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Assessment of composting processes in an automated aerobic fermentation system based on key parameters

Tamás Magyar [#], Rebecca Mayes, Péter Tamás Nagy

University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management, Institute of Water and Environmental Management, Hungary

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ABSTRACT

The poultry (broiler) industry is continuously increasing all over the world, therefore, the amount of waste generated in these facilities is also increasing. As a consequence of the above mentioned, the more efficient conversion of chicken manure to organic fertilizer is a key problem. The aims of the study are to investigate the changes in temperature and moisture content during composting of chicken manure in the oval tank fermentation system and to create a model for the evaluation of the performance of biodegradation processes. The moisture and temperature distribution models of the oval tank were created in Hydrus software. The results showed that the oval tank fermenter can be divided into two main zones. In the first zone, where the rate of biodegradation was relatively high, a heterogeneous temperature zone was found with continuously decreasing moisture content. The second zone was more homogenous in both temperature and moisture content. This stage represents the weak fermentation part of the technology and results in an elongated post fermentation section. Furthermore, statistically significant correlations were found between composting key parameters, such as ammonium content with temperature and organic matter content with organic nitrogen content. It was also concluded that the exact location of the manure turning and chopping mechanical system (MTCM) used for aeration had a high effect on the composting processes, as well as on the quality parameters of the mature compost.

1. Introduction

Composting is a well-known method in waste management that can be applied to the treatment of biodegradable wastes. The primary aim of composting is to decrease the effects of hazardous potential on the environment, as well as the volume of the generated organic wastes. It is an exothermic, aerobic degradation process where the final product is a stable, valuable material (equation 1) which can be used for different purposes (e.g. soil amendment) (Ashraf and Gregg, 2020).

$$\textit{organic waste} + O_2 \xrightarrow{\textit{microorganisms}} CO_2 + H_2O + \textit{stable compost} + \textit{heat} \qquad (1)$$

In the industrial scale fermentation facilities, the quality of the mature compost can be controlled by setting up the initial parameters of the feeding material and the operational circumstances. There are some key

[#] Corresponding autor: magyar.tamas@agr.unideb.hu

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parameters, which should be considered during the degradation process, since they have a significant effect on the final product quality (Asadu et al., 2019). One of the most important is the initial moisture content of the feeding material, because the aqueous medium is essential for the metabolism of microorganisms and for the enzymatic catalytic reactions. The optimal moisture content is in the range of 40 - 60 V/V % (Madejón et al., 2002). The higher moisture content inhibits the degradation process and turns it to an anaerobic degradation.

The decomposition process can be tracked by monitoring the temperature (Fernandes et al., 1994). The temperature provides information about which phase the degradation is in (Figure 1).

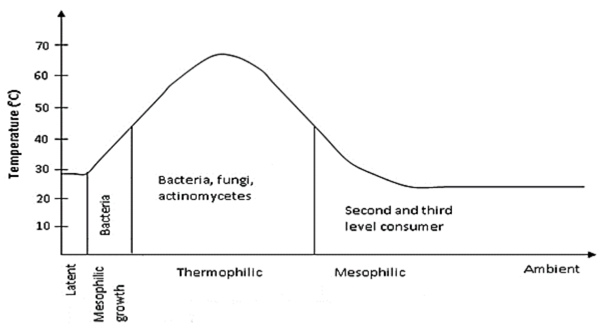

Figure 1. Patterns of temperature and microbial growth during composting (Bhatia et al., 2015)

According to Figure 1, a temperature elevation can be observed within a few hours after filling in the material to the fermentation system. The maximum temperature arises in the thermophilic phase and thereafter it starts to slightly decrease in the mesophilic phase until reaching the ambient temperature.

The carbon/nitrogen ratio is also a key parameter from the aspect of microorganisms. The microorganisms use these chemical elements as a cell-building substance (carbon for energy and nitrogen for protein production). The optimal C:N ratio should be in the range of 25 - 30:1 (Asadu et al., 2019). This ratio can be adjusted to the optimal by using additive materials (e.g. saw dust or straw).

