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Influence of Different Populations of the Earthworm Species "*Eudrilus eugeniae*" on Cashew Residues Stabilization during Vermicomposting

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Abstract

The population size of the earthworm *Eudrilus eugeniae* necessary for good stabilization of cashew residues was studied in this experiment. Thus, cashew apples and leaves separately and their mixtures with cow dung were mineralized with 5, 10, 15 and 20 individuals of the African nightcrawler *E. eugeniae.* Total organic carbon (C), total nitrogen (N), C:N ratio, pH, total potassium (K) and total available phosphorus (P) were measured at 0, 30, 60 and 90 days of the vermicomposting. The cocoons and earthworms numbers at the end of the experiment were also investigated. The pH was in the good range when mixing cashew residues with cow dung. C/N ratio showed good stabilization of the wastes CaA + CD, CaL + CD, and CaA + CaL + CD with 5, 10, 15 and 20 individuals of *E. eugeniae* at 2 or 3 months of vermicomposting. The results of this study may help in recycling cashew residues into organic fertilizer through vermicomposting when using the earthworms species *E. eugeniae.*

Subject Areas

Agricultural Science

Keywords

Cashew Apples, Cashew Leaves, Cow Dung, Vermicomposting, *Eudrilus eugeniae*

1. Introduction

Cashew (*Anacardium occidentale* L.) is widely cultivated in Côte d'Ivoire, with an annual production of 1.2 million tons, making the country the first producer in the world [1]. It is grown mainly from the center to the north of the country where it occupies about 43% of the cultivated surface [2]. Due to this intensive cultivation, cashew trees generate significant quantities of residues on the field including apples and leaves. In fact, 5 million tons of cashew apples, and 179,232 tons of leaves are produced per year [3]. Cashew apples and leaves are generally abandoned in the plantations where they undergo natural decomposition. The underutilization of cashew apples in Côte d'Ivoire is mainly due to the astringency of this fruit and certain ancestral taboos [4]. Cashew apples and leaves are known as lignocellulosic wastes and their decomposition in natural conditions is very slow because they contain high contents of lignocellulosic fibrous material such as phenol, lignin, tannin, and cellulose [5]. Production of large quantities of these organic wastes generally poses major environmental concerns, ranging from offensive odors, contamination of groundwater and soil, and disposal constraints [6]. During dry season, leaves are also the cause of bushfires which very often ravage plantations. Moreover, snakes can hide under the leaves and may bite women when collecting nuts.

However, crop residues are valuable for agriculture in developing countries. The use of crop residues in agriculture is not only linked to their richness in nutrients but also to their ability to control soils' runoff and erosion, which enhances water retention necessary for plants and microorganisms [7]. Thus, crop residues deserve treatment or conditioning to reduce the risks associated with their use.

Among organic residues treatment techniques, composting is the method mostly used by small farmers because of its reasonable operational cost and has thus enjoyed wide adoption in majority of Sahelian countries [8] for enhancing soil fertility and organic matter contents. Unfortunately, the composting period is long and during the process, there is a loss of nitrogen in the form of ammonia between 30% - 70%, carbon in the form of carbon dioxide nearly 50%, and phosphorus about 50% [9] [10]. Consequently, compost obtained at the end of the process may be less rich than the expectations of producers. Recently, another method of treating organic residues with earthworms (vermicomposting) has emerged. This technology is considered more suitable because it is low-cost, environmentally friendly and sustainable, and allows fairly good stabilization of organic residues before their use as fertilizer or soil conditioner [11] [12]. Vermicomposting is a natural mesophilic process in which organic waste undergoes biochemical decomposition through the collaborative metabolic activities of earthworms and microorganisms [13]. During this process, earthworms and endosymbiotic microorganisms in their gut secrete hydrolytic digestive enzymes, leading to the decomposition and mineralization of the organic matter in biomass waste into monomeric units, releasing nutrients and energy [14] [15]. In the process of vermicomposting, the earthworms generally called "ecological engineers" play a pivotal role [16]. The activity of earthworms contributes to waste volume reduction, resulting in earthworms casts that are nutrient rich components crucial for plant growth and it increases soil water retention [17] [18].

Eudrilus eugeniae (Kinberg, 1867) is one of the most common and widely earthworm used in vermicomposting under tropical and subtropical conditions. Different authors showed that cashew residues can be used as cultural material for the earthworm species *E. eugeniae* and therefore can be composted successfully with it [19]-[21]. But literature is still rare on the stabilization of cashew residues. In fact, earthworms' population size is known to influence vermicompost nutrient content and maturity time cause of intraspecific competition [22] [23]. The present study is conducted to evaluate the effect of different population size of the earthworm *Eudrilus eugeniae* on the physico-chemical properties of the vermicompost.

2. Materials and Methods

2.1. Study Site

The experiment was conducted at the experimental laboratory of the "Bioengineering Research Group" built in the courtyard of the slaughterhouse of Korhogo (Côte d'Ivoire). Korhogo is situated between latitudes 9˚27 N - 9˚35 N and longitudes 5˚37 W - 5˚45 W. The temperature and the humidity of the room were 30.62˚C ± 1.41˚C and 87.7% ± 1.51 % respectively.

2.2. Biological Materials

Healthy adults of *Eudrilus eugeniae* (commonly used for vermicomposting in West Africa) have been picked from a pile of cow dung to be used in the experiment. Individuals weighing 500 - 1200 mg were maintained in the laboratory with cow manure as culture material. Cow manure is largely produced in the north due to its suitability for cattle farming and about 2 million tons of cattle manure are produced per year [24]. Cashew residues were got from the areas of Mankono, Boundiali and Korhogo considered as the production centers. Cow dung was also collected in farming places in the town of Korhogo. Then, cashew residues were ground in the laboratory grinder (Moulinex, Double-Clic, France). The crushed samples were sieved to obtain particles between 125 μm and 250 μm.

2.3. Experimental Design

The containers used in the experiment were plastic with a volume = 3 L, diameter = 50 cm, depth = 15 cm. Six treatments were formed in the experiment. The first and second treatment were constituted of 300 g of ground cashew apple and cashew leaves respectively. The third treatment was a mixture of 150 g of cashew apple and 150 g of cashew leaves. The fourth treatment was formed of a mixture of 150 g of cashew apple and 150 g of cow dung when the fifth treatment was a mixture of 150 g of leaves and 150 g and cow dung. The sixth treatment was a mixture of 100 g of cashew apples, cashew leaves and cow dung. For each treatment, 5 batches of the earthworm species *E. eugeniae* (0, 5, 10, 15, and 20 individuals) were tested. Three repetitions were maintained for each treatment and batch of earthworm. The content of the containers was watered with distilled water, and the moisture was adjusted to 70% - 80%. The mixtures were turned over manually daily for two weeks to eliminate volatile gases which may be potentially toxic to earthworms. After the pre-composting period, the different batches of earthworms were used for the mineralization of the substrates. The containers were covered with their pierced cover for 90 days. Homogenized Samples were taken from the containers at 0, 30, 60 and 90 days. Day 0 refers to the initial characteristics of the wastes before the experiment starts. Day 30, 60 and 90 started from the day earthworms were introduced in the containers. The cocoons, earthworms and hatchlings were removed manually from each sample. The samples were air dried in the shade and the pH, total organic carbon (TOC), total N, total K and total available P were analyzed in Biological Systems Engineering Laboratory at Washington State University (USA). Distilled water suspension of each waste was used to measure the pH after mechanical agitation for 30 min and filtration through a Whatman No. 42 filter paper. Total nitrogen, and total carbon were determined using a TRUSPEC-CHN® (LECO, US) elemental analyzer [25]. Inductively coupled plasma mass spectroscopy (ICP-MS) analysis was used to analyze for the contents of total K, and P in the samples. This analysis was conducted based on the method described by Pecha *et al.* [26] in an ICP-MS (Agilent 7500cx) instrument. A 100-mg of dried sample in question was mixed with 3 mL concentrated nitric acid (HNO_3) (69% - 70%) and 2 mL 30% H_2O_2 and placed in a microwave digester (SPD, CEM corporation) at 300˚C and 250 psi for 5 min. The filtrate obtained via the Whatman No. 42 filter paper was used for the ICP-MS analysis.

2.4. Statistical Tests

Data were analyzed by factorial analysis of variance (ANOVA) using the SAS general linear model (GLM) procedure [27]. Least Significant Difference (LSD) multiple range-tests were used to determine significant differences between chemical components of the different substrates before and after vermicomposting and the number of earthworms and cocoons in the media at the end of the experiment. Significant differences between means were determined by P-values < 0.05 (*i.e.* $\alpha = 0.05$).

