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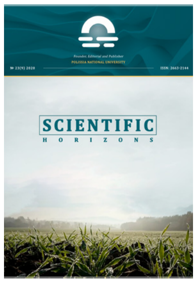

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Obtaining and Use of Compost from the Organic Component of Household Waste

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Abstract. The relevance of the study is conditioned by the need to develop and implement technological solutions for processing food and garden waste into compost. The purpose of this study is to investigate the methods of obtaining compost from the organic component of household waste and analyse composts for compliance with the requirements for their use as fertilisers. Theoretical research on the issues of the application of an organic component of a firm household waste as a raw material for compost production is carried out. According to statistical information on the accumulation of household waste in Ukraine, the amount of food and garden waste in the regions of Ukraine has been calculated. Modern methods of industrial processing of food and garden waste into compost are analysed, and the most effective technology from the standpoint of ecology and energy saving is determined. Data on the influence of composted digestate on crop yields are given. Composts were analysed for compliance with the requirements for their use as fertilisers The data show that the difference between the content of heavy metals in the composted digestate and compost from food waste is not significant and both composts meet the German quality requirements of compost. Data on the influence of composted digestate from food waste on the growth of winter grain yields are given. It has been found that the use of composts can supplement conventional mineral fertilisers in crop cultivation. The practical significance of the study is to determine the prospects of obtaining fertiliser from the organic component of solid waste and to determine its effectiveness when applied to the soil

Keywords: mineral fertilisers, composting, digestate, food and garden waste

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INTRODUCTION

In Ukraine, the problem of environmental pollution by household and industrial waste has become acute. In this regard, the Cabinet of Ministers in 2017 approved the National Waste Management Strategy until 2030. The strategy is aimed at solving problems in the field of waste management [1].

Biodegradable waste is not allowed to be disposed of in landfills in accordance with the EU Waste Management directive [2] and Directive 1999/31/EC on waste disposal [3]. It can be recycled using controlled biotechnological processes that partially or completely transform substances. One way to recycle biodegradable waste is to compost it. This strategy suggests processing the organic component of household waste by composting. This applies to waste from private households. This method requires a significant size of the land plot and it is a long, time-consuming process. The strategy provides for an increase in the volume of waste sent for recycling by up to 50% and the development of an action plan to reduce the volume of disposal of biodegradable household waste. The study suggests that measures aimed at reducing the volume of disposal of biodegradable household waste and increasing the volume of waste sent for processing should include: separate collection of solid household waste (SHW); commissioning of waste sorting lines; introduction of projects for biological processing of mixed household waste.

The organic component of solid household waste is a high-energy raw material for the production of biogas. For example, the theoretical yield of biogas from a tonne of kitchen waste is 180-200 m^3. For comparison, the theoretical yield of biogas from a tonne of solid household waste is 100 m^3, from a tonne of cattle manure – from 50 to 70 m^3, from a tonne of a mixture of manure and plant biomass – up to 150 m^3 [4]. One of the methods of energy utilisation of the organic part of solid waste is the technology of solid-phase methane fermentation (SMF). SMF is the process of recycling organic waste, the humidity of which does not exceed 80% and allows obtaining biogas, liquid fertilisers, and compost.

The Department of Renewable Organic Energy Carriers of IRE NASU deals with issues related to the production of biogas from various organic substrates, including the organic component of household waste. When obtaining biogas from household waste, after press separation of the fermented mass, digestate is formed, the solid fraction of which can be composted and used as fertilisers. Admittedly, compost from the organic component of household waste can be obtained by other methods. Therefore, the task is to analyse various methods of processing the organic component of household waste into compost.

Organic fertilisers consist of components of animal and plant origin, during the decomposition of which minerals are formed. Organic fertilisers contain plant nutrition elements in the form of organic compounds. Organic fertilisers include peat, manure, bird droppings, straw, and various types of compost. One of the sources of raw materials for the production of such fertilisers can be individual organic components extracted from solid household waste (SHW) and processed into compost. These organic components include food and garden waste (leaves of trees and shrubs, mown grass). Therefore, the task is to analyse compost for compliance with the requirements for their use as fertilisers.

In recent years, many research papers have been published that reflect the issues of obtaining compost from the organic component of household waste. Successful attempts to present the problems and possibilities of this direction are presented in [5-7]. O. Sagdeeva investigated composting of a mixture of food, agricultural and garden waste in an aerobic reactor depending on microbiological additives to accelerate this process [8]. M. Tereshchuk determined the energy parameters of the bio-raw material conversion process in a drum-type reactor [9]. Y. Xu reported on the need for pretreatment of household waste before its conversion to compost [10].

The principles of operation of well-known technologies of solid-phase methane fermentation of household waste are covered in [11]. Anaerobic technology of fermentation of several types of organic waste is considered in [12]. C. Yirong investigated the effect of ammonium on the fermentation of food waste [13]. L. Wilson investigated the process of fermentation of waste, for which the dry matter in the substrate starts from 40%. The author proposed using a hydrolysis reactor and recirculation of the liquid fraction of the fermented mass to accelerate the fermentation process [14]. A. Shewani was engaged in optimising the fermentation of solid waste by recycling percolate [15]. D. Pezzolla investigated the effect of Percolate recycling frequency on biogas yield [16]. The paper [17] presents Chinese technologies for waste fermentation.

