DOI: 10.2478/agriceng-2022-0011

ISSN 2083-1587; e-ISSN 2449-5999
2022,Vol. 26,No.1, pp.133-144
Agricultural Engineering
www.wir.ptir.org

INNOVATIVE TECHNOLOGY OF ACCELERATED COMPOSTING OF CHICKEN MANURE TO OBTAIN AN ORGANIC FERTILIZER WITH A HIGH CONTENT OF HUMIC ACIDS[1]

Oksana Balanda[a*], Daria Serafinowska[a], Olha Marchenko[a], Iryna Svystunova[a]

[a] Eco Energy Tech sp. z.o.o, ul. Małkowskiego 30/1, 70-304 Szczecin, Poland; oksik0410@ukr.net, 0000-0003-2074-8182; daria.serafinowska@gmail.com, 0000-0002-3529-135X; marcol@ukr.net, 0000-0002-2419-4191; irinasv@ukr.net, 0000-0001-8922-1261

* *Corresponding author: e-mail: daria.serafinowska@gmail.com*

ARTICLE INFO

Article history:
Received: May 2022
Received in the revised form: June 2022
Accepted: June 2022

Keywords:
chicken manure,
composting,
aerobic bacteria,
intelligent boxes,
thermophilic and transformation phases,
humic acids,
fulvic acids,
fertilizer

ABSTRACT

One of the most important fractions of soil organic matter which has significant environmental and agricultural importance is humus. The specific humus compounds of soil include the complex of amorphous organic humic substances which include humic acids, fulvic acids and humins. The effectiveness of the natural formation of active humic substances during composting processes depends on the chemical composition of organic residues and the environmental conditions influencing the development and activity of native microorganisms. The aim of the project was to build innovative composting boxes for chicken manure that allow to effectively obtain a fertilizer with the highest possible content of humic acids, by creating perfect and controlled conditions for the rapid development of indigenous thermophilic microorganisms and by combining it with the owned bio-acceleration technology. For perfect conditions (temperature, humidity, oxygen, pH) for the controlled growth of microorganisms, an algorithm of the dependence of the box operation parameters on the course of the biological process, was built. The product obtained after composting is an easily digestible complex organic fertilizer of brown-black colour, pH 7.5-8.0 and NPK 5:3:4 and a high content of native humic acids. Its use increases the growth of green mass of plants and improves soil fertility, which has been proved by the conducted pot research.

[1] Prepared as – a part of a project co-financed by EU funds, POIR.01.01.01-00-1492\19. "Development of technology for the production of safe organic fertilizers with the highest possible content of active humic acids with the use of poultry droppings and other types of animal manure for the purposes of agricultural use and restoration of the appropriate properties of agricultural land."

Introduction

Poland is the European leader in poultry production. The herd population for 2019 was estimated at 178,342 hens, including 53,190 laying hens (Statistical Yearbook of Agriculture, Central Statistical Office, Warsaw 2020). It is believed that the weight of manure excreted by birds during the day is about twice as much as the weight of the feed given. It is shown in Table 1 “The approximate weight and humidity of manure excreted by one hen”, considering the standards of technological design in the poultry industry.

Table 1.
Number of droppings and humidity.

Poultry groups by production purpose	Average manure output / litter per day, (g)	Manure moisture, (%)
Laying hens	189	71-73
Meat hens	288	71-73

Hen’s manure is biologically and chemically contaminated (Potapov and Kurochkin, 2018). It contains enormous amounts of pathogenic microorganisms, such as bacteria, viruses, fungi, and eggs of intestinal parasites of humans and animals. Soil fertilization with non-composted manure causes its pollution, which leads to microbiological contamination of the growing crops. It happens because the microorganisms contained in non-composted chicken manure are characterized by a long survival period (Kłapeć and Cholewa, 2012). Furthermore, manure can contain significant amounts of toxic heavy metals such as arsenic, copper and zinc and NH_3 emission (Finzi et al., 2019; Kopiec et al., 2014). Excess of these elements may be toxic to plants, adversely affect organisms which feed on these plants and leak into water systems through the surface runoff and eluviation of soil (Zbytek and Talarczyk, 2008). Feed additives in the form of veterinary drugs and growth stimulants which are used to increase production efficiency also contaminate the environment, including soil and surface waters.

