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Effect of the Population Size of the Earthworm *Eudrilus eugeniae* and the Composting Time on Heavy Metal Content during the Vermicomposting of Cashew Residues

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Abstract

Quality organic fertilizers contain low heavy metals content. This study aimed to determine the population size of the earthworm *Eudrilus eugeniae* necessary to obtain low levels of heavy metals in vermicompost produced from cashew residues and cow dung. Thus, in 300 g of each waste and their mixtures with cow dung, four population sizes of the African nightcrawler *E. eugenia* (5, 10, 15 and 20) were tested. Heavy metal contents of Zn, Cu, Pb, Cd, Cr and Ni were measured at 30, 60 and 90 days of the vermicomposting. Results showed that heavy metals such as Zn and Cu were more concentrated in the cashew residues. Ni contents were higher than the recommended level in organic fertilizer after mixing them with cow dung. Heavy metal contents were influenced by the composting time and the earthworm's population numbers. The batches of 15 and 20 individuals of *E. eugeniae* in 90 days showed better reduction in heavy metals content. These results indicate that when using cashew residues and cow dung for vermicomposting, 15 earthworms can be recommended to mineralize 300 g of waste in 90 days.

Keywords

Cashew Residues, Cow Dung, Heavy Metal Content, Vermicomposting, *Eudrilus eugeniae*

1. Introduction

In northern Côte d'Ivoire, cashew cultivation is widespread with 1.6 million hectares of plantations (Mighty, 2023). This crop is the major source of income for farmers of the north of the country due to the economic value of its fruit called "cashew nut" (Bassett, 2017). The annual production of cashew nuts in Côte d'Ivoire is 1.2 million tons, making the country the first producer in the world (ACA, 2025). Because of large orchard areas, lack of labor, and producers' willingness to control soil fertility, weeds and plant pathogens, farmers generally use a lot of inorganic inputs (Yao et al., 2020). These chemicals can also be absorbed by plants and stocked in different parts like apples, leaves, etc. Moreover, cashew plantations produced important quantities of apples and leaves that remain in the field (Soro, 2012). In fact, 5 million tons of cashew apples, and 179,232 tons of leaves are produced per year (Guero et al., 2021). Cashew apples and leaves are known as lignocellulosic wastes and their decomposition in natural conditions is very low because they contain high contents of lignocellulosic fibrous material such as phenol, lignin, tannin, and cellulose (Deobald & Crawford, 1997). Production of large quantities of these organic wastes generally poses major environmental concerns, ranging from offensive odors, contaminations of groundwater and soil, and disposal constraints (Elwell et al., 2001; Njewa et al. 2025). 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 nut pickers. However, these wastes if well treated can constitute valuable resources such as compost, providing high macronutrient and micronutrient content for crop growth, and improving soil structure and quality (Kalaivanan et al., 2017; Bambharolia et al., 2021). Composting is defined as the biological transformation of an organic byproduct into a different organic product that can be added to the soil without detrimental effects on crop growth (Williams, 2009). It is the most adequate method for pretreating and managing organic waste (Williams, 2009). In the process of composting, the bio-oxidation of the organic matter passes through a thermophilic stage (45˚C - 65˚C) where microorganisms liberate heat, carbon dioxide and water (Hosseini & Hamidi, 2013). 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% (Tiquia et al. 2002; Manga et al., 2022). Some composts may contain heavy metals that are generally absorbed by plants and can negatively affect human health after consumption (Han Ko et al., 2008). The long-term use of composts with higher heavy metals in crop cultivation may produce a risk of accumulating heavy metals in soils and crops, adversely influencing food security (Li et al., 2021; Zhao et al., 2022). In fact, Cd, Pb, and Ni are remarkably poisonous metals among all other elements for people and animals (Volpe et al., 2009). Cd enters into the human body through nourishment or water and remains in body for long time potentially causing kidney diseases, vomiting, stomach disorders, and anemia and other blood disorders. High contents of Pb in sustenance and water can cause sickliness and other blood issues in people (ATSDR, 2015). Permissible limits for Pb are very low; even a small quantity of Pb has clear toxic effects as compared to other heavy metals (Tchounwou et al., 2012). High concentrations of Ni deliver lethal indications including lung and blood malignancy, while Cr actuates mucodermal ulceration, diseases of the respiratory tract, and hypersensitivity such as in the skin (Georgieva et al., 2022).

Reduction of heavy metals content to their permissible limit is therefore a prerequisite in organic fertilizers application on soils. The permissible limit of heavy metal content refers to the maximum allowable concentration of specific metallic elements in soil established by regulatory authorities to protect human health and environmental safety (FAO/WHO, 2011).

Contrary to composting, another method called "vermicomposting" does not include a thermophilic stage but involves the use of earthworms for the degradation and the stabilization of organic wastes. During the vermicomposting, feed materials are converted into forms that are more soluble and available to plants than those in the native compounds (Karthikairaj & Isaiaasu, 2013). Vermicompost also contains biologically active substances such as plant growth regulators (Jesikha, 2013). Moreover, earthworms can absorb heavy metals such as Zn, Cd and Pb through their intestine as well as their skin (Li et al., 2010). Earthworms also decrease the bioavailability and the mobility of heavy metals in the vermicompost and therefore limit their absorption by plants (Hait & Tare, 2012). Recently, Kambou and Coulibaly (2026) showed that cashew apples and leaves are converted into vermicompost when mixing them with cow dung. But literature is still rare on heavy metals content reduction during the vermicomposting of cashew residues in function of earthworm population size and the composting time.

