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COMPOSTING OF ORGANIC WASTE WITH THE USE OF MINERAL ADDITIVES

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Abstract. Aerobic composting is one of the best available technologies for an integrated waste management system in terms of minimizing the anthropogenic impact on the environment, complying with the latest domestic and foreign developments, economic and practical acceptance of the technology. Organic production is rapidly spreading in the world as a holistic system of rational nature management that becomes the basis for the use of modern composting technologies for organic raw materials to obtain a quality product of processing. But composting is characterized by relatively low popularity in comparison with other methods of waste utilization due to a number of its disadvantages, such as a long production cycle and sometimes the unstable quality of a product obtained. Because of this, many studies in the field of solid waste recycling are devoted to methods of accelerating the composting process. This can be achieved in various ways, such as the development of high-performance composting machines and biotic changes (vermiculture, use of specialized crops and biocenoses of microorganisms), or abiotic (temperature, pH, etc.) parameters of the process.

The article presents the results of studying the effect of mineral additives on organic waste composting processes, with the aim of its accelerating in mesophilic and thermophilic temperature regimes with controlled parameters. To improve the efficiency of the composting process and compare the features of the processes, the soil was used as a microbiological inoculum, and mineral salts solutions as a mineral additive. The results of the studies allow us to conclude that it is advisable to compost plant waste with a mineral additive, both in the thermophilic and the mesophilic mode. The compost ripening period, with a mineral additive used, is 6 weeks. It is shown that the mineral complex accelerates the composting of the organic constituent of municipal solid waste by 2.2 times in the thermophilic mode, and by 1.4 times under the mesophilic conditions of the composting process, which proves the effectiveness of its use in recycling municipal solid waste to increase the general level of environmental safety.

Keywords: composting; waste; compostable mixture; mineral additive; mesophilic and thermophilic modes of composting.

КОМПОСТУВАННЯ ОРГАНІЧНИХ ВІДХОДІВ З ВИКОРИСТАННЯМ МІНЕРАЛЬНИХ ДОБАВОК

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Анотація. У статті представлено результати дослідження впливу мінеральної добавки на перебіг процесів компостування органічних відходів з метою його прискорення в мезофільному і термофільному температурних режимах з керованими параметрами. Для підвищення ефективності процесу компостування та порівняння особливостей перебігу процесів в якості мікробіологічного інокуляту використовували ґрунт, в якості мінеральної добавки – розчини мінеральних солей. Результати проведених досліджень дозволяють зробити висновок про доцільність компостування рослинних відходів з мінеральною добавкою як у випадку термофільного, так і у випадку мезофільного режимів. Період дозрівання компосту при використанні мінеральної добавки становить 6 тижнів. Показано, що мінеральний комплекс прискорює процес компостування органічної складової твердих побутових відходів у 2,2 рази за термофільного режиму і в 1,4 рази за мезофільних умов проведення процесу компостування, що свідчить про ефективність його використання в процесах переробки твердих побутових відходів з метою підвищення загального рівня екологічної безпеки.

Ключові слова: компостування; відходи; суміш, що компостується; мінеральна добавка; мезофільний і термофільний режими компостування

DOI: <http://dx.doi.org/10.15673/fst.v12i1.842>**Introduction. Formulation of the problem**

The degradation of soil cover is one of the most acute problems of modern nature management. With the exhaustion of humus and biophile elements in soils, there takes

place a sharp violation of organic and mineral nutrition of soil biota, an increase in oligotrophy, and a decrease in the general biological activity and fertility of soils, in their resistance to erosion, chemical, and bacterial contamination. The problem is especially urgent because of the deficiency

of organic fertilizers, without which the restoration of soil fertility is impossible.

Plant waste constitutes a significant part of municipal solid waste (MSW) both in cities and in households. It is agricultural waste, park and garden waste, and food scraps of plant origin. According to monitoring data on MSW landfill sites, plant waste is a significant proportion (25–30%) in the total amount of MSW and includes garden waste (15–17%) and food waste (10–13%) [1]. The most environmentally appropriate method to process this kind of waste is composting.

