Agronomy Research **19**(X), xxx–ccc, 2021
https://doi.org/10.15159/AR.21.116

Concentrations of CO_2 from composting under different treatments

I. Karandušovská[1], P. Hlinka[2], D. Páleš[3] and T. Szabóová[1]

[1]Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Building Equipment and Technology Safety, Tr.A. Hlinku 2, SK94976 Nitra, Slovakia
[2]Local Union of Ponitrie villages for separation and management of waste, Korytovská 20, SK95141 Lužianky, Slovakia
[3]Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Machine Design, Tr.A. Hlinku 2, SK 94976 Nitra, Slovakia
[*]Correspondence: ingrid.karandusovska@uniag.sk

Received: January 28th, 2021; Accepted: July 7th, 2021; Published: July 21st, 2021

Abstract. The aim of this study was to analyse the production of CO_2 concentrations in relation to the composting technology used. Three loose piles of bio-waste (V1, V2, V3) were created with the same volume. V1 reference pile was without any treatment. The biological preparation containing probiotic bacteria was added to the pile V2. The pile V3 was treated once a week by turning and watering. The degassing shafts were installed in each pile and the Multigas Monitor 1312 gas analyser with the Multipoint Sampler 1309 were used to measure of gas concentrations during the degradation process. Continuous 24-hour measurements of carbon dioxide concentrations from each pile were performed in the first, fourth, and seventh week of the degradation process to compare the amount of concentrations between piles in those weeks. At the beginning of the process, there were no significant differences in the production of CO_2 concentrations from the monitored piles V1, V2 and V3. In the fourth week, significantly higher values of CO_2 concentrations were recorded from the pile V3 ($P < 0.05$), which was turned and irrigated, than from V1 and V2. At week 7, significant differences were found between all treatments at the significance level ($P < 0.05$), with the highest values from the V3 pile. It has been shown that turning and humidifying results in the highest release of CO_2 into the air, but in a more rapid decomposition of the microorganisms, that reducing the time required to achieve a stable compost product and increasing the efficiency of the composting plant.

Key words: composting technology, carbon dioxide in compost, compost properties, environmental impacts, compost moisture.

INTRODUCTION

The increasing concern with greenhouse gas emissions and nutrients cycling creates a need for cost-effective, practical and environmentally sensible biowaste management strategies (Weidner et al., 2020). One of the easiest ways to treat biodegradable waste is composting. Plant residue material produced compost is an organic fertilizer source and it is commonly used for soil amendments (Akpinar et al., 2019). Improved soil structure associated with the application of organic substances can help reduce water irrigation requirements during droughts and increase soil moisture retention potential (Eden, 2017). Although the benefits of composting are evident, greenhouse gases can be generated and emitted to the atmosphere during this process, contributing to global warming by producing methane (Sánchez, 2015). The importance of gaseous emissions and odor nuisances from composting plants were reported by several researchers (Nasini et al., 2016; Arriaga et al., 2017). Dhamodharan et al. (2019) have reported the intensity of gas emissions from the composting process depends on three major components, that including the feedstock materials, the composting methodology adopted and the application of final compost. These emissions could be severe if the process is not well operated with proper aeration conditions and with the final compost, when is applied to the soil. However, the proper maintenance would majorly reduce the gas emissions. Previous studies have confirmed that composting reduces, by more than 30%, the volume of organic materials ending up in already overcrowded landfill sites (Hernández-Gómez et al., 2020) and converts waste into a hygienic and valuable product (Asadu et al., 2019; Zhang et al., 2019). It is an effective strategy in terms of diverting organic solid waste from landfills and improving the heating value of feedstock in the event of energy recovery (Vaverková et al., 2020). The waste from animal production, livestock excrements, residues of various crops can be used as a starting material for biogas production (Kažimírová et al., 2018) which is understood as a source of energy with zero carbon dioxide (CO_2) emissions into the atmosphere (Krištof & Gaduš, 2018). In the present study, the objective was to analyse the CO_2 production in relation to the composting technology used.

MATERIALS AND METHODS

Preparation of composting piles and measurement of CO_2 concentrations

An experiment to monitor carbon dioxide concentrations during the composting process was carried out in the summer period from 10th June to 2nd August 2019. The different organic raw materials (food bio-waste, green waste, garden wastes, tree clippings) were blended in certain ratios and mixed. Three loose piles of bio-waste (V1, V2, V3) were created at once and with the same volume (50 m^3). In each pile, there was a different technological process of processing waste into compost. The bio-waste in the reference pile V1 was untreated. In the second pile V2, a biological preparation was used to accelerate the degradation process containing probiotic bacteria, namely probiotic cultures of lactic fermentation (Bacillus subtilis var natto, Bifidobacterium animals, Bifidobacterium bifidum, Bifidobacterium longum, Lactobacillus acidophilus ...), yeasts (Saccharomyces cerevisiae) and organic sugar molasses. The dose was applied in a volume of 2 L m^{-3} mixed in 20 liter of water. The V3 pile was treated once a week by turning and watering. The first turning and watering was performed on the fourth day after the pile was founded. The Multigas Monitor 1312 gas analyser, together with the Multipoint Sampler 1309 (Innova, Denmark) were used to measure gas concentrations. The measurement system is based on Photoacoustic Infrared Detection, which delivers the ability to measure virtually any gas that absorbs in the infrared spectrum. These devices were placed in a separate isolated room with a constant temperature in the range of 10–20 °C. The degassing shafts were installed in each pile, which served as places for measuring the concentrations of CO_2. The PTFE sampling intake tube was introduced to the measuring points (each degassing shaft to divert landfill gas with the average volume flow 18 $m^3 h^{-1}$) from where the air samples were delivered to the Multipoint sampler and analyser. Continuous 24-hour measurements of carbon dioxide concentrations from each pile were performed always one day in the first, fourth, and seventh weeks of the degradation process to compare the concentrations of CO_2 between piles in those weeks.

