Project Deliverable 4.3:

Energy efficient composting

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1. INTRODUCTION

The main goal of the sludge hygienisation and composting technology is their natural use. The technology we propose to process sludge into compost allows both natural and agricultural use, because the compost produced is safe in terms of sanitation and contains fertilizing values. However, to be marketed and used as a fertilizer, it must obtain an appropriate fertilization permit-certification.

Composting is a process to improve sewage sludge, very beneficial and desirable because it is one of the basic elements of the closed cycle of organic matter in the environment. It allows to obtain a mature product, completely stable with the smell of earth. Compost is suitable for growing most plants, provides nutrients and increases soil fertility.

The expected scope of application of the fertilizer:

- in field crops,
- on grasslands,
- in fruit crops,
- in the cultivation of ornamental plants,
- for lawns,
- for land reclamation.

Due to its properties and nutrient content, it can be used for:

- fertilization of soils intended for agricultural use,
- fertilization of agricultural land (land) (host ecosystems),
- reclamation of land intended for agricultural use,
- fertilization of soils intended for non-agricultural use,
- arranging and maintaining green areas in residential, industrial and communication areas,
- production of flower and other substrates,
- production of seedlings of shrubs, trees, and other ornamental plants,
- land reclamation without soil, intended for agricultural, forestry, recreational and residential development,
- vegetable preservation of dusty and washed-out surfaces in mineral sediment storage sites and during earthworks.

Compost can replace a certain amount of artificial fertilizer, and in addition:

• is an irreplaceable structure-forming factor, especially on sandy and clay soils,

• improves soil aeration and water retention,

• perfectly keep moisture,

• stimulates soil acidity - it replaces liming on acidified soils with simultaneous fertilization,

• facilitates the formation of humus,

• covers the demand for organic compounds and activates soil fertility, replaces manure,

• stimulate soil life and biological activity,

• has an extended period of functioning in the soil compared to commonly used artificial fertilizers,

• filters surface pollutants from the atmosphere, binds harmful mineral compounds.

Composting is one of the most environmentally friendly ways to neutralize sewage sludge. Composting as a process for the treatment and disposal of organic waste of municipal, industrial, and agricultural origin is a well-known method, which is usually set for two purposes:

- neutralization, i.e., transformation of waste containing easily decomposable organic substances and pathogenic microorganisms into a stable material, not harmful to the environment, safe in terms of sanitary and hygiene, easy to store, transport and use,
- production of high-value organic fertilizer, compost that does not contain excessive amounts of components harmful to the environment, especially heavy metals and organic substances that are difficult to decompose.

Composting is a process that improves the second process of sludge stabilization and their hygienisation and preparation of material with high quality features, good structure, and commercial product.

This means that the processing of sewage sludge using the composting process, which significantly changes the properties of the sludge allows, (i) change the classification of sewage sludge from waste to product, (ii) enables the production of compost which after meeting certain requirements, can be qualified as a soil improver. The processing of sewage sludge for agricultural use is consistent with the Circular Economy strategy, the implementation of which results in:

- reducing the consumption of raw materials (in this case of artificial fertilizers),
- limitation of the amount of landfilled waste,
- an increase in the amount of waste used as part of recovery.

The energy efficiency of such a process is just as important as the reclassification of sewage sludge from waste to product. That's why in the STEP project deliverable 4.3 we focused on energy efficiency, too.

2. FIELD STUDIES

The aim of the research started at the beginning of 2018, apart from determining the influence of the proportion between the amount of ingredients in the mixture of organic materials on the course of the composting process of sewage sludge, was also to determine the energy efficiency of the composting process. The research was carried out on an industrial scale at the sewage treatment plant in Goleniów at the research was carried out in two parts. Information related to energy and fuel consumption by machines and devices was systematically recorded during field tests,

<u>Part I.</u>

The research was carried out during 2018-2021 using the technology of roofed windrow with a length of approx. 70 m and the dimensions of the trapezoidal cross-section: 3 m - width of the lower base and 1.5 m - height, periodically turned. The total area of the concrete composting place with roofing is 2.400 m^2. The parameters of the formed windrows (pictures 1÷3) were as follows:

- working plate length 60 m
- width of the working plate 40 m
- the maximum length of the windrow is 54 m
- width of the windrow base 3 m
- initial windrow height 1.6 m
- height of the windrow with the ready preparation 0.9÷1.1 m.

Part II.

The composting process in the second part was tested during 2021 using a new installation. The research was carried out in static composting conditions with forced aeration, running under a cover with a semi-permeable membrane of the GORECover type (pictures 4÷6). In accordance with the composting technology recommended by the manufacturer compost test was carried out without the addition of straw, using the mass ratio between sludge and wood chips of 1:1.

According to this technology, the dewatered sludge is mixed with wood chips only, which is supposed to improve the porosity of the mixture and increase the air flow efficiency. The process takes place under the cover of a semi-permeable membrane in conditions of intense air flow forced by the work of radial fans.

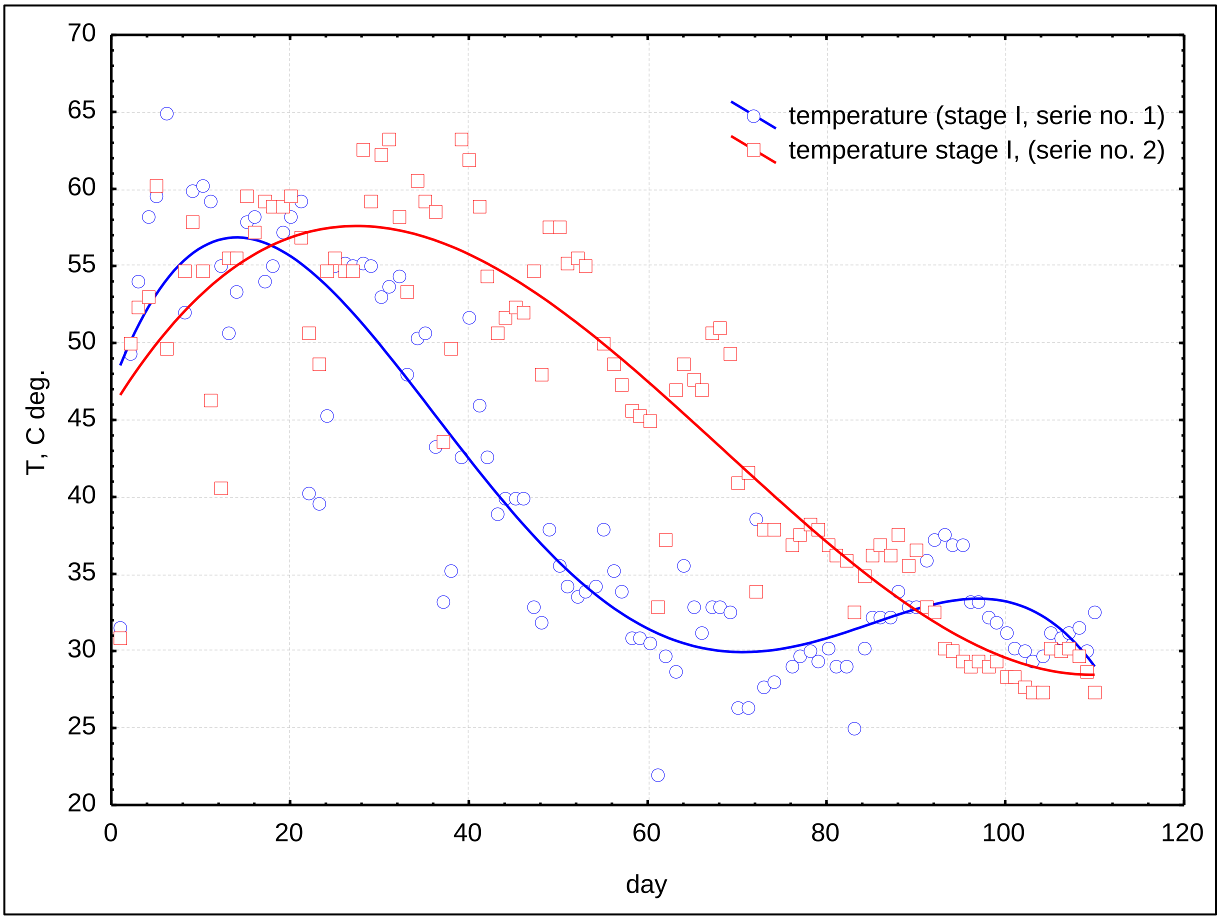
3. RECOMMENDED OPERATION DURING THE COMPOSTING OF SEWAGE SLUDGE WITH EFFECTIVE ENERGY AND FUEL CONSUMPTION