The chicken manure is generated in large amounts and relatively rich in nitrogen, as well as in potassium and phosphorus, therefore, it is one of the most often used materials for composting (Amanullah et al., 2010; Szabó et al., 2019). However, the chicken manure as waste from the poultry industry includes a mixture of excreta (manure, faeces, and urine), bedding material or litter (e.g. wood shavings or straw), waste feed, carcasses, broken eggs, and feathers removed from poultry houses (Raviv et al., 1999). Other wastes include those from cage, conveyer belt and water-flushing systems. Poultry manure is acquired through the regular cleaning of the poultry house (Kobierski et al., 2017).

The litter and manure component of the poultry house waste have a high nutritional value, and consequently they can be used as an organic fertiliser, thus recycling the nutrients such as nitrogen, phosphorous, and potassium. The poultry litter has traditionally been spread on soil as an amendment (Rynk et al., 1991). The mature compost can improve soil fertility and plant growth (Haga, 1999), however, immature compost applied on soil can contribute to N starvation (Bernal et al., 2009; Moral et al., 2009), phytotoxic effects, and presence of harmful microbes (Fang et al., 1999; Tiquia and Tam, 2000).

The high nitrogen content and balanced nutrients are the reason that chicken manure compost is the best kind of manure to use. It should be considered that the high nitrogen in the chicken manure can be dangerous to plants if the manure has not been properly composted. Raw chicken manure fertilizer can burn or even kill plants. Moreover, over-application of this material can lead to an enriching of water nutrients resulting in eutrophication of water bodies, the spread of pathogens, the production of phytotoxic substances, air pollution, and emission of greenhouse gases (Fan et al., 2000; Kelleher et al., 2002). Bitzer and Sims (1988) reported that excessive application of poultry litter in cropping systems can result of nitrate contamination in groundwater. Excessive application of fresh poultry manure on the farm may result in an excess accumulation of ammonia and damage the crop roots too (Köteles and Pereş, 2017; Tamás et al., 2017). Proper handling of the manure can be achieved through proper engineering of composting and appropriate practices of feed management (Bolan et al., 2010).

2. Materials and methods

2.1. Feeding material

Deep litter chicken manure and dehydrated hen manure were used from the Kisvárda slaughterhouse as a feeding material in the fermentation procedure. The maximum capacity of the plant is 11,000 t/year, which represents a 30 t daily usage. Taking this into account with the average composition of boiler chicken manure, a large amount of nutrient content (330 t of N, 220 t of P_2O_5 and K_2O) can be theoretically recovered and used as fertilizer.

The mixing ratio of the raw materials in the fermentation tank was 1/3 of broiler and 2/3 of chicken manure. The moisture content of the incoming chicken manure varied between 20 and 40 %. For the optimal fermentation the moisture content of the raw material should be adjusted to 40 - 45 % by adding water (150 l/intake).

2.2. The automated fermentation system

The Hosoya (oval tank) fermentation and drying technology is a Japanese-developed alternative method
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for poultry and pig manure. The Hosoya technology was launched in 1970 and is still being developed.

A study was undertaken by Georgakakis and Krintas (2000) to investigate and optimize an oval tank composting system in composting poultry manure at a typical poultry farm in Greece. The oval tank fermentation system is one of the two different treatment systems that have been applied for the treatment of wastes. The other one is the so-called Okada system, both of them of Japanese origin. These systems are based on the operation of specially designed manure turning and chopping mechanical systems (MTCM). The system consists of a series of rotating metallic knives or forks with which the waste is completely turned, aerated, and gradually pushed to the end of the specific tank. This installation consists of an open, shallow, and oval shaped concrete tank (Figure 2). The standard size of the tank is 60 m × 8.3 m.

