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Vermicomposting of coffee pulp using the earthworm *Eisenia fetida*: Effects on C and N contents and the availability of nutrients

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Abstract In Colombia, more than 1 million tons of coffee pulp are produced every year. Its transformation into compost by means of turned piles has led to a final product with poor physical and chemical characteristics and vermicomposting has been suggested as an alternative method of transforming these wastes into a useful organic fertilizer. The ability of the earthworm *Eisenia fetida* to transform coffee pulp into a valuable compost was evaluated. The influence of bed depth and time on different C fractions, N content and availability of nutrients was studied. The results showed that the C and N contents were not affected by the depth of the bed, whereas time affected both. An increase in the fractionation ratio, determined by calculating the C in the fraction smaller than 100 μm as a percentage of C in the samples as a whole, and low values of humic-like substances were recorded during vermicomposting. After ingestion of the pulp by the earthworms, an increase in available P, Ca, and Mg but a decrease in K were detected.

Key words Carbon · Coffee pulp · *Eisenia fetida* · Nitrogen · Nutrients · Vermicomposting

Introduction

The ability of earthworms to promote the rapid decomposition of organic materials in soils has often been recorded. Earthworm activity is important for the initial breakdown of plant and animal residues before this organic matter is recycled by the soil microflora (Edwards and Lofty 1977). Vermicomposting is a process by which biological degradation of organic wastes takes place in controlled conditions, due to earthworms feeding on the materials. Systems of growing earthworms range from simple low-technology systems in windrows, through heaps of boxes, to complex continuous breeding systems. The key to maximum productivity is the maintenance of aerobic conditions with optimal moisture and temperature (Edwards 1988). One of the most promising worms for vermicomposting is *Eisenia fetida*; its biology and main environmental requirements have been extensively reported (Kaplan et al. 1980; Hartenstein et al. 1981; Reinecke and Venter 1987; Edwards 1988).

Since increasingly large amounts of organic wastes are produced throughout the world, creating important environmental problems, vermicomposting among other alternatives has been considered as a way of transforming some of these wastes into useful compost for plants and soil while diminishing their negative environmental impact. Organic wastes from very different sources have been used in vermicomposting (Haimi and Huhta 1986; Edwards 1988; Cegarra et al. 1989). In Colombia, more than 1 million tonnes of coffee pulp are produced every year, a waste that has traditionally been transformed by means of spontaneous fermentation in piles often and under precarious aeration conditions. Such a deficient procedure usually leads to final products with poor fertilizing characteristics. There has been little if any research on coffee pulp composting and thus very few chemical data on this particular type of compost are available.

The aim the present work was to evaluate the ability of the earthworm *Eisenia fetida* to transform coffee pulp into a useful compost. The influence of bed depth and time of composting on the C and N content and on the availability of nutrients was studied.

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Materials and methods

The material used was coffee pulp, comprising the outer hull of the fruit and some of the juices after extraction of the seed. It was stored

Table 1 Analysis of coffee pulp (dry weight; P determined by Bray II method, K, Ca Mg after extraction with NH^{+}_{4}-acetate (pH 7), and trace elements after extraction with diethyltriaminepentaacetic acid)

Properties	Total content	Available elements
Moisture	81.4%	–
C	43.3%	–
N	3.02%	–
P	0.21%	210 mg kg^{-1}
K	3.30%	3.08%
Ca	0.62%	0.44%
Mg	0.13%	0.05%
Fe	245 mg kg^{-1}	6 mg kg^{-1}
Mn	235 mg kg^{-1}	200 mg kg^{-1}
Cu	35 mg kg^{-1}	3 mg kg^{-1}
Zn	375 mg kg^{-1}	201 mg kg^{-1}
B	30 mg kg^{-1}	22 mg kg^{-1}

in pits open to the air for 15 days, during which time it underwent a spontaneous fermentation which, although incomplete, reached temperatures of about 45°C. An analysis of total and available elements is shown in Table 1.

