

## EFFECT OF CHEMICAL INDICATORS AND RESPIRATORY ACTIVITY ON THE RESIDENCE TIME OF VERMICOMPOSTS

Pedro del Aguila-Juárez<sup>1\*</sup>, Rocio Vaca-Paulín<sup>1</sup>, Nadia de la Portilla-López<sup>1</sup>, Jorge Lugo-de la Fuente<sup>1</sup>, Gustavo Yáñez-Ocampo<sup>1</sup>, Patricia Rivera-García<sup>2</sup>, Armando Cervantes-Sandoval<sup>2</sup>

<sup>1</sup>Universidad Autónoma del Estado de México. Instituto Literario No. 100, Toluca de Lerdo, State of Mexico, Mexico. C. P. 50000.

<sup>2</sup>Universidad Nacional Autónoma de México, FES-Zaragoza. Av Guelatao No. 66, Ejército de Oriente Indeco II ISSSTE, Iztapalapa, Mexico City, Mexico. C. P. 09230.

\* Author for correspondence: delaguila.1959@gmail.com

### ABSTRACT

Vermicompost is considered an environmental quality for managing agricultural residues since it improves soil structure, provides nutrients, and helps to reduce environmental impact. The objective of this study was to determine the residence time using a kinetic model of carbon mineralization while also evaluating chemical and biological parameters obtained during vermicompost processing. Earthworms (*Eisenia fetida*) were used comparing different doses of residual sludge (LR) at 0, 10, 20, and 40 Mg, keeping constant the dose of domestic waste (RD) and cattle manure (EV) at a ratio of 1:1 (dry basis). An AxB factorial design was used, where A represented the LR dose and B the type of residues (RD and EV); thus, eight treatments with nine replicates were compared. The pH, organic matter (MO), total nitrogen, C/N ratio, respiratory activity, C mineralization, and residence time were determined. The results of the treatments indicate a slightly alkaline trend. MO was different among treatments, with a higher MO percentage in EV and LR with 40 Mg of LR ( $28.92 \pm 10.78\%$ ,  $F_{(7,88)} = 2.63$ ,  $p \leq 0.01$ ). The total N percentage was low, but the treatment containing 40 Mg of LR and RD ( $1.04 \pm 0.62\%$ ,  $F_{(7,88)} = 3.87$ ,  $p < 0.01$ ) stood out. C/N ratios  $< 20$ , which indicate stability, were recorded in the treatments with LR and EV. The vermicompost obtained from 40 Mg of LR and EV complied with a minimum residence time (less than 70 days) throughout processing, making it an excellent choice for agricultural use.

**Keywords:** stabilization, half-life, organic amendment, carbon kinetics.

### INTRODUCTION

The growing interest in the use of soil amendments, such as manures, composts, vermicomposts, and biochar, is due to their significant contribution to improving soil structure and their ability to provide nutrients for sustainable agriculture, aligned with the 2030 Agenda for Sustainable Development of the United Nations, where

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vermicompost plays a key role in mitigating environmental impact (Abbott *et al.*, 2018; Kauser and Khwairakpam, 2022). In addition to the interest in environmentally friendly composts, there is social concern about solid waste generation and decreasing its impact on the environment. An integrated management of this type of waste can be carried out, including its reduction, reuse, recycling, thermal energy recovery, and adequate waste confinement (Dümenci *et al.*, 2021; Tan *et al.*, 2021; Vorobeva *et al.*, 2022).

Amendments in organic agriculture offer valuable alternatives by utilizing a wide range of available organic wastes, such as manures, domestic wastes, and residual sludge. The latter are employed due to their contribution of nutrients and organic matter, either directly or after stabilization (Doan *et al.*, 2013; Abbott *et al.*, 2018; Rékási *et al.*, 2023). One solution to waste is vermicomposting, which consists of a biooxidative process in which the earthworm plays a key role and is considered a clean, sustainable, and effective technology to recycle organic waste (Das *et al.*, 2022; Ugak *et al.*, 2022; Chen *et al.*, 2023).

Vermicompost shortens the stabilization time of organic matter and supplies nutrients such as phosphorus, nitrogen, calcium, and magnesium. It also increases moisture holding capacity, microbial activity, and stable organic matter to the soil, increasing crop yields (Das *et al.*, 2021; Mahapatra *et al.*, 2022; Chen *et al.*, 2023; Gebrehana *et al.*, 2023). Vermicompost must meet minimum requirements for its production, whose raw material (diverse waste) is generated by agricultural, forestry, and livestock activities, as long as they are biodegradable, do not affect the quality of the final product, and represent no risk to human health or the environment, according to the Mexican standard (DOF, 2007).

The present study responds to the need to understand the vermicomposting process and its relationship with chemical and biological parameters. This understanding is essential to maximizing the efficiency of vermicompost and its capacity to oxidize agricultural residues effectively, so it must adhere to the maturity and stability of the product. Maturity shows to what extent the composting process is completed, while stability refers to a particular state of organic matter, specific stage, or decomposition of organic matter. It is assessed with parameters such as pH, total nitrogen, organic matter, C/N ratio, electrical conductivity, bulk density, and moisture content, among others. It can also be assessed using biochemical parameters such as enzyme activity, respiration, and mineralization, which are indicators of process dynamics (Nikaeen *et al.*, 2015; Mahapatra *et al.*, 2022).