Thereby, the proposed resolution is the production of organic fertilizers with a high content of humic acids from waste materials (chicken manure) using a composting method in intelligent composting boxes for the purpose of intensifying plant growth, enriching and fertilizing the soil, improving its structure and biological activity, and additionally for reclamation of highly degraded agricultural soils.

The innovative technology of fertilizer production is based on the concept of controlled and accelerated composting of hen’s manure using own preparation KOMPRE and designed intelligent composting boxes. KOMPRE preparation as a catalyst intensifies the development of a specific group of aerobic, thermophilic microorganisms and its enzymatic activity, whereas the intelligent boxes allow adjusting the conditions of the composting process to the changing needs of the multiplying microflora. During the composting process, the number of bacteria, able to decompose difficult dissolving compounds and cellulose, increases. KOMPRE belongs to preparations that actively stimulate biosynthesis of humic substances. At the same time, the enzymatic activity of the substrate increases the mobility of nutrients and binds heavy metals and toxins. The use of KOMPRE leads to a significant acceleration of organic waste processing in environmentally safe forms and at the same time provides production of a comprehensive organic fertilizer with a high content of humic acids. KOMPRE preparation is a complex organic composition, obtained by fermentation of sugars (it is not possible to present the composition due to the policy of confidentiality and the company's know-how).

Humic acids are one of the most important components of soil humus. It can be divided into humic acids, fulvic acids and humins. Humic acids are able to bind different insoluble nutrients and slowly release them along with the plant's requirement. The presence of humic acids in the soil forms optimal conditions for the development of beneficial microorganisms, responsible for the lumpy structure of the soil, which lead to an improvement of the water-air balance of the soil. The water capacity of the soil increases, which reduces the risk of drought. The sorption capacity improves significantly mainly due to the action of fulvic acids, which are responsible for retentive nutrients in the sorption complex, leading to better availability of nutrients for plants. Fulvic acids also limit the eluviation process of soils. It should be remembered that beneficial microorganisms develop in soils when the soil structure and abundance of air are suitable. Humic acids increase the biological activity of soils, optimize the pH, and enrich the soil with organic and mineral substances (Pikuła, 2016).

Materials and methods

Research material. Three types of chicken manure were tested (Table 2). The raw material was purchased from local farmers.

Table 2.
Parameters of chicken manure from several types of farms.

Parameters	Raw material	
	Cultivation: 6 weeks on a 20-25 cm long straw bedding	Cultivation: 40 days on straw pellets of low granulation
Humidity, (%)	47-48	50-52
Density, ($kg \cdot m^{-3}$)	460±21	534±32
Smell	ammonia	ammonia
Colour	straw yellow	straw yellow
pH	4.5	5.0
Sanitary cleanliness of the substrate	presence of the most bacteria of the coli group and salmonella, local presence of mould and there are parasite eggs	presence of the bacteria of the coli group, local presence of mould and there are parasite eggs
The presence of antibiotics and other inhibitory substances	not identified	confirmed

Intelligent Composting Boxes. The special composting boxes equipped with an automatic system of mixing, oxygenating, and spraying were used for the composting process. Initially the raw material was shredded using the homogenizer. Then the pre-prepared manure was weighted by operator and transported into the box chamber. During the composting process mixing was carried out two times per day. The manure humidity of the manure inside the composting chamber was maintained at the level of 55-60%. The oxygen concentration was ca. 10-20%. The measurement of the temperature was made 24 hours a day constantly. As a composting accelerator KOMPRE agent was used. It is a natural preparation which enhances the process of compositing.