This study aims to evaluate the effect of different population size of the earthworm species *Eudrilus eugeniae* on heavy metal content variation during the vermicomposting of cashew residues and their mixture with cow dung in function of time.

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 (Djiakariya, 2004). It was collected in farming places in the town of Korhogo. Cashew residues were got from the areas of Mankono, Boundiali and Korhogo considered as the production centers. In each area, the cashew residues were collected in three plantations. Then, cashew residues were mixed and 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 apples and cashew leaves respectively. The third treatment was a mixture of 150 g of cashew apples and 150 g of cashew leaves. The fourth treatment was formed of a mixture of 150 g of cashew apples and 150 g of cow dung when the fifth treatment was a mixture of 150 g of leaves and 150 g of cow dung. The sixth treatment was a mixture of 100 g of cashew apples, cashew leaves and cow dung. For each treatment, 4 batches of the earthworm species *E. eugeniae* (5, 10, 15, and 20 individuals) were tested for each treatment. 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 same containers at 30, 60 and 90 days. The start of the experiment was the day that earthworms were put in containers. The cocoons, earthworms and hatchlings were removed manually from each sample. The samples were air dried in shade at room temperature, ground in a stainless-steel blender and stored in plastic vials for chemical analysis. Heavy metals such as Zn, Cu, Pb, Cd, Ni and Cr were determined by atomic absorption spectrophotometer (AA-220 FS) after digesting the samples with concentrated HNO3: concentrated HClO4 (4:1, v/v).

2.4. Statistical Analyses

Data were analyzed by factorial analysis of variance (ANOVA) using the general linear model (GLM) procedure of the SAS statistical package (SAS, 1999). They were given as mean followed by standard deviation (M ± SD). Least Significant Difference (LSD) multiple range-tests were used to determine significant differences between wastes based on heavy metals content measured in the samples harvested at 30, 60 and 90 days of the vermicomposting process.

3. Results

3.1. Initial Heavy Metal Contents

Initial heavy metal contents of the different wastes in this study are presented in **Table 1**. Heavy metal content differed significantly from one waste to another.

The Zn concentration in the different wastes shifted between 94.11 and 6.4 mg/kg when Pb content was in the range of 4.01 - 0.38 mg/kg. For both metals, the highest concentration was measured in the treatment of cashew leaves mixed with cow dung (CaL + CD) and the lowest was recorded in cashew apples residue. Relatively to the other metals, the content was in the range of 14.53 - 0.89 mg/kg for Cu, 0.27 - 0.03 mg/kg for Cd, 2.61 - 0.22 for Ni and 1.43 - 0.92 for Cr. For all these metals, the highest concentration was observed in the medium Ca + CD and the lowest in cashew apples (CaA). In all the media, heavy metal concentrations differed significantly from one waste to another. However, in all the treatment, heavy metal contents were higher in CL than in CaA. When cashew residues were mixed with cow dung, heavy metal contents increased than when they were alone.

Table 1. Initial heavy metal content (mg/kg) in the different wastes.

Type of waste	Heavy metal content					
	Zn	**Pb**	**Cu**	**Cd**	**Ni**	**Cr**
CaA	6.4 ± 0.12^{e}	0.38 ± 0.04^{c}	0.89 ± 0.47^{d}	0.03 ± 0.01^{d}	0.22 ± 0.06^{c}	0.92 ± 0.24^{b}
CaL	42.15 ± 1.18^{c}	0.97 ± 0.21^{b}	8.23 ± 1.05^{b}	0.14 ± 0.01^{b}	0.55 ± 0.04^{b}	1.02 ± 0.31^{ab}
CaA + CaL	30.28 ± 2.26^{d}	0.71 ± 0.11^{b}	5.22 ± 0.84^{c}	0.08 ± 0.03^{c}	0.42 ± 0.12^{b}	1.03 ± 0.53^{ab}
CaA + CD	76.18 ± 1.64^{b}	3.64 ± 0.69^{a}	11.65 ± 1.35^{a}	0.19 ± 0.01^{ab}	2.25 ± 0.16^{a}	1.43 ± 0.57^{a}
CaL + CD	94.11 ± 4.32^{a}	4.01 ± 0.72^{a}	14.53 ± 1.55^{a}	0.27 ± 0.08^{a}	2.61 ± 0.73^{a}	1.37 ± 0.35^{a}
CaA + CaL + CD	88.07 ± 5.48^{a}	3.76 ± 0.53^{a}	12.84 ± 2.26^{a}	0.21 ± 0.04^{a}	2.55 ± 0.29^{a}	1.35 ± 0.51^{a}
F	34.62	41.56	27.43	56.18	30.29	2.27
P	<0.001	<0.001	<0.001	<0.001	<0.001	0.04

Values followed by the same letter in a column are not significantly different ($P > 0.05$) using LSD. **CaA:** Cashew apple, **CaL:** Cashew leaves, **CD:** Cow dung, **Zn:** Zinc, **Pb:** lead, **Cu:** copper, **Cd:** cadmium, **Ni:** nickel, **Cr:** chrome.

