BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi" din Iași
Volumul 69 (73), Numărul 3, 2023
Secţia
CHIMIE şi INGINERIE CHIMICĂ
DOI: 10.5281/zenodo.10072463

CHICKEN MANURE VALORISATION BY FORCED AERATION IN-VESSEL COMPOSTING AT LABORATORY SCALE

BY

GEORGE BARJOVEANU, PETRU APOPEI, DANIELA GAVRILESCU*, ANDREEA GHERGHEL and CARMEN TEODOSIU

"Gheorghe Asachi" Technical University of Iași, "Cristofor Simionescu" Faculty of Chemical Engineering and Environmental Protection, Iași, Romania

Received: August 15, 2023
Accepted for publication: September 28, 2023

Abstract. Intensive rearing of different animals has led to significant amounts of farming animal derived wastes, such as chicken manure, an important biodegradable waste that is still frequently applied in direct land fertilization as a method of disposal. Unfortunately, this is not a sustainable treatment option for chicken manure due to its intrinsic properties. In line with the waste management hierarchy options and with circular economy principles, chicken manure valorisation is possible after biological or chemical treatment, the first being even more desirable because it mimics the natural cycles. However, various materials must be added to the chicken manure to make susceptible to biodegradation. This study proposes the experimental laboratory-scale investigation of an in-vessel forced aeration process applied for the treatment and valorisation of chicken manure. The most suitable bulking agent out of 4 materials (sawdust, wheat straw, lignite and charcoal) and the various C:N ratio in waste-bulking agent mixtures were investigated. The results indicated that lignite is the most suitable bulking material, while a C:N ratio of a chicken-manure lignite mix of 10:6 is considered to give the best composting results.

Keywords: composting, chicken manure, waste valorisation, circular economy.

*Corresponding author; *e-mail*: daniela.gavrilescu@academic.tuiasi.ro

1. Introduction

The current linear economy model considers development based on increased production, consumption and this consequently generates an ever increasing quantity of wastes which generally ends-up in the environment. By contrast, circular economy, is a paradigm of reshaping the European economic eco-systems into strong and cyclic economies which maximizes resources use, closes product life cycles by enhancing reuse, recycling and recovery and supports businesses in a smooth transition towards circularity (EC, 2020). However, there are many challenges towards achieving this goal like: redesigning value chains and product life-cycles, aligning circularity with business interests and developing end-of-life businesses, promoting a circular behaviours among consumers, and designing effective policies, instruments and technologies to support all these to name just a few (Rademaker, 2022).

There are several type of waste streams that are considered important candidates for recycling and valorisation given their physical-chemical or other characteristics but also given their generation potential in terms of periodicity with which they are produced. Such a waste stream is formed by the wastes coming from bio-processes like the intensive rearing of animals while farming manure is one of the most prevalent organic wastes produced at global level (Tawfik *et al.*, 2023). Particularly, chicken manure poses important health and environmental challenges but also technical difficulties in its disposal (Nie *et al.*, 2015). Improper management and disposal of farming waste and particularly of chicken manure could generate very high environmental problems like: high rates of direct GHG emissions (Dhamodharan *et al.*, 2019) especially due to anaerobic processes that may occur during storage, improper treatment, eutrophication and bacteriological contamination of soils and water bodies (Bortolini *et al.*, 2020) especially during direct application on soils without any treatment. Odor and bad smell is another problem related to chicken manure, as well as its potential to spread dangerous infections.

With regard to treatment of chicken manure a strategy known as *waste-to-wealth* has gained a lot of attention in the last period (Elreedy *et al.*, 2015). Its objectives are drawn from the principles of circular economy (Devendran Manogaran *et al.*, 2022) it proposes the application of various technologies that will transform the waste into a valuable new resource, thus bringing added value, developing new technologies and creating multiple environmental benefits by at least solving the associated waste problems and avoiding creating new ones elsewhere (e.g. with virgin fertilizers).

Chicken manure poses challenges for its proper management due to high generation rates and strict elimination rules, but it also provides good opportunities for valorisation considering its high quantities of nutrients (nitrogen, phosphorus and potassium) which makes it a very suitable material to obtain fertilizers from.

