

## Influence of earthworms on organic waste composting and characterisation of vermicompost end products

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### Abstract

The aim of this work was to study the influence of earthworms on the composting process. Selected waste mixtures—pine sawdust + poultry litter (M1), cotton industry waste + poultry litter (M2), shredded paper + horse manure (M3), and cotton industry waste + horse manure (M4)—were composted for 85, 64, 60 and 60 days respectively in plastic boxes. The temperature variations during this process followed the typical three-phase pattern. At the end of this process 95, 80, 75 and 95 g of *Eisenia andrei* were added to each treatment respectively to initiate vermicomposting. Together, the composting and vermicomposting processes took between 105 and 175 days. Earthworm biomass decreased in M1 and M2, and increased in M3 and M4. The physical, chemical and biological variables measured, such as time to compost maturity, the changes in earthworm population, the C/N ratio, and the availability of nutrients, showed that M3 was the best medium for earthworm activity, and that M4 had the best chemical and physical properties as an organic manure. Mixtures containing poultry litter were not suitable for vermicomposting. However, M1 was the best mixture in a test involving the growth of ryegrass (*Lolium perenne* cv. Weterwald); compared to controls, a 120% dry weight yield was obtained.

**Additional key words:** biological changes, cast properties, composting process.

### Resumen

#### **Acción de las lombrices en el compostaje de residuos orgánicos y caracterización de los productos finales**

El propósito de este trabajo fue estudiar el papel de las lombrices en el proceso de compostaje. Las mezclas de residuos seleccionados, serrín de pino + cama de pollo (M1), residuos de la industria algodonera + cama de pollo (M2), papel desmenuzado + estiércol de caballo (M3), residuos de la industria algodonera + estiércol de caballo (M4), se compostaron durante 85, 64, 60 y 60 días, respectivamente, en recipientes de plástico. La variación de la temperatura durante el proceso siguió el patrón típico de tres fases. Al final del proceso de compostaje se agregaron 95, 80, 75 y 95 g de *Eisenia andrei* a cada tratamiento. Ambos procesos, compostaje y vermicompostaje, tomaron de 105 a 175 días. La biomasa de lombrices disminuyó en M1 y M2, y se incrementó en M3 y M4. Los parámetros físicos, químicos y biológicos medidos una vez que el compost estuvo maduro, el aumento en las poblaciones de lombrices en algunos tratamientos, la relación C/N y la disponibilidad de nutrientes, demostraron que el tratamiento M3 fue el mejor medio para la actividad de las lombrices y que el tratamiento M4 tuvo las mejores propiedades físico-químicas como abono orgánico. Las mezclas con cama de pollo no fueron convenientes para la acción de las lombrices, sin embargo en el test con ryegrass (*Lolium perenne* cv. Weterwald) la M1 obtuvo el mejor rendimiento de materia seca (120%).

**Palabras clave adicionales:** cambios biológicos, proceso de compostaje, propiedades de los residuos.

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### Introduction

The disposal of urban and industrial wastes by methods that minimise environmental pollution and which decrease the need for landfill space would be

very advantageous. Composting appears to be one such option; this process reduces the volume and weight of raw materials and generates a stable product (Chefetz *et al.*, 1996). The use of composted manure improves soil quality and reduces the energy consumption associated with the use of commercial fertilisers (DeLuca and DeLuca, 1997). The importance of earthworms in soil structure, organic matter processing and

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nutrient cycling has long been recognised (Edwards and Lofly, 1982; Blair *et al.*, 1995). In recent years, the use of earthworms in waste degradation has spurred interest in their processing large quantities of waste materials. The use of vermicompost as a peat substitute in greenhouses has been proposed. Barley and Jennings (1959), Atlavinyte and Vanagas (1982), Kale *et al.* (1992) and Zhao and Fun-Zhen (1992) have all shown that vermicompost increases the nutrient uptake and net production of some crops. However, some studies report that the characteristics of vermicompost, and its effect on soils, can vary widely depending on the earthworm species involved, the availability and quality of the organic matter, and the age of the casts (Scheu, 1987; Wolters and Joergensen, 1992; Blair *et al.*, 1995). Most studies of this type report separate data on composting and vermicomposting.

The aim of the present work was to study both the composting and vermicomposting processes in order to determine some of the physical, chemical and biological changes that occur, and to characterise the properties of the end products.

