COMPOSTING OF EXCESS SLUDGE FROM THE WASTEWATER TREATMENT PLANT WITH THE GREEN WASTE OF HOPS

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Abstract
The Savinja Valley in Slovenia has several municipal wastewater treatment plants (capacity slightly above 200,000 PE) and areas sown with high-quality hops (about 1600 ha). Because of problems with waste sludge, and with green cuttings of hops in the season, we tried to find out a simplified method, how to remove as many degradable organic substances as possible and at the same time, to stabilise produced compost. We looked for the optimal ratio between waste sludge (WS) and green cut of hops (GC), and maximum removal of organic substances in composting. Several experiments were made to determine which WS: GC ratio is most suitable for the best mineralisation of present organic material. Occasionally we measured pH value and the concentration of organic matters in the composting pile. At the end of the experiments, we tested the product to pathogenic bacteria (Salmonella sp.).

Key words: Aerobic stabilisation, composting, excess activated sludge, green cut, hops, sanitation.

Introduction
Organic biodegradable waste from many sources, such as agricultural waste, kitchen waste, urban solid food waste or municipal solid waste, can be easily composted. Many factors can contribute to the quality of the compost product as different organic wastes have different concentrations of nutrients such as nitrogen, phosphorus and potassium, which are the common macronutrients present in fertilizers. Main parameters that can be affecting the composting process are temperature, pH, moisture and carbon-nutrient ratio. One of suitable organic compounds for composting is also digested activated sludge. Composted sludge from wastewater treatment plants can be used for different purposes, such as for commercial compost or landfill cover. Sludge has an appropriate composition for composting except moisture. That is why we must combine excess sludge with other organics such as sawdust, green waste, grass cutting or other bulking agents. Activated sludge is most often composted under aerobic conditions, where the following parameters are essential: aeration, moisture content, carbon-to-nitrogen ratio (C/N ratio), pH, temperature, nutrients and the physical structure of organic materials.

The primary process of composting is the humification in which organic matter converts into humus. Humus plays an essential role in nature because it keeps moisture in the soil and promotes better structure (micro-porousness) of the land. The formation of humic substances influences by compost additives, microbial activity, temperature, pH, C / N ratio, moisture content and oxygen content. Composting is carried out in three phases: the phase of degradation of organic matter due to chemical transformations in the composting process; the cooling period, where complex organic substances and the maturation phase degraded, where higher organisms make the compost ripen; and humus formation. For the first stage of composting, mesophilic microorganisms are required, whose intense aerobic metabolism causes rapidly increasing temperatures in composting.

Chroni et al. found that the ratio of carbon (C) to nitrogen (N), pH, dry matter content, as well as the concentration of oxygen (O₂) and carbon dioxide (CO₂) influence to the composting process. Most of the researched microbes demonstrate their highest concentrations towards the end of the thermophilic phase. After that, there is a decrease in microbial groups. The population of all mesophilic and thermophilic bacteria is increased at the thermophilic phase, followed by a decline.
in temperature. Therefore, the thermophilic phase has the most significant influence on the microbial sequence highest temperature level.

Hernández et al. found that volatile organic matter, as well as water-soluble carbon fractions, decreased during composting, indicating that less stable carbon fractions are mineralized during the process. Microbial activity, which is measured by microbial respiration, is also reduced by composting, which shows a more durable product - compost.

Bilitewski et al. states in the study that composting is an essential nutrient ratio in the composting mixture as it affects the effectiveness of the degradation of organic matter with microorganisms.

Rivas-Nichorzion et al. investigated the types of microorganisms that develop during composting in relaxed heat and the degradation of organic molecules. They found that psychrophilic organisms occur in the temperature range from 0 °C to 30 °C, mesophilic microorganisms in the range of 30 °C to 45 °C, and thermophilic microorganisms in the field of 45 °C to 70 °C. The change in temperature changes the abundance of microorganisms, e.g. when the number of thermophilic organisms decreases, the number of mesophilic bacteria and fungi increases.

Cukjati et al. found that the abundance and diversity of microorganisms influence the presence of oxygen in the composting process. The maximum biodegradation in the compost takes place in the range of 15 % of the oxygen content. This content contributes to the prevention of anaerobic processes within the compost mass.

