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The influence of the C: N ratio on the composting rate

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Abstract

Sewage sludge was composted with the addition of straw and sawdust to modify the C: N ratio of dry matter. The experiment was conducted in closed and insulated bioreactors, at four C: N ratios: 9.2, 12.1, 17.0 and 26.4. The following parameters were measured during the composting process: temperature inside the bioreactor, aeration rate, ammonia and carbon dioxide emissions from the bioreactor. The composting process lasted 25 days. Temperature was measured after the end of composting, up to day 33 of the experiment. The measured parameters were used to calculate accumulated temperature and composting rate. The results indicate that the C:N ratio significantly influenced the temperature inside the bioreactor (the higher the C:N ratio, the higher the temperature and composting rate) as well as cumulative emissions of CO_2, H_2S and NH_3. The lowest cumulative gas emissions were noted in bioreactor R2 where the C: N ratio was very low at 12. Our results suggest that sewage sludge can be effectively composted with the addition of only 40% of straw / sawdust as bulking agents which increase substrate porosity and improve the C: N ratio. The substrate was effectively sanitized in all four bioreactors.

Keywords: *Composting; accumulated temperature; Ammonia; CO_2, CH_4 and H_2S emissions*

1. Introduction

Composting is a popular method of managing waste biomass from various production processes [1]. However, to date, natural composting has been used mainly in agriculture where the produced waste, such as plant material, is fed back into the production cycle as compost which constitutes a valuable and inexpensive natural fertilizer [2].

The management of non-agricultural biological waste, including sewage sludge, poses a significant challenge. Effective composting of sewage sludge is difficult for three reasons:

- Sewage sludge is characterized by an undesirable C:N ratio;
- Low porosity of the substrate impedes aeration;
- Sewage sludge has to be sanitized before it can be safely used as a fertilizer.

The influence of the C: N ratio on the composting process has been described by [3], and the effect of the aeration rate on composting has been discussed by [4]. The aeration rate in composted substrate, in particular in natural (non-mechanical) aeration systems, can be improved through the addition of bulking agents which improve the porosity of composted material [5]. The substrate is effectively sanitized when the temperature inside the composted prism exceeds 60 ℃ for minimum 3 days [6].

The following considerations play a very important role during composting:

- Substrate structure (porosity) and composition;
- Temperature inside the prism, as an indicator of the composting rate;
- Gas emissions, including greenhouse gas emissions-CO_2, H_2S, NH_3 and, occasionally, CH_4.

Gases are naturally released from the prism during composting [7], but gas emissions need to be controlled. The emissions of NH_3 and H_2S have to be minimized to reduce the adverse environmental

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impacts of composting (odor production) [8]. Lower NH_3 and CO_2 emissions are associated with lower nitrogen loss, higher content of nitrogen [9] and organic carbon [10] in the composted substrate, which significantly improves the fertilizing properties of the produced compost [11]. Accumulated temperature and cumulative gas emissions are indicative of the composting rate, and those parameters can be used to compare gas emissions from various substrates [12].

2. Materials and Methods

The aim of this study was to determine the influence of the C: N ratio on composting rate. The experimental design was described in detail by [13]. A diagram of the compost bioreactor is presented in Fig. 1.