## Material and Methods

The study consisted of three separate but related stages: i) the composting process, involving selected mixtures of local wastes, ii) the digestion of the composted mixtures by the earthworms, and iii) the characterisation of some of the chemical and physical properties of the end products.

### Composting process

This was performed in a ventilated room at  $20 \pm 5^\circ\text{C}$ , using mixtures of selected local wastes (Table 1). The different treatments (replicated four times) included: pine sawdust + poultry litter (M1), cotton industry

residues + poultry litter (M2), shredded paper + horse manure (M3), and cotton industry residues + horse manure (M4). The dry matter of each material (DMM) was determined by drying in an oven at  $105^\circ\text{C}$ . Some  $0.270 \text{ m}^3$  ( $2:1 \text{ v v}^{-1}$  dry weight) of each waste mixture was placed in perforated plastic boxes with a volume of  $0.350 \text{ m}^3$ . These wastes were turned and mixed thoroughly to initiate the composting process. Mixtures with their original moisture (MOM) content were wetted with deionised water to obtain a high moisture content of about 85%. The amount of water added was determined from the difference between the MOM and DMM. During composting, changes in moisture content were accounted for by weighing the boxes every five days and adding deionised water to maintain initial levels. To observe the variation in the volume of each mixture, a ruler was introduced into each box and changes in depth recorded. Volumes ( $\text{cm}^3$ ) were then determined. A thermometer was placed in each box to help detect the end of the composting process. The C/N ratio and the presence of nitrates plus a concurrent absence of  $\text{NH}_3$  were also measured to detect compost maturity. Samples from the upper 15 cm layer of each box (12 cores, 1.8 cm diameter) were collected and analysed in quadruplicate for total Kjeldahl N using the micro-Kjeldahl method. Ammonium-N and  $\text{NO}_3\text{-N} + \text{NO}_2\text{-N}$  were measured using the Griess-Ilosvay method (Keeney and Nelson, 1982). The compost was deemed to have reached maturity when there was an absence of  $\text{NH}_3$  and the temperature remained steady for five days.

### Earthworms used and the vermicomposting process

*Eisenia andrei* was the earthworm species selected for the vermicomposting procedure. The earthworms were raised in our laboratory from wild earthworms collected in compost. Cultures were established with young earthworms collected immediately after hatching. All cultures were maintained in plastic containers, ventilated at both ends, which were filled with organic residue (animal and vegetable) distributed freely over the waste surface. The moisture level of the food supply and habitat was maintained at 80-90% with deionised water. The plastic containers were placed in a ventilated greenhouse. The mean culture temperature was  $25^\circ\text{C}$  (range  $22\text{-}29^\circ\text{C}$ ).

To determine whether the composted mixtures were physical and chemically appropriate for earthworm

**Table 1.** Analysis of the original raw wastes

| Wastes                | C/N ratio | N<br>( $\text{g kg}^{-1}$ ) | OC<br>( $\text{g kg}^{-1}$ ) |
|-----------------------|-----------|-----------------------------|------------------------------|
| Pine sawdust          | 400       | 0.013                       | 5.2                          |
| Poultry litter        | 10.24     | 0.16                        | 1.7                          |
| Cotton industry waste | 570       | 0.01                        | 5.7                          |
| Horse manure          | 12.32     | 0.17                        | 1.9                          |

OC: organic carbon.

digestion, the following observations were made: time in days for earthworms to incorporate into the surface of the composted mixtures (ESC), time (in min) for earthworms to burrow into the mixture (EAM), compost digestion response time (days) (CD), difference in earthworm biomass between the beginning and end of the process (EB), and the production of cocoons (CP). According to the final volume of compost at the end of stage 1 (composting), earthworms were placed on the surface to initiate the second stage (vermicomposting); 95, 80, 75 and 95 g of earthworms were placed on M1, M2, M3 and M4 respectively.

The variables used to determine the end of vermicomposting were: earthworm permanence at the bottom of the compost for five days, and uniform particle size (i.e., when 95% of the volume of subsamples could pass through a 5 mm sieve).

