# Carbon dioxide and methane emissions during composting and vermicomposting of sewage sludge under the effect of different proportions of straw pellets

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**Abstract**: The aim of this study was to evaluate the carbon dioxide ($CO_2$) and methane ($CH_4$) emissions during composting and vermicomposting of sewage sludge under the effect of different proportions of straw pellets. Four treatments, including a control with three replicates, were designed to mix the initial sewage sludge with varying rates of pelletized wheat straw (0, 25%, 50% and 75% (w/w)). Over a 60-day period, vermicomposting with *Eisenia Andrei* treatments and composting were carried out. The results indicated that both composting and vermicomposting produce a significant ($p<0.001$) amount of $CO_2$ and $CH_4$ emissions from all treatments. Vermicomposting significantly reduced $CH_4$ emissions by 18%, 34%, and 38% and increased $CO_2$ emissions by 75%, 64%, and 89% for the treatments containing 25%, 50%, and 75% straw pellets respectively, compared to composting. However, $CO_2$ emissions decreased and $CH_4$ emissions increased during composting compared to vermicomposting. As a result of this finding, both composting and vermicomposting processes are recommended as an additive of pelletized wheat straw, depending on the target gas to be reduced.

**Keywords**: Thermophilic; earthworms; biosolids; greenhouse gases; composting

## 1. Introduction

Sewage sludge is the residual, semi-solid material that is produced as a by-product during the process of biological wastewater treatment or municipal waste-water. The large amounts produced in the recent decades represent an increasing, and improper disposal or management has resulted in a serious environmental pollution due to the putrescible nature of sewage sludge and waste management challenges [1]. The improper management of sewage sludge will cause secondary pollution such as pathogenic microbes, organic micro-pollutants, and toxic heavy metals. Therefore, sustainable and eco-friendly sewage sludge management is urgently required [2]. According to He et al. [3], currently, the annual production of sewage sludge in the European Union reaches over 10.96 million tons per year and 40 million tons in China [4]. This amount is increasing due to expedited urbanization and the increasing capacity of municipal wastewater treatment facilities [5].

Composting and vermicomposting are effective techniques and low cost methods to manage and reuse sewage sludge due to its safe and stable products that could be used as an organic fertilizer or soil conditioner for farming [6]. However, harmful gases, such as ammonia ($NH_3$), nitrous oxide ($N_2O$), and methane ($CH_4$), are emitted due to the mismanagement of sewage sludge. $CH_4$ and $CO_2$ are two of the most important greenhouse gases in the atmosphere. $CH_4$ is radiatively stronger than $CO_2$ on a mass basis and it is reported that the current global warming potential of $CH_4$ is 25 times higher than that of $CO_2$ over a 100 year period [7]. Most previous studies on composting and vermicomposting have focused on the feasibility of different organic wastes, the factors affecting the growth and reproduction rate of earthworms, as well as the quality of compost and vermicomposts [8]. However, little is known about the emissions of $CO_2$ and $CH_4$ during composting and vermicomposting of sewage sludge. Therefore, the aim of this study was to evaluate the carbon dioxide ($CO_2$) and methane ($CH_4$) emissions during composting and vermicomposting of sewage sludge under the effect of different proportions of straw pellets.

## 2. Materials and methods

### *2.1. Raw materials*

The experiment was carried out at the experimental station of the Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Science, Prague, in Cerveny Ujezd. The sewage sludge used in the experiments was collected from the waste-water treatment plant in the Czech Republic. Dried pelletized wheat straw was provided by Granofyt Ltd Company with a diameter of 10mm. The selected chemical properties of sewage sludge and pelletized wheat straw are listed in (Table 1) and for the treatments at the initial days (day-0) in (Table 2). *Eisenia Andrei* was used in this study for vermicomposting.