The production of high-class humus depends on the chemical purity of the raw materials as well as on keeping the compost recipe. High-quality compost cannot be obtained without the development of certain aerobic thermophilic bacteria. Decay processes, which are the main obstacle to the proper production of compost mass, develop whenever the compost mixture is left unattended and unattended. The metabolites and odor emitted from the anaerobic decomposition of organic matter from the compost windrow overgrown with putrefactive bacteria can permanently spoil the pre-mixed sludge mixture and contribute to the high nuisance of the sludge management for the environment. It depends on the type of bacteria that will develop in the compost whether the final product will have characteristics similar to compost soil. Bacteria determine the organoleptic characteristics of the product such as smell, lumpiness, earthy or greasy structure, and they also influence the hydration and the content of pathogens. The temperature above 55 ° C is a strong bactericidal agent, its effectiveness is equal to the chemical pasteurization process with quicklime. According to the literature, under thermophilic conditions, the complete destruction of live helminth eggs is achieved after 4 hours of exposure at a temperature above 50° C.

The condition for obtaining the final product safe for use in the natural environment as compost is the following factors:

Physical purity of input materials:

- excessive sludge
- structural materials
- Chemical purity of input materials,
- Correctness of the composting process.
- Appropriate product storage



The most important component that can potentially contaminate the entire compost is excess sludge from sewage treatment plants and sludge supplied from on-site treatment plants.

Sewage sludge is a waste that can be hazardous. It may result from the presence of pathogenic pathogens and parasites as well as the presence of harmful substances, including heavy metals, exceeding the permissible standards. The sewage system in the sewage treatment plant catchment is an open system, which may lead to theoretical, uncontrolled pollution of the sewage with toxic substances accumulating in the excessive sludge. For the above reasons, the study of dehydrated raw sludge is carried out at least 4 times a year. A representative sample of the finished compost preparation for testing is taken by an authorized sample-taker and the testing is carried out by an accredited laboratory. The sample is also prepared and tested for each mature batch of compost intended for use.

3.1. Static composting in open windrows with cyclic mixing (part I of field studies)

1. Preliminary compost windrow

The sludge dewatered in a mechanical dewatering station using a press with 80% hydration is placed on the compost yard on a prepared site with a spread layer of straw about 20 cm thick. The layer of sediment is interleaved with a layer of straw of a similar thickness several times. The individual layers of sediment and straw are sprinkled with the bark of conifers. The size of the initial windrow, depending on the available space, may reach: width 3.0 m, height 1.0 m, length - the operator of the composting plant decides

Picture 1. Preparing windrows

Picture 2. Preparing windrows – first mixing

The cross-section of the windrow is in the shape of an irregular mound. The initial windrow may be laid from the sludge delivered directly from the dewatering station or from the temporary storage site for dehydrated sludge. The construction of the initial windrow may take from one, even up to several days. After obtaining the appropriate size, the initial windrow is thrown onto the main compost windrow.

2. Compost windrow (initiation of the processes of oxygen decomposition of matter)

The purpose of turning/mixing a windrow with the compost turner machine is to provide oxygen for the growth of compost bacteria and to form the windrow to a suitable higher height with a compact shape of an isosceles triangle with a base of about 3 m.

The devices and control devices necessary to run the compost windrow from the initial windrow are: wheel loader, compost turner, digital thermometer.

After turning over, the mixture of materials used to build the initial windrow has a homogeneous structure throughout the entire cross-section, straw, sediment, and bark are mixed with each other. In the event of significant hydration of the windrow, which is manifested by spilling over the square and it is not possible to shape the appropriate height, structural material in the form of wood chips, shavings or more straw should be added to the mixture. After such an operation, the prism is more compact and does not require a significant area, and it is also easier to maintain a porous structure. The frequency of shifting the windrow in this phase depends on the moisture content of the sediment and the amount of material structural. The sludge with high humidity, exceeding 83%, included in the windrow must be thrown once a day.

Picture 3. Mixing windrows during composting process

Sludge with a moisture content of less than 80% can be shifted only once every 3 - 4 days. The decisive factor for the necessity to flip the windrow is the color of the material-mixture inside the windrow. Black color indicates an oxygen barrack and anaerobic processes - putrefactive, brown is the beginning of aerobic processes. An important feature indicating the beginning of the process is the increased temperature in relation to the ambient temperature. We test the temperature of the stocks every day at a distance of 10 m along the stock windrow. After immersing the lance in the prism (to the half of its depth), read the temperature after about 20 seconds. We note the temperature value and its place of measurement from the beginning - i.e. from the moment of the windrow formation to the end of the compost formation process. We test the humidity of the stocks much less frequently (more than once a month). The condition for completing the process initiation phase and moving to the main composting phase is to obtain a stable temperature inside the compost windrow, exceeding 50 ° C. In the first period, the switching frequency must be high, even once a day, otherwise aerobic compost bacteria will not develop due to the lack of oxygen. The greasy structure of the sediment in this phase is an obstacle to the penetration of air into the prism, without which aerobic bacteria decomposing organic matter with the release of heat will not develop. The sludge without oxygen turns black, which indicates the predominance of putrefactive processes in the windrow, while the mixture gives off a putrid smell, mainly hydrogen sulphide. Counteracting this is frequent shifting as a condition to initiate the composting process. The second condition is the development of specific bacterial groups, which are usually present in small amounts in the excess sediment, which allows spontaneous growth without external inoculation. The completion of the first initiation phase is significantly accelerated by inoculating the compost bacteria from the mature windrow to the initial windrow. In this case, it is possible to start the composting process after the first transfer of the initial windrow, even on the next day.

3. Compost windrow proper

The process of proper composting, regardless of the season and outside temperature, begins when the temperature inside the windrow exceeds 50 ° C.

Signs of entering the process of proper composting, in addition to the increased temperature, are intense evaporation, a sweetish smell resembling alcoholic fermentation mixed with the released ammonia and the brown color of the prism throughout the space. During the first month of the phase, the hydration of the mixture decreases from 75% to 45%, and the structure of the sediment itself changes from sticky to lumpy earthy. During the process at an elevated temperature, bacteriological and parasitological contamination is neutralized. During the entire cycle, the mixture is thrown at least a dozen times, which is a sufficient guarantee that each batch of input raw materials will reach the zone with increased temperature. The decisive factor to enable or disable the turning procedure in this phase is the temperature of the windrow.