Measuring points:

V1 – measurement in a pile without any treatment

V2 – measurement in a pile with addition of the biological preparation

V3 – measurement in a pile with optimization of process by turning and watering.

We hypothesized that there is no significant difference in CO_2 concentrations depending on the biowaste treatment technology used during the degradation process.

Physical-chemical properties

During the experiment, the temperature inside each pile was monitored manually every day. The Pfeuffer GT 1 needle thermometer was used to measure compost temperature. The average temperature was determined by taking three measurements at the left, middle, and right side in each pile at 30, 60 and 90 cm depths.

Determination of the compost moisture, pH and C/N nutrient ratio were performed in a certified laboratory. Samples were collected from the left, middle, and right side of each pile at 30, 60 and 90 cm depths. These samples were combined and mixed into one composite sample. The composite samples were collected from each pile at day 7, 28 and 49.

Determination of the weight of the final products

At the end of the composting process, the piles were sieved and weighed to examine the efficiency of each composting process. A Pezzolato drum sorter with a mesh size of 40 mm was used for sieving. The sorter has two belts, where one product falls out, which has been sieved with a fraction smaller than 40 mm and the fraction larger than 40 mm falls up on the other belt. A reinforced concrete bridge scale with a measuring accuracy of 20 kg was used to determine the weight.

Statistical analysis

All measured data were subjected to analysis of variance (ANOVA) test in Statistica 10. Post-hoc analysis by Tukey's test (HSD) was used to verify the significance of the differences with a probability level $\alpha = 0.05$.

RESULTS AND DISCUSSION

CO_2 concentrations from composting

The range of CO_2 concentrations varied considerably during the composting period. During the seven-week composting period, the minimum and maximum range of CO_2 concentrations from the pile V1 were 955.63 mg m^{-3} in the first week and 8,172.20 mg m^{-3} in the seventh week. From the pile V2, the range of CO_2 concentrations were from 986.35 mg m^{-3} at week 1st to 10,061 mg m^{-3} at week 7th. From the pile V3, the minimum CO_2 value was 969.22 mg m^{-3} at week 1st and the maximum was 37,462.00 mg m^{-3} at week 7th. Fig. 1 shows the average results of a 24-hour continues measurement of CO_2 production from three piles V1, V2 and V3 observed in the first, fourth and seventh weeks of compost maturation. The measurements showed that the amount of gas concentrations gradually increased during the process. In the first week, the production of CO_2 concentrations from the monitored piles did not differ significantly (P < 0.05) (Table 1). The mean values were 1,071.86 mg m^{-3} ± 57.66 (V1); 1,052.09 mg m^{-3} ± 28.12 (V2) and 1,053.94 mg m^{-3} ± 27.37 (V3). In the fourth week, statistically significantly higher gas concentrations were recorded from the V3 pile (P < 0.05), which was turned and irrigated, than from the pile of V1 and V2 (Table 1). The mean CO_2 concentrations were 4,498.80 mg m^{-3} ± 394.56 (V1); 4,651.96 mg m^{-3} ± 452.32 (V2) and 12,757.06 mg m^{-3} ± 1,673.52 (V3). These values were 2.8 times higher than from piles V1 and V2. In the seventh week, it was statistically proven that the highest gas concentrations were recorded from the V3 pile (P < 0.05) (Table 1). The mean CO_2 values were 6,642.41 mg m^{-3} ± 902.4 (V1); 8,359.11 mg m^{-3} ± 1,092.93 (V2) and 33,554.94 mg m^{-3} ± 2,619.42 (V3). The measured CO_2 values were 5 times higher from the V3 pile than from V1 and 4 times higher than from the V2 pile.