3.2. Heavy Metal Contents Variation during Vermicomposting

3.2.1. Zinc (Zn) and Lead (Pb)

The variation in Zn content during the vermicomposting of the six types of waste as a function of time and earthworm densities is shown in Table 2. Zn content did not vary respectively at 30, 60 and 90 days of the vermicomposting of cashew apples waste (CaA) whatever the number of earthworms used. Similar observations were noted in cashew leaves (CaL), and in the mixture of cashew leaves and cashew apples. At 30 days of the vermicomposting of the substrates CaA + CD, CaL + CD and CaA + CaL + CD, Zn content was similar whatever the density of earthworms used. At 60 and 90 days respectively, the lowest contents of Zn were obtained with 5 earthworms followed respectively by those obtained with 10 earthworms, 15 and 20 earthworms. However, Zn contents measured with 15 and 20 earthworms were statistically similar. When considering the composting time, there was a decrease in Zn content when the composting time increased.

Table 3 encapsulates Pb content during the vermicomposting with different earthworms densities in function of time. In the vermicompost harvested at 30, 60 and 90 days respectively, Pb content did not change statistically whatever the density of earthworms used. At 30 days of the vermicomposting of cashew leaves, Pb content was similar statistically whatever earthworms density used. Similar observations were made at 30 days in the vermicompost of CaL, CaA + CaL, CaA + CD, CaL + CD, and CaA + CaL + CD. In these latter substrates harvested at 60 and 90 days respectively, the lowest Pb contents were obtained with 15 and 20 earthworms when the highest was got with 5 earthworms.

Table 2. Variation in Zn content (mg kg^{-1}) of the different wastes during vermicomposting.

Type of waste	Time (days)	Number of earthworms				Statistical parameters	
		5	10	15	20	*F*	*P*
CaA	30	6.4 ± 1.22^{a}	6.37 ± 1.13^{a}	6.4 ± 1.54^{a}	6.32 ± 1.27^{a}	1.95	0.142
	60	6.41 ± 0.68^{a}	6.43 ± 1.78^{a}	6.5 ± 1.32^{a}	6.38 ± 1.15^{a}	1.31	0.36
	90	6.53 ± 0.71^{a}	6.46 ± 0.66^{a}	6.48 ± 0.81^{a}	6.45 ± 1.06^{a}	1.52	0.28
CaL	30	42.11 ± 2.06^{a}	42.23 ± 3.6^{a}	40.34 ± 1.85^{a}	41.17 ± 2.44^{a}	0.18	0.788
	60	40.74 ± 1.21^{a}	37.42 ± 4.83^{a}	36.18 ± 2.05^{a}	39.61 ± 1.62^{a}	1.79	0.27
	90	38.55 ± 0.83^{a}	35.61 ± 1.59^{a}	33.06 ± 2.37^{a}	36.25 ± 1.48^{a}	1.23	0.41
CaA + CaL	30	30.03 ± 4.16^{a}	29.34 ± 3.27^{a}	28.18 ± 3.56^{a}	27.31 ± 2.75^{a}	1.35	0.28
	60	28.47 ± 1.58^{a}	26.53 ± 2.34^{a}	26.62 ± 1.28^{a}	26.15 ± 2.40^{a}	1.86	0.174
	90	25.12 ± 1.41^{a}	23.28 ± 2.08^{a}	24.19 ± 1.43^{a}	22.77 ± 2.41^{a}	1.44	0.26
CaA + CD	30	74.01 ± 6.84^{a}	72.54 ± 6.29^{a}	72.11 ± 11.12^{a}	71.31 ± 8.03^{a}	0.26	0.871
	60	66.37 ± 8.09^{a}	61.58 ± 7.41^{ab}	54.25 ± 10.67^{b}	53.44 ± 8.92^{b}	3.42	0.03
	90	58.69 ± 5.83^{a}	43.26 ± 4.38^{ab}	36.04 ± 6.14^{b}	35.17 ± 6.35^{b}	20.67	<0.001
CaL + CD	30	90.63 ± 7.65^{a}	88.35 ± 4.36^{a}	80.65 ± 5.69^{a}	81.72 ± 6.48^{a}	0.73	0.46
	60	78.32 ± 8.93^{a}	61.29 ± 8.64^{ab}	53.27 ± 6.37^{b}	57.18 ± 7.53^{b}	4.78	0.002
	90	54.18 ± 4.28^{a}	43.34 ± 3.13^{b}	31.08 ± 5.43^{b}	30.29 ± 5.81^{b}	3.6	0.02
CaA + CaL + CD	30	79.39 ± 9.52^{a}	76.55 ± 6.25^{a}	74.39 ± 7.31^{a}	72.18 ± 9.24^{a}	0.84	0.32
	60	53.74 ± 5.08^{a}	47.24 ± 7.16^{ab}	41.81 ± 8.75^{b}	50.42 ± 8.52^{a}	2.58	0.03
	90	40.91 ± 4.27^{a}	33.68 ± 6.11^{ab}	27.83 ± 3.67^{b}	25.35 ± 8.41^{b}	4.23	0.005

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, **Zn:** Zinc.

Table 3. Variation in Pb content (mg kg^{-1}) of the different wastes during vermicomposting.

