear dependencies on the types and rates of fertilizers applied. At the same time, levels of cadmium, nickel, and lead in the plant and soil samples did not exceed the permissible values.

Keywords: compost based on sewage sludge, dung manure, sod-podzolic soil, agrochemical and biological properties, heavy metals, yield, quality of plant products

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Urban development exacerbates the problem of utilization of sewage sludge continuously generated at wastewater treatment plants. According to estimates, the annual volumes exceed 3 million t on dry weight basis, of which the use in agriculture accounts for 5–7% at most [1]. At the same time, sewage sludge and the derived products, including the ones produced using fermentation-based methods, feature high fertilization value and may serve as an important source of nutrients for plants. The widespread use of the sludge in agriculture is constrained by the potential occurrence of increased amounts of heavy metals or other contaminants [2–4] as well as insufficient information on the effect and aftereffect of different sludge on a soil–plant system [5, 6]. At the same time, based on the national and foreign experience, its introduction into the fields for cultivation of various crops appears to be the most feasible way for sludge's use [7–9]. Importantly, the necessity for application of municipal waste and, primarily, sewage sludge in agriculture is declared in the International Code of Conduct for Sustainable Use and Management of Fertilizers approved by FAO in 2019 [10], according to which the former is classified as a potential source of nutrients from reused and recycled materials. This determines an expediency of innovations and allocation of

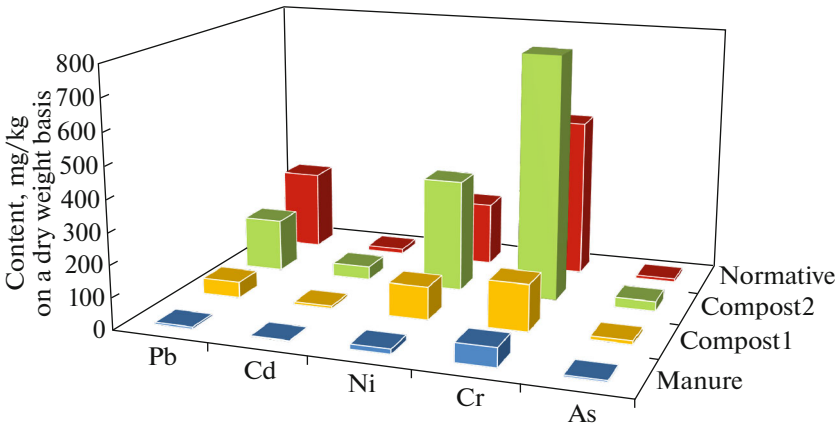

Fig. 1. Content of heavy metals and arsenic in organic fertilizers.

resources toward development of technologies for a safe use of this type of waste as fertilizers.

The goal of the paper is to evaluate agroecological efficiency of sewage sludge and the sludge-based fertilizers.

METHODS

The work was carried out in 2000–2021 in Moscow oblast (Barybino village) in the conditions of the long-term field experiment and involved investigation of the effect on the perennial grasses agrophytocenoses of two composts of sludge from Moscow wastewater of different storage periods. Compost one was prepared from digested sludge directly supplied from filter presses of Kur'yanovskaya aeration station; compost two included the sludge that was left to drain on sludge beds for 10 years. Wood shavings were added to the compost mass in the amount of 10% on dry weight bases in both cases. Variants with two dosages of dung manure supplied by a cattle farm were introduced to the experiment design in addition to the two compost types to compare the effectiveness of unconventional fertilizers. In the experiment, all the organic fertilizers were applied in the rates of 10 and 35 t/ha on dry weight basis. The dung manure contained (dry weight basis) 70% of organic matter, 2.7% of total nitrogen, 2.4% of phosphorus (P_2O_5), and 2.1% of potassium (K_2O) with pH_{KCl} at 7. Composts of the sludge of different storage periods featured high fertilizing value, contained 48–52% of organic matter and 2–2.1% of total nitrogen, and were characterized by neutral reaction of the medium. Compared to the manure, the composts were characterized by lower content of organic matter, nitrogen, and potassium but significantly outperformed it by the phosphorus content. At the same time, compost from sludge beds (compost two) was contaminated by zinc and cadmium, which levels exceeded the permissible concentrations by 31 and 49%, respectively. Total amount of heavy metals in this compost twice exceeded the same in compost one and was ten times as high as in the dung manure (Fig. 1).