3. Results

3.1. Changes in Physico-Chemical Characteristics of the Different Types of Waste during Vermicomposting

3.1.1. pH

The variation of the pH in the different substrates in function of composting timing and earthworms population size during the vermicomposting process is registered in Table 1. In cashew apples (CaA), pH varied from 4.22 ± 0.86 at day 0 to 4.47 ± 1.24 at day 90. At day 0, 30 60 and 90 respectively, there was no significant difference ($P > 0.05$) between the pH values measured with 0, 5, 10, 15 and 20 earthworms. The initial pH in cashew leave (CaL) was 5.29 ± 0.96. Statistically, there was no significant difference between pH in the compost mineralized with 5, 10, 15 and 20 individuals of *Edrilus eugeniae* at 30 and 90 days of the experiment respectively. But at 60 days, pH in cashew leave decomposed with 15 earthworms was significantly higher ($P = 0.02$) than others. When CaA and CaL were mixed, pH raised to 5.53 ± 0.72, corresponding to day 0 of the vermicomposting process. From day 30 to day 90, there was an increase in pH during the composting process when the earthworm's number increased. At 30 and 60 days, the highest pH was in the substrate in which 15 earthworms were introduced initially. At the end of the experiment (90 days), the pH obtained with 20 earthworms was higher (pH < 0.001) than those obtained with 0 and 5 earthworms. However, the pH got with 10 (5.91 ± 1.11), 15 (5.85 ± 1.62) and 20 (5.91 ± 1.11) earthworms were statistically similar. In the mixture of cashew apples and cow dung (CaA+CD), the pH was 5.87 ± 0.48. During the vermicomposting, pH differed significantly ($P < 0.01$) at 30 days of the process. At that date, the highest pHs were observed in the mixtures decomposed with 15 (5.9 ± 1.46) and 20 earthworms (5.89 ± 1.27). At 60 and 90 days respectively, the highest pH was 6.34 ± 1.23 with 10 earthworms and 6.57 ± 1.61 with 15 earthworms. When cashew leaves and cow dung were mixed, the pH of the mixture was 6.11 ± 0.67 before the experiment started. From day 30 to day 90, there was a variation in the pH of the mixture CaL + CD in function of earthworms population size. The lowest pH was obtained with 0 earthworm and the highest pHs were observed with 10, 15 and 20 earthworms that were statistically the same. When all the three substrates were mixed, pH values varied from 6.39 ± 0.83 in raw mixture to 6.85 ± 1.67 in the vermicompost mineralized with 20 earthworms after 3 months. At day 30, pH shifted from 6.27 ± 1.82 (with 0 earthworm) to 6.56 ± 0.59 (with 10 earthworms). At 60 days, the lowest pH (6.34 ± 1.57) was obtained with no earthworm and the highest was measured with 10 earthworms (6.84 ± 1.08). At the end of the experiment, pH was 6.33 ± 1.74 with no earthworm, 6.69 ± 1.42 with 5 earthworms, 6.81 ± 1.37 with 10 earthworms, 6.78 ± 1.69 with 15 earthworms and 6.85 ± 1.67 with 20 earthworms.

Table 1. Changes in the pH values (mean ± SD, n = 3) of the different type wastes during vermicomposting.

Type of waste	Composting timing (days)	Earthworm batches					*P*
		0	5	10	15	20	
CaA	0	4.22 ± 0.86[a]	4.22 ± 0.86[a]	4.22 ± 0.86[a]	4.22 ± 0.86[a]	4.22 ± 0.86[a]	1
	30	4.21 ± 1.03[a]	4.22 ± 1.12[a]	4.13 ± 1.07[a]	4.2 ± 1.2[a]	4.26 ± 0.63[a]	0.41
	60	4.23 ± 1.22[a]	4.24 ± 0.95[a]	4.23 ± 1.23[a]	4.24 ± 1.06[a]	4.25 ± 1.15[a]	0.84
	90	4.51 ± 0.88[a]	4.53 ± 1.26[a]	4.51 ± 1.35[a]	4.47 ± 1.24[a]	4.52 ± 0.67[a]	0.34
CaL	0	5.29 ± 0.96[a]	5.29 ± 0.96[a]	5.29 ± 0.96[a]	5.29 ± 0.96[a]	5.29 ± 0.96[a]	1
	30	5.33 ± 0.75[a]	5.32 ± 1.05[a]	5.34 ± 1.62[a]	5.33 ± 0.81[a]	5.37 ± 1.22[a]	0.15
	60	5.31 ± 1.14[c]	5.4 ± 0.94[bc]	5.46 ± 1.44[b]	5.48 ± 0.75[b]	5.63 ± 1.34[a]	0.02
	90	5.62 ± 1.23[a]	5.58 ± 1.17[a]	5.68 ± 0.69[a]	5.69 ± 1.25[a]	5.66 ± 1.61[a]	0.43

Continued

CaA + CaL	0	5.53 ± 0.72[a]	5.53 ± 0.72[a]	5.53 ± 0.72[a]	5.53 ± 0.72[a]	5.53 ± 0.72[a]	1
	30	5.52 ± 1.12[c]	5.53 ± 1.67[c]	5.76 ± 1.86[ab]	5.81 ± 1.15[a]	5.69 ± 1.32[b]	<0.001
	60	5.61 ± 1.08[c]	5.64 ± 1.16[bc]	5.71 ± 1.33[b]	5.88 ± 0.68[a]	5.86 ± 1.64[a]	<0.001
	90	5.67 ± 0.64[b]	5.69 ± 1.43[b]	5.86 ± 0.89[a]	5.85 ± 1.62[a]	5.91 ± 1.11[a]	<0.001
CaA + CD	0	5.87 ± 0.48[a]	5.87 ± 0.48[a]	5.87 ± 0.48[a]	5.87 ± 0.48[a]	5.87 ± 0.48[a]	1
	30	5.9 ± 0.92[a]	5.88 ± 1.55[a]	5.79 ± 1.24[b]	5.9 ± 1.46[a]	5.89 ± 1.27[a]	0.01
	60	6.11 ± 1.83[bc]	6.23 ± 1.26[b]	6.34 ± 1.23[a]	6.2 ± 1.82[b]	6.17 ± 1.16[bc]	<0.001
	90	6.18 ± 1.08[b]	6.26 ± 0.69[b]	6.45 ± 1.58[a]	6.57 ± 1.61[a]	6.49 ± 1.23[a]	<0.001
CaL + CD	0	6.11 ± 0.67[a]	6.11 ± 0.67[a]	6.11 ± 0.67[a]	6.11 ± 0.67[a]	6.11 ± 0.67[a]	1
	30	6.14 ± 0.88[b]	6.2 ± 1.28[ab]	6.21 ± 1.48[ab]	6.19 ± 1.09[ab]	6.23 ± 1.18[a]	0.002
	60	6.19 ± 0.93[c]	6.43 ± 1.07[a]	6.37 ± 1.21[b]	6.32 ± 1.53[b]	6.41 ± 1.01[a]	<0.001
	90	6.25 ± 0.56[c]	6.51 ± 1.77[b]	6.65 ± 1.62[a]	6.58 ± 1.27[ab]	6.62 ± 1.80[a]	<0.001
CaA + CaL + CD	0	6.39 ± 0.83[a]	6.39 ± 0.83[a]	6.39 ± 0.83[a]	6.39 ± 0.83[a]	6.39 ± 0.83[a]	1
	30	6.27 ± 1.82[c]	6.42 ± 1.69[b]	6.56 ± 0.59[a]	6.4 ± 1.39[b]	6.53 ± 1.46[a]	<0.001
	60	6.34 ± 1.57[c]	6.73 ± 1.53[ab]	6.84 ± 1.08[a]	6.79 ± 1.58[a]	6.62 ± 1.19[b]	<0.001
	90	6.33 ± 1.74[c]	6.69 ± 1.42[b]	6.81 ± 1.37[a]	6.78 ± 1.69[ab]	6.85 ± 1.67[a]	<0.001

Values followed by the same letter in a row are not significantly different ($P > 0.05$) using LSD. **CaA:** Cashew apple, **CaL:** Cashew leaves, **CD:** Cow dung.

3.1.2. Carbon

The variation of carbon content during the vermicomposting of the six types of waste is presented in Table 2. The carbon content in the raw cashew substrate was 37.86 ± 2.22%. During the composting process, there was no significant difference ($P > 0.05$) between carbon contents despite the increase in the number of earthworms at 30, 60 and 90 days. However, there was a decrease in carbon content with the increase of composting timing. Concerning cashew leaves, the non-composted material contained 42.29% ± 4.18% of carbon. After 30 days of the composting process, carbon content was not influenced by earthworms size used but at 60 and 90 days of the process respectively, carbon content varied significantly in function of earthworm size. At each these latter dates, the lowest carbon content was obtained in the substrates where 15 earthworms were introduced initially, and the highest contents were observed in the control (0 earthworm). Regarding the composting timing, there was a decrease in carbon content in function of the composting timing. When cashew apples and leaves were mixed, carbon content was 44.32% ± 6.03%. At 30 and 60 days of vermicomposting respectively, carbon content did not change significantly whatever the earthworms population size. However, it changed at 90 days of the composting process in function of earthworms batches. The carbon content at the end of the experiment was 41.69% ± 3.62% in the control (no earthworm), 36.53% ± 2.41% with 5 earthworms, 35.17% ± 3.08% with 10 earthworms, 33.88% ± 2.69% with 15 earthworms and 30.03% ± 2.34% with 20 earthworms. In the raw mixture of cashew apples and cow dung, carbon content was 42.15% ± 1.88%. Whatever earthworms population size at 30, 60 and 90 days, carbon content did not change significantly. Regardless of earthworms batches, carbon content decreased in function of composting timing. In the mixture of cashew leaves and cow dung, carbon content was 45.30% ± 3.22%. After 30 days of decomposition with 5, 10, 15 and 20 earthworms, there was no significant difference ($P > 0.05$) between carbon contents. At 60 and 90 days of composting, carbon content differed significantly in function of earthworms number used for the mineralization. At these latter periods, the lowest carbon content was 30.01% ± 3.76 % and 19.63% ± 2.38% with 15 individuals of *E. eugeniae*. However, there was a similarity between the contents got with 5, 10 15 and 20 earthworms at 60 and 90 days respectively.