Ngo with co-authors indicates the importance of moisture in the compost mixture. They found that the most suitable moisture content is 50-70 %, which occurs in the form of free liquid or the formation of metabolic moisture. The minimum humidity that still allows bacterial activity is 12-15 %. Considering that many organic substances are soluble in water, according to the authors, the best moisture will be 100 %. If the moisture content falls below 45 %, the composting process slows down, because microorganisms cannot function in such conditions, and consequently there is no degradation of organic matter.

Banegas et al. have composted two different types of waste sludge. They studied aerobic and anaerobic sludge with sawdust in varying proportions. They observed a significantly higher microbial activity in the aerobic pile of sludge than in the anaerobic one. Also, the levels of mineralization of organic particles were higher in the aerobic pile. The lowest thermophilic temperatures during composting were recorded when anaerobic sludge was mixed with sawdust 1:1, indicating the presence of toxic substances for microorganisms.

Grigatti et al. investigated the composting of three different mixtures consisting of waste from food processing, sludge from wastewater treatment plants and combinations of animals waste with the addition of a trimmed branch as a structural material. They found that all compost mixtures quickly reached the thermophilic temperature range (up to 70 °C) during the process.

Graves and Campbell state that the pH value, which is usually in the range of 5.5 to 9.0, plays an essential role in the composting process. They reported that the activity of the microorganisms is less effective at 5.5 or 9.0 than in the neutral pH 7. High pH, above 8.5 causes the conversion of nitrogen compounds into ammonia gas, which results in loss of nitrogen from compost. The loss of nitrogen in the form of ammonia in the atmosphere causes unpleasant odours and reduces the nutritive value of compost.

Sunar et al. studied the importance of sanitation during composting. The appropriate vegetative forms of human, animal and plant pathogenic organisms are destroyed by proper heat treatment. He concluded that for the execution of the process, the amount of compost should be exposed to
temperatures between 55 °C and 70 °C, in that the clearance and homogeneity of the material are ensured. The study was based on the review of the relationship between temperature and contact material involving activation of the pathogen (Salmonella spp.). The author showed that after eight days of composting, at the temperature of 66 °C, the sanitation of compost was achieved. The absence of Salmonella spp. was confirmed.

Materials and methods
For our experiments, we have prepared unique frames in which we put material for composting. Composting was performed using anaerobically treated, dewatered sludge from a municipal wastewater treatment plant. To the waste sludge, as a structural material, we added green cuttings of the hops. The tests were carried out in external weather conditions.

We carried out experiments with different types of piles, which differed in the composition of the compost mixture and the time of composting. All piles had 1 m³ combination of the activated sludge ratio: green cuttings of the hops (Figure 1).

![Figure 1: Pile consisting of waste activated sludge and green cuttings of hops](image)

During the composting process, we periodically rotated (turned around) the content of the pile and, if necessary, we moisturize the pile (Figure 2).

![Figure 2: Rotating of the composition of pile](image)
In the compost piles, the blowing air was drawn through the perforated tubes of 7 mm in diameter, which were located at the bottom of the pile (Figure 3).

![Figure 3: Scheme of composting pile with aeration](image)

**Methods**
The temperature of the pile was measured about 40 cm above the bottom of the pile with temperature meter Waterprof 8811 IP 66 (Figure 3). Dry matter in a pile was measured according to standard EN 14346:2006, loss of ignition was determined according to standard EN 15169:2007, bulk density was determined according to standard ISO 11272:2017, pH was measured by standard EN 12506:2004, and *Salmonella spp.* was determined according to standard CEN/TR 15215-3:2006.

Samples for analyses were taken from the homogenised material, after complete mixing (turning around) of a pile.

**Results and Discussion**
Composting was performed using waste anaerobically treated, dewatered sludge from a municipal wastewater treatment plant Kasaze (WS). To the waste sludge, as a structural material, we added green cuttings of the hops (GC). The tests were carried out in external weather conditions close to WWTP.

We carried out three experiments with different types of pile, which differed in the composition of the compost mixture and the time of composting. All piles had 1 m³ of volume and combination of the waste sludge: green cuttings of the hops (WS: GC).