KYIV Logan provides methods for processing digestate after anaerobic digestion of household waste [18]. KYIV Reilly highlights the suitability of digestate after fermentation of food waste for application to agricultural land as an organic fertiliser [19]. In France, there is a standard for the quality of organic additives NFU 44051, which in particular regulates the indicators of compost obtained from the organic component of solid waste [20]. Study on the processing of the organic component of solid household waste into compost helps to better understand the possibilities and future prospects for obtaining and using organic fertilisers from this raw material.

The purpose of the study is to investigate methods for obtaining compost from the organic component of household waste and to analyse compost for compliance with the requirements for their use as fertilisers. For the furtherance of this goal, the following *tasks* were set: to estimate the amount of food and garden waste by regions of Ukraine; to investigate various methods of processing the organic components of household waste into compost; to analyse composts for compliance with the requirements for their use as fertilisers.

MATERIALS AND METHODS

The research materials for this paper are fundamental and applied studies of Ukrainian and foreign authors on the problem of recycling the organic component of solid waste into compost. The solution of the tasks set in the study was carried out using well-known scientific theoretical methods: critical analysis, systematisation and generalisation of results. To search for scientific information, the method of obtaining a finished information product was applied. A detailed review of a number of research papers was carried out, from which the most informative works were selected for further use as research material. The selection criteria were the degree of study and completeness of the presentation of questions about the possibility of using the organic component of solid waste as a raw material for compost production. At the same time, research papers were considered in which:

– information on the component composition of food and garden waste is provided, and factors affecting this composition are revealed;

– studies related to the problem of obtaining organic fertilisers using various technologies for composting food and garden waste are reflected;

– technologies of industrial processing of food and garden waste into compost (composting and anaerobic fermentation in bioreactors), and the main advantages and disadvantages of these technologies are revealed;

– alternative methods of solid waste processing are given, and the basics of anaerobic decomposition of organic matter are described;

– the energy parameters of the bio raw material conversion process in a closed fermentation chamber are investigated;

– the issues of anaerobic digestion of several types of organic waste are considered and the need for pretreatment of raw materials before their conversion into compost is considered;

– study of industrial technologies of solid-phase methane generation from solid household waste, which are now the most common in the world, is reflected;

– data on the use of composted digestate from food waste as fertiliser are provided;

– composted digestate obtained from the organic component of household waste is compared with compost obtained by the conventional method from the same waste for the content of heavy metals in them;

– the indicators of composted digestates obtained by anaerobic digestion of the organic fraction of household waste according to the requirements of standards of different countries are considered.

To estimate the amount of food and garden waste in the regions of Ukraine, statistical data were used according to the official website of the State Statistics of Ukraine for various regions of Ukraine. To check the completeness of the selection of sources of scientific information and its ordering, the method of systematisation was used, and for its versatile assessment – the method of critical analysis, which analysed the scientific and practical achievements of specialists in obtaining compost from the household waste and its use to improve soils.

RESULTS AND DISCUSSION

Estimation of the amount of food and garden waste

Food waste includes food products that have completely or partially lost their consumer properties during their production, processing, use, or storage. They are formed in the residential sector and in public institutions. These also include food industry waste. In terms of the volume of food waste accumulation, then its significant share falls on households, retail chains, and the hospitality business.

The study provides brief reference material on the properties of the organic component of solid household waste. Food waste consists of food residues after cooking (the non-edible part of food products) and spoiled products. Figure 1 shows a histogram of the distribution of food waste components (a range of values is taken) [21].

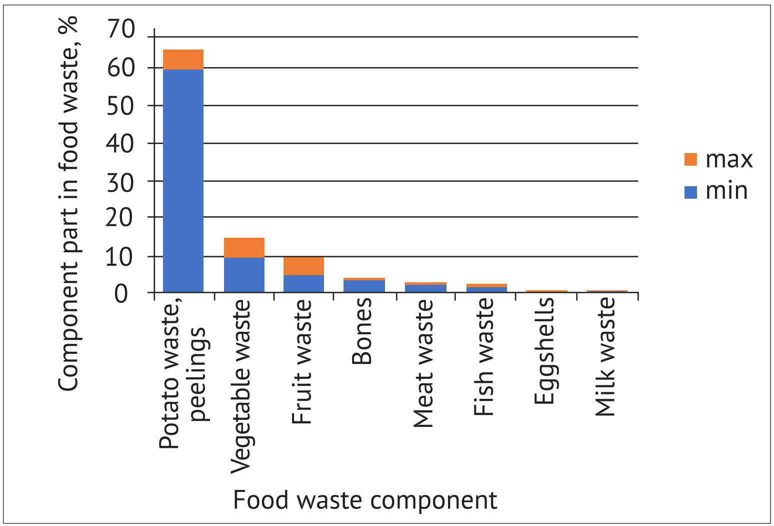

Figure 1. *Distribution of food waste components*

According to the data of [22; 23] and based on statistical information on the accumulation of household waste in Ukraine for 2019 [24], the amount of food and garden waste in the regions of Ukraine is estimated. According to the State Statistics of Ukraine, approximately 11.5-11.9 million tonnes of solid waste are generated in Ukraine annually. The total content of garden and park waste in their composition is approximately 15% [23]. As for food waste, according to the Food and Agriculture Organisation of the United Nations and the All-Ukrainian Environmental League, which conducted a joint assessment of its accumulation, the amount of this waste in Ukraine ranges from 20 to 55% of all SHW [22], or an average of 38%. Based on this, the amount of food and garden waste in the regions of Ukraine was estimated, which is shown in Table 1.