The low frequency of switching causes a gradual drop in temperature and the process stoppage, high frequency may, however, lead to excessive temperature exceeding 70 ° C and, consequently, a significant slowdown of the process following the increase in temperature due to the disappearance - destruction of compost bacteria. The environmental optimum for carrying out the process is the temperature within 60 ° C and humidity of 50%. Both the decrease in humidity below 40% and the increase in temperature above 70 ° C, which is observed during the process, can lead to a significant reduction in the composting rate. The frequency of shifting the windrow in phase I every two days gradually decreases to the value of once every two weeks, as the structure of the sediment changes to a more porous one, which maintains the temperature close to 60 ° C for a longer time, does not require shifting. Then the composting process is at its optimum, and the shifting barrack also lowers the cost of sludge treatment.

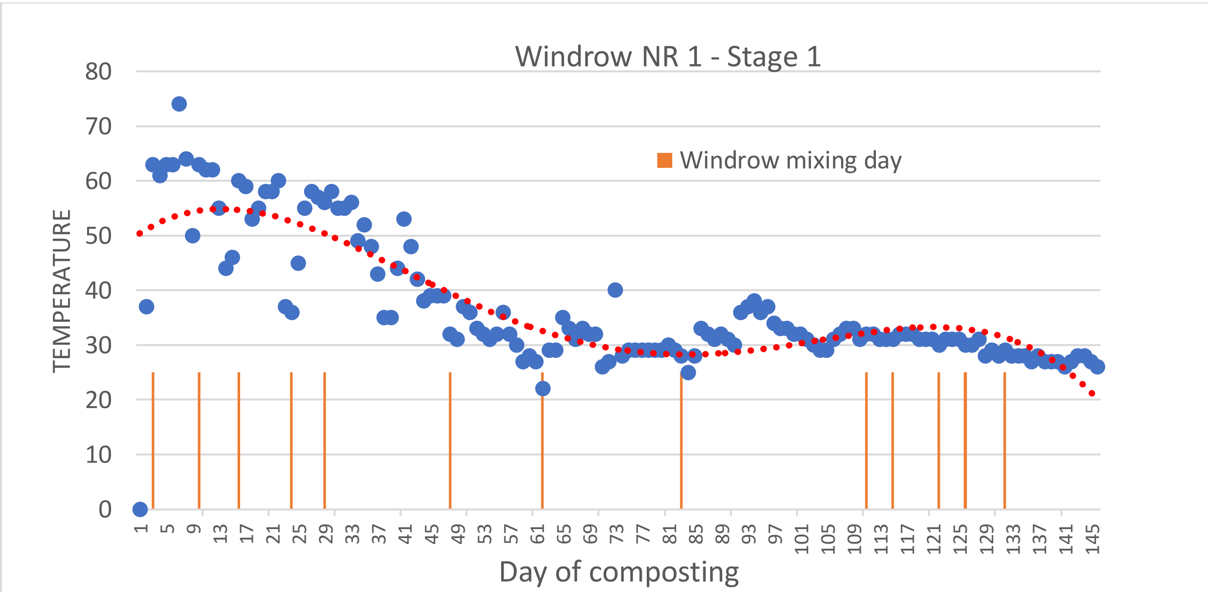
After 2 to 4 months of uninterrupted activity at high temperature, the windrow may enter the next phase III - that is, the maturation of the compost.

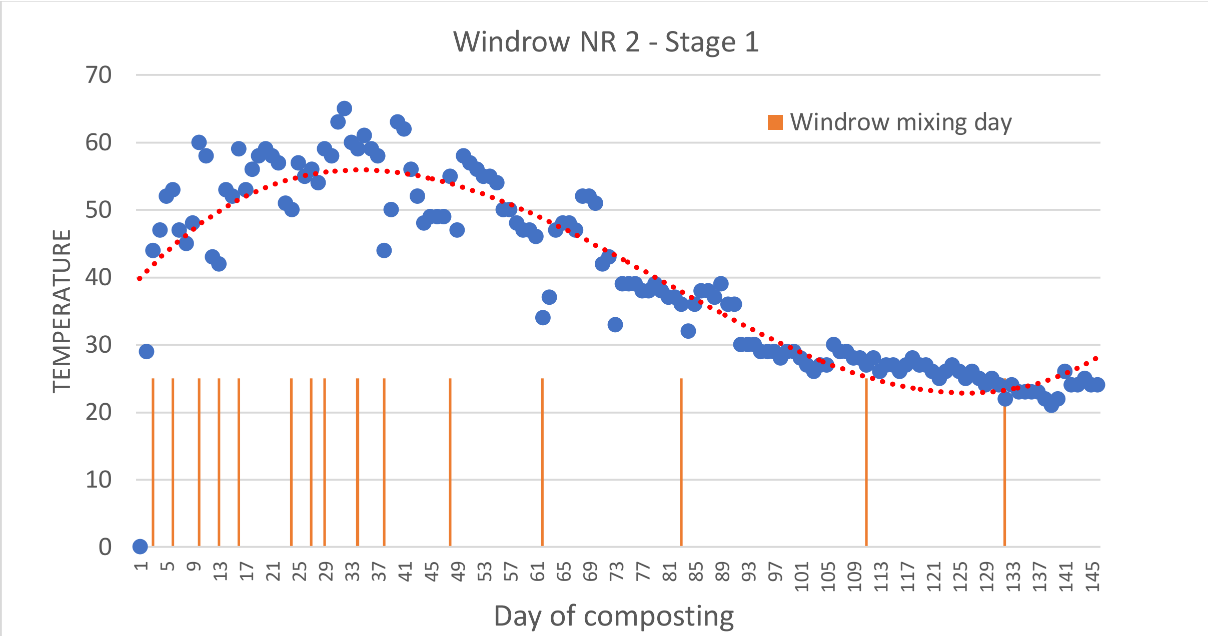
4. Correctness of the composting process.

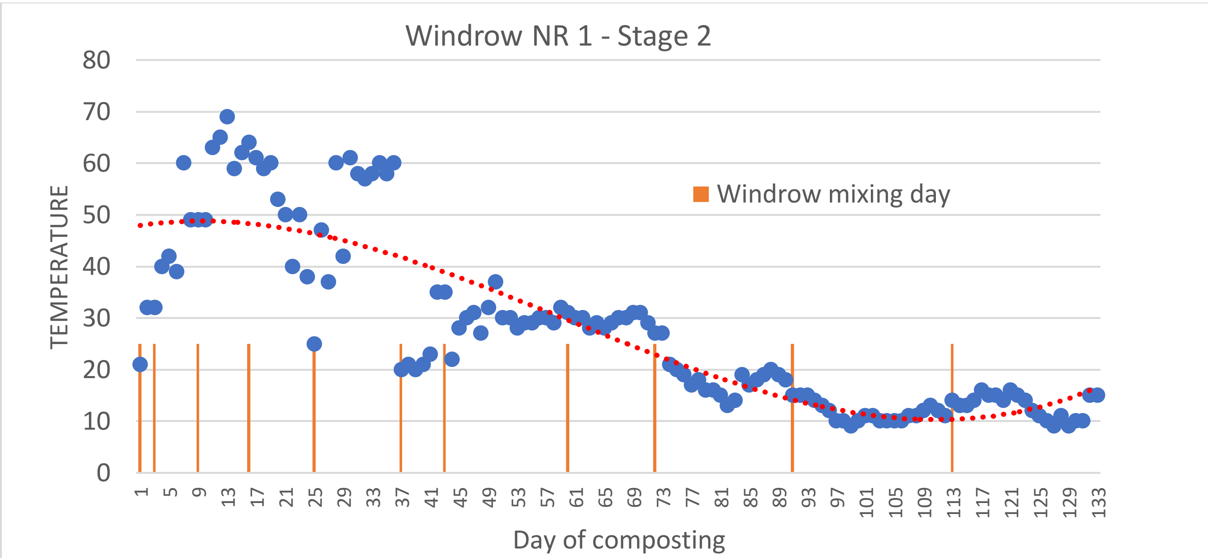
Properly conducted composting process, lasting from 2 to 3 months, requires the time necessary for the decomposition of organic matter many times longer than the condition necessary for hygienisation.