Table 1. Selected chemical properties of initial materials

| Parameters | Sewage Sludge(SS) | Pelletized wheat Straw(PWS) |
|---|---|---|
| pH-$H_2O$ | 6.99±0.03 | 8.30±0.52 |
| EC(mS/cm) | 0.617±0.11 | 0.680±0.07 |
| TOC (%) | 32.95±0.26 | 42.6±0.36 |
| TN (%) | 5.36±0.03 | 0.8±0.12 |
| C:N | 6.15±0.04 | 53.2±7.60 |

Table 2. Selected chemical properties of treatments at the initial (day-0)

| Treatments | pH-$H_2O$ | EC(mS/cm) | TOC (%) | TN (%) | C: N |
|---|---|---|---|---|---|
| T1 | 6.99±0.03 | 0.617±0.11 | 32.9±0.26 | 5.36±0.03 | 6.14±0.04 |
| T2 | 7.32±0.11 | 0.633±0.08 | 35.36±0.23 | 1.98±0.21 | 18.03±1.92 |
| T3 | 7.64±0.25 | 0.649±0.06 | 37.77±0.24 | 1.34±0.07 | 28.17±1.43 |
| T4 | 7.97±0.38 | 0.664±0.05 | 40.18±0.29 | 1.05±0.05 | 38.36±2.03 |

Values indicate mean ± standard deviation (n =3)

### *2.2.Experimental design*

The experiment included four treatments with three replications: (T1) 100% sewage sludge (control), (T2) 75% sewage sludge (SS) + 25% pelletized wheat straw (PWS), (T3) 50% sewage sludge (SS) + 50% pelletized wheat straw (PWS), (T4) 25% sewage sludge (SS) + 75% pelletized wheat straw (PWS) (w/w). The pelletized wheat straw was applied on a wet weight basis. In all the treatments, the substrate was homogenized and transferred to fermenter barrels for 60 days for composting and also the same treatments were transferred to worm-bins for vermicomposting. Each worm-bin received 377(57.4g) pieces of adult earthworms (*Eisenia andrei*). The moisture level of the material was maintained at about 70-80% of wet mass throughout the vermicomposting stage by spraying the surface with water at two-day intervals.

### *2.3. Measurements of carbon dioxide($CO_2$) and methane($CH_4$) during composting and vermicomposting*

Concentrations of $CO_2$ and $CH_4$ during both composting and vermicomposting were measured by a closed chamber technique. A tight-fitting lid with two ports for headspace gas sampling and air temperature measurement was used to connect one side tip of plastic tube to closed barrels for composting and a worm bin for vermicomposting, and the other side tip of plastic tube was connected with instruments during data recording. Measurements were done twice per day within 12hour intervals for 60 days by using the Gasko Infrared Gas Analyzer [9].

To calculate the cumulative $CO_2$, and $CH_4$ emissions, we summed daily values to get the total cumulative gas emissions during the whole experimental period [9].

$$A_{t(ab)} = \frac{(t_b - t_a).(F_{ta} + F_{tb})}{2} \quad (1)$$

Where $A_{t(ab)}$ is the cumulative emission between the measurement days (between ta and $t_b$), ta and $t_b$ are the measurement dates, and $F_{ta}$ and $F_{tb}$ are the gas fluxes on the two measurement dates. Therefore, the total cumulative emissions were calculated as the sum of cumulative emissions on each day using Equation (2):

$$Total\ cumulative\ emission = \sum A_{t(ab)} \quad (2)$$

### *2.4.Analysis of total carbon (TOC), total nitrogen (TN), pH, and EC*

The samples were taken for determination of TOC, TN, pH and EC, using standard methods. pH and electrical conductivity (EC) were measured in distilled water at 1:5(w/v). The values of total carbon (TOC) and total nitrogen (TN) were acquired with an elemental analyzer (Elemental Vario EL, German).

### *2.5. Statistical analyses*

The statistical analyses were carried out using the R version 4.0.2 statis tical package. ANOVA was used to test the significant sources of variation , and the following Tukey HSD test was used to compare the treatment me ans if the factors' effect was significant at $P < 0.05$. Two-way analysis of va riance (ANOVA) was performed to analyse the significant differences bet ween treatment and composting process methods.