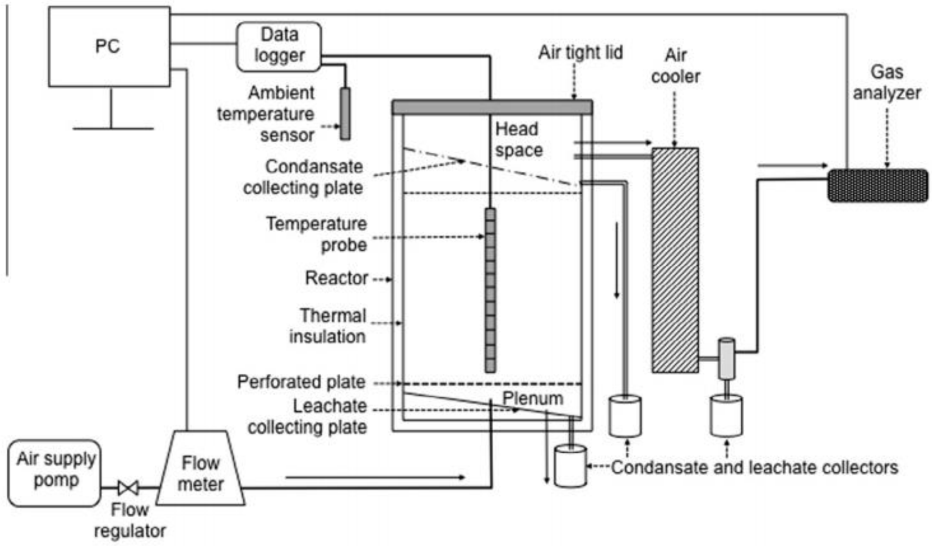

Fig. 1. Diagram of the compost bioreactor [13]

Closed bioreactors were insulated to minimize heat loss. The composted waste was sewage sludge combined with straw and sawdust in different proportions (Table 1). The composting process lasted 25 days in all bioreactors. Temperature was measured after the end of composting until the value of coefficient α_d reached zero.

All bioreactors were aerated. Aeration rates are presented in Fig. 2.

Table 1. Substrate composition in four experimental bioreactors.

Bioreactor	DM_75% - R1				DM _60% - R2			
	% DM	Dry weight	Fresh weight	C:N	% DM	Dry weight	Fresh weight	C:N
	%	kg	kg	--	%	kg	kg	--
Sewage sludge	75	8.35	60.2	9.2	60	7.6	50.2	12.1
Straw	5	0.6			5	0.6		
Sawdust	20	2.2			35	4.4		
Bioreactor	DM _45% - R3				DM _30% - R4			
Sewage sludge	45	6	52.2	17	30	5.6	71.1	26.4
Straw	5	0.6			5	0.9		
Sawdust	50	6.7			65	12.0		

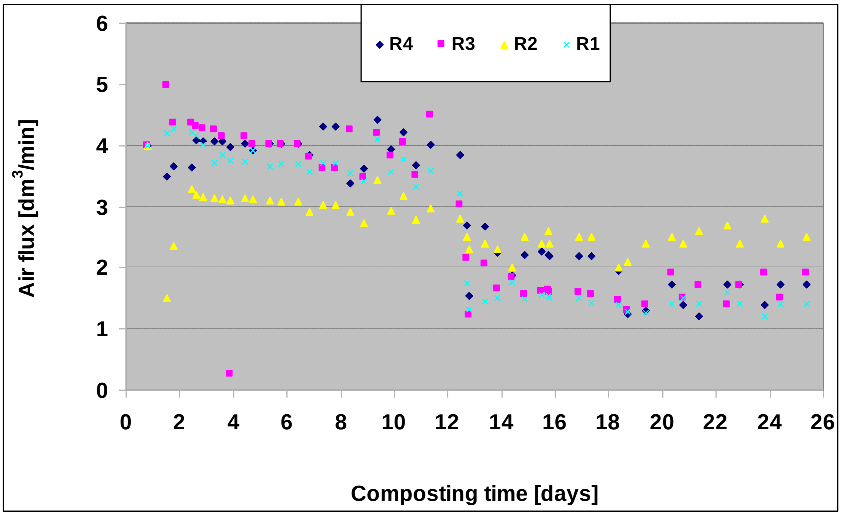

Fig. 2. Aeration rates in bioreactors.

Throughout the composting process, temperature inside the bioreactor was measured at 5 points, and the results were used to calculate the average temperature. The average temperatures during composting are presented in Fig. 3. In each bioreactor, the entire contents were stirred up at the beginning of the experiment and on composting day 13. The data in Fig. 3 point to an instantaneous increase in the composting rate after the second stirring.

