Vermicompost utilization: A way to food security in rural area

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Abstract

The increase in agricultural production as well as its nutritional quality at a cost bearable by producers is today a challenge in rural areas. Vermicompost is a low-cost organic amendment known for its effectiveness on agricultural productivity increase but little is diffused about its efficacy on nutritional quality. This study aimed to evaluate the benefits of vermicompost from cattle dung on Lagenaria siceraria yield and its edible parts content in mineral and in heavy metal compared to raw dung. The study was carried out in the region of Mankono the biggest area for L. siceraria production in Côte d’Ivoire during three cycle seasons. The experiment consisted of three treatments arranged in a complete randomized block design with four replicates. The agronomic parameters as yield, number of leaves and flowers per plant were evaluated. Also, mineral nutrients and heavy metal concentrations in roots, leaves and seeds were measured. Results showed that yield, number of leaves and flowers per plant were higher with the vermicompost than with the cattle manure and the control. The yield obtained with the vermicompost was 2.5 times and 20 times
higher respectively than that with the cattle manure and the control. Mineral concentrations in roots, leaves and seeds were the highest with the vermicompost when heavy metal contents were the lowest. The present study indicates that vermicompost utilization improves the yield and the nutritional quality of the edible parts of *L. siceraria* and hence could be recommended to producers for increasing productivity with keeping the health and safety of human.

**Keywords:** Agriculture, Food technology

1. **Introduction**

Reducing on-farm poverty necessarily involves improving agricultural productivity and its quality (Hansen et al., 2018). In the department of Mankono, the largest production area of the oleaginous form of *Lagenaria siceraria* in Côte d’Ivoire, productivity is still very low (75 kg.ha⁻¹ of husked seeds). This has made the cost of the kg expensive ($7.8 per kg) and therefore has led to a declining of its consumption per capita (Zoro Bi et al., 2006). *L. siceraria* seeds are usually prepared in sauce for honor guests during ceremonies (Zoro Bi et al., 2006). Nevertheless, *L. siceraria* is very prized for its nutritional qualities and has been reported to have numerous agronomic and economic potentials for peasants (Pradhan et al., 2015; Salifou et al., 2016; Upaganlawar, 2017). Besides that, *L. siceraria* is an excellent fruit in the nature consisting of all the essential constituents that are necessary for normal and good health of human beings (Essien et al., 2015; Minocha, 2015). Traditionally, *L. siceraria* fruits, leaves, roots and flowers are used in medicine as aphrodisiac, diuretic, antidote to certain poisons, scorpion stings, and alternative purgative (Jamuna et al., 2015). Scientific researchers have shown that *L. siceraria* possesses antihelmintic, antibacterial, antifungal, immunomodulatory, anti-allergic, analgesic, anti-inflammatory, antioxidant, free radical scavenging, cytotoxic, antihyperlipidemic, antidiabetic, hepatoprotective, anxiolytic and memory enhancing properties (Nigam et al., 2015; Ahmed et al., 2017; Upaganlawar, 2017). According to Zake et al. (2015), Panagos et al. (2018), low agricultural productivity is generally due to the deterioration of the physical and chemical soil quality. Thus, soil amendment is a prerequisite to increase agricultural productivity. Besides that, Mankono is a big cattle breeding area and large quantities of cattle wastes are produced (Dugué et al., 2007). These wastes are generally used by rural people to paint houses, spray on plants after mixing with water as pesticides and the largest part is utilized as fertilizer. Despite the use of cattle wastes as fertilizer, *L. siceraria* productivity is still slow and its leaves and roots are always insufficient for population’s health treatment. Nevertheless, animal wastes are valuable resources as soil fertilizers providing macronutrients and micronutrients for crop growth, and improving soil structure and quality (Gbenou et al., 2017) but they may contain heavy metals that can pollute soil.
and prevent nutrients absorption by plants (Ravindran et al., 2017; Mukhuba et al., 2018). In fact, long used of animal wastes can lead to the accumulation of heavy metals in soil affecting negatively plant growth, soil microbial diversity and activity and agricultural productivity (Yan et al., 2016). The elevated levels of heavy metals in soils had significant impacts on the population size and overall activity of the soil microbial communities which are essential in the decomposition of soil organic matter. Any decrease in microbial diversity or abundance may adversely affect nutrient absorption from the soil by plants. In addition, heavy metals can also be absorbed by plants and negatively affect human health after consumption (Kalaivanan and Ganesamurthy, 2016; Glavač et al., 2017; Ibrahim and Selim, 2018; Magaji et al., 2018). In fact, heavy metals are not easily biodegradable and consequently can be accumulated in human vital organs. This situation causes varying degrees of illness based on acute and chronic exposures (Zhang et al., 2018). It is therefore timely to treat animal manure before its use. This may be feasible if producers have the opportunity to bear the costs. Among organic material treatment methods, vermicomposting is known for its benefits. It is a low cost technology system and an accelerated process of bio-oxidation and stabilization of organic wastes involving interactions between earthworms and microorganisms (Lim et al., 2016; Baghel et al., 2018). During vermicomposting, worms ingest the large amount of wastes and grind it in gizzard. Then, they are digested chemically and are absorbed in the body. However, the rest of material is excreted out as “vermicastings” which accredit to the enrichment in soil porosity, aeration and production of soil aggregates. Earthworm’s excretion in the form of vermicastings are rich in NPK, micronutrients and valuable soil microbes and consists more water-stable aggregates as compared to the nearby soil (Sari et al., 2017; Baghel et al., 2018). In addition, trough vermicomposting, bulk density, water holding capacity, pH, electrical conductivity, nitrogen, phosphorous and potassium content are better than those obtained with composting process (Doan et al., 2015; Rakkini et al., 2018). Vermicomposting may also bring about a greater decrease of bioavailable heavy metals than in the composting process, and there is evidence that the vermicompost may contain more available hormone like compounds which accelerate plant growth than compost and therefore may shorten plants production cycle (Najar et al., 2015; Coulibaly et al., 2016; Lim et al., 2016).