## 3. Results and Discussions

### *3.1.Temperature during composting*

The temperature in each treatment reached its maximum during the composting process, with the significant differences between treatments (Figure 1). Variations in the temperature were the result of mixing with different percentages of pelletized wheat straw. The temperature of two treatments (T3 and T4) rapidly reached the thermophilic stage (>$50^0$C) on days 3 and 2 respectively. T4 reached the maximum thermophilic phase of 65.5°C in four days and 57.4°C for T3. The thermophilic phase lasted for 14 days in T4, and 10 days in T3. The maximum temperature for the remaining treatments was 37.6°C for T2 and 29.55°C for T1, temperatures gradually declining until the end of the experiments. Thus, the addition of pelletized wheat straw resulted in more intensive decomposition in the thermophilic phase, but in the cooling phase, the degradation process resulted in less heat in these mixtures due to the depletion of easily degradable organic compounds [10]). T1 (control) and T2 (25%PWS) delayed reaching the thermophilic stage and had no thermophilic phase at all, and the maximum temperature was $37.6^0$C for T2 and $29.55^0$C for control and lasted to maturity within the mesophilic temperatures. This might be due to the high moisture in these treatments.

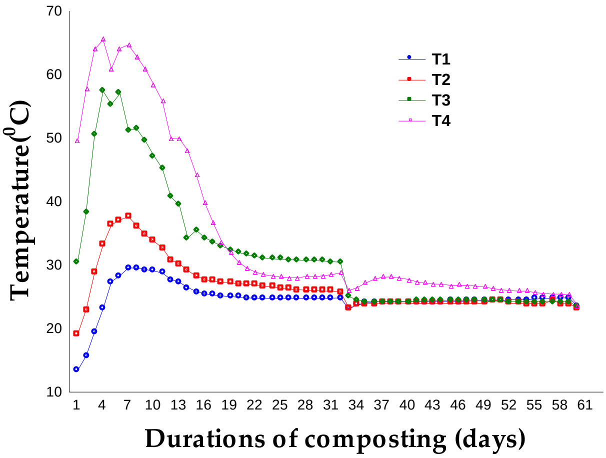


Figure 1. Evolution of temperatures during composting processes

### *3.2.pH and EC*

The pH of final compost and vermicompost for all treatments are showed in (Table 3). The proportions of pelletized wheat straw in the mixtures resulted in lower pH values during vermicomposting and this is probably due to the high content of organic acids (e.g. Succinic and Maleic acid) and directly proportional to the amount of straw in the treatments[11]. The pH of the compost (T1, T2, T3, and T4) was higher than vermicompost. However, the pH in vermicompost has decreased significantly ($p<0.05$). The similar pH behavior during vermicomposting of sewage sludge, crop straw, municipal solid waste, and livestock manure was also reported by other researchers [11]. The release of low molecular weight organic acids from organic decomposition and the increase in nitrification could decrease the pH during vermicomposting [12]. A decrease in pH during vermicomposting of different feeding materials has been reported [13, 14]. The lower pH of vermicompost might indicate that a more intense decomposition reaction is undergone during vermicomposting than in composting.

Table 3. Selected chemical properties of end product compost and vermicompost

| Processes | Treatments | pH-$H_2O$ | EC(mS/cm) | TOC (%) | TN (%) | C:N |
|---|---|---|---|---|---|---|
| C | T1 | 8.43±0.12 | 1.90±0.17 | 29.52±0.73 | 4.55±0.14 | 6.50±0.04 |
| | T2 | 8.32±0.09 | 1.43±0.09 | 32.43±0.79 | 3.69±0.03 | 8.84±0.32 |
| | T3 | 8.35±0.08 | 1.94±0.14 | 34.45±1.53 | 3.27±0.05 | 10.57±0.65 |
| | T4 | 8.01±0.06 | 0.80±0.06 | 37.95±0.02 | 2.76±0.15 | 13.88±0.80 |
| VC | T1 | 6.66±1.16 | 0.644±0.04 | 28.43±0.32 | 4.22±0.20 | 6.77±0.26 |
| | T2 | 6.47±1.5 | 1.186±0.22 | 31.96±0.89 | 3.58±0.04 | 8.94±0.35 |
| | T3 | 6.50±0.14 | 0.802±0.39 | 34.38±1.13 | 2.95±0.15 | 11.72±0.93 |
| | T4 | 6.65±0.31 | 1.21±0.12 | 35.32±0.37 | 3.08±0.06 | 12.15±0.32 |

