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Composting technology and product analysis based on the results of a pilot project in Lviv (Ukraine)

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ABSTRACT

Reducing the volume of solid waste disposal is the main task of Ukraine's modern waste management system. The significant share of organic fraction in municipal solid waste necessitates the use of effective methods for its management. Among the sustainable methods of organic waste treatment, composting holds a special place. This research is aimed at analyzing the environmental impact of industrial aerobic composting technology on the environment and the quality of the resulting product (compost) based on the results of a pilot project, which was first implemented in Ukraine in the city of Lviv. The impact on atmospheric air was analyzed by analyzing the dynamics of pollutant concentrations, measuring noise and vibration levels at the boundary of the sanitary protection zone of the composting station. The impact on water bodies was assessed by recording static and dynamic groundwater levels in a technical well. Physicochemical, microbiological, and antiparasitic indicators and the content of heavy metals determined the quality of the resulting compost. All studies were conducted following standardized methods. The research results were statistically processed using a standard statistical package and compared with the approved standards. It was established that the composting technology does not pose significant environmental risks to the air and groundwater and that the composting product meets the requirements of organic fertilizers. Matured compost is environmentally safe and suitable for use in agriculture. The experience of implementing a pilot project of aerobic industrial composting of organic waste in Lviv can be implemented in other cities of Ukraine to develop sustainable practices for managing the organic fraction of municipal solid waste.

Keywords: organic waste, municipal solid waste, aerobic composting, atmospheric air, groundwater, compost quality, organic fertilizer.

INTRODUCTION

The rapid growth of the population, in combination with urbanization, industrialization, rising living standards, incomes, and consumption of goods and services, has led to a steady increase in the generation of municipal solid waste (MSW). Proper management of this waste is essential for safe cities, but it is still a challenge for many developing countries. In low-income countries, more than 90% of waste is often disposed of in unregulated landfills (Kaza et al., 2018). In Ukraine, 93% of the generated MSW is disposed of at 5455 dumpsites and landfills with a total area of over 8.5 thousand hectares, most of which do not meet environmental safety requirements (Kovalenko et al., 2022).

The organic fraction of municipal solid waste (OFMSW) is significant, accounting for up to 46% globally and up to 64% in low-income countries (Lu et al., 2020). Food and garden waste in Ukrainian cities accounts for 35–50% of all MSW (Vaskina et al., 2024). The management of OFMSW is one of the most pressing environmental issues of current times (Rolewicz-Kalińska et al., 2020).

The disposal of OFMSW at landfills leads to air, water, and soil pollution (Vaverkova, 2019; Almansour et al., 2024). People living near these landfills suffer from air pollution and serious health problems (Siddiqua et al., 2022). The organic fraction turns landfills into biological reactors, from which intermediate and final products of the aerobic and anaerobic destruction of organic matter are released into the air (Nanda et al., 2021; Malovanyy et al., 2021). With no degassing equipment, dumpsites and MSW landfills become uncontrolled sources of greenhouse gas emissions. The products of the complete destruction of organic matter (CO_2 and CH_4) affect climate change (Dede et al., 2023). The accumulation of landfill gas in the bodies of MSW landfills and dumps leads to the most complex, uncontrolled, and long-lasting fires. As a result of open burning of MSW, carbon monoxide and dioxide (CO and CO_2), nitrogen oxides (NO_x), hydrochloric acid (HCl), hydrogen cyanide (HCN), volatile organic compounds are released into the atmosphere, persistent organic pollutants, ketones, aldehydes and metals such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), copper (Cu), nickel (Ni), selenium (Se) and zinc (Zn) (Bihałowicz et al., 2021; Ibrahim et al., 2020). The high moisture content of organic waste and precipitation falling on open landfills lead to leachate that contaminates groundwater (Korbut et al., 2023; Popovych et al., 2020). The leachate from landfills and MSW landfills is a highly concentrated solution of various organic and inorganic substances that keeps forming after their operation is terminated. Leachate leakage outside the landfill contaminates soils (Grynchyshyn, 2019). Disposal of food waste to dumps and landfills affects species biodiversity, as it creates a food base for saprophages, promotes the development of certain species of synanthropic entomofauna and avifauna (Arnold et al., 2021; Dementieieva et al., 2023).