Type of waste	Time (days)	Number of earthworms				Statistical parameters	
		5	10	15	20	*F*	*P*
CaA	30	0.41 ± 0.08^{a}	0.43 ± 0.06^{a}	0.45 ± 0.04^{a}	0.38 ± 0.08^{a}	1.65	0.24
	60	0.43 ± 0.03^{a}	0.41 ± 0.05^{a}	0.43 ± 0.06^{a}	0.43 ± 0.06^{a}	0.22	0.98
	90	0.43 ± 0.04^{a}	0.42 ± 0.03^{a}	0.44 ± 0.06^{a}	0.42 ± 0.06^{a}	0.38	0.86

Continued

CaL	30	0.95 ± 0.11^a	0.91 ± 0.13^a	0.89 ± 0.08^a	0.86 ± 0.08^a	1.94	0.14
	60	0.93 ± 0.09^a	0.87 ± 0.06^{ab}	0.84 ± 0.07^{ab}	0.82 ± 0.07^b	1.23	0.37
	90	0.88 ± 0.07^a	0.84 ± 0.08^{ab}	0.78 ± 0.06^{ab}	0.76 ± 0.08^b	1.58	0.21
CaA + CaL	30	0.62 ± 0.14^a	0.54 ± 0.11^{ab}	0.43 ± 0.10^b	0.41 ± 0.11^b	1.81	0.21
	60	0.51 ± 0.13^a	0.47 ± 0.12^{ab}	0.39 ± 0.09^b	0.34 ± 0.10^b	1.64	0.26
	90	0.44 ± 0.13^a	0.35 ± 0.13^{ab}	0.26 ± 0.09^b	0.21 ± 0.12^b	21.56	<0.001
CaA + CD	30	3.44 ± 1.15^a	3.18 ± 0.93^a	3.22 ± 1.05^a	2.86 ± 0.86^a	1.35	0.27
	60	2.73 ± 0.88^a	2.66 ± 0.76^a	2.12 ± 0.75^a	1.81 ± 0.59^a	1.45	0.42
	90	1.57 ± 0.52^a	1.13 ± 0.64^a	0.84 ± 0.82^b	0.76 ± 0.37^b	51.43	<0.001
CaL + CD	30	4.11 ± 1.06^a	4.23 ± 0.69^a	4.12 ± 1.46^a	4.1 ± 0.83^a	0.13	0.88
	60	3.27 ± 1.11^a	3.09 ± 0.77^a	2.64 ± 0.35^a	2.83 ± 0.58a	1.74	0.32
	90	3.04 ± 0.84^a	2.21 ± 1.21^b	1.25 ± 0.49^b	1.19 ± 0.73^c	43.18	<0.001
CaA + CaL + CD	30	3.64 ± 0.91^a	3.27 ± 1.22^a	3.16 ± 0.87^a	3.14 ± 0.55^a	0.17	0.83
	60	2.36 ± 0.76^a	2.21 ± 0.53^a	2.12 ± 0.41^a	2.01 ± 0.63^a	1.29	0.41
	90	2.13 ± 0.85^a	1.85 ± 0.24^{ab}	1.68 ± 0.39^{ab}	1.34 ± 0.51^b	4.16	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, **Pb:** lead.

3.2.2. Copper (Cu) and Cadmium (Cd)

The variation in Cu content during the vermicomposting of the different media is shown in Table 4. In cashew apples, Cu contents were statistically similar at 30, 60 and 90 days respectively whatever earthworms number used initially. Similar results were got during the vermicomposting of CaL, CaA + CaL, CaA + CD, and CaA + CaL + CD. In the mixture of CaL and CD, there was a variation in Cu content at 90 days of the vermicomposting process. The lowest Cu contents were 4.92 ± 1.11 mg kg^{-1} measured with 15 earthworms and 4.67 ± 0.35 mg kg^{-1} obtained with 20 earthworms. These latter Cu contents were statistically identical. When considering composting time, Cu content decreased when it increased.

Table 5 shows Cd content variation in the different media during vermicomposting of the different substrates. It appeared that in the vermicompost obtained from CaA, CaL, and CaA + CaL, Cd content remained similar statistically whatever earthworms number at 30, 60 and 90 days respectively. At 30 days of the vermicomposting of CaA + CD, CaL + CD and CaA + CaL + CD, Cd content did not vary statistically whatever earthworm density. But it changed at 60 and 90 days respectively in these latter substrates. At the same dates, the lowest Cd contents were obtained in the media where 15 and 20 earthworms were put initially, and the highest Cd contents were measured in the substrates mineralized with 5 and 10 earthworms. Cd contents measured when using 15 and 20 earthworms were statistically similar in the vermicompost from CaL + CD, and CaA + CaL + CD. Regarding the composting timing, Cd content decreased when it increased.

Table 4. Variation in Cu content (mg kg^{-1}) of the different wastes during vermicomposting.

