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Microbiological processing of sewage sludge into organo-mineral fertilizer on the example of Astanaand Aktau

Aigerim Issabekova[1], Zhanat Idrisheva[2]*, Zina Tungushbayeva[1], Assyl Shakhanova[3], Manira Zhamanbayeva[2], Arailym Amantayeva[1], Elnara Kuandykova[4], Indira Raiymbekova[1]

1. Department of Biology, Faculty of Natural Sciences and Geography, Abai Kazakh National Pedagogical University, Almaty, Kazakhstan
2. School of Earth Sciences, D. Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan
3. Satbayev University, Almaty, Kazakhstan
4. Kazakh National Agrarian Research University, Department of Soil Science, Agrochemistry and Ecology

** Corresponding author's E-mail: Zhanat_Idrisheva@mail*

ABSTRACT

Sludge from wastewater treatment is a complex and challenging by-product of water treatment processes. Despite the technical, environmental, and health challenges, this material can be valuable in agriculture, industry, and energy production. Sewage sludge with organic matter is considered a macro source of micro and macro elements. New technologies and compliance with health and environmental standards are essential for better sludge management. Considering the need for sustainable resources and environmental protection, the future of sludge use looks promising and can help reduce environmental impacts and increase resource efficiency. The introduction of organic matter into the soil by affecting different physical, chemical, nutritional, and biological characteristics of the soil can improve or increase the growth of plants. As a result of microbial processes and under the influence of intracellular and extracellular enzymes, the ground is provided for plant growth by changing the form of elements from organic to inorganic form. This study investigates the effect of different levels and frequencies of fertilization with sewage sludge on soil activity and quality. For this purpose, wastewater and soil analyses were used, and wastewater treatment was evaluated using two liquid sludge methods for organic fertilizer and bulking materials for mineral fertilizer. The results showed that by changing the volume of treated materials and the amount of wastewater added to the soil, the characteristics of the soil change over a 2-year period. In general, the application of sewage sludge increased the organic carbon and total soil nitrogen and enzyme activities in the soils treated with sewage sludge.

Keywords: Sludge, wastewater treatment, organo-mineral fertilizer.
Article type: Research Article.

INTRODUCTION

Increasing urbanization and industrialization have led to a sudden increase in the volume of wastewater produced worldwide. The problems caused by the lack of wastewater treatment on the environment have made it an absolute necessity (Kominko *et al.* 2017; Cusilayme-Barrantes *et al.* 2023; Ali 2023). After passing through operational units and conventional treatment processes, municipal wastewater should be separated into two parts, sewage, and sludge, each of which must have a quality that meets environmental standards to return to nature. Sewage sludge is obtained through various treatment methods to remove suspended and soluble pollutants from wastewater by separating solids from liquids, chemically and biologically, in the wastewater treatment plant. It is an essential by-product of the treatment process (Kominko *et al.* 2019; Ram *et al.* 2024). Due to the sudden increase in the volume of treated wastewater, large volumes of sludge need to be disposed in an environmentally safe manner.