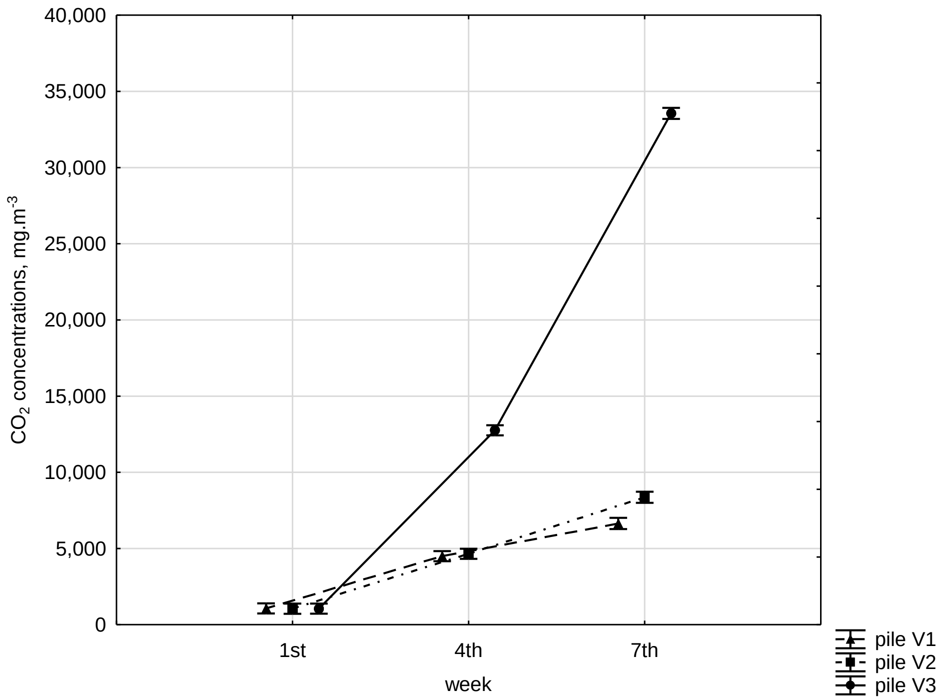

Figure 1. Two-factor analysis of variance CO_2 concentrations from pile V1, V2, V3 in the first, fourth and seventh week of the bio-waste decomposition (F test results, P = 0.0000).

The CO_2 concentrations had an increasing trend in all three piles monitored during the process, the highest concentrations were produced from the turned V3 pile. As reported by Dhamodharan et al. (2019) the amount and characterization of the gases emitted from composting process vary and are related to the initial feedstock materials composted and the composting methodology adopted. The data agreed with the results of Nasini et al. (2016) who found an increase in the CO_2 concentrations during the process and the maximum concentrations of CO_2 occurred at the end of the process. This behaviour was expected during the oxidative phase when aerobic microorganisms were involved. Composting is strictly an aerobic process, but however anaerobic conditions prevail in few zones of the windrow piles which are unavoidable. These zones lead to the formation of CH_4 due to the insufficient diffusion of oxygen from the windrow piles (Dhamodharan et al., 2019). The production of CH_4 concentrations during experiment were published (Hlinka et al., 2019), it was found that CH4 concentrations in both V1 and V3 pile had a growing trend throughout the process. In the V2 pile with the addition of the bio-preparation, the CH_4 concentrations increased shortly after the pile formation and the highest CH4 concertation's production was already in the fourth week.

Table 1. Results of significant differences in CO_2 concentrations between V1, V2 and V3 piles in the monitored weeks by Tukey HSD test; variable CO_2; mg m^{-3}, probabilities for post hoc at the level of significance $\alpha = 0.05$

Pile	Mean CO_2 concentrations	*P* - value		
1st week				
V1	$1{,}071.86 \pm 57.66^a$	0.05901		0.0974
V2	$1{,}052.09 \pm 28.12^a$		0.97518	
V3	$1{,}053.94 \pm 27.37^a$			
4th week				
V1	$4{,}498.80 \pm 394.56^a$	0.76826		0.0000
V2	$4{,}651.96 \pm 452.32^a$		0.00002	
V3	$12{,}757.06 \pm 1{,}673.52^b$			
7th week				
V1		0.00024		0.0001
V2	$8{,}359.11 \pm 1092.93^b$		0.00010	
V3	$33{,}554.94 \pm 2{,}619.42^c$			

Notes: letters a, b, and c indicate the significance of the difference, and same letters indicate the difference is not significant.