Type of waste	Time (days)	Number of earthworms				Statistical parameters	
		5	10	15	20	*F*	*P*
CaA	30	0.92 ± 0.02^a	0.9 ± 0.07^a	0.87 ± 0.05^a	0.88 ± 0.07^a	2.27	0.15
	60	0.84 ± 0.06^a	0.86 ± 0.06^a	0.85 ± 0.09^a	0.83 ± 0.11^a	1.32	0.251
	90	0.87 ± 0.11^a	0.86 ± 0.08^a	0.88 ± 0.07^a	0.86 ± 0.07^a	1.54	0.26
CaL	30	8.33 ± 1.16^a	8.18 ± 1.07^a	8.11 ± 0.92^a	8.25 ± 1.01^a	1.63	0.24
	60	8.21 ± 1.21^a	7.67 ± 0.74^a	7.54 ± 0.60^a	7.46 ± 0.94^a	1.35	0.29
	90	8.12 ± 0.88^a	6.42 ± 0.44^a	6.02 ± 0.68^a	6.15 ± 0.80^a	0.41	0.72
CaA + CaL	30	5.22 ± 0.62^a	5.16 ± 0.39^a	5.17 ± 0.42^a	5.13 ± 0.58^a	0.24	0.86
	60	5.08 ± 0.43^a	4.83 ± 0.57^a	4.62 ± 0.61^a	4.41 ± 0.54^a	0.17	0.81
	90	4.77 ± 0.86^a	4.23 ± 0.75^a	3.73 ± 0.73^a	3.64 ± 0.67^a	0.27	0.89
CaA + CD	30	11.41 ± 1.13^a	10.38 ± 1.42^a	10.15 ± 1.09^a	10.08 ± 0.93^a	1.3	0.47
	60	9.88 ± 1.23^a	9.21 ± 1.01^a	8.02 ± 1.33^a	7.86 ± 1.40^a	1.95	0.14
	90	6.27 ± 0.65^a	6.11 ± 0.72^a	5.24 ± 0.64^a	4.79 ± 0.68^a	1.39	0.32
CaL + CD	30	13.22 ± 0.97^a	13.19 ± 1.14^a	12.68 ± 1.55^a	12.52 ± 1.78^a	1.41	0.26
	60	11.54 ± 1.25^a	10.46 ± 1.03^a	8.87 ± 0.69^a	8.91 ± 0.72^a	1.88	0.19
	90	9.13 ± 0.89^a	8.75 ± 0.86^a	4.92 ± 1.11^b	4.67 ± 0.35^b	14.78	< 0,001
CaA + CaL + CD	30	12.48 ± 0.68^a	12.21 ± 0.80^a	11.29 ± 1.22^a	11.15 ± 2.13^a	1.23	0.3
	60	10.34 ± 1.23^a	10.02 ± 0.94^a	8.44 ± 0.58^a	8.31 ± 0.82^a	4.43	0.40
	90	6.74 ± 0.66^a	7.65 ± 0.81^a	4.3 ± 0.61^a	4.14 ± 0.49^a	1.46	0.48

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; **Cu:** copper.

Table 5. Variation in Cd content (mg kg^{-1}) of the different wastes during vermicomposting.

Type of waste	Time (days)	Number of earthworms				Statistical parameters	
		5	10	15	20	*F*	*P*
CaA	30	0.03 ± 0.01^a	0.04 ± 0.01^a	0.04 ± 0.01^a	0.04 ± 0.01^a	1.81	0.25
	60	0.04 ± 0.01^a	0.03 ± 0.01^a	0.05 ± 0.02^a	0.06 ± 0.01^a	1.24	0.177
	90	0.06 ± 0.01^a	0.05 ± 0.02^a	0.06 ± 0.01^a	0.04 ± 0.01^a	1.85	0.171
CaL	30	0.16 ± 0.07^a	0.13 ± 0.04^a	0.14 ± 0.06^a	0.15 ± 0.05^a	1.33	0.29
	60	0.14 ± 0.04^a	0.11 ± 0.02^a	0.11 ± 0.06^a	0.1 ± 0.04^a	0.72	0.48
	90	0.12 ± 0.05^a	0.11 ± 0.06^a	0.12 ± 0.03^a	0.09 ± 0.06^a	2.01	0.23
CaA+CaL	30	0.09 ± 0.04^a	0.08 ± 0.03^a	0.06 ± 0.03^a	0.06 ± 0.04^a	1.67	0.27
	60	0.07 ± 0.03^a	0.06 ± 0.04^a	0.05 ± 0.02^a	0.04 ± 0.01^a	1.04	0.38
	90	0.06 ± 0.04^a	0.05 ± 0.02^a	0.04 ± 0.03^a	0.05 ± 0.02^a	2.26	0.17
CaA + CD	30	0.22 ± 0.13^a	0.19 ± 0.06^a	0.17 ± 0.08^a	0.16 ± 0.07^a	1.12	0.33
	60	0.18 ± 0.08^a	0.16 ± 0.07^a	0.12 ± 0.03^{ab}	0.09 ± 0.05^b	41.64	<0.001
	90	0.16 ± 0.04^a	0.13 ± 0.06^a	0.08 ± 0.04^b	0.06 ± 0.05^b	10.82	<0.001

Continued

CaL + CD	30	0.23 ± 0.11ᵃ	0.19 ± 0.08ᵃ	0.21 ± 0.15ᵃ	0.19 ± 0.07ᵃ	0.06	0.86
	60	0.18 ± 0.06ᵃ	0.11 ± 0.04ᵃ	0.1 ± 0.06ᵃ	0.02 ± 0.01ᵇ	69.21	<0.001
	90	0.13 ± 0.09ᵃ	0.09 ± 0.03ᵃᵇ	0.06 ± 0.02ᵇ	0.07 ± 0.03ᵇ	57.26	<0.001
CaA + CaL + CD	30	0.24 ± 0.13ᵃ	0.18 ± 0.07ᵃ	0.19 ± 0.06ᵃ	0.15 ± 0.04ᵃ	2.21	0.19
	60	0.2 ± 0.05ᵃ	0.16 ± 0.1ᵃᵇ	0.12 ± 0.04ᵇ	0.11 ± 0.06ᵇ	83.55	<0.001
	90	0.15 ± 0.09ᵃ	0.1 ± 0.06ᵃᵇ	0.06 ± 0.03ᵇ	0.05 ± 0.03ᵇ	40.07	<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, **Cd:** cadmium.

