



## Determination of the costs of the vermiculture production process in Quinindé Canton

## Determinación de los costos del proceso productivo de la vermicultura en el cantón Quinindé

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### Abstract

Vermiculture represents a sustainable biotechnological alternative for the management of organic waste and the production of high-quality compost. The objective of this study was to determine the production costs of the vermiculture process in Quinindé canton, Esmeraldas province, Ecuador. The research was conducted using a completely randomized design (CRD) with four treatments and their respective replicates: T1 (100% Musaceae rachises and stems), T2 (30% oil palm rachis + 70% organic waste), T3 (100% organic waste), and T4 (30% cattle manure + 70% organic waste), using Californian red worms (*Eisenia foetida*) at an initial density of 1 kg per experimental unit. The results showed that the treatment with oil palm rachis achieved the highest substrate reduction rate (67.0%), while the treatment with Musaceae achieved the highest earthworm multiplication rate (236%). Regarding production costs, the organic-waste treatment had the lowest total cost (US\$15.89 per total treatment biomass), while the oil-palm-rachis treatment had the highest profit margin (US\$37.10). The selling prices of worm castings ranged from US\$0.21 to US\$0.37 per kilogram, making them economically viable for small- and medium-sized producers. It is concluded that vermiculture is a profitable and sustainable alternative for agricultural waste management in the region, with the potential to contribute to the circular economy and sustainable agriculture.

**Keywords:** vermiculture, *Eisenia foetida*, vermicompost, production costs, sustainable agriculture, organic waste.

### Resumen

La vermicultura representa una alternativa biotecnológica sostenible para el manejo de residuos orgánicos y la producción de abono de alta calidad. El presente estudio tuvo como objetivo determinar los costos de producción del proceso productivo de la vermicultura en el cantón Quinindé, provincia de Esmeraldas, Ecuador. La investigación se desarrolló mediante un diseño completamente al azar (DCA) con cuatro tratamientos y sus respectivas repeticiones: T1 (raquis y tallos de musáceas 100%), T2 (raquis de palma aceitera 30% + residuos orgánicos 70%), T3 (residuos orgánicos 100%) y T4 (estiércol bovino 30% + residuos orgánicos 70%), utilizando lombriz roja californiana (*Eisenia foetida*) con una densidad inicial de 1 kg por unidad experimental. Los resultados obtenidos demostraron que el tratamiento con raquis de palma obtuvo la mayor tasa de reducción de sustrato (67,0%), mientras que el tratamiento con musáceas obtuvo la mayor tasa de multiplicación de lombrices (236%). Con respecto a los costos de producción, el tratamiento con residuos orgánicos obtuvo el menor costo total (\$15,89 por biomasa total del tratamiento), mientras que el tratamiento con raquis de palma obtuvo el más alto margen de ganancia (\$37,10). Los precios de venta del humus de lombriz oscilaron entre \$0,21 y \$0,37 por kilogramo, siendo económicamente viables para pequeños y medianos productores. Se concluye que la vermicultura constituye una alternativa rentable y sostenible para la gestión de residuos agrícolas en la región, con potencial para contribuir a la economía circular y la agricultura sostenible.

**Palabras clave:** vermicultura, *Eisenia foetida*, vermicompost, costos de producción, agricultura sostenible, residuos orgánicos.



## Introduction

The sustainable management of organic waste has become one of the most important challenges facing agriculture today, particularly in tropical regions such as Ecuador's coastal region, where organic waste is generated in large volumes (Enebe and Erasmus, 2023).

In this context, vermiculture has emerged as a promising biotechnology that uses the capacity of Californian red worms to transform this waste into a high-quality fertilizer known as vermicompost or worm castings (Dervash et al., 2024).

Vermiculture, also known as earthworm farming, involves a process of bio-oxidation and transformation of organic waste through the synergistic action of Californian red worms and associated microorganisms (Ratnasari et al., 2023).