Currently, in most cases, the elimination of chicken manure is done by landfilling, or direct land application with or without previous conditioning. There are several technological options suitable for chicken manure treatment that will actively transform the waste into a new product, albeit with the same purpose as the direct use of the waste, which is land fertilization. These technologies usually refer to aerobic and anaerobic digestion, composting, pyrolysis and gasification. Anaerobic digestion involves breaking down the organic matter in chicken manure in the absence of oxygen to produce biogas (methane and carbon dioxide). Aerobic digestion is similar to its anaerobic counterpart, but oxygen is present and the breakdown of organic matter is performed by aerobic microorganisms. Composting is the process of breaking down chicken manure with the help of aerobic microorganisms, oxygen and heat at a slower rate. Incineration, pyrolysis and gasification rely on the thermal destruction of chicken manure at high temperatures to produce ash and gaseous emissions in aerobic (incineration) or anaerobic conditions (Devendran Manogaran *et al.*, 2022). Except composting, which is by far the most used and the most available for farmers, the other processes require technical expertise and high capital costs for implementation albeit they can generate high-value products (biogas, etc.). However, the new technologies for chicken manure treatment have to be developed and applied in order to realize the elimination of primary and secondary environmental impacts and risks.

Composting is the process in which a mixture of biodegradable substrate (e.g. chicken manure) and other materials used as bulking agents, water and air, are subjected to an aerobic microbial activity which breaks down organic matter under specific conditions that lead to an end-product which is stable from a biologic point of view, free of pathogens and can be safely used as a fertilizer (Haug, 2018). The composting process is divided into four stages (Fig. 1). In the first stage, a rapid breakdown of simple organic matter (sugars, amino acids, proteins) occurs due to mesophilic microorganisms, which proliferate at temperatures of between 20°C and 45°C. This creates heat which leads to temperatures of 65–68°C where the mesophilic microorganisms are replaced with thermophilic ones, which furthermore degrade more complex organics (fats, cellulose, hemicellulose, and lignin). The high temperature also contributes to the destruction of pathogens in this phase. A second longer mesophilic phase happens after the thermophilic one, during which the temperature of the substrate decreases and the remaining sugars and proteins are further degraded. The final stage, which is also the longest, is commonly referred to as the maturation phase, humic substances are formed (Akdeniz, 2019).

From an engineering and operational point of view, any composting process is governed by factors like temperature, moisture, C:N ratio, porosity, and aeration rate which affect primarily the biological processes in terms of microbial communities, metabolism, kinetics and the quality of the final product. All these parameters needs to be carefully monitored and controlled in order to have a high quality compost. All the technologies used in composting try to control these process parameters in an effective way and to minimise time and energy consumption. The most important composing technologies include windrows, static bins and in-vessel systems (Sanchez *et al.*, 2017). Windrow composting and static bins are the most widely used type of composting systems, but their main disadvantages refer to the long time needed for the process and hence the wide space needed. In-vessel systems provide high-temperature, short-time composting but they require special attention in controlling several important parameters.

Considering all the aspects presented above, the objective of this study is to present a series of laboratory scale experiments of in-vessel composting of chicken manure which were performed to determine an optimal additional carbon source that would support and sustain the composting process at high temperatures in order to minimize the process duration. Four variants of substrate-filler materials were initially tested (saw-dust, wheat-straw, charcoal and lignite), and then only the influence of the initial C:N ratio was studied only for one filler material (lignite).

2. Materials and Methods

2.1. Experimental set-up

The experiments were performed in a series of laboratory-scale reactors, which are schematically presented in Fig. 1. A series of three composting reactors (Fig. 2) were used in parallel for different experimental conditions.