Sod-podzolic heavy loamy soils contained 0.8% of organic carbon and 118 and 119 mg/kg of mobile P_2O_5 and K_2O, respectively, (after Kirsanov) in the 0–20 cm layer with pH_{KCl} at 4.6.

Orchard grass (*Dactylis glomerata* L.) VIK 61 was sown under a cover of spring barley (*Hordeum vulgare* L.) Zazerskii 85 during the trial establishment in 2000. All the organic fertilizers were introduced into the soil in 2000 with the aftereffect studied over the subsequent years. The microfield experiment of randomized design was arranged in bottomless containers 0.25 m^2 in size (0.5 × 0.5 m) and replicated three times.

The study was conducted using the conventional procedures [11]. Mathematical processing of the experimental data was done with analysis of variance using STRAZ software.

Table 1. Effect of sewage-sludge based composts and dung manure on the yield of perennial grasses (mean for 2000–2021)

Variant	Yield/forage unit/m^2	Gain, %
Control	121	–
Compost 1, 10 t/ha	135	12
Compost 1, 35 t/ha	171	41
Compost 2, 10 t/ha	141	17
Compost 2, 35 t/ha	161	33
Manure, 10 t/ha	155	28
Manure, 35 t/ha	209	73
LSD_{05} (least significant difference)	23	

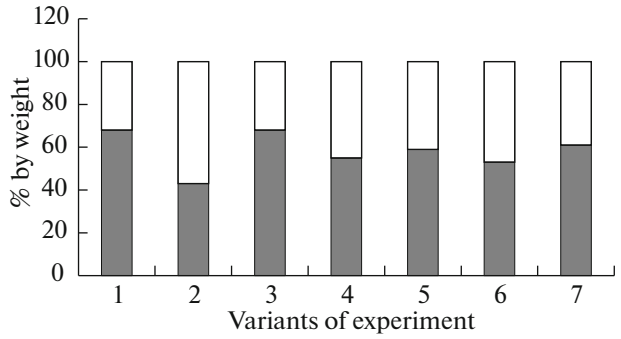

Fig. 2. Botanical composition of grass stands depending on a type and application rate of organic fertilizers (2021): (1) control; (2) compost 1, 10 t/ha; (3) compost 1, 35 t/ha; (4) compost 2, 10 t/ha; (5) compost 2, 35 t/ha; (6) manure, 10 t/ha; (7) manure, 35 t/ha: □ forbs; ■ grasses.

RESULTS AND DISCUSSION

Based on data from the 22-year investigations, application of both types of sewage sludge composts at the high rates (35 t/ha on dry weight basis) statistically significantly increased the yield of perennial grasses compared to the control without fertilizers (Table 1). The manure ensured the maximum (in the experiment) gain in the grasses yield in the variant with the high rate of 35 t/ha. In other words, application of the increased rates of both composts of the sludge and conventional dung manure in cultivation of perennial grasses was characterized by the statistically significant and prolonged aftereffect. When compared, the effect of the two composts was recorded to be higher in the case of the compost with a lower level of contamination by heavy metals, which contained nontreated (fresh) sludge, in a variant with increased rate; the gain amounted to 41% compared to the control.

Studying the dynamics of botanical composition of the grass stands revealed (Fig. 2) a successful development of grasses (Poaceae or Gramineae) in agrophytocenoses in the 22nd year of the experiment. This was marked both in the control without application of fertilizers (content of grasses at 68%) and in the variants with high rates of the composts (59–68%).

The grass component was primarily composed of the common meadow-grass (*Poa pratensis* L.), common bent (*Agrostis tenuis* Sibth.), and orchard grass (*Dactylis glomerata* L.). Forbs accounted for a significant proportion of the grass stand in fertilizer-treated variants (from 32 to 57%) and primarily included autumn hawkbit (*Leontodon autumnalis* L.) and moneywort (*Lysimachia nummularia* L.).

Agrochemical properties of the soil changed due to exposure to composts of sewage sludge and dung manure (Table 2). Application of all tested organic fertilizers at high rates increased humus content in the soils in the first year and during 5 years as the aftereffect compared to the control at a trend level. By the end of the observation period, content of organic carbon in soil remained at the control level in the variants with composts. Overall, in agrocenoses of perennial grasses used for haying for a long period, composts of sewage sludge did not have a significant negative effect on a humus state of sod-podzolic soil.