The reuse and recycling of OFMSW is classified as the most favorable approach to managing MSW within the circular economy and achieving sustainable development goals (Sayara et al., 2020). Sustainable methods of OFMSW management involve the use of biological processes, such as composting and anaerobic digestion, which are widely used around the world (Cerda et al., 2018). The composting process is becoming increasingly popular both at home and in large industrial enterprises. It is an effective alternative to landfilling biodegradable waste, allowing for maintenance or increasing the content of organic matter in the soil, reducing the volume of solid waste, and saving on disposal costs (Abbas et al., 2024). The separation of OFMSW is an important step for efficient composting (Cao et al., 2023; Grynchyshyn et al., 2023). However, improper management of the composting process can affect air quality through greenhouse gas (methane and nitrous oxide) and odor (ammonia, hydrogen sulfide, etc.) emissions (Li et al., 2023). The quality and safety of the compost produced, as well as the presence of heavy metals in it, are cause for concern (Manea et al., 2024).

In 2022, the Ukrainian government adopted Law No. 2320-IX "On Waste Management". This law aims to reduce the generation and increase the recycling and reuse of MSW. In this context, the introduction of OFMSW composting is an urgent task. For the first time in Ukraine, the practice of industrial aerobic composting of OFMSW was introduced as a pilot project in 2020 in Lviv. In this regard, there is a need to study the environmental impact of the technology and assess the quality of the final product (compost). The research is necessary for the scientific substantiation of the massive scale-up of aerobic composting technology in other cities of Ukraine.

MATERIALS AND METHODS

Lviv is one of the largest cities in western Ukraine (Figure 1). The population of the city as of the end of 2024 is about one million people. The intensive development of urban infrastructure, the increase in the number of transport and industrial facilities creates a number of environmental challenges for the city. Lviv is one of the leaders in Ukraine in implementing environmental initiatives and sustainable development projects, in particular, modern approaches to waste management are being actively applied.

In September 2020, Lviv joined the Zero Waste Cities project as part of the Zero Waste Cities program by signing a Memorandum between the

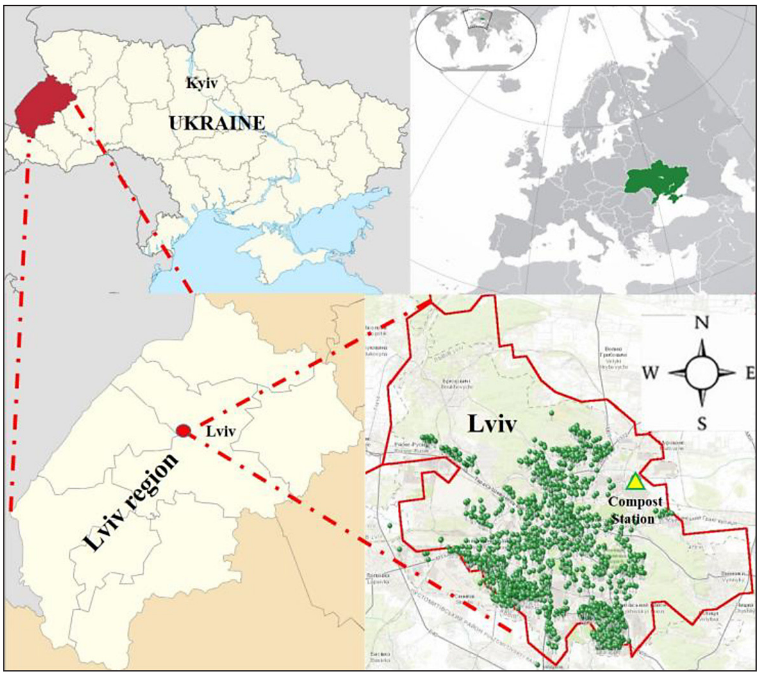

Figure 1. Location of the composting station and containers for collecting organic waste in the city of Lviv

Lviv City Council and Zero Waste Europe. The city officially became the first non-EU participant in the initiative. The pilot project of composting organic waste in Lviv is carried out at a specially equipped station, which is a structural unit of the Lviv municipal enterprise «Green City». The composting station is located in the northeastern part of the city, in an industrial zone, which provides convenient access for the transportation of organic waste (Figure 1). The location of the station facilitates efficient logistics and minimizes the impact on residential area.

Special containers for collecting organic waste from the population have been installed within the city to separate OFMSW (Figure 2). As of the end of 2024, organic waste collection containers were installed at 1468 MSW collection sites (Figure 1).

In 2024, the composting station received 9025 tons of organic waste and produced 2020 tons of compost (Figure 3).

