TECHNOLOGICAL PARAMETERS OF COMPOST PRODUCTION BASED ON SEWAGE SLUDGE AND CEREAL STRAW

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Abstract. One of the main issues of modern agricultural production in the conditions of the climate crisis and growing moisture deficit is to preserve soil fertility. This issue is especially acute in Ukraine, where manure production per hectare of arable land has fallen by more than 10 times in recent decades due to declining livestock numbers. One of the few sources of organic raw materials that can be used to maintain soil fertility is municipal sewage sludge. According to generalized data, the nitrogen content in sewage sludge is 1.6-7% in dry matter, reaching 7.4% in activated sludge, the ratio of nitrogen to carbon varies from 1:11 to 1:5, sludge moisture depending on the processing technology is in the range from 72 to 93%. It is established that for effective composting of sewage sludge it is necessary to add to the compost mixture carbon raw materials, the most expedient type of which is the non-grain part of the harvest, straw. It is determined that the rational ratio of dry matter of sewage sludge and cereal straw in a balanced compost mixture will be, respectively, 29% and 71%. This ratio also reduces the relative content of inorganic pollutants (plastic, heavy metals, etc.) contained in the sludge by 2.76 times. As a result of the numerical experiment, an adequate regression model of the influence of the factors of sewage sludge moisture and the required nitrogen-carbon ratio on the moisture content of the compost mixture was obtained. Using the obtained model, it was found that for the maximum recommended values of compost mixture moisture (65%) and nitrogen-carbon ratio (C:N = 30), the maximum moisture content of sewage sludge that can be used to balance the compost mixture without additional moisture is 88.7%, which is lower than the values of sludge moisture after settling tanks. With this in mind, advanced technological schemes for wastewater treatment with compost production were proposed.

Keywords: compost, balancing, sewage sludge, cereal straw.

Introduction

One of the urgent problems of Ukrainian agricultural production is the degradation of agricultural soils, caused by a catastrophic reduction in the application of organic fertilizers due to the decline in the number of cattle and pigs in Ukraine. Thus, according to our calculations, the reduction of cattle heads from 24.6 million in 1991 to 3.1 million in 2021, pigs from 19.1 to 6.0 million, respectively, led to a drop in manure production per 1 hectare of arable land from almost 10 to 0.5-0.7 tons. At the same time, one of the few sources of organic raw materials that can be used to maintain soil fertility is the sludge of municipal wastewater [1; 2]. One of the most expedient and ecologically desirable ways to use municipal wastewater sludge is to prepare compost based on it [3], followed by its use as organic fertilizers [4; 5].

Numerous studies have established the effectiveness of use of sewage sludge as the main nitrogen-containing substrate in the preparation of compost. At the same time, the main attention is paid to the use of such local carbonaceous components to balance such mixtures as rice straw [6-8], wheat straw [3; 9-12], mushroom substrate [9], leaves [3; 7; 13], pistachio wastes and date-palm straw [4], cotton waste, maize straw, and sweet sorghum bagasse [14] etc.

According to generalized data [15-17], the nitrogen content in sewage sludge is 1.6-7% in dry matter, reaching 7.4% in active sludge. The average generalized nitrogen content in sewage sludge in Ukraine according to the analysed sources is 4.5%.

It is known that the rational parameters of a quality mixture for compost preparation are the ratio of nitrogen and carbon in the range of 1: 25-1: 30 and the humidity of the compost mixture about 60-65% [18].

According to [15], the ratio of nitrogen and carbon in sewage sludge varies from 1:11, even 1:16 [19], to 1: 6-1: 5, the generalized average value of the ratio of nitrogen and carbon in sewage sludge is on levels 1:10. The humidity of sewage sludge, depending on the technology of its processing, is in the range of 91-93% [15] to 72-84% [17].

These data indicate that for effective composting of sewage sludge it is necessary to add carbon raw materials to the compost mixture.

A huge source of carbonaceous organic matter in Ukraine is the non-grain part of the grain crop, straw [20]. Today Ukraine is one of the world leaders in the production of grain and oilseeds. According to various forecasts, grain production in Ukraine will reach 100 million tons in the coming years. The amount of non-grain part of the crop (straw), respectively, will be a comparable amount.