The experiment was carried out in the open in the coffee-growing region of Venice, Antioquia, Colombia, at a height of 1650 m above sea level. The average temperature and rainfall were 23°C and 2000 mm, respectively, distributed in such a way that the beds of pulp maintained an average moisture content of 70–80%. In an area of 15 m^2 and with a slope of 2%, four cuts 0.20 deep, 0.50 wide, and 3 m long were made. They were filled with gravel and then four wooden containers measuring 0.75×0.50 m were placed over each of the four gravel-filled cuts. The containers were 0.20, 0.40, 0.60, and 0.80 m deep (treatments 1–4, respectively) and had permeable synthetic glass fibre bottoms. Each container was filled with coffee pulp, which was hot because of the spontaneous fermentation it had undergone during storage. The pulp cooled down momentarily due to the aeration brought about by the filling process, then heated up again to reach around 40°C. Five days later, when the temperature of the beds had fallen to below 30°C, the containers were inoculated with the earthworm *Eisenia fetida* (average weight 0.22 g), pre-adapted to a substrate consisting of coffee pulp. Inoculation was carried out according to the volume of the different beds with 885, 1170, 2655, and 3540 worms (treatments 1–4, respectively).

Because the containers were outdoors, the amount and time of rainfall were considered to have some influence on the potential leaching of nutrients during the vermicomposting process and thus rainfall data were collected from a weather station located 2 km from the experimental site. The rainfall computed for the intervals between samplings (4, 35, 56, 77, and 98 days after inoculation) was 163.2, 153.2, 137.4, 4.3, and 16.6 l m^{-2} respectively. Precipitation was rarely heavy during the experiment, except on day 41 when 93.5 l m^{-2} was recorded.

Samples were taken from every container, mixing three subsamples at different depths from every bed. These samples were sieved to 4 mm on the day they were taken and the moisture content was determined by drying at 60°C. A subsample of this dry material was ground to a size of less than 20 μm, the C content was determined by microanalysis (Navarro et al. 1991), and N by the Kjeldahl method. The material sieved to 4 mm was submitted to physical fractionation using the Bruckert (1982) method adapted to this material. This consisted of stirring a quantity of fresh material equivalent to 20 g dry weight with 200 ml of distilled water and three glass balls in a plastic vessel placed on a rotary shaker turning at 150 rpm for 4 h. The aqueous sample was sieved at 100 μm and the fraction<100 μm was separated and oven-dried for 48 h at 60°C on a filter paper of known weight before being weighed again. The fraction was then ground to 20 μm and the C and N contents determined as for the whole material. A new parameter, the fragmentation ratio, expressed by calculating the quantity of C in the fraction<100 μm as a percentage of the C measured in each sample before physical fractionation, was also determined during vermicomposting. Humic-like substances were extracted from the fraction<100 μm by stirring 1 g of the material with 20 ml of 0.4 *M* KOH for 24 h and centrifuging at 10500 g for 20 min. This process was repeated three times and the extracts were then mixed. The C content of the extracts was determined by the method of Walkley and Black (1934) and N by the Kjeldahl method.

Total and available elements were determined in the vermicompost samples obtained at the end of the process (98 days) as in the original material. C and N were determined as described above and the total contents of the other elements were determined after nitric-perchloric digestion, colorimetrically (Murphy and Riley 1962), K, Ca, Mg, Fe, Cu, and Zn by atomic absorption spectroscopy, and B colorimetrically (Bingham 1982). Available P was determined by Bray II followed by colorimetric determination, available K, Ca, and Mg by extraction with NH_4Ac at pH 7 (Thomas 1982) and measurement by atomic absorption spectroscopy, and available microelements also by atomic absorption spectroscopy after extraction with diethyltriaminepentaacetic acid according to Lindsay and Norvell (1978). Available B was extracted with warm water and evaluated colorimetrically as for total B.

All the data were processed statistically (two-way analysis of variance) in a random design. The effect of treatment, sampling time, and the interaction between both were evaluated.