In the EU and in the world, organic production is rapidly spreading as a holistic system of rational nature management that becomes the basis for the use of modern composting technologies for organic raw materials to obtain a quality product of processing.

Solid waste recycling into compost is quite a well-developed method of its disposal and subsequent use. The main advantages of the application of composting technologies in waste treatment are the return of available plant nutrients from the waste to the ecosystem cycle, the reduction of the waste amount, with the parallel utilization of other organic waste products in the compost (leaves, grass, manure, purifying sludge, municipal water, etc.). However, the total share of waste recycled by composting remains low. For example, in Europe, about 2% of waste is recycled by composting. A number of composting plants have been built in the CIS, but almost all of them produce low quality compost [2].

Analysis of recent research and publications

Composting is a way of disinfecting household, agricultural, and some industrial solid wastes, based on the decomposition of organic substances by microorganisms. The final product of the decomposition is a hygienically pure non-toxic humusy substance that is successfully used primarily as stimulating regeneration of soil ecosystems, and secondarily, as an organic fertilizer.

Aerobic composting is one of the best technologies available for an integrated waste management system due to its anthropogenic environmental impact as small as possible, complying with the latest national and foreign developments, affordable and practicable technology.

But composting is not as popular as other methods of waste utilization due to a number of its disadvantages, such as a long production cycle, and sometimes, the unstable quality of the product obtained. Because of this, many studies of MSW recycling are devoted to methods of accelerating the composting process. This can be achieved in a variety of ways, such as the development of high-performance composting devices and modifying the biotic parameters of the process (vermicomposting, use of specialized crops and biocenoses of microorganisms) or the abiotic ones (temperature, pH, etc.).

Aerobic composting systems are divided into open and closed, with forced pneumatic (pressure and suc-

tion), mechanical, or combined aeration systems. Today, many composting systems that process organic waste to be further used as organic fertilizers are known and have found their use in various sectors of economy [3]:

1) composting in heaps (according to the way of manure accumulation and storage, there is ordinary accumulation, 'hot composting' by the Krantz method, preparation of 'cold' compacted manure);

2) composting in piles (natural composting in pile without technological interventions, composting with periodic turning the pile, composting with uncontrolled natural aeration, composting with controlled forced aeration);

3) composting on mechanized sites;

4) composting in semi-closed mechanized buildings (composting in tunnel type structures, in containers);

5) composting in closed mechanized buildings (bio-fermentation platform chambers, vertical bio-fermentation systems, composting with the use of biodrums).

Closed-type bioreactors can be used to speed up the process of composting and to ensure optimum progress of the process. In bioreactors, to accelerate the decomposition processes, the waste is mixed, and air is additionally supplied. During the recycling process, optimum decomposition parameters are supported: certain humidity, temperature, oxygen content, pH, phosphorus and nitrogen content, certain ratios of C:N, C:P, and C:H are maintained. These conditions make it possible to obtain high-quality compost in a very short time, reducing the composting process to several weeks.

The main factors that influence the process of composting are temperature, aeration, humidity, and pH of the medium.

Temperature is one of the most important parameters that ensures the efficiency of composting. It significantly changes in the composting process due to the thermal effect that occurs as a result of oxidative destruction of covalent bonds in oxidized substances. Usually, in any composting process, four temperature stages are distinguished: mesophilic, thermophilic, cooling, and the stage of the final maturation of compost.

Studies have shown that microorganisms of the thermophilic stage play a major role in the decomposition of organic substrates. They decompose more than 2/3 of lignin in the composting process, while at the mesophilic stage, microorganisms mainly process substances that are easily decomposed, and at the stages of cooling and maturation, it is the remaining humus matter that is decomposed. On the basis of this, scientists assume that thermophilic microorganisms can transform most of the organic substances that are decomposed by mesophilic microorganisms at other stages. In other words, the mesophilic stage, as well as the cooling and maturation stages, are not necessary parts of the composting process, and, accordingly, the composting period can be greatly reduced if the composted

mixture is artificially heated to maintain the necessary conditions for the growth of thermophiles [4].

