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Chemical and Physical Characterization of Vermicompost Produced from Organic Substrates

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present research was based on the evaluation of some physical and chemical properties of humus, using *Eisenia foetida* for the transformation of substrates. It was established under a completely randomized experimental design, six treatments were evaluated: T1; Bovine manure, T2; Sheep manure, T3; Cocoa shell, T4; 50% Bovine Manure and 50% Sheep Manure; T5; 50% Bovine manure and 50% Cocoa shell, T6; 50% Sheep manure and 50% Cocoa shell, with four repetitions respectively. The variables evaluated were major elements (N, P, K, S, Ca and Mg), as

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well as the C/N ratio, pH, MO, granulometry and EC. The results showed that the type of manure directly influences the quality of humus as a substrate, highlighting T2 with 0.486% in P. It is important to note that the origin, age and storage of the materials influence the mineral composition and part of the plant used, such as the cocoa fruit, which is a sink in K, reflecting T3 with 2.723% in K, 2.116% in N and 37.089% in MO above all treatments. Therefore, the choice of materials and their pre-composting processes must be adequate to feed the worms and some physical and chemical parameters required to obtain the quality and quantity of humus as a substrate, since an unexamined decision can reach to increase the mortality of worms by 100%.

Keywords: Agroecological alternatives; organic fertilizers; humus.

1. INTRODUCTION

Organic agriculture uses a great variety of technological options with the aim of reducing and retrieving production costs, protecting health, improving the quality of life and the quality of the environment, and intensifying biological interactions and beneficial natural processes [1].

Residual organic materials, such as those coming from harvest and livestock activities, usually end up in the environment, saturating food chains, however, they may have a better destiny if they are transformed into composts, which are potentially reliable for use as a mean for lant growth [2].

The harnessing of–agro-industrial waste in the production of agricultural substrates is an important alternative for the recycling of these materials, in addition to their agronomic, social, economic, and ecological importance, contributing in a positive way to the increase in production and the improvement of crop quality [3].

These wastes, after going through the vermicomposting process, present ideal characteristics to be used as substrates [4]. Vermicomposting is defined as the degradation and biological stabilization of organic matter, after the digestion of organic waste by earthworms, with the species *Eisenia foetida* being the most used [5]. The product of vermicomposting is an organic fertilizer obtained from plant waste or animal manure, previously stabilized and neutral [6-10].

In the state of Chiapas, exist a large amount of organic matter left over from agricultural activities, such as cocoa husks and livestock activities related to cattle, horse, and sheep production, which are sometimes not used properly and can affect the environment because they are carried directly to drainage systems and bodies of water.

In this context, the present study proposes the use of agro-industrial residues from cocoa husks mixed with different types of manure to obtain organic substrates through vermicomposting, using the Californian red earthworm (*Eisenia foetida*).

2. MATERIALS AND METHODS

The research was carried out in the municipality of Huehuetán, in the state of Chiapas. The experimental site is geographically located at 15°22'40,96" LN and -92°22'40,96" LO with an altitude of 65 masl, as shown in Fig. 1.

The type of climate that predominates in Huehuetán, Chiapas, according to CONAGUA [11], has a warm humid climate with summer rains that corresponds to Aw (w) ig. The National Meteorological Service (NMS) with its climatological normals, mentions that the annual rainfall in Huehuetán is 2420.5 mm and has an average maximum temperature of 34.6℃ , average of 28.2℃ and a minimum of 21.8℃.

2.1 Experimental Design

A completely randomized experimental design was employed, using three substrates and their combinations at 50%, resulting in six treatments. Considering four replications per treatment, a total of 24 experimental units were obtained. To differentiate one treatment from the others, a letter with its respective number was assigned for the total number of replications for each treatment, presented as follows:

T1- Bovine manure (100%)
T2- Sheep manure (100%)
T3- Cocoa husk (100%)
T4- Bovine manure (50%) / Sheep manure (50%)
T5- Bovine manure (50%) / Cocoa husk (50%)
T6- Sheep manure (50 %) / Cocoa husk (50%)

Fig. 1. Geographic location of the study area

2.2 Experimental Materials

The vermicomposting stage was carried out in commercial plastic grids (37.79 cm wide x 54.48 cm long x 32.5 cm high), with a total volume of 0.066 m^3, of which 0.03 m^3 were used with fresh material from each of the treatments. The grids were covered with small-pore wire mesh to prevent the entry of animals and insects and to favor aeration.