C=composting, VC= vermicomposting, values indicate mean ± standard deviation (n =3),

The EC value was higher in compost than in vermicompost made from the same raw material and treatments (Table 3). The EC gradually increased in all of the treatments, which could be explained by the release of bonded elements during earthworm digestion [15, 16], and the release of minerals during the decomposition of organic matter in the form of cations in the vermicompost [17]. The final EC was within the recommended limit of 2dS/m [18] for all the treatments, which indicates an ideal vermicompost/compost for application to plants. The increased EC during the period of vermicomposting processes is in consistency with that of earlier workers [19, 20], which was probably due to the degradation of organic matter releasing minerals such as exchangeable Ca, Mg, K, and P in the available forms, that is, in the form of cations in the vermicompost and compost [17].

## *3.3. Emissions of $CO_2$ and $CH_4$ during composting and vermicomposting*

### *3.3.1. Carbon dioxide ($CO_2$)*

The $CO_2$ emissions increased at the beginning of composting and vermicomposting (Figure 2a, c) because of rapid degradation of easily degradable organic matter and thereafter gradually decreased until the end of composting/vermicomposting. This finding reveals the findings reported by Awasthi et al. [21] and Meng et al. [6] during the composting of the sewage sludge. During the first 13 days, the $CO_2$ emissions in control (T1) were higher than the other treatments (T2, T3, and T4) during composting. But, the $CO_2$ emissions in this treatment T1 is lower during vermicomposting. This result was possible because the earthworms inhibited microbial activity and reduced the readily available OM [22].Significant differences were found between the four treatments and the composting/vermicomposting process (P <0.001). These findings indicate that pelletized wheat straw may be lost in the inhibition after the thermophilic stage, most likely due to self-degradation at high temperature [23]. The temperature and pH of T1, T2, T3, and T4 also support this conclusion. A sharp drop in $CO_2$ emissions on day 14 and a small peak on day 20 appeared in all treatments (Figure 2a).