After mixing CaA, CaL and CD, carbon content was 40.95% ± 4.10%. After 30 days of composting, carbon content remained similar statistically. At 60 and 90 days of composting respectively, carbon content differed significantly from one population size to another. At both dates, the lowest carbon content was obtained with 15 earthworms when the highest was measured in the control.

Table 2. Changes in C content (%) (mean ± SD, n = 3) of the different type wastes during vermicomposting.

Type of waste	Composting timing (days)	Earthworm batches					*P*
		0	5	10	15	20	
CaA	0	37.86 ± 2.22^{a}	37.86 ± 2.22^{a}	37.86 ± 2.22^{a}	37.86 ± 2.22^{a}	37.86 ± 2.22^{a}	1
	30	40.21 ± 3.46^{a}	38.57 ± 2.06^{a}	37.24 ± 1.83^{a}	36.13 ± 1.63^{a}	36.49 ± 2.54^{a}	0.55
	60	35.54 ± 1.74^{a}	36.05 ± 2.47^{a}	34.18 ± 2.11^{a}	35.22 ± 1.88^{a}	35.61 ± 2.09^{a}	0.14
	90	34.11 ± 2.65^{a}	36.43 ± 0.98^{a}	34.35 ± 1.52^{a}	35.15 ± 2.72^{a}	33.74 ± 1.74^{a}	0.19
CaL	0	42.29 ± 4.18^{a}	42.29 ± 4.18^{a}	42.29 ± 4.18^{a}	42.29 ± 4.18^{a}	42.29 ± 4.18^{a}	1
	30	41.67 ± 2.41^{a}	40.83 ± 3.19^{a}	41.62 ± 2.6^{a}	40.77 ± 3.56^{a}	43.09 ± 3.18^{a}	0.22
	60	40.15 ± 3.66^{a}	34.76 ± 1.27^{ab}	31.16 ± 2.27^{b}	29.53 ± 2.83^{b}	30.36 ± 2.76^{b}	0.006
	90	39.02 ± 1.75^{a}	30.91 ± 1.06^{ab}	28.47 ± 1.81^{b}	20.12 ± 2.27^{c}	20.54 ± 1.54^{c}	0.003
CaA + CaL	0	44.32 ± 6.03^{a}	44.32 ± 6.03^{a}	44.32 ± 6.03^{a}	44.32 ± 6.03^{a}	44.32 ± 6.03^{a}	1
	30	43.87 ± 5.94^{a}	42.64 ± 3.44^{a}	46.12 ± 4.26^{a}	43.03 ± 4.37^{a}	43.94 ± 4.17^{a}	0.41
	60	43.61 ± 2.41^{a}	40.47 ± 4.19^{a}	43.39 ± 2.63^{a}	40.31 ± 3.84^{a}	41.16 ± 5.21^{a}	0.27
	90	41.69 ± 3.62^{a}	36.53 ± 2.41^{ab}	35.17 ± 3.08^{ab}	33.88 ± 2.69^{ab}	30.03 ± 2.34^{b}	0.012
CaA + CD	0	42.15 ± 1.88^{a}	42.15 ± 1.88^{a}	42.15 ± 1.88^{a}	42.15 ± 1.88^{a}	42.15 ± 1.88^{a}	1
	30	39.27 ± 4.53^{a}	36.29 ± 3.91^{a}	37.25 ± 2.41^{a}	38.16 ± 3.46^{a}	35.69 ± 2.52^{a}	0.256
	60	33.95 ± 2.81^{a}	28.61 ± 2.55^{a}	29.19 ± 1.7^{a}	26.44 ± 251^{a}	25.37 ± 2.88^{a}	0.78
	90	28.18 ± 4.01^{a}	23.56 ± 3.38^{a}	23.01 ± 2.01^{a}	20.93 ± 1.83^{a}	19.26 ± 2.12^{a}	0.067
CaL + CD	0	45.30 ± 3.22^{a}	45.30 ± 3.22^{a}	45.30 ± 3.22^{a}	45.30 ± 3.22^{a}	45.30 ± 3.22^{a}	1
	30	44.65 ± 2.48^{a}	42.23 ± 3.76^{a}	41.64 ± 3.47^{a}	42.59 ± 2.24^{a}	41.26 ± 4.35^{a}	0.002
	60	42.83 ± 3.15^{a}	33.81 ± 4.09^{b}	30.41 ± 4.74^{b}	30.01 ± 3.76^{b}	30.87 ± 3.19^{b}	<0.001
	90	40.11 ± 2.73^{a}	23.54 ± 3.14^{b}	20.18 ± 3.21^{b}	19.63 ± 2.38^{b}	20.13 ± 3.13^{b}	<0.001
CaA + CaL + CD	0	40.95 ± 4.10^{a}	40.95 ± 4.10^{a}	40.95 ± 4.10^{a}	40.95 ± 4.10^{a}	40.95 ± 4.10^{a}	1
	30	38.76 ± 4.32^{a}	36.42 ± 2.87^{a}	35.93 ± 3.84^{a}	37.15 ± 2.77^{a}	34.84 ± 3.63^{a}	0.68
	60	37.84 ± 1.44^{a}	29.54 ± 2.18^{ab}	21.59 ± 1.52^{b}	20.68 ± 2.64^{b}	22.39 ± 3.31^{b}	0.002
	90	37.96 ± 2.67^{a}	24.66 ± 1.24^{ab}	19.11 ± 0.69^{b}	18.92 ± 1.07^{b}	19.46 ± 3.45^{b}	<0.001

Values followed by the same letter in a row are not significantly different ($P > 0.05$) using LSD. **CaA:** Cashew apple, **CaL:** Cashew leaves, **CD:** Cow dung.

3.1.3. Nitrogen

The percentage of nitrogen during the vermicomposting of the different types of waste is shown in Table 3. In the raw cashew apples, nitrogen content was 0.87% ± 0.03%. There was no significant variation in nitrogen content at 30, 60 and 90 days of the composting process respectively with 0, 5, 10, 15 and 20 individuals of *E. eugeniae*. However, there was an increase in its content regarding vermicomposting timing. In cashew leaves, nitrogen content was 0.67% ± 0.07%. At 30 and 60 days of the vermicomposting, nitrogen content did not differ statistically whatever the number of earthworms introduced initially for wastes mineralization. But after three months, the content of nitrogen in the control was lower than those observed with 5, 10, 15 and 20 earthworms. In the mixture of cashew apples and cashew leaves, the nitrogen content was 1.57% ± 0.22%. During the composting process, nitrogen content was similar with 10, 15 and 20 earthworms and higher than those got with 0 and 5 earthworms at 30, 60 and 90 days. In the mixture of cashew apples and cow dung and that of cashew leaves and cow dung, nitrogen percentage was 1.21% ± 0.13% respectively. At 30, 60 and 90 days of the composting process of both substrates, nitrogen content differed significantly ($P < 0.05$) in function of earthworms population size. At these latter dates, the highest nitrogen contents were obtained with 10, 15 and 15 earthworms which were statistically identical. In the mixture of the three types of wastes (CaA, CaL, CD), nitrogen content was 0.98% ± 0.12%. It varied significantly in function of earthworms number at 30, 60 and 90 days respectively. The highest nitrogen content at each date was obtained with 10, 15 and 20 earthworms which were statistically similar. Regarding the composting timing, nitrogen content increased with it.

Table 3. Changes in N content (%) (mean ± SD, n = 3) of the different types of waste during vermicomposting.