Among the earthworm species most widely used for waste decomposition, the Californian red worm (*Eisenia foetida*) stands out because of its high reproductive capacity, tolerance of variable environmental conditions, and efficiency in converting organic substrates (Alcívar, 2023). This species can process an amount of organic matter equivalent to its own body weight each day, generating a final product rich in nutrients and beneficial microorganisms (Canales-Gutiérrez et al., 2021).

The resulting vermicompost is characterized by a higher concentration of available nutrients, a larger beneficial microbial load, the presence of plant growth hormones, elevated levels of soil enzymes, and long-term nutrient-retention capacity without negative environmental impacts (Domínguez et al., 2019). Studies have shown that vermicompost contains approximately four times more nitrogen, 25 times more phosphorus, and two and a half times more potassium than cattle manure (Riascos-Vallejos et al., 2022).

In Ecuador, vermiculture has grown exponentially over the past decade because of the increasing demand for organic products and the need to implement sustainable agricultural practices (Chirinos et al., 2020). Ecuador has favorable climatic conditions for vermiculture, especially along the coast, where temperature and humidity are optimal for the reproduction of *E. foetida* (Campoverde et al., 2020).

Quinindé canton has ideal agroecological characteristics for implementing vermiculture. The local economy is based on banana, African oil palm, and cacao crops, which generate large volumes of organic waste that are underused in most cases (Vásquez and Iannacone, 2017). Transforming this waste through vermiculture would not only help reduce environmental pollution but would also generate a high-value-added product for crop fertilization.

Production costs are a determining factor in the economic viability of any agricultural venture (Marnetti, 2012). In vermiculture, these costs include the initial investment in infrastructure, the purchase of Californian red worms, substrate preparation, labor, and irrigation water (Colín-Navarro et al., 2018). Accurate knowledge of these costs allows producers to set prices, evaluate project profitability, and make decisions about production scale.

Despite the potential of vermiculture in the canton, information is lacking on the production costs associated with the different types of locally available substrates. This information is essential for guiding farmers in material selection (Palacios-Valenzuela et al., 2021). Moreover, an economic comparison of different treatments makes it possible to identify those offering the best cost-benefit ratio.

This study is based on the hypothesis that vermicompost production costs vary significantly according to the type of substrate used and that this variation directly affects the profitability of the production process. The research seeks to generate technical and economic information that will enable local producers to optimize their vermiculture processes and contribute to the development of more sustainable agriculture in Quinindé canton.

The objective of this study was to determine the production costs of the vermiculture production process in Quinindé canton, Ecuador.

## Materials and methods

The study used a completely randomized design (CRD) with a quantitative approach to evaluate the biological efficiency and production costs of vermicompost made from agricultural substrates available in Quinindé canton, Esmeraldas province.

The indicators evaluated were the substrate reduction rate, which reflects the efficiency of organic-matter degradation, and the earthworm multiplication rate, which indicates the suitability of the substrate for the development of *E. foetida*. In addition, total production costs and the selling price of worm castings per kilogram were calculated for each treatment.

The experiment was organized into four treatments according to the type of substrate available in the area, selected for its abundance in the canton's agricultural activities. The four treatments were T1 (100% Musaceae rachises and stems), T2 (30% oil palm rachis + 70% organic waste from vegetables, legumes, and produce), T3 (100% organic waste from vegetables, legumes, and produce), and T4 (30% cattle manure + 70% organic waste from vegetables, legumes, and produce). Each treatment began with 1 kg of Californian red worms (*E. foetida*) and was conducted with two replicates (A and B). The trial lasted

16 weeks, during which substrate and earthworm biomass were recorded.