Results and discussion

Changes in C and N in the whole material

The effects of treatment and time on the vermicomposting of coffee pulp are shown in Table 2. There were no significant differences in C content between the different treatments although significantly different values were obtained for the different sampling times ($P<0.01$). The highest C content was observed on day 35 (second sample) with a mean value for the four treatments of 57.48%. The final C values tended to decrease and reach their initial percentage. The maximum on day 35 may be attributed to the earthworms and their associated microflora metabolizing the most labile organic substances during the early weeks of the experiment, thus selectively enriching the substrate in more complex organic compounds with a chemically more condensed structure and richer in C, such as lignin. Hervas et al. (1989) reported that the lignin moiety of lignocellulosic complexes is not metabolized by earthworms or by their microbial gut flora. Alternatively, there may have been a transfer of C from the earthworms to the pulp during this period, either through mucus secretion or earthworm mortality. The subsequent fall in C levels was probably due to substrate mineralization, brought about by the metabolic activity of the growing earthworm biomass and associated microflora. Satchell and Martin (1984), using loss-on-ignition values, demonstrated a reduction in organic matter and a corresponding increase in mineral matter in cultures containing worms.

The analysis of variance showed that total N did not differ significantly between treatments (Table 2), although samples taken at different times did show significant differences ($P<0.01$), with a fall in N levels being noticeable on days 56 and 77. The last sample showed that the N level (3.67%) had increased to a value close to the initial content. The treatment×time interaction (Fig. 1) was also significant ($P<0.05$), the previously mentioned fall in total

Table 2 Effects of treatment and time on C and N content during vermicomposting of the coffee pulp (dry weight; *Ex.* extractable; values within columns followed by the same letter are not significantly different at the 0.01 probability level)

	Whole material		Fragmentation ratio	Fraction <100 μm			
	C (%)	N (%)		C (%)	Ex. C (%)	Ex. N (ppm)	Ex. C:N
Treatment							
1	40.97	3.33	16.5	41.32	0.86	184	47
2	44.86	3.58	16.9	42.37	0.86	201	43
3	45.09	3.19	14.9	40.56	0.87	188	46
4	45.39	3.26	15.8	39.68	0.87	178	49
Time (days)							
14	42.30bc	3.38abc	9.7d	42.31b	0.89a	318a	28
35	57.48a	3.69a	12.4cd	46.35a	0.88ab	197b	45
56	44.39b	2.91c	15.4c	37.53d	0.83c	174b	48
77	37.24c	3.04bc	23.6a	38.07cd	0.87ab	153b	57
98	40.22bc	3.67ab	19.1b	40.63bc	0.86b	94c	91

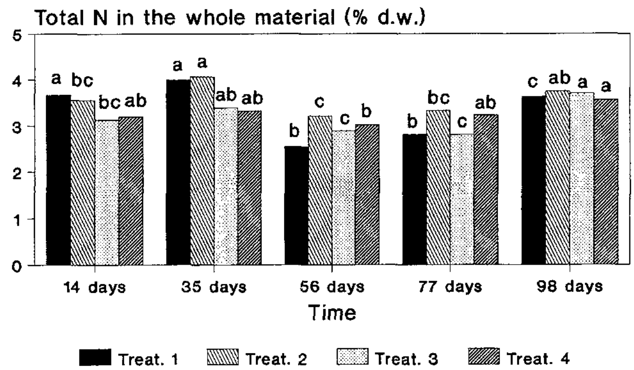

Fig. 1 Effect of treatment×time interaction on total N content during vermicomposting of coffee pulp (*d. w.* dry weight). For the same treatment, values followed by the same letter are not significantly different at the 0.05 probability level

N levels being more pronounced in treatment 1 and barely discernible in treatment 4.