The materials used (bovine manure, sheep manure and cocoa husks) were pre compost before inoculation with the worm, to provide adequate conditions to the substrate for the adaptation of the worm. Once the grids were inoculated, they were watered daily to maintain the substrate humidity at 80%.

The earthworm *Eisenia foetida* also called "red Californian", was used, which was placed at a density of 100 adults per 0.03 m^3 of fresh material. The worms used were mature and developed individuals, which presented the clitellar structure formed. After three months, the humus was recovered for its evaluation and characterization through chemical and physical properties.

2.3 Chemical Analysis

Chemical analyses were performed according to the Mexican standard for vermicompost [12], where the percentage of organic matter (OM), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sulfur (S), calcium (Ca), C/N ratio, pH and electrical conductivity (EC) were determined.

The pH was determined with a potentiometer on approximately 50 g of saturated paste of the material and after 1 h of rest. The saturated paste was then filtered, the liquid was collected, and the electrical conductivity (EC) was measured, the units used were dSm^{-1}. The calculation of organic matter (OM) and the carbon-nitrogen ratio (R:C/N) were carried out with the determination of organic carbon using the Walkey-Black method. The major elements N, P, K, S, Ca and Mg were determined after total digestion of the compost, a process by which all the organic components are mineralized. These elements were then determined by atomic absorption photometric spectrometry and colorimetry, the latter for P. The N was determined by the Kjeldahl method. All these analyses were carried out in the soil laboratory of the Faculty of Agricultural Sciences (FCA), Campus IV, of the Autonomous University of Chiapas (UNACH).

2.4 Physical Analysis

Physical analyses were carried out according to the Mexican standard [12]. The EC was measured at a fertilizer water ratio (1:5 w/v) with a potentiometer (Orion Star model A211, Iowa, USA). The mean particle diameter (Mpd) was determined by granulometric analysis, using the sieving method for the ASTM √2 sieve series.

2.5 Statistical Analysis

The data obtained was processed using SAS software version 9.0. To establish the statistical difference between the variables, an analysis of variance (ANOVA) was performed and in cases statistical differences were found, they were compared with Tukey's test (ρ≤ 0.05).

3. RESULTS AND DISCUSSION

3.1 Characteristics of the Obtained Vermicompost

3.1.1 Phosphorus (P), potassium (K), calcium (Ca), sulfur (S) and magnesium (Mg)

Table 1 shows, apart from N, the total element contents for the different vermicomposts evaluated. The results show that the quality and quantity of the composts are affected by the different materials used.

In the case of P, treatment T2 (100% sheep manure) stands out with a value of 0.486 %, differing statistically from the rest of the treatments. This result corresponds to that cited by Rincones [13], who propose adequate values of 0.4 % or higher. Similar results were obtained by Srivastava [14], who obtained the highest P value in vermicompost from manure.

Treatment T3, with the highest percentage of cocoa husk, has the lowest value among treatments (0.043%), because of its vegetable origin and has no nutritional value. This behavior could have influenced the values observed in treatment T5 (the second lowest value) in the presence of 50% cocoa husk. Similar results were reported by David-Santoya [15], who obtained the lowest phosphorus values (0.2%) with the highest combination of cocoa husk in their treatments.