During the experimental period, the environmental and physicochemical conditions of the experimental units were monitored. Substrate moisture was maintained between 70 and 80% and adjusted through periodic irrigation with non-chlorinated water (100 L per experimental unit) to ensure optimal conditions for microbial and earthworm activity. Ambient temperature ranged from 22 to 28 °C, a range considered suitable for the development and reproduction of *E. foetida* according to Díaz et al. (2008). Substrate pH was determined at the beginning and end of the process using a pH meter. Initial values ranged from 6.5 to 7.5, a condition that favored both microbial activity and earthworm well-being while avoiding extreme acidity or alkalinity that could compromise organic-matter decomposition. The following formulas were used for the biological analysis:

Substrate reduction rate (%)

$$\frac{\text{Biomasa inicial} - \text{Biomasa final}}{\text{Biomasa inicial}} \times 100$$

Earthworm multiplication rate

$$\frac{\text{Biomasa final} - \text{Biomasa inicial}}{\text{Biomasa inicial}}$$

Labor cost was estimated as 30% of total cost (TC), and the retail selling price (RSP) was calculated by applying a 30% profit margin to the production cost divided by the final product biomass. Substrate costs were determined on the basis of local prices in Quinindé canton, including materials, Californian red worms, water, and labor.

## Results and discussion

### Substrate reduction rate

Evaluation of the substrate reduction rate is a fundamental indicator of the efficiency of the vermicomposting process, reflecting the capacity of earthworms and associated microorganisms to degrade organic matter (Wang et al., 2024). Table 1 presents the initial and final biomass recorded for each treatment.

**Table 1.** Initial and final substrate biomass by treatment type and replicate.

| Treatment | Substrate              | Initial biomass (kg) | Final biomass (kg) |
|-----------|------------------------|----------------------|--------------------|
| T1A       | Musaceae               | 276.10               | 93.64              |
| T1B       | Musaceae               | 312.74               | 121.36             |
| T2A       | Oil palm rachis + O.W. | 295.10               | 97.27              |
| T2B       | Oil palm rachis + O.W. | 307.35               | 106.36             |
| T3A       | Organic waste          | 219.12               | 92.73              |
| T3B       | Organic waste          | 191.72               | 88.18              |
| T4A       | Cattle manure + O.W.   | 191.00               | 135.00             |
| T4B       | Cattle manure + O.W.   | 175.07               | 91.36              |

Note: The letters A and B accompanying treatments T1A through T4B correspond to the replicates. O.W. = organic waste from vegetables, legumes, and produce.

The substrate reduction rates calculated for each treatment are shown in table 2, demonstrating variation among the different substrate types.

**Table 2.** Substrate reduction rate by treatment.

| Treatment | Substrate       | Reduction rate (%) | Mean reduction rate (%) |
|-----------|-----------------|--------------------|-------------------------|
| T1A       | Musaceae        | 66.1               | 63.65                   |
| T1B       | Musaceae        | 61.2               |                         |
| T2A       | Oil palm rachis | 67.0               | 66.45                   |
| T2B       | Oil palm rachis | 65.9               |                         |
| T3A       | Organic waste   | 57.9               | 55.90                   |
| T3B       | Organic waste   | 53.9               |                         |
| T4A       | Cattle manure   | 10.5               | 29.15                   |
| T4B       | Cattle manure   | 47.8               |                         |

Note: The letters A and B accompanying treatments T1A through T4B correspond to the replicates.

The results show that treatment T2A (oil palm rachis + organic waste) achieved the highest reduction rate (67.0%), followed by T1A (Musaceae) at 66.1% and T2B at 65.9%. These values were consistent with those reported by Paco et al. (2011), who observed reduction rates of 60-70% when vermicomposting plant waste over similar periods.

The high reduction rate observed in the oil-palm-rachis treatment may be attributed to the lignocellulosic composition of this material, which favored microbial and enzymatic activity during the degradation process (Khatua et al., 2018). According to Liu et al. (2020), substrates with higher biodegradable carbon contents tended to show higher humification rates and, consequently, greater volume reduction.

In contrast, treatment T4A (cattle manure) showed the lowest reduction rate (10.5%), which was atypical and may have been related to suboptimal moisture or temperature conditions during the experimental period. Studies by Santos Calderón et al. (2021) reported reduction rates of 45-55% for cattle-manure-based substrates, suggesting that environmental or management factors may have influenced the low performance observed in T4A.