The importance of vermicompost in agricultural productivity increase has been largely demonstrated (Guo et al., 2015; Olle, 2016; Ashiya and Rai, 2017; Kumar et al., 2017; Shrimal and Khan, 2017; Makkar et al., 2017; Zaremanesh et al., 2017; Adilğlu et al., 2018). In spite of important works on vermicompost effect on plant growth, little is known about the effect of vermicompost on L. siceraria growth and mineral nutrients and heavy metals contents in the different parts of the plant compared to raw material. The objective of the present study was to evaluate the effect of the vermicompost from cattle waste on the growth of Lagenaria
2. Materials and methods

2.1. Survey area

The field study was conducted in the village of Sikawakaha in Mankono district in North-West Côte d’Ivoire. The village is situated between latitudes 8°03’N - 8°30’N and longitudes 6°11’W - 6°22’W at an altitude of about 335 m above sea level. Based on the meteorological records from the nearby station, the mean annual rainfall of the area was 1315 mm with a mean annual temperature of 25.5 °C. Monthly rainfall and temperature data were collected from an automatic weather station established in the village near the experimental site. The mean annual rainfall for the period was 1221 mm. January was the driest month with an average rainfall of 10 mm. In September, rainfall was the most important of the year with an average of 237 mm. The annual mean minimum temperature was 27.6 °C and the annual mean maximum temperature was 33.6 °C. The soil of the department of Mankono is moderately ferralitic or feebly desaturated (Dugué et al., 2007). It has a particularly gravelly horizon with a high frequency of concretions.

2.2. Biological materials

Cattle wastes were collected in different farms to be used. The excreta were constituted of a mixture of faeces and urine without any bedding material. The different wastes were air-dried before their use in order to facilitate their manipulation and reduce odor. Healthy adults of *Eudrilus eugeniae* weighing between 500–1200 mg were collected in the experimental area for the vermicomposting because at this weight, earthworms’ consumption and reproduction is high (Coulibaly and Zoro Bi, 2010). The seeds of *L. siceraria* were obtained from the previous harvest of the selected producers for the experiment.

2.3. Preparation of vermicompost

For vermicompost preparation, 3 pits (1 m × 1 m × 1 m) were dug and cemented to avoid nutrients loss (Prabha et al., 2007). Fifty kilos of each dried cattle waste were put in each of them and watered with well water and the mixtures were turned over manually everyday for 15 days to eliminate volatile gases which may be potentially toxic to earthworms (Garg et al., 2006). The moisture content of the pits was adjusted to 70–80%. Moisture helps worms (*E. eugeniae*) to have a thin film of water to carry out gas and prevents them from losing weight and dehydration (Gunadi et al., 2002; Manna et al., 2003; Lowe and Butt, 2005). After pre-composting, each of the four pits has received 750 individuals of *E. eugeniae*.
for good stabilization of the compost before its use (Coulibaly et al. 2011, 2014). The pits were covered with coconut palm leaves to avoid colonization by pests and to maintain humidity for three months.

Before the start of the experiment, three samples of the soil, the raw cattle manure and the vermicompost were taken for chemical analysis. The samples were air dried in the shade and the pH, the total organic carbon (TOC), the total N, the total K and the total available P were evaluated. Distilled water suspension of each waste was used to measure the pH after mechanical agitation for 30 min and filtration. N was analyzed by using the Kjeldhal method (Tandon, 1993). P and K were determined by using spectrometric methods (Olsen et al., 1954; Stanford and English, 1949, respectively). TOC was determined according to the method used by Baize (1988).

2.4. Experimental design

Sikawakaha village is divided into three different sub-villages or gotes. One farmer was selected per gote for geographically distribution of the experiment all over the village. The choice of the farmers primarily considered their dedication and long experience in *L. siceraria* growth (at least ten years) and did not consider wealth status or specific farm and field properties.

Three randomized complete block design with four replicates separated each other were used for the experiment. A block was composed of twelve plots with 25 m per size either an area of 625 m$^2$. Each bloc was corresponded to a farmer field design with four replicates and the plots were separated each other by an aisle of 5 m. Seedlings of *L. siceraria* were made three crop cycles. The sowing was done on the same day in July for all treatments with 3 seeds per hole at a depth of 2–3 cm at each cropping cycle. A distance of 3 m was separating lines and sowing points. The lifting occurred 15 days after the sowing and seedlings were thinned to keep only the strongest plant at each sowing point. The four replicates with cattle manure and those with the vermicompost received 2.5 kilos of their corresponding fertilizer and on a surface of 1.131 m$^2$ around each plant either 2.77 t.ha$^{-1}$. The plots intended to control did not receive fertilizer. After the spreading, fertilizers were buried at a depth of 15 cm in the soil with a hoe to avoid leaching and to facilitate nutrients absorption.