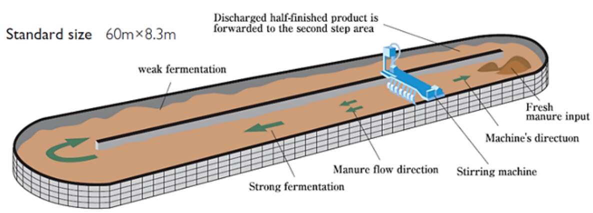

Figure 2. Arrangement and processes of the automated industrial fermentation system

Fresh manure is batch fed daily to the oval tank and an equivalent quantity of final material is removed from the exit. The tank is filled with the waste material up to a total depth of 1.0 - 1.2 m. The stirring machine with double rotors ensures the continuous mixing of the manure in the fermentation tank.

The MTCM in the fermentation system completes a full run along the oval tank in approx. 2.5 h. On a daily basis, a maximum of 5 full runs can then be completed. One complete run results in the displacement of 1.5 m of manure along the tank or a maximum of 7.5 - 8.0 m after 5 runs completed in 24 h. Therefore, the minimum travelling time for fresh manure to reach the exit of the 120 m long channel is 12 - 14 days. During the turning and pushing of manure by the MTCM system, surrounding air is incorporated and moisture is lost by evaporation. The fermentation system controls the initial moisture content by mixing the incoming fresh manure with the recirculated dry old material in the channel and this helps to start the composting process. Moisture control of the material in the oval tank is necessary to avoid blockages of the MTCM operation (Hosoya and Co., 1996). A particle size of less than approx. 12 mm is formed from the initially muddy-textured raw material due to the turning effect of the MTCM system in the oval channel. The reduction of particle size accelerates the degradation due to the higher specific surface area available for microbes and increases the porosity providing the appropriate aeration conditions. In the technology, 3 - 5 cm thick fermented manure remains at the bottom of the fermentation tank as a microbial starter.

In this paper the performance of the oval tank fermentation system was studied by taking samples of poultry manure during a run and analyzing them for moisture content, dry matter content, and different nitrogen forms, such as organic nitrogen and inorganic forms (nitrate and ammonium). The temperature of the material during the fermentation was also monitored.

2.3. Sampling strategy

In order to create an appropriate model for the temperature and moisture distribution of the oval tank, temperature measurements and sample collections were performed monthly, from April to November in 2019. In this paper, the results of the June measurements represent the effect of hot and dry circumstances on the processes of the fermentation. Sampling cross sections was adjusted to the sensors of the fermentation tank based on earlier observations (Figure 3). In total, 21 sampling cross sections were selected and placed more frequently after the feeding point because of the initial strong fermentation, where higher temperature and moisture gradients were expected.

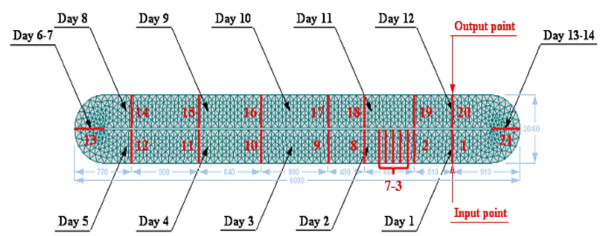

Figure 3. The location of sampling cross sections (days show the movement of the manure)

The temperature of the material was measured at three different points along each of the cross sections. One was the middle of the tank and the other two measuring points were 30 cm from the edges of the tank. Every measuring point was on the bottom of the tank. The samples were collected from the middle of each section for analytical purposes.

2.4. Applied measuring methods

Testo 922 mobile thermometer was used for temperature measuring (accuracy ± 0.5 °C). The moisture content was determined from the collected samples by weight loss method in the laboratory (MSZ-08-0221-1:1979). The moisture content was measured by drying in an oven at 105 °C for 12 h, or until constant dry weight was obtained.

In order to determine the exact quantity of inorganic nitrogen forms the Kjeldahl method was used alongside the photospectrometric method in accordance with the Hungarian Standards (MSZ-08-1744-1:1988; MSZ 20135:1999). The quantity of organic nitrogen was calculated based on the previously described methods. The organic content was estimated by the loss on ignition method (MSZ-08-0012-6:1981).