Type of waste	Composting timing (days)	Earthworm batches					*P*
		0	5	10	15	20	
CaA	0	0.87 ± 0.03[a]	0.87 ± 0.13[a]	0.87 ± 0.13[a]	0.87 ± 0.13[a]	0.87 ± 0.13[a]	1
	30	0.87 ± 0.04[a]	0.89 ± 0.03[a]	0.88 ± 0.09[a]	0.89 ± 0.08[a]	0.88 ± 0.1[a]	0.86
	60	0.88 ± 0.1[a]	0.89 ± 0.21[a]	0.89 ± 0.06[a]	0.89 ± 0.11[a]	0.89 ± 0.16[a]	0.81
	90	0.89 ± 0.09[a]	0.88 ± 0.14[a]	0.89 ± 0.19[a]	0.88 ± 0.23[a]	0.89 ± 0.21[a]	0.84
CaL	0	0.67 ± 0.07[a]	0.67 ± 0.07[a]	0.67 ± 0.07[a]	0.67 ± 0.07[a]	0.67 ± 0.07[a]	1
	30	0.66 ± 0.12[a]	0.69 ± 0.13[a]	0.71 ± 0.11[a]	0.73 ± 0.18[a]	0.7 ± 0.11[a]	0.45
	60	0.68 ± 0.08[a]	0.76 ± 0.26[a]	0.79 ± 0.17[a]	0.78 ± 0.14[a]	0.77 ± 0.09[a]	0.32
	90	0.71 ± 0.05[b]	0.82 ± 0.08[a]	0.85 ± 0.12[a]	0.87 ± 0.21[a]	0.9 ± 0.18[a]	0.43
CaA + CaL	0	1.57 ± 0.22[a]	1.57 ± 0.22[a]	1.57 ± 0.22[a]	1.57 ± 0.22[a]	1.57 ± 0.22[a]	1
	30	1.59 ± 0.17[b]	1.63 ± 0.18[ab]	1.65 ± 0.25[ab]	1.66 ± 0.25[ab]	1.69 ± 0.46[a]	0.003
	60	1.59 ± 0.34[b]	1.68 ± 0.41[ab]	1.72 ± 0.18[a]	1.86 ± 0.37[a]	1.78 ± 0.29[a]	0.002
	90	1.6 ± 0.11[c]	1.76 ± 0.35[b]	1.84 ± 0.28[ab]	1.87 ± 0.34[a]	1.83 ± 0.62[ab]	<0.001
CaA + CD	0	1.21 ± 0.13[a]	1.21 ± 0.13[a]	1.21 ± 0.13[a]	1.21 ± 0.13[a]	1.21 ± 0.13[a]	1
	30	1.22 ± 0.19[b]	1.28 ± 0.27[b]	1.32 ± 0.34[ab]	1.38 ± 0.17[a]	1.27 ± 0.27[b]	0.012

Continued

	60	1.22 ± 0.16[c]	1.36 ± 0.12[b]	1.43 ± 0.44[ab]	1.54 ± 0.53[a]	1.51 ± 0.55[a]	<0.001
	90	1.24 ± 0.08[c]	1.49 ± 0.46[b]	1.61 ± 0.31[a]	1.65 ± 0.44[a]	1.66 ± 0.34[a]	<0.001
CaL + CD	0	1.02 ± 0.15[a]	1.02 ± 0.15[a]	1.02 ± 0.15[a]	1.02 ± 0.15[a]	1.02 ± 0.15[a]	1
	30	1 ± 0.07[c]	1.22 ± 0.09[b]	1.24 ± 0.43[a]	1.31 ± 0.33[a]	1.28 ± 0.41[a]	<0.001
	60	1.11 ± 0.24[b]	1.57 ± 0.33[a]	1.66 ± 0.39[a]	1.66 ± 0.58[a]	1.64 ± 0.63[a]	<0.001
	90	1.13 ± 0.32[c]	1.56 ± 0.13[b]	1.69 ± 0.51[a]	1.73 ± 0.63[a]	1.71 ± 0.42[a]	<0.001
CaA + CaL + CD	0	0.98 ± 0.12[a]	0.98 ± 0.12[a]	0.98 ± 0.12[a]	0.98 ± 0.12[a]	0.98 ± 0.12[a]	1
	30	0.97 ± 0.14[b]	1.17 ± 0.08a[b]	1.23 ± 0.19[a]	1.26 ± 0.73a	1.29 ± 0.17[a]	<0.004
	60	1 ± 0.11[b]	1.29 ± 0.19[a]	1.38 ± 0.36[a]	1.41 ± 0.28[a]	1.35 ± 0.26[a]	<0.001
	90	1.02 ± 0.09[c]	1.46 ± 0.16[ab]	1.55 ± 0.42[ab]	1.63 ± 0.39[a]	1.58 ± 0.41[a]	<0.001

Values followed by the same letter in a row are not significantly different ($P > 0.05$) using LSD. **CaA:** Cashew apple, **CaL:** Cashew leaves, **CD:** Cow dung.

3.1.4. C/N Ratio

Table 4 shows the variation of C/N ratio during the vermicomposting process. C/N ratio was 43.52 ± 5.19 in cashew apples. It varied from 46.21 ± 3.11 to 41.46 ± 5.74 at 30 days, from 40.38 ± 4.53 to 40.01 ± 4.09 at 60 days and from 38.32 ± 2.17 to 39.94 ± 3.57 at 90 days of the process with 0, 5, 10, 15, and 20 earthworms. In non-composted cashew leaves, C/N ratio was 63.12 ± 9.84. At 30 days of the composting process, C/N ratio was similar whatever the number of earthworms used for mineralization. But at 60 and 90 days respectively, C/N ratio varied significantly in function of the population size. The lowest C/N ratio was 22.82 ± 5.33 obtained with 20 earthworms and 23.13 ± 4.23 with 15 earthworms. With the mixture of cashew apples and cashew leaves, C/N ratio was 28.22 ± 6.94. At 30 and 60 days respectively, C/N ratio remained similar despite the variation in earthworms number. But a variation was observed in the ratio at 90 days of the vermicomposting. After mixing cow dung with cashew apples and cashew leaves respectively, C/N ratio was 34.83 ± 6.22 and 44.41 ± 10.22. At 30 days of the vermicomposting, C/N did not differ whatever the earthworms batches used initially. But, at 60 and 90 days of the vermicomposting, C/N ratio differed significantly from one batch of earthworm to another. In all cases, C/N ratio obtained at 90 days was lower than others. In the mixture of cashew apples, cashew leaves and cow dung, C/N ratio was 41.78 ± 9.37. At 30 days, C/N ratio was 39.95 ± 7.56 in the control and did not change statistically from those got with 5, 10, 15 and 20 earthworms. At 60 and 90 days respectively, the highest C/N content was obtained in the control, and the lowest contents were measured with 10, 15 and 20 earthworms.

Table 4. Changes in C:N (mean ± SD, n = 3) of the different type wastes during vermicomposting.

Type of waste	Composting timing (days)	Earthworm batches					*P*
		0	5	10	15	20	
CaA	0	43.52 ± 5.19[a]	43.51 ± 5.19[a]	43.52 ± 5.19[a]	43.51 ± 5.19[a]	43.52 ± 5.19[a]	1
	30	46.21 ± 3.11[a]	43.33 ± 4.22[a]	42.31 ± 3.26[a]	40.59 ± 4.35[a]	41.46 ± 5.74[a]	0.67

Continued

	60	40.38 ± 4.53[a]	40.50 ± 4.71[a]	38.40 ± 4.66[a]	39.57 ± 5.13[a]	40.01 ± 4.09[a]	0.79
	90	38.32 ± 2.17[a]	41.39 ± 3.84[a]	38.59 ± 3.02[a]	39.94 ± 3.57[a]	37.91 ± 2.28[a]	0.85
CaL	0	63.12 ± 9.84[a]	63.11 ± 9.84[a]	63.11 ± 9.84[a]	63.12 ± 9.84[a]	63.11 ± 9.84[a]	1
	30	63.13 ± 8.12[a]	59.17 ± 7.67[a]	58.61 ± 8.36[a]	55.84 ± 6.42[a]	61.55 ± 7.08[a]	0.39
	60	59.04 ± 6.31[a]	45.73 ± 4.16[b]	39.44 ± 3.62[b]	37.85 ± 4.64[b]	39.43 ± 6.27[b]	0.003
	90	54.95 ± 2.65[a]	37.69 ± 3.53[b]	33.49 ± 4.15[bc]	23.13 ± 4.23[c]	22.82 ± 5.33[c]	<0.001
CaA + CaL	0	28.22 ± 6.94[a]	28.22 ± 6.94[a]	28.22 ± 6.94[a]	28.23 ± 6.94[a]	28.23 ± 6.94[a]	1
	30	27.59 ± 2.23[a]	26.15 ± 3.76[a]	27.95 ± 2.56[a]	25.92 ± 3.2[a]	26.00 ± 1.68[a]	0.83
	60	27.42 ± 1.56[a]	24.08 ± 1.29[a]	25.23 ± 1.23[a]	21.67 ± 1.94[a]	23.12 ± 2.07[a]	0.72
	90	26.05 ± 1.44[a]	20.75 ± 0.86[ab]	19.11 ± 0.82[ab]	18.11 ± 1.05[ab]	16.41 ± 0.77[b]	<0.001
CaA + CD	0	34.83 ± 6.22[a]	34.83 ± 6.22[a]	34.83 ± 6.22[a]	34.83 ± 6.22[a]	34.83 ± 6.22[a]	1
	30	32.18 ± 5.67[a]	28.35 ± 4.35[a]	28.21 ± 3.86[a]	27.65 ± 4.24[a]	28.10 ± 2.13[a]	0.54
	60	27.83 ± 2.11[ab]	21.03 ± 3.42[ab]	20.41 ± 2.18[ab]	17.17 ± 1.86[b]	16.80 ± 0.52[b]	<0.001
	90	22.72 ± 2.49[ab]	15.81 ± 2.78[ab]	14.29 ± 2.06[ab]	12.68 ± 1.29[b]	11.60 ± 1.37[b]	<0.001
CaL + CD	0	44.41 ± 10.22[a]	44.41 ± 10.22[a]	44.41 ± 10.22[a]	44.41 ± 10.22[a]	44.41 ± 10.22[a]	1
	30	44.65 ± 5.14[a]	34.61 ± 4.43[b]	33.58 ± 3.19[b]	32.51 ± 6.68[b]	32.23 ± 4.16[b]	0.005
	60	38.58 ± 2.34[a]	21.53 ± 1.94[b]	18.32 ± 1.53[b]	18.08 ± 1.34[b]	18.82 ± 1.53[b]	<0.001
	90	35.49 ± 3.21[a]	15.08 ± 2.35[b]	11.94 ± 2.07[b]	11.35 ± 0.86[b]	11.77 ± 0.47[b]	<0.001
CaA + CaL + CD	0	41.78 ± 9.37[a]	41.78 ± 9.37[a]	41.78 ± 9.37[a]	41.78 ± 9.37[a]	41.78 ± 9.37[a]	1
	30	39.95 ± 7.56[a]	31.13 ± 1.44[ab]	29.21 ± 3.72[b]	29.48 ± 4.76[b]	27.01 ± 1.93[b]	0.006
	60	37.84 ± 2.13[a]	22.89 ± 1.62[b]	15.64 ± 1.29[b]	14.67 ± 1.68[b]	16.58 ± 1.54[b]	<0.001
	90	37.21 ± 1.64[a]	16.87 ± 0.78[b]	12.32 ± 1.12[b]	11.61 ± 1.48[b]	12.32 ± 4.06[b]	<0.001