Another important parameter for aerobic composting is aeration. There are three types of aeration of compacted mixtures: forced aeration by means of blowing air into piles, compost heaps, or appropriate apparatuses for the aerobic process; passive aeration carried out by placing a horizontal pile in the wind rose direction, and by means of special perforated pipes laid inside the pile (they provide passive inflow of air into the processed mixture); the method of composting with natural aeration, without the use of any devices, but taking the wind rose into account.

According to the study that determines the optimal degree of aeration, the most effective way of aeration of a compostable mixture of agricultural waste is forced aeration with an airflow rate of 0.41 l/min/kg of dry compostable material [5].

Research Materials and Methods

The water content of the compostable mixture is essential for the production of high-quality compost. Usually, the process goes on quite effectively with 35–65% water content in the compost heap. Maintaining these values is especially important during forced aeration when the water is removed along with the emitted gases. To ensure high efficiency of the process, the moisture content of the compostable mixture should not be lower than 50%.

The pH value in the mixture is another important indicator of the efficiency of the composting process. Typically, the pH of the compostable mixture varies from slightly acidic (as a result of the carboxylic acids synthesis) to slightly alkaline (due to the formation of ammonium ions) in the range of 4.5 to 8.1. As a rule, these values are closely related to the activity of microorganisms that take part in composting [6].

The technologies of rationalized methods of preparing manure and other organic wastes was paid attention to at the beginning of the 20th century. Based on the layer-by-layer method of composting in piles in the 1930s, the technology of composting with layer-by-layer formation of semi-deep piles (the Indore method) was suggested [7,8]. Some search was aimed at developing a variety of ways to accelerate the composting process by changing the abiotic parameters of the process [9,10].

Among modern researchers of the composting process as a rational way of waste management, innovative are the works by M. V. Gatsenko [11], M. K. Linyk [12], O. O. Lyashenko [13], V. V. Shatsky [14], in which much attention is paid to the problems of composting technology, the mechanization of the substrate preparation, the optimization of the controlled parameters of the process, the design of piles, the composition of the substrate, and the proportion of the main nutrients in it. However, along with the issue of accelerating the composting process to reduce organic waste, the formation of competitive organic fertilizers, which, according to ecological and economic indicators, can meet the needs of the country's agro-industrial complex, remains relevant.

The purpose of this research was to study the possibility of accelerating the composting process of plant waste by means of mineral additives. It was assumed that adding them to the raw material would lead to the activation of microbial activity in the initial stages of the process.

In the course of this study, the following **tasks** were to be performed:

1) to investigate the influence of mineral additives on the processes occurring when organic waste is composted in the mesophilic and thermophilic modes;

2) to study the conditions of composting processes under the main abiotic and biotic parameters – by changing the temperature, pH, and number of microorganisms in the composted mixture, the carbon (CO₂ emissions) from the reactor;

3) to determine the maturity of the compost according to the germination index and the ratio of the total carbon and nitrogen content in the composted mixture.

As a raw material for composting, a mixture of food (potato, squash, and carrot peelings, cabbage leaves), agricultural (weed), and garden (deciduous litter) waste, in a weight ratio of 1:1:1, was used. Deciduous litter was used as a filler. The raw material was chopped to a size of 10–15 mm, dried in air for 2 hours, and loaded into the reactor. Mineral salts (calcium nitrate, potassium dihydrogen phosphate and magnesium sulfate) were used as additives to improve the composting process and to compare the peculiarities of the processes. It should be noted that, according to the research results [15], the structure of microbial complexes is an integral part of the detailed soil characteristics. That is why it is practical to use the soil's microbial complexes as a microbiological additive for composting in natural conditions.

The experiment was being conducted for 6 weeks in three stationary reactors, each 3 dm³ in volume, with forced aeration. The terms of the experiment are given in Table 1.