This research is useful in learning about several chemical and biological factors, including respiratory activity, which is widely utilized as an indicator of soil microbial activity. The metabolic activity of soil microorganisms is determined by quantifying CO<sub>2</sub>, whose emission increases in the presence and activity of earthworms because they promote the decomposition and stabilization of the substrate (Chen *et al.*, 2023). Similarly, the support of mathematical models with predictions in the operation is required to help optimize costs, calculate time in process efficiency, and extrapolate

its effects in the agricultural field (Dümenci *et al.*, 2021). The work by Sharma *et al.* (2021) validates the maturity of a vermicompost by applying a response surface model (RSM) and artificial neural network (ANN) with flower residues and cow dung, considering the C/N ratio and CO<sub>2</sub> evolution rate as maturity parameters. The use of kinetic models of carbon mineralization using zero, first, and second-order differential equations helps to predict the degradation of organic matter and its evolution, as well as the residence time or maturation during the process, relying on the respiratory activity expressed as the rate of CO<sub>2</sub> decomposition (Denes *et al.*, 2015; Ugak *et al.*, 2022).

The hypothesis of this research is that residence time in vermicompost production, together with the application of a kinetic model of carbon mineralization and the measurement of chemical and biological parameters, play a critical role in the quality and efficiency of vermicompost. The relationship between the factors and the composition of the waste used is presumed to influence the final outcome of the vermicompost. Therefore, the objective is to determine the optimum residence time for vermicompost production using *Eisenia fetida* earthworms and evaluate doses of 0, 10, 20, and 40 Mg ha<sup>-1</sup> of residual sludge (LR), keeping constant the domestic waste (RD) and cattle manure (EV) in the process. This analysis is based on the measurement of chemical and biological parameters to identify the most effective dose and its agricultural use.

## MATERIALS AND METHODS

### Experimental site location

The study was carried out in the laboratory of the Faculty of Sciences of the Autonomous University of the State of Mexico (UAEMex), located at km 15.5 of the Toluca-Ixtlahuaca highway, State of Mexico, Mexico (19° 24' 32" N, 99° 41' 20" W).

### Solid waste sampling

Organic wastes collected included cow manure (EV) from the post of the Veterinary Faculty of the UAEMex, domestic waste (RD) from the cafeteria of the University campus "El Cerrillo" UAEMex, and residual sludge (LR) from the filter press of the municipal wastewater treatment plant Toluca Norte, which is management by the company Operadora de Ecosistemas S.A. C.V. The pH values, amount of organic matter (MO), organic carbon, C/N ratio, and concentration of various components were recorded for each sample (Table 1).

### Vermicomposting

Plastic tubs or containers measuring 20 x 30 x 20 cm (width x length x height) were used, each perforated at the base for oxygen circulation, and a mesh was used at the top to avoid worm escape. In each tub, the worm (*Eisenia fetida*) with a feeding preference

**Table 1.** Chemical characteristics of organic wastes used in vermicomposting (M ± DE).

Parameter	Domestic waste (RD)	Bovine manure (EV)	Residual sludge (LR)
pH	6.8 ± 0.3	7.4 ± 0.6	7.1 ± 0.4
MO (%)	18.5 ± 0.2	23.3 ± 0.7	30.4 ± 0.4
Organic C (%)	10.7 ± 0.6	13.5 ± 0.9	17.6 ± 0.7
C/N	28.5 ± 1.2	16.5 ± 1.5	9.5 ± 1.1
N (%)	1.1 ± 0.6	2.4 ± 0.8	4.1 ± 1.2
K (%)	0.9 ± 0.5	1.2 ± 0.7	1.4 ± 0.6
Ca (mg kg <sup>-1</sup> )	11.5 ± 3.7	9.2 ± 2.8	10.4 ± 2.7
Mg (mg kg <sup>-1</sup> )	0.6 ± 0.1	0.9 ± 0.1	1.0 ± 0.2
Cu (mg kg <sup>-1</sup> )	130.0 ± 2.9	235.0 ± 6.8	490.0 ± 9.9
Zn (mg kg <sup>-1</sup> )	75.0 ± 1.4	65.0 ± 1.9	115.0 ± 1.5
Cd (mg kg <sup>-1</sup> )	3.0 ± 0.6	2.0 ± 0.3	2.0 ± 0.76
Ni (mg kg <sup>-1</sup> )	25.0 ± 1.7	17.0 ± 1	82.0 ± 1.1
Cr (mg kg <sup>-1</sup> )	50.0 ± 0.6	47.0 ± 0.3	124.0 ± 0.6
Pb (mg kg <sup>-1</sup> )	54.0 ± 0.8	31.0 ± 0.1	99.0 ± 0.5

M: mean; SD: standard deviation; MO: organic matter.

of organic matter was added, validating indicators of sexual maturity: individuals of a faint red color, a well-developed clitellum, average size of 4 to 6 cm, and weight of 0.5 g per individual. Twenty adult earthworms per kg of substrate were included, as reported by Gupta and Garg (2008).

To evaluate the stability of the vermicompost, combinations of different types of organic wastes were carried out using an AxB factorial experiment. This study was developed under a completely randomized design that included eight treatments and nine replicates for each of them. The design included the following treatments: T1 = cattle manure (EV) + earthworms; T2 = EV + residual sludge (LR) 10 Mg + earthworms; T3 = EV + LR 20 Mg + earthworms; T4 = EV + LR 40 Mg + earthworms; T5 = domestic residue (RD) + earthworms; T6 = RD + LR 10 Mg + earthworms; T7 = RD + LR 20 Mg + earthworms; T8 = RD + LR 40 Mg + earthworms. The variables considered were the type of waste (animal and domestic) and residual sludge doses of 0, 10, 20, and 40 Mg. The above-mentioned amounts are defined as values that do not exceed the residual sludge standard.