Physical and chemical characteristics of biowaste

The main factors controlling the compost process are those characteristics of an aerobic biological process such as temperature, moisture, pH and C/N ratio (Ermolaev et al., 2015; Bohacz, 2019). The values were $pH_{V1} = 7.31 \pm 0.26$, $pH_{V2} = 7.54 \pm 0.18$ and $pH_{V3} = 7.54 \pm 0.18$, humidity $h_{V1} = 67.42\% \pm 0.30$, $h_{V2} = 67.53\% \pm 0.28$ and $h_{V3} = 67.56\% \pm 0.28$ and a nutrient ratio $C/N_{V1} = 32.23/1 \pm 0.05$, $C/N_{V2} = 32.17/1 \pm 0.02$, $C/N_{V3} = 32.18/1 \pm 0.01$ from the samples of material taken at week 1st from each pile (Fig. 2, 3, 4). Referring to Reyes-Torres et al. (2018) these values can be considered satisfactory to ensure efficient decomposition. The optimal moisture content for composting depends on the waste typology, but it is often set at a 60–70% fresh weight basis. The C/N ratio is an important factor to control the microbiological metabolisms (Godwin et al., 2017). As reported by several authors (Sánchez et al., 2015; Guidoni et al., 2018), to achieve a C/N ratio of 25–30/1 in mature compost, it is necessary to optimize the C/N in fresh compost in the range 20–40/1. The C/N ratio below 20/1 produces an excess of ammonia and unpleasant odours, while the C/N ratio above 40/1 does not provide enough N for microbial growth and a fast composting process (Wang & Zeng, 2018). At week 4th, from laboratory tests of the chemical-physical properties of material samples from each pile, slightly higher pH values were found than at the beginning of the process, namely $pH_{V1} = 7.55 \pm 0.25$, $pH_{V2} = 7.74 \pm 0.29$ and $pH_{V3} = 7.77 \pm 0.32$. Humidity in each pile decreased to $h_{V1} = 45.98\% \pm 0.30$, $h_{V2} = 46.78\% \pm 0.45$ and $h_{V3} = 48.34\% \pm 0.32$ and the C/N nutrient ratio decreased to $C/N_{V1} = 23.62/1 \pm 0.23$, $C/N_{V2} = 26.25/1 \pm 0.07$, $C/N_{V3} = 25.23/1 \pm 0.06$ (Fig. 2, 3, 4). From the collected samples from each pile at week 7th, optimal values of $pH_{V1} = 7.88 \pm 0.26$, $pH_{V2} = 7.96 \pm 0.27$ and $pH_{V3} = 7.92 \pm 0.29$ were found, which conform to the safe compost standards (Zhang et al., 2017). The humidity decreased to $h_{V1} = 33.1\% \pm 0.57$, $h_{V2} = 40.45\% \pm 0.33$ and $h_{V3} = 43.34\% \pm 0.38$

and the nutrient ratio decreased to C/N_{V1} = 22.53/1 ± 0.13, C/N_{V2} = 23.58/1 ± 0.12, C/N_{V3} = 22.25/1 ± 0.13 (Fig. 2, 3, 4). These results are consistent with the knowledges of several authors (Tibu et al., 2019; Xu et al., 2020) who have been reported that during the maturation (fermentation) of compost, part of the carbon, such as carbon dioxide decreases and the C/N ratio narrows. Al-Bataina et al. (2016) stated that C/N ratio decreased with increase in compost age. These were indicative of reduction in carbon content of the treatments by microbe activities, as well as evolution of nitrogen.

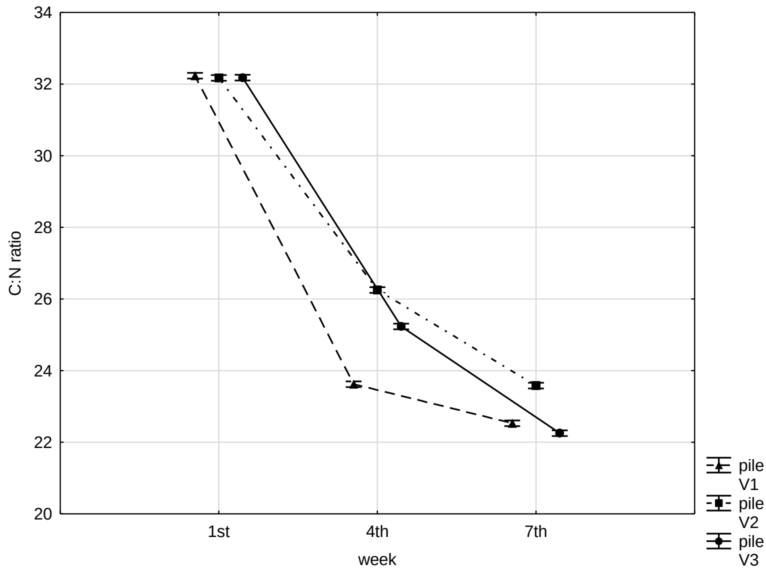

Figure 2. Two-factor analysis of variance C/N ratio of material from piles V1, V2, V3 in the first, fourth and seventh week of the bio-waste decomposition (F test results, *P* = 0.0000).

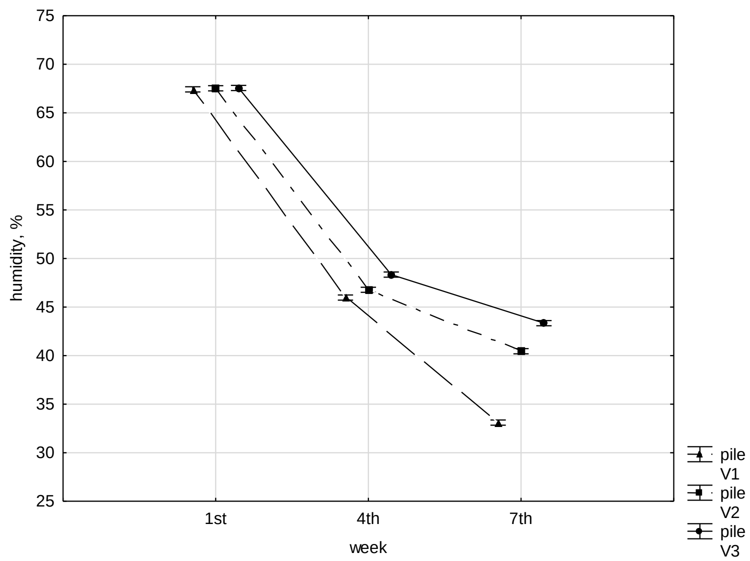

Figure 3. Two-factor analysis of variance humidity of material from piles V1, V2, V3 in the first, fourth and seventh week of the bio-waste decomposition (F test results, *P* = 0.0000).