Table 1 – Experiment conditions

Reactor number	Inoculum	Additive	Ambient temperature, °C
1	soil	–	18–20
2	soil	mineral	18–20
3	soil	mineral	55

Into each reactor, a compostable mixture (CM) was placed in an amount of 1.2 kg (2/3 volume) with a humidity of about 75%, which was mixed with 100 g of soil (southern low-humus black earth soil typical of the region) as the inoculum. Besides, into reactors 2 and 3, solutions of mineral salts were added in the amount of 150 g/kg of dry CM for the weight ratio Ca(NO₃)₂*4H₂O:KH₂PO₄:MgSO₄*7H₂O = 4:2:1

Reactors 1 and 2 were isolated from the ambient temperature. Reactor 3 was placed into a thermostat with a temperature of 55°C for thermophilic composting.

Composting lasted for 6 weeks during which the compostable mixture was stirred and humidified daily to maintain a moisture level of about 70–75%. Each week, samples of about 10 g were taken for analysis.

The control of the parameters of the composting process was carried out by changing the temperature, pH, and the number of microorganisms in the compostable mixture, as well as the CO₂ emissions from the reactor [16]. The maturity of the received compost was determined by the germination index [17] and the ratio of the total carbon and nitrogen content in the compostable mixture [18].

The temperature inside the compostable mixture was measured with an alcohol thermometer fixed in the reactor lid. The lower end of the thermometer was located in the compostable mixture.

Once a week, a gas fraction was taken from the reactors with disposable plastic syringes of 50 cm³. The syringe was attached to the gas outlet in the reactor. Then, the reactor was shaken to remove the gases from the compostable mixture, and after 5 minutes, 50 cm³ of the sample gas mixture was taken. The amount of carbon dioxide in the sample was determined with a gas chromatograph *Chromatec Crystal 5000.2*.

The compostable mixture samples of about 5 g were placed into metal boxes and dried into a constant mass to determine the moisture content, total carbon and total nitrogen. When the mass of the samples became constant, they were crushed in a porcelain mortar. Then they were sifted through a sieve with a mesh size of 0.25 mm, and then, used to determine total organic carbon by Tyurin and total nitrogen by Kjeldahl [18]. The portions of wet samples weighing 5 g were placed into 250 ml conical flasks, mixed with 50 cm³ of distilled water, shaken in a shaker for 1 hour, and then filtered through a folded filter to determine the pH, the number of mesophilic and thermophilic microorganisms, and the germination factor.

The pH of the aqueous extract was determined with a laboratory pH meter. The number of microorganisms was determined by cropping on a solid nutrient medium in a Petri dish by the Koch method.

The germination rate was determined by the number of seedlings that had sprouted out of every ten radish seeds, and the lengths of seedlings in water extracts from compost, as compared with the control (distilled water).

The quality control of the finished product was determined by the C/N ratio and by the total nitrogen content in the dry matter.

Results of the research and their discussion

In literature, there is enough information on biochemical, microbiological and other aspects of the composting process of organic waste generated in agricultural and municipal sectors, food industry, etc. So further on, it was necessary to assess whether the inoculation of compost mixtures with mineral additives affects the process of composting organic waste. In general, the completeness of the com-

posting process is characterized by two parameters – the ‘stability’ and the ‘maturity’ of compost. In spite of their conceptual difference, they are concurrently used to determine the degree of decomposition of organic matter (OM) during the composting process. Parameters were chosen to assess the intensity of decomposition of OM (temperature, OM content, soluble organic carbon (SOC), and ammoniacal nitrogen) as well as its stability (respiratory activity and cellulolytic activity, number of bacteria and micromycetes) and maturity (pH, phytotoxicity).

The results of the studies of the pH change in the compostable mixture are shown in Fig. 1. The initial pH value of the raw material was slightly acidic, close to neutral (6.3). In the reactors with a mineral additive in the thermophilic conditions, the pH of the medium initially changed in the slightly acidic pH range, then the medium became close to neutral, and in the mesophilic conditions the pH at first slightly increased to 7.6 pH units, then decreased to 5.4, and then the pH of the medium varied to neutral. The final pH value in all composts was approximately the same (6.9–7.6), that indicates the completion of the maturation process of the compost mixture. The pH of the control sample in the 6th week of composting was 5.9 pH units, which indicated that there were some biochemical processes in it.