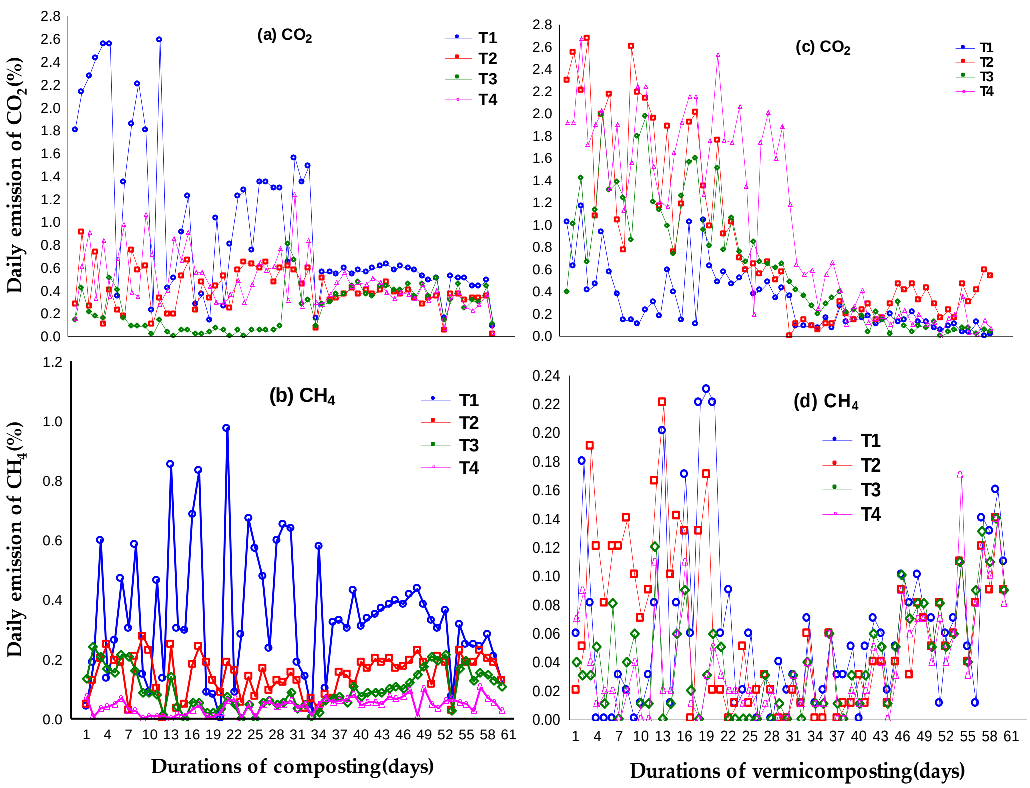


Figure 2. Daily emissions of $CO_2$ and Methane $CH_4$ during composting (a, b) and vermicomposting(c, d)

This observation could be attributed to the anaerobic environment caused by the strong degradation of OM during the first 14 days. The subsequent turn on day 10 destroyed the anaerobic conditions. Similar results were also reported in previous studies [21] for sewage sludge composting.

### 3.3.2. *Methane ($CH_4$)*

$CH_4$ from all treatments during the composting and vermicomposting processes is displayed in (Figure 2b, d). The results of this study showed that $CH_4$ concentrations for all treatments peaked relatively early in both composting and vermicomposting processes within 1-3 weeks ,after which emission rates gradually declined until the end of the experiment. Therefore, it could also be assumed that the $CH_4$ emissions should also be the highest during the start of the process. Several researchers reported similar findings, namely that the highest levels of $CH_4$ emissions occurred at the start of the composting and vermicomposting processes [24]. $CH_4$, a major GHG generated during composting and vermicomposting, is a significant contributor to global warming. The production of $CH_4$ is attributed to methanogen deoxidization of $CO_2/H_2$ and acetic acid under low oxygen conditions [25].