Table 1. Mean values of phosphorus (P), potassium (K), calcium (Ca), sulfur (S) and magnesium (Mg) in vermicompost produced with *E. foetida*

Treatment	P (%)	K (%)	Ca (%)	S (%)	Mg (%)
1	0.323 ^{b}	0.400 ^{d}	0.413 ^{c}	1.460 ^{ba}	0.120 ^{ba}
2	0.486 ^{a}	1.29 ^{cb}	0.696 ^{a}	1.776 ^{a}	0.166 ^{a}
3	0.043 ^{d}	2.723 ^{a}	0.593 ^{ba}	0.853 ^{d}	0.096 ^{b}
4	0.373 ^{b}	0.623 ^{d}	0.480 ^{bc}	1.273 ^{bc}	0.146 ^{ba}
5	0.150 ^{c}	0.650 ^{cd}	0.420 ^{c}	0.973 ^{dc}	0.126 ^{ba}
6	0.366 ^{b}	1.816 ^{b}	0.660 ^{a}	1.360 ^{b}	0.130 ^{ba}
CV	**12.46%**	**18.71%**	**11.1%**	**10.29%**	**15.35%**
ESx	**0.001**	**0.054**	**0.003**	**0.017**	**0.000**

** Values with equal letters per column do not differ statistically (P ≤ 0.05). Treatment: 1: bovine manure, 2: sheep manure, 3: cocoa husk, 4: bovine manure (50%)/sheep manure (50%), 5: bovine manure (50%)/cocoa husk (50%), 6: sheep manure (50%)/cocoa husk (50%)*

Table 2. Mean values of pH and electrical conductivity (EC) in vermicompost produced with *E. foetida*

Treatments	pH	EC (dSm^{-1})
1	6.69 ^{d}	4.296 ^{b}
2	7.90 ^{b}	6.920 ^{a*}
3	7.42 ^{c}	2.656 ^{c}
4	7.27 ^{c}	6.096 ^{a}
5	8.89 ^{b}	3.456 ^{cb}
6	9.37 ^{a*}	9.370 ^{a}
CV	**1.485**	**10.779**
ESx	**0.012**	**0.249**

** Values with equal letters per column do not differ statistically (P ≤ 0.05). Treatment: 1: bovine manure, 2: sheep manure, 3: cocoa husk, 4: bovine manure (50%)/sheep manure (50%), 5: bovine manure (50%)/cocoa husk (50%), 6: sheep manure (50%)/cocoa husk (50%)*

Table 3. Mean values of nitrogen (N), organic matter (OM) and carbon/nitrogen ratio (C/N) in vermicompost produced with *E. foetida*

Treatments	N (%)	OM (%)	C/N
1	1.576 bc	30.358 bc	11.17 a*
2	2.060 ba	25.570 dc	7.208 b
3	2.116 a*	37.089 a*	10.163 a
4	1.436 c	25.946 dc	10.771 a
5	1.94 bac	33.284 ba	10.005 a
6	1.99 ba	21.550 d	6.28 b
CV	**10.4%**	**7.766**	**10.406%**
ESx	**0.037**	**5.06**	**0.929**

** Values with equal letters per column do not differ statistically (P ≤ 0.05). Treatment: 1: bovine manure, 2: sheep manure, 3: cocoa husk, 4: bovine manure (50%)/sheep manure (50%), 5: bovine manure (50%)/cocoa husk (50%), 6: sheep manure (50%)/cocoa husk (50%)*

In relation to K (Table 1), the value was particularly high in the cocoa husk material (T3), due to the high amounts that are naturally absorbed and translocated by this crop from the soil and that remain in these wastes. Studies obtained by Rojas-Molina [16] and related to the rate of decomposition and release of nutrients in cocoa residues, show differences in the results depending on the part of the plant being evaluated as a source; in this case, the fruit is the major sink for K.

In the case of Ca, there were significant differences between the materials, being higher in sheep manure (0.696 %) and its combination with cocoa husk (0.660 %). However, these values are below those obtained by Sharma and Garg [17], who report concentrations of 2.3 %. To increase the total calcium contents in the treatments, it is advisable to place crushed eggshells, since Antoni-Huanca [18] mentions that the external layers of eggshells can contain up to 95 % calcium carbonate by weight and when incorporated in vermicompost, these will increase their Ca concentrations.

