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Physico-Chemical Characterization of Biofertilizers from Vermicomposting Agricultural Residues in Côte D'ivoire

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ABSTRACT

Vermicomposts and vermiwashs obtained from pre-composted cassava peelings (Ca.Pe), cocoa shells (Co.Sh) and cashew nut shells (Ca.Nu) were assessed for physical characteristics and nutrients content. Five types of substrates were made from cassava (VC1), cashew (VC2), cassava and cashew (VC3), cassava and cocoa (VC4), cocoa and cashew (VC5). About 45 kg of each pre-compost was then placed in a plastic compost bin to be digested by 600 g of earthworms (*Eudrilus eugeniae*) for 11 weeks. The biofertilizers obtained were analyzed for their total organic carbon, macronutrients and micronutrients content. The pH of the different types of vermicomposts (VC) varied from 5.8 to 8.15. NPK levels varied and depended on the type of substrates used for vermicomposting. Highest values were found in vermicompost from mixed substrates. VC5(18.01; 3.89 and 18.7g/kg), VC4(20.99; 1.29 and 13.7g/kg) and VC3(17.91; 0.91 and 8.72g/kg), VC2(18.06; 0.39 and 4.64g/kg) and VC1(21.19; 0.34 and 2.25g/kg. The pH of the vermiwashs (VW) was alkaline (7.65 to 9.25) and their NPK content was lower than that of the VCs: VW1 (2.09; 0.08 and 2.18g/L), VW2(0.49; 0.09 and 0.44g/L), VW3 (0.33; 0.12 and 1.05g/L), VW4 (2.18; 0.18 and 2.50g/L) and VW5 (0.27; 0.18 and 1.99g/L).

INTRODUCTION

Sustainable agriculture is partly based on the integration of renewable resources, such as fertilizers produced biologically from organic residues (Kumar *et al.*, 2022). Among the many possibilities to make organic fertilizers, vermicomposting is one of the most sustainable practices. Vermicomposting is the stabilization of organic waste through the interaction of earthworms and micro-organisms to produce vermicompost and vermiwash rich in organic matter, organic carbon, nitrogen, phosphorus, potassium and trace elements (Esakkiammal & Sornalatha, 2016). Vermicompost is characterized by an excellent granular, friable, finely divided and homogeneous structure (Misra *et al.*, 2005; Andrianantenaina, 2019). Vermiwash, on the other hand, is the odorless liquid that is collected after the water has passed through the worm activity columns, transporting the dead worms and micro-organisms as well as any dissolved substances (Nayak *et al.*, 2019). Vermicomposting offers many advantages, as the products resulting from this process sometimes have essential physicochemical parameters that are higher than in normal compost, except for organic carbon (Abinaya *et al.*, 2024). Several studies have demonstrated their efficiency in maintaining fertility and correcting deficiencies in soil organic matter and mineral elements (Amritha & Jayasree, 2020). The fertilizing value of vermicomposts and vermiwashs is important to predict its application (Filipović *et al.*, 2023). This fertilizing value depends on the nature and composition of the organic substrates. Studies carried out by Atiyeh *et al.* (2000) have shown that mixing different vermicomposts produced from different substrates such as household waste, livestock manure, mown grass, coffee parchment, and cocoa shell increases nutrients by converting it into the form available to plants with a positive effect on growth and plant quality. In Côte d'Ivoire, cocoa bean production generates 4.4 million tons of cocoa pod residue each year, most of which is abandoned in the bush (Koffi *et al.*, 2024). Similarly, cassava peelings and cashew nut shells are left over. Vermicomposting can help transform these residues into usable organic matter (Lohri *et al.*, 2017).

Apart from ordinary composting, few works have been conducted on vermicomposting agricultural wastes.

The aim of this study is to determine the physical characteristics and assess the chemical composition of vermicompost and vermiwash obtained from agricultural residues such as cocoa shells, cashew shells and cassava peelings.

