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SOIL SCIENCE

Use of Sewage Sludge and Organic Matter Regime of Sod-Podzolic Soil

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Abstract—It is shown that sewage sludge formed during sewage treatment contains a significant amount of organic matter, nitrogen, and ash elements, which can be used by plants. The paper presents the results of a 3-year microplot experiment on sod-podzolic soil to determine the effect of sewage sludge added together with sawdust, peat, and straw at different ratios (the total rate was 60 t/ha). The parameters of the soil organic matter regime (content, reserves, and group and fractional composition) were studied. The substrates used with sewage sludge led to a significant increase in all parameters compared to the control experiment (without fertilizers). A trend towards a decrease in the fertilizing effect was observed when the ratio between sewage sludge and additional organic components increased from 1 : 1 to 1 : 3. Fresh sludge used together with peat or sawdust at a 1 : 1 ratio proved to be more effective than the compost based on sewage sludge.

Keywords: sewage sludge, soil organic matter, peat, sawdust, straw

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The sharp decline in the production of organic fertilizers that has been observed in Russia in recent decades is caused by a decrease in the livestock sector of agriculture. These changes have affected crop production due to a decrease in soil fertility. It has been proven [1] that it is necessary to annually introduce over 6 t/ha of organic fertilizers for humus reproduction; however, their use is currently limited in some regions of the central zone of the Russian Federation. Therefore, the current volume of traditional organic fertilizers, including those produced from green manuring and straw plowback, is insufficient for the needs of current crop farming.

Recent studies [2–4] have shown that sewage sludge composting makes it possible to obtain a valuable organic fertilizer. However, a limiting factor for the large-scale production of such composts is lack of material and financial resources. In addition, high-quality composts are produced after the multiple mixing of a mixture, which takes much time. These factors make us search for less expensive ways of using sewage sludge (SS) in crop farming. One of these methods is to add fresh SS together with organic substrates (peat, sawdust, or straw) [5–11].

In addition to the problem of increasing soil fertility reproduction using SS, there is also another, no less important problem in contemporary society. The growth of the urban population leads to an intensification in the activity of urban sewage treatment facilities. Wastewater from industrial plants, storm drains, and residential buildings enter settlers, where SS is formed in the digesters. Its volume is 1000 m^3 per day. Sludge is located in silt detention ponds on the territory of the treatment facilities and occupies a significant area. Effective technologies for utilizing and neutralizing SS have not yet been developed and sludge is stored for decades here.

Therefore, the purpose of this research was to find ways to effectively use sewage sludge in the agro-industrial complex and determine the most appropriate rates of its addition based on soil monitoring and taking into account the yield of field crops.

METHODS

The field experiment was carried out at the experimental site of the Tver State Agricultural Academy in 2015–2017. The site has a sod medium-podzolic gleyic sandy-loam soil on fluvioglacial deposits underlain by moraine. Prior to the experiment, the topsoil had a slightly acid reaction (pH_{KCl} 15.7) and was highly rich in mobile phosphorus (241 mg/kg of soil) and moderately rich in exchange potassium (124 mg/kg of soil). The humus content did not exceed 1.3% and the degree of base saturation was not more than 60% in the soil.

The studied sewage sludge was obtained on the territory of the treatment facilities of the Tver Vodokanal enterprise. Organic substrates that were additionally added to the soil together with SS were selected taking

Table 1. Chemical composition of initial organic substrates

Parameter	SS	Sawdust	Peat	Straw	Compost
Moisture, %	67	69	61	12.3	52.0
Ash content, %	33	9.8	10.2	29	10.7
pH_{KCL}	7.5	4.8	5.1	–	6.1
N_{total}, %	3.43	4.8	5.1	0.43	2.10
$P_2O_{5\ total}$, %	1.70	0.46	0.35	0.8	0.33
K_2O_{total}, %	0.29	0.3	0.15	0.8	0.15
C_{org}, %	33.6	45.0	44.9	46.6	44.3
C/N	9.8	125.2	16.0	108	21.0

into account their abundance in the Central Nonchernozemic zone of Russia, in particular, in Tver oblast. They included spruce sawdust, rye straw, and lowland peat. Prior to the experiment, a chemical analysis (Table 1) of all initial organic components was performed using methods according to GOST [12–17]. The results of the bacteriological analysis of SS did not reveal pathogenic microflora.