Substrate sampling was carried out for each treatment every 15 d, up to 90 d. Substrate samples were carefully stored in plastic bags for subsequent laboratory analysis. Two reloads of 3.5 kg of organic waste were made at days 45 and 75 to guarantee the necessary food supply for the earthworms throughout the experiment.

### Variables evaluated

The samples were dried at room temperature, homogenized, ground, and sieved for chemical analysis in the laboratory to evaluate pH, MO, and total N. The C/N ratio

was obtained by dividing the concentration of organic C by total nitrogen. Samples for the study of respiration and mineralization were taken at 15 and 75 d. They were then stored in plastic bags at a temperature of 4 °C, ensuring their conservation until the kinetics were carried out.

### Chemical and biological analysis of the vermicompost

The following laboratory parameters were determined: pH using a potentiometer (inoLab® pH 7110, Mexico), total nitrogen (NT) using the Kjeldahl method (Bremner and Mulvaney, 1982), organic carbon (CO) (Walkley and Black, 1934), and the C/N ratio, all based on the Mexican standard (DOF, 2007). Respiratory activity was measured using the Kassem and Nannipieri (1995) method.

### Mineralization model to determine residence time

The mineralization process was determined, which required the use of respiratory activity data to generate a kinetic model that considers the available carbon, as represented by the first-order differential equation (Equation 1) proposed by Ugak *et al.* (2022).

$$\frac{dC}{dt} = -KC \quad (1)$$

where  $dC/dt$  is the mineralization rate,  $K$  is the mineralization constant, and  $C$  is the residual carbon concentration.

Numerical calculations yield the residence time, or so-called half-life ( $t_{1/2}$ ), which compares the time required for the potentially mineralizable fraction to decrease its concentration by half (Equation 2). The value 0.693 represents the inverse of  $\ln 2$  and is obtained by calculating the half-life by solving the associated differential equation. This operation was carried out using the carbon mineralization rate data.

$$t_{1/2} = \frac{0.693}{K} \quad (2)$$

### Experiment design and statistical analysis

An AxB factorial design was used, with factor “A” representing the three LR doses used (10, 20, and 40 Mg ha<sup>-1</sup>) and a control, and factor “B” representing the two types of residues (EV and RD), for a total of eight treatments with nine replicates each. The chemical variable data was analyzed using Statgraphics Centurion XV (Statgraphics.net, Madrid, Spain), and means were compared using Tukey’s test ( $p < 0.05$ ). In addition, the respiratory activity and mineralization of mineralized C were graphed.

## RESULTS AND DISCUSSION

### Chemical results during vermicomposting process

Significant pH variations were recorded between treatments with and without LR addition ( $F_{(7,88)} = 3.58, p \leq 0.02$ ). The treatment containing 40 Mg of LR and EV, as well as the two treatments without LR addition (EV  $(7.29 \pm 0.23)$  and RD  $(7.2 \pm 0.24)$ ) presented a neutral behavior. However, the other treatments that included different doses of LR, EV, and RD showed a slightly alkaline behavior with pH values between  $7.39 \pm 0.21$  and  $7.63 \pm 0.27$  (Table 2).

Based on this factor, it is reasonable to conclude that the treatment with EV and 40 Mg of LR (T4) has a good potential for agriculture. The Mexican standard (DOF, 2007) establishes a pH range between 5.5 and 8.5 that makes it suitable for use in agriculture. Authors such as Sharma and Garg (2017) and Hassan *et al.* (2022) have shown that vermicompost produced from household waste and horse, cow, and buffalo manures has a pH range of 7.2 to 7.3, thus showing beneficial neutrality levels for plant development. The treatments with these pH values distinguish them notably from the others. The dynamics shown by pH in vermicomposting are attributed to the production of CO<sub>2</sub> and the accumulation of organic acids produced by the microorganisms, and are related to changes in the nitrogen balance. These effects are probably influenced by the presence of earthworms in the vermicomposting process (Hait and Tare, 2011)..

Significant differences ( $F_{(7,88)} = 2.63, p \leq 0.01$ ) in organic matter (MO) concentration were observed among the different treatments. The kind of residue played an important

**Table 2.** Average values and standard deviation of pH, organic matter (MO) concentration, N and C/N ratio of the different treatments used for vermicomposting.

Treatments	pH	MO (%)	N (%)	C/N
T1	$7.29 \pm 0.23c$	$20.32 \pm 9.21c$	$0.29 \pm 0.09d$	$22.36 \pm 13.58b$
T2	$7.52 \pm 0.30ab$	$20.03 \pm 7.05c$	$0.37 \pm 0.16d$	$25.33 \pm 13.3b$
T3	$7.53 \pm 0.25ab$	$22.18 \pm 9.20b$	$0.89 \pm 0.96b$	$16.78 \pm 5.66c$
T4	$7.24 \pm 0.38c$	$28.92 \pm 10.78a$	$0.51 \pm 0.34c$	$19.88 \pm 8.39c$
T5	$7.20 \pm 0.24c$	$16.56 \pm 6.14d$	$0.47 \pm 0.15c$	$37.83 \pm 10.37ab$
T6	$7.41 \pm 0.25abc$	$18.70 \pm 8.78cd$	$0.80 \pm 0.04b$	$37.40 \pm 18.61b$
T7	$7.39 \pm 0.21bc$	$19.00 \pm 11.42cd$	$1.04 \pm 0.62a$	$23.87 \pm 9.42bc$
T8	$7.63 \pm 0.27a$	$15.64 \pm 5.73d$	$0.46 \pm 0.06cd$	$48.86 \pm 11.63a$