The range of laboratory analyses. To get accurately acquainted with the transformation processes of organic matter and indigenous mineral components that occur during biomass composting and to determine the resulting compost, the following was indicated:

1. Moisture in percentage by weight-dryer method.
2. Density in kg per cubic meter by weight-volume measurement.
3. pH by potentiometric method.
4. Determination of the organic carbon content by the dry combustion method at 800°C and the wet combustion method by the method of Tiurin.
5. Determination of the total phosphorus by the titration method.
6. Determination of the total potassium by the method of flame photometry.
7. Determination of the total mass fraction of nitrogen and mass fraction of ammonium nitrogen by the distillation method of Kjeldahl.
8. The content of heavy metals Cd, Cr, Ni, Pb, As, Cu, Zn – subcontracted to a certified research unit.
9. Quantitative fractional composition of humic substances in differently matured composts according to the modified Schnitzer and Nikitin methods. The determination of the fractional composition was made by separating individual groups of organic compounds. For this purpose, the possibility of extracting compounds from the sample with the use of appropriate reagents acting as solvents was used.
10. Presence of live eggs of intestinal parasites Ascaris spp., Toxocara spp., Trichuris spp. by isolation, incubation, and microscopic observation. Presence of Coli and Salmonella bacteria – plate test. The presence of antibiotics and other inhibitory substances - plate test.
11. Organoleptic evaluation of raw materials. Before the experiments started, the colour, smell, appearance, and structure were determined by organoleptic methods. More than three samples were tested by three different researchers independently.
12. Biological test with the use of cress (*Lepidium sativum* L.), for determining the effect of water extracts from differently matured composts on the germination of cress seeds. The plant germination and growth test were carried out pursuant to the applicable standard (PN – EN ISO 11269-1: 2013-06). Water extracts prepared in the proportion of compost and distilled water were used to assess the germination power and development of cress seedlings. During the preparation of the solutions, the samples were mechanically mixed on a shaker at the speed of 300 rpm for 30 minutes. The extracts prepared in this way were filtered through a membrane filter. 50 grains of cress were placed on a paper-lined glass petri dish and sprinkled with the filtrate until the entire surface of the paper was wetted. The cultivation was carried out at the temperature of 25°C, the number of germinated seeds was counted after 48 hours. For control purposes cress seeds sown on blotting paper moistened with distilled water were used.
13. Experiment on micro-plots (60x40x12cm) with the use of diverse types of plants, assessing their growth and development under controlled lighting conditions and temperature of 25°C. For the control purpose universal subsoil without the addition of compost

was used for each species. For all tests, the same type of universal subsoil prepared on peat basis, pH 5.5-6.5, was used, which allowed to note all the differences.

Results and discussion

The composting process is a natural method of neutralizing waste, consisting in the biodegradation of organic matter in the presence of oxygen involving microorganisms. Interacting process parameters, the appropriate values of which determine the expected final result, are influenced by the process course and its efficiency. The resulting product, in most cases, is an ecological fertilizer used to enrich the soil without harming the environment.

The course of the process can be written using the equation:

$$\text{chicken manure} + \text{microorganisms} + O_2 \rightarrow \text{stabilizer} + H_2O + CO_2 + \text{heat}$$

Correctly running composting process can be divided into four stages:

1. Mesophilic phase (called as the pre-composting stage) lasts from several hours to several days. An intense increase in temperature, during which mesophilic organisms take part in the decomposition of organic matter is during the first several tens of hours.
2. Thermophilic (intensive composting) phase is characterized by the rapid degradation of proteins, fats, complex carbohydrates, cellulose, and hemicellulose. The increase in temperature to over 55°C causes the lysis of most organisms pathogenic for humans and animals and inactivation of weed seeds.
3. Transformation phase - the temperature decreases and the hardly decomposing compounds such as: lignin, waxes, fats, resins break down in this phase.
4. Maturating phase, determined as secondary composting, the material is cooled down during this phase. The resulting stable compost fraction (humus) is the end product of the process (Jędrczak, 2007).

The duration of the individual phases may differ from each other depending on the composting technology used. To improve the composting process, innovative compost boxes were built, which by creating perfect and controlled conditions, allow for the rapid development of family microorganisms and multiplied acceleration of the thermophilic phase and the phase of transformation. For their proper functioning, an algorithm of the process was created depending on the given biological parameters of the substrate (temperature, oxygen content, humidity). The first stage of processing is the preparation for composting which consists of very precise dosing of the water solution of KOMPRE into the poultry droppings and its distribution in the entire volume of the material. The preparation is added with the use of a mobile mixing device set with a control system and operating parameters, making the flow of the process dependent on moisture, density, and weight of the entry material.