Values followed by the same letter in a row are not significantly different ($P > 0.05$) using LSD. **CaA:** Cashew apple, **CaL:** Cashew leaves, **CD:** Cow dung.

3.1.5. Phosphorus and Potassium

Phosphorus and potassium content during the vermicomposting process with different batches of earthworms are presented in Table 5 and Table 6 respectively. Relatively to phosphorus, its content was 1.23% ± 0.21% in raw cashew apples. At 30 days, it increased to 1.25% ± 0.14% in the control and did not change statistically whatever earthworms population size. At 60 and 90 days, phosphorus content remained similar statistically whatever earthworms population. Similar trend was observed during the vermicomposting of cashew leaves. In the mixtures CaA + CaL, CaA + CD, CaL + CD and CaA + CaL + CD, the highest phosphorus contents were obtained with 10, 15 and 20 earthworms which were statistically similar. As for potassium content, it was 0.88% ± 0.03% in raw cashew apples and 0.48% ± 0.01% in cashew leaves. At dates 0, 30, 60 and 90 respectively, potassium content did not differ significantly from one population size to another. In CaL, the highest potassium contents were measured with 10 and 20 earthworms. In general, potassium content did not differ significantly whatever earthworms population at a same date.

Table 5. Changes in *P* content (%) (mean ± SD, n = 3) of the different type wastes during vermicomposting.

Type of waste	Composting timing (days)	Earthworm batches					*P*
		0	5	10	15	20	
CaA	0	1.23 ± 0.21[a]	1.23 ± 0.21[a]	1.23 ± 0.21[a]	1.23 ± 0.21[a]	1.23 ± 0.21[a]	1
	30	1.25 ± 0.14[a]	1.24 ± 0.12[a]	1.23 ± 0.16[a]	1.24 ± 0.13[a]	1.23 ± 0.14[a]	0.28
	60	1.26 ± 0.23[a]	1.24 ± 0.18[a]	1.24 ± 0.2[a]	1.25 ± 0.15[a]	1.25 ± 0.11[a]	0.81
	90	1.25 ± 0.15[a]	1.26 ± 0.23[a]	1.25 ± 0.16[a]	1.26 ± 0.17[a]	1.26 ± 0.23[a]	0.88
CaL	0	0.13 ± 0.06[a]	0.13 ± 0.06[a]	0.13 ± 0.06[a]	0.13 ± 0.06[a]	0.13 ± 0.06[a]	1
	30	0.22 ± 0.08[a]	0.26 ± 0.06[a]	0.27 ± 0.06[a]	0.28 ± 0.08[a]	0.26 ± 0.06[a]	0.43
	60	0.36 ± 0.04[a]	0.41 ± 0.05[a]	0.44 ± 0.04[a]	0.37 ± 0.04[a]	0.43 ± 0.07[a]	0.58
	90	0.45 ± 0.06[a]	0.53 ± 0.09[a]	0.58 ± 0.07[a]	0.49 ± 0.07[a]	0.51 ± 0.07[a]	0.67
CaA + CaL	0	0.57 ± 0.14[a]	0.57 ± 0.14[a]	0.57 ± 0.14[a]	0.57 ± 0.14[a]	0.57 ± 0.14[a]	1
	30	0.64 ± 0.08[a]	0.66 ± 0.1[ab]	0.69 ± 0.08[ab]	0.73 ± 0.05[a]	0.64 ± 0.09[b]	0.024
	60	0.71 ± 0.09[b]	0.83 ± 0.06[a]	0.77 ± 0.05[ab]	0.84 ± 0.06[a]	0.72 ± 0.07[b]	0.013
	90	0.76 ± 0.1[b]	0.89 ± 0.07[a]	0.94 ± 0.09[a]	0.96 ± 0.11[a]	0.89 ± 0.07[a]	<0.001
CaA + CD	0	0.66 ± 0.08[a]	0.66 ± 0.08[a]	0.66 ± 0.08[a]	0.66 ± 0.08[a]	0.66 ± 0.08[a]	1
	30	0.74 ± 0.1[b]	0.76 ± 0.07[ab]	0.78 ± 0.06[ab]	0.81 ± 0.0.07[a]	0.87 ± 0.08[a]	0.004
	60	0.75 ± 0.08[b]	0.83 ± 0.08[ab]	0.87 ± 0.11[a]	0.89 ± 0.01[a]	0.89 ± 0.04[a]	0.002
	90	0.76 ± 0.06[b]	0.86 ± 0.06[ab]	0.92 ± 0.09[a]	0.93 ± 0.08[a]	0.92 ± 0.05[a]	<0.001
CaL + CD	0	0.27 ± 0.11[a]	0.27 ± 0.11[a]	0.27 ± 0.11[a]	0.27 ± 0.11[a]	0.27 ± 0.11[a]	1
	30	0.34 ± 0.1[a]	0.38 ± 0.08[a]	0.4 ± 0.02[a]	0.43 ± 0.03[a]	0.37 ± 0.06[a]	0.65
	60	0.39 ± 0.04[b]	0.44 ± 0.09[ab]	0.49 ± 0.01[a]	0.54 ± 0.04[a]	0.42 ± 0.03[ab]	0.011
	90	0.41 ± 0.02[b]	0.52 ± 0.05[a]	0.57 ± 0.08[a]	0.61 ± 0.07[a]	0.56 ± 0.05[a]	0.006
CaA + CaL + CD	0	0.51 ± 0.06[a]	0.51 ± 0.06[a]	0.51 ± 0.06[a]	0.51 ± 0.06[a]	0.51 ± 0.06[a]	1
	30	0.56 ± 0.08[b]	0.64 ± 0.07[ab]	0.68 ± 0.05[a]	0.69 ± 0.04[a]	0.66 ± 0.04[a]	0.026
	60	0.63 ± 0.03[b]	0.72 ± 0.06[ab]	0.73 ± 0.03[a]	0.76 ± 0.08[a]	0.71 ± 0.07[ab]	<0.019
	90	0.68 ± 0.08[b]	0.83 ± 0.06[a]	0.89 ± 0.04[a]	0.86 ± 0.07[a]	0.84 ± 0.06[a]	<0.001

Values followed by the same letter in a row are not significantly different ($P > 0.05$) using LSD. **CaA:** Cashew apple, **CaL:** Cashew leaves, **CD:** Cow dung.

Table 6. Changes in K content (%) (mean ± SD, n = 3) of the different type of wastes during vermicomposting.

Type of waste	Composting timing (days)	Earthworm batches					*P*
		0	5	10	15	20	
CaA	0	0.88 ± 0.03[a]	0.88 ± 0.03[a]	0.88 ± 0.03[a]	0.88 ± 0.03[a]	0.88 ± 0.03[a]	1
	30	0.88 ± 0.02[a]	0.89 ± 0.06[a]	0.88 ± 0.11[a]	0.89 ± 0.10[a]	0.87 ± 0.06[a]	0.87
	60	0.91 ± 0.08[a]	0.9 ± 0.03[a]	0.89 ± 0.07[a]	0.9 ± 0.05[a]	0.88 ± 0.04[a]	0.71
	90	0.89 ± 0.1[a]	0.88 ± 0.04[a]	0.91 ± 0.08[a]	0.92 ± 0.04[a]	0.91 ± 0.06[a]	0.64
CaL	0	0.48 ± 0.01[a]	0.48 ± 0.01[a]	0.48 ± 0.01[a]	0.48 ± 0.01[a]	0.48 ± 0.01[a]	1
	30	0.51 ± 0.13[b]	0.55 ± 0.06[b]	0.62 ± 0.05[ab]	0.67 ± 0.06[a]	0.65 ± 0.01[a]	0.041
	60	0.64 ± 0.09[c]	0.72 ± 0.04[bc]	0.83 ± 0.08[a]	0.88 ± 0.12[a]	0.76 ± 0.07[b]	0.003
	90	0.68 ± 0.1[b]	0.87 ± 0.06[a]	0.88 ± 0.06	0.91 ± 0.09[a]	0.87 ± 0.03[a]	<0.001