According to [17; 21], the nitrogen-carbon ratio for straw, in general, is in the range of 1:48 to 1: 150 and averages 1:80 with an average nitrogen content of 0.7% in dry matter and average humidity of 12%. The carbon content is from 0.34% in rye straw to 1.29% in legume straw at a C:N ratio of 100-110:1 and 20-25:1, respectively. Therefore, for general calculations, it can be assumed that on average in dry matter straw contains 0.5% nitrogen, 40% available carbon and has a moisture content of 12%.

These data allow us to determine the required moisture content of sewage sludge for the formation of a two-component compost mixture based on sewage sludge and straw, as well as to establish the main technological parameters of compost production based on sewage sludge and straw.

Materials and methods

To establish the technological parameters of compost production based on sewage sludge and grain straw, we used the known method of balancing (determination of mass parts of components) of a two-component compost mixture, given in [18]. The method is to solve a system of equations:

$$\begin{cases} X_C m_N + Y_C m_C = C \\ X_N m_N + Y_N m_C = N \end{cases}, \tag{1}$$

where C – proportion of carbon in the compost mixture;
N – proportion of nitrogen in the compost mixture;
X_C, Y_C – relative carbon content, respectively, in materials X and Y;
X_N, Y_N – relative nitrogen content, respectively, in materials X and Y;
m_N, m_C – relative share of components X and Y of the two-component compost mixture.

After finding the mass particles of carbon and nitrogen in the two-component compost mixture on the basis of the calculated data on the humidity of the components and the specified nitrogen-carbon ratio a numerical experiment was carried out. The variables were the mass fraction of moisture in W_{SL} wastewater sludge and the desired ratio of the mass fraction of carbon to the mass fraction of nitrogen C:N. The variation factors were 0.70-0.95 and 25: 1-30: 1, respectively. The mass fraction of moisture in the compost mixture was used as an optimization criterion.

The data obtained as a result of the numerical experiment were processed by methods of mathematical statistics [22]. To analyse the results of the numerical experimental studies the program RegMod "Methodology for modelling normatives by regression analysis" was used, which implements known methods of correlation and regression analysis [23; 24]. According to the results of the numerical experiment, mathematical models were built - regression equations in the form of second-order polynomials [25].

Results and discussion

For further analysis, we take the following generalized average values of the parameters of the components of the two-component compost mixture: nitrogen content in sludge – X_N = 0.045; carbon content in sludge – X_C = 0.45; nitrogen content in straw – Y_N = 0.005; the content of available carbon in straw – Y_C = 0.40; the desired nitrogen-carbon ratio C:N = 25:1.

Taking into account the above, having solved the system of equations with respect to the arguments m_N and m_C, the mass fractions of the components in the dry matter will be:

$$m_N = \frac{NY_C - CY_N}{X_N Y_C - X_C Y_N}, \tag{2}$$

$$m_C = \frac{CX_N - NX_C}{X_N Y_C - X_C Y_N}. \tag{3}$$

Based on the application of dependences (2) and (3), it is possible to establish a rational ratio of dry matter of sewage sludge and grain straw in a balanced compost mixture, which will be equal to 29% and 71%, respectively.

It should be noted that the addition of such a significant proportion of straw will reduce the relative content of heavy metals and other inorganic contaminants in the compost mixture. It should be borne in mind that in the process of composting the mass of the mixture can be reduced by 20% or more [26] as a result of the microbial environment action.

One of the main aspects of the researchers' efforts is the problem of high concentrations of heavy metals in sewage sludge [3; 8; 12; 14] and reducing their content both in the composting process and in the use of these composts in the cultivation of crops [4; 5; 11]. However, studies [12] found that continuously aerated composting treatment exhibited better compost quality and lower potential toxicity of heavy metals in mature compost. In the study [13] the authors prove the possibility of effectively reduced bio-availability of heavy metals by adding to the compost mixture based on sewage sludge biochar amended with lime. Research [14] found that composting appeared to reduce As, Pb, and Cr availability by stabilizing these three metals and making them more stable and less mobile.