This set of devices as a machine at the first stage of conversion allows for:

- preparation of technological water
- thorough mixing of the preparation with technological water
- process air preparation
- substrate weight measurement
- measurement of the amount of technological water
- dosing of KOMPRE preparation to the pressure device
- control of the fluid dispensing process.

Each delivery of chicken manure is placed separately in one compost box to prevent contamination and to keep the material homogeneous until reaching the end of the composting process.

At the next stage of processing, the material is being transferred to the intelligent compost boxes. The main elements of the compost box construction are shown in Figure 1.

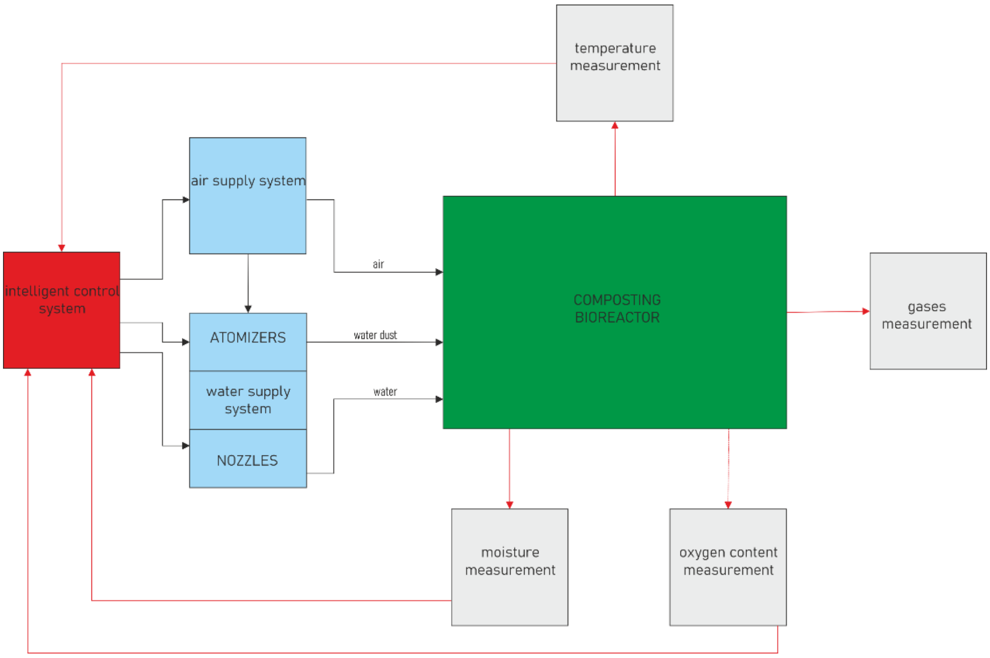

Figure 1. Main elements of intelligent composting boxes.

To create perfect conditions (temperature, humidity, oxygen) for the controlled growth of microorganisms, an algorithm for the dependence of the box operation parameters on the course of the biological process was developed. Each of the given parameters was controlled and monitored by a relevant device.

1. OXYGEN. Aeration system - nozzles. The nozzles are positioned over the entire perimeter of the boxes, the technological air is provided into the composted material at a constant pressure in aeration channels. The system works in a positive aeration system. The capacity of the working nozzles is selected accordingly to the composting phase, the current oxygen content, and the temperatures in the box. During the process it is necessary to provide the microorganisms with the optimal amount of oxygen because it is extremely important to ensure adequate air exchange to keep the process at the same level regardless of time. But too much air also causes the waste to dry out quickly and the process to stop. If the dried material is stored in open air, there is a risk of anaerobic decomposition after wetting the waste, which in turn results in a lot of odours. The designed aeration system eliminates all hazards related to aeration. The aeration nozzles are designed and

constructed in such a way that the composted material has a constant supply of oxygen and at the same time, they also act as a leachate drainage system. Determining the activity of microorganisms and thus the quality of the obtained product, the aeration process is extremely important for maintaining an appropriate level of oxygen in the composted heap and providing appropriate conditions for thermophilic microorganisms. The optimal level of aeration in the piles ranged from 10 to 20% and was adjusted to the appropriate stage of microbial development.