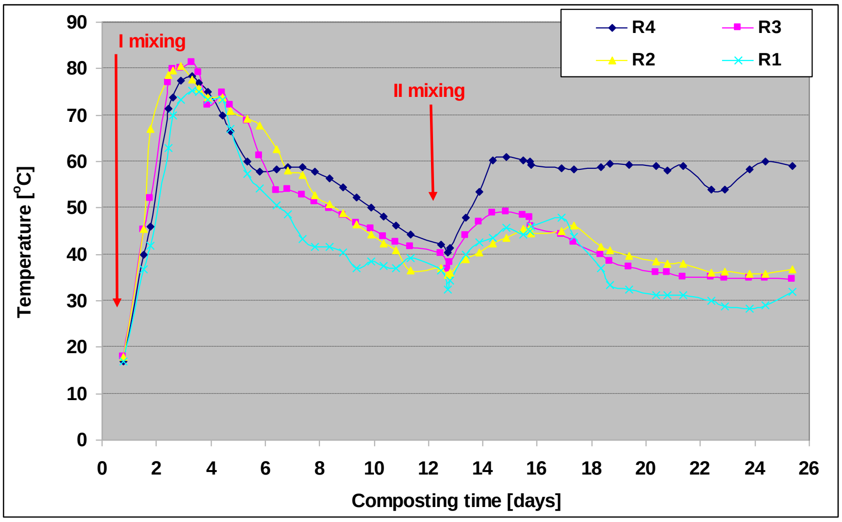

Fig. 3. Average temperatures in 4 bioreactors.

Temperature was also measured outside the bioreactors. The content of CO_2, O_2, NH_3, H_2S and CH_4 in the exhaust air outlet was measured in every reactor throughout the experiment. Accumulated temperature was calculated according to formula 1.

$$T_C = \int_0^t T_a \Delta t \qquad (1)$$

where:

T_C – the accumulated temperature [°C];
t – composting time [h];
T_a – the average temperature inside the bioreactor [°C];

The rate of the composting process was calculated with the use of formula 2.

$$\alpha_{di} = f'(T_{ci}) \tag{2}$$

where:
α_{di} - Composting rate (dynamic coefficient α_d) on i'day;
T_{ci} – the value of accumulated temperature on i'day [°C];

3. Results

Accumulated temperature and cumulative value emissions of NH_3, CO_2 and H_2S are presented in Fig. 4-Fig. 7. Methane was not released from any bioreactor during the entire composting process.

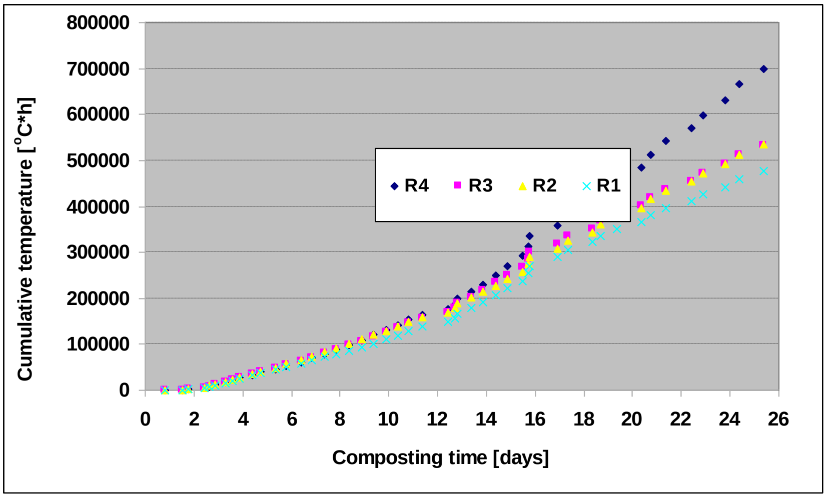

Fig. 4. Accumulated temperature.