At the end of the vegetative phase, the number of leaves per plant was evaluated. Fruits were harvested at ripening, weighed individually and their number per plant was determined. Seeds were extracted, washed and dried in the open air on tarps after a week of fermentation. The number of seeds per fruit and the weight of 100 seeds were determined and the yield was calculated by combining the data over plots and seasons. Roots were harvested around the base of the plants in each block. Then the
radius (r) of harvest was measured, and the rhizosphere (Rh) was determined by the following formula: \( \text{Rh} = \pi r^2 \).

Roots, leaves and seeds were analyzed to determine the nutrients content as Calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P), and heavy metal concentrations as zinc (Zn), copper (Cu), lead (Pb), cadmium (Cd), nickel (Ni), chromium (Cr), arsenic (As), and barium (Ba) in function of the organic fertilizers. Nutrients and heavy metals contents were determined by means of atomic absorption spectrophotometer (AA-220 FS) after digestion of the samples with concentrated HNO3: concentrated HClO4 (4:1, v/v) at the Engineering Laboratory of the University “Vasile Alecsandri” of Bacău, Romania.

The 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 constitute homogenous groups. Significant differences were determined at \( P \leq 0.05 \).

3. Results

3.1. Characteristics of the different substrates

Table 1 encapsulates the characteristics of the soil, raw cattle waste (RCW) and the vermicompost from cattle waste (VCW). Substrates had very variable characteristics. Statistically, there were significant differences between the pH of the substrates. The RCW (pH = 8.35) and the VCW (pH = 7.23) were alkaline when the soil (pH = 5.09) was acid. Concerning the total organic carbon (TOC) and the total nitrogen (TN) respectively, they differed significantly from one substrate to another. The highest TOC was obtained in the RCW followed respectively by that in the VCW and in the soil. Relatively to the TN, it was higher in the VCW and lower in the soil. The C:N ratio differed significantly in the three substrates. The highests were obtained in the soil (95.74) and in

| Type of Substrate | pH     | TOC (mg.kg\(^{-1}\)) | TN (mg.kg\(^{-1}\)) | C:N | TP (mg.kg\(^{-1}\)) | TK (mg.kg\(^{-1}\)) |
|-------------------|--------|-----------------------|----------------------|-----|---------------------|---------------------|
| Soil              | 5.09 ± 0.05\(^a\) | 12100 ± 100\(^c\) | 127 ± 24\(^c\) | 95.74 ± 0.53\(^a\) | 33950 ± 300\(^a\) | 67800 ± 250\(^b\) |
| RCW               | 8.35 ± 0.06\(^b\) | 468970 ± 112\(^a\) | 5243 ± 154\(^b\) | 89.37 ± 1.37\(^a\) | 2795 ± 460\(^b\) | 7317 ± 200\(^a\) |
| VCW               | 7.23 ± 0.05\(^b\) | 214725 ± 112\(^b\) | 7524 ± 200\(^a\) | 27.86 ± 1.62\(^b\) | 4978 ± 380\(^b\) | 5223 ± 230\(^b\) |

Values followed by the same letter in a column are not significantly different (\( P > 0.05 \)) using LSD.
the RCW (89.37) and the lowest was observed in the VCW (27.86). The total phosphorus (TP) and the total potassium (TK) respectively differed significantly from one substrate to another. The decreasing order of TP was 33950 mg.kg\(^{-1}\) for the soil, 4978 mg.kg\(^{-1}\) for the RCW and 2795 mg.kg\(^{-1}\) for the RCW. The highest TK content was obtained in the RCW followed respectively by those of the soil and of the VCW.

3.2. Influence of organic inputs on agronomic parameters of *L. siceraria*

The growth of the different agronomic parameters of *L. siceraria* in function of organic inputs is registered in Table 2. It appeared that the number of male and female flowers per plant was higher with the vermicompost than those got with the raw cattle manure and the control (without fertilizer). Relatively to the ratio of male and female flowers, the highest was obtained on the plots fertilized with the raw cattle manure and the lowest with the vermicompost and the control. Statistically, there was a significant difference between the numbers of fruits per plant in function of the type of organic inputs. The highest number of fruits per plant (7.75 ± 1.97) was obtained with the vermicompost and the lowest (1.32 ± 0.98) on the plots that did not received fertilizer (control). The intermediate number of fruits per plant (4.88 ± 1.33) was got with the raw cattle manure. The number of branches per plant was similar despite the type of organic fertilizer. Concerning the rhizosphere, the