2. HUMIDITY. Two ways of applying technological water.
3. Humidity is a critical parameter of the composting process that directly affects the air content in the compost pores, the activity of microorganisms and the temperature of the process. The optimal moisture content for composted waste should be in the range of 55-60% (Bernal et al., 2009; Wang et al., 2015). The oxygen flow in the compost pores becomes impeded, resulting in the formation of anaerobic conditions conducive to the waste rot as the humidity exceeds 65%. Respectively humidity has a major influence on the transport of soluble nutrients for microorganisms in the composted material.
4. TEMPERATURE. The temperature is being monitored by sensors at various levels of the deposited material in a constant mode 24 hours a day.

Temperature is a parameter easy to measure and monitor during the process. Its values not only determine the speed of decomposition by microorganisms of organic material, but also destruction of pathogens. An excessive level may inhibit the growth and activity of nitrifying bacteria; thus, its value should not exceed 75°C due to the possibility of the microbial population disappearance, which would lead to inhibition of the composting process (Onwosi et al., 2017).

From the moment of starting the process, with increasing temperature and, accordingly, the number of microorganisms, the pH increased, and the moisture of the material decreased. After exceeding the temperature of 60°C, the organic matter decomposes rapidly and the humic substances are actively formed, and when the temperature exceeds 75°C, the thermophilic microorganisms die.

The change of pH is an important parameter that, like the temperature, influences the amount and activity of microorganisms in the composting process (Sundberg, 2005; Zhang et al., 2010). The medium reaction changes from acidic (4.5-5.0) in the initial phase, via neutral to alkaline (7.5-8.0) in the maturation phase during composting.

The obtained data show that the ready material in the form of an organic fertilizer meets all the standards for organic fertilizers in the context of heavy metals content per kilogram of dry matter (Table 3). After 3 days of composting, the sanitary cleanliness of the product was obtained, i.e., no living eggs of intestinal parasites Ascaris spp., Toxocara spp., Trichuris spp. and no bacteria E. Coli and Salmonella were found (Figure 3).

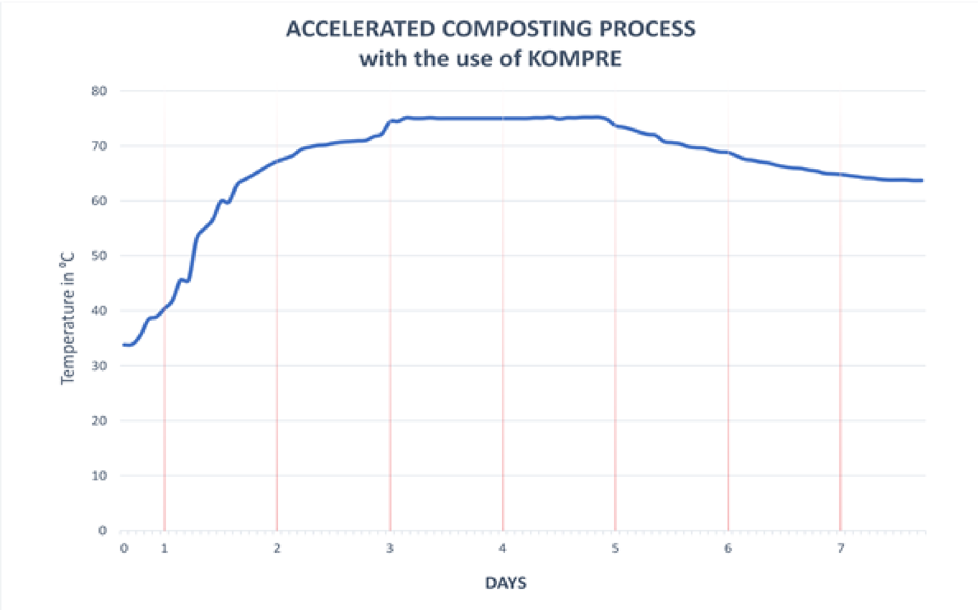

Figure 2. Temperature changes in intelligent boxes during the composting process.