Table 1*. Amount of food and garden waste by regions of Ukraine, thousand tonnes*

No.	Regions of Ukraine and Kyiv city	Amount of waste, thous. tons		Total, thous. tons
		Food waste	Garden and park waste	
1.	Vinnytska Oblast	99	39	138
2.	Volynska Oblast	66	26	92
3.	Dnipropetrovska Oblast	476	188	664
4.	Donetska Oblast	270	107	377
5.	Zhytomyrska Oblast	88	35	123
6.	Zakarpatska Oblast	122	48	170
7.	Zaporizka Oblast	182	72	254
8.	Ivano-Frankivska Oblast	104	41	145
9.	Kyivska Oblast	469	185	654
10.	Kropyvnytska Oblast	80	32	112
11.	Luhanska Oblast	57	23.	80
12.	Lvivska Oblast	180	71	251
13.	Mykolayivska Oblast	127	50	177
14.	Odeska Oblast	256	101	357
15.	Poltavska Oblast	128	51	179
16.	Rivnenska Oblast	80	32	112
17.	Sumska Oblast	108	43	151
18.	Ternopilska Oblast	55	22	77
19.	Kharkivska Oblast	513	202	715
20.	Khersonska Oblast	25	10	35
21.	Khmelnytska Oblast	87	35	122
22.	Cherkaska Oblast	109	43	152
23.	Chernivetska Oblast	111	44	155
24.	Chernihivska Oblast	145	57	202
25.	Kyiv city	545	215	760
Total		**997**	**394**	**1391**

Source: *calculated by the authors based on data from the State Statistics of Ukraine on the accumulation of household waste by regions [24], and data on the percentage of food waste (38%) and garden and park waste in their composition (15%) [22; 23]*

As can be seen from the table, the largest amount of food and garden waste was generated in the Kharkivska, Dnipropetrovska, Kyivska oblasts and in Kyiv. The content of food and garden waste in solid waste tends to be unstable and is directly related to the season of the year and the geographical location of the area where this waste accumulates [25].

Based on the above reference material on the properties of the organic component of solid household waste, the amount of food and garden waste was estimated in the regions of Ukraine, which allows determining the possibility of their use for the production of organic fertiliser and biogas both at the state and regional levels.

Analysis of methods for processing the organic component of household waste into compost

The practice of composting in agriculture goes back a long time. As early as 4,500 years ago, Mesopotamians used compost to improve soil fertility and increase crop yields, which was reflected in their first cuneiform texts. Composting was known to the Mayan civilisation, the ancient Egyptians, Romans, and Greeks. In the middle of the 20th century, mineral fertilisers took the place of compost. However, in private households, waste composting is actively used to this day. Preparations for optimising conditions and speeding up the process in compost pits became marketable. For example, the use of the EM preparation "Baikal" accelerates composting and produces high-quality compost in six weeks [6].

Composting is also widespread in urban households using microorganisms such as bokashi [7]. Not so long ago, a useful invention appeared in stores – a compost container, inside which the necessary temperature regime is maintained. With the help of this invention, residents of villages and summer residents have the opportunity to make their own compost.

Nowadays, research is underway in the field of accelerating the processes of industrial composting of household waste. Thus, in [8], information is provided that the introduction of a bacterial complex accelerates the composting process of the organic household waste by 3.3 times under thermophilic conditions and by 2.1 times under mesophilic conditions of the composting process.

In Ukraine, there are a number of companies that produce compost based on manure, bird droppings, peat, sapropel, etc. Unfortunately, the production of compost on an industrial scale based on the organic component of household waste has not become widespread. At the beginning of 2020, the first city composting station for organic waste was launched in Lviv. This station processes food and garden waste into compost. During 2020, more than 2,500 tonnes of waste were processed [26]. The produced compost can be purchased by residents for the needs of their farms and agricultural enterprises.

The use of the organic solid household waste (SHW) for compost production would help to reduce the volume of landfills, reduce greenhouse gas emissions from them, prevent the formation of smog, and, as a result, preserve public health. Methods of industrial processing of food and garden waste into compost include: composting of digestate obtained by solid-phase methane fermentation of household waste; composting of household waste by conventional methods. Next, the study considers these methods in detail.

1. *Composting of the solid fraction of digestate obtained by solid-phase methane fermentation of household waste*. SMF – the process of recycling organic waste, the humidity of which does not exceed 80% and allows obtaining biogas and digestate. Digestate, which is obtained from droppings, manure, a mixture of droppings, and a mixture of manure with plant biomass, is an organic fertiliser [19]. The solid fraction of digestate may contain heavy metals, depending on the garbage collection and sorting system. At the same time, unsorted household waste contains a sufficient amount of heavy metals [10; 12]. The solid fraction of digestate obtained from food and garden waste can be composted and used as fertilisers [18]. The centralised approach to SMF of food industry waste is currently used only in Europe and California [5], where the disposal of organic waste in landfills is prohibited at the legislative level.