## Chemical and physical characterisation

The vermicomposts produced were dried at 65°C to determine their dry matter content. Samples of each were taken to analyse their content in organic C (Nelson and Sommers, 1982), total nitrogen (using the semi-micro Kjeldahl method and employing a steam distillation apparatus) (Bremner and Mulvaney, 1982), and extractable phosphorus (determined colorimetrically by the ammonium molybdate-ascorbic acid method) (Murphy and Riley, 1962). The Mehlich I-extractable K, Fe, Mn, Cu and Zn contents were determined using an atomic absorption spectrophotometer (Page *et al.*, 1982). pH was measured using a glass-calomel electrode (solid: water, 1:2.5). The loss of volume by the products was obtained from the difference between that of each raw waste mixture and the final product. The final moisture of the end product was determined by drying at 65°C. The particle-size of the vermicompost was measured using a 5 mm sieve; sieve yield was determined as a  $v\ v^{-1}$  ratio.

## Plant bioassays

To assess the quality and maturity of the vermicomposts, plant growth tests were performed. One gram of ryegrass seeds (*Lolium perenne* cv. Weterwald) was scattered on each type in 0.5 L pots (three replicates and one control pot for each). These seeds were covered with a thin layer of vermiculite to prevent

drying, and watered daily with tap water. The moisture content of the control substrate and the vermicompost were maintained at water retention capacity. The plants were harvested 20 days after sowing and the dry matter yield obtained with each treatment was determined.

## Results

### Compost process

With the exception of M3, the temperature variation during composting (Fig. 1) followed the typical three-phase pattern of many composting systems. Initially, in the mesophilic phase, heat was generated and the temperature increased rapidly. This was followed by a thermophilic phase in which the temperature increased to about 50°C for 10 days before gradually decreasing to 30°C. It then remained almost constant for the rest of the process. Selected physicochemical variables were monitored for 100 days, including the pH and the presence of  $\text{NO}_3^-$ /absence of  $\text{NH}_3$  (Table 2). Compost maturity was reached at 85, 64, 60 and 60 days by M1, M2, M3 and M4 respectively.

The compost volume loss was determined before initiating the vermicomposting stage (data not shown).

### Earthworms and the vermicomposting process

Table 3 shows the behaviour of the earthworms during the vermicomposting process. The response time for their acceptance and adaptation to the composted mixtures (ESC) was different in M1 compared to the

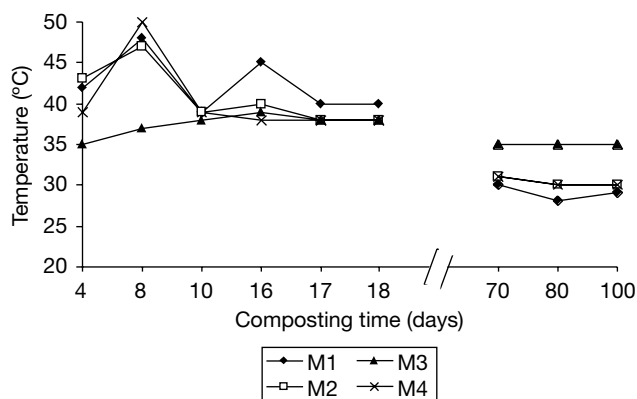


Figure 1. Changes in compost temperature over time.

**Table 2.** Physical and chemical changes over 100 days of the process

| Treatment | Days                         |                   |     |                              |                   |     |                              |                   |     |                              |                   |     |
|-----------|------------------------------|-------------------|-----|------------------------------|-------------------|-----|------------------------------|-------------------|-----|------------------------------|-------------------|-----|
|           | 35                           |                   |     | 60                           |                   |     | 73                           |                   |     | 100                          |                   |     |
|           | NH <sub>4</sub> <sup>+</sup> | N-NO <sub>3</sub> | pH  | NH <sub>4</sub> <sup>+</sup> | N-NO <sub>3</sub> | pH  | NH <sub>4</sub> <sup>+</sup> | N-NO <sub>3</sub> | pH  | NH <sub>4</sub> <sup>+</sup> | N-NO <sub>3</sub> | pH  |
|           | (mg kg <sup>-1</sup> )       |                   |     | (mg kg <sup>-1</sup> )       |                   |     | (mg kg <sup>-1</sup> )       |                   |     | (mg kg <sup>-1</sup> )       |                   |     |
| M1        | 60                           | nd                | 8.3 | 60                           | nd                | 7.6 | 70                           | 10                | 7.2 | 20                           | 70                | 6.8 |
| M2        | 67                           | nd                | 8.2 | nd                           | nd                | 6.8 | nd                           | nd                | 6.7 | nd                           | 30                | 6.7 |
| M3        | nd                           | nd                | 8.2 | nd                           | 77                | 8.0 | nd                           | 6                 | 8.3 | nd                           | nd                | 8.1 |
| M4        | nd                           | nd                | 8.0 | nd                           | nd                | 7.9 | 10                           | nd                | 7.3 | nd                           | 50                | 7.2 |