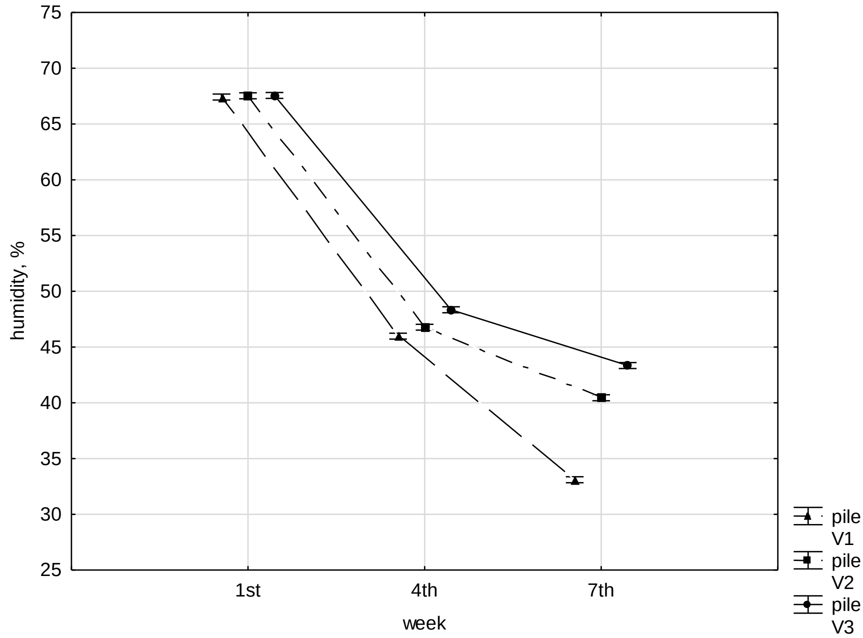

Figure 4. Two-factor analysis of variance pH of material from piles V1, V2, V3 in the first, fourth and seventh week of the bio-waste decomposition (F test results, P = 0.82856).

By analysing significant differences using Tukey's HSD test, the values of the chemical properties of C/N biowaste did not show the significance of the differences in e first week of the composting process between the composted piles. At weeks 4 and 7, there were significant differences in C/N ratio values between treatment methods V1, V2 and V3 (Table 2). The moisture content of the composted material was not significantly different in the first week, in the fourth and seventh weeks there were already significant differences between all composting methods V1, V2 and V3 (Table 3). The pH values of the composted material were not significantly different in the first, fourth and seventh weeks between all composting methods V1, V2 and V3 (Table 4).

Table 2. Results of significant differences in C/N ratio between V1, V2 and V3 piles in the monitored weeks by Tukey HSD test; variable C/N ratio, probabilities for post hoc at the level of significance α = 0.05

Pile	C/N ratio	*P* - value		
1st week				
V1	32.23 ± 0.05^{a}	0.10199		0.80075
V2	32.17± 0.02^{a}		0.80075	
V3	32.18 ± 0.01^{a}			
4th week				
V1	23.62± 0.23^{a}	0.00013		0.00013
V2	26.25 ± 0.07^{b}		0.00013	
V3	25.23 ± 0.06^{c}			
7th week				
V1	22.53 ± 0.13^{a}	0.00013		0.00074
V2	23.58 ± 0.12^{b}		0.00013	
V3	22.25 ± 0.13^{c}			

Notes: letters a, b, and c indicate the significance of the difference, and same letters indicate the difference is not significant.

Table 3. Results of significant differences in humidity between V1, V2 and V3 piles in the monitored weeks by Tukey HSD test; variable humidity; %, probabilities for post hoc at the level of significance $\alpha = 0.05$

Pile	Humidity, %	*P* - value		
1st week				
V1	67.42 ± 0.30^a	0.73628		0.60895
V2	67.53 ± 0.28^a		0.97633	
V3	67.56 ± 0.28^a			
4th week				
V1	45.98 ± 0.30^a	0.00103		0.00013
V2	46.78 ± 0.45^b		0.00013	
V3	48.34 ± 0.32^c			
7th week				
V1	33.1 ± 0.57^a	0.00013		0.00013
V2	40.45 ± 0.33^b		0.00013	
V3	43.34 ± 0.38^c			

Notes: letters a, b, and c indicate the significance of the difference, and same letters indicate the difference is not significant.

Table 4. Results of significant differences in pH values between V1, V2 and V3 piles in the monitored weeks by Tukey HSD test; variable pH, probabilities for post hoc at the level of significance α = 0.05

Pile	pH	*P* - value		
1st week				
V1	7.31 ± 0.26a	0.089511		0.095236
V2	7.54 ± 0.18a		0.99952	
V3	7.54 ± 0.18a			
4th week				
V1	7.55 ± 0.25a	0.396254		0.291111
V2	7.74 ± 0.29a		0.97483	
V3	7.77 ± 0.32a			
7th week				
V1	7.88 ± 0.26a	0.829846		0.951706
V2	7.96 ± 0.27a		0.95668	
V3	7.92 ± 0.29a			

Notes: same letters indicate the difference is not significant.