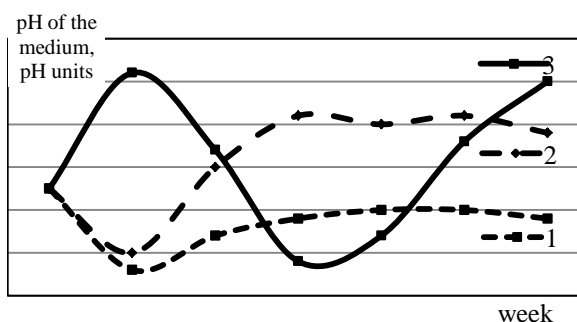


Fig. 1. pH change of the compostable mixture in mineral fertilizer reactors in the mesophilic (2) and thermophilic modes (3) as compared to the control sample (1)

We can infer how active the microorganisms are from the intensity of their breathing (oxygen consumption or carbon dioxide emissions).

Fig. 2 shows the dependence of changes in the CO₂ concentration in the reactor space on the duration of the biodegradation process. This dependence illustrates how the activity of colonies of microorganisms changes during composting. The activity of microorganisms is much higher in the reactor that is in thermophilic conditions.

In reactors 2 and 3, the greatest activity value is for the period from the second to the third week, which suggests that the introduction of mineral additive stimulates the increase in the activity of the microbiocenosis in the initial stages of composting.

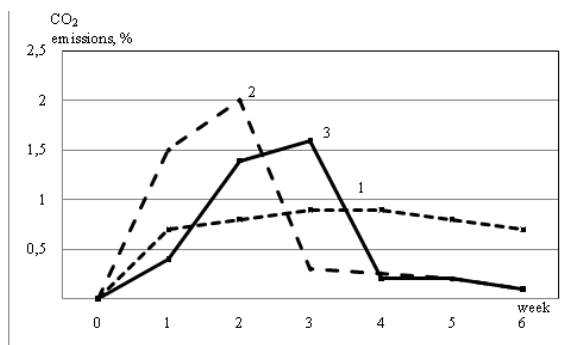


Fig. 2. Change in CO₂ emissions from the reactors during the process of mixture composting in the reactors, with a mineral additive in the mesophilic (2) and thermophilic modes (3), as compared to the control sample (1), % CO₂

The nature of the dependence of the change in total carbon number on the duration of composting presented in Fig. 3 is approximately the same for all reactors: in the first 4 weeks, a large amount of the organic matter (about 20%) is mineralized, then carbon is consumed insignificantly (3–4%). The maximum rate of the organic matter destruction in all reactors was observed after the second week.

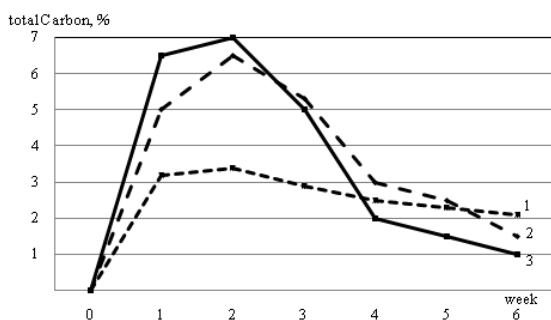


Fig. 3. Change in the rate of total carbon losses in the compostable mixture in the reactors with a mineral additive in the mesophilic (2) and thermophilic modes (3), as compared to the control sample (1), %/week

Total carbon losses were more significant in reactor 3 (22%) than in reactor 2 (about 21%). Thus, the total losses and the rate of total carbon losses are more pronounced during thermophilic composting, which indicates the intensity of the organic matter decomposition in this mode.

The nature of the change in the total nitrogen content in the compostable mixture is virtually identical for all reactors (Fig. 4). In reactors 2 and 3, a mineral additive containing nitrate ions was introduced, that is why the content of nitrogen in the compostable mixture after the first week is higher than in the raw material. The maximum rate of nitrogen loss in all reactors was observed after the third week, and in the reactor, which operated under the thermophilic conditions, it was

more significant and amounted to 4.5 g/kg CM per week.