Means with different letters per column represent statistical difference (Tukey  $p \leq 0.05$ ). F: Fisher;  $p$ : probability. AxB: interaction of A (LR dose) and B (type of residue). Treatments contained combinations of cow manure (EV), earthworms (L), residual sludge (LR), and domestic waste (RD). T1: EV and L; T2: EV and 10 Mg LR; T3: 20 Mg LR and L; T4: 40 Mg LR and L; T5: RD and L; T6: RD and 10 Mg LR; T7: RD and 20 Mg LR; T8: RD and 40 Mg LR.

influence in these discrepancies, with LR and EV exhibiting a larger concentration of MO than RD. For 10 Mg of LR, a value of  $20.03 \pm 7.05$  % was recorded (T2), while for 20 Mg of LR, it was  $22.18 \pm 9.2$  % (T3) and for 40 Mg of LR it reached  $28.92 \pm 10.78$  % (T4). In contrast, those without LR and only with EV presented a value of  $20.32 \pm 9.21$  % (T1), and those containing RD showed  $16.56 \pm 6.14$  % (T5). Treatments combining LR and RD, such as 40 Mg LR with  $15.64 \pm 5.73$  % (T8), 10 Mg LR with  $18.7 \pm 8.78$  % (T6), and 20 Mg LR with  $19 \pm 11.42$  % (T7), exhibited different MO concentrations without showing differences (Table 2). The combination of EV and 40 Mg of LR (T4) stood out for its higher MO concentration, in contrast to the MO concentration found in the mixture of RD and 40 Mg of LR.

The average MO concentration at the end of all treatments was  $20.17 \pm 9.27$  %, which agrees with Ghaffari *et al.* (2022) and the Mexican standard (DOF, 2007). This value indicates an acceptable range of MO between 20 and 50 %, confirming that the results obtained comply with the recommended standards. The decreased proportion of MO in the treatment containing only RD is due to substrate degradation facilitated by the earthworm and mineralization activated by microorganisms, which is consistent with Das *et al.* (2022), Chen *et al.* (2023), and Gebrehana *et al.* (2023). Similarly, Wang *et al.* (2021), Mahapatra *et al.* (2022), and Rékási *et al.* (2023) reported that stable organic residues contribute nutrients such as nitrogen, phosphorus, and potassium to soil in both organic and inorganic forms. However, nitrogen in its organic form is converted to greenhouse gases, which may result in its loss.

Significant differences were observed in the total nitrogen percentage among treatments ( $F_{(7,88)} = 3.87$ ,  $p \leq 0.01$ ), highlighting those constituted of LR and RD, with higher values of  $0.47 \pm 0.15$  (T5),  $0.8 \pm 0.04$  (T6), and  $1.04 \pm 0.62$  % (T7). Treatments with LR and EV ranked second with results of  $0.37 \pm 0.16$  (T2),  $0.89 \pm 0.96$  (T3), and  $0.51 \pm 0.34$  % (T4). Treatments containing only RD ( $0.46 \pm 0.06$  %, T8) and EV ( $0.29 \pm 0.09$  %, T1) showed significant differences in nitrogen levels, although with low values (Table 2).

These results underline the significant influence of the combination of LR and RD on nitrogen percentages, followed by the synergy between LR and EV. Specifically, the combination of RD and 20 Mg of LR showed the highest nitrogen percentage, while the lowest concentration was recorded in the EV-only treatment. The importance of carefully considering the composition of the materials utilized is emphasized, as this might have a considerable impact on nitrogen availability in the agricultural system. Although the average value is below the Mexican standard (DOF, 2007), which has a range between 1 and 4 % N, only T7 met it ( $1.04 \pm 0.6$  % N), which was made with LR 20 Mg and RD. According to Ahmed and Deka (2022), Cai *et al.* (2022), Das *et al.* (2021, 2022), and Kauser and Khwairakpan (2022), the addition of nitrogenous mucous substances, decomposing tissues, hormones, and enzymes promotes the earthworm's metabolic activity as well as the production of humic and fulvic acids during the vermicomposting process.

The C/N ratio derived from the quotient between the percentages of carbon and nitrogen exhibits significant differences ( $F_{(7,88)} = 3.58$ ,  $p \leq 0.002$ ) among treatments,

influenced by the amount of LR and the type of residue. The highest C/N ratios are those containing LR and RD, recording  $48.86 \pm 11.6$  for treatment T8 and  $37.4 \pm 18.1$  for T6, including the one containing only RD, with  $37.8 \pm 10.3$ . On the other hand, the treatments containing LR and EV presented lower values in the C/N ratio. Ratios of  $25.3 \pm 13.3$  were recorded for the treatment with 10 Mg of LR,  $16.7 \pm 5.6$  for that with 20 Mg of LR, and  $19.8 \pm 8.3$  for that with 40 Mg of LR. This group also includes the treatment containing only EV, with a ratio of  $22.3 \pm 13.3$ .

These results highlight the significant influence of the amount of LR residues and the type of residue on the C/N ratio, which plays a crucial role in understanding the decomposition dynamics and nutrient availability in the evaluated systems. Importantly, the composite treatment with 40 Mg of LR and EV exhibits the best chemical stability in terms of C/N ratio, which positions it as an adequate and suitable option for use in agricultural practices. These results provide valuable information to optimize residue management strategies and improve soil quality.