Temperature evolution

The temperature of treatments increased rapidly after the experiments were started (Fig. 5), the maximum temperatures (68 °C, 66 °C, 65 °C) were observed at day 2.

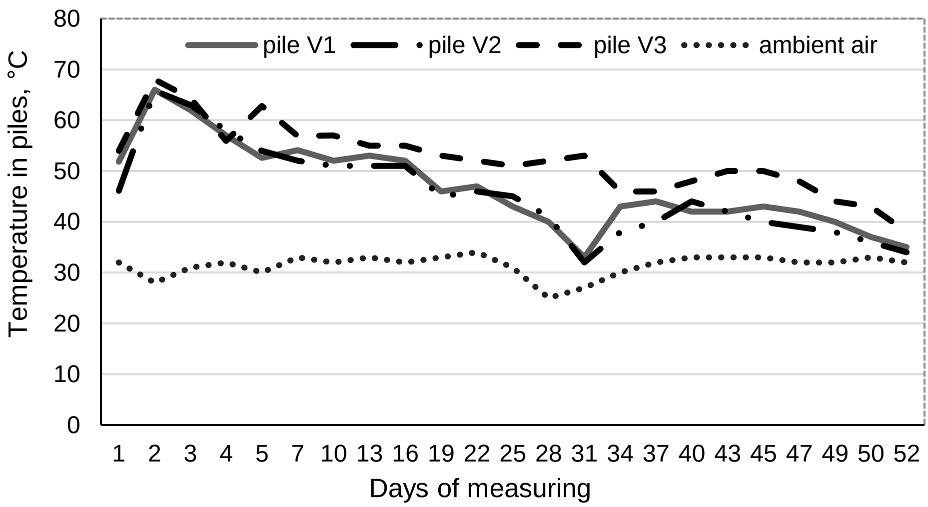

Figure 5. Temperature profile in pile V1, V2, V3 and ambient air during the composting process.

Then the temperature decreased gradually during the process between 60 and 50 °C and the degradation process took place in the thermophilic phase. The thermophilic phase of all treatments was long enough to satisfy the requirement for sanitation effect. Chaher et al. (2020) stated that the maintenance of a temperature above 55 °C for two consecutive weeks is the requirements of compost evaluation in terms of guaranteeing the removal of pathogens. The drop in temperature demonstrated that almost all the complex organic compounds were well-degraded during the mesophilic and thermophilic phases (Akyol et al., 2019; Calabi-Floody et al., 2019, Chaher et al., 2020). During the V3 treatment, there were a few small temperature fluctuations due to the mechanical turning of the compost pile. A similar trend was observed by Cook et al. (2015) and Yang et al. (2019) according to which it is possible to improve the structure of the matrix and to displace biodegradable substances to reactivate the microbial activity when the composting piles were turned.

Weight of the final products

At the end of the degradation process, sieving and weighing of each pile were performed to determine the weights of the resulting products in terms of the processing technology used. Table 5 gives an overview of the weights of each pile before sieving, after sieving and the percentage of compost produced from each pile. It was found that turning and irrigation in the V3 pile had a significant effect on the degradation of organic matter. This may be attributed to the increased oxygen provided by turning the windrow and by higher temperature that enhanced microbial activity. Weight loss in the V3 pile was lowest (18.44%, V1 = 23.26% and V2 = 21.85%) which means that due to the treatment, the highest rate of waste degradation was achieved, and we achieved the highest percentage of the final product in the form of compost (Table 2). These results suggest that the decomposition rate in the turned pile proceeded much faster than the unturned ones. The composting process, with its requirements for turning and aeration is one of the important steps to produce a good quality compost product (He et al., 2020). As reported (Han et al., 2018; Reyes-Torres et al., 2018), appropriate management such as turning ensure enough oxygen for microbial activities to release heat and reducing greenhouse warming potential (GWP) during aerobic composting.

Table 5. Weights of each pile before sieving and after sieving

Pile	Mass (kg)			Percentage of the initial mass at the end of experiment
	whole pile	seedlings	compost	
V1	2,580	600	1,980	76.74%
V2	3,020	660	2,360	78.15%
V3	2,820	520	2,300	81.56%

CONCLUSIONS

The measurements showed that the production of monitored CO_2 concentrations in the summer period was the lowest at the beginning of composting process. The amount of gas concentrations gradually increased during the process. The aim of this study was to analyse the production of CO_2 in relation to the composting technology used. Our assumption that there is no significant difference in CO_2 concentrations depending on the biowaste treatment technology has only been partially confirmed using statistical methods. At the beginning of the process, in the first week, there were no significant differences in the production of CO_2 concentrations from the monitored piles. In the fourth week, significantly higher values of CO_2 concentrations were recorded from the V3 pile ($P < 0.05$), which was turned and irrigated, than from the V1 and V2 piles. At week 7, significant differences were found between all treatments at the level of significance ($P < 0.05$) with the highest values from the V3 pile. Turning affected several important physical and chemical parameters such as temperature, carbon loss and the resulting amount of product. The final product from the three composting treatments was significantly different in terms of C/N ratio and compost moisture. The results suggest that using a technological process, we can produce a higher amount of quality compost. It has been shown that turning and humidifying results in the highest release of CO_2 into the air, but in a more rapid decomposition of the microorganisms, thus reducing the time required to achieve a stable compost product and increasing the efficiency of the composting plant.