Table 3.
Comparison of the content of heavy metals in the sample with the requirements for organic fertilizers

Element	Cd	Cr	Ni	Pb	As	Cu	Zn
Unit	$(mg \cdot kg^{-1})$ dry matter						
PFC requirements for organic fertilizer	1.5	200	50	120	40	300	800
The values obtained in the study	0.37	6.63	7.08	2.57	0.60	116.92	630.60

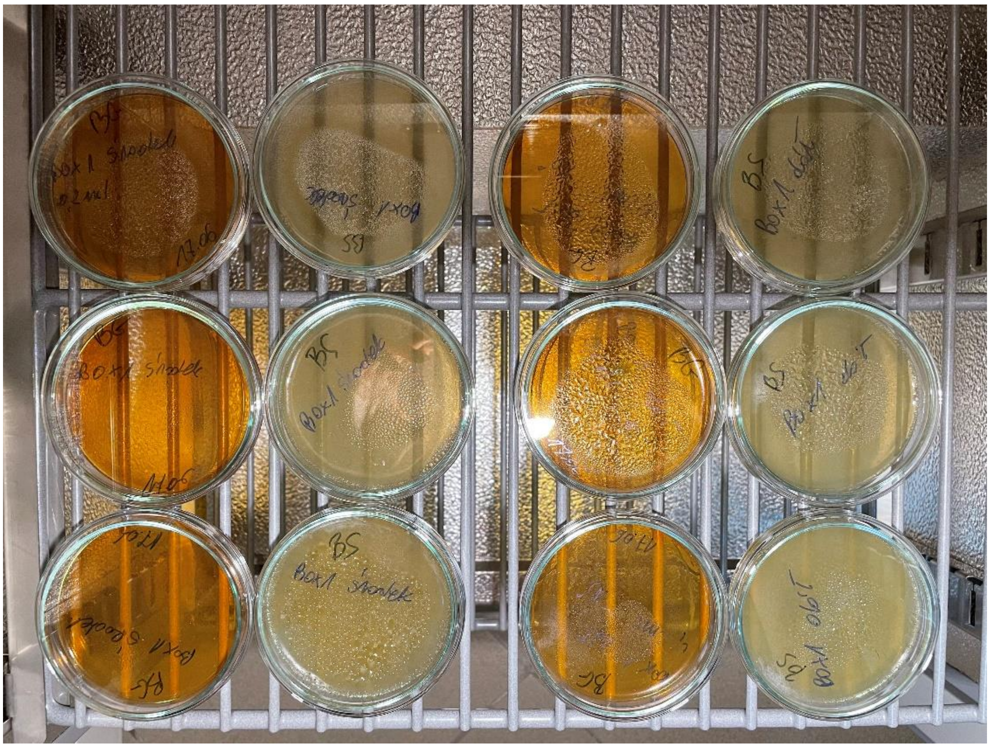

Figure 3. Test for the presence of coliforms and Salmonella in the material after 3 days of composting.

The organic compounds contained in the compost or formed as decomposition products of other compounds are subject to the humification process (Siebielska, 2013). Therefore, as a result of resynthesis by thermophilic microorganisms, humus compounds are formed, creating humus, which is the main component of the soil. In the fertilizer obtained after 7 days of composting, the total content of active humic substances is up to 45%, of which 16-19% are fulvic acids and 21-26% humic acids. It is an easily digestible complex organic fertilizer of brown and black colour, pH 7.5-8.0 and NPK 5: 3: 4. Another effect of composting is the reduction of the material volume down to about 12-13% and its weight to 9-10%.