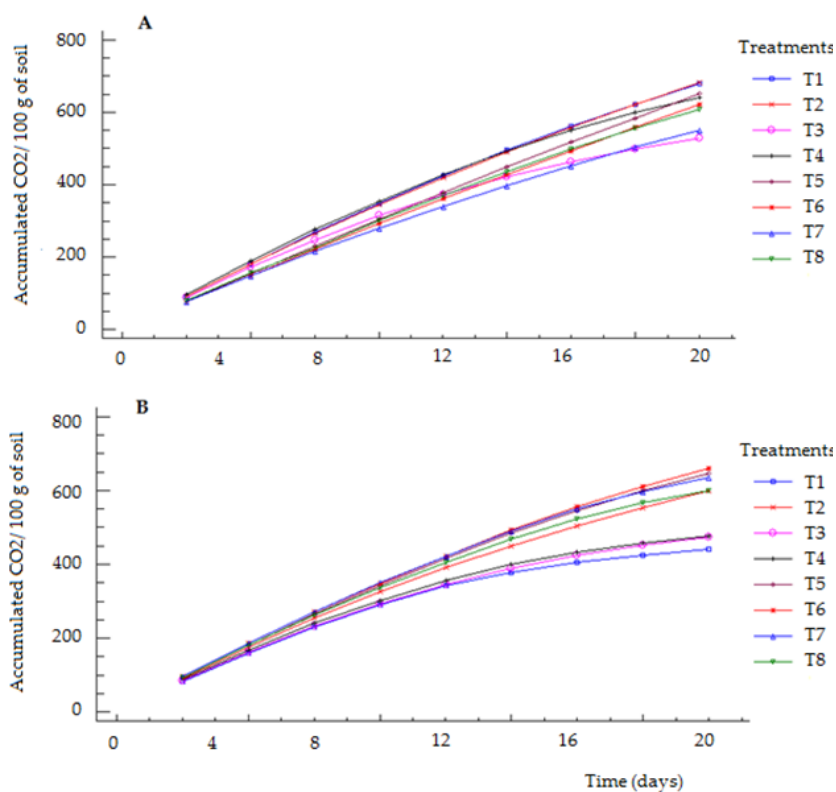
The C/N ratio is often used to evaluate compost stability (Chen *et al.*, 2023). Authors such as Katakula *et al.* (2021) and Dümenci *et al.* (2021) mention that a C/N ratio less than 20 indicates good quality vermicompost since soluble MO is biodegradable and contains stable high molecular weight compounds. If the C/N ratio is high, N is deficient to produce bacterial protein and the growth of organisms that decompose organic matter is reduced. Also, Das *et al.* (2021) and Gebrehana *et al.* (2023) explain that the quality of nutrients and the earthworm species present in the waste influence the C/N ratio, which is an important factor in favoring the growth rate of earthworms.

#### **Respiration, carbon mineralization and carbon residence time**

The respiratory activity in the treatments represented by factors "A" and "B" shows a similar behavior between them. Likewise, the respiratory activity at the initial time (15 d) (Figure 1A) is higher compared to that observed in the treatments for the final time (75 d) (Figure 1B). At first, the respiratory activity values vary from 640.21 to 814.68 mg CO<sub>2</sub> 100 g<sup>-1</sup> soil. On the other hand, at the end, values ranging from 475.98 to 659.01 mg CO<sub>2</sub> 100 g<sup>-1</sup> soil were recorded.

Respiratory activity at the initial time was notably higher in those treatments containing RD and LR, registering a value of  $741.7 \pm 48$  mg CO<sub>2</sub> 100 g<sup>-1</sup> soil. In contrast, treatments with a combination of EV and LR presented lower respiratory activity, with an average of  $616.8 \pm 8.6$  mg CO<sub>2</sub> 100 g<sup>-1</sup> soil. A similar pattern was observed at the final time, where the treatments with RD and LR exhibited higher respiratory activity, reaching a value of  $631.4 \pm 29$  mg CO<sub>2</sub> 100 g<sup>-1</sup> soil. In contrast, the mixture of EV and LR showed lower respiratory activity, with an average of  $516.29 \pm 70$  mg CO<sub>2</sub> 100 g<sup>-1</sup> soil. This variation can be attributed to the presence of a consortium of microorganisms derived from the waste residues and the vermicomposting process, which is in agreement with Suthar (2009).

It is worth mentioning that the respiratory activity was ascending at the beginning of the vermicomposting process, which is due to an accelerated degradation of the



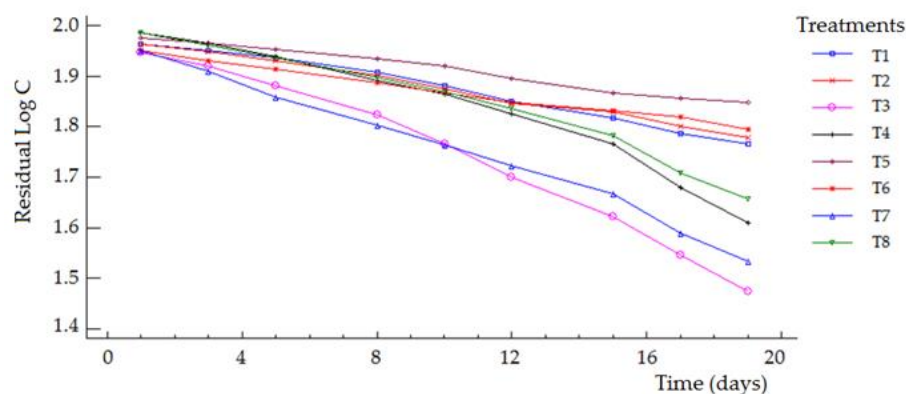
**Figure 1.** CO<sub>2</sub> evolution of the vermicompost in the eight treatments. A: at 15 d of incubation; B: at 75 d. Treatments contain combinations of cow manure (EV), worm castings (L), residual sludge (LR) and domestic waste (RD): T1 EV and L; T2 EV and 10 Mg of LR; T3 20 Mg of LR and L; T4 40 Mg of LR and L; T5 RD and L; T6 RD and 10 Mg of LR; T7 RD and LR; and T8 RD and 40 Mg of LR.