| Parameters                              | Type of organic fertilizer |
|-----------------------------------------|----------------------------|
|                                        | Control | Cattle manure | Vermicompost |
| Number of male flowers per plant        | 17.52 ± 5.61\(^c\) | 64.37 ± 12.74\(^b\) | 101.36 ± 21.13\(^a\) |
| Number of female flowers per plant      | 3.14 ± 1.27\(^c\)  | 7.11 ± 2.31\(^b\)  | 12.55 ± 4.72\(^a\)  |
| Ratio of male and female flowers        | 5.61 ± 2.18\(^b\)  | 9.11 ± 2.69\(^a\)  | 6.67 ± 2.15\(^b\)  |
| Number of fruits per plant              | 1.32 ± 0.98\(^c\)  | 4.88 ± 1.33\(^b\)  | 7.75 ± 1.97\(^a\)  |
| Number of branches per plant            | 37 ± 8.77\(^a\)    | 40 ± 10.09\(^a\)   | 42.42 ± 18.23\(^a\) |
| Rhizosphere (m\(^2\))                   | 1.766 ± 0.14\(^a\) | 1.133 ± 0.11\(^b\) | 1.132 ± 0.12\(^b\) |
| Length of root (cm)                     | 75.55 ± 12.28\(^a\) | 59.84 ± 13.11\(^b\) | 59.82 ± 14.21\(^b\) |
| Length of stem (cm)                     | 349 ± 107\(^a\)    | 624 ± 114\(^b\)    | 874 ± 169\(^a\)    |
| Ratio of root and stem                  | 0.22 ± 0.01\(^a\)  | 0.09 ± 0.01\(^b\)  | 0.07 ± 0.01\(^b\)  |
| Number of leaves per plant              | 56 ± 17.84\(^b\)   | 88 ± 21.53\(^a\)   | 92 ± 22.62\(^a\)   |
| Number of seeds per fruit               | 237.84 ± 67.73\(^b\)| 387.84 ± 87.73\(^b\)| 461.94 ± 92.53\(^a\)|
| Weight of 100 seeds (g)                 | 13.63 ± 4.47\(^b\) | 19.68 ± 5.94\(^a\) | 20.19 ± 2.42\(^a\) |
| Yield (t/ha)                            | 0.031 ± 0.01\(^c\) | 0.254 ± 0.01\(^b\) | 0.623 ± 0.12\(^a\) |

Values followed by the same letter in a column are not significantly different (*P* > 0.05) using LSD.
largest was observed (1.766 ± 0.14 m²) in control plots and the smallest in the plots fertilized with the vermicompost and with the raw cattle manure. However, there was no significant difference between the rhizosphere obtained with the vermicompost and that got with the raw cattle manure. The longest stem was measured in the plots fertilized with the vermicompost followed respectively by that obtained with the cattle manure and with the control. There was a significant difference between the numbers of seeds per fruit. The highest was got with the vermicompost followed respectively by those obtained with cattle manure and control. The number of leaves per plant and the weight of 100 seeds respectively varied similarly. The highest numbers were observed with the vermicompost and the cattle manure and the lowest on the control plots. The yield of *L. siceraria* obtained with the vermicompost was higher than those harvested with the raw cattle manure and with the control and was 2.5 times higher than that with cattle manure and 20 times higher than that on control plots.

### 3.3. Influence of organic inputs on mineral and heavy metal content in the different parts of *L. siceraria*

The mineral contents in the parts of *Lagenaria siceraria* are registered in Table 3. The Ca content varied from 86.66 mg.kg⁻¹ to 1025.24 mg.kg⁻¹. The other concentrations ranged from 146.2 mg.kg⁻¹ to 6757 mg.kg⁻¹ for Mg, from 38.95 mg.kg⁻¹ to 240.33 mg.kg⁻¹ for P and from 1526 mg.kg⁻¹ to 11361 mg.kg⁻¹ for K. The highest contents in Ca, Mg and P were found with the vermicompost followed respectively by those obtained with the cattle manure and with the control. For Ca and Mg, the highest content was measured in the leaves of the plants that received the vermicompost and the lowest in the seeds of the plants from the control plots. For each

| Treatment          | Plant parts | Ca         | Mg          | P            | K            |
|--------------------|-------------|------------|-------------|--------------|--------------|
|                    | Roots       | 86.66 ± 18.42a | 146.02 ± 68.56b | 38.95 ± 11.63g | 11361.85 ± 999.85a |
| Control            | Leaves      | 100.03 ± 49.73c | 172.30 ± 60.27g | 92.08 ± 22.54e | 9162.78 ± 1000.02d |
|                    | Seeds       | 65.78 ± 20.12b | 148.53 ± 62.67h | 147.33 ± 54.76c | 1526 ± 322.04h   |
|                    | Roots       | 112.44 ± 55.22f | 229.35 ± 79.81f | 51.05 ± 19.88f  | 4415.98 ± 674.67c |
| Cattle manure      | Leaves      | 189.85 ± 74.46d | 282.112 ± 88.27d | 117.08 ± 41.16f | 4165.98 ± 666.28f |
|                    | Seeds       | 124.9 ± 60.11c  | 243.2 ± 86.79g  | 187.33 ± 67.05h | 3690 ± 568.79g   |
|                    | Roots       | 874.12 ± 198.67b | 4416.33 ± 746.46c | 83.67 ± 33.45g  | 10678.12 ± 896.72b |
| Vermicompost       | Leaves      | 1025.24 ± 746.27c | 6757 ± 847.69a  | 150.21 ± 69.74a | 10073.7 ± 933.21c |
|                    | seeds       | 674.5 ± 106.85c  | 5825 ± 849.37h  | 240.33 ± 83.28a | 4428 ± 101.36e   |

Values followed by the same letter in a column are not significantly different (*P* > 0.05) using LSD.