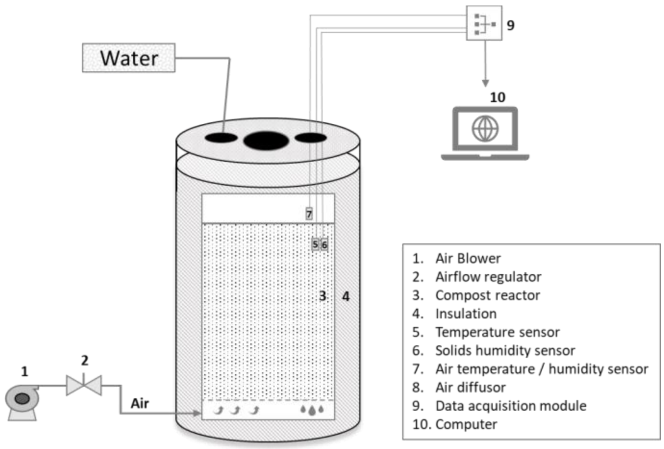

Fig. 1 – Experimental Set-up.

The composting reactor has consisted of a 30 L reaction vessel which was fitted at the bottom with an air diffusor on which the reaction mass was supported. The reactor was insulated with polymeric foam in order to preserve inside temperature. An air blower fitted with a regulator was used to provide intense aeration to support the composting process. A monitoring system which comprised several temperature and humidity sensors, a data acquisition module and recording computer was realized and used for monitoring data collection. Initially temperature and humidity were the target parameters to be monitored, but after the start of the experiments, only the temperature was measured because the humidity sensors (for both solid and air phases) were completely saturated.

Fig. 2 – Experimental Composting reactors.

Mixing, which is important as it provides homogenization among the three phases involved in composting process (solids, water and the gases) was performed manually at regular intervals (once per day). Aeration was done intermittently with the help of a time-regulator (2 minutes off, one minute off) at a constant rate of 200 $L \cdot h^{-1}$.

2.2. Chicken manure characterization

Chicken manure and the other materials characterization was performed by using standard methods for the determination of humidity, total solids, volatile fraction, non-biodegradable fraction and ash fraction, according to EN 15934:2012 (ISO 2012) and EN 15935:2021 (ISO 2021). The carbon content was determined by a method which involved the mineralization of the volatile organic content by potassium dichromate for 1 h at 120^0C and then the titration of the excess dichromate with ferrous sulphate. The nitrogen content was determined by a standard Kjeldahl method which involved the mineralization of nitrogen compounds to ammonia and then the determination of NH_4^+ ion in aqueous phase according to ISO 7150-1:1984 (ISO 1984). The chicken manure characteristics presented in table 1 show that the material used in the experiments in general falls in the average characteristics of similar manures, as presented by the Phyllis biomass database (Doorn, 1999).

Table 1

Chicken manure, filler materials and compost composition

	Unit	Chicken manure	Chicken manure*	Sawdust	Wheat straw	Lignite	Charcoal	Final compost
Substrate input	fraction	1	1	2.3	1.97	2.35	1.91	
Total solids	fraction	0.76	0.80	0.65	0.89	0.75	0.92	0.65
Volatile solids	fraction	0.68	0.81	0.95	0.94	0.36	0.36	
Biodegradable solids	fraction	0.51	-	0.2	0.35	0.1	0.1	
Ash	fraction	0.24	0.20	0.07	0.11	1.13	1.12	
Water	fraction	0.24	0.31	0.35	0.22	0.59	0.15	0.35
Carbon content, %d.m.	%	37	46.67	49.53	48.93	49.23	56.4	
Nitrogen content, %d.m.	%	4.03	4.69	1.41	0.65	0.67	0.66	
C:N		9.18	10	35.12	75.27	73.47	85.45	25:1

*average according to the Phyllis data base

2.3. Composting experiments

Two series of experiments were performed in order to investigate how these amendment and filler materials would impact the composting process.

In the first series the nature of the filler material was investigated by conducting a series 4 experiments in parallel during in which the initial mix or substrate made of chicken manure, filler material and water was calculated to a C:N ratio of 25:1 and an initial water content of 65%. In our case, the filler materials play a double role in the composting process: the first is to provide a carbon source which contributes to the initial C:N ratio which subsequently makes the biological mineralization a self-sustainable process. The second function of these materials is to provide a support, a matrix for the chicken manure to form a tri-phase system in which the solid phase (chicken manure – filler material mix), water and air are as homogeneous as possible. From the data presented in Table 1, it may be observed that lignite and charcoal are the best options given their very high carbon and low nitrogen contents which means that a small amount of these materials were needed to achieve the initial C:N ratio of 25:1.