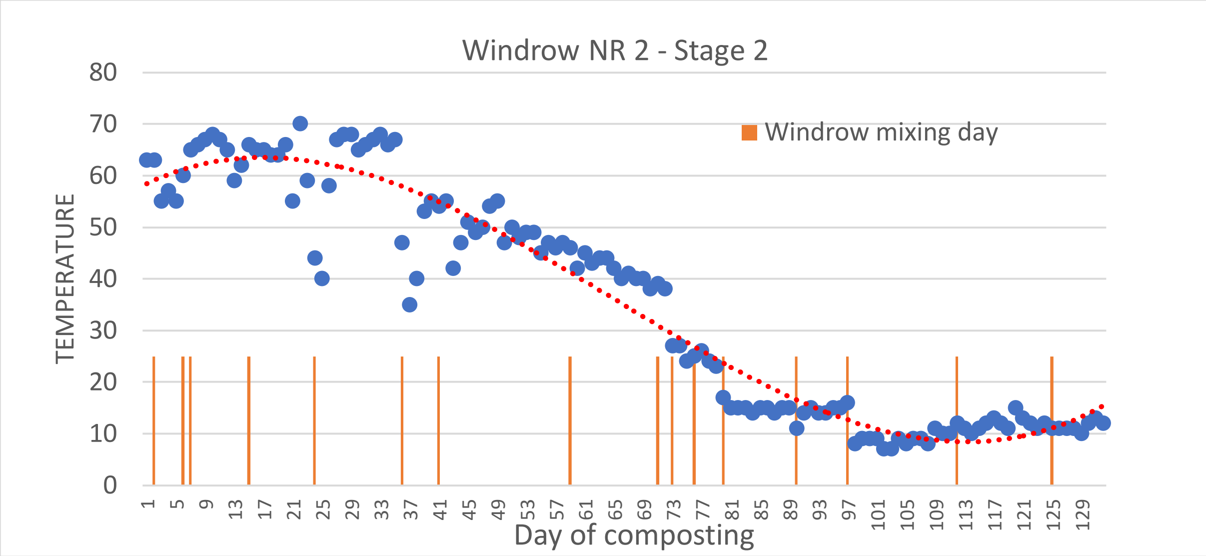
During this time, the windrow is thrown many times, which guarantees the passage of each part of the windrow through the high temperature zone. Lumpy compost is characterized by a self-regulating temperature. After exceeding 55 ° C, most thermophilic bacteria form endospores - spore forms that do not produce heat. When the compost is cooled to below an intolerable temperature, active vegetative forms that produce heat reappear. The rate of re-conversion of thermophilic bacteria from spores recorded after the temperature drop is very high compared to other bacteria or microorganisms, therefore the renewal of the process is fast. A compost windrow, which has optimal humidity conditions, with a sufficient substrate content in the form of organic matter, can regulate the temperature itself. During the composting temperature rise to over 70° C has been reported. The probable cause of this is the development of thermophilic methane bacteria or the spontaneous oxidation of short-chain carbon compounds formed from pre-decomposed compounds composed by compost bacteria.