SS was added in spring 2015 for spring plowing together with organic substrates at different ratios (1 : 1, 1 : 2, and 1 : 3); the total rate of its addition was 60 t/ha. The variant without fertilizers served as a control. We also used a variant with compost, which was prepared based on SS and sawdust (60 t/ha) on the territory of the sewage treatment plant, as a control. Therefore, the experimental design included the following variants: (1) without fertilizers (control); (2) compost; (3) SS : sawdust, 1 : 1; (4) SS : sawdust, 1 : 2; (5) SS : sawdust, 1 : 3; (6) SS : peat, 1 : 1; (7) SS : peat, 1 : 2; (8) SS : peat, 1 : 3; (9) SS : straw, 1 : 1; (10) SS : straw, 1 : 2; and (11) SS : straw, 1 : 3. The experiment was carried out in the grain–grass field link with the following crop rotation: vetch–oat mix (oats of the Krechet variety and spring vetch of the Lgovskaya-22 variety), winter rye of the Tatyana variety, and spring barley of the Gonar variety.

The content of soil organic matter and its group and fractional composition were studied using Tyurin's method modified by Ponomareva and Plotnikova [18].

RESULTS AND DISCUSSION

SS added into the soil together with different organic substrates and the finished compost contributed to a growth in organic matter in all variants with fertilizers (Fig. 1). The largest amount of organic matter in the year with direct action (1.50%, increase by 0.23% compared to the control) was revealed after adding the SS : peat mixture at a 1 : 1 ratio. A comparable increase was recorded in the variants using SS with sawdust and SS with straw, where the increase compared to the control reached 0.21 and 0.19%, respectively.

It should be noted that the SS/filler ratio of these dominant variants was 1 : 1; other combinations contributed to an increase in organic matter in the soil by 0.08 to 0.15%. Thus, the variant with SS : sawdust at a 1 : 3 ratio was characterized by the minimum content of organic matter: the increase compared to the control was only 0.08%. In addition, the effect of SS combined with organic fillers at a 1 : 1 ratio on the content of organic matter in the soil proved to be more effective than the effect of the finished compost: by 0.02% than straw compost, 0.04% than sawdust compost, and 0.06% than peat compost.

A similar trend was also observed in the second study year. The highest content of organic compounds was revealed in the variant using SS with peat at a 1 : 1 ratio (1.49%, increase by 0.24% compared to the control) and SS with sawdust at the same ratio (increase by 0.22% compared to the control). The other variants had a positive but much lower increase in the content of organic matter.

During all study years, the content of organic compounds continued to decrease in all variants. Undoubtedly, this pattern is determined by the gradual mineralization of SS in the soil, which is also noted by other researchers [8, 11]. A similar preservation of organic matter was observed in the variants using SS with sawdust or peat at a 1 : 1 ratio. The content of organic matter was 1.47–1.48% in these variants, which is 0.22–0.23% higher than that in the control variant. The effect of finished compost produced at the wastewater treatment plant on this parameter was somewhat lower: the content of organic matter was 1.42%.

All the mixtures added to the soil contributed to an increase in the reserves of organic matter (Table 2) compared to the control variant. On average, their maximum increase over 3 years was recorded in the variant using the SS : peat mixture at a 1 : 1 ratio (increase by 6.54 t/ha compared to the control). The high resulting values with a mathematically confirmed increase compared to the control variant were also observed for the SS : sawdust mixture at a 1 : 1 ratio (increase by 5.99 t/ha compared to the control), SS : peat mixture at a 1 : 2 ratio (increase by 5.44 t/ha com-

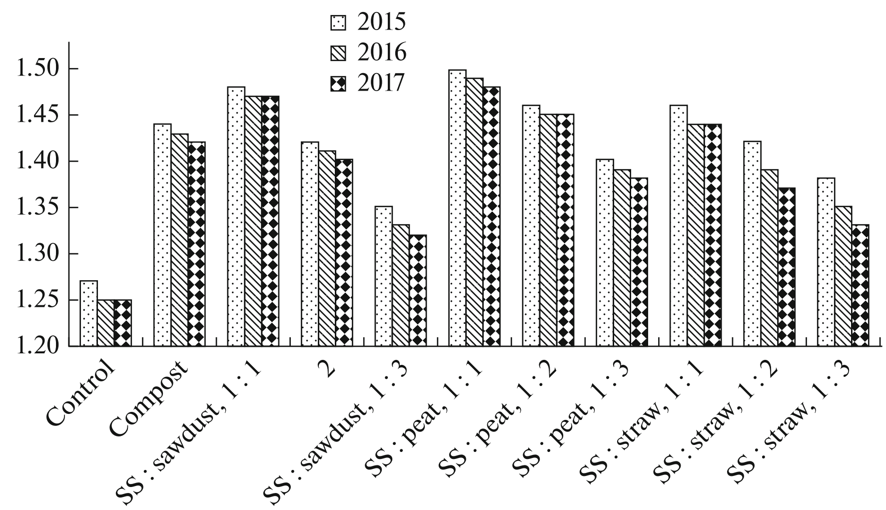

Fig. 1. Content of organic matter in sod-podzolic soil in the variants of the experiment, % per dry weight.