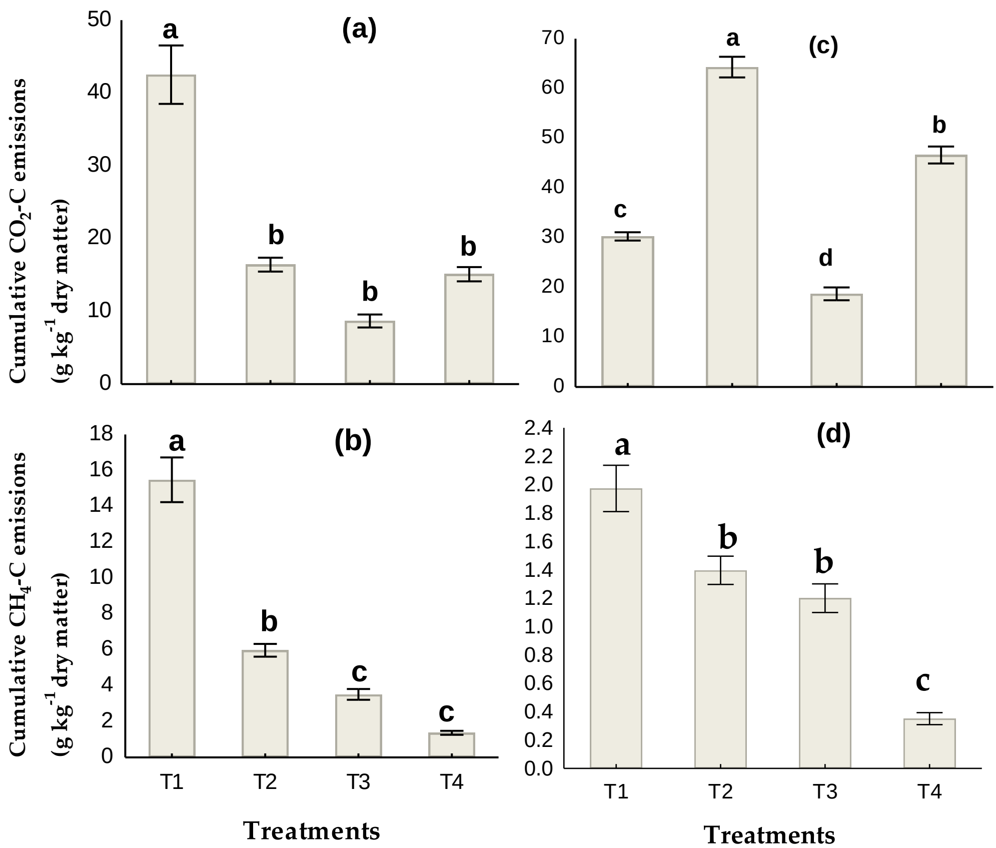


Figure 3. Total cumulative emissions of $CO_2$-C (a), $CH_4$-C (b) after 60 days of composting, $CO_2$-C(c), CH4-C (d) during vermicomposting. Bars indicate the standard error of the means (n=3). Different letters indicate significant differences among the treatments (*p<0.05*)

Thereafter, as an organic matter (OM) decomposed and oxygen was replenished through turning, the $CH_4$ emissions of all treatments declined sharply and remained at a low level during the maturation phase of composting and vermicomposting. The pattern of $CH_4$ emissions observed resembles the patterns reported by Ma et al. [26] and Wang et al. [27]. Since microorganisms can rapidly degrade organics in the thermophilic phase, a dramatic reduction in $O_2$ levels can be observed in the compost [28]. In all treatments, the emission of $CH_4$ is higher during composting than vermicomposting and the higher results are measured in the control area.

Total cumulative $CO_2$ differed by composting method ($P<0.001$), as did their interaction ($P<0.001$) (Figure 3). Vermicomposting increased total cumulative $CO_2$ emissions when compared with thermophilic composting. Composting had an effect on total cumulative $CH_4$ emissions ($P<0.001$). Vermicomposting decreased $CH_4$ emissions by 74.5% from a high proportion of pelletize wheat straw T4 compared with thermophilic composting.

### *3.4.Total Organic Carbon(TOC), Total Nitrogen(TN) and C: N ratio*

The TOC, TN and C: N ratio content for all treatments is presented in (Table 3). It can be seen that the TOC and C: N contents decreased in both compost and vermicompost as compared with initial treatments. However, the TN content increased in both compost and vermicompost. The increase in TN content was caused by the loss of ammonia volatilization at relatively high temperatures and a pH that was not suitable for nitrification and denitrification [29]. Zhang et al. [30] attributed the increase in TN during vermicomposting of sludge and the increase was due to the activity of worms. C: N ratio for all treatments decreased with both composting and vermicomposting processes. The C: N ratio indicates the maturity of compost/vermicompost since it reflects stabilization and mineralization rates during vermicomposting [31]. Our results are corroborated by previous studies by [32] who reported up to 50.86% and 48.8% reduction in C: N ratio during vermicomposting of cow dung, and cow dung with vegetable waste, respectively. The final C: N ratio recorded for all the treatments was within the recommended value for soil applications <20 [33].

## 4. Conclusions

The composting and vermicomposting processes of sewage sludge emitted a considerable amount of $CH_4$ and $CO_2$, the main environmental threat to global climate change. The highest values were at the beginning of the experiment and gradually decreased. The emission of $CH_4$ and $CO_2$ during composting and vermicomposting is linked to the fate of C present in the waste substrate. Vermicomposting reduces $CH_4$ emissions and accelerates the decomposition process. The addition of different proportions of pelletized wheat straw increases $CO_2$ and $CH_4$ emissions during composting. Vermicomposting increases $CO_2$ emissions, implying that vermicompost is at a more advanced stage of decomposition than thermophilic compost. From this finding, as an additive of pelletized wheat straw, both composting and vermicomposting processes are recommended depending on the target gas to be reduced.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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