The Musaceae treatments (T1A and T1B) showed consistent behavior, with reduction rates of 66.1 and 61.2%, respectively. These results agreed with Mendoza (2023), who reported similar degradation efficiencies for cellulose-rich plant substrates. The slight difference between replicates (4.9 percentage points) was within the range of normal variability reported in the literature for vermicomposting experiments (Rincones et al., 2023).

### Multiplication rate of *Eisenia foetida*

The earthworm multiplication rate was a critical parameter for evaluating substrate suitability and the conditions of the vermicomposting system (Bravo et al., 2018). Table 3 presents the initial and final biomass of the earthworm populations in each treatment.



**Table 3.** Initial and final biomass of Californian red worms by treatment.

| Treatment | Substrate       | Initial biomass (g) | Final biomass (g) |
|-----------|-----------------|---------------------|-------------------|
| T1A       | Musaceae        | 1,000               | 1,310             |
| T1B       | Musaceae        | 1,000               | 3,360             |
| T2A       | Oil palm rachis | 1,000               | 2,090             |
| T2B       | Oil palm rachis | 1,000               | 1,070             |
| T3A       | Organic waste   | 1,000               | 2,400             |
| T3B       | Organic waste   | 1,000               | 160               |
| T4A       | Cattle manure   | 1,000               | 1,010             |
| T4B       | Cattle manure   | 1,000               | 2,340             |

Note: The letters A and B accompanying treatments T1A through T4B correspond to the replicates.

The calculated multiplication rates reveal markedly different responses among treatments and replicates, as shown in table 4.

**Table 4.** Earthworm multiplication rate by treatment.

| Treatment | Substrate       | Multiplication rate (%) |
|-----------|-----------------|-------------------------|
| T1A       | Musaceae        | 31                      |
| T1B       | Musaceae        | 236                     |
| T2A       | Oil palm rachis | 109                     |
| T2B       | Oil palm rachis | 7                       |
| T3A       | Organic waste   | 140                     |
| T3B       | Organic waste   | -84                     |
| T4A       | Cattle manure   | 1                       |
| T4B       | Cattle manure   | 134                     |

Note: The letters A and B accompanying treatments T1A through T4B correspond to the replicates.

Analysis of the multiplication rates revealed marked heterogeneity among treatments and replicates, with values ranging from -84% (T3B) to 236% (T1B). Treatment T1B (Musaceae) showed the highest multiplication rate (236%), indicating optimal conditions for the development and reproduction of *E. foetida* in this specific substrate.

These results partially agreed with Alcívar (2023), who found that plant-waste-based substrates favored earthworm reproduction because of their suitable C/N ratio and moisture content. However, the marked difference between T1A (31%) and T1B (236%) suggested that additional factors, such as substrate homogeneity, degree of pre-composting, or the specific

microenvironmental conditions of each experimental unit, significantly influenced the results.

The negative value observed in T3B (-84%) indicated a drastic reduction in the earthworm population, which may be attributed to adverse conditions such as excess moisture, accumulation of toxic gases, or pathogen development (Cuzco, 2019). According to Romero et al. (2018), high mortality rates in vermicomposting systems were frequently associated with imbalances in the substrate carbon-to-nitrogen ratio or the presence of compounds toxic to earthworms.

The cattle-manure treatments (T4A and T4B) showed contrasting responses, with rates of 1% and 134%, respectively. This variability was consistent with the observations of Canales et al. (2020), who reported that cattle manure required an adequate prior maturation process to prevent the generation of heat and gases that adversely affected earthworms. The difference between replicates may be explained by variation in the degree of stabilization of the manure used.

It is important to note that, according to Díaz et al. (2008), the optimal temperature for the reproduction of *E. foetida* is 15-25 °C, a range that may have been exceeded in some experimental units during the study period. Vidaña-Martínez et al. (2017) also noted that initial population density and food availability were determining factors in earthworm population dynamics.