Currently, 26 SMF technologies have been implemented on an industrial scale by commercial companies [27]. The most common and thoroughly studied technologies are those with a single stage of fermentation. These technologies differ in the method of mixing and the mode of fermentation of the substrate. Among the well-known single-stage SMF technologies are the following ones: "Kompogas", "Dranco", "Valorga", "Bekon".

Belgian company OWS it started building biogas plants in 1997. As of the end of 2020, 32 biogas plants were built, which are designed for processing household waste, food waste, industrial organic waste, energy crops, and garden and park waste [28]. The essence of the technology is that household waste is sorted by separating metals, glass, plastic, and the like. The prepared substrate enters a container in which it is mixed with digestate. The mixture is then heated and pumped to the top of the reactor. The mixture moves down the reactor, a vertical structure with a cone-shaped bottom, while self-mixing of waste occurs. Most of the digestate is used for mixing with a fresh portion of waste. The remaining part of the digestate, together with bio-waste, is sent for composting. According to the manufacturer of biogas plants with the "Dranco" reactor, the yield of biogas – 103-147 m^3/t of waste, the dry matter content (DM) – 20-35%, the substrate retention time in the reactor – 15-30 days [28]. The duration of composting digestate with bio-waste is 14 days. Composting of digestate occurs as follows: First, the inert component and the light fraction are separated from the digestate using the "Sordisep" process. The organic component of digestate is composted in structures with automatic control of the composting process, air circulation, oxygen content, and temperature. This method of composting was called tunnel composting. It is designed for aerobic treatment of bio-waste, mixed household waste, kitchen waste, and digestate [28].

French company Valorga International was founded in 1981 to develop solid waste treatment technologies. In the mid-80s, the anaerobic digestion process was introduced on an industrial scale at the French enterprises

La Buisse and Amies for the biological treatment of mechanically treated SHW [29].

The essence of the technology is that waste is automatically sorted, crushed, and the heavy fractions and other pollutants are removed. The sorted waste is fed to the lower part of the reactor, where the inlet is located. From the inlet, the raw material moves around the baffle to the outlet on the opposite side, creating a flow in the reactor. The reactor consists of a vertical steel cylinder with a central baffle. Part of the biogas enters the cogeneration plant, the other part is fed by a compressor to the reactor [29]. According to the manufacturer of biogas plants with the "Valorga" reactor, the yield of biogas – 80-160 m^3/t of waste, the DM content – 25-35%, the substrate retention time in the reactor – 16-35 days [11; 29]. Digestate is dehydrated using a screw press, and the solid fraction is composted. The duration of digestate composting is approximately two weeks.

"Kompogas" technology. The Swiss company Hitachi Zosen Inova started building biogas plants in 1992. By end of 2020, 100 biogas stations were built using SMF "Kompogas" technology, which is designed for processing the organic fraction of urban solid waste, garden and park waste of biological origin (grass, leaves, branches) [30]. The essence of the technology is that the waste enters the shredder, where it is pre-treated to a particle size of less than 10 mm, after which it is mixed in a container with a liquid fraction of the fermented mass and diluted with water to a DM content of 23-28% in the substrate. The prepared mixture is fed to a horizontal reactor with internal slow-rotation rotors. With the help of axial rotors, the substrate is homogenised and moved from the inlet to the outlet. Plug flow reactor with continuous loading of raw materials. Dry heavy components of the substrate are held in a suspended state. The fermented mass is divided into two fractions using a press separator: solid and liquid. Part of the liquid fraction is used for mixing with a new portion of the substrate, the other part is stored in the lagoon and, if necessary, used as liquid fertilisers. The dry part of the fermented mass is composted in a composter [30]. According to the manufacturer of biogas plants with the "Kompogas" reactor, the yield of biogas – 110-130 m^3/t of waste, the DM content – 23-28%, the substrate retention time in the reactor – 15-30 days [30]. The compost yield is 500 kg per tonne of waste [31]. The duration of digestate composting is approximately two weeks. The result is high-quality, nutrient-rich compost.

Notably, recently two stages of fermentation have been used for household waste. For this purpose, studies of the fermentation process are conducted. L. Wilson suggested using a hydrolysis reactor and recirculating filtrate. It was proposed to use filtrate in the hydrolysis reactor to start the fermentation process, the proportion of which is 10% of the initial substrate for dry matter [14]. D. Pezolla showed that the maximum yield of biogas from food waste occurred when percolate was fed four times a day [16]. A. Shevani investigated the optimisation of solid waste fermentation with the addition of straw and cow manure by recycling percolate [15]. It should also be noted that K. Jurong indicated that high concentrations of ammonium lead to inhibition of the fermentation process and instability of the biogas yield. The author established limit concentrations of ammonium, which should not exceed 5 g/dm^3 [13].

In [17], the Chinese technologies "VPD" and "TPAD" are presented, which use two stages of fermentation. They have better indicators of organic matter decomposition compared to single-stage SMF technologies.