MO and the continuous feeding of the substrate by the earthworm, coinciding with Gómez-Brandón *et al.* (2022) and Chen *et al.* (2023). On the other hand, the respiratory activity of the treatments reaches a maximum and begins to stabilize, which is due to the decrease in respiratory activity due to the loss of available carbon sources and the presence of compounds rich in lignin and cellulose (Gusain and Suthar, 2020).

#### Carbon mineralization in the vermicompost

A significant change in carbon mineralization was observed in the treatments containing EV and LR; these mineralized at a faster rate compared to those containing RD and LR from day eight onwards. At this point, mineralization rate showed the following sequence: T4 ( $K_2 = -12.2 \times 10^{-3}$ ) > T3 ( $K_2 = -11.1 \times 10^{-3}$ ) > T1 ( $K_2 = -10.8 \times 10^{-3}$ ) > T2 ( $K_2 = -7.5 \times 10^{-3}$ ). This change possibly suggests a transition from labile to recalcitrant carbon after day eight, which slowed carbon degradation in all treatments.

As of day 10, a significant difference was seen between treatments T5, T6, T7, and T8, which contained RD and LR residues. The mineralization rate sequence in this case was the following: T8 ( $K_2 = -7.59 \times 10^{-3}$ ) > T7 ( $K_2 = -7.37 \times 10^{-3}$ ) > T5 ( $K_2 = -6.81 \times 10^{-3}$ ) > T6 ( $K_2 = -6.57 \times 10^{-3}$ ). This variation is probably related to the amount of organic matter present in each treatment (Figure 2).



**Figure 2.** Carbon mineralization rate curves at 75 d of incubation of the treatments. Treatments contained combinations of cow manure (EV), worm castings (L), residual sludge (LR), and domestic waste (RD): T1 EV and L; T2 EV and 10 Mg of LR; T3 20 Mg of LR and L; T4 40 Mg of LR and L; T5 RD and L; T6 RD and 10 Mg of LR; T7 RD and LR; and T8 RD and 40 Mg of LR.

As incubation time progressed, the treatments gradually entered a stage of stability, where the easily degradable material began to be depleted, thus decreasing degradation activity and carbon dioxide release (Alvarez and Alvarez, 2000). In terms of mineralization rate, treatments T1, T3, and T4 demonstrated a higher rate compared to those involving RD and LR, with T4 predominating. According to Chen *et al.* (2023), in order to assess the direct and indirect contributions of earthworms to carbon mineralization, a feeding model incorporating cow dung and stubble residues should be considered and related to the respiration model.

#### Carbon residence time of the mathematical model

The half-life of the mineralized organic carbon of each treatment was determined, focusing mainly on the K values at 60 d. Based on this information, a classification into three groups was carried out, considering the residence time. The first group covers the interval of  $t < 70$  d, where T3 (57 d), T4 (62 d), and T1 (64 d) are included. The second group comprises the interval  $70 < t < 100$  d, consisting of T2, T8 (91 d), and T7 (92 d). Finally, the third group encompasses those with  $t > 100$  d, being represented by T5 (105 d) and T6 (102 d) (Table 3).

**Table 3.** Carbon mineralization constants and half-life values at day 75 of the vermicomposting process for each treatment.

Treatments	Mineralization constants K1 and K2		Residence time (d <sup>1</sup> )
	K <sub>1</sub> (d <sup>-1</sup> ) (10 <sup>-3</sup> )	K <sub>2</sub> (d <sup>-1</sup> ) (10 <sup>-3</sup> )	
T1	-5.60	-10.80	64
T2	-15.50	-7.58	91
T3	-8.90	-11.10	62
T4	-8.65	-12.20	57
T5	-10.80	-6.81	102
T6	-7.58	-6.57	105
T7	-11.10	-7.37	94
T8	-12.20	-7.59	91

K<sub>1</sub> and K<sub>2</sub>: kinetic constants of carbon mineralization. Treatments contained combinations of cow manure (EV), worm castings (L), residue sludge (LR), and domestic residue (RD): T1 EV and L; T2 EV and 10 Mg of LR; T3 20 Mg of LR and L; T4 40 Mg of LR and L; T5 RD and L; T6 RD and 10 Mg of LR; T7 RD and LR; and T8 RD and 40 Mg of LR.

When validating the optimum residence time for vermicompost production, it is observed that the treatments containing EV and LR (T3 and T4) and only EV (T1) allow obtaining vermicompost in less than 70 d. Among these treatments, the one that incorporates 40 Mg of LR and EV (T4) stands out, achieving a time of 57 d and exhibiting ideal chemical and biological qualities for its use in agriculture. Therefore, it is considered that the T4 treatment is not only efficient in producing vermicompost in a reduced time, but also suitable for its application in agricultural soils and environmental improvement.