5. Examples of temperatures and mixing day during fields tests with 5-month composting period

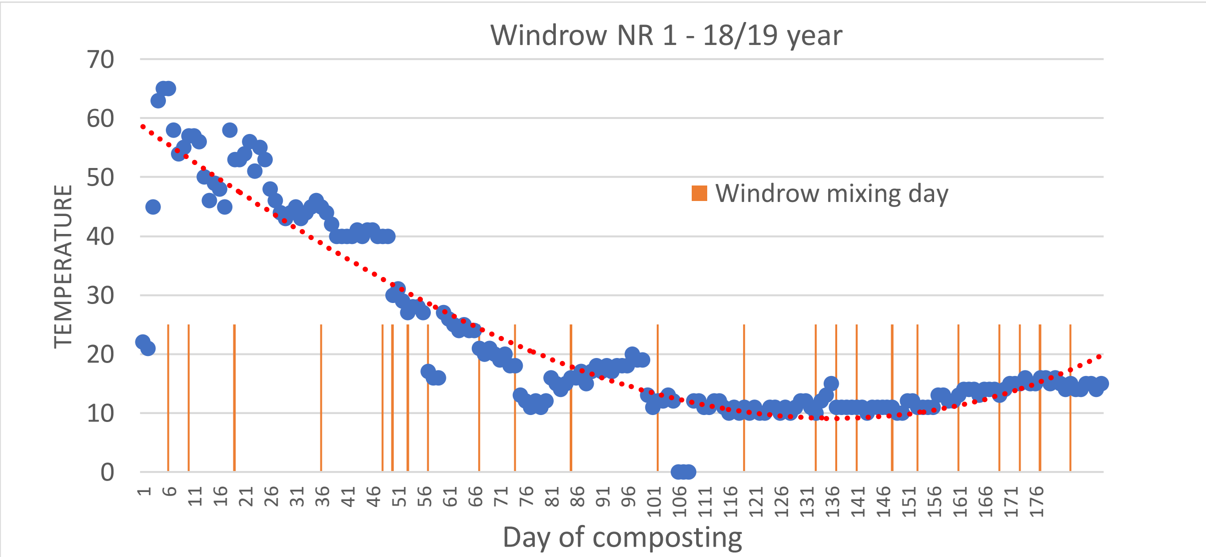


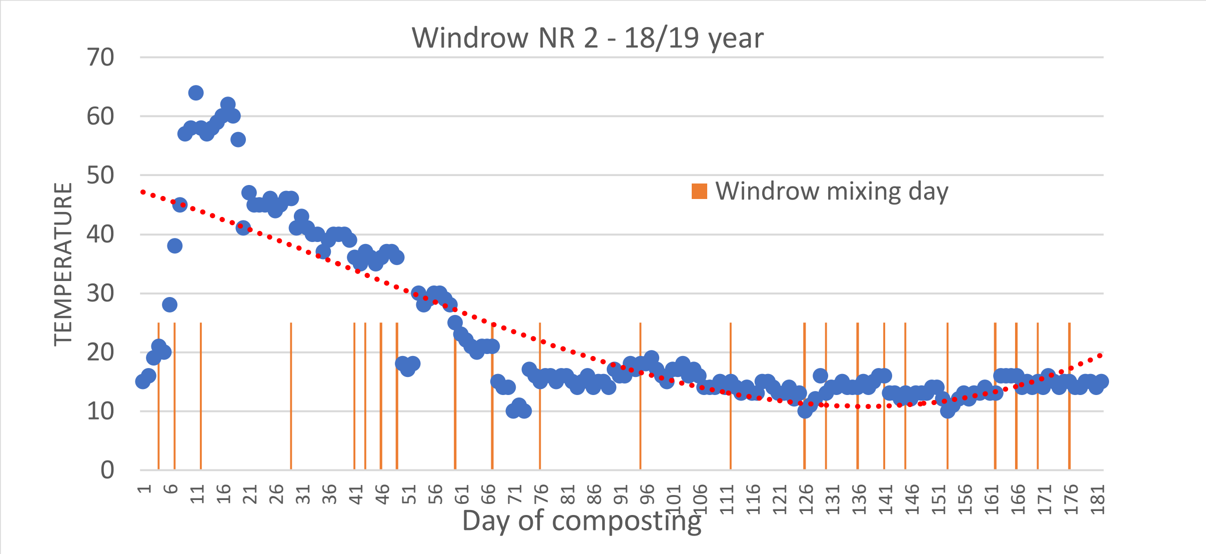

Windrow NR 2 - Stage 1
Windrow mixing day
TEMPERATURE
Day of composting

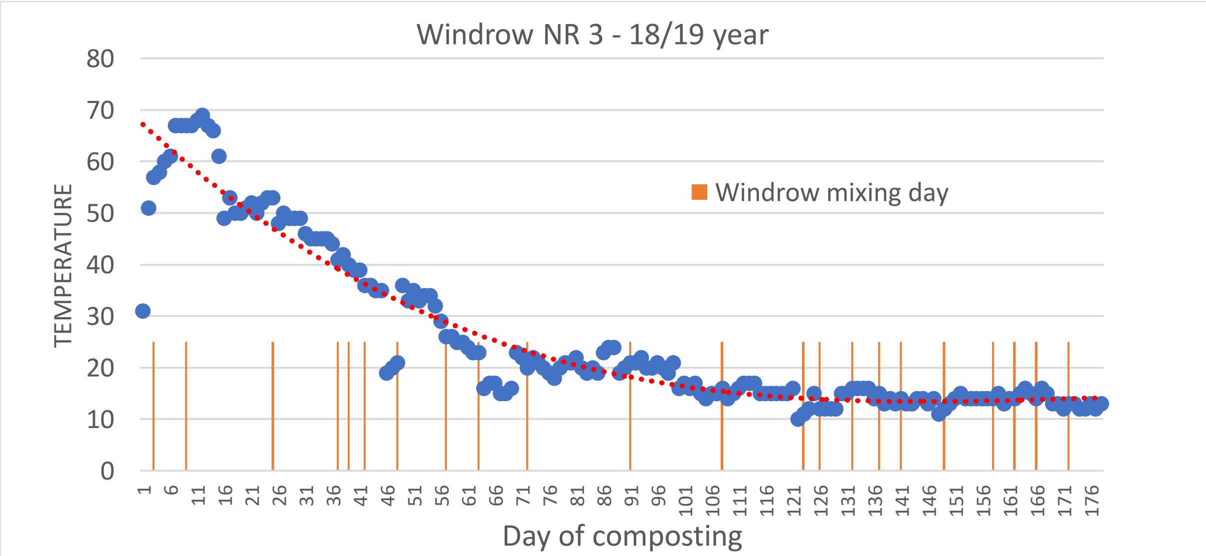

Windrow NR 1 - Stage 2
Windrow mixing day
TEMPERATURE
Day of composting



6. Examples of temperatures and mixing day during fields tests with 6-month composting period



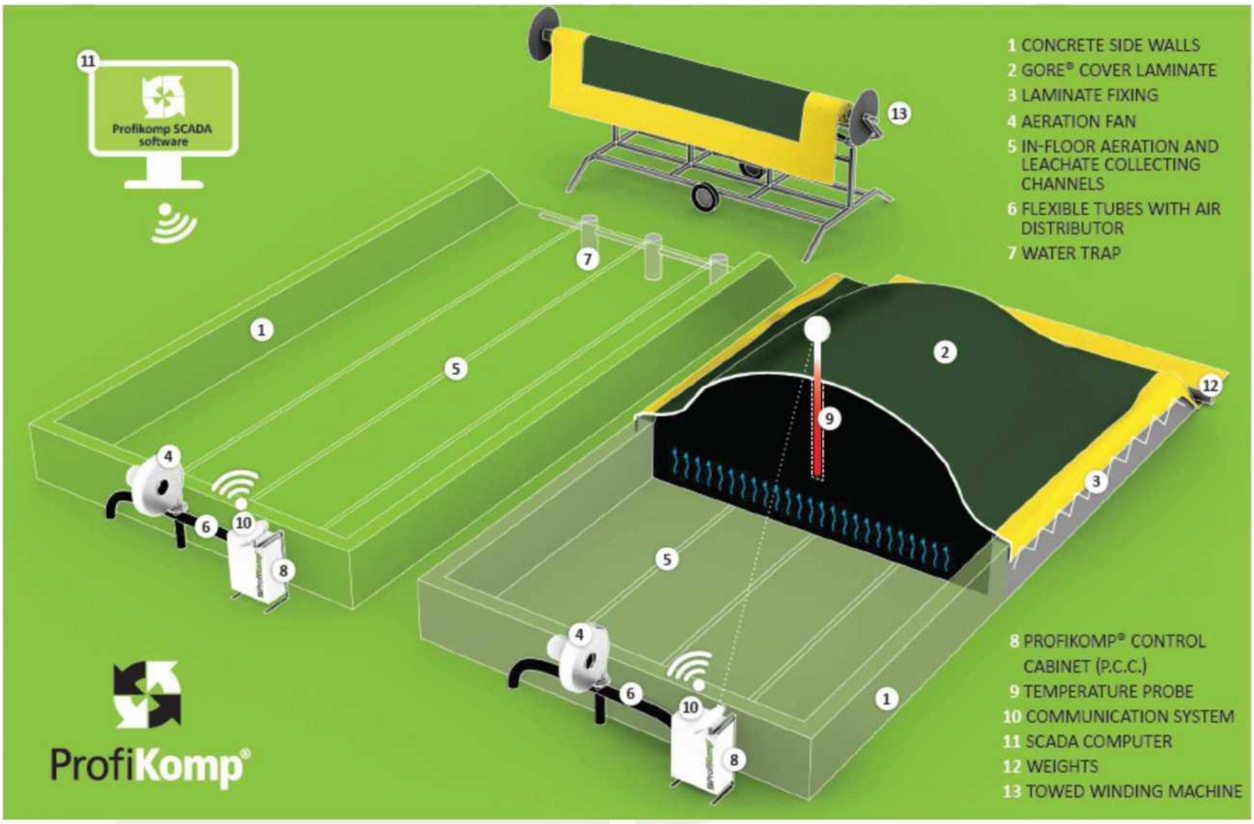




3.2. Static composting with forced aeration, running under a cover with a semi-permeable membrane impact of composts (part II of field studies)

Biological processing takes place in the windrows delimited by side walls - bioreactors. There are 6 bioreactors in the composting plant in Goleniów. The internal width of the bioreactor is 8 m and the length is 18 m. The prism is limited by 1.5 m high concrete sidewalls

Technology ProfiKomp® consists of three main components: GORE® Cover laminate, integrated aeration system and control system.



Picture 4. Technological scheme

Picture 5. Floor aeration system and drainage channels.

Picture 6. Aeration system - fan

Picture 7. Mechanical rewinder

Picture 8. Mechanical rewinder

GORE® Cover laminate provides the necessary conditions for biological degradation. With a pore size of around 0.2 µm, it also acts as an effective barrier to spores and microbes and contributes to low emissions (i.e. VOC, ammonia, dust) while providing adequate protection for plant workers and local residents.