![Table 3. Nutrients content (mg.kg⁻¹) in the parts of *L. siceraria* in function of waste treatment.](image-url)
treatment, the highest contents in Ca and Mg were observed in the leaves followed respectively by those in the seeds and in the roots. Relatively to K, the highest content was found in the seeds followed respectively by that in the leaves and in the roots. Contrary to the previous elements, the highest content in K was observed in the roots followed by that in the leaves and in the seeds. Mineral contents in the different parts of *L. siceraria* changed in function of the type of fertilizer. Potassium (K) content was the highest in the roots, the leaves and in the seeds whatever the type of fertilizer and was followed by Mg. The decreasing order of the mineral content found respectively in the roots, the leaves and in the seeds was K > Mg > P > Ca and that with the control and cattle manure. In contrast, with the vermicompost, the decreasing order was K > Mg > Ca > P.

Table 4 encapsulates heavy metal contents in the different parts of *L. siceraria* in function of the type of fertilizer. Heavy metal contents varied in function of the organic inputs. The concentration of Zn varied from 1.35 to 111.62 mg.kg⁻¹ when that of Pb ranged from 0.06 to 0.73 mg.kg⁻¹. Relatively to Cu, Cr, Ni, As, Cd, and Ba content, it ranged from 0.05 mg.kg⁻¹ to 30.42 mg.kg⁻¹ for Cu, from 0.02 mg.kg⁻¹ to 0.86 mg.kg⁻¹ for Cr, from 0.12 mg.kg⁻¹ to 2.13 mg.kg⁻¹ for Ni, from 0.05 mg.kg⁻¹ to 1.02 mg.kg⁻¹ for As, from 0.03 mg.kg⁻¹ to 0.11 mg.kg⁻¹ for Cd, and from 0.46 mg.kg⁻¹ to 11.04 mg.kg⁻¹ for Ba. According to the ANOVA test, heavy metal contents were significantly different in each part of *L. siceraria*. However, except for the highest content in Pb and Cr that were found with the control, the highest contents in Zn, Cu, Ni, As, Cd, and Ba were observed with the cattle manure and the lowest were obtained with the vermicompost. Also, it was noticed that whatever the treatment, the highest metal content was found in the roots followed in decreasing order by those in the leaves and in the seeds. The decreasing order of heavy metal content in the roots, the leaves and the seeds respectively was Zn > Cu > Ba > Ni > Cr > Pb > As > Cd.

In our study, the maximum Zn content (111.62 mg.kg⁻¹) was lower than the tolerated limit (150 mg.kg⁻¹) in food. Lead contents in roots (0.73 mg.kg⁻¹), leaves (0.54 mg.kg⁻¹) and seeds (0.32 mg.kg⁻¹) in the control plots were higher than the 0.3 mg.kg⁻¹ defined as recommended limit. Relatively to Cu content, the edible parts of *L. siceraria* showed higher contents with cattle manure and these values were higher than the permitted limit (10 mg.kg⁻¹). Chrome (Cr) contents measured with the control and the cattle manure in the edible parts of the plant were higher than the permitted limit (0.1 mg.kg⁻¹). Concerning Ni, only cattle manure showed higher contents than the 1.1 mg.kg⁻¹ indicated as the maximum limit for Ni in food. The maximum limit for As (0.3 mg.kg⁻¹) was overpassed in the roots of the plants from control and cattle manure plots. Barium maximum limit (2 mg.kg⁻¹) was lower than the one in the edible parts obtained with the control and the cattle manure. All contents in Cd in this study were lower than the maximum Cd limit (0.2 mg.kg⁻¹).
Table 4. Heavy metal content (mg.kg\(^{-1}\)) in the edible parts of *L. siceraria* in function of cattle treatment compared to their permitted limit.