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Sludge management has become one of the most critical environmental issues in recent years with the development of wastewater treatment plants, either by building new treatment plant units or improving existing facilities. Due to its nutrients and physical properties, sewage sludge is introduced as a fertilizer and soil quality modifier (in forestry, agriculture, and landscaping). Considering the lack of organic matter in Kazakhstan soils and the environmental effects caused by the excessive use of chemical fertilizers, sewage sludge can be a suitable substitute for chemical fertilizers as a potential source (Rodrigues *et al.* 2023). On the other hand, due to the importance of organic matter and its constructive effects on the soil's physical, chemical, and fertility properties, sewage sludge can be known as one of the pillars of soil fertility. This is because the characteristics of wastewater are different from one city to another and because different physical, chemical, and biological processes are used to remove organic and mineral substances from wastewater. As a result, the output sludge quality will also be different in the treatment plants (Yousefi-Behzadi *et al.* 2023). For this purpose, in this study, an effort will be made to investigate the sludge produced in the urban treatment plant and finally evaluate the possibility of using this sludge as a biofertilizer. Sewage treatment plants generally have problems with producing and disposing of dry sludge. Since the volume of dry sludge produced in treatment plants is generally large and there is no specific use for them, the problem of accumulation of dry sludge in the area of treatment plants is always discussed. Disposing of these materials is very important due to environmental considerations and storage restrictions. Hence, proper management of production sludge in treatment plants is essential. Bouhia *et al.* (2024) have shown that rice waste called stubble, the second outer shell of rice, is tiny during threshing by the shredder. It is currently unused as an agricultural waste dump, and sometimes, agricultural land is burned, which is considered one of the polluting factors of the environment. Therefore, according to the composition of stubble, which has high carbon and suitable nitrogen, this material can be used to produce quality organic fertilizer and sewage sludge. Also, Espinoza *et al.* (2023) have shown that adding bulking materials to sewage sludge increases the microscopic activity of sludge and can lead to producing mineral fertilizer with the right amount and the desired quality. Also, Bouhia *et al.* (2022) investigated the effect of adding sludge from paper mills during a sweet corn-cabbage crop rotation on soil enzyme activities. The results of this experiment showed that in the treatment of sludge immediately after its addition, the activity of acid and alkaline phosphatase and aryl sulfatase enzymes increased compared to the chemical fertilizer and control treatments. This increase was attributed to the high carbon content of the sludge and, as a result, the increase in soil microbial activity and their production of enzymes. Also, this study's results showed that the soil's enzymatic activity was gradually reduced. Finally, the level of the enzymatic activity of the soil was reduced to the level equivalent to the control treatment. These researchers attributed the drop in enzyme activity to the decrease in the available energy of microorganisms due to the decomposition of sludge over time. On the one hand, the lack of organic materials in agricultural soils, the mass production of waste materials, and the environmental problems resulting from them require that these materials be used as organic fertilizers in a good and conscious way (Arifin *et al.* 2023; Bouhia *et al.* 2023; Moulaei *et al.* 2024). Using sewage sludge in agricultural fields can contaminate these lands with heavy metals. Although this work adds significant amounts of nutrients and organic materials to the soil, in many countries, some laws limit the use of sewage sludge to stabilize the soil ecosystem. This study aims to investigate the production methods of inorganic-organic fertilizer from urban sewage to evaluate its effect as a fertilizer on agricultural soils and land so that it can solve the wastewater treatment problem and consider its application in agricultural industries, since fertilizer reduce the cost. The results obtained from this research showed that by adding sewage sludge to the soil as an organic fertilizer, the amount of nutrients and the activity of the phosphatase enzyme in the soil increased. Sludge application also increased soil organic matter and elevated plant dry weight. Using root symbiotic fungi increased the effect of sludge on element concentration and root dry weight. In general, the production of different types of growth-promoting substances, such as some enzymes and microorganisms, improves the availability of nutrients, plant growth, and nutrition and helps plant growth and health. It should be noted that this result was obtained with a single application of sludge. The long-term increase of sludge needs to be further studied due to the possibility of increasing the concentration of heavy elements in the soil and the possibility of toxicity.

MATERIALS AND METHODS

Considering the increasing development of urban wastewater treatment plants in the country and the production of a significant amount of sludge, it is necessary to make arrangements to use this valuable product in the wastewater treatment plant. Sludge disposal methods include land application, sanitary burial, burning, and