Continued

CaA + CaL	0	0.63 ± 0.17^{a}	0.63 ± 0.17^{a}	0.63 ± 0.17^{a}	0.63 ± 0.17^{a}	0.63 ± 0.17^{a}	1
	30	0.68 ± 0.13^{a}	0.67 ± 0.09^{a}	0.71 ± 0.15^{a}	0.72 ± 0.08^{a}	0.76 ± 0.13^{a}	0.51
	60	0.72 ± 0.08^{b}	0.78 ± 0.12^{ab}	0.77 ± 0.04^{ab}	0.81 ± 0.05^{a}	0.86 ± 0.06^{a}	0.023
	90	0.86 ± 0.06^{b}	0.89 ± 0.1^{ab}	0.96 ± 0.09^{a}	0.97 ± 0.07^{a}	0.95 ± 0.09^{a}	0.031
CaA + CD	0	0.74 ± 0.07^{a}	0.74 ± 0.07^{a}	0.74 ± 0.07^{a}	0.74 ± 0.07^{a}	0.74 ± 0.07^{a}	1
	30	0.79 ± 0.06^{a}	0.83 ± 0.03^{a}	0.84 ± 0.04^{a}	0.78 ± 0.11^{a}	0.81 ± 08^{a}	0.45
	60	0.84 ± 0.04^{a}	0.89 ± 0.08^{a}	0.92 ± 0.06^{a}	0.87 ± 0.09^{a}	0.88 ± 0.04^{a}	0.86
	90	0.88 ± 0.04^{b}	0.95 ± 0.05^{ab}	1.02 ± 0.02^{a}	0.98 ± 0.05^{a}	0.97 ± 0.04^{a}	0.010
CaL + CD	0	0.57 ± 0.04^{a}	0.57 ± 0.04^{a}	0.57 ± 0.04^{a}	0.57 ± 0.04^{a}	0.57 ± 0.04^{a}	1
	30	0.62 ± 0.04^{a}	0.67 ± 0.03^{a}	0.65 ± 0.03^{a}	0.66 ± 0.02^{a}	0.63 ± 0.05^{a}	0.67
	60	0.71 ± 0.03^{b}	0.84 ± 0.02^{ab}	0.92 ± 0.06^{a}	0.89 ± 0.01^{a}	0.76 ± 0.04^{b}	<0.001
	90	0.83 ± 0.05^{b}	0.93 ± 0.06^{a}	1.15 ± 0.08^{a}	1.01 ± 0.06^{a}	0.94 ± 0.03^{a}	<0.001
CaA + CaL + CD	0	0.61 ± 0.07^{a}	0.61 ± 0.07^{a}	0.61 ± 0.07^{a}	0.61 ± 0.07^{a}	0.61 ± 0.07^{a}	1
	30	0.68 ± 0.05^{a}	0.67 ± 0.06^{a}	0.7 ± 0.06^{a}	0.77 ± 0.07^{a}	0.75 ± 0.03^{a}	0.79
	60	0.74 ± 0.03^{b}	0.72 ± 0.03^{b}	0.86 ± 0.08^{a}	0.88 ± 0.05^{a}	0.87 ± 0.04^{a}	0.021
	90	0.81 ± 0.04^{b}	0.96 ± 0.04^{a}	0.95 ± 0.05^{a}	0.99 ± 0.06^{a}	1.11 ± 0.09^{a}	<0.001

Values followed by the same letter in a row are not significantly different ($P > 0.05$) using LSD. **CaA:** Cashew apple, **CaL:** Cashew leaves, **CD:** Cow dung.

3.2. Growth and Fecundity Parameters of *Eudrilus eugeniae*

Table 7 encapsulates the growth and fecundity parameters of *Eudrilus eugeniae* in the different wastes. In cashew apples waste, earthworms did not survive. In cashew leaves, earthworms number varied from 24 to 136 and from 102 to 176 in the mixture of cashew apples and cashew leaves. In cashew apples mixed with cow dung, earthworms number shifted between 153 to 203 and between 186 to 255 in cashew leaves mixed with cow dung. In the mixture of the three wastes, earthworms number fluctuated between 172 and 266. However, earthworms number harvested differed significantly in function of the initial population used. Whatever, the initial population, the highest number of earthworms was obtained in the mixture of the three wastes.

Regarding earthworm biomasses, they were higher in the mixture of the three wastes than those in the other types of wastes. Also, the number of cocoons harvested at the end of the experiment differed significantly from one type of waste to another. The highest cocoons number was counted in the mixture of the three wastes compared to others.

Table 7. Growth and fecundity parameters (mean ± SD, n = 3) in different type of waste after 90 d of vermicomposting.

Growth and fecundity parameters	Initial number of earthworms used	Type of waste						*P*
		CaA	CaL	CaA + CaL	CaA + CD	CaL + CD	CaA + CaL + CD	
Total number of earthworms	5	0	24 ± 3.19	102 ± 11.02	153 ± 8.69	186 ± 4.51	172 ± 3.69	<0.001

Continued

	10	0	41 ± 2.21	132 ± 13.24	185 ± 9.16	234 ± 10.2	261 ± 5.75	<0.001
	15	0	134 ± 5.63	176 ± 11.52	196 ± 7.67	255 ± 9.44	278 ± 6.08	<0.001
	20	0	136 ± 4.84	164 ± 12.15	203 ± 8.42	249 ± 6.83	266 ± 8.26	<0.001
Total biomass of earthworms (g)	5	0	1.11 ± 0.18	5.19 ± 0.65	7.19 ± 0.35	7.53 ± 0.32	7.88 ± 0.12	<0.001
	10	0	2.38 ± 0.56	5.46 ± 0.39	7.73 ± 0.41	8.86 ± 0.91	9.27 ± 0.58	<0.001
	15	0	6.22 ± 0.71	6.66 ± 0.64	8.26 ± 1.11	9.13 ± 0.74	9.64 ± 0.46	0.002
	20	0	6.27 ± 0.68	6.54 ± 0.36	8.61 ± 0.68	8.95 ± 0.59	10.11 ± 0.47	0.004
Total number of cocoons	5	0	13 ± 1.47	10 ± 0.63	47 ± 1.15	54 ± 0.64	76 ± 0.29	<0.001
	10	0	21 ± 4.12	19 ± 0.55	33 ± 0.61	41 ± 0.58	52 ± 0.43	<0.001
	15	0	34 ± 3.59	38 ± 0.86	28 ± 0.49	48 ± 0.6	56 ± 0.68	<0.001
	20	0	30 ± 2.25	41 ± 0.73	32 ± 0.72	35 ± 0.77	47 ± 0.52	<0.001

Values followed by the same letter in a row are not significantly different (P > 0.05) using LSD. **CaA:** Cashew apple, **CaL:** Cashew leaves, **CD:** Cow dung.

4. Discussion

4.1. Variation in Physicho-Chemical Properties of Wastes during Vermicomposting

pH. Soil pH is a "master variable" in plant nutrition, primarily controlling nutrient solubility, availability, and microbial activity in the soil. An optimal pH (6.0 - 7.5) ensures essential nutrients like nitrogen, phosphorus, and potassium are soluble and accessible to roots, while extreme pH levels can cause nutrient deficiencies, toxicities, and reduced yields [28] [29]. In our experiment, pH varied from 4.22 to 4.52 in cashew apples, from 5.29 to 5.69 in cashew leaves and from 5.53 to 5.91 in the mixture of cashew apples and cashew leaves. These results could be linked to the fact that cashew leaves and apples are known as lignocellulosic residues. Therefore, their decomposition is slow, and they might need more than 90 days to reach optimal pH essential for good absorption of nutrients by plant roots. When mixed with cow dung, pH varied from 5.87 to 6.57 in cashew apples and from 6.11 to 6.65 in cashew leaves. In the mixture of the 3 residues (cashew apples, cashew leaves and cow dung), pH fluctuated between 6.27 and 6.85. These results showed good pH promoting nutrients absorption. Cow dung might be basic and that could improve the pH of the cashew residues. For cashew apples, optimal pH was obtained after 60 or 90 days of composting with the different population of earthworms. Regarding the composting timing, there was an increase in pH when it increases. The increase of the pH during the vermicomposting or the composting process could be linked to the mineralization of nitrogen and phosphorus. In fact, earthworm activity, including the secretion of enzymes (phosphatase) and microbial action, leads to the mineralization of nutrients. The breakdown of organic nitrogen compounds produces ammonia, which contributes to an increase in pH. The metabolic processes and decomposition of organic matter by worms result in the release of inorganic phosphorus and other mineral constituents that act to raise the pH. The transformation of organic matter into stable vermicast involves the conversion of ammonia into nitrates in the later stages, but the overall reduction of volatile fatty acids and production of ammonium generally results in a higher pH. Also, during the composting process, the initial organic acids produced during early decomposition are consumed or degraded by microbial activity, reducing the overall acidity.