| Treatment          | Plant parts | Zn    | Pb    | Cu    | Cr    | Ni    | As    | Cd    | Ba    |
|--------------------|-------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Control            | Roots       | 8.74 ± 2.32\(^c\) | 0.73 ± 0.01\(^a\) | 3.18 ± 1.08\(^c\) | 0.86 ± 0.1\(^a\) | 1.01 ± 0.11\(^c\) | 0.48 ± 0.01\(^b\) | 0.05 ± 0.01\(^b\) | 3.48 ± 1.02\(^c\) |
|                    | Leaves      | 3.89 ± 1.22\(^d\) | 0.54 ± 0.02\(^b\) | 2.92 ± 1.01\(^d\) | 0.48 ± 0.1\(^c\) | 0.47 ± 0.12\(^d\) | 0.08 ± 0.01\(^d\) | 0.03 ± 0.01\(^b\) | 2.35 ± 0.28\(^c\) |
|                    | Seeds       | 1,929 ± 0.14\(^d\) | 0.32 ± 0.01\(^c\) | 2.205 ± 1.1\(^c\) | 0.46 ± 0.1\(^c\) | 0.39 ± 0.11\(^de\) | 0.05 ± 0.00\(^d\) | 0.04 ± 0.01\(^b\) | 1.78 ± 0.47\(^c\) |
| Cattle manure      | Roots       | 111.62 ± 56.21\(^a\) | 0.24 ± 0.01\(^d\) | 30.42 ± 9.16\(^a\) | 0.7 ± 0.01\(^b\) | 2.13 ± 0.11\(^a\) | 1.02 ± 0.01\(^a\) | 0.11 ± 0.00\(^a\) | 11.04 ± 2.41\(^a\) |
|                    | Leaves      | 108.61 ± 57.02\(^a\) | 0.13 ± 0.01\(^b\) | 29.24 ± 8.18\(^a\) | 0.71 ± 0.01\(^b\) | 1.43 ± 0.19\(^b\) | 0.2 ± 0.01\(^c\) | 0.05 ± 0.00\(^b\) | 9.12 ± 1.74\(^ab\) |
|                    | Seeds       | 71.45 ± 22.11\(^b\) | 0.12 ± 0.01\(^a\) | 24.65 ± 7.88\(^b\) | 0.66 ± 0.01\(^b\) | 1.29 ± 0.31\(^b\) | 0.16 ± 0.01\(^c\) | 0.03 ± 0.00\(^b\) | 7.99 ± 1.32\(^b\) |
| Vermicompost       | Roots       | 7.41 ± 2.01\(^c\) | 0.14 ± 0.01\(^c\) | 1.03 ± 0.01\(^f\) | 0.04 ± 0.00\(^b\) | 0.21 ± 0.01\(^ef\) | 0.11 ± 0.01\(^ed\) | 0.03 ± 0.00\(^b\) | 0.87 ± 0.17\(^d\) |
|                    | Leaves      | 1.35 ± 0.14\(^d\) | 0.09 ± 0.01\(^f\) | 0.05 ± 0.00\(^e\) | 0.02 ± 0.00\(^e\) | 0.19 ± 0.01\(^ef\) | 0.08 ± 0.00\(^d\) | 0.04 ± 0.00\(^b\) | 0.46 ± 0.12\(^e\) |
|                    | seeds       | 1.64 ± 0.17\(^d\) | 0.06 ± 0.01\(^g\) | 0.06 ± 0.01\(^g\) | 0.02 ± 0.00\(^e\) | 0.12 ± 0.01\(^f\) | 0.06 ± 0.00\(^d\) | 0.03 ± 0.00\(^b\) | 0.56 ± 0.11\(^e\) |
| Metal permitted content (mg.kg\(^{-1}\)) in food | | 150 | 0.3 | 10 | 0.1 | 1.1 | 0.3 | 0.2 | 2 |
| Reference for heavy metal permitted limit in food | Nair et al. (1997) | Jusko et al. (2008) | Nair et al. (1997) | WHO and EU (1983) | SLI (2000) | ATSDR (2000) | EC (2006) | ATSDR (2007) |

Values followed by the same letter in a column are not significantly different (P > 0.05) using LSD.
4. Discussion

4.1. Characteristics of the substrates

The soil in this study was acid when that of the raw cattle manure was alkaline. The acidic of the soil might be linked to the accumulation of some chemical compounds in the soil during the past years. In fact, *Lagenaria siceraria* was grown on some cotton old plots where a lot of inorganic fertilizers and pesticides are used. It has been demonstrated that the use of inorganic fertilizers and pesticides provoke a decrease of soil pH (Xie et al., 2009; Sradnick et al., 2013). In addition, there was a decrease in the pH of cattle manure after the vermicomposting. The drift observed in the pH may be due to a greater mineralization of N and P into nitrites/nitrates and orthophosphate because of the presence of a higher density of earthworms. The bioconversion of organic material into intermediate substances of organic acids, the formation of organic acids and the volatilization of ammonia could also account for the decrease in pH. Similar observations were reported by Garg et al. (2006), Gunadi and Edwards (2003), and Atiyeh et al. (2000). However, our results were in contrast with those of Datar et al. (1997) who reported an increase in pH after the vermicomposting of solid wastes. There was a decrease in the total carbon content and an increase in total nitrogen content after the vermicomposting compared to raw cattle manure. The decrease in carbon content could be due to the mineralization of the carbon by earthworms and microorganisms during the vermicomposting and the mineralization may have resulted in the loss of carbon as CO₂ during the process of vermicomposting. Nitrogen increase in the vermicompost could be linked to its addition in the form of mucus, nitrogenous excretory substances, growth-stimulating hormones and enzymes from earthworms (Senapati et al., 1980).

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 during the vermicomposting process. The decrease in C:N ratio could also be due to an increase in N mineralization and its immobilization by earthworms.

The increase in TP content after the vermicomposting could have been induced by the mineralization and the mobilization of phosphorus through bacterial and faecal phosphatase activity of earthworms. The direct action of worm gut enzymes and the stimulation of microflora could increase phosphorus (Edwards and Lofty, 1977). Our result was in agreement with those of Satchell and Martin (1984) and Le Bayon and Binet (2006) who observed an increase in phosphorus during the vermicomposting of paper waste sludge and organic substrates, respectively. They attributed the increase in phosphorus to the activities of the earthworms. In contrast,
Lopez-Hernandez et al. (1993) observed a decrease in phosphorus in the casts of *Pontoscolex corethrurus*. This difference may be due to the initial characteristics of the animal wastes used in our experiment and those of the soil used in their experiment. In contrast to TP, there was a decrease in TK content after vermicomposting of the raw cattle manure. This could be due to earthworm’s activity that increased waste porosity and consequently hastened the leaching of potassium toward the bottom during the water flow. Similarly, Orozco et al. (1996) reported a decrease in potassium in the vermicomposting of coffee pulp waste. Contrary to our results, Delgado et al. (1995) observed an increase in K content during the vermicomposting of sewage sludge. These differences could be attributed to the chemical nature of the initial raw wastes.