In our case, taking into account the results obtained above, we can say that for the conditions of municipal sewage treatment plants of Ukraine the relative content of inorganic contaminants (heavy metals and plastics) contained in sludge but absent in straw, taking into account 20% weight reduction composting, can be significantly reduced. Accordingly, with the reduction of the organic component of sludge, the positive effect of adding straw on the relative content of heavy metals in the compost will decrease.

Given the agronomic conditions of grain harvesting in Ukraine, it can be argued that the moisture content of straw during the harvest period will fluctuate quite slightly, at 1-3%. On the contrary, the moisture of sewage sludge varies in a much wider range depending on the technology of wastewater treatment and the place in the technological process.

The obtained data allow us to conduct a numerical experiment and establish the influence of factors such as sewage sludge moisture and the desired nitrogen-carbon ratio on the moisture content of the compost mixture. The simulation results are shown in Table 1.

Table 1

Influence of mass fraction of moisture in sewage sludge and the nitrogen-carbon ratio of compost mixture on the mass fraction of moisture in the compost mixture (numerical experiment results)

Mass fraction of moisture in sewage sludge	**Nitrogen-carbon ratio C:N**		
	30.0	27.5	25.0
	Mass fraction of moisture in the compost mixture		
0.95	0.809	0.829	0.848
0.90	0.674	0.702	0.730
0.85	0.572	0.603	0.635
0.80	0.494	0.524	0.556
0.75	0.431	0.460	0.491
0.70	0.380	0.407	0.436

The obtained data presented in Table 1 are well approximated by polynomial dependence:

$$W_{CP} = 1.9621 - 4.31081 W_{SL} - 0.0111848 CN + 3.61933 W_{SL}^2 \quad (4)$$

where W_{CP} – mass fraction of moisture in the compost mixture;
W_{SL} – mass fraction of moisture in sewage sludge;
CN – desired ratio of the mass fraction of carbon to the mass fraction of nitrogen.

Dependence (4) is adequate at the 99% confidence level. The coefficient of multiple determination is D = 0.998995, the coefficient of multiple correlation R = 0.999497. The value of the Fisher Test

F = 4639.23; the probability of the F-test $p \approx 0.999$. All model coefficients are significant at a confidence level of at least 99%.

The regression model (4) was obtained for the average values of nitrogen and carbon content in sewage sludge. Substantiation of the parameters of a certain system of wastewater treatment for organic fertilizers should be based on the results of laboratory studies of nutrient content.

The obtained data allow us to conclude that excessive dehydration of sewage sludge is not required to avoid additional costs in the preparation of the compost mixture. Substituting the maximum recommended values of the compost mixture moisture ($W_{CP} = 0.65$) and nitrogen-carbon ratio ($C:N = 30$) into the obtained equation, we can find the values of maximum sewage sludge moisture that can be used to balance the compost mixture without additional moisture. The desired value will be $W_{SL} = 0.887$, or 88.7%, which is lower than the values of sludge moisture after settling tanks [27].

Widespread use of sewage sludge as a substrate for the preparation of organic fertilizers determines the feasibility of appropriate improvement of existing national wastewater treatment technologies [28; 29].

Therefore, for use in composting production of sludge accumulated on sludge sites, it is advisable to use a proportion of fresh sludge with a moisture content of more than 90% and above to balance the compost mixture for moisture.

The given analysis allows us to offer such a technological scheme of compost preparation on the basis of sludge in the sewage treatment systems functioning in Ukraine.

In the scheme shown in Fig. 1, the composting operation provides stabilization of the organic matter of the solid phase of wastewater. Composting is the result of the activity of aerobic microorganisms that consume organic matter present in the compost mixture. Mature compost is characterized by the lack of readily available nutrients for the bacterial environment. In this aspect, the action of microorganisms in the composting process is corresponding to the action of the bacterial environment of aeration tanks.