In the second experimentation phase the effect of the C:N ratio was investigated by performing a series of experiments with a single filler material and testing several initial C:N ratios.

During all experiments the solid phase temperature was recorded as a measure of the overall process behaviour and periodically materials samples were collected and analysed.

3. Results

3.1. Filler materials effect on composting process

The primary objective of the laboratory-scale experiments was to evaluate the potential of using affordable and recyclable carbon sources like the wheat-straw and sawdust which are materials readily-available at any farm. Data presented in figure 3, shows that the over a period of approximately 7 days, the compost mix containing wheat straw has had a very slow start of the microbial activity and it reached the thermophilic stage only in the sixth day of the process. This behaviour is probably due to the poor mixing inside the composting reactor, which was demonstrated by direct observation. The reaction mass inside this reactor din not have a homogeneous appearance as in the other cases, but it was very wet and the chicken manure was basically stuck to the wheat straws which hindered proper air circulation through the composting substrate.

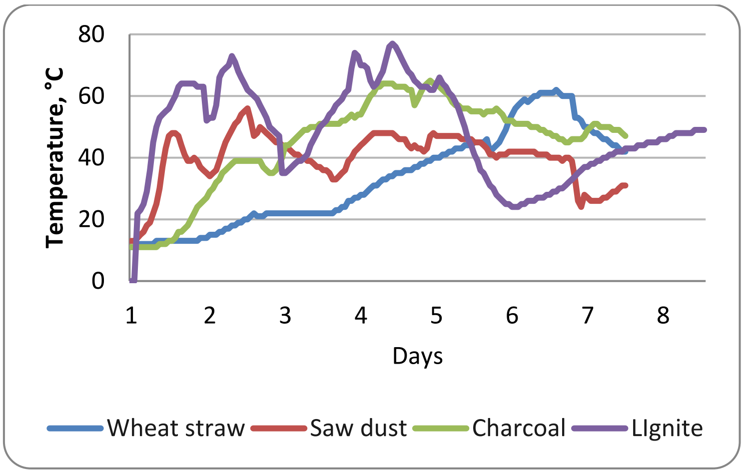

Fig. 3 – Temperature profiles during chicken manure composting.

By contrast, in the other three cases, higher temperatures were recorded much faster inside the reactors, and the temperature profiles demonstrate that the composting processes have reached the thermophilic statuses. With respect to the highest temperature reached, this was achieved in the case of the lignite-chicken manure mix (with a maximum of 77°C), followed by the charcoal (65°C), the wheat straw (62°C) and the saw dust (56°C). It is important to note that in case of the sawdust-chicken manure mix, the temperature did not achieve a proper thermophilic phase and this is probably due to the fact that saw dust does not provide the same surface area as in the case of charcoal and lignite. With respect to the charcoal, it may be noted that this was introduced in the reactor as a powder and it was very well mixed. During the regular inspections in the reactors, it was noted that it has formed 2-3 cm wide agglomerated spheres of composting mix which contained organic material that was not properly aerated and mineralized. The best mix from a granulometric and homogenization point of view was the one realized with lignite particles in the range 1-6 mm and which provided sufficient support and contact with the solid and liquid phases and allowed for enough air to get in contact with the organic material. This is proven by the high temperatures reached in case of this mix, but also in the duration of these high temperature regimes.

From a duration point of view, the longest the composting process is maintained at high temperatures, the faster the organic material mineralization occurs. However, maintaining temperature in the thermophilic zone (55 – 65°C, with a maximum of 70°C) is the most difficult operational task during the high aeration in-vessel composting process, as this is primarily achieved by varying the aeration supply to the reactor. Moreover, overcoming the critical temperature of 70°C may lead to sudden death of the thermophilic microorganisms and the abrupt and complete stop of the entire process. Considering all these aspects, the temperature control of the process is critical.