2.5. Modelling software

The two-dimensional version of the Hydrus software was used for modelling the water and temperature distribution in the oval tank during the biodegradation processes. The software applies a finite element model for simulating the movement of water, heat and multiple solutes in variably saturated media. The mathematical background of the software was the Richards equation for saturated-unsaturated water flow and convection-dispersion type equations for heat and solute transport.

The 2D geometry of the fertilizer oval tank was created as a first step, where the target finite element size was adjusted to 0.1 m. The duration of biodegradation processes was set to 14 days in the model according to the fermentation technology. The applied main parameters of feed material were 800 kg/m^3 bulk density, 55 % solid content, and 70 % organic content in the solid matter. In addition, the previously carried out results of in situ water content and temperature measurements were used as initial conditions. Finally, the “no flux” boundary condition was applied at the inner and outer circumference of the model tank.

3. Results and discussion

In this chapter, the results of temperature and moisture distribution models, as well as the analytical evaluation was introduced in June 2019. The correlations among the investigated parameters were statistically performed to obtain a comprehensive view about how the different parameters can effect on the performance of the fermentation system.

3.1. Temperature and moisture distribution models

The highest moisture content (expressed in grams/unit mass) was measured at the feeding point (0.428) (Figure 4), however, this value was adjusted for optimization at the beginning of the biodegradation processes and remained constant until the sampling point 9 (16.8 m). A rapid and sudden decrease can be observed after the high moisture content section as a result of the intensive heat generation in the thermophilic phase (between sampling point 9 and 13). The other part of the oval tank (after turning point) showed a slightly decreasing moisture content. The moisture content of the output material represented approximately 0.204, which was appropriate for pellet production from the composted material by pressure agglomeration technologies.

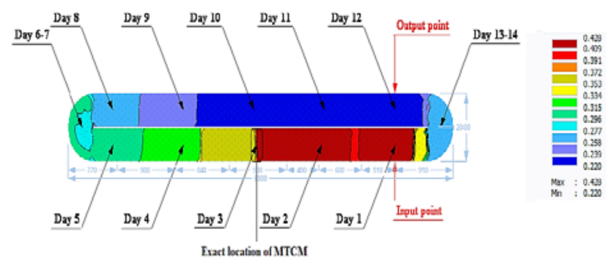

Figure 4. The moisture content model of the fermentation system (June 2019)

The fermentation tank can be divided into two main zones including the decomposition phases based on the results of the temperature distribution model (Figure 5). Heterogeneous temperatures were measured between sampling points 1 and 12 (this strong fermentation zone was divided into mesophilic and thermophilic phases by the MTCM system), as a result the inner, centre, and outer parts of the oval tank could be separated from each other. The centre part had the highest average temperature value (50.55 °C), higher on average than 7.27 °C compared to the inner parts and 3 °C compared to the outer parts. Weak fermentation zone (transient and maturation phases) was observed from the turning point (sampling point 13) to the output point (sampling point 21). The average temperature in this zone was 33.42 °C, the calculated standard deviation was ± 1.54 °C. The ambient temperature was 24.4 °C, when the measurements were carried out.

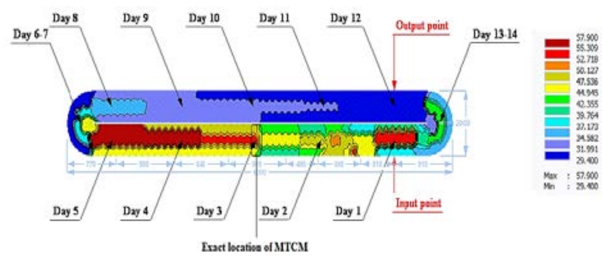

Figure 5. The temperature distribution model of the fermentation system (June 2019)

The temperature heterogeneity in the fermentation tank can be explained by the exact location of MTCM system. According to the above mentioned, higher microbiological activity and heat generation were formed, where the MTCM passed through earlier.