Carbon. Carbon content is considered as the key indicator of soil health and the essence of life on earth heavily depends on it. Carbon content decreases with soil fertility. The main reason for this decrease is the presence of organisms that mineralize the organic substances essential to their metabolism in the form of carbon dioxide [30]. Organic carbon content in fertile soils varies between 10% and 30% [30] [31]. In the present study, carbon content was higher than 30 during the vermicompost of cashew apples whatever the population size of earthworms. In the vermicompost of cashew leaves, carbon content was 20.12% and 20.54% after 90 days with 15 and 20 earthworms respectively. When cashew apples and leaves were mixed, carbon content was higher than 30 whatever the earthworms population size and the vermicomposting timing. In the mixture of cashew apples and cow dung, carbon content was in the range 10% - 30% after at 60 and 90 days of composting with 5, 10, 15 and 20 individuals of *E. eugeniae*. In the mixture of cashew leaves and cow dung, carbon content was in the optimum range after 90 days of vermicomposting with 5, 10, 15 and 20 earthworms. In the mixture of cashew apples, leaves and cow dung, carbon content was in the optimum range at 60 and 90 days of composting with 5, 10, 15 and 20 earthworms. Regarding the composting timing, there was a decrease in carbon content when timing and earthworms increased. This could be due to the activity of earthworms and microorganisms that mineralize carbon. Mineralization generally resulted in the loss of carbon as CO_2 during the process. Similarly, Coulibaly *et al.* [22] observed a decrease in carbon content during the vermicomposting of different types of animal wastes in function of the timing and the population size of earthworms used.

Nitrogen. Nitrogen content increased during the vermicomposting in the different cashew residues and when earthworms number increased. However, there was a similarity between nitrogen content got with 10, 15, and 20 individuals of *E. eugeniae*. The increase in nitrogen was probably due to the mineralization of organic matter by earthworms during vermicomposting. The similarity between nitrogen content for the treatments with 10, 15 and 20 earthworms in the different types of wastes suggest that up to 10 individuals of *E. eugeniae* can be considered as the limit for earthworm density to prevent competition. Another explanation for the increase in nitrogen could be its addition in the form of mucus, nitrogenous excretory substances, growth-stimulating hormones and enzymes from earthworms [32], which may be more important after 90 days.

C:N ratio. The C:N ratio is the most important chemical parameter for determining the maturity of organic wastes in a state of decomposition [33]. It allows the assessment of the biodegradability of organic matter. According to Senesi [34] and Mathur *et al.* [35], a C/N ratio equal to 20 or lesser than 20 indicates high soil fertility. In our experiment, C/N ratio of the cashew apples vermicompost oscillated between 43.52 and 37.91 which is higher than 20. Similar observations were made during the vermicomposting of cashew leaves. However, C/N ratio in the vermicompost of cashew leaves mineralize with 15 and 20 earthworms were respectively 23.13 and 22.82. These latter were below the 25 indicated by the Test Methods for the Examination of Composting and Compost [36] as an index of maturity. These results indicated that the vermicomposting of cashew apples needed more than 90 days due to the complexity of its composition. In contrast, cashew leaves can be composted with 15 and 20 individuals of *E. eugeniae* for 90 days. When cashew apples and cashew leaves were mixed with cow dung, C/N ratio was below 25 when using 5, 10, 15 and 20 earthworms for 60 or 90 days. The same remark was made when composting the mixture of cashew apples, leaves and cow dung with 5, 10, 15 and 20 earthworms. When earthworms were not used in the composting process, C/N ratio was higher than 20 whatever the composting timing. In addition, there was a decrease in C/N ratio when the composting timing increases. The C/N ratio lesser than 25 in the vermicompost of the different mixtures with 5, 10, 15 and 20 earthworms at 60 and 90 days could be explained by the fact that these population sizes and timing are suitable for good vermicompost. Contrary to vermicomposting, 90 days is not enough to obtain mature compost when using composting process. These differences could be linked to the activity of earthworms that accelerate wastes decomposition. Mixing cashew residues with cow dung could increase their palatability to earthworms that accelerate their mineralization and that was shown by the maturity of the vermicompost of the mixtures with cow dung at 60 days. The decrease in C/N ratio when the composting timing increases might be linked to the decrease in carbon content and the increase in nitrogen content during the vermicomposting process. In fact, the loss of carbon in the form of carbon dioxide in the process of respiration and the production of mucus and nitrogenous excrements enhanced the level of nitrogen which lowered the C:N ratio.

Phosphorus and potassium. There was a slight increase in phosphorus and potassium content when the number of earthworms increased. This increase was also noted with the increase in the composting timing. The increase in P content during vermicomposting could have been induced by the mineralization and the mobilization of phosphorus through bacterial and faecal phosphatase activity of the earthworms. The direct action of worm gut enzymes and the stimulation of microflora could increase phosphorus [37]. Our result agreed with those of Satchell and Martin [38] and Le Bayon and Binet [39] who observed an increase in phosphorus during the vermicomposting of paper waste sludge and organic substrates, respectively. They attributed the increase in P to the activities of earthworms. In contrast, Lopez-Hernandez *et al.* [40] observed a decrease in P in the casts of *Pontoscolex corethrurus*. This difference may be due to the initial characteristics of the animal waste used in our experiment and those of the soil used in their experiment. Regarding potassium content, similar observations were made by Delgado *et al.* [41] who observed an increase in K content during the vermicomposting of sewage sludge. In contrast, Orozco *et al.* [42] reported a decrease in K in the vermicomposting of coffee pulp waste. Coulibaly *et al.* [22] noted a decrease in K content during the vermicomposting of cow, sheep, pig and chicken waste. These differences could be attributed to the chemical nature of the initial raw wastes.

4.2. Growth and Fecundity of *Eudrilus eugeniae* on Wastes

Contrary to other treatments, earthworms did not survive in cashew apples substrates. At the end of the experiment, earthworms reproduced more in the mixture of the residues with cow dung than when they were alone. These results could be explained by the initial characteristics of cashew residues. Cashew apples might contain more complex compounds like lignin and cellulose making it hard for earthworms. When adding cow dung, it might reduce the rate of complex compounds. Therefore, mixtures with cow dung become favorable for earthworms. According to several authors, earthworms preferred organic matter that contained low complex compounds such as lignin and cellulose [43]-[45].

5. Conclusion

This study demonstrated the use of vermicomposting to recycle cashew apples and leaves into organic fertilizer when using the African nightcrawler earthworm *E. eugeniae* under laboratory conditions. Based on the maturity index and the pH, cashew residues are recommended to be mixed with cow dung to obtain good vermicompost. Thus, when mixing 150 g of cashew residues with 150 g of cow dung, or 100 g of cashew apples, cashew leaves and cow dung, 5, 10, 15 and 20 individuals of *E. eugeniae* are required for a composting period of 60 or 90 days.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] ACA (African Cashew Alliance) (2025) The International Cashew Market. https://africancashewalliance.com/sites/default/files/splits/africashewsplits_week_42_market_report_2025_aca.pdf

[2] Sanoko, F.K., Koffi, K.J.M., Coulibaly, F.L., Fondio, L., Adiko, Y.O. and Malezieux, E. (2025) Study of the Development of Cashew (*Anacadium occidentale* L.) Yield Components at Tree Level in Northern Côte d'Ivoire.

[3] Guero, M., Drion, B. and Karsch, P. (2021) Partners for Innovation: Study of the Biomass Potential in Côte d'Ivoire. Final Report RVO Project.

[4] Soro, D. (2012) Couplage de procédés membranaires pour la clarification et la concentration du jus de pomme de cajou: Performances et impacts sur la qualité des produits. Thèse de Doctorat, Institut des Régions Chaudes Montpellier SuprAgro

(France), 135 p.

[5] Deobald, L.A. and Crawford, D.L. (1997) Lignocellulose Biodegradation. In: Hurst, C.J., Knudsen, G.R., Stetzenbach, L.D. and Walter, M.V., *Manual of Environmental Microbiology*, ASM Press, 730-737.

[6] Elwell, D.L., Keener, H.M., Wiles, M.C., Borger, D.C. and Willett, L.B. (2001) Odorous Emissions and Odor Control in Composting Swine Manure/Saw Dust Mixes Using Continuous and Intermittent Aeration. *Transactions of the ASAE*, **44**, 1307-1316.

[7] Erenstein, O. (2002) Crop Residue Mulching in Tropical and Semi-Tropical Countries: An Evaluation of Residue Availability and Other Technological Implications. *Soil and Tillage Research*, **67**, 115-133. https://doi.org/10.1016/s0167-1987(02)00062-4

[8] Folefack, A.J.J. (2008) Factors Influencing the Use of Compost from Household Waste in the Centre Province of Cameroon. *Journal of Human Ecology*, **24**, 77-83. https://doi.org/10.1080/09709274.2008.11906103

[9] Tiquia, S.M., Richard, T.L. and Honeyman, M.S. (2002) Carbon, Nutrient, and Mass Loss during Composting. *Nutrient Cycling in Agroecosystems*, **62**, 15-24. https://doi.org/10.1023/a:1015137922816

[10] Manga, M., Evans, B.E., Ngasala, T.M. and Camargo-Valero, M.A. (2022) Recycling of Faecal Sludge: Nitrogen, Carbon and Organic Matter Transformation during Co-Composting of Faecal Sludge with Different Bulking Agents. *International Journal of Environmental Research and Public Health*, **19**, Article 10592. https://doi.org/10.3390/ijerph191710592

[11] Suthar, S. (2010) Vermicompost: An Environmentally Safe, Economically Viable and Socially Acceptable Nutritive Fertilizer for Sustainable Farming. In: Sinha, R.K., *Special Issue on Vermiculture Technology* (Vol. 10), International Journal of Global Environmental, 265-293.