disposal in lagoons. Land application is one of the methods of using sludge and one of the most common disposal methods in many developed and developing countries. This matter has become so important that the application of sewage sludge in agriculture has become a common thing during the past decades. However, since untreated sewage sludge contains many pathogenic microbes and microorganisms during the sludge treatment process, using sewage sludge in the agricultural sector leads to health concerns and threatens public health. On the one hand, forecasts show that the urban population in the country will increase by 80% by 2030 compared to 2020. The minimum and maximum urban sewage will be 4.5 and 6.2 billion cubic meters, respectively, which shows an increase of 120% compared to 2020. Based on the average annual growth, the availability of the network will increase by 79%, and the wastewater treated by activated sludge, aeration, and trickle filter systems will be at least 2.5 and at most 3 billion cubic meters. On the other hand, when the country's population increases, food demand upraises. Creating a balance of food in the soil to increase the quantity and quality of agricultural production is one of everyone's duties. During the last forty years, major disturbances in the fertility of Kazakhstan soils have appeared with the unbalanced increase in the consumption of chemical fertilizers, especially the unbalanced use of phosphate fertilizers. Since the abundant addition of nitrogen to the soil has reduced the carbon-to-nitrogen ratio and increased the speed of decay and the reduction of soil organic matter, the gradual and continuous reduction of organic matter itself has caused the destruction of the soil structure. In addition, the specific gravity of the soil has increased, while its permeability has decreased. Therefore, the country's agricultural soil fertility has mainly decreased with the unbalanced consumption of chemical fertilizers, along with the reduction of the soil's ability to retain water and ventilation disorders. Considering the high production and consumption of chemical fertilizers in Kazakhstan, it is clear that if sewage sludge is used correctly and safely (from the point view of the environment), the energy used in the production of commercial fertilizers and other soil conditioners and the energy used to bury the sludge in places reduced burial. From an economic point of view, it will be economical to use sludge on the ground as a biological fertilizer. Based on what was mentioned, the importance of using sludge in current conditions (growth of urbanization and increase in volume of production sludge) for use in biological processes and improvement of soil quality is undeniable. Based on this, the possibility of using sludge produced by refineries is an important source for plant nutrition and the agricultural sector. This research was conducted in Astana's research station, located in Kazakhstan. The height of the station is 1630 meters above sea level, and according to the coupon classification, it has a dry and semi-arid climate with cool and dry summers. The research site is located in the center of Kazakhstan along the Ishim River in a very flat and semi-arid plain area at 51° 10' N latitude and 71° 26' E longitude. The chemical characteristics of Astana city's sewage sludge in different decomposition stages are given in Table 1. As can be seen, these samples have a neutral pH and relatively little EC, which is suitable for the growth of plants. The percentage of dissolved organic carbon in the digester is much less than in the raw sludge, indicating the rapid decomposition of organic materials. The reduction of the nitrogen percentage of the treated sludge in the digester can also be attributed to the sublimation and release of ammonia, which eliminates the unpleasant odors of the sludge. The ratio of carbon to nitrogen in sludge is much less than desirable for the vermicompost production process, which explains the necessity of adding bulking materials containing much carbon.

Sludge production process in wastewater treatment

Stages of sludge production in primary and secondary treatment: Sludge in wastewater treatment is obtained from two main stages: primary and secondary. In the primary treatment stage, suspended solids and large particles are separated from the wastewater, and sedimentation occurs. This sedimentation produces "primary sludge," which includes solid and organic materials. This type of sludge is rich in organic matter and usually bulky.

Biological treatment and production of secondary sludge: In the secondary treatment stage, wastewater is treated using microorganisms, leading to the production of secondary sludge. It is mainly comprises microbes and dissolved organic matter produced by biological processes in wastewater treatment. This sludge also needs proper processing and disposal.

Sludge treatment and preparation for final use: After producing sludge in these steps, it can be processed in different ways to reduce its volume or turn it into usable materials. Drying, lime stabilization, composting, and even biogas production can help optimize sludge utilization. These processes aim to reduce volume, control odors, eliminate pathogens, and reduce environmental hazards.

Table 1. Characteristics of sewage sludge of Astana City.

Feature	Sampling steps			
	Primary	**Purified in the digester**	**Wet sludge inside the lagoon**	**Dry sludge inside the lagoon**
pH	7.10	7.52	6.91	7.31
Electrical conductivity	1.8	1.6	1.5	1.5
Organic carbon	2.11	18.32	16.78	17.43
Nitrogen	3.18	2.77	4.11	3.66
Nitrogen to carbon ratio	6.41	6.56	3.45	4.91
phosphorus	1.01	2.63	2.22	1.35
Potassium	0.35	0.31	0.22	0.25
Calcium	13.3	14.9	13.3	12.4
Magnesium	3.7	3.2	2.7	4.8
Sodium	1.95	1.27	0.99	1.11

Chemical and physical composition of sewage sludge

Organic and mineral substances in sludge: The sludge obtained from wastewater treatment contains various compounds. Its organic matter includes proteins, lipids, and carbohydrates, mainly derived from wastewater biodegradation. Minerals such as phosphorus, nitrogen, and heavy metals are also present in the sludge, which can act as a source of fertilizer for plants or as a pollutant in the environment.