3.2. Analytical results

The correlation between temperature and ammonium is shown in Figure 6. The maximum measured temperature was 57.9 °C in the thermophilic phase, where a local minimum of ammonium concentration was also observed due to the exact location of the stirring machine. The MTCM intensified the ammonium release from the compost material to the environment during the aeration.

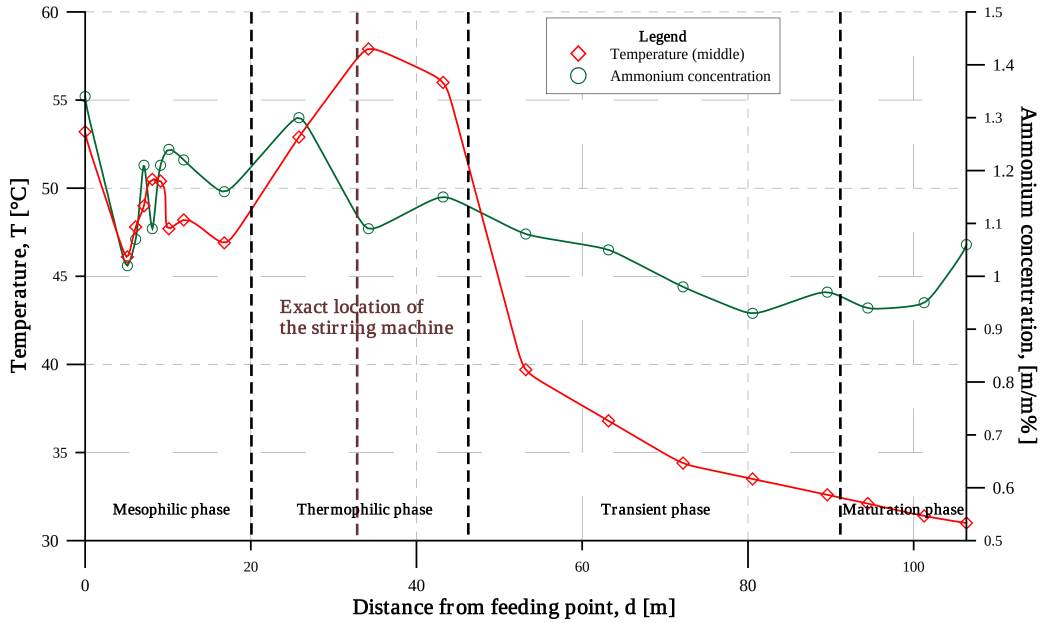

Figure 6. The measured temperatures and ammonium concentrations in the fermentation system (June 2019)

The mesophilic phase lasted for approximately 20 m in the oval channel, followed by the thermophilic phase (26 m), and a relatively long transient phase (46 m) according to the temperature measurements. At the end of the fermentation process (maturation phase) the initial ammonium concentration (1.34 m/m %) decreased by 29.1%. The significant correlation between the two parameters was also statistically proved (R^2=0.734; $p<0.05$).

The results of organic content and organic nitrogen content measurements can be seen in Figure 7. The organic content was in the range of 68.6 - 82.0 m/m %, while the organic nitrogen content represented 3.2 - 5.43 m/m % in the oval tank. In case of both parameters, the peak values were found near to the input point (sampling cross section 5). After reaching the maximum values, a rapid decrease can be seen on the curves in the following 35 meters. A strong linear correlation was found between organic content and organic nitrogen content (R^2=0.841; $p<0.05$).

The rates of different nitrogen forms were also examined during the composting processes (Figure 8). The predominance of organic nitrogen (73.32 - 83.15 %) was clearly observed in contrast to ammonium (16.74 - 26.4 %) within the nitrogen forms. The rate of nitrate was negligible and it varied in the range of 0.11 - 0.28 %.