In phytotoxicity tests, different doses of the fertilizer from $2g \cdot L^{-1}$ to $5g \cdot L^{-1}$ were tried to determine whether the obtained product after composting did not contain any substances that inhibit germination and the initial growth and development of Lepidium sativum L. plants. Figure 4 clearly shows no toxic effects were recorded.

with the addition of fertilizer 0.2g·100ml^{-1} | with the addition of fertilizer 0.5g·100ml^{-1}

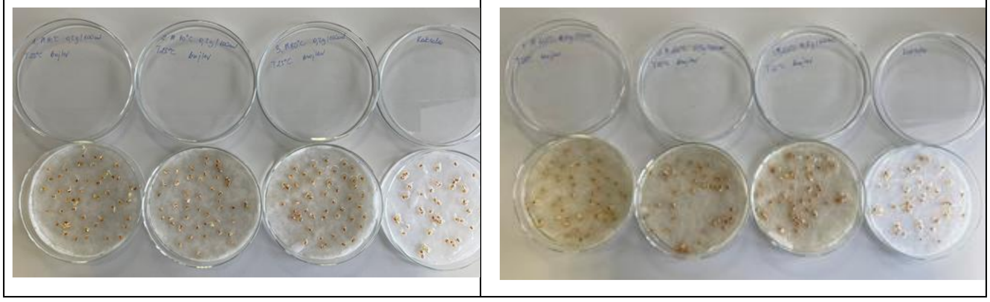

Figure 4. Biological tests for phytotoxicity with cress (Lepidium sativum L.): 3 replicates and control.

In subsequent experiments carried out on the effect of the obtained fertilizer at a dose of 30g·m^{-2} on the increase of distinct types of garden plants in green mass (Table 4), a positive effect was noted. The highest increase in green mass (almost 50% was recorded for Radish and Basil).

Table 4.
Comparison of the growth and increase in green mass of various plants under laboratory conditions with the addition of fertilizer in the amount of 30 g·m^{-2}.

Plant species	Control (g·5g^{-1}) seeds	Experience (g·5g^{-1}) seeds	Increase (%)
Radish (*Raphanus sativus*)	740	1460	49
Calendula *(Calendula officinalis)*	155	245	37
Dill *(Anethum graveolens)*	48	70	31
Parsley *(Hordeum vulgare)*	68	106	36
Carrot *(Daucus carota)*	159	245	35
Basil *(Ocimum basilicum)*	840	1690	50

Conclusions

Chicken manure contains a significant amount of organic matter which can be successfully used in the production of a fertilizer. The manure composting process in innovative boxes with the use of KOMPRE allows for easy and quick development of family aerobic thermophilic microorganisms. For perfect conditions (temperature, humidity, oxygen) of the controlled growth of microorganisms, an algorithm of dependence of the box operation parameters on the course of the biological process was developed.

The composting process, carried out with the participation of KOMPRE and intelligent composting boxes, will result in rapid disintegration and re-synthesis of intermediate products into biologically active substances, i.e., humic and fulvic acids and humins.

The end product is an easily digestible complex organic fertilizer of brown-black colour, pH 7.5-8.0 and NPK 5:3:4, it is a source of active humic substances (up to 45%). During the conducted tests, it was shown that the obtained fertilizer substances based on chicken manure, which are the subject of the research, showed a positive effect on the growth of green mass of plants (up to 50%). Systematic fertilization of soils with this innovative organic fertilizer in a longer period will lead to the growth of organic matter and humus, which will contribute to the improvement of the physical and biological properties of the soil.

The presented technology of obtaining organic fertilizer with a high content of humic acids from chicken manure and its effect on plants can be considered innovative and pro-ecological, which will help to intensify the processing of waste from large farms in shortened terms (up to 7 days).

References

Bernal, M. P., Alburquerque, J. A., Moral, R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment. *A review, Bioresources Technology, 100*, 5444-5453.

Finzi, A., Riva, E., Bicoku, A., Guido, V., Shallari, S., Provolo, G. (2019). Comparison of techniques for ammonia emission mitigation during storage of livestock manure and assessment of their effect in the management chain. *Journal of Agricultural Engineering, L:881*, 12-19.

Jędrczak, A. (2007). Biologiczne przetwarzanie odpadów. *Wydawnictwo Naukowe PWN*.

Kłapeć, T. and Cholewa, A. (2012). Zagrożenia dla zdrowia związane ze stosowaniem nawozów organicznych i organiczno-mineralnych. *Medycyna Ogólna i Nauki o Zdrowiu*, *18*(2), 131-136.