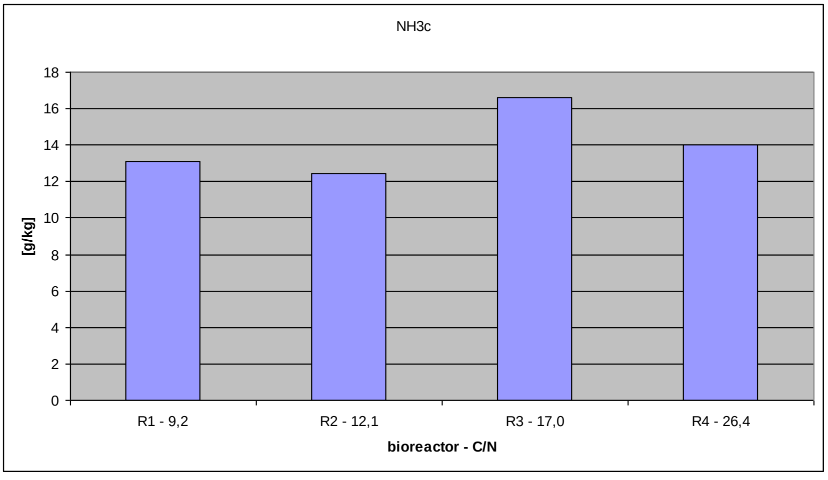

Fig. 5. Value of cumulative NH_3 emissions.

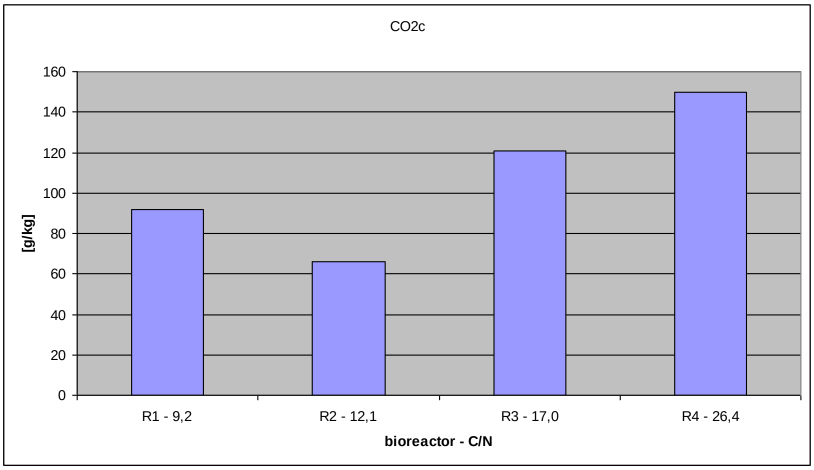

Fig. 6. Value of cumulative CO_2 emissions.

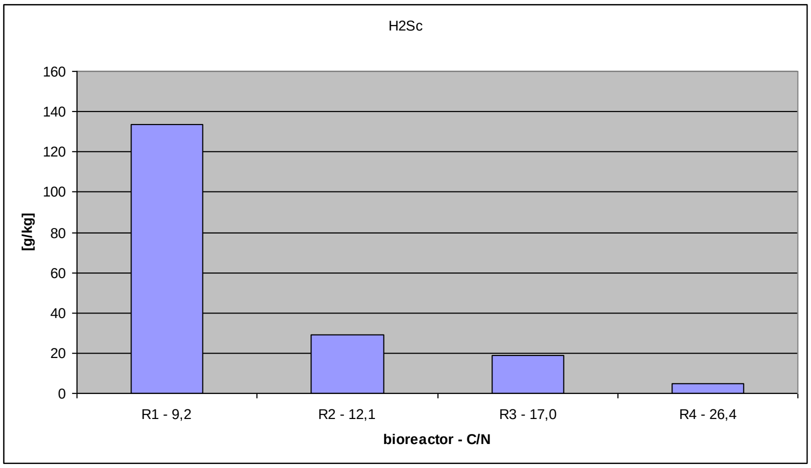

Fig. 7. Value of cumulative H_2S emissions.

Changes in the composting rate (coefficient α_d) on each day of the composting process are presented in Fig. 8.