3.2.3. Chrome (Cr) and Nickel (Ni)

Table 6 encapsulates the variation of Cr content during the vermicomposting of the six treatments. At 30, 60 and 90 days respectively of the vermicomposting of CaA, CaL, CaA + CaL, CaA + CD, and CaL + CD, the Cr content did not change whatever the initial number of earthworms used. In the mixture of the three wastes (CaA + CaL + CD), there was no significant difference between the Cr contents obtained with 5, 10, 15 and 20 earthworms at 30 and 60 days respectively. But at 90 days of the vermicomposting process, the lowest Cr contents were obtained respectively with 15 earthworms (0.43 ± 0.19 mg kg^{-1}) and with 20 earthworms (0.46 ± 0.13 mg kg^{-1}) and they were statistically the same.

Table 6. Variation in Cr content (mg kg^{-1}) of the different wastes during vermicomposting.

Type of waste	Time (days)	Number of earthworms				Statistical parameters	
		5	10	15	20	*F*	*P*
CaA	30	0.94 ± 0.32ᵃ	0.95 ± 0.46ᵃ	0.98 ± 0.23ᵃ	0.97 ± 0.58ᵃ	0.48	0.72
	60	0.96 ± 0.27ᵃ	0.97 ± 0.34ᵃ	0.98 ± 0.52ᵃ	0.99 ± 0.73ᵃ	0.7	0.51
	90	0.97 ± 0.14ᵃ	1.1 ± 0.16ᵃ	1.15 ± 0.67ᵃ	1.18 ± 0.65ᵃ	1.3	0.26
CaL	30	1.12 ± 0.75ᵃ	0.93 ± 0.62ᵃ	0.86 ± 0.38ᵃ	0.84 ± 0.43ᵃ	1.02	0.44
	60	0.83 ± 0.49ᵃ	0.76 ± 0.55ᵃ	0.65 ± 0.27ᵃ	0.58 ± 0.26ᵃ	0.12	0.75
	90	0.71 ± 0.37ᵃ	0.62 ± 0.41ᵃ	0.44 ± 0.22ᵃ	0.41 ± 0.32ᵃ	1.8	0.29
CaA + CaL	30	1 ± 0.45ᵃ	0.89 ± 0.63ᵃ	0.82 ± 0.54ᵃ	0.85 ± 0.46ᵃ	0.43	0.19
	60	0.95 ± 0.72ᵃ	0.76 ± 0.46ᵃ	0.76 ± 0.37ᵃ	0.73 ± 0.42ᵃ	0.31	0.54
	90	0.88 ± 0.58ᵃ	0.61 ± 0.33ᵃ	0.54 ± 0.0.29ᵃ	0.55 ± 0.35ᵃ	0.86	0.35
CaA + CD	30	1.33 ± 0.88ᵃ	1.21 ± 0.72ᵃ	1.17 ± 0.66ᵃ	1.16 ± 0.70ᵃ	1.59	0.243
	60	1.19 ± 0.61ᵃ	1.14 ± 0.69ᵃ	1.06 ± 0.42ᵃ	1.08 ± 0.51ᵃ	2.22	0.19
	90	0.95 ± 0.49ᵃ	1.05 ± 0.53ᵃ	0.68 ± 0.37ᵃ	0.72 ± 0.44ᵃ	1.18	0.32
CaL + CD	30	1.26 ± 0.72ᵃ	1.23 ± 0.86ᵃ	1.16 ± 0.54ᵃ	1.14 ± 0.59ᵃ	1.11	0.37
	60	1.15 ± 0.64ᵃ	1.11 ± 0.73ᵃ	1.07 ± 0.60ᵃ	1.12 ± 0.73ᵃ	0.24	0.87
	90	1.1 ± 0.67ᵃ	1.02 ± 0.26ᵃ	0.73 ± 0.39ᵃ	0.76 ± 0.57ᵃ	0.39	0.71
CaA + CaL + CD	30	1.24 ± 0.62ᵃ	1.19 ± 0.54ᵃ	0.92 ± 0.46ᵃ	1.12 ± 0.34ᵃ	0.43	0.67
	60	1.18 ± 0.25ᵃ	1.08 ± 0.38ᵃ	0.77 ± 0.35ᵃ	0.73 ± 0.26ᵃ	1.16	0.31
	90	0.84 ± 0.36ᵃ	0.81 ± 0.42ᵃ	0.43 ± 0.19ᵇ	0.46 ± 0.13ᵇ	6.22	<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, **Cr:** chrome.