2. *Composting in closed reactors.* If land resources are limited, raw materials are composted in closed reactors. Reactors are containers, such as pallets with three walls, or fully enclosed rotating drums. The main condition for composting is mixing and aeration of raw materials [32]. Currently, the most common type of closed reactors are drum-type reactors. Such reactors are capable of processing a large amount of waste in a relatively short period of time (up to 2-3 weeks) [9]. The essence of composting in closed reactors is that raw materials are loaded into the reactor gradually. Inside the reactor, raw materials are mixed and oxygen is constantly supplied. Aeration is carried out by supplying hot air, while controlling the level of humidity and oxygen [9].

3. *Row composting*. The essence of row composting is that compost is formed in long, narrow piles. The equipment for turning and aeration of collars affects the width and height of the composting piles. The size of land plots affects the length of piles. Turning is usually carried out by a bucket loader or tractor. Over time, the piles settle. Row composting can be applied throughout the year. To retain moisture and heat in the piles and to protect them from animals, coverings are used [32]. Field composting requires large areas, and there is a need for environmental protection measures.

4. *Composting in static aerated piles*. The essence of this type of composting is that a perforated pipe is laid in static aerated piles. Aeration of the piles is provided by mechanical fans that supply air through holes in the pipes. The pipe itself is covered with a layer of porous material, on which raw materials are laid, pre-thoroughly mixed. To retain heat and moisture, the pile is usually covered with geotextile material or ready-made compost [32].

Next, the study compares the above methods for obtaining compost from household waste. Consequently, field composting requires large areas, and there is a need for environmental protection measures. Composting in closed reactors is used in conditions of limited land resources. Composting in closed reactors allows controlling and regulating the oxygen content and temperature in the reactors, but at the same time requires large capital and operating costs. Composting of the solid fraction of digestate is usually carried out in automated closed reactors. This method of composting involves the production of biogas.

Thus, compost from the organic component of household waste can be obtained using such industrial technologies as composting household waste and the solid fraction of digestate obtained by solid-phase methane fermentation of household waste. After analysing the above methods of processing the organic component of solid waste into compost, it can be concluded that taking into account energy saving and environmental protection, compost from the solid fraction of digestate obtained by solid-phase methane fermentation of household waste has significant advantages over the other methods, since, as a result of waste processing, the biogas and compost are obtained, and the emission of greenhouse gases into the atmosphere is zero. The process is carried out in bioreactors that are completely isolated from the environment, and there are no greenhouse gas emissions into the atmosphere. Confirmation of this is found in [33].

Analysis of compost for compliance with the requirements for its use as fertilisers

Compost is a source of organic matter and minerals of natural origin, which are vital for soils. In the process of composting in the organic mass, there is an increase in the content of nutrients available to plants. Thanks to its nutrients, compost increases the level of humus, restores soil fertility, improves the structure and increases the moisture capacity of the soil. Improving the condition of the soil would help to increase the yield of agricultural crops. Such types of organic fertilisers as compost and digestate require testing of their agronomic efficiency and environmental safety in vegetation and field studies. It is necessary to check the environmental safety of organic fertilisers with previously established agronomic efficiency.

A number of EU-27 member states have developed standards and specifications for compost and digestate. In Germany, there is a quality assurance system for digestate, which is controlled by the "Bundesgütegemeinschaft Kompost (BGK)" (Federal Compost Quality Association) and "Güte Gemeinschaft Gärprodukt (GGG)" (Digestate Quality Association). The quality criteria for digestate and instructions for its use in this country are called RAL-GZ 245. Belgium has a voluntary quality assurance system for digestate. In the UK, the quality standards for digestate are called BSI PAS (publicly available certificate of the British Standards Institute 110:2010). The Swedish Quality Guarantee is called SPCR 120. In Switzerland, there are quality guidelines for the solid and liquid fractions of digestate.

In France, compost entering the market must meet the French standard for the quality of organic additives NFU 44051. According to this standard, the indicators of compost with the organic component of solid waste should be within the following limits: dry matter content – more than 30%; organic matter content – 15-25%; phosphorus – not less than 1%; nitrogen – not less than 1%; potassium – at least 1%; C/N ratio – more than 8. The concentration of heavy metals in compost should not exceed the following values, mg/kg DM: zinc – 600; nickel – 60; mercury – 2; lead – 180; copper – 300; chromium – 120; cadmium – 3; arsenic – 18 [20]. Composted digestate obtained at the plant in Burk en Bres meets the French standards NFU 44051 according to the technology of SMF "Dranco", in particular in terms of heavy metals concentration, mg/kg DM: zinc – 402; nickel – 57; mercury – 0.2; lead – 66; copper – 126; chromium – 67; cadmium – 0.8; arsenic – 2.4 [20].