At the composting station, food waste containing foreign impurities is sent to the KONSORT bag ripper, where it is released from the packaging and separated from impurities (plastic, metal, glass) in a disk separator. After that, the food waste is loaded into the KKG-HL-30COMPOST disinfection container (Figure 4a). Waste is sterilized for 48 hours at a temperature of 72–80 °C and ensures the destruction of bacteria and the neutralization of various odors.

Garden and park waste (branches, tree trunks) that arrives at the composting station is crushed into chips using a wood chipper (Figure 4b). Food waste with a moisture content of 70–80% is mixed with wood, leaves and grass chopped to a size of 5–40 mm in a ratio of 3:1. To make the composting process more efficient, the biological products microbiophytes and vermeobiogumates are added in an amount of 0.001%. The mixture is placed in piles for maturation using a front loader NT-1200 and a MANITOU MLT-X 732 95P ST3A S1 telescopic loader (Figure 4c). For preventing decay of organic waste in the piles, they are mixed every 3–5 days and aerated with a BACKHUS A30 mixer (Figure 4d). The composting process lasts from 3 to 5 months and is accompanied by heat generation. The temperature in the piles can reach 70 °C. After 3–5 months, the matured, stabilized composting product is sieved on a set of equipment to separate the coarse fraction, which is used as a natural bacterial preparation for enriching the organic matter in the piles (Figure 4e). The final product (compost) is stored at a special site (Figure 4f).

The environmental impact of the industrial aerobic composting process was determined by the dynamics of pollutants in the atmospheric air, measurement of vibration and noise levels at the border of the sanitary protection zone

Figure 2. Containers for collecting organic waste in the city of Lviv

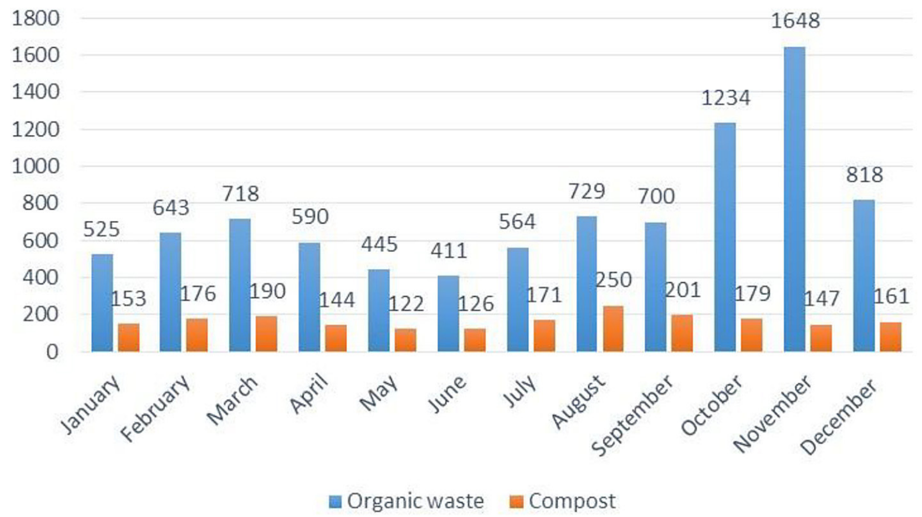

Figure 3. Monthly dynamics of organic waste (food and garden waste) entering the composting station in the city of Lviv and the volume of compost production in 2024, tons

(25 m), and hydrological observations of the groundwater regime.

The air pollutants' concentrations were analyzed using measurements from a stationary air monitoring post. The equipment analyzes the content of nitrogen dioxide, carbon monoxide, sulfur dioxide, ozone, nitrogen oxides, hydrogen sulfide, and ammonia in the air 72 times a day. The sampling methods comply with Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. The analysis used the concentrations of pollutants in the air recorded in April, May, and June 2024.

Noise and vibration levels from the composting station's process equipment were measured using a VSHV-003-M2 noise and vibration meter with DN-3-M1 and DN-4-M1 vibration sensors during the daytime. Measurements were made at representative locations that take into account the maximum potential environmental impact, including prevailing wind directions and terrain features that could contribute to increased noise or vibration propagation.

Hydrological observations of the groundwater level were conducted in a technical well located 200 meters from the composting station. The studies were conducted by recording static and dynamic water levels using a measuring tape at different times of the year.