ACKNOWLEDGMENTS. This publication was supported by the Operational Program Integrated Infrastructure within the project: Demand-driven research for the sustainable and inovative food, Drive4SIFood 313011V336, cofinanced by the European Regional Development Fund.

REFERENCES

Akpinar, C., Demirbas, A. & Ortas, I. 2019. The Effect of Different Compost Compositions on Arbuscular Mycorrhizal Colonization and Nutrients Concentration of Leek (allium Porrum L.) Plant. *Communications in Soil Science and Plant Analysis* **50**, 1–12. doi.org/10.1080/00103624.2019.1659299

Akyol, C., Ince, O. & Ince, B. 2019. Crop-based composting of lignocellulosic digestates: focus on bacterial and fungal diversity. *Bioresour Technology* **288**, 121549. doi.org/10.1016/j.biortech.2019.121549

Al-Bataina, B.B., Young, T.M. & Ranieri, E. 2016. Effects of compost age on the release of nutrients. *International Soil and Water Conservation Research* **4**(3), 230–236. doi.org/10.1016/j.iswcr.2016.07.003

Arriaga, H., Viguria, M., López, D.M. & Merino, P. 2017. Ammonia and greenhouse gases losses from mechanically turned cattle manure windrows: A regional composting network. *Journal of Environmental Management* **203**, 557–563. doi.org/10.1016/j.jenvman.2017.06.006

Asadu, C.O, Egbuna, S.O, Chime, T.O., Eze, Ch.N., Kevin, D., Mbah, G.O. & Ezema, A.C. 2019. Survey on solid wastes management by composting: optimization of key process parameters for biofertilizer synthesis from agro wastes using response surface methodology (RSM). *Artificial Intelligence in Agriculture* **3**, 52–61. doi.org/10.1016/j.aiia.2019.12.002

Bohacz, J. 2019. Changes in mineral forms of nitrogen and sulfur and enzymatic activities during composting of lignocellulosic waste and chicken feathers. *Environ Sci Pollut Res* **26**,10333–10342. doi.org/10.1007/s11356-019-04453-2

Calabi-Floody, M., Medina, J., Suazo, J., Ordiqueo, M., Aponte, H., Mora, M.L.L. & Rumpel, C. 2019. Optimization of wheat straw co-composting for carrier material development. *Waste Management* **98**, 37–49. doi.org/10.1016/j.wasman.2019.07.041

Cook, K.L., Ritchey, E.L., Loughrin, J H., Haley, M., Sistani, K.R. & Bolster, C H. 2015. Effect of turning frequency and season on composting materials from swine high-rise facilities, *Waste Management* **39**, 86–95. doi.org/10.1016/j.wasman.2015.02.019

Dhamodharan, K., Varma, V.S., Veluchamy, Ch., Pugazhendhi, A. & Rajendran, K. 2019. Emission of volatile organic compounds from composting: A review on assessment, treatment and perspectives, *Science of The Total Environment* **695**, 133725. doi.org/10.1016/j.scitotenv.2019.133725

Eden, M., Gerke, H H. & Houot, S. 2017. Organic waste recycling in agriculture and related effects on soil water retention and plant available water: a review, *Agron. Sustain. Dev.* **37**, 11. https://doi.org/10.1007/s13593-017-0419-9

Ermolaev, E., Jarvis, A., Sundberg, C., Smars, S., Pell, M. & Jönsson, H. 2015. Nitrous oxide and methane emissions from food waste composting at different temperatures. *Waste Management* **46**,113–119. doi.org/10.1016/j.wasman.2015.08.021

Godwin, C.M., Whitaker, E.A. & Cotner, J.B. 2017. Growth rate and resource imbalance interactively control biomass stoichiometry and elemental quotas of aquatic bacteria. *Ecology* **98**(3), 820–829. doi.org/10.1002/ecy.1705

Guidoni, L.L.C., Marques, R.V., Moncks, R.B., Botelho, F.T., da Paz, M.F., Corrêa, L.B. & Corrêa, É.K. 2018. Home composting using different ratios of bulking agent to food waste. *J Environ Manag* **207**, 141–150. doi.org/10.1016/j.jenvman.2017.11.031

Han, Z., Sun, D., Wang, H., Li, R., Bao, Z. & Qi, F. 2018. Effects of ambient temperature and aeration frequency on emissions of ammonia and greenhouse gases from a sewage sludge aerobic composting plant. *Bioresource Technology* **270**, 457–466. doi.org/10.1016/j.biortech.2018.09.048