In Fig. 3 the sinusoidal appearance of the temperature profiles in case of the lignite, charcoal and sawdust mixes is an effect of trying to maintain the process in the thermophilic zone (55 – 65°C) and this was achieved by turning off the air supply and turning over manually the material inside the reactor which has led to a temporary decrease in temperature.

Furthermore, because composting is a surface process, like all aerobic microbial degradation processes, providing the necessary surface area for the three phases contact is another important parameter which is set by the mixing regime. Mixing is performed in order to refresh and replenish newly exposed organic matter to forced aeration, while enhancing microbial growth and to limit the existence of anaerobic zones inside the composting reactor.

Given these results it was decided that the next series of experiments in which the initial C:N ratio was investigated was performed solely with the chicken manure – lignite mix.

3.2. Initial C:N ratio

The initial C:N ratio is a very important parameter in composting because this is the trigger factor that initiates first mesophilic phase of the process and then the proliferation of microorganisms. Basically composting occurs spontaneously at a C:N ratio higher than 16, while all microbial activity is considered to be stopped at a C:N value less than 10. This value is also used as an indicator for compost stability. So, in order perform a high-rate composting process, high C:N values are needed to be provided in the initial mix.

This series of experiments was performed at three different chicken manure – lignite ratios (10:12, 10:8 and 10:6) which has corresponded to C:N ratios of 35:1, 28:1 and 23:1 respectively.

The temperature profiles presented in Fig. 4 present the three composting phases: the first mesophilic phase, the thermophilic one and the second mesophilic phase. It may be noticed, that for all mixes, the thermophilic phase was achieved and during the mesophilic phase high temperatures were also reached.

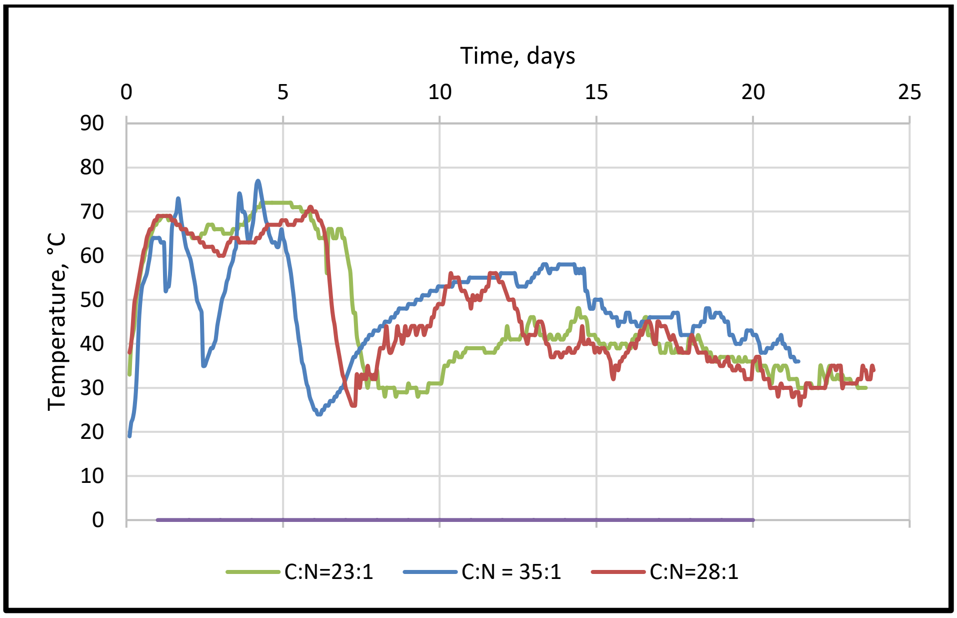

Fig. 4 – Temperature profiles during chicken manure composting.

In case of the higher initial C:N ratio (35:1) it may be noticed that during the mesophilic phase high temperatures were reached (of over 55°C) uncommonly high (usually 35 to 45°C is recorded during this phase). This may indicate that actually the thermophilic phase was not over yet and this may be due to the very high organic load that needed to be mineralized which in turn may indicate that the C:N ratio was too high. Although the process rate was pretty high, and high temperatures were reached, this situation is not really wanted in the composting process because the primary target is to break down the chicken manure and not to burn unnecessary filler materials. The profiles in Fig. 4 demonstrate that the same results may be achieved also at lower initial C:N values (e.g. 10:8 and 10:6 respectively).