MATERIALS AND METHODS

Study site

The study was carried out at the CNRA (National Agricultural Research Centre) research station (06°08'06.9''N and 05°53'52.7''W). The composting unit was installed indoors in a well-ventilated building protected from pests. The locality is in an area with an average annual rainfall of between 1,300 and 1,400 mm and an average temperature of around 27°C (Kassin *et al*, 2008; Bongoua, 2009).

Collection, preparation and pre-composting of agricultural residues

The raw materials used for making biofertilizers consisted of cassava peelings (Ca.Pe), cocoa shells (Co.Sh) and cashew nut shells (Ca.Nu). The cocoa shells came from different cocoa farms located around the Gagnoa research station, the fresh cassava peelings were collected in the town of Gagnoa from cassava processors and the

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cashew nut shells were collected from a shelling plant in Korhogo, in the north of Côte d'Ivoire. The various residues were sun dried, crushed in a mechanical grinder and sieved with a mesh size of 4 mm. Five treatments were created from these three residues (Table 1). Each treatment was fermented in brick bins measuring 1 m long, 1 m wide and 0.4 m high. The pre-composting time varied from one organic substrate to another. It was 72 days for Ca.Pe; 60 days for Ca.Pe + Ca.Nu and Ca.Pe +Co.Sh; 48 days for Ca.Nu and Ca.Nu + Co.Sh

Table 1: Treatment composition

Treatments	Treatment composition	Initial quantity of treatments
1	Ca.Pe	60 kg cassava peelings
2	Ca.Nu	60 kg cashew nut shells
3	Ca.Pe + Ca.Nu	30kg cassava peelings + 30kg cashew shells
4	Ca.Pe +Co.Sh	30kg cassava peelings + 30kg cocoa shells
5	Ca.Nu + Co.Sh	30kg cashew shells + 30kg cocoa shells

Ca.Pe (Cassava peelings); Ca.Nu (Cashew nut shells); Co.Sh (Cocoa shells)

Vermicomposting system

The vermicomposting system used was a continuous-mode reactor system. The reactor consisted of plastic drums graduated from 0 to 100 liters (Essehi *et al.*, 2021; Zziwa *et al.*, 2021). The drums were fitted to a plastic tap at the base and placed on a table of 3 m long, 0.5 m wide and 1.70 m high (Figure 1). Watering cans with a capacity of 4 liters were placed above each drum to moisten the organic matter. The vermiwash (compost juice) were collected in pots placed below each tap. The drums were covered by a lid with a top opening to aerate the contents and create darkness to facilitate the appearance of worms on the surface in daylight. The device was placed in a protected, well-ventilated environment. Plastic drum was filled with gravel, sand, 30 kg of pre-decomposed organic matter, 600 g of earthworms (*Eudrilus eugeniae*) and 15 kg of pre-decomposed organic matter, for a total of 45 kg (Ansari & Sukhraj, 2010; Essehi *et al.*, 2021).

Figure 1: Vermicomposting system (Essehi *et al.*, 2021)

A: Watering can; B: Composting table; C: Lid with surface opening; D: Graduated barrel (0 to 100L) E: Plastic faucet; F: Canister of vermiwash

Vermicomposting process monitoring

Vermicomposting was monitored in two ways. Firstly, water was added drop by drop using watering cans, and secondly, the temperature and humidity of the different composts were measured every week using a multi-parameter electronic field meter. Fertilizing products were obtained by collecting earthworm droppings (vermicompost or castings), which were deposited on the surface of the drum every 10 days. The excrement was weighed and dried in the shade for 21 days before being stored. The vermiwash produced was also collected progressively in plastic drums. The quantities of each treatment were measured and stored at room temperature. Two days before each collection, the taps are left fully open to allow the worms to return to the bottom of the barrel and facilitate the collection of the excrements. The process lasted eleven weeks. After each collection, all the organic matter in the barrel was homogenized by turning it over.

Sampling

Every 10 days and for 11 weeks, 250 g of each type of fresh vermicompost was sampled. The fresh vermicompost collected was weighed and dried in the shade at room temperature for 21 days before being stored at room temperature. At the end of the vermicomposting process, a single pile consisting of replicates of each type of vermicompost was obtained. One kg sample of each type of vermicompost was used for laboratory analysis. A total of five vermicompost samples were obtained.
For the vermiwash, the liquid was collected progressively and stored in drums at room temperature. At the end of the process, one liter sample of vermiwash was used for analysis.