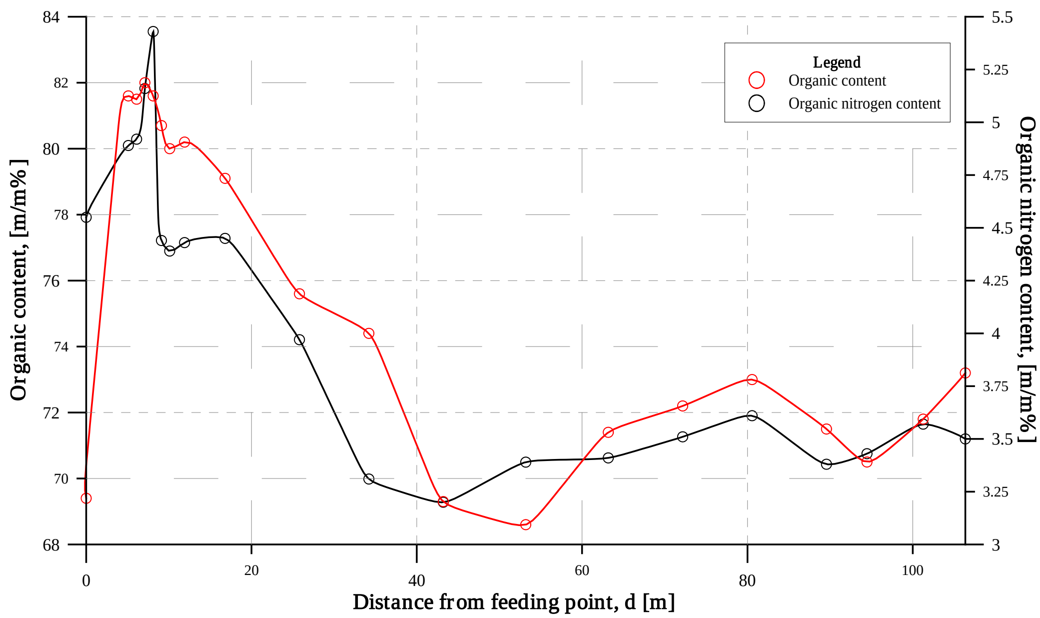

Figure 7. The measured organic contents and organic nitrogen contents in the fermentation system (June 2019)

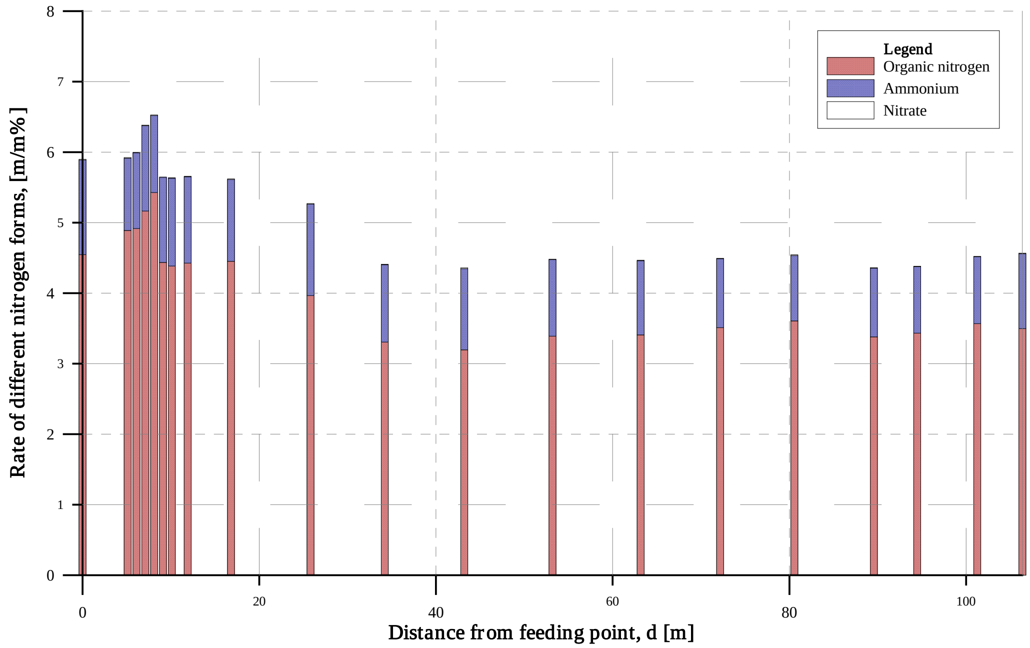

Figure 8. The rates of different nitrogen forms in the fermentation system (June 2019)