**Experiment 1**
According to Fard we tried to prepare a mixture of WS: GC ratio 1:1 and found out that such a combination was too much liquid. That's why we decided on a ratio of 1: 1.5 (WS: GC), or 40 %: 60 % (weight ratio).

The pile the structure was: 61 % of organic compounds, 39 % of inorganic compounds; 26 % of dry matters, and bulking mass was 475 kg/m³.
We measured the air temperature and the temperature in a pile. We occasionally mixed the pile and took the sample for measuring of pH value and organic matters. The pile was aerated 15 min every hour. Composting took place for 100 days. Results are shown in Figure 4.

![Temperature graph](image)

**Figure 4**: Temperature in the pile and air temperature; vertical lines represent the time when we mixed the pile.

Results show that the temperature increased over time but did not occur in the thermophilic zone. Whenever we mixed (turned around) the pile, the temperature decreased. The leading causes of cooling were twofold: firstly, too frequent mixing (turning around) of the pile composition, and secondly, excessive aeration of the pile. Therefore, the temperature in a pile was stabilised after the 80th day.

Periodically we measured pH value and found out that pH was in normal range according to literature. The pH value was between 7.0 and 7.8 (Figure 4).

We periodically measured the concentration of organic matters in the compost pile (Figure 5).
We found that the level of organic matter decreased from 61% to 45% in 40 days, to 43% in 80 days, and 42.6% in 100 days, respectively. Total mineralisation was not sufficient according to literature\(^3\). We decided to change the operation conditions.

**Experiment 2**

Based on the results of the first experiment, we prepared the following composting technique:

- the mixture of WS: GC was 40%: 60% (weight),
- composition of the product: organic matter 67%, inorganic substance 33%, dry matter 31% and bulk density 420 kg / m\(^3\),
- aeration of the pile - 15 minutes two times a day,
- we turned around the pile less frequently.

From time to time, we mixed the pile and measured pH value.

Composting took place for 50 days. Results are shown in Figure 6.
The results show that the composting took place completely different than in experiment 1. After ten days, the thermophilic phase was reached, which means that the composting was done well (Figure 6). After about 20 days, the temperature in the pile stabilised and remained practically constant to the end of the experiment.

pH during the investigation was between 7.1 and 7.5.

Mineralization also took place much better than in experiment 1 (Figure 7).
The level of organic matter decreased from 67.0 % to 31.5 % in 17 days, and to 30.2 % in 50 days, respectively.

**Experiment 3**
To confirm the composting system, we prepared another experiment where the WS: GC ratio was changed. The parameters in a pile were as follows:
- the mixture of WS: GC was 35 %: 65 % (weight),
- composition of the product: organic matter 68 %, inorganic substance 32 %, dry matter 30 % and bulk density 410 kg/m³.
- aeration of the pile - 15 minutes two times a day.

Composting took place for 50 days. Results are shown in Figure 8.

![Figure 8: Temperature and pH values in a pile](image)

After ten days, the thermophilic phase was reached, which means that the composting was done well (Figure 8). Already after 15 days, the temperature in a pile stabilised and remained practically constant to the end of the experiment.

pH during the experiment was between 7.1 and 7.8.
Mineralization also took place in a similar way as in experiment 2 (Figure 9).
The level of organic matter decreased from 68.0 % to 34.8 % in 17 days, and to 33.0 % in 50 days, respectively.

**Conclusions**

It can be concluded that green cuttings of hops can be considered an excellent bulking agent for use with sewage sludges. Both weight proportions WS: GC (40 %: 60 % and 35 %: 65 %) seem to be suitable for strong mineralisation of mixture. However, the ratio 40 %: 60 % seems better for composting because we obtained better results for the mineralisation of the mixture in the compost pile. Starting concentration of organic compounds was 67 %, after 17 days was 31,5 %, and 30,2 % after 50 days, respectively. The composting time of 20 days in an open field (in the area of WWTP) under aerobic conditions followed by the maturation of 30 days can be suitable for decreasing of organic compounds, to the acceptable level and for sterilisation of the compost. The simplified method for composting can be appropriate for prospective application in industrial scale, where we should upgrade a system with suitable mechanisation and automation. At the end of the experiments, we tested the product to pathogenic bacteria and found out that in composted sludge *Salmonella sp.* was not present.

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References