Pathogens and Harmful Substances: Sewage sludge can contain pathogenic microorganisms such as bacteria, viruses, and parasites, which may lead to health hazards if not managed properly. The presence of harmful chemicals such as heavy metals (such as lead and mercury) and complex organic compounds can also limit the use of sludge.

Physical properties of sludge: Due to its high moisture content, sewage sludge usually has a soft and moist consistency. Its density and volume depend on the compounds in the sludge and the purification methods. The high volume of water in sludge is one of the main challenges in its management, requiring drying and stabilization processes to make it usable.

RESULTS

Based on objective observations that were usually made on sewage sludge samples in these treatment plants, the results showed that the sludges produced by this treatment plant are in most stinky conditions with a dark brown to black color. In this research, several methods have been used to purify and prepare fertilizer from wastewater: bulking materials for mineral fertilizer production and liquid fertilizer production for organic fertilizer production.

Method 1. Using bulking materials

Table 2 shows the chemical characteristics of bulking materials used for vermicompost production. The carbon-to-nitrogen ratio of wood chips from sparrow tongue trees and wheat straw in this experiment was lower than the figures mentioned in the sources (Bouhia *et al.* 2022; Espinoza *et al.* 2023) due to the partial decay of the samples used.

Chemical properties of sewage sludge and bulking materials in this experiment: sawdust's carbon-to-nitrogen ratio was considered 5/300.

Method 2: Using liquid fertilizer production

In order to produce liquid fertilizer from sludge, 500 mL of 0.25 M soda solution (NaOH) was poured into 50 grams of sludge sample and placed on a shaker for 24 hours. Then it was centrifuged at 4000 rpm for 20 minutes. After centrifuging the sample, the liquid parts inside the centrifuge containers (liquid fertilizer) were separated from the remaining solids at the bottom of the centrifuge container. The above experiment was repeated three times on the remaining solids, demonstrating the rigor and precision of our method. In this way, the remaining solids were transferred into a 500-mL Erlenmeyer flask and 500 mL of 0.25 M soda solution was poured on them

and placed on a shaker for 24 hours and then centrifuged at 4000 rpm for 20 minutes. At this stage, the resulting liquid fertilizer was separated, and once again, all the described steps were performed on the remaining solids from the second stage. The liquid fertilizers obtained from each stage were kept separately, not mixed, and relevant analyses were performed on each liquid fertilizer.

Table 2. Chemical properties of additive bulking materials.

Feature	Bulking material		
	Plant leaf	Wood chips	Straw
Organic carbon	19.1	24.4	28.6
Nitrogen	1.33	0.11	0.71
Nitrogen to carbon ratio	17.1	246.5	37.8
phosphorus	0.20	0.02	0.04
Potassium	0.22	0.10	0.85
Calcium	3.3	4.7	7.1
Magnesium	2.30	3.18	2.41
Sodium	0.66	0.44	0.59

The effect of fertilizer use on soil performance

Using sewage sludge increases the introductory soil respiration rate, so the basic soil respiration rate increases from 16 to 124 mg CO_2/kg soil per hour in the 10-cm layer and from 32 to 92 mg CO_2/kg soil. It has shown an increase of 10-20 cm per hour in the layer. Also, the results showed a significant difference with different amounts of sewage sludge consumption in soil respiration. As shown in Fig. 1, in high amounts of sewage sludge consumption, the rate of respiration increased over time, and the lowest rate of respiration wass observed in the case of bulking materials only, which is probably due to the high presence of organic substances in the soil and their accumulation in the soil.

Table 3. Concentration of heavy metals in biological sludge liquid fertilizer.