In the Mg, the differences between the materials were minor, with the highest value in sheep manure (T2), slightly below the results found by Hernández-López [19] with a result of 0.28 % magnesium in horse manure. With respect to sulfur, sheep manure (T2) was the one that presented the highest percentage (1.776%), being below the results obtained by Capulin-Grande [20] who reported a concentration of 4.8% of S in liquid bovine manure.

3.1.2 Hydrogen potential (pH) and electrical conductivity (EC)

As shown in Table 2, in five of the six treatments, the pH values were greater than 7. The highest pH value was for the combination of sheep manure and cocoa husk (9.37), while the lowest was for the bovine manure (6.69). The alkaline pH of vermicompost can be attributed to the initial decomposition of organic matter, the formation of ammonium ions, and the generation of organic compounds with an alkaline reaction [21]. Huaccha [21] reports that, during vermicomposting, alkalinization of the medium takes place due to the generation of ammonium and degradation of organic acids by the activity of aerobic organisms.

According to Ramírez-Gerardo [1], the pH values recorded (6.69 to 9.37) in the vermicompost indicate that they went through a probably insufficient aerobic degradation process, since ideally, the expected pH after a composting process should be neutral to slightly basic, so it is possible that the processes for composting for this study are relatively incomplete, probably because the final cooling stage, where the mesophilic microbial activity restarts [22], does not occur or is very short.

However, it should be remembered that the function of Morren's glands within the worm morphology is to secrete calcium carbonate and produce alkaline digestion, so slightly alkaline pH values are to be expected in different worm humus [17].

The means of the electrical conductivity values between treatments showed significant differences. The ranges varied from 2.65 to 9.37 dSm^{-1}, i.e., they showed ~~a~~ very high variability, which, explains the high coefficient of variation (Table 2). Similar results were obtained by López-Méndez [23], who observed that when manure and vegetable residue are added to the mixture, the EC of the vermicompost reaches 5 and 8 dSm^{-1}, which if compared with the Mexican standard [12], indicates that most of the treatments exceed the established range by the standard, except for treatments T3 and T5, which were in the established range (≤ 4 dSm^{-1}). In this regard, Ramírez-Gerardo [1], mentions that mixing manure with vegetable residue causes an increase in EC attributable to the source material and the process of obtaining the organic fertilizer.

3.1.3 Nitrogen (N), organic matter (OM) and carbon/nitrogen ratio (C/N)

Regarding nitrogen (Table 3), the cocoa husk (T3) and sheep manure (T2) treatments showed the highest values, while the combination of bovine manure and sheep manure (T4) was the treatment with the lowest value. However, the Mexican standard [12], establishes that the optimum range should be 1% to 4% N, so the six treatments are within the established range.

There was a significant difference between T6 (sheep manure and cocoa husk) and the others, since it had a lower organic matter (OM) content. The range of the means was 21.55 to 37.09% (Table 3), which, compared to the Mexican standard [12], indicates that vermicompost should contain 20% to 50% OM. This shows that the OM contents of the six treatments are within the optimum range.

The OM, besides having a direct influence on soil fertility, is an important factor in the presence and availability of micronutrients [24]. Therefore, in treatment T3, which presented a higher organic matter content, micronutrients are probably more readily available. This translates into a richer compost in terms of humified organic matter content and more available nutrients for the plant to take advantage of [2].

Regarding the C/N ratio (Table 3), treatment T1 (bovine manure) was the one that showed the highest value, possibly due to the high amounts of remaining fiber that come from *the animals' diet and that, in a certain way, remain in good quantities in the raw material* used [25]. Treatments T3, T4 and T5 did not differ statistically from treatment T1. Based on the Mexican Standard [12], all treatments have an adequate C/N value (< 20).