He, X., Han, L. & Huang, G. 2020. Analysis of regulative variables on greenhouse gas emissions and spatial pore gas concentrations with modeling during large-scale trough composting. *Journal of Cleaner Production* **277**, 124066. doi.org/10.1016/j.jclepro.2020.124066

Hernández-Gómez, A., Calderón, A., Medina, C., Sanchez-Torres, V. & Oviedo-Ocaña, E.R. 2020. Implementation of strategies to optimize the co-composting of green waste and food waste in developing countries. A case study: Colombia. *Environmental Science and Pollution Research.* doi.org/10.1007/s11356-020-08103-w

Hlinka, P., Karandušovská, I. & Mihina, Š. 2019. Monitoring of gas production during the biowaste composting. *Acta technologica agriculturae* **22**(3), 75–79. doi.org/10.2478/ata-2019-0014

Chaher, N.E h., Chakchouk, M., Abdallah, N., Nelles, M. & Hamdi, M. 2020. Potential of windrow food and green waste composting in Tunisia. *Environmental Science and Pollution Research.* doi.org/10.1007/s11356-020-10264-7

Kažimírová, V., Gaduš, J. & Giertl, T. 2018. Verification of suitability of substrate composition for production and quality of biogas. *Acta technologica agriculturae* **21**(3), 115–118. doi.org/10.2478/ata-2018-0021

Krištof, K. & Gaduš, J. 2018. Effect of alternative sources of input substrates on biogas production and its quality from anaerobic digestion by using wet fermentation. *Agronomy Research* **16**(3), 769–783. doi.org/10.15159/AR.18.146

Nasini, L., De Luca, G., Ricci, A., Ortolani, F., Caselli, A., Massaccesi, L., Regni, L., Gigliotti, G. & Proietti, P. 2016. Gas emissions during olive mill waste composting under static pile conditions. *International Biodeterioration & Biodegradation* **107**, 70–76. doi.org/10.1016/j.ibiod.2015.11.001

Reyes-Torres, M., Oviedo-Ocaña, E.R, Dominguez, I., Komilis, D. & Sánchez, A. 2018. A systematic review on the composting of green waste: feedstock quality and optimization strategies. *Waste Management* **77**, 486–499. doi.org/10.1016/j.wasman.2018.04.037

Sánchez, A., Artola, A., Font, X., Gea, T., Barrena, R., Gabriel, D., Sánchez-Monedero, M.A., Roig, A., Cayuela, M.L. & Mondini, C. 2015. Greenhouse gas emissions from organic waste composting. *Environmental Chemistry Letters* **13**, 223–238. doi.org/10.1007/s10311-015-0507-5

Tibu, C., Annang, T.Y., Solomon, N. & Yirenya-Tawiah, D. 2019. Effect of the composting process on physicochemical properties and concentration of heavy metals in market waste with additive materials in the Ga West Municipality, Ghana. *International Journal of Recycling of Organic Waste in Agriculture* **8**, 393–403. doi.org/10.1007/s40093-019-0266-6

Vaverková, M.D, Adamcová, D., Winkler, J., Koda, E., Petrželová, L. & Maxianová, A. 2020. Alternative method of composting on a reclaimed municipal waste landfill in accordance with the circular economy: benefits and risks. *Science of The Total Environment* **723**, 137971. doi.org/10.1016/j.scitotenv.2020.137971

Wang, S. & Zeng, Y. 2018. Ammonia emission mitigation in food waste composting: a review. *Bioresour Technology* **248**, 13–19. doi.org/10.1016/j.biortech.2017.07.050

Weidner, T., Graça, J., Machado, T. & Yang, A. 2020. Comparison of local and centralized biowaste management strategies – A spatially-sensitive approach for the region of Porto, *Waste Management* **118**, 552–562. doi.org/10.1016/j.wasman.2020.09.013

Xu, Z., Li, G., Huda, N., Zhang, B., Wang, M. & Luo, W. 2020. Effects of moisture and carbon/nitrogen ratio on gaseous emissions and maturity during direct composting of cornstalks used for filtration of anaerobically digested manure centrate, *Bioresource Technology* **298**, 122503. doi.org/10.1016/j.biortech.2019.122503

Yang, F., Li, Y., Han, Y., Qian, W., Li, G. & Luo, W. 2019. Performance of mature compost to control gaseous emissions in kitchen waste composting. *Science of The Total Environment* **657**, 262–269. doi.org/10.1016/j.scitotenv.2018.12.030

Zhang, D., Luo, W., Yuan, J., Li, G. & Luo, Y. 2017. Effects of woody peat and superphosphate on compost maturity and gaseous emissions during pig manure composting. *Waste Management* **68**, 56–63. doi.org/10.1016/j.wasman.2017.05.042

Zhang, S., Wen, J., Hu, Y., Fang, Y., Zhang, H., Xing, L., Wang, Y. & Zeng, G. 2019. Humic substances from green waste compost: an effective washing agent for heavy metal (Cd, Ni) removal from contaminated sediments. *Journal of Hazardours Materials* **366**, 210–218. doi.org/10.1016/j.jhazmat.2018.11.103