4. Conclusions

The performance of the oval tank fermentation system was studied by taking samples of poultry manure during a run and analyzing them for moisture content, dry matter content, and different nitrogen forms, such as organic nitrogen and inorganic forms. The temperature of the material during the fermentation was also monitored.

The two dimensional version of the Hydrus software was used for modelling the moisture and temperature distribution in the oval tank during the biodegradation processes. The results pointed out that the initial turning and mixing contributed to a high temperature and moisture content drop. It was found that the studied oval tank fermenter can be divided into two main zones considering the changing temperature and moisture content. In the first zone, where the rate of biodegradation was high, there was a heterogeneous temperature zone with continuously decreasing moisture content. The second zone was more homogenous in both temperature and moisture content. This stage represented the weak fermentation part of the technology and resulted in an elongated post fermentation section. The changes of temperature and moisture content along the tank fermenter were the same and there was a strong connection between them in the examined period.

Furthermore, statistically significant correlation was found between ammonium content and temperature as well as between organic matter content and organic nitrogen content. It was also concluded that the exact location of the MTCM system used for aeration has a high effect on the composting processes, thus on the quality parameters of the mature compost too.

The results pointed out that after the thermophilic phase there was sufficient time for composting. Therefore, this system can be used as an efficient treatment for chicken manure to decompose and obtain a valuable base organic fertilizer.

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Procena procesa kompostiranja u automatizovanom sistemu aerobne fermentacije na osnovu ključnih parametara

Tamás Magyar [#], Rebecca Mayes, Péter Tamás Nagy

Univerzitet u Debrecenu, Fakultet za poljoprivredne i prehrambene nauke i upravljanje životnom sredinom, Institut za upravljanje vodama i zaštita životne sredine, Mađarska

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Živinski stajnjak
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Kompostiranje
Model za distribuciju vlage i temperature
Ključni parametri

I Z V O D

Živinarska industrija (uzgajanje brojlera) se kontinuirano razvija u celom svetu, a samim tim raste i količina otpada nastalog u tim postrojenjima. Kao posledica gore navedenog, efikasnije pretvaranje živinskog stajnjaka u organsko đubrivo predstavlja ključni problem. Cilj ovog istraživanja je ispitati promene temperature i sadržaja vlage tokom kompostiranja živinskog stajnjaka u ovalnom rezervoaru za fermentaciju i napraviti model za procenu efikasnosti postupka biorazgradnje. Modeli distribucije vlage i temperature u ovalnom rezervoaru su kreirani u softveru Hydrus. Rezultati su pokazali da se ovalni rezervoar za fermentaciju može podeliti u dve glavne zone. U prvoj zoni, gde je stopa biorazgradnje bila relativno visoka, utvrđeno je postojanje heterogene temperaturne zone sa konstantnim opadanjem sadržaja vlage. Druga zona je bila homogenija u pogledu temperature i sadržaja vlage. Ova faza predstavlja slabu fermentaciju u okviru tehnologije i kao rezultat toga dolazi do stvaranja izduženog područja nakon što se postupak fermentacije završi. Osim toga, utvrđene su i statistički značajne korelacije između ključnih parametara kompostiranja, kao što je korelacija između sadržaja amonijuma i temperature i između sadržaja organske materije i organskog azota. Takođe je zaključeno da tačna lokacija mehaničkog sistema za okretanje i usitnjavanje stajnjaka (MTCM), koji se koristio za aeraciju, ima veliki uticaj na proces kompostiranja kao i na parametre kvaliteta zrelog komposta.