Laboratory analysis

The laboratory analyses consisted of determining the pH, C/N, and the mineral elements content (N, P, K, Ca, Mg) of the vermicompost and the vermiwash. The pH was measured using a BUTECH ION 2700 pH meter.
The organic carbon content was determined by calcination at 375°C for 16 hours using the Walkler-Black method (1934) and in accordance with standard NF U 44-160. The organic matter content was determined by multiplying the organic carbon content by 1.724. Total nitrogen was determined using the Kjedahl method in accordance with standard NF ISO 11261: June 1995. The C/N ratio was determined by calculating the ratio of organic carbon and nitrogen content. Exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}) were determined using the ammonium acetate extraction method at pH 7 in accordance with standard NFX 31-108 :2002. The quantities of mineral elements were read using an ICP spectrometer. Extraction and spectrophotometric determination of total phosphorus was carried out in accordance with ISO 11263 :1994

RESULTS AND DISCUSSION

Trends of temperature and humidity during vermicomposting

Temperature during vermicomposting fluctuated between 24 and 29°C, with an average of 26.9°C (Figure 2). Moisture levels varied almost constantly during the vermicomposting process. The average moisture content varied between 64% and 69% (Figure 3).

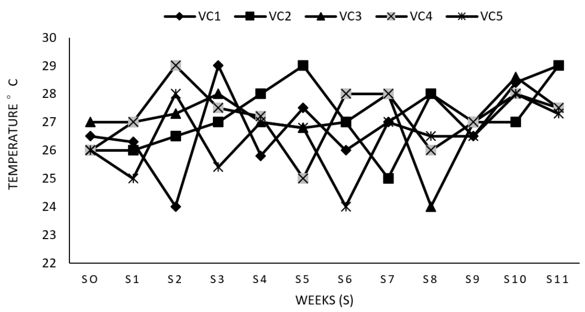

Figure 2: Temperature changes during vermicomposting

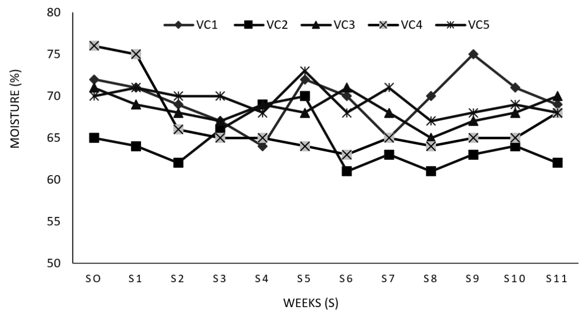

Figure 3: Moisture during vermicomposting

Amount of vermicompost (VC) and vermiwash (VW) produced

The vermicomposts obtained were odorless and homogeneous (Figure 4). The quantities of VC and VW collected depend on the activity of the earthworms in the different substrates. The total fresh weight of VC after 11 weeks is presented in Table 2. At the end of the fresh process, the highest quantity of fresh matter was obtained with vermicomposts (VC) from Ca.Pe (23705 g) followed by Ca.Nu and Ca.Pe + Ca.Nu with 18282 g and 18492 g respectively. The lowest quantity was obtained with Ca.Nu + Co.Sh (10945g).

For the vermiwash, table 2 shows that treatment VW1 obtained from Ca.Pe yielded the highest (42.20L), the lowest volumes were collected with VW4 (Ca.Pe + Co.Sh) and VW5 (Ca.Nu + Co.Sh), which produced an average of 33.10 and 27.40L respectively.