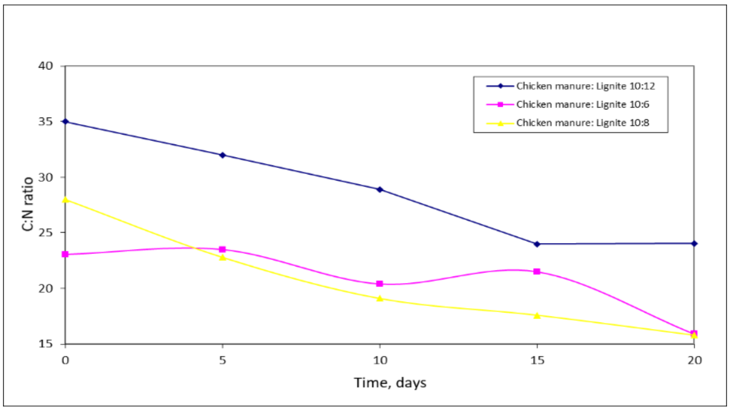

Fig. 5 – C:N variation during the composting processes of chicken manure.

The variation of C:N ratio during the composting process, as presented in figure 5, show that in the case of mix with the initial C:N value of 35:1 the drop during the composting phase is more accentuated compared to the other two cases, but the final value is around 25 which indicates that the process is far from over. In case of the 10:8 and 10:6 ratios the descending trend is not so abrupt which may indicate a slower rate for mineralization and the final C:N value is around 16, which also indicates that the stabilization process is not yet finished.

4. Conclusions

This study has proposed the investigation of lab scale composting process for chicken manure treatment and valorisation. Based on the experimental results the following conclusions may be drawn:

It was possible to demonstrate the feasibility of a forced-aeration in-vessel composting process applied for chicken manure mixed with different carbon sources which acted as well as filler materials. Bulking agents like wheat straw did not lead to conclusive results as it did not lead to proper mineralization, while the saw dust experiment did not reach the thermophilic phase. Except wheat straw, better results were obtained in the case of lignite, which proved to be the most suitable filler material among the other three options.

Another research direction was to investigate the effect of the initial C:N ratio over the composting process. In this respect it may be concluded that although a higher initial C:N ratio gives high temperatures and fast process ratio, it becomes really difficult to control the process efficiency, given the high thermal inertia of the system and limited process response.

These experiments have pointed out the crucial role of parameters like the aeration and mixing regimes. Aeration is the process parameter by which temperature and moisture in the reaction vessel are controlled and such, the aeration rate needs to be carefully monitored and controlled during all the process stages in order to provide constant and high oxygen level at the solid-liquid interface where the aerobic biological microbes decompose organic matter. Aeration has to be carefully controlled and correlated with the mixing, as too little aeration leads to generation of anoxic or even anaerobic conditions, while too much aeration leads to heat and humidity loss, hindering the high rate thermophilic processes.

We may conclude that these results demonstrate the potential treatment of chicken manure and lignite mix by forced aeration in-vessel composting and that future research may be carried out at pilot level which may provide a better platform to study in depth the influence of aeration and mixing on process yield and other important parameters like nitrogen loss.

Acknowledgements. This work was supported by a grant funded by the Regional Operational Program 2014 -2020, POR/1/1.1/OS 1.2/1, project number 136527, contract no: 7288/2021, “Integrated solutions for chicken manure waste management”- Chicken Waste.

REFERENCES

Akdeniz N., *A systematic review of biochar use in animal waste composting*, Waste Manage., **88**, 291-300 (2019).

Bortolini S., Macavei L.I., Saadoun J.H., Foca G., Ulrici A., Bernini F., Malferrari D., Setti L., Ronga D., Maistrello L., *Hermetia illucens (L.) larvae as chicken manure management tool for circular economy*, J. Clean. Prod., **262**, 121289 (2020).