The model used to determine residence times proves to be practical and useful for predicting the duration of the vermicomposting process, which agrees with Dümenci *et al.* (2021) and Chen *et al.* (2023), who emphasized that mathematical models optimize the process and reduce costs, which benefits agricultural producers.

## CONCLUSIONS

Regarding pH, all treatments are slightly alkaline, which suggests that the process is effective at regulating pH. The concentration of organic matter in the treatments is deemed appropriate by the Mexican standard, with a higher percentage in T4 and T3, and the influence of the substances on vermicompost quality is noted. The amount of N in the treatments was low by standard, but its stability was demonstrated by the C/N ratio, which was only met at doses of 20 and 40 Mg of residual sludge and cow dung.

Respiratory activity was more dynamic in the treatments with domestic waste and residual sludge than those containing cow manure and residual sludge. In terms of mineralization rate and residence time, the vermicompost with 40 Mg and cow manure (T4) had an optimal processing time (less than 70 days) and met the standards, making it suitable for agriculture, while the other treatments may have a different purpose, such as forestry or restoration applications.

## REFERENCES

- Abbott LK, Macdonald LM, Wong, MTF Webb MJ, Jenkins SN, Farrell M. 2018. Potential roles of biological amendments for profitable grain production—A review. *Agriculture, Ecosystems and Environment* 256: 34–50. <https://doi.org/10.1016/j.agee.2017.12.021>
- Ahmed R, Deka H. 2022. Vermicomposting of patchouli bagasse—A by product of essential oil industries employing *Eisenia fetida*. *Environmental Technology and Innovation* 25: 102232. <https://doi.org/10.1016/j.eti.2021.102232>
- Álvarez R, Álvarez CR. 2000. Soil organic matter pools and their associations with carbon mineralization kinetics. *Soil Science Society of America Journal* 64 (1): 184–189. <https://doi.org/10.2136/sssaj2000.641184x>
- Bremner JM, Mulvaney RG. 1982. Nitrogen total. In Page AL, Miller RH, Keeney DR. (eds.), *Methods of soil analysis, part 2. Chemical and microbiological properties*. American Society of Agronomy: Madison, WI, USA, pp: 575–624.
- Cai L, Gong X, Ding H, Li S, Hao D, Yu K, Ma Q, Sun X, Munner MA. 2022. Vermicomposting with food processing waste mixture of soybean meal and sugarcane bagasse. *Environmental Technology and Innovation* 28: 102699. <https://doi.org/10.1016/j.eti.2022.102699>
- Chen Y, Zhang Y, Shi X, Shi E, Zhao T, Zhang Y, Xu L. 2023. The contribution of earthworms to carbon mineralization during vermicomposting of maize stover and cow dung. *Bioresource Technology* 368: 128283. <https://doi.org/10.1016/j.biortech.2022.128283>
- Das D, Abhishek K, Banik P, Bhattacharya P. 2021. A valorization approach in recycling of organic waste using low-grade rock minerals and microbial culture through vermicomposting. *Environmental Challenges* 5: 100225. <https://doi.org/10.1016/j.envc.2021.100225>
- Das D, Abhishek K, Banik P, Swain DK. 2022. Comparative evaluation of changes in soil bio-chemical properties after application of traditional and enriched vermicompost. *Environmental Technology and Innovation* 28: 102956. <https://doi.org/10.1016/j.eti.2022.102956>
- Denes J, Tremier A, Menasseri-Aubri S, Walter C, Gratteau L, Barrington S. 2015. Numerical simulation organic waste aerobic biodegradation: A new way to correlate respiration kinetics and organic matter fractionation. *Waste Management* 36: 44–56. <https://doi.org/10.1016/j.wasman.2014.11.013>
- Doan TT, Ngo PT, Rumpel C, Nguyen BV, Jouquet P. 2013. Interactions between compost, vermicompost and earthworms influence plant growth and yield: A one-year greenhouse experiment. *Scientia Horticulturae* 160: 148–154. <https://doi.org/10.1016/j.scienta.2013.05.042>
- DOF (Diario Oficial de la Federación). 2007. NORMA Oficial Mexicana NMX-FF-109-SCFI-2008 Humus de lombriz (lombricomposta), especificaciones y métodos de prueba. Gobierno de México. Secretaría de Economía, Secretaría de Agricultura, Ganadería, Desarrollo Rural,