Figure 4: Vermicomposting products: Vermicompost (VC1) and Vermiwash (VW1) from cassava peelings

Table 1: Quantity of vermicompost and vermiwash obtained in the drums

Treatments	Treatment composition	Vermicompost (VC)		Vermiwash(VW)
		Fresh weight (g)	**Dried weight (g)**	**Volume (L)**
1	Ca.Pe	23705,66	9176,33	42,20
2	Ca.Nu	18282,66	8106,66	35,30
3	Ca.Pe + Ca.Nu	18492,66	8599,33	38,60
4	Ca.Pe + Co.Sh	14713	6623,66	33,10
5	Ca.Nu + Co.Sh	10945,33	4706,33	27,40

Ca.Pe (Cassava peelings); Ca.Nu (Cashew nut shells); Co.Sh (Cocoa shells)

PH and mineral content of the vermicompost and vermiwash

Figure 5 shows that the pH of the vermicomposts varied from 5.8 to 8.15 depending on the composition of the substrate. Vermicomposts VC3, VC4 and VC5 from the combination of residues have a pH around neutrality of 6.7, 7.2 and 7.3 respectively. The vermicompost VC1 made of cassava peelings had a pH of 8.15 and VC2 made of cashew nut shells had a low pH of 5.8.

The pH values of all the vermiwash were above 7. The values ranged from 7.65 (VW2) to 9.55 (VW4).

In all the composting units, the vermicomposts have values close to neutrality and the vermiwashs have values above 7.

Organic component of vermicomposts and vermiwashs

The C/N ratios of all the vermicomposts were between 14 and 28. VC2, VC3, VC4 and VC5 have values above 20. The highest C/N ratio (C/N=28) was observed in vermicomposts VC2 and VC3. Vermicompost VC1 had the lowest C/N=14 (Table 3). Regarding the organic

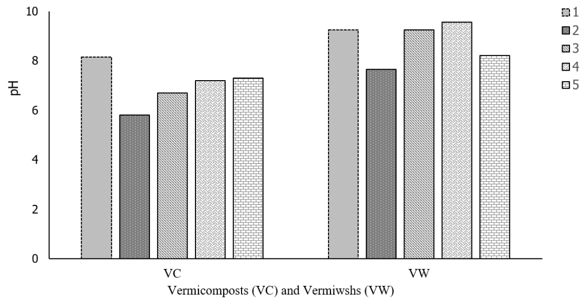

Figure 5: pH of vermicomposts and vermiwash

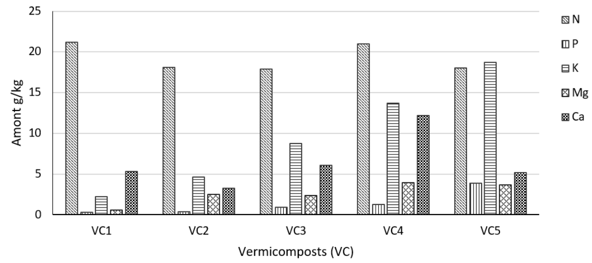

Figure 6: Mineral content of vermicomposts

matter (OM), all the vermicomposts had contents above 50%. The highest contents were recorded in the treatments containing cashew nuts VC2, VC3 and VC5, with contents of 88.89, 86.5 and 85.69% respectively. The OM content of vermiwash was lower than that of vermicomposts, ranging from 32 to 66%.

Table 3: Organic elements content of Vermicomposts (VC) and Vermiwashs (VW)

Treatments	**Organic parameters**		
Vermicomposts	**C (%)**	**OM (%)**	**C/N**
VC1	30,88	53,11	14,6
VC2	51,68	88,89	27,1
VC3	50,29	86,5	28,7
VC4	44,49	76,52	21,8
VC5	49,82	85,69	27,8
Vermiwashs			
VW1	23,47	40,37	-
VW2	38,68	66,53	-
VW3	25,44	43,76	-
VW4	18,94	32,58	-
VW5	26,16	45	-

Mineral elements content of vermicomposts

Figure 5 shows that Nitrogen concentrations range from 17.91g/kg (VC3) to 21.29g/kg (VC1). Potassium levels are high, with values ranging from 2.25 to 18.7 g/kg. VC4 and VC5 containing cocoa shells in their composition are more concentrated in potassium with contents of 13.70 and 18.70 g/kg respectively. Calcium is the third most important element in vermicomposts. The levels range from 3.23 g/kg (VC2) to 12.20 g/kg (VC4). Phosphorus levels ranged from 0.34 to 3.89/kg. VC1, VC2 and VC3 contained less than 1g/kg, with only VC4 and VC5 containing more than 1g/kg. The magnesium content of VC1 is less than 1g/kg. The other four vermicomposts had almost identical contents, above 2g/kg: VC2 (2.53g/kg), VC3 (2.35g/kg), VC4 (3.93g/kg) and VC5 (3.68g/kg).