As required by law, pathogenic microorganisms are safely destroyed by the heat generated during the processing process.

The membrane also protects the compost from rainfall, but at the same time allows the free flow of moisture and carbon dioxide thanks to the breathable texture.

Due to the unique parameters of membrane, the technology is considered a closed system.

The SCADA system performs the following tasks:

- Downloads and collects data from the PLC labeled PCC about the temperature values of the prisms, and this data is stored and visualized by the software.
- The air ventilator operates according to the selected control type and the measurement data received by the PLCs. The operational status is continuously recorded and stored in the database.
- The computer records manual and automatic interventions.
- All data arriving at the computer is stored in a database on the computer's hard drive.

- Saved database data are visualized in charts.
- In the event of a logout or power failure, the software continues the control operation from the point where it stopped working based on the saved data.

Aerobic composting is an oxygen-requiring process, so the degradation of organic materials by microorganisms takes place under controlled conditions. When composting, microorganisms consume oxygen ($O2$) while feeding on organic matter. Active composting produces a lot of heat and significant amounts of carbon dioxide ($CO2$), and water vapor are released into the air. $CO2$ and water losses can be half the weight of the input materials, thus reducing the volume and weight of the final product.

Understanding the basics of composting enables operators to manipulate the process to meet environmental or quality specifications.

Suggested timeframes for biological treatment in bioreactors are as follows:

The 42 days of actively managed composting period are divided into 2 phases, a processing time of 21 days in phase 1 (intensive or thermophilic phase) including hygienisation, and a processing time of 21 days for phase 2 (maturation).

The aeration during the individual processing cycles is carried out in accordance with the limit values established for the raw material. It is not necessary to adjust the humidity during the processing phases as long as the pretreatment and mixing have been done properly and the substrate is homogeneous.

3.3. Common operation for static composting in open windrows with cyclic mixing and static composting with forced aeration, running under a cover with a semi-permeable membrane impact of composts.

1. Compost maturation.

Compost maturation does not require arranging into oblong compost windrows with a trapezoidal cross-section, convenient due to the ease of turning. To reduce the surface area, high compost storage, even up to a height of 5 m, is possible.

The maturation time depends on the type of structural material and ranges from 2 to 6 months. All the processes of organic matter mineralization, although they are slowing down, are still ongoing. During this time, coarser particles of wood or straw are humified, and the compost acquires the structure and organoleptic properties of the garden soil.

The final effect of obtaining clean compost with a homogeneous composition is possible thanks to the work of the sieve for sieving the compost. Thanks to the work of the sieve, it is possible to:

. obtaining a homogeneous compost structure,

. cleaning the compost from accidental contamination,

. recovery of structural material, larger undecomposed fractions for re-composting (inoculation of new initial windrows)

Maturation occurs after an intensive or thermophilic composting phase, while final stabilization and humification take place, resulting in an end product called compost. The intensive phase will be finalized if the temperature of the compost drops below 40-45 ° C and the "self-heating" will stop when the temperature drops below 30 ° C.

During maturation, the following changes occur:

- decomposition of lignin and cellulose that were not readily available for degradation;
- the reproduction of fungi and actinomycetes follows the degradation of lignin, which means that these organisms produce a base material (from lignoproteins and other substances through polymerization) for humification
- degradation of substances (left over from the intensive phase), preventing plant growth
- preparation of an emission-free end product for post-treatment (e.g. screening)

The compost sieving procedure is not strictly necessary, but the advantages of screened compost and the significant acceleration of the process initiation due to inoculation with material screened from the ripening windrows should be an incentive to use final screening. In addition, accidental contamination with non-compostable waste is inevitable during the composting processes and the collection of waste materials for composting.

Sieving before the maturation phase can be done with a 30-50 mm perforated drum screen, thus separating the non-degraded material. Maturing takes place in a triangular or trapezoidal windrow. The size and further processing of the windrow depends on the quality of the intensive phase (if the organic matter decomposes easily and there is sufficient moisture). The oxygen supply should also be taken into account during maturation, so regular turning of the windrow (weekly or every 14 days) can be ensured. Intensive aeration is recommended if the height of the windrow exceeds 2.5-3.0 m during maturation.

2. Compost sieving

Foreign materials and organic matter that has not yet been decomposed are separated by sieving, so that homogeneous, good-quality compost can be produced. The size of the screen perforation depends on the later use of the compost:

- compost particles larger than 40 mm are suitable for mulching,
- for arable land, they should be less than 15-20 mm,
- in the case of gardens, the particle size should be less than 10 mm.

Most often, compost is sifted on drum screens, the main features of which are:

- The main part of the screen is a rotating perforated drum, the active surface of which is constantly cleaned with a rotating brush;
- One screen can generate two fractions, but by combining more screens into one string or using them in parallel, optionally more fractions can be separated. In practice, composting plants use two separate types of equipment together. The first conducts a preliminary screening (40-50 mm); the second sieves the fine fraction (> 80-100 mm) formed by the first sieve to separate an even finer particle size (15-20 mm). The screening capacity of the combined use of the two types of equipment is greater than the separate use of the two devices, both of which perform fine screening.
- Drum perforations can be of various sizes (5-100 mm) and shapes (square or round);
- The screening equipment is self-propelled during its production; - The drums can be changed quickly;

- They can be easily combined with other separation methods (e.g. magnetic separators, air separators). Manufacturers of the most popular types offer this kind of additional equipment, which can also be installed on screens;
- The capacity can be effectively regulated by changing the feed speed of the material and the screen itself;
- They are available in mobile versions, which are the most typical for composting plants;
- Only low maintenance required;

In addition to drum screens, composting plants often use flat, vibrating and star screens. With these machines, a wide range of applications can be covered, for example, it is also possible to separate material with a high moisture content compared to the use of a drum screen. However, these machines are not yet used in many composting plants because:
- their mobile version does not exist (e.g. vibrating screen);
- have high maintenance requirements (star screen);
- mesh sizes are more difficult to change (vibrating screen, star screen)

3. Compost storage

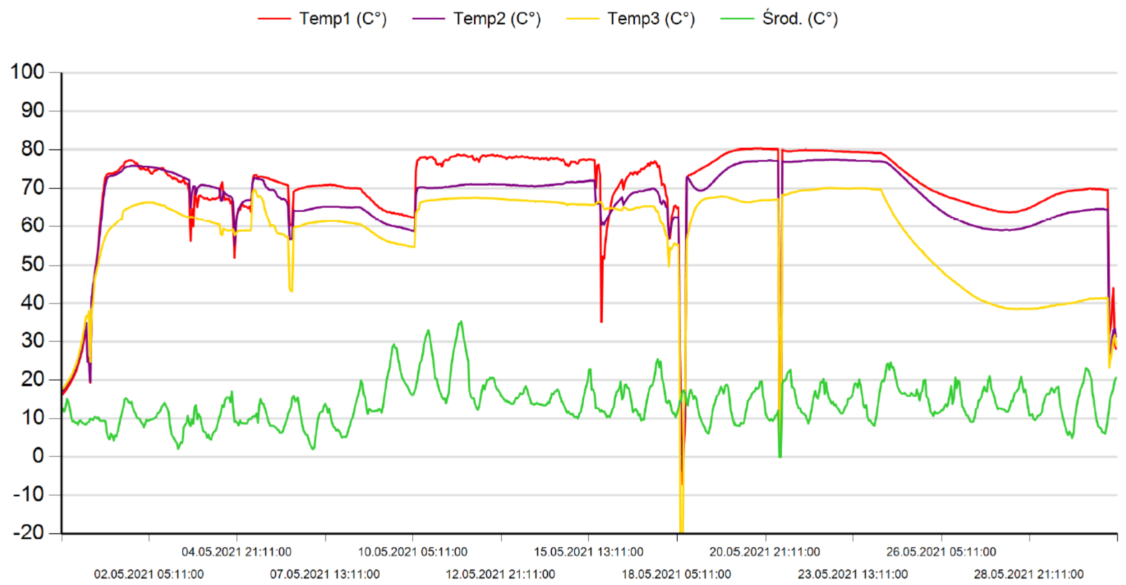
Nitrogen appears as a bond in humic substances in the final compost product (after the maturation phase). Appropriate moisture content creates conditions for humification and partial mineralization during compost storage, therefore oxygen supply is essential. Anaerobic conditions can also occur in the screened compost product and therefore the quality of the compost may vary.