- Pesca Y Alimentación. Ciudad de México, México. [https://www.dof.gob.mx/nota\\_detalle.php?codigo=5044562&fecha=10/06/2008](https://www.dof.gob.mx/nota_detalle.php?codigo=5044562&fecha=10/06/2008) (Recuperado: enero 2024).
- Dümenci NA, Yolcu OC, Temel FA, Turan NG. 2021. Identifying the maturity of co-compost of olive mill waste and natural mineral materials: Modelling via ANN and multi-objective optimization. *Bioresource Technology* 338: 125516. <https://doi.org/10.1016/j.biortech.2021.125516>
- Gómez-Brandón MG, Fornasier F, de Andrade N, Domínguez J. 2022. Influence of earthworms on the microbial properties and extracellular enzyme activities during vermicomposting of raw and distilled grape marc. *Journal of Environmental Management* 319: 1156554. <https://doi.org/10.1016/j.jenvman.2022.115654>
- Gebrehana ZG, Gebremikael MT, Beyene S, Sleutel S, Wesemael WML, de Neve S. 2023. Organic residue valorization for Ethiopian agriculture through vermicomposting with native (*Eudrilus eugeniae*) and exotic (*Eisenia fetida* and *Eisenia andrei*) earthworms. *European Journal of Soil Biology* 116: 103488. <https://doi.org/10.1016/j.ejsobi.2023.103488>
- Ghaffari H, Tadayon MR, Bahador M, Razmjoo J. 2022. Biochemical and yield response of sugar beet to drought stress and foliar application of vermicompost tea. *Plant Stress* 5: 100087. <https://doi.org/10.1016/j.stress.2022.100087>
- Gupta R, Garg VK. 2008. Stabilization of primary sewage sludge during vermicomposting. *Journal of Hazardous Materials* 153 (3): 1023–1030. <https://doi.org/10.1016/j.jhazmat.2007.09.055>
- Gusain R, Suthar S. 2020. Vermicomposting of duckweed (*Spirodela polyrhiza*) by employing *Eisenia fetida*: Changes in nutrient contents, microbial enzyme activities and earthworm biodynamics. *Bioresource Technology* 311: 123585. <https://doi.org/10.1016/j.biortech.2020.123585>
- Hait S, Tare V. 2011. Vermistabilization of primary sludge. *Bioresource Technology* 102 (3): 2812–2820. <https://doi.org/10.1016/j.biortech.2010.10.031>
- Hassan SAM, Taha RA, Zaied NSM, Essa EM, El-Rheem A. 2022. Effect of vermicompost on vegetative growth and nutrient status of acclimatized Grand Naine banana plants. *Heliyon* 8 (10): e10914. <https://doi.org/10.1016/j.heliyon.2022.e10914>
- Kassem A, Nannipieri P. 1995. *Methods in applied soil microbiology and biochemistry*. Academic Press: New York, NY, USA. 576 p. <https://doi.org/10.1016/B978-0-12-513840-6.X5014-9>
- Katakula AAN, Handura B, Gawanab W, Itanna F, Mupambwa HA. 2021. Optimized vermicomposting of goat manure vegetable food waste mixture for enhanced nutrient release. *Scientific African* 12: e00727. <https://doi.org/10.1016/j.sciaf.2021.e00727>
- Kauser H, Khwairakpam M. 2022. Organic waste management by two-stage composting process to decrease the time required for vermicomposting. *Environmental Technology and Innovation* 25: 102193. <https://doi.org/10.1016/j.eti.2021.102193>
- Mahapatra S, Hibzur Ali M, Kundan S. 2022. Assessment of compost maturity-stability indices and recent development of composting bin. *Energy Nexus* 6: 100062. <https://doi.org/10.1016/j.nexus.2022.100062>
- Nikaeen M, Nafez AH, Bina B, Nabavi BF, Hassanzadeh A. 2015. Respiration and enzymatic activities as indicators of stabilization of sewage sludge composting. *Waste Management* 39: 104–105. <https://doi.org/10.1016/j.wasman.2015.01.028>
- Rékási M, Ragályi P, Sándor DB, Szabó A, Rivier PA, Farkas C, Uzinger N. 2023. Effect of composting and vermicomposting on potentially toxic element contents and bioavailability

- in sewage sludge digestate. *Bioresource Technology Reports* 21: 101307. <https://doi.org/10.1016/j.biteb.2022.101307>
- Sharma K, Garg VK. 2017. Management of food and vegetable processing waste spiked with buffalo waste using earthworms (*Eisenia fetida*). *Environmental Science and Pollution Research* 24: 7829–7836. <https://doi.org/10.1007/s11356-017-8438-2>
- Sharma D, Pandey AK, Yadav KD, Kumar S. 2021. Response surface methodology and artificial neural network modelling for enhancing maturity parameters during vermicomposting of floral waste. *Bioresource Technology* 324: 124672. <https://doi.org/10.1016/j.biortech.2021.124672>
- Suthar S. 2009. Vermistabilization of municipal sewage amended with sugarcane trash using epigeic *Eisenia fetida* (Oligochaeta). *Journal of Hazardous Materials* 163 (1): 199–206. <https://doi.org/10.1016/j.jhazmat.2008.06.106>
- Tan Z, Ren Y, Han J, Chen S. 2021. Evolving pattern and improvement path of China's solid waste management policies. *Chinese Journal of Population, Resources and Environment* 19 (4): 358–368. <https://doi.org/10.1016/j.cjpre.2022.01.009>
- Ugak MA, Yacer AZ, Lamaning J, Subin EK, Rajin M, Saalah S, Tze FWH, Abang S. 2022. Comparative study on passive aerated in-vessel composting of food wastes with the addition of Sabah ragi. *Carbon Resources Conversion* 5 (3): 200–210. <https://doi.org/10.1016/j.crcon.2022.05.004>
- Vorobeva D, Scott JL, Oliveira T, Neto M. 2022. Adoption of new household waste management technologies: The role of financial incentives and pro-environmental behavior. *Journal of Cleaner Production* 362: 132328. <https://doi.org/10.1016/j.jclepro.2022.132328>
- Walkley A, Black IA. 1934. An examination of the Degtjareff Method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37 (1): 29–38. <https://doi.org/10.1097/00010694-193401000-00003>
- Wang Z, Chen Z, Niu Y, Ren P, Hao M. 2021. Feasibility of vermicomposting for spent dulling fluid from nature-gas industry employing earthworms *Eisenia fetida*. *Ecotoxicology and Environmental Safety* 214: 111994. <https://doi.org/10.1016/j.ecoenv.2021.111994>

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