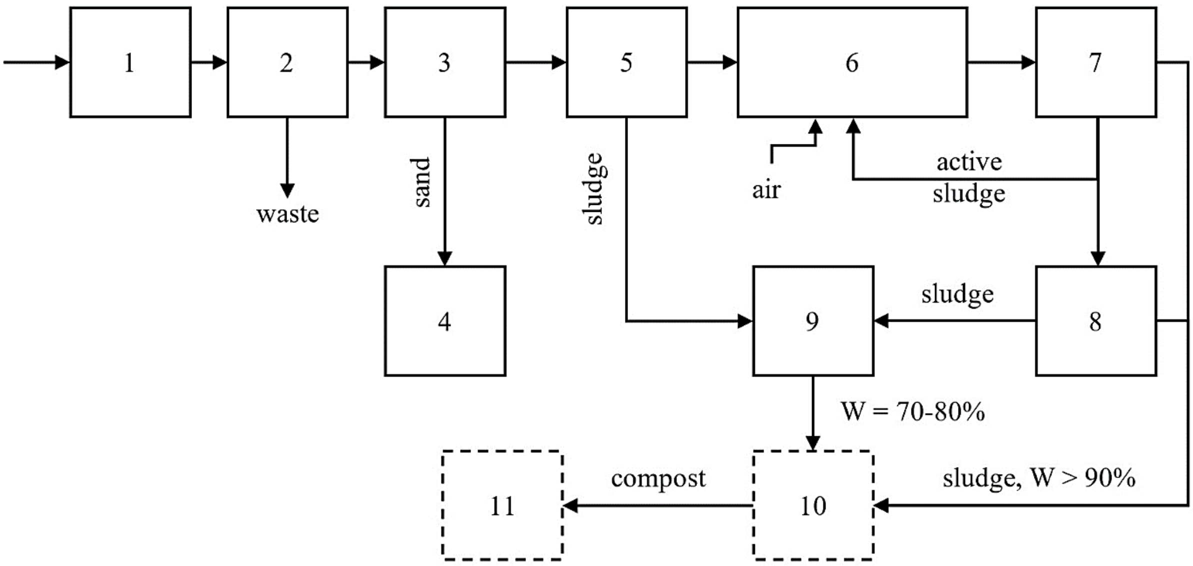

Fig. 1. **Technological scheme of wastewater treatment with compost production:** 1 – receiving chamber; 2 – lattice; 3 – sand traps; 4 – sand areas; 5 – primary settling tanks; 6 – aerotanks; 7 – secondary settling tanks; 8 – sludge sealants; 9 – silt sites; 10 – composting site; 11 – site for maturation and accumulation of compost

Conclusions

1. According to the average generalized data, the nitrogen content in the sewage sludge of municipal enterprises of Ukraine is 1.6-7% in dry matter, reaching 7.4% in activated sludge, the ratio of nitrogen and carbon varies from 1:11 to 1:5, sludge moisture depending on the processing technology is in the range from 72 to 93%.

2. The rational average ratio of dry matter of sewage sludge and straw in a balanced compost mixture will be 29% and 71%, respectively. This ratio will significantly reduce the relative content of inorganic contaminants (plastic, heavy metals) contained in sludge, but absent in straw.
3. For the maximum recommended values of compost mixture moisture (65%) and nitrogen-carbon ratio (C: N = 30), the maximum humidity of sewage sludge that can be used to balance the compost mixture without additional humidification is 88.7%, which is lower than the values of sludge moisture after settling tanks. With this in mind, an improved technological scheme of wastewater treatment with compost production is proposed.

Author contributions

Conceptualization, V.B.; methodology, V.B. and O.A.; software, V.B. and D.M.; validation, O.A. and V.L; formal analysis, V.B and V.L.; investigation, V.B., D.M., O.A. and V.L.; data curation, V.B., O.A. and V.L.; writing – original draft preparation, V.B., D.M., O.A. and V.L.; writing – review and editing, V.B. and D.M.; visualization, O.A., V.L.; project administration, V.B.; funding acquisition, V.B. All authors have read and agreed to the published version of the manuscript.

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