4.2. Effect of organic inputs on agronomic parameters of *L. siceraria*

The highest number of flowers, leaves and fruits per plant, seeds per fruit and yield obtained with the vermicompost compared to those with raw cattle dung could be explained by higher nutritional value of the vermicompost than that of raw cattle manure. Indeed during vermicomposting, transit of waste through the digestive tract of earthworms would have a better mineralization and consequently increase the content of minerals in vermicomposts (Ndegwa and Thompson, 2001). The mucus secreted by earthworms during the vermicomposting process might increase nitrogen content. It has also been shown by Tripathi and Bhardwaj (2004), Suthar (2007) that earthworms have in their mucus nitrogenous substances as well as growth hormones and enzymes that promote plant growth. The assimilation of nitrogen by plants could favorably influence the agronomic parameters mentioned above, which differ significantly with the type of organic inputs. Also, minerals might be more available in the vermicompost compared to cattle manure. That mobility of nutrients in the vermicompost might make easier their absorption than those contained in the raw cattle manure. Contrary to the above agronomic parameters, the rhizosphere was larger in the control plots than those with the cattle manure and the vermicompost. That could be linked to the fact that the abundance of minerals and nitrogen in particular stimulates longer stem elongation than that of roots. The root length therefore decreases with increasing soil fertility. Indeed, the root system would develop more when there is a nutrient deficiency in the soil. And this, to search for nutrients essential to the development of the plant. On the other hand, in the presence of sufficient nutrients, the root system would be limited to the fertile zone to absorb the nutrients. Similarly Atger and Edelin (1994), Fageria and Moreira (2011) have observed that roots system was more developed in non fertilized soil than in fertilized soil.
4.3. **Effect of organic inputs on mineral content in the edible parts of *L. siceraria***

The importance of calcium, magnesium, potassium and phosphorus in human and animal has been well recognized (Eruvbetine, 2003; Soetan et al., 2010; Stone et al., 2016). Deficiencies or disturbances in the nutrition of any cause a variety of diseases and can arise in several ways (Favus et al., 2006). These minerals contents were studied in *L. siceraria* widely used in rural areas. Mineral nutrients content varied significantly in the different parts of the plant. That might be linked to the initial differences between substrates (soil, cattle manure, vermicompost) chemical composition. In general, it appeared that with the treatments of control and cattle manure, the higher concentrations of Ca, Mg, P and K were found in roots followed in decreasing order by those in leaves and seeds. Contrary to control and raw cattle manure, nutrients contents were higher in leaves and seeds with vermicompost. Moreover, the mineral contents in the roots were higher with the vermicompost than those with the control and with the raw cattle manure. That might be explained by the mobility of the minerals. There could be two steps for nutrients mobility. The first one could be at the soil level that permits the accumulation of nutrients within roots and might be influenced by the soil or substrate physico-chemical characteristics like soil texture, structure, pH, etc. According to Fageria and Zimmermann (1998), Ca, Mg, P and K uptake by plants decreases in acidic soil. In fact, the action of pH on the physical, chemical and biological properties of the soil creates a favorable environment for mineral nutrition and plant growth (Cayuela et al., 2006; Doucet, 2006). Nutrient uptake by plants is better for pH near neutral (Doucet, 2006). For example, in basic soils, phosphorus associates with calcareous, whereas in acidic soils it combines with iron, becoming insoluble. In both cases, it is unavailable for plants. On the other hand, at neutral pH, it is soluble and therefore easily assimilated by the plant. A pH between 6.2 and 7.5 is synonymous with fertile soil (Harter, 2007). In our experience, the soil was acidic (5.09), the raw cattle manure basic (8.35) and the vermicompost pH was close to neutral (7.23).

The second level might be within plants after minerals absorption and might depend on the capacity of roots to liberate nutrients. Thus, with control and raw cattle manure, Ca, Mg, P and K might be less mobile after their absorption and large concentrations could be locked into roots vacuoles. That could explain the weak contents in leaves and seeds. In contrast, with the vermicompost, nutrients might be more mobilized at both levels: during their absorption from the soil or the substrate to roots and within the plant once incorporated into roots and that could explain their higher concentrations in leaves and seeds. The mobility at the two levels with the vermicompost might be induced by earthworms as they are known to increase nutrients mobility through their activity. According to Ndegwa and Thompson (2001), Saranraj and Stella (2012), macronutrients such
as nitrogen, potassium, phosphorus calcium, and magnesium are made more soluble and available by earthworms in vermicompost for the plant. However calcium was less concentrated in seeds than in leaves. Contrary to calcium, potassium, phosphorus and magnesium were more concentrated in seeds than in leaves and roots. That could be explained by their mobility. Calcium might be immobile after its absorption and remain into roots where it is absorbed when P, K and Mg are remobilized after their absorption and leave the original place to where they are needed greatly as seeds. Our result is in agreement with that of Hanger (2008) who observed a decrease in calcium content from roots to seeds and he explained his result by its immobility after entering into roots. In addition there could be a reverse concentration between calcium and the other elements as magnesium, potassium and phosphorus. Similarly, Wallace and Mueller (2008) have detected in plants opposite concentrations in calcium and some minerals as potassium, magnesium, sodium and ammoniac. They explained their result by the fact that the cations K\(^+\), Mg\(^{++}\), Na\(^+\), NH\(_4\)\(^+\), and H\(^+\) could directly and indirectly depress Ca uptake and distribution. On the other hand, the potassium contents in the plant parts were higher than those of Ca, Mg and P. That could be possibly related to the preferential accumulation of potassium in roots vacuoles as well as in leaves and seeds vacuoles. That accumulation might decrease with calcium, magnesium and phosphorus when moving towards meristematic cells.