The quality of the resulting compost was determined by physicochemical, microbiological, antiparasitic, and heavy metal content. To determine the content of large fractions in the compost, particles larger than 50 mm were manually removed. The analysis was performed in triplicate to increase the reliability of the results. Physicochemical studies of the compost included the determination of a set of indicators. The pH value was determined by the potentiometric

Figure 4. Composting stages: a – disinfection; b – wood chipping; c – formation of piles; d – aeration; e – sieving; f – storage

method using a glass membrane electrode in compost samples with initial moisture content, following the methodology established in DSTU 7882:2015. The moisture content was determined by DSTU EN 12048:2005. The method is based on measuring the weight loss of a compost sample during drying to a constant weight. The organic component (mass fraction of organic carbon and organic matter content) was assessed using thermogravimetric analysis by DSTU EN 8454:2015. The principle of the method is to record the weight loss of the sample after treatment in a muffle furnace at 800 °C. The potassium content of the compost was determined by the flame photometric method according to DSTU 7949:2015. Total phosphorus was analyzed by a photometric method according to DSTU EN 15956:2015 and DSTU EN 15959:2015. Total nitrogen was determined spectrophotometrically (λ = 430 nm) according to DSTU 7911:2015 with Nessler's reagent. The nitrate content was determined by the gravimetric method using nitron by DSTU ISO 4176:2003. The mass fraction of ash was determined following the requirements of DSTU EN 130039:2005 as a residue of combustion. The content of heavy metals Cd, Co, Cr, Cu, Mn, Pb, Zn was determined by atomic absorption spectrometry using the C-115MI device.

Microbiological analyses of the final compost included the determination of the bacterial index of the *E. coli* group by a method based on statistical analysis of the results of microbial growth in a series of water samples following DSTU 7469:2013; the horizontal method was used to detect Salmonella according to DSTU ISO 12824:2004, and Clostridium perfringens was determined by DSTU ISO 7937:2006. Antiparasitic analyses, namely the presence of helminth eggs and intestinal protozoan cysts, were performed by flotation, and the presence of helminth larvae by sedimentation (Amoah et al, 2017).

Statistical data processing was performed with standard software. The results are presented as the mean value with the corresponding standard deviation (n = 9).

The quality of the resulting product (compost) as an organic fertilizer was assessed by the standard UA.SOU HCS 03.09-014:2010 Household waste: Technology for processing organic matter contained in household waste (in Ukraine) and the regulatory document Technical Specifications TU U 20.1-13838331-001:2021 "Organic Fertilizer" approved in Ukraine. The compliance of the reported indicators with the regulatory parameters determines the opportunities and scope for further use of compost.

RESULTS AND DISCUSSION

The impact of aerobic composting technology on atmospheric air

The aerobic composting of organic waste is accompanied by the release of pollutants into the air, the concentrations of which do not exceed the maximum permissible concentrations at the boundary of the sanitary protection zone of the composting station (Table 1).

By comparing the minimum and maximum values of pollutant concentrations during the composting cycle, the greatest variability was found for ammonia (NH_3), its concentration increasing 90 times from the minimum value (Table 1). This change in the concentration of NH_3 indicates its intensive release at certain stages of composting due to aerobic decomposition of organic matter. It was found that ammonia is formed as a result of microbial degradation of proteins and nucleic acids contained in organic waste. Temperature increases in the range of 45–55 °C during the composting process lead to an increase in NH_3 emissions (Martins et al., 2023), which result in the loss of 20–45% of the initial N (Cao et al., 2019). Applying hyperthermophilic pretreatment to composting organic matter can significantly reduce ammonia emissions by reducing proteolytic bacteria involved in protein breakdown. This process improves nitrogen retention and minimizes ammonia volatilization

Table 1. Concentrations of pollutants in atmospheric air at the border of the sanitary protection zone of the industrial aerobic composting station for organic waste in the city of Lviv

Pollutant	Concentration range, mg/m³		Maximum permissible concentration[a], mg/m³
	Min	Max	
CO	0.166	0.507	5
NO_2	0.002	0.070	0.2
SO_2	0.016	0.174	0.5
O_3	0.001	0.008	0.16
NO	0.012	0.036	0.4
H_2S	0.0002	0.0011	0.008
NH_3	0.0002	0.1800	0.2

Note: [a] – Standard Ministry of Health from May 10, 2024, No. 813. Maximum permissible concentrations of chemical and biological substances in the atmospheric air of populated areas (in Ukraine).

(Huang et al., 2023). Therefore, the standard ammonia concentrations at the edge of the composting station's sanitary protection zone may indicate the effectiveness of food waste sterilization, inhibiting proteolytic bacteria responsible for ammonia release.

The measured noise and vibration levels during the operation of installations, mechanisms, machines, and other production equipment of the composting station on the border of its sanitary protection zone during the daytime do not exceed the permissible limits (Table 2 and 3).