### Production costs and selling prices

The economic analysis was a fundamental component in determining the viability and sustainability of vermiculture systems (Vásquez & Iannaccone, 2017). Tables 5 through 8 detail the production costs for each treatment.

**Table 5.** Production costs of treatment T1 (Musaceae) per kilogram.

| Component                  | T1A quantity | T1A cost (US\$) | T1B quantity | T1B cost (US\$) |
|----------------------------|--------------|-----------------|--------------|-----------------|
| Musaceae rachis (kg)       | 276.10       | 6.07            | 312.74       | 6.88            |
| Water (L)                  | 100          | 2.50            | 100          | 2.50            |
| Californian red worms (kg) | 1            | 5.50            | 1            | 5.50            |
| Labor                      | -            | 4.13            | -            | 4.46            |
| TOTAL COST                 | -            | 18.20           | -            | 19.34           |

Note: A and B correspond to replicates 1 and 2 of each treatment.

**Table 6.** Production costs of treatment T2 (oil palm rachis) per kilogram.

| Component                  | T2A quantity | T2A cost (US\$) | T2B quantity | T2B cost (US\$) |
|----------------------------|--------------|-----------------|--------------|-----------------|
| Organic waste (kg)         | 206.57       | 4.55            | 215.15       | 4.73            |
| Oil palm rachis (kg)       | 88.53        | 8.85            | 92.21        | 9.22            |
| Water (L)                  | 100          | 2.50            | 100          | 2.50            |
| Californian red worms (kg) | 1            | 5.50            | 1            | 5.50            |
| Labor                      | -            | 6.42            | -            | 6.59            |
| TOTAL COST                 | -            | 27.82           | -            | 28.54           |

Note: A and B correspond to replicates 1 and 2 of each treatment.

**Table 7.** Production costs of treatment T3 (organic waste) per kilogram.

| Component                  | T3A quantity | T3A cost (US\$) | T3B quantity | T3B cost (US\$) |
|----------------------------|--------------|-----------------|--------------|-----------------|
| Organic waste (kg)         | 219          | 4.82            | 191.72       | 4.22            |
| Water (L)                  | 100          | 2.50            | 100          | 2.50            |
| Californian red worms (kg) | 1            | 5.50            | 1            | 5.50            |
| Labor                      | -            | 3.85            | -            | 3.67            |
| TOTAL COST                 | -            | 16.67           | -            | 15.89           |

Note: A and B correspond to replicates 1 and 2 of each treatment.

**Table 8.** Production costs of treatment T4 (cattle manure) per kilogram.

| Component                  | T4A quantity | T4A cost (US\$) | T4B quantity | T4B cost (US\$) |
|----------------------------|--------------|-----------------|--------------|-----------------|
| Organic waste (kg)         | 133.70       | 2.94            | 122.55       | 2.70            |
| Cattle manure (kg)         | 57.30        | 5.73            | 52.52        | 5.25            |
| Water (L)                  | 100          | 2.50            | 100          | 2.50            |
| Californian red worms (kg) | 1            | 5.50            | 1            | 5.50            |
| Labor                      | -            | 5.00            | -            | 4.79            |
| TOTAL COST                 | -            | 21.67           | -            | 20.74           |

Note: A and B correspond to replicates 1 and 2 of each treatment.

The selling prices and profit margins calculated for each treatment are consolidated in table 9, allowing an overall comparison of profitability.

The economic analysis shows that treatment T3B (100% organic waste) had the lowest total production cost (US\$15.89), while T2B (oil palm rachis) had the highest cost (US\$28.54). The US\$12.65 difference among treatments represented a variation of 79.7%, highlighting the importance of substrate selection in the economics of the production process.

Selling prices per kilogram of worm castings ranged from US\$0.21 (T1B and T4A) to US\$0.37 (T2A), values that were competitive in the local organic-fertilizer market. According to

the study by Vásquez and Iannacone (2017) on vermiculture in Peru, selling prices for worm castings vary considerably according to region and target market, with reported ranges of US\$0.15 to US\$0.50 per kilogram in Latin America.