Table 7 shows the variation in Ni content during the vermicomposting in function of earthworms density and the composting time. At 30, 60 and 90 days respectively, Ni contents were similar in CaA, and CaL. In their mixture, there was no significant difference in Ni content at 30 and 60 days respectively whatever earthworms density. But Ni content changed significantly at 90 days of the composting process. The lowest Ni contents were obtained with 15 and 20 earthwoms and the highest was measured with 5 earthworms. When CaA and CaL were mixed respectively with cow dung, Ni content remained similar statistically whatever the composting time and earthworms density used for the mineralization.

Table 7. Variation in Ni content (mg kg^{-1}) of the different wastes during vermicomposting.

Type of waste	Time (days)	Number of earthworms				Statistical parameters	
		5	10	15	20	*F*	*P*
CaA	30	0.23 ± 0.16ᵃ	0.25 ± 0.09ᵃ	0.25 ± 0.13ᵃ	0.26 ± 0.11ᵃ	0.16	0.82
	60	0.26 ± 0.12ᵃ	0.27 ± 0.08ᵃ	0.29 ± 0.16ᵃ	0.27 ± 0.07ᵃ	0.13	0.91
	90	0.28 ± 0.08ᵃ	0.24 ± 0.11ᵃ	0.28 ± 0.08ᵃ	0.26 ± 0.08ᵃ	0.17	0.86
CaL	30	0.57 ± 0.21ᵃ	0.52 ± 0.15ᵃ	0.48 ± 0.29ᵃ	0.47 ± 0.26ᵃ	1.84	0.23
	60	0.53 ± 0.17ᵃ	0.41 ± 0.26ᵃ	0.44 ± 0.19ᵃ	0.42 ± 0.17ᵃ	1.71	0.18
	90	0.5 ± 0.23ᵃ	0.38 ± 0.18ᵃ	0.35 ± 0.14ᵃ	0.38 ± 0.16ᵃ	1.25	0.33
CaA + CaL	30	0.4 ± 0.11ᵃ	0.36 ± 0.22ᵃ	0.33 ± 0.16ᵃ	0.31 ± 0.19ᵃ	1.35	0.28
	60	0.34 ± 0.17ᵃ	0.29 ± 0.13ᵃ	0.26 ± 0.12ᵃ	0.28 ± 0.14ᵃ	1.44	0.37
	90	0.3 ± 0.09ᵃ	0.24 ± 0.18ᵃᵇ	0.21 ± 0.09ᵃᵇ	0.19 ± 0.15ᵇ	0.32	0.54
CaA + CD	30	0.19 ± 0.04ᵃ	0.21 ± 0.11ᵃ	0.16 ± 0.06ᵃ	0.17 ± 0.08ᵃ	0.42	0.20
	60	0.12 ± 0.08ᵃ	0.13 ± 0.07ᵃ	0.09 ± 0.03ᵃ	0.08 ± 0.05ᵃ	0.87	0.36
	90	0.07 ± 0.02ᵃ	0.06 ± 0.03ᵃ	0.07 ± 0.04ᵃ	0.04 ± 0.02ᵃ	0.11	0.94
CaL + CD	30	2.24 ± 1.17ᵃ	2.15 ± 0.79ᵃ	1.76 ± 0.86ᵃ	1.84 ± 0.65ᵃ	2.41	0.12
	60	2.12 ± 1.01ᵃ	1.88 ± 0.53ᵃ	1.35 ± 0.73ᵃ	1.28 ± 0.49ᵃ	1.11	0.35
	90	2.06 ± 0.86ᵃ	1.57 ± 0.74ᵃ	1.11 ± 0.82ᵃ	1.1 ± 0.61ᵃ	1.15	0.31
CaA + CaL + CD	30	2.41 ± 0.68ᵃ	2.09 ± 0.92ᵃ	2.06 ± 0.81ᵃ	1.89 ± 1.23ᵃ	1.63	0.23
	60	2.18 ± 0.75ᵃ	1.67 ± 0.84ᵃ	1.25 ± 0.79ᵃ	1.24 ± 0.68ᵃ	1.06	0.42
	90	1.84 ± 0.83ᵃ	1.06 ± 0.77ᵃᵇ	0.86 ± 0.64ᵃᵇ	0.83 ± 0.47ᵇ	84.36	<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, **Ni:** nickel.

4. Discussion

4.1. Initial Heavy Metal Contents

The presence of heavy metal in cashew leaves and apples could be linked to their initial presence in the soil. In fact, heavy metals are oligoelement that can be absorbed by plants when they are present in the soil or in the cultural substrate. That presence could also be explained by the ability of cashew tree to accumulate the heavy metals in its parts. Heavy metal content differed significantly from one type of waste to another. For each waste, Zn occupied the highest concentration, followed by Cu, Pb, Ni, Cr, and Cd. The variation in heavy metal concentration in function of the waste type could be linked to the time they were exposed to pesticides. In fact, leaves are more exposed to pesticides than apples. Thus, leaves absorbed more chemicals than apples that spent only 2 to 3 months on the tree. Yao et al. (2020) indicated that farmers use a lot of agrochemicals in the main production areas of cashew in Côte d'Ivoire. According to Soro et al. (2020), many cashew farmers in the North of Côte d'Ivoire use many types of pesticides to control pests and diseases that attack this crop. The authors also demonstrated that the use of these pesticides does not respect good agricultural practices and that can lead to their accumulation in fruits, leaves and soil and to environmental pollution. The highest concentration of Zn in the different wastes could be explained by its concentration in the agrochemicals used on cashew orchards compared to other metals. Several authors showed that glyphosate is the most agrochemical used in cashew orchards in Côte d'Ivoire (Soro et al., 2020; Yao et al., 2020). Serra et al. (2011) showed that the application of glyphosate interfered with mineral nutrition of plant and the total contents of Zn and Cu. That could explain their higher content in the cashew residues. Heavy metal contents increased when they were mixed with cow dung. Animal waste might contain important quantity of metals. Coulibaly et al. (2011) found higher content of heavy metals in cow, pig, chicken and sheep wastes. Similarly, Sims and Wolf (1994), Nicholson et al. (1999) observed a higher concentration of heavy metal in different animal wastes. The higher concentration of heavy metal in animal waste could be due to the unfitness of animals to accumulate them in their bodies and reject them in their wastes. In the mixture of cashew residues with cow dung, Ni contents were higher than the 2 mg/kg indicated by AFNOR (2002, 2006) as maximum permissible Ni content in organic amendments. This shows the necessity of reducing its concentration before applying the residues on soil as fertilizer.