The obtained results of noise and vibration levels lead to a reasonable conclusion about the safe level of physical factors in the sanitary protection zone of the aerobic composting plant for organic waste.

Impact of aerobic composting technology on water bodies

During the entire composting period, the moisture content of the mixture in the piles remains at 50–60%. Water from the water supply network is used to moisten it. Water is also needed during the composting process to dissolve the biological products before adding them to the mixture. The composting site is located on an asphalt pavement. The slope of the composting station site provides leachate drainage to a separate tank. The collected leachate is used to re-wet the piles. Monitoring of the hydrological regime of groundwater is carried out to identify possible changes in their level affected by leachate from the plant, assess seasonal fluctuations in water levels, and prevent contamination of aquifers. Groundwater level fluctuations were recorded in 2024 (Table 4).

The difference between the static and dynamic groundwater levels (Table 4) does not exceed the limits of natural fluctuations (up to 4 m) (Mareddy et al., 2017). The observed changes between static and dynamic groundwater levels may be due to natural factors (precipitation, seasonal evaporation). The observations indicate the stability of the hydrological regime in the area of the composting station. The absence of sharp changes in the water level suggests that the organic waste composting technology implemented in Lviv does not have a negative impact on groundwater.

Compost quality

Studying the quality of compost is important for its further use. As an organic fertilizer suitable

Table 2. Noise levels at the border of the sanitary protection zone of the industrial aerobic composting station for organic waste in the city of Lviv

Date of observation	Noise level, dB		Normative value[a], dB
	Min	Max	
March, 2024	49	40	55
April, 2024	49	40	
September, 2024	46	39	
December, 2024	45	39	

Note: [a] – State sanitary standards for permissible noise levels in residential and public buildings and on the territory of residential buildings: Order of the Ministry of Health of Ukraine dated 02/22/2019 No. 463

Table 3. Vibration levels at the border of the sanitary protection zone of the industrial aerobic composting station for organic waste in the city of Lviv, average values for 2024

Geometric mean frequencies of octane bands, Hz	Vibration level, dB			Normative value[a], dB
	X	Y	Z	
2	50.1±1.2	51.0±1.4	52.2±0.4	69.5
4	52.4±1.7	51.5±1.0	50.4±2.5	69.5
8	50.0±1.7	49.9±1.1	52.2±1.5	69.5
16	52.5±1.9	53.3±1.8	53.6±0.9	75.5
31.5	54.3±1.1	56.4±1.8	54.9±1.0	81.5
63	58.2±1.7	57.4±4.7	57.1±4.8	87.5

Note: [a] – State Building Regulations B 2.2-12:2018 Planning and development of territories

Table 4. Results of hydrological monitoring of the groundwater regime of a technical well

The date of the observation	Static level, m	Dynamic level, m
March, 2024	2.6	6.1
May, 2024	3.5	4.4
September, 2024	3.6	4.6
November, 2024	2.3	4.0

for use in agriculture, compost must meet a set of regulatory indicators. The determined physical and chemical parameters of compost meet the established standards (Table 5).

Aerobic composting takes place on the surface of the organic mass, and therefore, its efficiency depends on the surface area of the organic matter. Small particles with a large contact surface are better saturated with oxygen, thus accelerating microbiological activity and decomposition (Ho et al., 2022). The content of coarse fractions in the finished compost is within the normal range (Table 5), indicating effective waste shredding, which ensures uniform decomposition of organic matter. The neutral-alkaline pH of the compost is favorable for its use in agriculture. The high mass fraction of organic matter and the significant content of key mineral nutrients (K, P, N), exceeding the standard values, indicate the high nutritional value of the compost. The nitrate content in the compost is within the permissible limits, ensuring the safety of its use. The balance between organic carbon and ash confirms the balance of the compost mineral composition. Therefore, the studied physicochemical parameters indicate the high quality of the compost, which makes it suitable for agricultural use.

However, there are restrictions on the use of compost in agriculture due to the excess of the permissible content of heavy metals, as well as the presence of unsatisfactory microbiological and antiparasitic indicators that may pose a potential threat to soil, plants, and human health (Hargreaves et al., 2008). The results of studies of the content of heavy metals in compost show that their content meets the permissible standards for organic fertilizers obtained by composting the organic fraction of household waste and intended for agricultural use (Table 6).

The low concentrations of heavy metals in the compost confirm its safety in terms of toxic elements and indicate the possibility of using it in agriculture.