M1: pine sawdust + poultry litter. M2: cotton industry residues + poultry litter. M3: shredded paper + horse manure. M4: cotton industry residues + horse manure. nd : not detected.

rest of the treatments; some dead earthworms were found on the surface of this material. Earthworm biomass (EB) decreased by 65% with M1 and by 75% with M2, but increased by 105% with M3 and 37% with M4. Cocoon production (CP) was observed in M3 and M4 (in agreement with the increase in biomass) 30 days after the incorporation of the earthworms. The entire process (composting and vermicomposting) lasted 175, 124, 135 and 105 days for M1, M2, M3 and M4 respectively. As a result of CO<sub>2</sub> production, water evaporation and particle-size reduction during the process, reductions were observed in the volume of all the vermicomposts (Fig. 2) (e.g., a 12% volume loss was seen for M1 and a 86% loss for M4).

### Chemical and physical characterisation

The final mean moisture content of the vermicomposts was 65%. Sieve yield (v v<sup>-1</sup>) was 91% for M1, 70% for M2, 13% for M3 and 96% for M4. The low sieve yield for M3 was due to the high moisture content (90%). Table 4 shows some selected properties of the end products. The C/N ratios for the treatments were high except for M4, in agreement with the composition of its original material.

**Table 3.** Biological variables recorded during the vermicomposting process

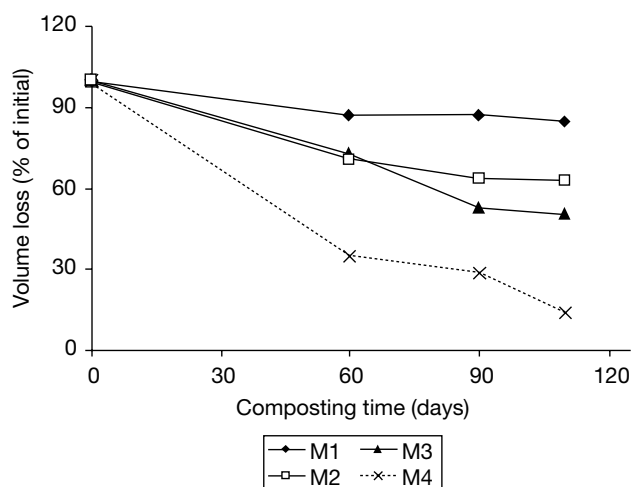
| Treat-<br>ment | ESC<br>(days) | EAM         | CD<br>(days) | EB<br>(%) | CP        |
|----------------|---------------|-------------|--------------|-----------|-----------|
| M1             | 85            | 15 min 10 s | 90           | -65       | Not found |
| M2             | 64            | 8 min 51 s  | 60           | -75       | Not found |
| M3             | 60            | 7 min 28 s  | 75           | 105       | Found     |
| M4             | 60            | 8 min 40 s  | 55           | 37        | Found     |

### Plant bioassay

The average dry weight of ryegrass plants grown in the vermicompost samples was compared to that obtained in the control and the following yields were obtained: 120% for M1, 112% for M2, 49% for M3 and 65% for M4.

### Discussion

The results confirm the favourable influence of earthworms in the degradation of composted wastes, and show that the production of vermicompost is possible under controlled conditions. The end products obtained had a low concentration of N available for plant growth, showed moderate increases in available P and K, and supplied sufficient quantities of micronutrients. The material obtained from M3 was the best