In Ukraine, there is no state standard regulating the quality requirements of composted digestate and the norms for its introduction into agricultural land. This is conditioned by the fact that composted digestate obtained as a result of methane fermentation of food waste is not used in Ukraine, although the practice of producing and using composted digestate based on other types of raw materials is used. Therefore, when determining the suitability of composted digestate as a fertiliser, it is advisable to use standards for fertilisers, for example, the standard of housing and communal services of Ukraine "Household waste. Technology of processing organic matter that is part of the household waste of SOU ZhKH 03.09-014:2010" [34]. The standard sets out the procedure for composting the organic fraction that is part of household waste and its anaerobic processing, and also provides recommendations for the use of compost. According to this standard, the agrochemical and physicochemical parameters of compost with an organic component of solid waste for use as fertiliser in agriculture should be within the following limits: the mass fraction of organic matter should not be less than 40% per dry product; the mass fraction of total nitrogen, phosphorus, and potassium per dry product should be more than 1.8; 2.0, and 0.1%, respectively. The content of fractions with a size higher than 50 mm should not exceed 2%; the wet content should be from 20 to 80%; the pH value should be 6.5-8 [34].

The concentration of heavy metals in compost should not exceed the following values, mg/kg DM: zinc – 2500; nickel – 200; Mercury – 15; lead – 750; copper – 1500; chromium – 750; cadmium – 30 [34]. Thus, regarding the content of heavy metals in compost, the established standards according to the French standard for the quality of organic additives NFU 44051 are more stringent in comparison with the Ukrainian standard of housing and communal services of Ukraine "Household waste. Technology of processing organic matter that is part of household waste SOU ZhKH 03.09-014:2010". In ripe compost, the matter should be homogeneous and loose, the components of raw materials that make up its composition should not differ. Plant seeds should lose their ability to germinate in compost. In accordance with the SOU ZhKH 03.09-014:2010, the presence of pathogenic microflora and viable helminth eggs in compost is not allowed. It must have no smell, or the smell must have an "earthy" character. Compost should contain humic acids. The colour of the compost should range from dark brown to black.

Composted digestate obtained by anaerobic digestion of the organic fraction of household waste is an important source of humus, rich in nutrients such as nitrogen, phosphorus and potassium, which help to improve the properties of the soil. The introduction of digestate into the soil helps to preserve and improve soil fertility, its structure, the activity of soil microorganisms, retain moisture in the soil, and protect the soil from erosion.

The use of composted digestate from food waste as fertiliser gives an effect even higher than that of more conventional analogues. For example, in England, composted digestate from food waste provided a 10% increase in winter grain yields over an average of 3 years, while compost from green mass – 7%; mixed compost (from green mass and food waste) – by 8%; slurry – by 9%; manure with straw – by 10%. Consequently, the effect of using composted digestate from food waste is not inferior to manure with straw. Therefore, it can be used as a fertiliser to increase soil fertility [35].

G. Riedel compared compost obtained by various methods for the content of heavy metals in them. The author considered composted digestate from food waste and compost from the same food waste. G. Riedel found that the content of heavy metals in composted digestate has the following values, mg/kg DM: zinc – 197; nickel – 11.5; mercury – 0.097; lead – 26.8; copper – 71.5; chromium – 23; cadmium – 0.366. For comparison, the content of heavy metals in compost from food waste has the following values, mg/kg DM: zinc – 191; nickel – 14.4; mercury – 0.126; lead – 37.4; copper – 59.9; chromium – 22.1; cadmium – 0.455. The content of heavy metals in compost from garden and park waste has the following values, mg/kg DM: zinc – 147; nickel – 12; mercury – 0.096; lead – 27; copper – 38.9; chromium – 20; cadmium – 0.383 [36]. Thus, in all indicators, the difference between the content of heavy metals in composted digestate and compost from food waste is insignificant and both composts meet the German quality requirements of compost [36].

Therefore, the study analysed composted digestates for compliance with the requirements for their use as fertilisers. Data suggest that composted digestate obtained at the plant in Burk en Bres meets the French standards NFU 44051 and the Ukrainian standard of housing and communal services of Ukraine "Household waste. Technology of processing organic matter that is part of household waste SOU ZhKH 03.09-014:2010". There are also data showing that the difference between the heavy metal content of composted digestate and food waste compost is insignificant and both composts meet the German compost quality requirements. The use of composted digestate from food waste provided an increase in the yield of winter cereals by 10%. The use of compost allows supplementing conventional mineral fertilisers in the cultivation of agricultural crops.

CONCLUSIONS

Based on the results of the conducted research on the production and use of compost from the organic component of household waste, it was established:

1. The organic component of household waste (food and garden waste) is a promising raw material for compost production. The study estimated the amount of food and garden waste in the regions of Ukraine, which allows determining the possibility of their use for the production of organic fertiliser and biogas both at the state and regional levels.

2. Industrial technologies for obtaining compost from organic household waste are presented and analysed. It is shown that the use of organic household waste for compost production will help reduce the volume of solid waste in landfills, reduce greenhouse gas emissions from them, and prevent the generation of smog. It is revealed that compost from the solid fraction of digestate obtained by solid-phase methane fermentation of household waste has significant advantages over conventional composting, provided that energy-saving and environmental protection are taken into account.

3. Compost can be used as fertiliser in agriculture for landscaping urban and adjacent areas, roads, forest plantations, etc. Composted digestate obtained at the plant in Burk en Bres meets the French standards NFU 44051 and the Ukrainian standard of Housing and communal services of Ukraine "Household waste. Technology of recycled organic matter that is part of household waste SOU ZhKH 03.09-014:2010". A comparative analysis of the content of heavy metals in composted digestate and compost from food waste is carried out. Both of these composts have been shown to meet German quality requirements. The use of compost allows supplementing conventional mineral fertilisers in the cultivation of agricultural crops.