Total losses of nitrogen in reactor 3 were the largest (about 16 g/kg of dry compostable mixture), which is a sign of an increase in nitrogen losses in thermophilic composting when the mineral additive was introduced. However, the total nitrogen content in reactors 2 and 3 at the end of composting was 31 and 29 g/kg of the dry compostable mixture, respectively, which is 35–40% higher than in the control sample.

The maturity of compost is estimated by the mass ratio of total carbon and total nitrogen (C/N) in it. According to international standards, quality compost should have C/N below 25. Table 2 shows the dependence of the C/N change on the duration of composting. The C/N ratio reaches the minimum values after the second week of composting and then does not change significantly. At the same time, it practically does not depend on the temperature, but significantly decreases when nitrogen is applied with a mineral additive.

The final C/N ratio in all compost obtained is less than 25, which indicates that compost maturation is reduced to about a half after adding the mineral additive, taking into account the rate of its change.

The results of the study indicate that the radish seed germination index gradually decreases, with an increase in the length of composting (Fig. 5). Compost with germination index less than 80% is considered to be phytotoxic compost, more than 80%, – mature compost.

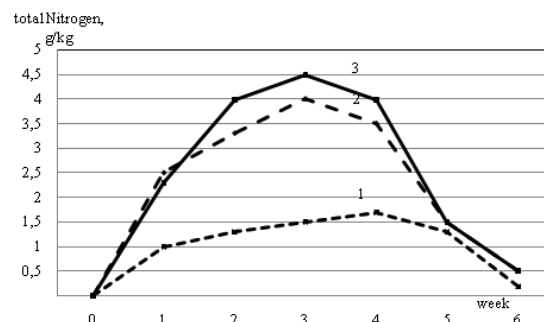


Fig. 4. Change in the rate of the total nitrogen losses in the compostable mixture in the reactors with a mineral additive in the mesophilic (2) and thermophilic modes (3), as compared to the control sample (1), g/kg CM per week

Table 2 – Changes in the total carbon to total nitrogen ratio, C/N

Reactor number	Time, weeks						
	0	1	2	3	4	5	6
1	36.0	35.5	35.0	34.5	33.0	32.2	29.5
2	36.0	33.0	31.5	30.4	28.5	26.3	22.3
3	36.0	32.2	30.7	29.8	26.7	23.3	21.5

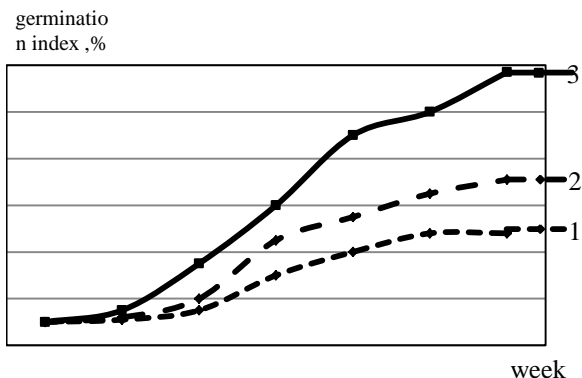


Fig. 5. Changes of the germination index during composting in the CM in the mineral additive reactors in the mesophilic (2) and thermophilic modes (3), as compared to the control sample (1), %

After 6 weeks of composting, the composts in reactors 2 and 3 are characterized by a germination index of more than 100%. This fact indicates that the composts, besides containing no phytotoxins, also have a stimulating effect on the germination process. The experimental data of the research allow us to conclude

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that the compost maturation in thermophilic conditions is faster than in the mesophilic ones, and the duration of compost maturation with the mineral additive is accelerated by 2.2 times under the thermophilic conditions, and by 1.4 times under the mesophilic ones.

Conclusion

Thus, the results of the conducted studies allow us to conclude that it is practical to compost plant waste with a mineral additive, both in the case of thermophilic and in the case of mesophilic composting.

The period of compost maturation with the use of a mineral additive is 6 weeks. It has been shown that the mineral complex accelerates the composting process of the organic component of municipal solid waste about twice, both in the thermophilic mode and in the mesophilic conditions of the composting process. It proves the effectiveness of its use in recycling municipal solid waste to increase the general level of environmental safety.

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