Mineral elements content of vermiwash

Vermiwash contains low concentrations of mineral elements, particularly nitrogen, with values ranging from 0.27g/L (VW5) to 2.18g/L (VW4) (Figure 7). Phosphorus levels varied between 0.08 and 0.19g/L. Magnesium and calcium levels appear to be low, with values below 0.25g/L. Only potassium was found in high concentrations in all the vermiwashes, with values ranging from 0.4 to 2.50g/L.

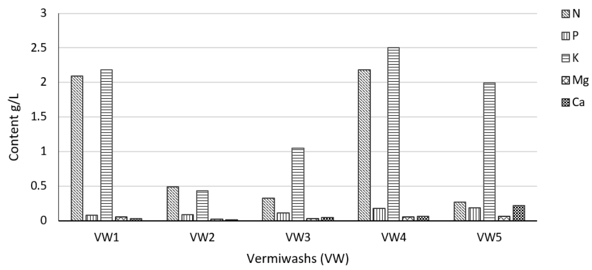

Figure 7: Mineral content of vermiwashs

DISCUSSION

biofertilizers made of crop residues using the vermicomposting technique involves two phases. A thermophilic decomposition phase and a composting phase in the presence of earthworms of the genus *Eudrilus Euginae*.

In this study, an average temperature of 26°C and a moisture content of the organic substrate of 60% allowed an efficient vermicomposting process. Similar results have been reported by Ansari & Rajpersaud (2012) while vermicomposting water hyacinths and grass clippings. Temperatures comprise between 25-30°C are defined as the optimum temperature for good activity and growth of earthworms of the genus *Eudrilus Euginae* in an organic substrate (Awadhpersad *et al.*, 2021). Moisture content of the substrate is considered critical. According to Sierra *et al.* (2011), excess moisture is harmful to worms because it affects respiration.

pH regulates the rate at which nutrients are dissolved and absorbed by plants. (Ansari & Rajpersaud, 2012). All the vermiwah obtained have pH values above 7, most likely due to the release of organic nitrogen in the form of ammonia, which dissolves in the compost water reducing the concentration of H^+ ions (Beaudette, 2014). Highest pH values were found in substrate containing cassava peelings.

The vermicomposts produced were alkaline to slightly acidic depending on the substrate. Vermicompost from cashew nuts shells were the most acid. Similarly, a pH range of 5 to 8 was found for water hyacinths and grass (Ansari & Rajpersaud, 2012). Vermicomposts from household waste can vary from 8.5 to 9.5 (Rubabura *et al.* 2020). Composts with pH values of 7 to 9 are considered mature and stable (Pujol, 2012; Rubabura *et al.*, 2020). Their pH depends on the chemical composition of the substrate. pH values around neutrality was obtained with a mixture of cassava peelings and cashew shells (VC3), a mixture of cassava peelings and cocoa pod shells (VC4) and cashew shells and cocoa shells (VC5). This type of vermicompost could be attributed to the production of high concentrations of CO_2 and organic acids during vermicomposting process, which regulate and shift the pH of vermicompost towards neutrality (Ayed *et al.*, 2005; Pattnaik & Reddy, 2010; Awadhpersad *et al.*, 2021). It appears that although vermiwash and vermicomposts are derived from the same substrates, their pH values are different.