REFERENCES

[1] Order of the Cabinet of Ministers of Ukraine No. 820-r "On Approval of the National Waste Management Strategy in Ukraine until 2030". (2017, November). Retrieved from https://www.kmu.gov.ua.

[2] Directive of the European Parliament and of the Council No. 2008/98/EC "On waste and repealing certain Directives". (2006, April). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098#ntr4-L_2008312EN.01000301-E0004.

[3] Directive of the Supreme Council of Ukraine No. 1999/31/EC "About waste disposal". (1999, April). Retrieved from https://www.kmu.gov.ua/storage/app/sites/1/55-GOEEI/direktiva-radi-1999-31-es.pdf.

[4] Eder, B., & Schultz, H. (2011). *Biogas plants.* Kyiv: Zorg Ukraine.
[5] Clarke, W.P. (2018). The uptake of anaerobic digestion for the organic fraction of municipal solid waste Push versus pull factors. *Bioresource Technology,* 249, 1040-1043. doi: 10.1016/j.biortech.2017.10.086.
[6] Beletskaya, G.A., & Matyushenko, I.V., (2019). Composting of organic waste in domestic conditions. *Natural Science Almanac*, 26, 16-23.
[7] Prykhodko, V., & Hiulakhmedova, K. (2019). Organizational and legal aspects of bioorganic waste management in Ukraine. In *Problems of ecological safety: Materials of the XVII international scientific and technical conference* (pp. 203-207). Kremenchuk.
[8] Sagdeeva, O., Krusir, G., Tsykalo, A., & Leuenberger, G. (2018). Research of composting processes of solid domestic wastes food composition. *Technogenic and Ecological Safety,* 4(2), 13-21. doi: 10.5281/zenodo.1244572.
[9] Tereshchuk, M., Klius, S., Tsyvenkova, N., & Chuba, V. (2021). Investigation of energy parameters of biomaterial conversion process in closed fermentation chamber. *Renewable Energy*, 1(64), 87-97. doi: 10.36296/1819-8058.2021.1(64).87-97.
[10] Xu, Y., Zhang, C., Zhao, M., Rong, H., Zhang, K., & Chen, Q. (2017). Comparison of bioleaching and electrokinetic remediation processes for removal of heavy metals from wastewater treatment sludge. *Chemosphere,* 168, 1152-1157. doi: 10.1016/j.chemosphere.2016.10.086.
[11] Nozhevnikova, A.N. (Ed.). (2016). *Biotechnology and microbiology of anaerobic processing of organic municipal waste.* Moscow: University Book.
[12] Awe, O.W., Zhao, Y., Nzihou, A., Minh, D.P., & Lyczko, N. (2018). Anaerobic co-digestion of food waste and FOG with sewage sludge – Realising its potential in Ireland. *International Journal of Environmental Studies,* 75(3), 496-517. doi: 10.1080/00207233.2017.1380335.
[13] Yirong, C., Zhang, W., Heaven, S., & Banks, C. (2017). Influence of ammonia in the anaerobic digestion of food waste. *Environmental Chemical Engineering*, 5(5), 5131-5142. doi: 10.1016/j.jece.2017.09.043.
[14] Wilson, L.P., Sharvelle, S.E., & De Long, S.K. (2016). Enhanced anaerobic digestion performance via combined solids- and leachate-based hydrolysis reactor inoculation. *Bioresource Technology,* 220, 94-103. doi: 10.1016/j.biortech.2016.08.024.
[15] Shewani, A., Horgue, P., Pommier, S., Debenest, G., Lefebvre, X., Decremps, S., & Paul, E. (2017). Assessment of solute transfer between static and dynamic water during percolation through a solid leach bed in dry batch anaerobic digestion processes. *Waste Biomass Valorization,* 9(47), 1-9. doi: 10.1007/s12649-017-0011-1.
[16] Pezzolla, D., Di Maria, F., Zadra, C., Massaccesi, L., Sordi, A., & Gigliotti, G. (2017). Optimization of solid-state anaerobic digestion through the percolate recirculation. *Biomass Bioenergy*, 96, 112-118. doi: 10.1016/j.biombioe.2016.11.012.
[17] Fu, Y., Luo, T., Mei, Z., Li, J., Qiu, K., & Ge, Y. (2018). Dry anaerobic digestion technologies for agricultural straw and acceptability in China. *Sustainability,* 10(12), article number 4588. doi: 10.3390/su10124588.
[18] Logan, M., & Visvanathan, C. (2019). Management strategies for anaerobic digestate of organic fraction of municipal solid waste: Current status and future prospects. *Sage Journals*, 37(1S), 27-39. doi: 10.1177/0734242X18816793.
[19] Reilly, M., Cooley, A.P., Richardson, B., Duarte, T., & Theodorou M.K. (2021). Electrocoagulation of food waste digestate and the suitability of recovered solids for application to agricultural land. *Journal of Water Process Engineering,* 42, article number 102121. doi: 10.1016/j.jwpe.2021.102121.
[20] De Baere, L., & Mattheeuws, B. (2017). Production of clean compost out of mixed MSW: A giant leap towards zero waste. In M. Kühle-Weidemeier, & K. Büscher (Eds.), *Resources and Energy from Municipal Waste* (pp. 554-567). Melbourne: Australian Council for Educational Research.
[21] Collection and utilization of food waste. (2010). Retrieved from https://www.waste.ru/modules/section/item.php?itemid=98.
[22] Ukraine is reducing food waste. (2021). Retrieved from http://www.fao.org/europe/news/detail-news/ru/c/1379542/.
[23] Prykhodko, V., & Hiulakhmedova, K. (2018). The characteristic of bioorganic component of municipal solid waste. *Visnyk of V.N. Karazin Kharkiv National University Series "Ecology",* 19, 82-90. doi: 10.26565/1992-4259-2018-19-08.
[24] Official website of the State Statistics Service of Ukraine. (2021). Retrieved from http://www.ukrstat.gov.ua.
[25] Fisgativa, H., Tremier, A., & Dabert, P. (2016). Characterizing the variability of food waste quality: A need for efficient valorisation through anaerobic digestion. *Waste Management*, 50, 264-274. doi: 10.1016/j.wasman.2016.01.041.
[26] The composting station is our most successful project to date. (2021). Retrieved from https://city-adm.lviv.ua/news/city/housing-and-utilities/283844-stantsiia-kompostuvannia-tse-stanom-na-sohodni-nash-naiuspishnishyi-proekt-sviatoslav-yevtushenko.
[27] Wellinger, A. (2013). *Mechanical-biological treatment.* Retrieved from https://www.ieabioenergy.com/wp-content/uploads/2013/09/5043.pdf.
[28] Official website of the "OWS". (2021). Retrieved from https://www.ows.be.
[29] Official website of the "Valorga International". (2021). Retrieved from https://www.valorga.fr.