Devendran Manogaran M., Shamsuddin R., Yusoff M.H.M., Lay M., Siyal A.A., *A review on treatment processes of chicken manure*, Clean. Circ. Bioecon., **2**,100013 (2022).

Dhamodharan K., Varma V.S., Veluchamy C., Pugazhendhi A., Rajendran K., *Emission of volatile organic compounds from composting: A review on assessment, treatment and perspectives*, Sci. Total. Environ., **695**, 133725 (2019).

Doorn J. van, *Phyllis: ECN database on composition of biomass and waste*, ECN-B--99-012, 1999 (last updated 2023), https://phyllis.nl/Browse/Standard/ ECN-Phyllis.

Elreedy A., Tawfik A., Kubota K., *Hythane (H_2 + CH_4) production from petrochemical wastewater containing monoethylene, glycol via stepped anaerobic baffled reactor*, Int. Biodeterior. Biodegrad., 2015, **105**, 252-261.

EC, 2020 EC-European Commission, Directorate-General for Communication, Circular economy action plan – For a cleaner and more competitive Europe, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/05068

Haug R., *The practical handbook of compost engineering*, Routledge, 2018.

ISO EN 15934:2012(MAIN), *Sludge, treated biowaste, soil and waste - Calculation of dry matter fraction after determination of dry residue or water content*, International Standardization Organization, 2012.

ISO EN 15935:2021, *Soil, waste, treated biowaste and sludge - Determination of loss on ignition*, International Standardization Organization, 2021.

ISO EN 7150-1:1984, *Water quality - Determination of ammonium - Part 1: Manual spectrometric method*, International Standardization Organization, 1984.

Nie H., Jacobi H.F., Strach K., Xu C., Zhou H., Liebetrau J., *Mono-fermentation of chicken manure: Ammonia inhibition and recirculation of the digestate,* Bioresource Technology, 2015, **178**, 238-246.

Rademaker A., *Transitioning to a circular economy: what are the challenges*?, Israel public policy institute, 2022, Oct 17, https://www.ippi.org.il/transitioning-to-a-circular-economy-what-are-the-challenges/

Sanchez O.J., Ospina D.A., Montoya S., *Compost supplementation with nutrients and microorganisms in composting process,* Waste Manag., 2017, **69**, 136-153.

Tawfik A., Eraky M., Osman A.I., Ai P., Zhou Z., Meng F., Rooney D.W., *Bioenergy production from chicken manure: a review*, Environ. Chem. Let., 2023, https://doi.org/10.1007/s10311-023-01618-x

VALORIFICAREA DEȘEURILOR DE TIP DEJECȚII DE PĂSĂRI PRIN COMPOSTARE CU AERARE FORȚATĂ LA SCARĂ DE LABORATOR

(Rezumat)

Creșterea intensivă a diferitelor animale a condus la creșterea semnificativă a cantităților de deșeuri provenite de la ferme, așa cum este cazul dejecțiilor de păsări, o categorie importantă de deșeuri biodegradabile, care sunt încă eliminate prin aplicare în mod direct ca amendament pe soluri. Din păcate, această modalitate de tratare nu reprezintă o variantă durabilă de tratament a dejecțiilor de păsări, din cauza proprietăților lor intrinseci. În acord cu principiile opțiunilor ierarhizate de management al deșeurilor și ale economiei circulare, valorificarea deșeurilor de tip dejecții de păsări este posibilă prin tratament biologic sau chimic, primul fiind și mai dezirabil deoarece imită mai bine ciclurile naturale. Cu toate acestea, pentru ca dejecțiile de păsări să devină susceptibile pentru biodegradare, trebuie amestecate cu alte materiale. Acest studiu propune o analiză experimentală, desfășurată la scară de laborator, a unui proces de compostare care se desfășoară într-un reactor, cu aerare forțată, pentru tratarea și valorificarea dejecțiilor de păsări. Au fost analizate cele mai potrivite materiale de aglomerare (rumeguș, paie de grâu, lignit și cărbune), pentru mai multe rapoarte C:N. Rezultatele indică faptul că lignitul este cel mai bun agent de aglomerare, iar raportul dejecții păsări:lignit de 10:6 conduce la cele mai bune rezultate ale compostării.