The C/N ratio is an indicator of compost stability and maturity, but also an important indicator of the mineralization and decomposition of the initial raw material. The final C/N ratio depends on the origin of the waste and its relative nitrogen content (Dieng *et al.*, 2019). The C/N ratios of the vermicomposts obtained are above 20, except for VC1. values around 25 characterize a stable vermicompost (Hien *et al.*, 2018). Such ratios were obtained in studies carried out by Sall (2014) and Hien *et al.* (2018) with composts and vermicompost from plant debris, respectively. According to Amery *et al.* (2021), organic fertilizers with a low C/N ratio release a relatively large proportion of their nutrients rapidly in the first year, whereas fertilizers with a high C/N ratio release their nutrients slowly but over a longer period. The results of work by Djéké *et al.* (2011) showed that cocoa shell grindings with a C/N ratio of 25.7 helped to improve the mineralization of soil organic carbon. Our study indicates that compost made of cassava will mineralize faster than the others.

The quality of the different vermicompost and vermiwash were related to the chemical and biochemical composition of the organic substrates used as food sources for the earthworms.

Vermicompost containing cassava peelings were the most productive due to an increased activity of earthworms in these substrates. These results corroborate those of Saravanan *et al.* (2018) who showed that cassava peelings prove to be a suitable substrate for *Eisenia fetida* worms. They contain cyanide and are therefore easily degradable, whereas cocoa residues and cashew nut shells contain large quantities of lignocellulosic matter (Coulibaly *et al.*, 2019), which is more difficult to digest. The biodegradation of agricultural residues depends on several factors, in particular the matrix structure of the residues (granulometry, void space, exchange surfaces, etc.), which determines the access routes for micro-organisms (Pujol, 2012). According to Xu *et al.* (2023), lignocellulosic waste has a high natural resistance to hydrolysis, which explains why it is less fermentable than sugar-rich waste. When the litter is highly porous, earthworm activity is maximized.

Concerning vermiwash, the differences observed between the quantities collected depend on the capacity of the substrates to retain water in their constitutional matrix (Pujol, 2012). The weight losses observed after drying the vermicomposts in the treatments containing cassava peelings were greater than in the treatments without cassava peelings. From these results, we can deduce that the higher the water retention capacity of the substrates, the greater the leaching.

The level of the macro-elements mainly the carbon content show that biofertilizers are rich in organic matter. The high quantities of Nitrogen found in the different types of vermicomposts could be due to the activity of the earthworms which increase the nitrogen level of substrates by adding their excretory products, mucus secretion, fluid body, enzymes and even through the putrefaction of dead earthworm tissue in vermicomposts (Rubabura *et al.*, 2020). In general, vermicomposts made from a mixture of residues had higher mineral element contents than vermicomposts made from a single residue. In a study by Hien *et al.* (2018) on cocoa shells and grass clippings, higher values of mineral content were obtained from the mixture of the two residues.

The different types and the specificity of the organic residues used in each treatment can explain the differences in the mineral content of each biofertilizer. Vermicomposts and vermiwash can therefore be used in combination or not on crops. The positive effects of this biofertilizers were demonstrated by Awadhpersad *et al.* (2021) to improve the physical and chemical properties of the soil with the combined input of vermicompost and vermiwash. The use of vermicompost and vermiwash can improve resistance to pathogens and early ripening of tomato fruits Makkar *et al.* (2017). Marius *et al.* (2020) showed that cassava variety reached its best agronomic potential when grown with cocoa shell compost as fertilizer. Gupta & Dahiya (2021) have shown that vemicompost from rice straw provides a good quality biofertilizer that improves soil quality and promotes plant growth, health, and yield.

CONCLUSION

This study showed that vermicomposting, through the action of earthworms, makes it possible to eliminate waste by transforming it into biofertilizers (vermicompost and vermiwash). The fertilizing element content of which varies according to the type of residue composted.

Vermicomposts VC4 and VC5 containing cocoa shells were the richest in NPK and vermicomposts VC1 and VC2 made up of cassava peelings and cashew nut shells respectively were the poorest. The C/N ratio of the vermicomposts was greater than 20, except for VC1 (C/N=14). Despite these differences, the vermicomposts obtained were richer in OM and NPK than the vermiwash. Based on the chemical characteristics, these two biological products can be used as fertilizer independently or in combination to optimize soil fertility. Composting crop residues leads to the production of environmentally friendly fertilizers.

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