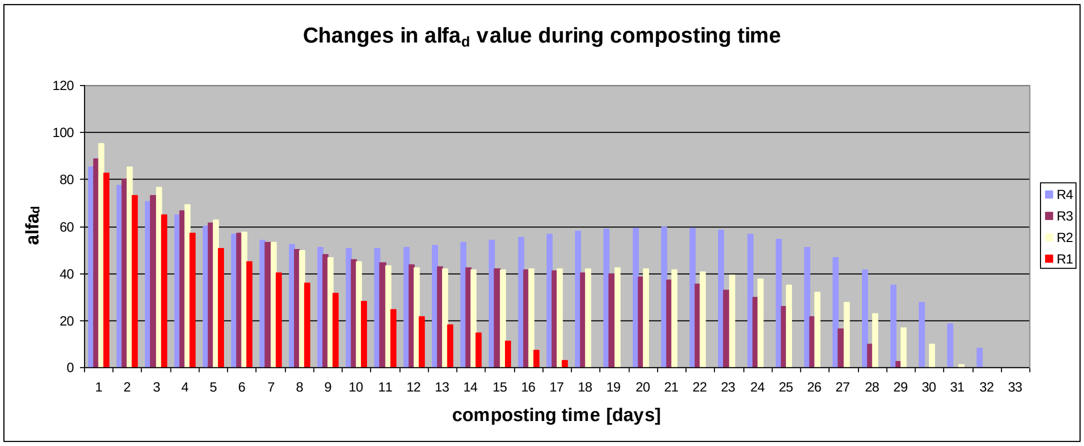

Fig. 8. Composting rate (coefficient α_d) on each day of the composting process.

The measured parameters and the calculated data indicate that:

- The observed changes in temperature were similar in all 4 bioreactors, but high temperature was maintained for the longest time in reactor R4 with the highest C: N ratio. The diagram of accumulated temperature indicates that the highest temperature was achieved in R4 on day 26, whereas the lowest temperature was noted in R1 with the lowest C: N ratio. The analyzed substrates were effectively sanitized (temperature higher than 60 ℃ for more than 3 days) in all bioreactors;
- Cumulative gas emissions in g/kg of substrate:
- Cumulative NH_3 emissions were highest in R3 and lowest in R2. In all bioreactors, ammonia emissions ceased to increase on composting day 18;
- Cumulative CO_2 emissions were highest in R4 and lowest in R2;
- In all bioreactors, H_2S emissions ended on day 5. Cumulative H_2S emissions were significantly highest in R1 (more than 130 g/kg), similar in R2 and R3 (around 20 g/kg), and lowest in R4 (below 10 g/kg);
- The observed changes in the value of coefficient α_d indicate that the first stage of composting ended on day 18 in R1, but on day 32 in R4. The rate of composting was higher in R2 than in R3 which was characterized by a higher C:N ratio.

4. Conclusions

- An increase in the C: N ratio is associated with an increase in accumulated temperature, prolonged composting and a higher composting rate.
- Cumulative NH_3 emissions were similar in all four bioreactors (12.1-16.5 g/kg), and they were not influenced by the C: N ratio.
- The observed changes in cumulative CO_2 emissions were highly correlated with the changes in accumulated temperature. However, the lowest cumulative CO_2 emissions were noted in R2.
- Cumulative emissions of odorous gases during the composting process were highest in R1 which was characterized by the lowest C: N ratio, the highest proportion of sewage sludge, the highest substrate density and the lowest aeration rate. In the remaining bioreactors, cumulative emissions of odorous gases were at a similar level.
- The composting process in bioreactor R2 (60% of sewage sludge in dry matter) had the least detrimental impact on the environment. Bioreactor R2 was characterized by a very high composting rate, a very high accumulated temperature, the lowest cumulative emissions of NH_3 and CO_2 (in g/kg), and a low C: N ratio of 12. Bioreactor R2 delivered the optimal conditions for composting sewage sludge by reducing the proportions of bulking agents (straw/sawdust) required for effective composting.

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