Gamarra-Lezcano [25] and Raza [26] mention that C/N ratios between 10 and 25, are indicative of adequate mineralization by the microorganisms present in the materials, which implies that with low C/N values, the microorganisms will be more efficient in the decomposition of organic matter.

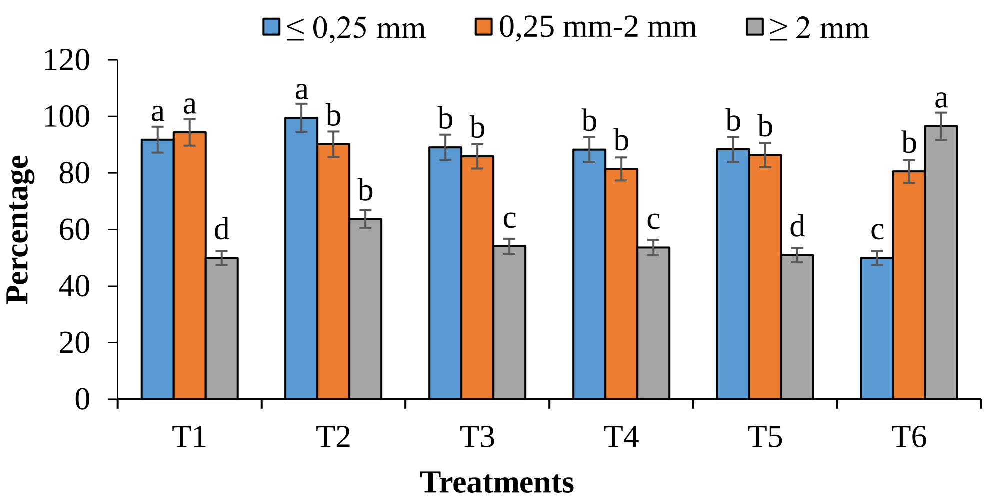

Fig. 2. Granulometry of vermicompost produced with *E. foetida*

Treatments with equal letters per column do not differ statistically (P ≤ 0.05). Treatment: 1: bovine manure, 2: sheep manure, 3: cocoa husk, 4: bovine manure (50%)/sheep manure (50%), 5: bovine manure (50%)/cocoa husk (50%), 6: sheep manure (50%)/cocoa husk (50%)

3.2 Granulometry

The substrates analyzed showed statistically significant differences in relation to particle size (Fig. 2). Treatments (T1) and (T2) presented the highest percentage of particles smaller than 0.25 mm. All substrates presented the highest percentage of particles with sizes between 0.25 and 2 mm, which is considered to have a fine particle size that facilitates the supply of nutrients to the soil and to the plants. Treatment T6 was the substrate with the highest percentage of particles larger than 2 mm, in addition to the lowest proportion of particles smaller than 0.25 mm. According to González-Cueto [27], in coarser materials, the particle size can be adjusted by grinding processes.

According to Abad [28], substrates must have a granulometry of 0.25 to 2.5 mm to be used in the field. The evaluation of eleven types of materials with potential use as substrates of plant and mineral origin carried out by Camacho [29], reported that more than 65% of the particles are within the range of 0.25 to 2.5 mm, coinciding with the results obtained in this work, which allows establishing that the substrates obtained can be used for the desired purposes.

4. CONCLUSIONS

The concentration of nutrients is variable depending on the components of the substrate, however, the choice of materials and their pre-composting processes must be adequate to feed the worms and some physical and chemical parameters required to obtain a safe and sustainable product., since an unexamined decision can increase the mortality of worms by 100%.

All treatments presented an adequate C/N ratio (< 20), which indicates that the microorganisms will be more efficient in the decomposition of organic matter and incorporation into the soil.

Vermiculture is an option for obtaining humus as quality substrates for sustainable agriculture, which could be used as organic fertilizer to increase soil fertility.

5. RECOMMENDATIONS

It is recommended that the humus obtained in this study be applied in a crop to analyze its performance and check its effectiveness.

Experiment with other types of substrates to compare their nutritional value in humus.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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