**Figure 2.** Volume loss vs. composting time.

**Table 4.** Characteristics of the end products (vermicompost)

| Treatment | pH    | C/N ratio | N                     | P     | K     | Cu                     | Mn    | Fe    |
|-----------|-------|-----------|-----------------------|-------|-------|------------------------|-------|-------|
|           |       |           | (g kg <sup>-1</sup> ) |       |       | (mg kg <sup>-1</sup> ) |       |       |
| M1        |       |           |                       |       |       |                        |       |       |
| Mean      | 7.2   | 16.8      | 0.08                  | 0.08  | 0.29  | 0.29                   | 82.7  | 6.3   |
| SE        | ±0.08 | ±0.06     | ±0.02                 | ±0.01 | ±0.03 | ±0.04                  | ±2.01 | ±0.37 |
| M2        |       |           |                       |       |       |                        |       |       |
| Mean      | 6.7   | 22.7      | 0.07                  | 0.07  | 0.76  | 0.20                   | 15.2  | 2.8   |
| SE        | ±0.29 | ±0.38     | ±0.01                 | ±0.01 | ±0.01 | ±0.03                  | ±0.39 | ±0.13 |
| M3        |       |           |                       |       |       |                        |       |       |
| Mean      | 8.2   | 15.5      | 0.14                  | 0.06  | 0.06  | 0.10                   | 14.8  | 1.5   |
| SE        | ±0.10 | ±0.41     | ±0.05                 | ±0.01 | ±0.01 | ±0.013                 | ±0.8  | ±0.21 |
| M4        |       |           |                       |       |       |                        |       |       |
| Mean      | 7.3   | 11.9      | 0.14                  | 0.06  | 0.74  | 0.21                   | 10.8  | 1.3   |
| SE        | ±0.05 | ±0.19     | ±0.02                 | ±0.01 | ±0.03 | ±0.01                  | ±1.5  | ±0.1  |

SE: standard error.

medium for earthworm reproduction, probably due to its high moisture content. M4 was the best in terms of its physical and chemical properties. However, the proper evaluation of compost maturity was difficult.

The results on the biological background of the vermicomposting process (Table 3) agree with those reported by Hartenstein *et al.* (1979) and Kaplan *et al.* (1980). These authors indicate the greatest biomass and maximum weight gain of earthworms in domestic dung or activated sludge to be achieved at temperatures of 20-29°C and at moisture levels of 70-85%. Hartenstein *et al.* (1979) found cocoon production in *E. andrei* to began when the earthworms were about four to six weeks old. Maximum cocoon production was attained when they were about 11 weeks old, after which point it declined. This might due to the high C/N ratio produced (see below), which has an initially detrimental effect on the number of earthworms. Hence, any increase in earthworm populations seems to occurs only after this initial decrease.

Table 4 shows that the C/N ratios for the treatments were all relatively high except for M4. The actual ratio obtained depended on the composition of the original material. Lee (1985) indicates that earthworms must ingest and re-ingest the organic matter available to them. It is known, however, that earthworms do not ingest all the plant litter, dung or other organic material that they move. A C/N ratio of 10-12 is considered an indicator of stability and that the organic matter is decomposed

(Jimenez and Garcia, 1992). Lee (1985) reports that the pH of earthworm casts is generally close to neutral, as seen in treatments M1, M2 and M4 (Table 4).

The availability of P in vermicompost is often significantly greater than in bulk soil. This can be attributed to the quantities of phosphorus ingested by earthworms in the organic matter they consume; this passes through the intestine and is excreted in their casts. Some authors believe that the greater release of P from casts is due to enhanced microbial activity (Lee, 1985; Scheu, 1987). However, others suggest it is due to increased phosphatase activity (Lavelle and Martin, 1992).

M3 and M4 had high pHs, possibly due to the excretion of ammonia into the earthworm intestine; this is therefore related to the vermicompost N content. The availability of nutrients in earthworms casts is generally greater than in bulk soils. However, the total N content found was low, probably because most of this element was mineralised as a result of microbial activity in stage 1. In this study, despite the high N content of the poultry manure, horse manure was a better substrate for the production of available N.

High K concentrations were found in the earthworm humus; a consequence of the high content of the original substrates. Other authors have reported similar results (Tiwari *et al.*, 1989; Basker *et al.*, 1992).

Lee (1985) suggests that differences in trace element contents may explain the effects of the composts on earthworm reproduction. This author also suggests that

the mineral contents of vermicompost can sometimes indicate the availability of trace elements to plants, and that they provide a measure of the importance of earthworms in transferring them. It is known that earthworms feed selectively on organic material, and thus they take in the trace elements available. However, the total amount involved must be small compared to the total amount of trace elements accessible in the soil.

The dry matter yield of the ryegrass plants grown in the four vermicomposts showed that the latter were mature and able to release enough nutrients to provide for good plant growth. However, further studies are needed on the effects of earthworms on different materials and at different scales. The quality of the vermicomposting end products and their content in available nutrients may be dependent on factors other than those analysed in this study. Further work is required to determine those involved.

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