The studied microbiological and antiparasitic indicators of the compost meet the established regulatory standards (Table 7).

The high content of *E. coli* bacteria in compost poses an increased risk of pathogen contamination of fresh products and fruits that are usually consumed raw (Olaimat, et al., 2012). The absence of bacteria of the genus Salmonella and Clostridium perfringens, eggs and larvae of helminths, and cysts of intestinal protozoa indicates the effectiveness of the thermal regime during composting, which contributes to the destruction of potentially pathogenic microorganisms and prevents their spread (Toledo, et al., 2018). The absence of Salmonella, Clostridium perfringens,

Table 5. Physico-chemical indicators of compost

Indicators	Value	Normative values
Content of fractions larger than 50 mm, %	1.5±0.2	not more than 2 [a]
pH	7.5±0.4	6.5–8 [a]
Moisture content, %	44.2±4.1	20–80 [a]
Organic matter, %	63.6±3.8	not less than 40 [a]
Potassium, %	0.5±0.1	not less than 0.1 [a]
Phosphorous, %	2.7±0.3	not less than 2.0 [a]
Nitrogen, %	2.0±0.2	not less than 1.8 [a]
Nitrates, mg/kg dry matter	56.2±2.7	not more than 200 [b]
Organic carbon, %	7.2±0.4	not less than 5 [b]
Ash, %	38.4±2.2	10–60 [b]

Note: [a] – UA.SOU HCS 03.09-014:2010, [b] – TU U 20.1-13838331-001:2021.

Table 6. Heavy metal content in the compost

Chemical element	Content, mg/kg of dry matter	
	Compost	Normative values [a]
Cd	0.50 ± 0.08	30
Co	4.47 ± 0.53	100
Cr	3.45 ± 0.58	750
Cu	67.48 ± 13.69	1500
Mn	110.3 ± 16.32	2000
Pb	8.31 ± 0.94	750
Zn	383.22 ± 13.46	2500

Note: [a] – UA.SOU HCS 03.09-014:2010.

Table 7. Microbiological and antiparasitic indicators of compost

Indicators	Compost	Normative values [a,b]
Index of bacteria of the *E. coli* group, cfu/dm^3	< 10000	Not more than 10000
Salmonella, in 25 g	Not detected	Not allowed
Clostridium perfringens, in 1 g	Not detected	Not allowed
Helminth eggs	Not detected	Not allowed
Helminth larvae	Not detected	Not allowed
Intestinal protozoa cysts	Not detected	Not allowed

Note: [a] – UA.SOU HCS 03.09-014:2010, [b] – TU U 20.1-13838331-001:2021.

eggs, and larvae of helminths, cysts of intestinal protozoa in the compost (Table 7) indicates the sanitary and biological safety of the compost.

Thus, the analysis of the impact of aerobic composting technology on certain components of the environment, which is practiced in Lviv, determined the absence of significant environmental risks. The final product created as a result of composting is a high-quality organic fertilizer that can be used as an organic fertilizer in agriculture.

CONCLUSIONS

The research conducted to analyze the operation of an industrial aerobic composting plant and the quality of the resulting product led to a series of important conclusions about the environmental friendliness of the technology and its practical significance.

As a result of organic waste processing in the amount of 9025 tons per year, the content of pollutants (CO, NO_2, SO_2, O_3, NO, H_2S, NH_3) in the air at the border of the sanitary protection zone of the composting station does not exceed the maximum permissible concentrations. Noise load and vibrations during the operation of the composting station's production equipment in the daytime do not exceed the standard values within the sanitary protection zone.

The presence of an asphalted site and leachate collection system at the aerobic composting station prevents groundwater contamination and ensures the sustainability of the groundwater hydrological regime.

The physical, chemical, and microbiological characteristics of the compost meet the standards for organic fertilizers, which allows it to be used in agriculture. The content of heavy metals (Cd, Co, Cr, Cu, Mn, Pb, Zn) in the compost does not exceed the standard values, which reduces environmental risks when it is used. The absence of Salmonella, Clostridium perfringens, helminth eggs and larvae, and intestinal protozoan cysts in the compost ensures its sanitary and biological safety.

Consequently, the analysis of the technology of industrial aerobic composting of the organic fraction of municipal waste in Lviv demonstrates its environmental friendliness and the possibility of creating a high-quality end product – organic fertilizer. The project of aerobic composting of organic matter is a successful case study of a local initiative in the field of sustainable organic waste management and can be scaled up to other Ukrainian cities.

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