**Table 9.** Selling price and profit margin by treatment.

| Treatment | Final biomass (kg) | Total cost (US\$) | 30% margin (US\$) | Price/kg (US\$) | Price/lb (US\$) | Price/qq (US\$) |
|-----------|--------------------|-------------------|-------------------|-----------------|-----------------|-----------------|
| T1A       | 93.64              | 18.20             | 23.66             | 0.25            | 0.11            | 11.48           |
| T1B       | 121.36             | 19.34             | 25.14             | 0.21            | 0.09            | 9.42            |
| T2A       | 97.27              | 27.82             | 36.17             | 0.37            | 0.17            | 16.90           |
| T2B       | 106.36             | 28.54             | 37.10             | 0.35            | 0.16            | 15.86           |
| T3A       | 92.73              | 16.67             | 21.67             | 0.23            | 0.11            | 10.62           |
| T3B       | 88.18              | 15.89             | 20.66             | 0.23            | 0.11            | 10.65           |
| T4A       | 135.00             | 21.67             | 28.17             | 0.21            | 0.09            | 9.49            |
| T4B       | 91.36              | 20.74             | 26.96             | 0.30            | 0.13            | 13.42           |

Note: A and B correspond to replicates 1 and 2 of each treatment.

Selling prices per kilogram of worm castings ranged from US\$0.21 (T1B and T4A) to US\$0.37 (T2A), values that were competitive in the local organic-fertilizer market. According to the study by Vásquez and Iannacone (2017) on vermiculture in Peru, selling prices for worm castings vary considerably according to region and target market, with reported ranges of US\$0.15 to US\$0.50 per kilogram in Latin America.

Treatment T2B showed the highest reported absolute profit-margin figure (US\$37.10), which was attributed to the higher cost of the inputs used (oil palm rachis). However, from an economic-efficiency perspective, treatment T3B offered the best cost-benefit ratio because it had the lowest production cost while maintaining a competitive selling price (US\$0.23/kg).

Labor costs represented between 22% and 25% of total cost in all treatments, consistent with Colín-Navarro et al. (2018), who identified labor as one of the main cost components in small- and medium-scale vermiculture systems. Optimizing this component by implementing efficient management practices could contribute significantly to cost reduction.

Compared with conventional chemical fertilizers, whose prices have increased significantly in recent years because of geopolitical and market factors (Peralta et al., 2019), the vermicompost produced in this study represents an economically viable and environmentally sustainable alternative for farmers in Quinindé canton.

## Conclusion

The experimental analysis conducted in Quinindé canton shows that vermicompost production costs vary according to the type of substrate used. Treatment T3B (100% organic waste) had the lowest total production cost (US\$15.89), whereas treatment T2B (oil palm rachis) obtained the highest reported absolute profit margin (US\$37.10), with a cost of US\$28.54 and a selling price



of US\$0.35 per kilogram. These differences show that substrate selection directly influences the profitability of the production process.

From a biological perspective, the Musaceae substrate (T1B) favored the highest earthworm multiplication rate (236%), while oil palm rachis (T2A) produced the greatest substrate reduction (67.0%). Selling prices per kilogram of worm castings ranged from US\$0.21 to US\$0.37, values that are competitive in the local organic-fertilizer market. Overall, the results confirm that vermiculture using locally sourced agricultural substrates is economically viable for small- and medium-scale producers in Quinindé canton and represents a concrete alternative for the recovery and valorization of agricultural waste and the strengthening of sustainable production systems.

#### Conflict of Interest

The authors declare that they have no conflicts of interest at any stage of this publication.

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### CRedit author contribution statement

**Mercy Jacqueline Cabrera Arrobo:** Conceptualization, methodology, investigation, formal analysis, writing - original draft, writing - review & editing, supervision, project administration. **Fernando Rodolfo Intriago Mendoza:** Investigation, data curation, formal analysis, writing - review & editing. **Darwin Francisco Talledo Villacreses:** Investigation, data curation, visualization, writing - review & editing.