pared to the control), and SS : straw mixture at a 1 : 1 ratio (increase by 5.02 t/ha compared to the control). The lowest values of the parameter were recorded after adding the SS : sawdust mixture at a 1 : 3 ratio (increase by 2.22 t/ha compared to the control) and SS : straw mixture at a 1 : 3 ratio (increase by 2.84 t/ha compared to the control). The reserves of organic matter in the soil proved to be significantly lower in the variant with compost based on sludge than in the variants using SS with sawdust or peat at a 1 : 1 ratio. The wide ratio of SS to the used substrates (1 : 3) was ineffective with respect to reserves compared to the compost.

It is known that organic fertilizers not only increase the total content of organic matter but also improve its group composition. The dynamics of variation in the group composition of soil organic matter in all variants was studied during 3 years of fertilizer transformation (Table 3).

The initial composition of the organic matter of the sod-podzolic sandy loam soil is fulvate–humate: the HA : FA was 0.87% and the proportion of the FA aggressive fraction was 8.2% and that of nonhydrolyzable residue was 19.6%. The composition of organic matter changed little in the control variant over the study years and its initial type was maintained

Table 2. Reserves of organic matter (t/ha) in the arable layer (0–20 cm) of sod-podzolic soil

Variant	2015	2016	2017	Mean
Control	34.29	33.75	33.04	33.69
Compost	38.88	38.61	38.49	38.66
SS : sawdust:				
1 : 1	39.96	59.68	39.41	39.68
1 : 2	38.34	38.07	37.83	38.08
1 : 3	36.45	35.91	35.37	35.91
SS : peat:				
1 : 1	40.50	40.23	39.95	40.23
1 : 2	39.42	39.15	38.82	39.13
1 : 3	37.80	37.53	37.16	37.50
SS : straw:				
1 : 1	39.16	38.88	38.09	38.71
1 : 2	38.32	37.53	36.91	37.59
1 : 3	37.26	36.45	35.87	36.53
$LSD_{0.5}$	0.69	0.98	0.95	0.87

Table 3. Composition of organic matter (% to total C) of sod-podzolic sandy loam soil in a 0–20-cm layer

Variant	2015				2016				2017			
	Σ_{HA}	Σ_{FA}	HA/FA	C of nonhydrolyzable residue	Σ_{HA}	Σ_{FA}	HA/FA	C of nonhydrolyzable residue	Σ_{HA}	Σ_{FA}	HA/FA	C of nonhydrolyzable residue
Control	37.1	43.1	0.86	19.8	37.0	43.3	0.86	19.7	36.8	43.6	0.84	19.6
Compost	39.1	43.4	0.90	17.5	38.5	42.7	0.90	18.8	38.2	42.0	0.91	19.8
SS : sawdust:												
1 : 1	42.3	42.7	0.99	15.0	40.8	41.6	0.99	17.6	39.4	40.4	0.98	20.2
1 : 2	40.1	42.9	0.93	17.0	39.7	41.8	0.93	18.5	39.0	40.9	0.95	20.1
1 : 3	39.1	43.4	0.90	17.5	38.5	42.7	0.90	18.8	37.8	41.5	0.91	20.7
SS : peat:												
1 : 1	41.8	41.0	1.02	17.2	41.2	41.6	0.99	17.2	40.6	42.3	0.96	17.1
1 : 2	39.9	40.7	0.98	19.4	39.4	41.0	0.98	19.6	38.9	41.4	0.94	19.7
1 : 3	38.6	40.8	0.95	20.6	37.8	39.8	0.95	20.4	37.1	39.7	0.93	20.2
SS : straw:												
1 : 1	40.2	41.0	0.98	18.8	40.0	42.7	0.98	17.3	39.4	43.2	0.91	17.4
1 : 2	39.6	43.0	0.92	17.4	39.2	42.9	0.92	17.9	38.7	42.7	0.91	18.6
1 : 3	38.9	43.7	0.89	17.4	38.2	43.9	0.90	17.9	37.6	43.8	0.88	18.8
LSD_{05}	0.7	1.1	0.04	0.4	0.7	1.2	0.04	0.4	0.7	1.3	0.04	0.4

throughout this period. This is probably due to the fact that, in addition to the use of SS, the control variant also included the cultivation of cereals, from which a certain amount of biomass entered the soil in the form of plant residues, thereby maintaining total organic matter in the soil, as well as its group and fractional composition, at a constant level. In the first year of transformation of organic mixtures, an increase in the content of organic matter in the topsoil was observed in all variants with fertilizers, mainly owing to an increase in the amount of humic acids in this soil layer.