[12] Yuvaraj, A., Karmegam, N. and Thangaraj, R. (2018) Vermistabilization of Paper Mill Sludge by an Epigeic Earthworm Perionyx Excavatus: Mitigation Strategies for Sustainable Environmental Management. *Ecological Engineering*, **120**, 187-197. https://doi.org/10.1016/j.ecoleng.2018.06.008

[13] Kaur, T. (2020) Vermicomposting: An Effective Option for Recycling Organic Wastes. In: *Organic Agriculture*, IntechOpen, 1-17. https://doi.org/10.5772/intechopen.91892

[14] John Paul, J.A., Karmegam, N. and Daniel, T. (2011) Municipal Solid Waste (MSW) Vermicomposting with an Epigeic Earthworm, Perionyx Ceylanensis Mich. *Bioresource Technology*, **102**, 6769-6773. https://doi.org/10.1016/j.biortech.2011.03.089

[15] Negi, R. and Suthar, S. (2013) Vermistabilization of Paper Mill Wastewater Sludge Using Eisenia Fetida. *Bioresource Technology*, **128**, 193-198. https://doi.org/10.1016/j.biortech.2012.10.022

[16] Enebe, M.C. and Erasmus, M. (2023) Mediators of Biomass Transformation—A Focus on the Enzyme Composition of the Vermicomposting Process. *Environmental Challenges*, **12**, Article 100732. https://doi.org/10.1016/j.envc.2023.100732

[17] Edwards C.A. and Subler S. (2011) Human Pathogen Reduction during Vermicomposting. In: Edwards, C.A., Arancon, N.Q., Sherman, R., *Vermiculture Technology*, CRC Press, 249-261.

[18] Zhi, W., Li, L., Dong, W., Brown, W., Kaye, J., Steefel, C., *et al.* (2019) Distinct Source Water Chemistry Shapes Contrasting Concentration-Discharge Patterns. *Water Re-*

sources Research, **55**, 4233-4251. https://doi.org/10.1029/2018wr024257

[19] Naik, S. and Dodake, S.B. (2016) Composting of Organic Residues as Influenced by Effective Microorganisms and Earthworms. *Journal of the Indian Society of Coastal Agricultural Research*, **34**, 38-42.

[20] Kalaivanan, D., Adiga, D. and Lakshmipathi, J. (2017) Compost from Cashew Leaf Litter Cashew Apple Waste. *Kisan World*, **44**, 48-50.

[21] Coulibaly, S.S., Ndegwa, P.M., Ayiania, M. and Zoro, I.A.B. (2019) Growth, Reproduction, and Life Cycle of *Eudrilus eugeniae* in Cocoa and Cashew Residues. *Applied Soil Ecology*, **143**, 153-160. https://doi.org/10.1016/j.apsoil.2019.06.015

[22] Coulibaly, S.S., Kouassi, K.I., Tondoh, E.J., Bi, I.A., *et al.* (2011). Impact of the population size of the earthworm *Eudrilus eugeniae* (Kinberg) on the Stabilization of Animal Wastes during Vermicomposting. *Philipine of Agricultural Scientists*, **94**, 359-367.

[23] Coulibaly, S.S. (2014) Optimisation de la technique de vermicompostage des déchets d'élevage pour une production rentable et saine de la forme oléagineuse de *Lagenaria siceraria* (Molina) Standl. (Côte d'Ivoire). Thèse de Doctorat, Université Nangui Abrogoua, Abidjan (Côte d'Ivoire).

[24] Djiakariya, C. (2004) Analyse thématique des données du Recensement Nationale de l'Agriculture 2001: Secteur des ressources animales. Abidjan (Côte d'Ivoire).

[25] Pereira Ferraz, G., Frear, C., Pelaez-Samaniego, M.R., Englund, K. and Garcia-Perez, M. (2016) Hot Water Extraction of Anaerobic Digested Dairy Fiber for Wood Plastic Composite Manufacturing. *BioResources*, **11**, 8139-8154. https://doi.org/10.15376/biores.11.4.8139-8154

[26] Pecha, B., Arauzo, P. and Garcia-Perez, M. (2015) Impact of Combined Acid Washing and Acid Impregnation on the Pyrolysis of Douglas Fir Wood. *Journal of Analytical and Applied Pyrolysis*, **114**, 127-137. https://doi.org/10.1016/j.jaap.2015.05.014

[27] SAS (1999) User's Guide, Version 6. 4th Edition, SAS Institute Inc.

[28] Brady, N.C. and Weil, R.R. (1999) The Nature and Property of Soils. Prentice Hall.

[29] Minasny, B., Hong, S.Y., Hartemink, A.E., Kim, Y.H. and Kang, S.S. (2016) Soil pH Increase under Paddy in South Korea between 2000 and 2012. *Agriculture*, *Ecosystems & Environment*, **221**, 205-213. https://doi.org/10.1016/j.agee.2016.01.042

[30] Francou, C. (2003) Stabilisation de la matière organique au cours du compostage de déchets urbains: Influence de la nature des déchets et du procédé de compostage-Recherche d'indicateurs pertinents. Thèse de doctorat, Institut National de Paris-Grignon, Paris (France).

[31] Serra-Wittling, C. (1995) Valorisation de compost d'ordures ménagères en protection des cultures: Influence de l'apport de composts sur le développement de maladies d'origine tellurique et le comportement de pesticides dans un sol. Thèse de Doctorat, Institut National de Paris-Grignon, Paris (France).

[32] Senapati, B.K., Dash, M.C., Rane, A.K. and Panda, B.K. (1980) Observation on the Effect of Earthworms in the Decomposition Process in Soil under Laboratory Conditions. *Comparative Physiology and Ecology*, **5**, 140-142.

[33] Sánchez-Monedero, M.A., Cegarra, J., García, D. and Roig, A. (2002) Chemical and Structural Evolution of Humic Acids during Organic Waste Composting. *Biodegradation*, **13**, 361-371. https://doi.org/10.1023/a:1022888231982

[34] Senesi, N. (1989) Composted Materials as Organic Fertilizers. *Science of the Total Environment*, **81**, 521-542. https://doi.org/10.1016/0048-9697(89)90161-7

[35] Mathur, S.P., Owen, G., Dinel, H. and Schnitzer, M. (1993) Determination of Compost Biomaturity. I. Literature Review. *Biological Agriculture & Horticulture*, **10**, 65-85. https://doi.org/10.1080/01448765.1993.9754655

[36] TMECC (2002) Test Methods for the Examination of Composting and Compost. Holbrook. US Composting Council Research and Education Foundation.

[37] Edwards, C.A. and Lofty, J.R. (1977) Biology of Earthworms. Chapman and Hall Ltd.

[38] Satchell, J.E. and Martin, K. (1984) Phosphatase Activity in Earthworm Faeces. *Soil Biology and Biochemistry*, **16**, 191-194. https://doi.org/10.1016/0038-0717(84)90111-1

[39] Le Bayon, R.C. and Binet, F. (2006) Earthworms Change the Distribution and Availability of Phosphorous in Organic Substrates. *Soil Biology and Biochemistry*, **38**, 235-246. https://doi.org/10.1016/j.soilbio.2005.05.013

[40] Lopez-Hernandez, D., Lavelle, P., Fardeau, J.C. and Niño, M. (1993) Phosphorus Transformations in Two P-Sorption Contrasting Tropical Soils during Transit through Pontoscolex Corethrurus (Glossoscolecidae: Oligochaeta). *Soil Biology and Biochemistry*, **25**, 789-792. https://doi.org/10.1016/0038-0717(93)90124-t

[41] Delgado, M., Bigeiego, M., Walter, L. and Calbo, R. (1995) Use of California Red Worm in Sewage Sludge Transformation. *Turrialba*, **45**, 33-41.

[42] Orozco, F.H., Cegarra, J., Trujillo, L.M. and Roig, A. (1996) Vermicomposting of Coffee Pulp Using the Earthworm Eisenia Fetida: Effects on C and N Contents and the Availability of Nutrients. *Biology and Fertility of Soils*, **22**, 162-166. https://doi.org/10.1007/bf00384449

[43] Knapp, E.B., Elliott, L.F. and Campbell, G.S. (1983) Carbon, Nitrogen and Biomass Interrelationships during the Decomposition. *Soil Biology and Biochemistry*, **18**, 15-22.

[44] Jawson, M.D. and Elliott, L.F. (1986) Carbon and Nitrogen Transformations during Wheat Straw and Root Decomposition. *Soil Biology and Biochemistry*, **18**, 15-22. https://doi.org/10.1016/0038-0717(86)90097-0

[45] Manna, M.C., Jha, S., Ghosh, P.K. and Acharya, C.L. (2003) Comparative Efficacy of Three Epigeic Earthworms under Different Deciduous Forest Litters Decomposition. *Bioresource Technology*, **88**, 197-206. https://doi.org/10.1016/s0960-8524(02)00318-8