Composts should be stored on a hard surface. At least one side of the storage area should have a retaining wall that allows better use of space and easier loading. The storage space of the finished compost should (recommended) be sufficient to provide the capacity necessary for the quarterly compost production.

The following aspects should be considered when storing:

- The size of the storage area should be selected so that it can be stored at least 25%, but if possible 50% of the annual production of compost (the size of the storage area depends to a large extent on the planned use of the compost.)
- The screened fine particle compost can only be stored in a larger pile if it is adequately matured. To maintain its quality, compost stored in larger piles must be turned over / re-piled regularly (every 4-6 weeks). The frequency of turning depends on the maturity of the compost and the height of the pile (the higher the pile, the more often it is necessary to turn it). If the temperature of the pile rises to more than 30 ° C after overturning, the compost is still in a stabilizing or maturing phase and must be properly processed
- Even taking into account the previous considerations, the compost should not be stored in a pile with a height of more than 3 m.
- If the compost must be stored for a long time in a pile that is higher than 3 m, it is not necessary to sieve on a fine sieve after the maturation period, but only before immediate use (thanks to this the compost has a better structure, so anaerobic conditions cannot happen like this easy to unfold during storage).
- Attention should be paid to the separation and labeling of different compost lots if they are stored together, especially if the quality of the lots is different.
- The planning and maintenance of the storage sites must be done in such a way that the hygienized compost is not contaminated (e.g. by proper separation of the storage sites for raw materials and finished compost, avoiding the use of contaminated equipment.)

4. Sample temperatures and mixing day during field tests with a 42-day composting period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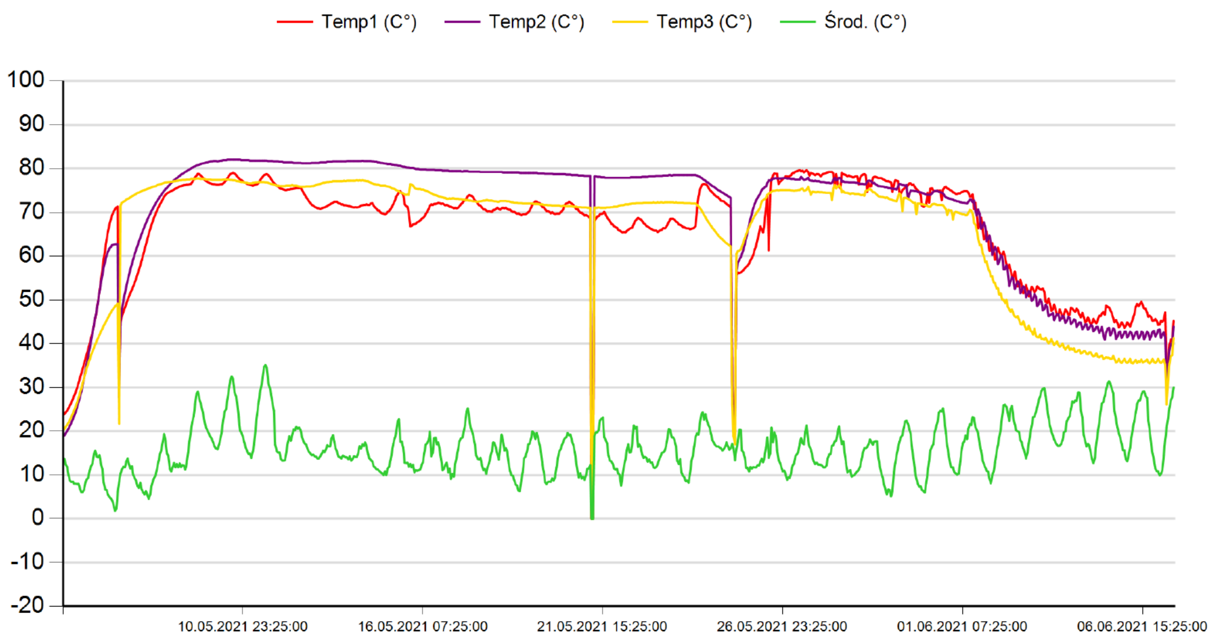
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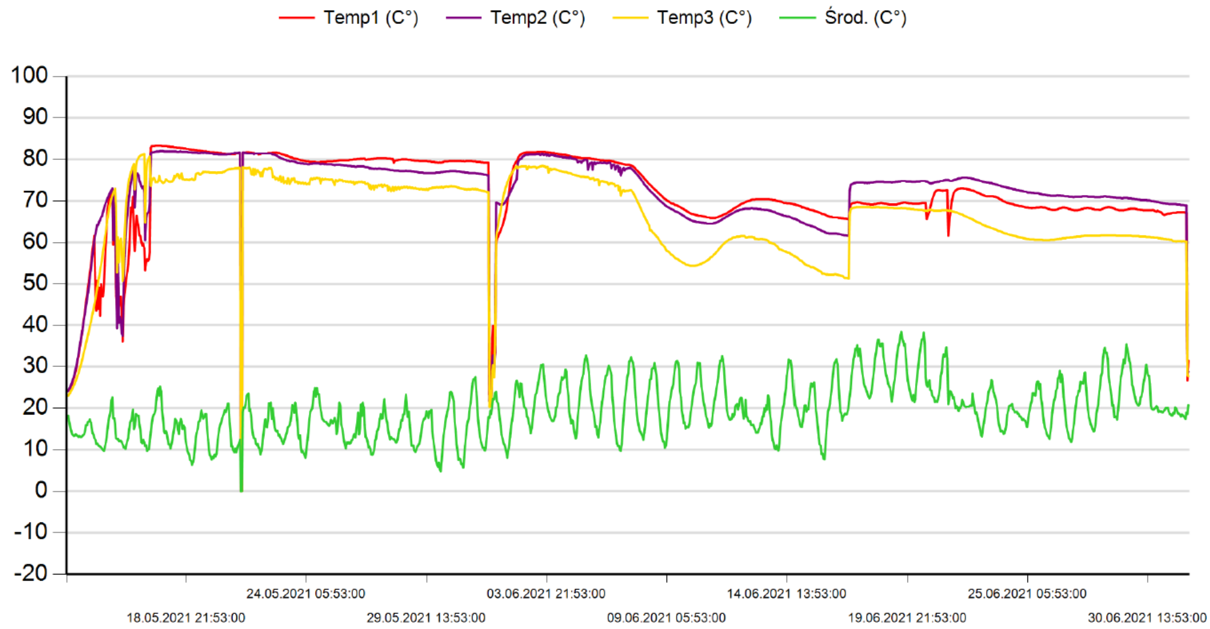

4. ENERGY AND FUEL CONSUMPTION DURING COMPOSTING

4.1. Static composting in open windrows with cyclic mixing

The following machines and equipment that consume energy or fuel are used in the following processes during composting:

1. preparation of materials in which they participate:
    a. agricultural tractor with a trailer

b. woodchipper for cutting branches

c. wheel loader

2. preparation of the windrows in which they participate
    a. wheel loader
    b. compost turner (mixing of windrows)

3. turning of windrows
    a. compost turner
    b. wheel loader (cleaning and pushing)

4. sieving mature compost
    a. wheel loader (cleaning and pushing)
    b. sieve (sifter)

5. Packing the compost into the big bag
    a. wheel loader (cleaning and pushing)
    b. weight / packing machine

Table 1. Technical data for static composting in open windrows with cyclic mixing.