While analyzing the increase in humic acids in the group composition of organic matter after adding organic fertilizers, Russian researchers [19, 20] came to the conclusion that they increased owing to the addition of free humic acids themselves (which are part of fertilizers) into the soil. Changes in the amount of fulvic acids were less significant after adding SS with organic substrates.

Our experiment recorded a decrease in the concentration of FAs in the soil in variants using SS and peat (39.7–42.3%). The changes mainly covered the FAs of fraction two (more stable fraction combined with calcium), which tended to increase, as well as fraction three (combined with stable clay compounds in the form of aluminum and iron sesquioxides) (their number decreased in some cases).

In 2015, the content of humic acids increased most significantly after adding SS with sawdust and SS with peat at a 1:1 ratio. The increase was 5.2 and 4.7% compared to the control, respectively. A significant difference was revealed between these types of substrates. The increase in the concentration of HAs was lower in the variants with other types of fertilizers (by 1.5–3.1%). Along with the change in their content, there was a certain redistribution of their fractional composition. The content of fraction one (the most mobile fraction combined with nonsilicate forms of sesquioxides), which is weakly correlated with the mineral part of the soil, changed most significantly. The highest increase in this fraction was observed in the variant with the SS : peat mixture at a 1 : 1 ratio (the increase reached 4.0% compared to the control), while the addition of SS with organic fillers at a 1 : 3 ratio into the soil or the use of the compost yielded the lowest increase. The amount of HAs was 1.3–2.0% higher in fraction one than in the control variant.

The use of fertilization in the second year contributed to a slight increase in the content of both humic and fulvic acids. Thus, the increase in the proportion of HAs was particularly observed in the variant with the SS : sawdust mixture at a 1 : 1 ratio (the increase was 1.5% over 1 year). By the end of the growing season in the first after-effect year, the HA : FA ratio decreased by 0.01–0.02%. As in the previous study year, the widest value of this parameter was recorded in the SS : sawdust and SS : peat variants at a 1 : 1 ratio (0.99 and 1.02%, respectively). The composition of organic matter improved mainly owing to an increase in the amount of HAs in fraction one. Changes in the content of organic matter influenced the HA to FA ratio in all variants with fertilization so that it was 0.90–0.99% by the end of the first after-effect year, while it barely reached 0.86% in the control.

In the third year of the experiment, the concentration of HAs significantly (by 0.2–1.4%) decreased in all variants compared to the second year. This led to a decrease in the HA to FA ratio; the lowest decrease was recorded in the control variant (by 0.2%). This result may be determined by the fact that sawdust, peat, and straw are aerating and moisture-absorbing materials that maintain the conditions required for the successful mineralization of organic substances [21]. The content of humic acids tended to increase during the three experimental years owing to the growth in the concentration of HAs in free fraction one, which could soon be mineralized due to the weak bonds with soil particles [1].

Contemporary agrochemical studies [19, 22] also prove that, unlike mineral fertilizers, the addition of organic fertilizers into soil significantly influences the content of HA and FA fractions in the humus. According to Bogatyreva et al. [19], the addition of organic fertilizers at the rate of 40–60 t/ha per crop rotation contributes greater to providing the humus with humic acids, in particular, with agronomically valuable fraction two; at the same time, the content of mobile fractions of fulvic acids decreases in this case.

The concentration of the nonhydrolyzable residue of organic matter slightly increased throughout the experiment in the variants where the proportion of peat, sawdust, and straw increased compared to SS. It can be assumed that this increase is determined by the presence of recalcitrant components of organic substrates, in particular, lignin organic compounds, which are less intensively mineralized [23]. The mathematical processing of the experimental results revealed a slight effect of SS on the concentration of FAs in the soil, while the content of HAs significantly varied with respect to the variant.

Therefore, our research suggests that sewage sludge has a fertilizing effect on sod-podzolic sandy loam soil and positively influences the organic matter regime. The use of SS with sawdust, peat, or straw leads to an increase in the concentration of organic matter proportionally to the volume of added sludge. In addition, it has an aftereffect on the content and composition of organic matter.

The best result was observed after adding SS with peat or sawdust at a 1 : 1 ratio. The finished compost was 0.04–0.06% less effective than these variants with respect to the content of organic matter. The substrates positively influenced the fractional and group composition of organic matter. The addition of SS contributed to an increase in the HA to FA ratio by 0.02–0.16 compared to the control owing to the enrichment of the soil with humic acids.

COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

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