Table 2. Dynamics of agrochemical soil properties depending on a type and application rate of organic fertilizers*

Variant	2000, Effect	Years of aftereffect			
		2001	2005	2010	2018
Humus, % C					
Control	0.75	0.72	0.69	0.99	0.70
Compost 1, 10 t/ha	0.75	0.69	0.64	0.92	0.80
Compost 1, 35 t/ha	0.79	0.89	0.98	0.95	0.70
Compost 2, 10 t/ha	0.71	0.69	0.69	0.86	0.80
Compost 2, 35 t/ha	0.79	0.89	0.81	0.89	0.70
Manure, 10 t/ha	0.77	0.86	0.92	0.91	0.80
Manure, 35 t/ha	0.88	0.95	0.98	1.02	0.80
LSD_{05}			0.08		
Mobile phosphorous (P_2O_5), mg/kg					
Control	110	110	111	105	107
Compost 1, 10 t/ha	180	125	110	152	133
Compost 1, 35 t/ha	320	300	310	370	207
Compost 2, 10 t/ha	160	140	90	148	117
Compost 2, 35 t/ha	220	240	260	277	239
Manure, 10 t/ha	130	110	90	95	114
Manure, 35 t/ha	270	220	180	168	152
LSD_{05}			24		
Mobile potassium (K_2O), mg/kg					
Control	96	96	55	92	109
Compost 1, 10 t/ha	101	99	39	98	113
Compost 1, 35 t/ha	90	102	39	98	104
Compost 2, 10 t/ha	95	96	35	99	109
Compost 2, 35 t/ha	99	100	42	100	115
Manure, 10 t/ha	109	115	50	100	103
Manure, 35 t/ha	120	109	98	118	121
LSD_{05}			12		
pH_{KCl}					
Control	3.8	3.9	3.9	4.2	3.9
Compost 1, 10 t/ha	3.8	4.1	4.4	4.3	4.0
Compost 1, 35 t/ha	4.2	4.5	4.8	4.5	4.0
Compost 2, 10 t/ha	3.9	4.0	4.3	4.2	4.0
Compost 2, 35 t/ha	4.1	4.5	4.5	4.4	4.0
Manure, 10 t/ha	4.5	4.6	4.7	4.5	4.0
Manure, 35 t/ha	4.5	4.6	4.7	4.5	4.1
LSD_{05}			0.4		

* Calculated for the entire data massif.

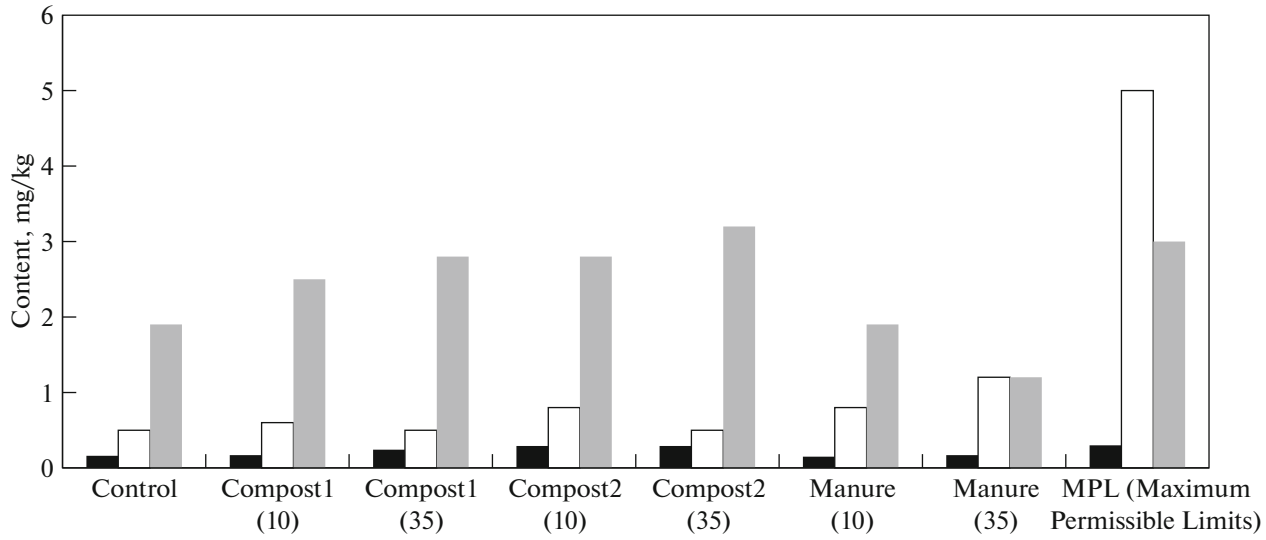

Fig. 3. Effect of organic fertilizers on content of heavy metals in dry matter of perennial grasses (mean for 2001–2018). (LSD_{05}: Cd—0.04; Pb—0.7; Ni—0.3 mg/kg): ■—Cd; □—Pb; ▒—Ni.