4.4. Effect of organic inputs on heavy metal content in the edible parts of *L. siceraria*

Heavy metal concentrations varied from one part to another in *L. siceraria*. In addition, they were detected in each part of the plant. The presence of heavy metals in the roots, leaves and seeds of *L. siceraria* could be linked to their initial presence in the soil and cattle dung. 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 *L. siceraria* to accumulate the heavy metals in its parts. Similarly, Punz and Sieghardt (1993), Kumar et al. (2014) found higher content of different heavy metal in edible vegetables. They explained their results by the capacity of vegetables to accumulate more specific metal. Despite the type of organic fertilizer, the highest concentration of heavy metal in roots, leaves and seeds of *L. siceraria* was found with Zn and Cu. That might be attributed to their higher amount in the soil or in cattle manure due to the addition of Zn in the form of zinc oxide and Cu in the form of copper sulphate respectively to feeds for larger cattle and to suppress bacterial action in the gut and to maximize feed utilization by the animal.

Generally, the highest concentrations in heavy metals were found in roots followed respectively by those in leaves and seeds. That variation in heavy metal

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contents could be explained by their mobility. They might be less mobile so that they could not move rapidly to the above parts of the plant. Roots of *L. siceraria* might develop a system of sequestration of heavy metal that reduces the amount for the other parts of the plant. Adriano (1986), Kabata-Pendias and Pendias (1992), Baker and Senft (1995) and Juste et al. (1995) observed a significant Cu accumulation in roots of several plants than in the leaves and fruits. According to Bisson et al. (2003), the amount of Pb absorbed by plants is rapidly immobilized in the vacuoles of root cells or restraint by the walls of the endoderm that explain the higher Pb content in roots than in leaves and fruits of plants. Furthermore, heavy metal contents obtained in our study were smaller than those recorded by Kouakou (2009) in lettuce leaves, spinach and amaranth. That difference could be due to the capacity of plants to accumulate heavy metals. Song et al. (1996), Zhuang and Wang (2000) have reported a variation in heavy metal contents in plants in function of their species. For each type of fertilizer, Cd seems to be uniformly distributed in the different parts of *L. siceraria*. This indicates that, in *L. siceraria*, Cd concentrations were in equilibrium between roots, leaves and seeds. That could explain the mobility of cadmium, its easily absorption by roots and transportation to shoots and consequently uniformly distributed in plant organs. This result is in agreement with that of Sekara et al. (2005) who found similar Cd distribution in roots, leaves, stems and fruits of pumpkin, cabbage, barley, maize, chicory and red beet. In addition, Fodor et al. (2001) investigated the mobility and distribution of lead in cucumber and he found that it was similarly distributed in the parts of cucumber. Moreover, in each part of *L. siceraria*, heavy metal contents were lower with the vermicompost than those obtained with the cattle manure and the control. Also, in this study all the heavy metal contents obtained in the roots, the leaves and the seeds were under their respective maximum permitted limit in food and that indicated that vermicompost could be used to produce safety food. In contrast, higher content in heavy metals were found in *L. siceraria* edible parts while using raw cattle manure as fertilizer. This result could be explained by earthworm’s activity. According to Nicholson et al. (1999), Ogiyama et al. (2005), animal manure contains heavy metals which can be absorbed by plants along with nutrients and stored in leaves and fruits. The lowest contents in heavy metal with the vermicompost might be linked to earthworms as they are known to reduce heavy metal content in the vermicompost by accumulating them in their bodies. This result could also be explained by the ability of earthworms to bind heavy metals and thus preventing their absorption by plants. According to Hait and Tare (2012), earthworms by their activity can decrease the bioavailability and the mobility of heavy metals in the vermicompost and therefore limit their absorption by plants. The immobility and non-bioavailability of heavy metals during vermicomposting could be due to two major types of cellular adaptation to toxicity of metals: one involves binding of metals to nuclear proteins and the formation
of inclusion nuclear bodies; the second type is a cytoplasmic process involving synthesis of a specific metal binding protein, metallothionein within the chloragogous tissue.

5. Conclusions

It can be concluded that vermicompost from cattle manure increases agronomic parameters compared to raw cattle dung. The use of vermicompost favors the increase of mineral nutrients content in leaves, seeds and roots of *L. siceraria*. It also decreases heavy metals concentrations in the different parts of the plant under the recommended limits for safe feed and thus could be more recommended for plant production and food security.

Declarations

Author contribution statement

Sifolo S. Coulibaly, Flavien Ettien Edoukou, Kouadio I. Kouassi, Narcis Barsan, Valentin Nedeff, Bi I. A. Zoro: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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