Metals	Average slurry liquid fertilizer	The concentration of metals according to the standard of the Food and Agriculture Organization (Joint FAO 2011).
Iron	11.4 ± 10.0	-
Chromium	0.35 ± 0.31	1-83
Nickel	1.40 ± 0.11	30-42
Lead	0.11 ± 0.10	2.2-110
Zinc	2.23 ± 1.75	-
Copper	0.93 ± 0.71	4-240
Cadmium	0.02 ± 0.01	0-15

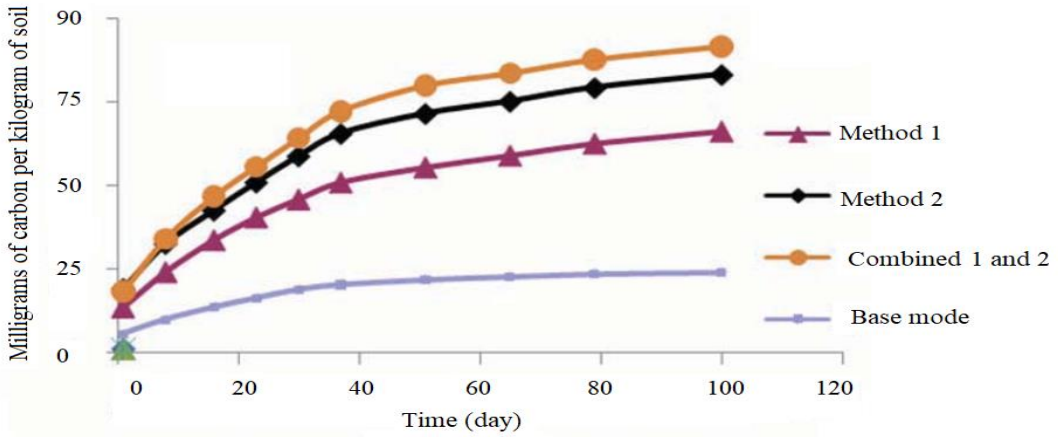

Fig. 1. Effect of various methods and amount of treatment.

To investigate the production of organic and mineral fertilizers from urban sewage during a two-year study, the results are presented in Fig. 2. As it has been shown, it is possible to convert wastewater into mineral and organic fertilizer with the methods presented in this research at a rate of over 80%, which can be effective in wastewater treatment, increasing environmental productivity and reducing costs.

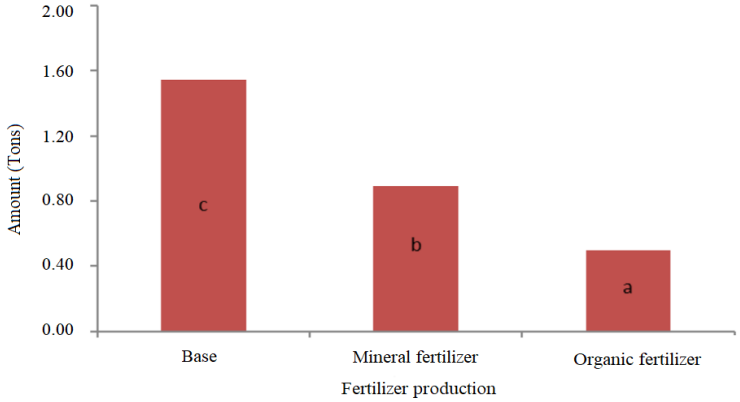

Fig. 2. Comparing fertilizer percentage produced from wastewater.

CONCLUSION

This research evaluated the effect of urban wastewater treatment in Astana by adding bulking materials and fertilizer. Applying sewage sludge separately and combined with different chemical fertilizers increased the amount of organic carbon, microbial respiration, and microscopic activity of acid and alkali in sewage and fertilizer production. The results showed that the combined use of bulking materials and fertilizer liquid had the best performance in wastewater treatment and fertilizer production over two years, and the measured amount of carbon dioxide, microbial respiration, and microscopic activity was higher. Using sludge in fertilizer production has many advantages, including reducing fossil resource consumption, greenhouse gas emissions and optimal use of waste. This method can help sustainable development and reduce the adverse environmental effects caused by improper sludge disposal. In addition, the anaerobic digestion process can also reduce health risks from sludge.

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