Works related to 1 compost windrow (50 tons of sludge (7,5 ton TS), 6 tons of straw, 13 tons of wood chips, 4 tons of inoculation) - 14 tons of the finished product												
1	**2**			**3**			**4**		**5**		**6**	
PROCESS	**MATERIAL PREPARATION**			**WINDROW PREPARATION**			**WINDROW TURNING**		**SIEVING COMPOST**		**PACKING THE COMPOST INTO THE BIG BAG**	
	agricultural tractor with a trailer	**woodchipper for cutting branches**	**wheel loader**	**wheel loader: transportation of straw; arranging the sediment, chips, inoculation**	**manual unrolling of straw bales**	**compost turner (mixing of windrows)**	**compost turner (mixing of windrows)**	**wheel loader (cleaning and pushing)**	**wheel loader: backfilling the sieve and transporting the screened material**	**sieving mature compost**	**weigt/packing machine**	**wheel loader: filling into bags and removal of filled bags**
employee working hours	4,5	8,0	8,0	8,0	2,0	3,0	1,0	0,4	5,0		8,0	6,0
operating hours of the equipment	4,5	8,0	8,0	8,0		3,0	1,0	0,4	5,0	4,0	8,0	6,0
fuel consumption (liter)	27,0	72,0	56,0	56,0		27,0	9,0	2,8	35,0	36,0		35,0
energy consumption (kWh)											2,0	
the number of cycles in the full production process	1,0	1,0	1,0	1,0	1,0	1,0	25,0	25,0	1,0	1,0	1,0	1,0

4.2. Static composting with forced aeration, running under a cover with a semi-permeable membrane impact of composts

The following machines and equipment are used in the following process during composting:

1. preparation of materials:
    a. agricultural tractor with a trailer
    b. woodchipper for cutting branches
    c. wheel loader
2. preparation of the windrows:
    a. wheel loader
    b. compost turner (mixing of windrows)
3. loading (backfilling) of the biological reactor of windrows in which they participate:
    a. wheel loader (cleaning and pushing)
4. composting process:
    a. aeration:
        i. fan
    b. relocation of sludge between reactors:
        i. membrane winder
        ii. wheel loader
5. sieving matured compost:
    a. wheel loader (cleaning and pushing)
    b. sieve (sifter)
6. packing the compost into the big bag:
    a. wheel loader (cleaning and pushing)
    b. weight / packing machine

Table 2. Technical data for static composting with forced aeration, running under a cover with a semi-permeable membrane impact of composts

Works related to 1 compost windrow (50 tons of sludge, 13 tons of wood chips, 4 tons of inoculation)										
	1			2		3				4
PROCESS	**MATERIAL PREPARATION**			**WINDROW PREPARATION**		**FILLING THE BOX**				**COMPOSTING I-stage**
	agricultural tractor with a trailer	**woodchipper for cutting branches**	**wheel loader**	**wheel loader: transportation of straw; arranging the sediment, chips, inoculation**	**compost turner (mixing of windrows)**	**wheel loader: transports the mixture from the composting plant to the box**	**wheel loader: transporting the wood chips from the composting plant to the pit to cover the channels**	**Fan: aeration from the start of loading to cover with a membrane**	**Winder - winding the membrane on the shaft and unrolling it over the box, inserting the probe**	**Fan: aeration**
employee working hours	9,00	24,00	24,00	8,00	8,00	5,00	2,00		1,00	
operating hours of the equipment	9,00	24,00	24,00	8,00	8,00	5,00	2,00	24,00	1,00	63,00
fuel consumption (liter)	54,00	216,00	168,00	56,00	56,00	45,00	14,00			
energy consumption (kWh)								36,00	17,00	94,50
the number of cycles in the full production process	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0

Works related to 1 compost windrow/box (85 tons of sludge, 60 tons of wood chips, 60 tons of inoculation)									
	5				6	7		8	
PROCESS	**FILLING THE BOX**				**COMPOSTING II-stage**	**MATURATION COMPOST**		**SIEVING COMPOST**	
	wheel loader: transports the mixture from the composting plant to the box	**wheel loader: transporting the wood chips from the composting plant to the pit to cover the channels**	**Fan: aeration from the start of loading to cover with a membrane**	**Membrane winder - winding the membrane on the shaft and unrolling it over the box, inserting the probe**	**Fan: aeration**	**Membrane winder - removing the probe, rolling the membrane, rearranging the winder**	**Wheel loader: transports the mixture from the box to the composting plant to the box**	**Wheel loader: backfilling the sieve and transporting the screened material**	**Sieving matured compost**
employee working hours	5,00	2,00		1,00				8	8
operating hours of the equipment	5,00	2,00	24,00	1,00	63,00			8	8
fuel consumption (liter)	45,00	14,00						56	56
energy consumption (kWh)			36,00	17,00	94,50				
the number of cycles in the full production process	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0

5. SUMMARY

Table below shows the average consumption of energy and fuel during composting without consumption of energy and fuel for dewatering sludge.

Table 3. Technical parameters of composting processes.

PROCESSS	Static composting in open windrows with cyclic mixing	static composting with forced aeration, running under a cover with a semi-permeable membrane impact of composts
1	2	3
employee working hours	54	111
operating hours of the equipment	55	285
fuel consumption (liter)	356	1 034
energy consumption (kWh)	2	293

Table below shows the average consumption of fuel and energy compared to the amount of dewatered sludge.

Table 4. Average consumption of fuel and energy compared to the amount of dewatered sludge

Sludge composting methods	**Employee working hours**	**Fuel (diesel) consumption**	**Energy consumption**
	hour/ton	liter/ton	kWh/ton
Static composting in open windrows with cyclic mixing	1,1	7,1	0,0
Static composting with forced aeration, running under a cover with a semi-permeable membrane impact of composts	1,3	12,2	3,4

Table below shows the average consumption of fuel and energy compared to the amount of dewatered sludge

Table 5. Average consumption of fuel and energy compared to the amount of dewatered sludge

Sludge composting methods	**Employee working hours**	**Fuel (diesel) consumption**	**Energy consumption**
	hour/ton TS	liter/ton TS	kWh/ton TS
Static composting in open windrows with cyclic mixing	7,2	47,5	0
Static composting with forced aeration, running under a cover with a semi-permeable membrane impact of composts	8,7	81,0	23,0

6. CONCLUSIONS

Composting is low-energy process:

a. static composting in open windrows with cyclic mixing does not needs almost any electric energy, it needs only the fuel – diesel.
b. static composting with forced aeration, running under a cover with a semi-permeable membrane impact of composts also does not needs a lot of electric energy.