Kopeć, M., Gondek, K., Orłowska, K., Kulpa, Z. (2014). Wykorzystanie odpadów z ubojni drobiu do produkcji kompostu. *Inżynieria Ekologiczna, 37*, 143-150.

Onwosi, C.O., Igbokwe, V.C., Odimba, J.N., Eke, I.E., Nwankwoala, M.O., Iroh, I.N., Ezeogu, L.I. (2017). Composting technology in waste stabilization: on the methods, challenges and future prospects. *Journal of Environmental Management, 190*, 140-157.

Pikuła, D. (2016). Rola substancji humusowych oraz innowacyjne produkty zwiększające ich zawartość w glebie. *Studia i raporty IUNG-PIB, 48(2)*, 81-93.

Potapov, M.A., Kurochkin, A.A. (2018). To the question of improving the technology of processing bird manure. *Innovative Technique and Technology, 1*, 25-29.

Siebielska, I. (2013). Degradacja WWA I PCB w procesach biologicznej przeróbki wybranych odpadów biodegradowalnych. *Wydawnictwo Politechniki Koszalińskiej, 239*.

Sundberg, S. (2005). Improving Compost Process Efficiency by Controlling Aeration, Temperature and pH. *Acta Universitatis Agriculturae, 103*, 6652-6880.

Wang, Y., Ai, P., Cao, H., Liu, Z. (2015). Prediction of moisture variation during composting process: A comparison of mathematical models. *Bioresource Technology, 193*, 200-205.

Zbytek, Z., Talarczyk, W. (2008). Gnojowica a ochrona środowiska naturalnego. *Technika rolnicza ogrodnicza leśna, 4*, 25-28,

Zhang, J., Gao, D., Chen, T. B., Zheng, G. D., Chen, J., Ma, C., Guo S-L., Du, W. (2010). Simulation of substrate degradation in composting of sewage sludge. *Waste Management, 30*, 1931-1938.

INNOWACYJNA TECHNOLOGIA PRZYSPIESZONEGO KOMPOSTOWANIA ODCHODÓW KURZYCH W CELU UZYSKANIA NAWOZU ORGANICZNEGO O WYSOKIEJ ZAWARTOŚCI KWASÓW HUMUSOWYCH

Streszczenie. Humus jest jedną z najważniejszych frakcji materii organicznej gleby, która ma istotne znaczenie dla środowiska i rolnictwa. Poszczególne składniki próchnicy obejmują grupę amorficznych substancji próchnicznych, w tym kwasy humusowe, fulwowe i huminy. Skuteczność naturalnego tworzenia się aktywnych substancji próchnicznych podczas procesu kompostowania zależy od składu chemicznego osadów organicznych i warunków środowiskowych, które mają wpływ na rozwój i aktywność natywnych mikroorganizmów. Celem projektu było zbudowanie innowacyjnych skrzyni kompostowych na odchody kurze pozwalające na skuteczne uzyskanie nawozu o możliwie najwyższej zwartości kwasów humusowych poprzez stworzenie idealnych i kontrolowanych warunków dla szybkiego rozwoju miejscowych mikroorganizmów termofilnych oraz poprzez połączenie ich z własną technologią bio-akceleracji. Dla uzyskania idealnych warunków (temperatura, wilgotność, tlen, pH) dla kontrolowanego wzrostu mikroorganizmów, stworzono algorytm zależności parametrów operacyjnych skrzyni. Produkt uzyskany w drodze kompostowania jest łatwo rozkładalnym złożonym nawozem organicznym o brązowo-czarnym kolorze, pH 7,5-8,0 oraz NPK 5:3:4 i wysokim poziomie natywnych kwasów humusowych. Jego zastosowanie pozytywnie wpływa na wzrost zielonej masy roślin i poprawia żyzność gleby, co zostało udowodnione przeprowadzonymi badaniami.

Słowa kluczowe: odchody kurze, kompostowanie, bakterie tlenowe, inteligentne skrzynie, fazy termofilne i transformacyjne, kwasy humusowe, kwasy fulwowe, nawóz.