The fall in N levels noticed on days 56 and 77 was probably due to the increased demand for this element by the earthworms, which needed it for growth, thus immobilizing it and extracting it from the substrate. This effect was particularly noticeable in the shallower beds (treatment 1), since earthworm activity was more intense in these, probably due to better aeration. It was less noticeable in the deeper beds (treatment 4) which the earthworms were clearly unable to explore fully in the time the experiment lasted. Cortez et al. (1989), using ^{15}N labelled wheat straw as litter, found that earthworms were capable of assimilating 9.4% of the total N ingested. This explanation for the fall in N levels may be consistent with the hypothesis that leaching losses of soluble nutrients induced by rainwater were greatest during the first half of the experiment when the wettest conditions were observed, with rainfall rising to 93.5 l m^{-2} in only 24 h on day 41. The subsequent limitation in the development of the earthworm population, when the proportion of fresh organic matter in the substrate diminished, might explain the increase in total N on day 98, since part of the earthworm biomass must have been incorporated as more or less decomposed organic matter in the resulting vermicompost.

Changes in C and N in the fraction smaller than 100 μm

The fine fraction (<100 μm) was principally made up of pulp ingested and excreted by the earthworms and was considered to be the most humified fraction of the substrate. Therefore, the increase in this fraction during vermicomposting, as shown by the fragmentation ratio, was used as an index of the transformation of pulp into vermicompost. No significant differences in the fractionation ratio were found between the different treatments (Table 2) although there were considerable differences for the time factor ($P<0.01$), this parameter increasing with time (from 9.7 at 14 days to 19.1 in the final sampling). This indicates a progressive increase in the <100 μm fraction in the substrate as vermicomposting progressed.

The C values in the <100 μm fraction from the four treatments were not significantly different (Table 2), although significant differences were observed with respect to time ($P<0.01$), the C content following a similar pattern to that in the whole material, which can be explained identically in the same way. There was an increase in C on day 35, and then a decrease, with similar values in the following sampling. Extractable C values were very similar over the four treatments, with a mean value of 0.87% (Table 2), and these again were significantly different ($P<0.01$) over time, the lowest value being detected in samples taken on day 56. As mentioned above, the heavy rainfall of day 41 probably increased leaching losses of extractable C, which might explain the data obtained on day 56. Since extractable C can be considered as an indicator of the content of humic-like substances in the substrate, the low values recorded (only about 2% of the C in the fine fraction) lead to the same doubts as expressed by Hervas et al. (1989), who suggested that the claims from vermicompost manufacturers concerning the high percentage of humic acids in this material should be carefully reconsidered. The increase in the fragmentation ratio during vermicomposting and the low values recorded for humic-like substances in the substrate, which scarcely varied during the experiment, suggest that the earthworms simply broke the coffee pulp down.

The extractable N in the fine fraction was not significantly affected by treatment (Table 2) although it was by

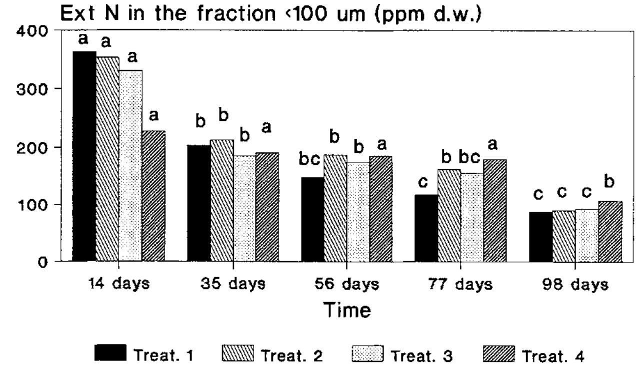

Fig. 2 Effect of treatment×time interaction on extractable (*Ext*) N content during vermicomposting of coffee pulp (*d. w.* dry weight). For the same treatment, values followed by the same letter are not significantly different at the 0.05 probability level

time (P<0.01), falling throughout the vermicomposting process but particularly on the second sampling day and also at the end of the experiment. This fall in extractable N with time, which was probably the result of immobilization, indicates an increasing impoverishment of this element in the soluble humic-like substances with a strong increase in the C:N ratio in these substances (Table 2). This C:N ratio might therefore be useful in determining the degree of transformation undergone during vermicomposting. The effect of treatment×time on extractable N (Fig. 2) was also significant (P<0.05), treatment 1 showing the sharpest fall while the fall in treatment 4 was not so pronounced. This must also be connected with differences in the degree of worm activity and the effect of rainwater mentioned above, with the two phenomena varying according to the thickness of the compost bed.