4.2. Changing in Heavy Metal Contents during Vermicomposting

During the vermicomposting of the different residues of cashew and their mixture with cow dung, the heavy contents measured at 90 days were generally lower than those obtained at 30 and 60 days. That decrease might be due to earthworms activities. The decrease in heavy metal contents might be more linked to the composting time than to earthworm density due to the fact that the wastes used in this experiment are lignocellulosic wastes. Their mineralization by earthworms could take more time than soft waste. Similar observations have been made by Kaushik and Garg (2003) during the vermicomposting of various types of waste when using Eisenia fetida as earthworm. The lowest heavy metal content obtained at 90 days could be explained by the fact that it is the time necessary for its significant reduction during the vermicomposting process. The decrease in heavy metal content during the vermicomposting is also a mark of stability of the vermicompost.

The lower heavy metal content obtained with the densities of 15 and 20 earthworms could be explained by a higher assimilation of heavy metals by these batches of earthworms. Contrary to the previous densities, 90 days might be insufficient to 5 and 10 earthworms to assimilate the maximum concentration of heavy metals contained in the 300 grams of the wastes. Earthworms are known to assimilate heavy metal in their bodies and reject nutrients in their faeces after wastes ingestion. By their action, heavy metal can be immobilized in the vermicompost and cannot be absorbed by the plants. Our results agree with those of Becquer et al. (2005) and Maity et al. (2008) who observed a reduction in heavy metal content during composting with Eisenia fetida. Coulibaly et al. (2011) also noted a reduction in heavy metal content during the vermicoposting of several wastes when using the African nightcrawler *Eudrilus eugeniae*. According to Oste et al. (2001), Hobbelen et al. (2006) and Li et al. (2010), earthworms are capable to live in soil polluted by heavy metal because they can accumulate heavy metal in their bodies. Heavy metal concentrations increased when mixing the cashew residues with cow dung compared to when they are alone. That indicated a higher degree of pollution of cow dung by heavy metals, particularly Zn and Cu which content were higher than the other heavy metals. This result could be attributed to the addition of Zn in the form of zinc oxide and Cu in the form of copper sulphate respectively to feeds for larger cow and to suppress bacterial action in the gut and to maximize feed utilization by the animal. The decrease of heavy metal concentration at the end of the vermicomposting in the different substrates showed the ability of *E. eugeniae* to accumulate them. The adult earthworm was speculated to have such an ability to store high concentrations of heavy metal in the non-toxic forms, as reported by Morgan and Morgan (1998). In fact, the authors observed Pb phosphate nodules in earthworms and postulated that this was a Pb storage mechanism. Saxe et al. (2001) showed that earthworms have evolved more efficient biochemical regulation strategies for elements whose presence exert selective pressure during evolutionary processes. Earthworms can reduce possible toxic effects of superfluous heavy metals by utilizing them for physiological metabolism. Taking Cu and Zn for example, they interact with many chemicals and participate in detoxification processes, as part of the enzymes of the antioxidant systems, such as superoxide dismutase and in metallothioneins (Sanchez-Chardi & Nadal, 2007). Similarly, Redeker et al. (2007) observed that Tubifex tubifex, one of the oldest described aquatic oligochaetes, was able to sequester superfluous Cd in the granules fraction and by proteins as metallothionein-like proteins in the heat stable fraction. The heavy metal contents obtained in the six types of wastes at the end of the experiment with 15 and 20 individuals of *Eudrilus eugeniae* were lower than the 3, 120, 300, 2, 180 and 300 mg/kg indicated by AFNOR (2006) as maximum permissible heavy metal content for Cd, Cr, Cu, Ni, Pb and Zn respectively in a good quality organic amendment. The lowest concentrations of heavy metals obtained in the composted wastes with 15 and 20 earthworms might be due to a faster reproduction of these sets of earthworms in the 300 g of waste than the others, allowing thus more accumulation of heavy metals in their bodies.

5. Conclusion

Earthworm population size and the composting time influenced heavy metals content during the vermicomposting of cashew residues and their mixture with cow dung. The highest reduction in heavy metals content was obtained after 90 days of composting when using 15 or 20 individuals of the earthworm *E. eugeniae* initially. Regarding heavy metals content, 15 earthworms can be recommended for the vermicomposting of 300 g of waste over 90 days.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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