[30] Official website of the "Hitachi Zosen Inova". (2021). Retrieved from https://www.hz.inova.com.
[31] Trzcinski, A.P., & Stuckey, D.C. (2017). Microbial biomethane from solid wastes: Principles and biotechnogical processes. In F.D. Harzevili, & S. Hiligsmann (Eds.), *Ch.4: Microbial Fuels Technologies and Applications* (pp. 77-151). New York. doi: 10.1201/9781351246101.
[32] Program to promote green modernization of the Ukrainian economy. (2016). Retrieved from https://eco.kiev.ua/assets/files/Dod.5.-Vidhodi-silskogo-gospodarstva.pdf.
[33] Shah, G.M., Tufail, N., Bakhat, H.F., Imran, M., Murtaza, B., Farooq, A.B.U., Saeed, F., Waqar, A., & Rashid, M.I. (2017). Anaerobic degradation of municipal organic waste among others composting techniques improves N cycling through waste-soil-plant continuum. *Journal of Soil Science and Plant Nutrition,* 17(2), 529-542. doi: 10.4067/S0718-95162017005000038.
[34] Standard of housing and communal services of Ukraine "Household waste. Technology for processing organic matter that is part of household waste. SOU HCS 03.09-014:2010". (2016). Retrieved from https://www.minregion.gov.ua/wp-content/uploads/2016/01/SOU-ZHKG-03.09-014_2010.pdf.
[35] How biogas plants produce fertilizer. (2020). Retrieved from https://propozitsiya.com/ua/yak-u-biogazovyh-ustanovkah-dobryvo-vyroblyayut.
[36] Riedel, H., & Marb, C. (2008). Heavy metal and organic contaminants in Bavarian composts – An overview. In *International congress CODIS 2008* (pp. 63-64). Solothurn.

Отримання і використання компосту із органічної складової побутових відходів

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Анотація. Актуальність дослідження обумовлена необхідністю розробки та впровадження технологічних рішень щодо переробки харчових і садово-паркових відходів у компост. Мета даної роботи – аналіз методів отримання компосту з органічної складової побутових відходів і аналіз компостів на відповідність до вимог для їхнього використання як добрив. Проведено теоретичні дослідження питань, пов'язаних із застосуванням органічної складової твердих побутових відходів в якості сировини для отримання компосту. За даними статистичної інформації щодо накопичення побутових відходів в Україні розраховано кількість харчових і садово-паркових відходів. Проаналізовано сучасні методи промислової переробки харчових і садово-паркових відходів у компост. Встановлено, що отримання компостованого дигестату з використанням твердофазної метанової ферментації з урахуванням екології та енергозбереження має суттєві переваги перед іншими методами отримання компосту. Виконано аналіз компостів на відповідність до вимог для їхнього використання в якості добрив. Наведено дані, які показують, що різниця між вмістом важких металів у компостованому дигестаті та компості з харчових відходів незначна і обидва компости відповідають вимогам якості компосту. Наведено дані щодо впливу компостованого дигестату з харчових відходів на зростання врожайності озимих зернових культур. З'ясовано, що використання компостів дає змогу доповнити традиційні мінеральні добрива при вирощуванні сільськогосподарських культур. Практична цінність роботи полягає у визначенні перспективи отримання добрива з органічної складової твердих побутових відходів та у визначенні його ефективності при внесенні в ґрунт

Ключові слова: мінеральні добрива, компостування, дигестат, побутові відходи, харчові та садово-паркові відходи