Evaluation of other parameters at the end of vermicomposting

No significant differences in final moisture were recorded between the four treatments (mean value 79.9%, Table 3). A significant difference in pH was observed only for treatment 4 which had a pH of 7.8 (P<0.01) which was noticeably higher than that recorded for the other three treatments. This high value was presumably related to less effective leaching by rainwater, due to the deeper beds used in this treatment and the inability of the worms to explore this bed fully in the time allowed.

The final population density of worms also depended significantly on treatment (P<0.01), treatment 1 showing a significantly lower density than the other treatments. This may have been due to greater activity of the worms in the shallower beds in the presence of better aerobic conditions, allowing rapid extraction of the nutritional contents of the pulp thus leading to a limitation in the worm population, which showed a final value of 316 worms kg^{-1}. Treatments 2, 3 and 4 had higher final worm densities than treatment 1, and were not significantly different. The final weight of substrate was also lower in treatment 1, the

Table 3 Moisture, pH, and other parameters evaluated at the end of vermicomposting (values within columns followed by the same letter are not significantly different at the 0.01 probability level)

Treatment	Moisture (%)	pH	Population density (worms kg^{-1})	Loss weight of substrate (%)
1	76.3	6.7b	316b	70.4a
2	79.8	6.6b	470a	65.4b
3	81.2	6.9b	560a	62.5bc
4	82.4	7.8a	519a	60.2c
Mean	79.9	7.0	466	64.6

weight loss being significantly less (P<0.01) as the depth increased (Table 3).

The fertilizer value of the final vermicompost

The level of available P in the vermicompost (Table 4) was quite high, with a mean value of 345 ppm over the four treatments. The lowest values were observed in the samples taken from treatment 4 (P<0.01) which, again, can be explained by the smaller degree of exploration by worms in the beds corresponding to this treatment. In addition, the higher pH of the vermicompost samples in treatment 4 compared with the other three treatments would have favoured P insolubility. The mean increase in available P in the vermicompost compared with the original pulp was about 64% (Tables 1, 4). Mansell et al. (1981) showed that plant litter contained more available P after ingestion by earthworms, and they attributed this increase to physical breakdown of the plant material by the worms. Also, Satchell and Martin (1984), working with *Eisenia fetida* in an experimental medium of paper waste sludge plus phyton, found an increase of 25% in total extractable P estimated by Olsen's method. They related this increase to the increase in phosphatase activity in worm feaces, by the direct action of gut enzymes and indirectly by stimulation of the microflora.

There were no significant differences in exchangeable cations between treatments, the mean values of K being relatively high, Ca low and Mg extremely low (Table 4) compared with data reported by Edwards and Burrows (1988) for different vermicomposts obtained from cattle

Table 4 Fertilizer value of vermicompost (dry weight; values within columns followed by the same letter are not significantly different at the 0.01 probability level)

Treatment	Available (ppm)		Exchangeable cations (%)			Ca:Mg	Mg:K
	P	B	Ca	Mg	K		
1	395a	20.8a	0.70	0.15	2.04	4.7	0.07
2	375a	22.3a	0.68	0.13	2.15	5.2	0.06
3	340ab	10.8b	0.63	0.16	2.16	3.9	0.07
4	270b	7.9c	0.62	0.09	2.43	6.9	0.04
Mean	345	15.2	0.66	0.13	2.20	5.2	0.06