The analysis of phosphate status of the soils generally demonstrated its improvement due to exposure to all types of the organic fertilizers applied both at the high (35 t/ha) and low (10 t/ha) rates. At the same time, potassium status of the soil needed to be optimized during particular periods, specifically, by the fifth year of the aftereffect from the fertilizers.

All organic fertilizers involved in the experiment improved a reaction of the medium, particularly when applied at the high rates, in the first year after the application. A pH_{KCl} value in the variants with fertilizers differed little from the control by the 18th year of the aftereffect.

No accumulation of heavy metals was observed in the soil both at the onset and termination of the experiment (Table 3). One exception was a variant with compost of sewage of a higher level of contamination drained on sludge beds at the aeration station, at a rate of 35 t/ha; compared to the control, cadmium and nickel contents in the soil were higher 1.5–2-fold and 1.5–2.4-fold, respectively. At the same time, total content of heavy metals in the soil did not exceed regulatory standards of the Russian Federation with the use of all the studied organic fertilizers both in the high and low rates.

Quality of plant products is of major importance when analyzing the effect of unconventional fertilizers on agrocenoses [7, 9, 11]. Over 2020–2021 on average, perennial grasses in the variants with sewage sludge-based composts regardless of the application rates featured the crude protein, phosphorous, and potassium contents either at the levels approaching the control or the variants with application of the dung manure (Table 4).

No well-defined dependencies were observed on a type and application rate of the fertilizers with respect to accumulation of heavy metals in perennial grasses over the study period on average (Fig. 3). Additionally, the content of cadmium, nickel, and lead in the grass dry matter remained within the maximum permissible limits (MDU 123-4/28-87).

Therefore, the prolonged (during 22 years) use of organic fertilizers produced by way of fermentation of sewage sludge mixtures with wood residue was recorded to have a positive effect on the reaction of the medium, major agrochemical and hygienic and sani-

Table 3. Effect of organic fertilizers on total content of heavy metals in soil, mg/kg

Variant	Cd		Ni		Pb	
	2001	2021	2001	2021	2001	2021
Control	0.2	0.4	4.0	3.2	6.0	1.1
Compost 1, 10 t/ha	0.2	0.5	4.0	6.5	6.0	1.1
Compost 1, 35 t/ha	0.2	0.3	4.0	6.4	6.1	1.1
Compost 2, 10 t/ha	0.2	0.5	4.0	7.0	6.2	1.4
Compost 2, 35 t/ha	0.4	0.6	6.0	7.8	6.5	1.1
Manure, 10 t/ha	0.1	0.2	3.0	5.8	6.0	1.1
Manure, 35 t/ha	0.1	0.2	3.0	5.0	6.0	1.2
LSD_{05}	0.1		1.1		0.3	
APC (approximate permissible concentrations) (HN (hygienic normatives) 2.1.7.2511-09)	1.0		40		65	

Estimated for the entire data massif.

Table 4. Effect of organic fertilizers on quality parameters in perennial grasses

Variant	Content, %		
	crude protein	P	K
Control	10.3	0.39	3.3
Compost 1, 10 t/ha	10.0	0.42	3.0
Compost 1, 35 t/ha	9.7	0.43	3.0
Compost 2, 10 t/ha	9.6	0.43	3.3
Compost 2, 35 t/ha	10.4	0.46	3.4
Manure, 10 t/ha	9.3	0.38	3.1
Manure, 35 t/ha	9.5	0.42	2.9
LSD_{05}	0.9	0.04	0.3

tary indicators of the soil, and yield of perennial grasses as well as their productive longevity without compromising a quality of the plant products.

The highest effect in the experiment was achieved due to application of the compost produced of non-treated sludge less contaminated by heavy metals directly supplied from filter presses of Kur'yanovskaya aeration station (Moscow) at the rate of 35 t/ha on dry weight basis. Hay yield of perennial grasses increased by 41%, relative to the control without fertilizers, due to application of compost. The gains varied between 28 and 73% depending on the application rate in the variants with the use of conventional manure of cattle dung.

CONFLICT OF INTEREST

The author declares that she has no conflicts of interest.

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