and pig manure and potato waste. During the processing of the coffee pulp the earthworms in the present study, Ca and Mg were changed into forms more readily available to plants, the exchangeable forms of these cations increasing in the vermicompost compared with the raw coffee pulp (Tables 1, 4). However, exchangeable K decreased in the worm-worked substrate, which may have been related to greater leaching of K compared with the other cations. For plant nutrition, however, the vermicompost showed a poor balance of these three macronutrients. Although the Ca:Mg ratio was adequate, the Mg:K ratio was probably too low. Edwards and Burrows (1988) found similar Ca:Mg ratios to those reported here but much greater Mg:K ratios. They recommended the use of $MgSO_4$ to supplement the Mg deficiency usually found in vermicomposts. In calcareous soils with a high Ca and Mg content, this vermicompost would be adequate.

Lastly, the available B content of the vermicompost (15.2 ppm on average) was very high compared with normal soils. The effect of treatment was quite significant (P<0.01), although the levels of available B fell in treatments 3 and 4.

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References

Bingham FT (1982) Boron. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. Part 2. Chemical and microbiological properties. Agronomy 9, Am Soc Agron, Madison, Wis, pp 431–448

Bruckert S (1982) Analysis of the organo-mineral complexes of soils. In: Bonneau M, Souchier B (eds) Constituents and properties of soils. Academic Press, London, pp 214–237

Cegarra J, Frutos C, Tercero A, Roig A, De Godos A (1989) Study of soluble humic substances from newly prepared organic fertilizers. Sci Total Environ 81/82:579–588

Cortez J, Hameed R, Bouché MB (1989) C and N transfer in soil with or without earthworms fed with ^{14}C- and ^{15}N-labelled wheat straw. Soil Biol Biochem 21:491–497

Edwards CA (1988) Breakdown of animal, vegetable and industrial organic wastes by earthworms. In: Edwards CA, Neuhauser EF (eds) Earthworms in waste and environmental management. SPB Academic, The Hague, pp 21–31

Edwards CA, Burrows I (1988) The potential of earthworm composts as plant growth media. In: Edwards CA, Neuhauser EF (eds) Earthworms in waste and environmental management. SPB Academic, The Hague, pp 211–219

Edwards CA, Lofty JR (1977) Biology of earthworms. John Wiley and Sons, New York

Haimi J, Huhta V (1986) Capacity of various organic residues to support adequate earthworm biomass for vermicomposting. Biol Fertil Soils 2:23–27

Hartenstein F, Hartenstein E, Hartenstein R (1981) Gut load and transit time in the earthworm *Eisenia foetida*. Pedobiologia 22:5–20

Hervas L, Mazuelos C, Senesi N, Saiz-Jimenez C (1989) Chemical and physicochemical characterization of vermicomposts and their humic acid fractions. Sci Total Environ 81/82:543–550

Kaplan DL, Hartenstein R, Neuhauser EF, Malecki MR (1980) Physicochemical requirements in the environment of the earthworm *Eisenia foetida*. Soil Biol Biochem 12:347–352

Lindsay WL, Norvell WA (1978) Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci Soc Am J 42:421–428

Mansell GP, Syers JK, Gregg PEH (1981) Plant availability of phosphorus in dead herbage ingested by surface-casting earthworms. Soil Biol Biochem 13:163–167

Murphy J, Riley JP (1962) A modified simple solution method for the deremination of phosphate in natural water. Anal Chim Acta 27:31–36

Navarro AF, Cegarra J, Roig A, Bernal MP (1991) An automatic microanalysis method for the determination of organic carbon in wastes. Commun Soil Sci Plant Anal 22:2137–2144

Reinecke AJ, Venter JM (1987) Moisture preferences, growth and reproduction of the compost worm *Eisenia foetida* (Oligochaeta). Biol Fertil Soils 3:135–141

Satchell JE, Martin K (1984) Phosphatase activity in earthworms faeces. Soil Biol Biochem 16:191–194

Thomas GW (1982) Exchangeable cations. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. Part 2. Chemical and microbiological properties. Agronomy 9, Am Soc Agron, Madison, Wis, pp 159–165

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 Sci 37:29–38